Link Light Rail

North Link and Airport Link Design Criteria Manual

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ACRONYMS/ABBREVIATIONS

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A

AAR	Association of American Railroads
AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
ACS	Access Control System
ADA	Americans with Disabilities Act
ADAAG	The Americans with Disabilities Act Accessibility Guidelines for Buildings and Facilities
Ag	Gross Area
AHCW	Automatic Highway Crossing Warning
AHJ	Authority Having Jurisdiction
AISC	American Institute of Steel Construction
AJCHN	American Joint Committee on Horticulture
ANSI	American National Standards Institute
APS	Auxiliary Power Supply
APTA	American Public Transit Association
AREA	American Railway Engineering Association
AREMA	American Railroad Engineering and Maintenance-of-Way Association
ASHRAE	American Society of Heating, Refrigerating and Air-conditioning Engineers
ASME	American Society of Mechanical Engineers
ASTM	American Society for Testing and Materials
AT&T	American Telephone and Telegraph Company
ATC	Applied Technology Council
ATP	Automatic Train Protection
AWS	American Welding Society
AWWA	American Water Works Association

B

B	Hydrostatic Pressure and Buoyancy
BICSI	Building Industry Consulting Service International
BMP	Best Management Practices

C

C&S	Communication and Signaling
CAN	Control Access Network
CB	Communications Backbone
CBD	Central Business District
CCER	Central Communications Equipment Room
CCS	Central Control System
CCTV	Closed Circuit Television Cameras
CDCS	Central Data Collection System
CE	Clearance Envelope
CF	Centrifugal Force
CFD	Computational fluid dynamics

CFM	Cubic Feet per Minute
CIL	Central Instrument Locations
CL	Collision Loads
CMT	Construction and Maintenance Tolerances
CO	Carbon Monoxide
CPTED	Crime Prevention through Environmental Design
CQC	Complete Quadratic Combination
CS	Curve to Spiral
CW	Chorded Wall
CWR	Continuous Welded Rail

D

dBA	Ground Borne Noise
DCFS	DC Feeder System
DCM	Design Criteria Manual
DF	Direct Fixation
DL	Dead Loads
DOT	Department of Transportation
DR	Derailment Loads
DS	Differential Settlement
DSTT	Downtown Seattle Transit Tunnel
DX	Direct Expansion

E

E	Earth Pressure
Ea	Superelavation
EA	Environmental Assessment
ECS	Environmental Control Systems
EIA	Electronic Industries Association
EIS	Environmental Impact Statement
EMI	Electromagnetic Interference
EMP	Emergency Management Panel
EPP	Emergency Preparedness Plan
EQ	Earthquake Force
ETB	Electric Trolley Bus
ETEL	Emergency Telephone System
ETS	Emergency Trip Stations
EVS	Emergency Ventilation Shafts

F

FACP	Fire Alarm Control Panel
FC	Fare Collection

FCC	Federal Communications Commission
FCS	Field Control System, formerly SCADA
FDC	Fire Department Connections
FEIS	Final Environmental Impact Statement
FHWA-SA	Manual for Design and Construction Monitoring of Soil Nail Walls by the Federal Highway Administration
F/LS	Fire Life Safety
FLSC	Fire Life Safety Committee
FM	Factory Mutual
FEMA	Federal Emergency Management Association
FMECA	Failure Modes, Effects, and Criticality Analyses
FONSI	Finding of No Significant Impact
FPM	Feet per Minute
FPS	Fire Phone System
FPVP	Fire Protection Valve Pits
FRP	Fiberglass Reinforced Plastic
FSD	Fire/Smoke Dampers
FTA	Federal Transit Administration
FTP	Fare Transaction Processors

G

GTE	General Telephone Company

H

HDPE	High Density Polyethylene
HMI	Human Machine Interface
HUD	Housing and Urban development
HVAC	Heating Ventilation and Cooling System
Hz	Hertz

I

I	Impact
ICEA	Insulated Cable Engineers Association
IBC	International Building Code
IDS	International District Station
IEC	International Electrotechnical Commission
IMC	International Mechanical Code
IPC	International Plumbing Code
IEEE	Institute of Electrical and Electronic Engineers
IESNA	Illuminating Engineering Society of North America
IFC	International Fire Code
IH	Horizontal Impact

ISO	International Organization for Standardization
ITE	Institute of Transportation Engineers
ITS	Intelligent Transportation Systems
ITU	International Telecommunications Union
IV	Vertical Impact

K

Ko	Lateral Stress Coefficient
KVM	Keyboard/Video/Mouse

L

L	Failure Rates
LAHT	Low-Alloy High-Tensile
LED	Light Emitting Diode
Ldn	Day-Night Noise level
Leq	Existing Noise level
LF	Longitudinal Force
LINK	Link Light Rail
LL	Live Loads
Lmax	Maximum Noise Level
LOS	Level of Service
LOS	Line of Sight
LOS A	Concourse Area (including Fare Vending)
LOS C	Platform Waiting Zones
LOS D	Walkways and concourse Connectors
LRFD	Load and Resistance Factor Design
LRT	Light Rail Train
LRV	Light Rail Vehicle

M

MCBF	Mean Cycles Between failures
MCC	Motor Control Center
MDBF	Mean Distance Between Failure
MDE	Maximum Design Earthquake
MDL	Monitoring and Diagnostic Logic
MLK	Martin Luther King (Blvd.)
MMS	Maintenance Management System
MOU	Memorandum of Understanding
MOW	Maintenance of Way
mph	miles per hour
MSE	Mechanically Stabilized Earth Walls
MTBF	Mean Time Between Failures
MTBSF	Mean Time Between Service Failures

MTTR	Mean Time To Repair
MUTCD	Manual of Uniform Traffic Control Devices

N

NDSWC	National Design Specifications for Wood Construction
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NESC	National Electrical Safety Code
NETA	National Electrical Testing Association
NFPA	National Fire Protection Association
NMS	Network Management System
NOS	Network Operating System
NRC	Noise Reduction Coefficient

O

O&M	Operations and Maintenance
OCC	Operations Control Center
OCS	Overhead Contact System
ODE	Operating Design Earthquake
OMG	Object Management Group
OS	Office Service Network
OSHA	Occupational Safety and Health Act
OTM	Other Track Materials
OWF	Other Wayside Factors

P

PA	Public Address
PA/VMS	Public Address and Variable Message Signs
PABX	The hardware and firmware required to provide voice communications in specific locations for Link staff use.
PAP	Passenger Assistance Phone
PC	Point of Curvature
PCI	Pre-stressed Concrete Institute
PCMCIA	Plug in Memory Card
PDA	Personal Digital Assistance
PDR	Preliminary Design Review
PET	Passenger Emergency Telephone
PFTP	Portable Fare Transaction Processor
PFM	Pedestrian per Foot width of walkway per Person
PGA	Peak Ground Acceleration
PGD	Peak Ground Displacement
PGV	Peak Ground Velocity
PIM	Person per inch per minute

PIP	Passenger Information Phones
PLC	Programmable Logic Controllers
plf	Pounds per Linear Feet
PM10	Particulate Matter
POP	Proof of Payment
PSE	Puget Sound Energy
Psi	Pounds per square inch
PT	Point of Tangency
PTE	Portable Test Equipment
PVC	Polyvinyl Chloride

Q

QRA	Quantified Risk Assessment

R

RC	Running clearances
RFC	Regional Fare Coordination
ROD	Record of Decision
ROW	Right-of-Way
RPZ	Residential Parking Zones
RUS	Rural Utility Service

S

S	Shrinkage and Creep Forces
SBC	Seattle Building Code
SBD	Safe Braking Distance
SCADA	Supervisory Control and Data Acquisition System
SEI	Software Engineering Institute
SEPA	State Environmental Policy Act
SF	Stream Flow Pressure and Flooding
SFD	Seattle Fire Department
SHPO	State Historic Preservation Officer
SI	English/International System of Units
SMACNA	Sheet Metal and Air Conditioning Contractors National Association
SPC	Seismic Performance Category
SSC	Standard Specifications for Facilities Construction
SSIM	Seattle Street Improvement Manual
ST	Sound Transit
ST	Spiral to tangent
ST*art*	Sound Transit Art Program
SWPPP	Stormwater Pollution Prevention Plan

T

T	Thermal Force
TES	Traction Electrification System
TIA	Telecommunications Industry Association
TOR	Top of Rail
TPSS	Traction Power Substations
TS	Tangent to Spiral
TVM	Ticket Vending Machines
TWC	Train to Wayside Communications

U

U.S.	United States
UL	Underwriters Laboratory
UPC	Uniform Plumbing Code
UML	Unified Modeling language
UPS	Uninterruptible Power Supply
USDOT	United States Department of Transportation
USGS	United States Geological Survey
UW	University of Washington

V

VAV	Variable Air Volume
VdB	Ground -Borne Vibration
VDE	Vehicle Dynamic Envelope
VMS	Variable Messaging System

W

W	Wind Load on Structure
WAC	Washington Administrative Code
WBC	Washington Building Code
WL	Wind Load on Live Load
WSBC	Washington State Building Code
WSBCC	Washington State Building Code Council
WSDOT	Washington State Department of Transportation
WSFC	Washington State Fire Code
WUTC	Washington Utilities and Transportation Commission

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1. GENERAL

1.1 INTRODUCTION

This chapter establishes the criteria to guide the Preliminary Engineering and Final Design of the Link light rail transit system (Link). Link, for the purpose of these criteria, denotes a system utilizing overhead electric power distribution to coupled, motorized vehicles traveling on steel wheels, through local city streets, elevated guideways, and subways. The Link system traverses the jurisdictional boundaries of WSDOT, the University of Washington, the Port of Seattle, the City of Seattle, the City of Tukwila, the City of SeaTac, and the City of Tacoma. The current Link System includes a street car line that operates exclusively in the City of Tacoma, and an initial segment which operates in Seattle and Tukwila. This criteria update is applicable to a southern extension through SeaTac and a northern extension to the University of Washington area and beyond.

1.2 COLLABORATION

Collaboration is the primary method that Sound Transit will use in development of the Link system. Sound Transit defines collaboration as the willingness of various parties to share their perspectives to identify and solve political, social, economic, engineering, architectural, and artistic challenges. This process involves free interaction among engineers, artists, architects, planners, code officials, administrators, and the public. In a successful collaboration, all participants remain open to each other, listen carefully, and challenge with sensitivity.

1.3 REFERENCE DOCUMENTS

The work governed by these Design Criteria will be performed in municipal jurisdictions, state right-of-ways, or unincorporated county jurisdictions. In some cases, there may be specific differences between codes and standards of these various jurisdictions traversed by the Link system. It is the express intent of Sound Transit for these Design Criteria to be in substantial compliance with the codes and standards of the local jurisdictions. Whenever the phrases “local jurisdiction”, “municipal jurisdiction”, “municipality”, or “authority having jurisdiction”, are noted, these terms shall be understood to mean WSDOT, King County, Port of Seattle, City of Seattle, City of SeaTac, City of Tacoma, or City of Tukwila as the authority having jurisdiction. The codes and standards of these municipalities shall govern design to the greatest extent possible, as long as they do not violate federal or state law. In some cases, Sound Transit may believe that municipal or other jurisdictional codes and requirements are not in the best interest of the project or are excessive in either requirements or interpretation. Sound Transit reserves the right to petition or protest and seek code variance on

certain issues whether or not these requirements or codes are referenced in these criteria. The hierarchy of code enforcement shall be federal, (such as OSHA, EPA), State, (such as WSDOT, WISHA), and then municipal. Where there is a difference between codes, the most restrictive shall apply.

1.3.1 Applicable Local Jurisdictional Codes and Standards

1.3.1.1 Washington State Department of Transportation (WSDOT)

A. Standard Plans – For Road, Bridge and Municipal Construction

B. Design Manual for Roadway Design

C. Standard Specifications for Road, Bridge, and Municipal Construction

D. Highway Runoff Manual

E. WSDOT Pedestrian Facilities Guidebook

F. WSDOT – Design Manual – Bridges and Structures

1.3.1.2 City of Seattle

A. Seattle Standard Plans for Municipal Construction

B. Seattle Standard Specifications for Road, Bridge and Municipal Construction, Vol. 1 & 2

C. Seattle Transportation Street and Sidewalk Pavement Opening and Restoration Rules

D. Seattle Street Improvement Manual

E. City of Seattle Traffic Signal Design Guide

F. Seattle Stormwater, Grading and Drainage Control Code

G. International Building Code (IBC) as amended by the City of Seattle

H. International Fire Code (IFC) as amended by the City of Seattle

I. Seattle Floodplain Regulations

J. International Mechanical Code (IMC) with Seattle Amendments

K. Seattle Energy Code

L. Washington State Energy Code with Seattle Amendments

M. International Plumbing Code (IPC)

N. Seattle Electrical Code

O. Noise Control Code (Seattle Municipal Code 25.08 Noise Control)

P. City of Seattle Transportation Strategic Plan

Q. Seattle Lighting Design Criteria (Chapter 15, Seattle Energy Code)

1.3.1.3 Port of Seattle

A. Stormwater Management Manual Vol. 1 – Design/Volume II

B. Design Standards and Guidelines

C. Ecology Manual 2005

D. Buildings and Construction Title 13

E. Regulations for Airport Construction, 2004 Edition

1.3.1.4 City of Tukwila

A. Infrastructure Design and Construction Standards

B. Water District No. 125 and City of Tukwila

1.3.1.5 King County

A. Hydraulics Manuals

B. Surface Water Design Manual (SWDM), 2005

C. King County Road Standards

1.3.1.6 City of SeaTac

A. City of SeaTac Comprehensive Plan

B. City of SeaTac Municipal Code (Chapter 13.30 Environmental Rules and Procedures, Zoning Code Title 15)

C. Transit Supportive Land Use Master Plan

D. City Center Plan

E. Draft Station Area Plans

F. Design Standards for High Capacity Transit Facilities (Chapter15.36)

G. Water District No. 125

1.3.1.7 City of Tacoma

A. Public Works Department Design Manual

1.3.1.8 Other Codes and Standards

A. International Building Code (IBC) with local amendments

B. National Electrical Code (NEC) with local amendments

C. National Fire Protection Association (NFPA)

D. International Plumbing Code (IPC)

E. International Fire Code with local amendments

F. Washington State Building Code

G. OSHA/WISHA Standards

H. NEMA (National Electrical Manufacturers Association)

I. MUTCD (Manual of Uniform Traffic Control Devices)

1.4 APPLICATIONS

A. The material contained in the following chapters provides a uniform basis for design and can be expected to undergo refinement and expansion during preliminary engineering and final design.

B. These criteria do not substitute for engineering judgment and sound engineering practice. Specific exceptions may apply in special cases. The designers are responsible for identifying all necessary departures from the criteria contained in this document, and bringing them to the attention of the Project Manager. All changes to the criteria must be reviewed and approved by Sound Transit Link Change Control Board (CCB) prior to use in the design. Application for change of criteria, addition to the criteria, and other questions shall be submitted in writing to Sound Transit. Although this criteria draws specific code and standard issues to the attention of the Architect/Engineer, they are fully responsible for preparation of designs that fully meet all current applicable codes whether or not such codes are noted in this criteria.

1.5 PROJECT GOALS

The basic goal of the Link project is to provide commuters and other travelers with the benefits of improved public transportation in a cost-effective, environmentally sensitive, and socially responsible manner.

1.5.1 Proven Hardware

A. The Link system shall be designed to use proven subsystems hardware and design concepts. All of the major subsystems, such as light rail vehicles, communications, ticket vending machines, signaling and traction power equipment, shall be supplied by established manufacturers, have a documented operating history of previous and current usage, and be available off the shelf, so far as practicable. The same requirements shall apply to spare parts. Waiver of these requirements shall be considered only where the alternative subsystem offers substantial technical and cost advantages, is in an advanced state of development, and has accumulated substantial test data under near-revenue conditions.

B. Specifications for the Link system shall be prepared in such a way as to encourage competitive bidding by established manufacturers of transportation equipment.

1.5.2 Design Life

A. The Link system's fixed facilities (structures and buildings) shall be designed for continued operation over a minimum period of 50 years before complete refurbishment or renovations are necessary due to wear and tear and obsolescence.

B. Major fixed system equipment (such as substation hardware, shop machinery and light rail vehicles) shall be designed for a minimum of 30 years before major overhaul or complete replacement becomes necessary, assuming that approved maintenance policies are followed.

1.5.3 Service Integration

The Link route is to be part of the overall regional transportation system. Specific provisions shall be made for the efficient interchange of passengers with private and other public transportation modes.

1.6 LAND USE AND URBAN DESIGN

1.6.1 Land Use Guidelines

A. The Link system should be designed, where possible and desirable, to stimulate urban development and redevelopment while avoiding drastic changes that disrupt the public commerce or social interaction. Positive changes such as street improvements shall be incorporated where there is opportunity to do so and where cost-sharing agreements can be made. Joint development of the transit right-of-way shall be considered.

B. Displacement of buildings and public activity areas shall be minimized. Retail establishments shall be protected from construction activities. Creation of physical barriers to land use functions and reduction in traffic circulation capacity shall be avoided to the extent it is practicable to do so.

C. The project shall be implemented in such a way as to maintain consistency with local and regional land use plans, insofar as possible. Exceptions shall be coordinated with the appropriate authority having jurisdiction.

1.6.2 Urban Design Guidelines

A. The design of the Link system shall consider the viewpoint of the user, the adjacent residential or business community, and the nearby pedestrian or motorist. In this regard, the items of concern include potential noise impacts and mitigative measures, historic preservation, visual intrusion, visual barriers, station access, continuity and transition of structures, separation of alignment, common system elements, and maintenance. Historic properties whose physical and/or visual environments may be altered by the project were identified in the FEIS as appropriate mitigation as described in the ROD. During construction, standard practices shall be employed to minimize the impact on these properties. As much as possible, trucks and other equipment will be routed away from historic properties. With regard to operational impact, standard methods of physical protection and photographic record keeping may be necessary. Photographic record keeping, if required, will document the properties' environments before start up of rail operations. The Washington State Historic Preservation Office shall be consulted regarding the mitigation measures to be employed at each affected site.

B. The Link system shall be designed to minimize visual intrusion on public and private spaces. The system shall neither obscure scenic views nor exert undue shade influence on adjacent land use. In addition, the design shall comply with the requirements presented in the Final Environmental Impact Statement on environmental related issues.

1.7 ST*art*, SOUND TRANSIT ART PROGRAM

A. Sound Transit is committed to providing seamless integration of art, engineering, landscape architecture, signage, graphic design, and architecture of its facilities. The Sound Transit Board of Directors has adopted two documents that set the guidelines for the Sound Transit Public Art Program. Motion No. 40 (1997) and Resolution No. 98-01 are included in the Appendix of this manual. Chapter 27, ST*art*, Sound Transit Art Program of these criteria, covers the ST*art* program in more detail. Chapter 27, ST*art*,

Sound Transit Art Program shall be considered as a component of all other chapters in this manual.

B. Through a collaborative process with artists, engineers, and designers, art shall be an important premise for this system in pursuit of its overall goals. Traditional views of art shall be expanded and broadened by accepting art as a possibility in every aspect of design and engineering. Artists will be working directly with architects and engineers to determine these possibilities. This artistic process will also be another venue for community involvement of Sound Transit facilities.

C. Art shall also be integrated throughout the system to help provide richness to the human experience of transit. The design of the Light Rail System shall consider the viewpoint of the user, the adjacent residential or business community, and the nearby pedestrian or motorist. Design of the system shall be sensitive to the various levels experienced by these particular groups. The quality of the design and sensitivity to adjacent areas and edges of impact shall be at the highest level.

1.8 SOUND TRANSIT BOARD MOTIONS AND RESOLUTIONS

The Sound Transit Board has adopted several resolutions with respect to the functioning and appearance of the Link light rail facilities. These motions or resolutions are documented in Appendix A.

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2. OPERATIONS

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2. OPERATIONS

2.1 INTRODUCTION

This chapter defines operating requirements for design of Link light rail (Link) facilities and systems.

2.2 DEFINITIONS

A. Alignment Classifications:

1. Exclusive

   A right-of-way without at-grade crossings, which is grade-separated or protected by a fence or substantial barrier. (Examples are underground alignments, aerial structures, and freeway medians).

2. Semi-Exclusive

   A right-of-way that is longitudinally separated and protected from parallel traffic, but which crosses non-parallel roads and railroads at-grade. Separation may be achieved by mountable or unmountable curbs, barriers, safety fences, or lane striping. Protection at grade crossings may be provided by automatic crossing gates or traffic signal.

3. Mixed Traffic

   A right-of-way that is shared by vehicular traffic, such as a street, transit/pedestrian mall, or dedicated transitway shared by bus and rail.

B. Cab Signals

A device located in the control compartment (cab) of a light rail vehicle that indicates to the train operator the permissible speed of the track ahead.

C. Consist

The number of cars that make up a train.

D. Crossover

A pair of turnouts that connect two tracks enabling a train to operate from one track onto the other.

E. Grade Crossing

A location where rail transit or railroad tracks cross a street at the same level or grade.

F. Headways

1. General time (usually expressed in minutes and seconds) separation between successive train movements passing a given point.
2. Design Headway

   A measure specified in train control design to identify how closely one train must be able to safely follow another at normal speed.

3. Minimum Operating Headway

   The minimum operating headway that can realistically be scheduled for service. Typically, this includes the design headway plus a cushion to accommodate minor delays during actual train operations.

4. Peak Period Headway

   The headway required to provide a system capacity sufficient to carry projected peak hour ridership at the point of greatest load. For lines with low projected ridership, headways may be set by policy rather than by demand.

5. Single Tracking Headway

   a. Single tracking is performed when a train service is required to operate in both directions (in one direction at one time) on one track due to the other track not being available.

   b. Train control and signaling shall, however, enable trains to run on the left-hand track when circumstances require.

   c. The single tracking headway should ideally be no greater than twice the peak period headway and in no case should it exceed 15 minutes without written approval from Sound Transit.

G. Mainline

Designated track (outside the yard facility) for the operation of scheduled passenger trains and other authorized on-track vehicles.

H. Light Rail Vehicle (LRV)

An electrically powered rail vehicle used for transporting passengers.

I. Line Capacity

The maximum number of LRV trains that can safely operate under normal signaling conditions past a fixed point in one direction per unit of time.

J. Normal Speed

The maximum authorized speed for any given location.

K. Operations & Maintenance Facility

A location for:

1. The storage, servicing and repair of LRVs,
2. Train operating personnel reporting and training,
3. System supervision and control, and
4. Link Light Rail Transportation and staff headquarters.

L. Operations Control Center (OCC)

A location from which staff can monitor and control train movements and other operational functions related to the Link System. (Normally located at the Operations and Maintenance Facility).

M. Pocket Track

A train storage track connected to the mainline tracks with the capability of berthing a train of maximum consist length. A pocket track is typically placed between two mainline tracks and is connected to both tracks at each end of the pocket. Pocket tracks placed between two platforms at mid line stations can simplify the scheduled turn back of trains.

N. System Capacity

The total number of passengers that can be carried past a fixed point in one direction in a set amount of time is typically 1 hour.

O. Tailtrack

A mainline track designated for train storage outside of signal territory commonly at a terminal station.

P. Terminal Station

1. ***Permanent Terminal:*** A passenger rail station at the end of the line. A station is considered a permanent terminal if it serves as the end of rail revenue operations for more than two years.

2. ***Temporary Terminal:*** A passenger rail station that will serve as the end of rail revenue operations for a period of no more than 2 years.

Q. Train

One or more light rail vehicles that operate as a single unit.

R. Vehicle Capacity

The number of passengers a car is designed to carry.

2.3 OPERATIONAL OBJECTIVES

A. All aspects of system operations and maintenance (O&M) planning shall provide for the safety and well being of passengers, employees and the neighborhood, and shall be consistent with the following objectives:

1. Provide a safe, reliable, efficient and cost effective rail transit service;

2. Provide system capacity that is adequate to meet projected demand of the specified design year;

3. Do not preclude an expansion of system capacity to meet anticipated future needs;

4. Minimize full life cycle costs, which include both capital and annual operating costs;

5. Support a staged implementation of the system;

6. Design for operational contingencies to support continued safe service during system failures;

7. Establish and maintain an integrated regional rail transit service with other urban transit services;

8. Provide a level of System Safety and Security that is equal to, or better than, current transit industry standards;

9. Availability of the system shall be equal to or exceed the availability of comparable properties in the United States; and

10. All contract specifications shall include a level of spare parts to support failures in a timely manner and meet operational objectives for service delivery.

2.4 OPERATIONS AND MAINTENANCE PLAN

A. The Operations and Maintenance criteria described in this chapter shall apply to all projects and design disciplines.

B. An Operations and Maintenance Plan prepared for each light rail project shall serve as the operational basis of design for that project, defining planned service levels and capacities along with planned methods of operations and maintenance.

2.5 SERVICE LEVEL CRITERIA

Service levels shall be determined from the criteria described in the following sections.

2.5.1 Patronage

A. The Link light rail projects shall be designed to provide capacity sufficient for the peak-hour, peak-direction passenger link volumes projected for the design year. Ridership projections for the design year are provided in the Operations Plan, and are typically for either the morning or evening peak hour.

B. All equipment and facilities shall be designed to accommodate peak 15-minute passenger flow rates. The peak 15-minute flow rate is defined as a peak-within-the-peak taken as 28.75 percent of peak hour projections; thus the peak 15-minute flow rate is expected to be 1.15 times the average peak hour flow rate.

C. Patronage projections shall be used as the basis for determining service levels and fleet size requirements for the initial year of revenue operation. Exit calculation, according to NFPA 130, shall be used in designing for the maximum occupant capacity and the required exit widths. (See Chapter 18, Fire/Lift Safety, section 18.2.1, Occupancy). To account for growth during initial years of operations, add a factor of 30 percent to the patronage projections to reflect a revised fleet size requirement. Design of the light rail projects shall not preclude future expansion of system capacity to accommodate this level of ridership with a minimum of operational disruption.

2.5.2 Operating Route

A. All mainline and branch light rail lines shall have a minimum of two mainline tracks, one track for operation of trains in each direction.

B. Under normal conditions, train movements shall operate on the right-hand track.

2.5.3 Operating Hours

Link light rail lines shall be designed to enable train service to operate either continually (24 hours per day, 7 days per week) or to close each night and resume the following morning. For the latter case, a 20-hour daily operation, 7 days per week, shall serve as the basis of design, although shorter operating days shall not be precluded.

2.5.4 Passenger Trip Time

Total one-way trip time from terminal to terminal shall not exceed the equivalent trip time established at the completion of the conceptual design phase by more than 5 percent without express written permission of Sound Transit. Total one-way trip time includes running time, station dwell time, and delay time (e.g., waiting at traffic signals), if applicable. For analyses purposes, a station dwell time of 20 seconds (30 seconds in the trunk section) is used when computing the total passenger trip time. Twenty seconds per station shall be used as the average station stop time for the entire line. Should a 100 percent low floor car be used, station dwell times may be reduced by 20 percent.

2.5.5 Operating Headway/Design Headway

A. The minimum operating headway shall support a level of service that provides an operating capacity sufficient to meet long-term demand (design-year patronage projections plus long-term growth factor, see section on patronage). Minimum peak operating headway shall not be greater than 10 minutes without Sound Transit's approval.

B. Design headway shall be at least 30 seconds shorter than the minimum operating headway and shall not be greater than 150 seconds.

2.5.6 Fleet Size

A. Fleet size shall be based upon peak-hour/peak-direction patronage projections for the specified target year, total round trip time, peak-period headway, number of vehicles per train, allowable load factor per train, gap train, and operational and maintenance spare vehicles. Total round trip time includes running time, station dwell time, delay time (if applicable), and turnback (terminal station) time for both directions of operation.

B. An allowable peak period load factor shall be determined to be 2.0. That is equivalent to one standee for every seated passenger.

C. Vehicle loading for scheduled operations shall not exceed the service load of the vehicle (approximately four persons per square meter).

D. The number of vehicles in the fleet shall be such that, with a limited number of vehicles unavailable for service due to maintenance, there will still be a sufficient number available for revenue service throughout the day, plus at least one full-length train at the ready as an operational spare (i.e., standby equipment). The vehicle fleet size shall be 115 percent of the sum of vehicles required for peak service plus the operational spare.

2.5.7 Light Rail Vehicles (LRV)

A light rail vehicle is an articulated car that can operate as a single unit or coupled with other units to make a train for revenue service with a total length not to exceed 380 feet $\pm$ 8 feet.

2.5.8 Service Dependability

A. The availability of the system shall be computed as the ratio of operating hours minus the total downtime divided by the operating hours. The downtime shall take into account the sum of all recorded revenue service delays of more than 2 minutes (a level of delay, which is normally tolerable by a passenger).

$$A = \frac{OH - \sum Dwt}{OH}$$

Where:
A is the availability of the system
OH is the total operating hours
∑Dwt is the sum of all recorded revenue service delays longer than 2 minutes

B. Reliability of the system components shall be such that the specified system availability target can be achieved.

C. The overall availability target for the entire rail system shall not be less than 99.90%

2.6 SYSTEM OPERATIONS

2.6.1 General

A. Trains will operate on exclusive, semi-exclusive, and/or non-exclusive right-of-way. The permissible operating speed shall be a function of

the right-of-way classification and the degree of train protection and grade crossing protection provided.

B. Operating speed shall not exceed the civil design speed. Geometric parameters such as curve radius, spiral length, and superelevation shall be calculated so as to provide the maximum safe operating speed compatible with passenger comfort level.

C. To eliminate interference, delays, and speed reductions on Sound Transit rail projects, railroad and bus operations shall be segregated to the maximum extent possible. Sound Transit revenue service LRV trains, commercially operated freight and Sound Transit commuter rail vehicles and railroads shall each operate on their own tracks. At-grade crossings of LRVs and railroad tracks shall be protected by full interlocks.

D. Link light rail lines shall be designed to include the hardware, software, and/or operations rules and procedures required to identify and respond to system failures and anomalies so as to minimize their impact upon the service furnished to patrons. The ability to maintain a near normal train service under failure modes shall be a high priority.

2.6.2 Special Trackwork

A. Special trackwork shall be provided and configured to operate the system and to provide operational flexibility required during different periods of the day or during emergencies, delays, failures, repairs, and maintenance.

B. Special trackwork at terminal stations shall be capable of sustaining the design peak period headway.

C. Tail tracks shall be located at temporary and permanent terminal stations.

D. All main line special trackwork shall be fully automatic. In the Yard areas, Train to Wayside Communications (TWC) Systems shall be installed to allow the train operator to control the switch position from the driving cab.

E. Special trackwork configurations shall include, but not be limited to, the following:

2.6.2.1 Turnouts

A. All non-diverging main line trackwork routes at turnouts shall be capable of sustaining the maximum civil design speed at that location for trains traveling on the main line.

B. High use main line trackwork at turnouts (such as terminal junctions, tail tracks used for scheduled turn back of trains, etc.) shall be capable of sustaining a nominal operating speed of 25 mph for trains deviating from the main line and traversing the turnout.

C. All other main line trackwork at turnouts (turnouts used periodically for single-tracking and unscheduled turnbacks) shall be capable of sustaining a nominal train operating speed of no less than 20 mph.

D. The civil design speed of turnouts in the yard shall be able to sustain a minimum speed of 10 mph, unless otherwise approved by Sound Transit.

E. All main line trackwork at equilateral turnouts shall be capable of sustaining the highest maximum civil speeds achievable.

2.6.2.2 Crossovers

A. Crossovers shall be located in such a manner as to ensure an achievable single-tracking headway of no greater than 15 minutes, including 20-second dwell times (except in trunk sections where it shall be 40 seconds) at each station along the single-track section.

B. Double crossovers (scissors-type) shall be provided on the approach side of a terminal station. If civil constraints do not permit the double crossover, two single crossovers can be substituted with Sound Transit approval.

2.6.2.3 Pocket Track

A. Pocket or storage tracks shall be capable of holding at least one train of maximum length.

B. Pocket tracks shall be spaced at distances no greater than 10 miles for efficient off line storage of trains as part of the line's failure management strategy. The yard and tail tracks at terminal stations may be considered for off-line storage in lieu of a pocket track.

C. Pocket or storage tracks shall be provided at potential mid-line turn back locations.

D. Mid-line pocket tracks shall be designed to enable entry and exit at both ends of the pocket track and onto the main line.

2.6.2.4 Tail Tracks

A. Tail tracks shall be provided at each permanent and temporary terminal station unless otherwise approved by Sound Transit.

B. At permanent terminal stations, each tail track shall be capable of accommodating a train of maximum consist length while at the same time providing sufficient safe braking distance (SBD) for trains entering the platform at 25 mph. Where it is not feasible to provide tail tracks of such lengths, then a lower train entry speed must be posted and entered in the train speed control circuit to enable safe breaking.

C. At temporary terminal stations, each tail track shall be capable of accommodating a train of maximum consist length while at the same time providing sufficient safe braking distance for trains entering the platform at 25 mph. If this is not possible, then with Sound Transit's approval, a train must be able to enter the platform at not less than 10 mph, (without requiring a full stop prior to continuing to the platform) while the tail track is occupied by a full-length consist.

D. Tail tracks shall be on tangent track, unless otherwise approved by Sound Transit.

2.6.3 Operations Control Center (OCC)

A. Regulation and supervision of train operations and supervisory control of the associated electrical, mechanical, and communications subsystems shall be performed at the Operations Control Center. This facility shall function as the nerve center of system operations. Every aspect of mainline and station operations, mainline maintenance activities, and any maintenance-of-way that affects mainline operation shall be controlled, coordinated, and monitored from the OCC located in the Operations and Maintenance Facility or at other locations as designated by Sound Transit. The Link light rail project response to failures and anomalies shall include either automatically or manually initiated changes in the system configuration, modifications of system operating strategies, and recovery operations. Personnel shall have the capability of overriding or modifying all automatically initiated failure management strategies. It also is the focal point for emergency communications and interaction with emergency responders.

B. The design of the Link light rail projects shall include the appropriate and required visual and audible means for disseminating information to patrons on the platforms.

2.6.4 Operations & Maintenance Facilities

A. An operations and maintenance (O&M) facility shall accommodate the functions of vehicle storage, maintenance and cleaning, component repair, painting, and major vehicle overhaul and repair. Exclusion of any of these functions from the O&M facility shall require Sound Transit approval of an alternative plan for its accomplishment.

B. Maintenance-of-way (MOW) activities shall be conducted and administered at the main yard. If civil constraints will not permit the MOW facility to be located in the main yard, then it shall be located at a satellite facility adjacent to the mainline and with easy access to any point on the line.

C. A facility shall be provided for transportation personnel, including train operators, line supervisors, instructors, crew dispatchers, and division managers. Operations and maintenance staff shall be co-located. The facility shall include dispatch counter, separate men's/women's lockers, showers and toilets, extra's lounge, instruction/conference room, lunchroom, office supplies/copy room, and offices for managers and supervisory staff.

2.6.5 Freight Railroad Operations

Freight railroad vehicles will not be permitted to operate on LRV tracks, unless specially authorized by Sound Transit.

2.6.6 Signaling

A. A signal system sufficient to safely maintain separation of train movements while maximizing line capacity shall be provided on all mainline tracks and in tunnels. On non-exclusive right-of-way, trains shall operate on line-of-sight.

B. Signaling system shall be designed to meet the ultimate design year peak period headway.

2.6.7 Passenger Facilities

A. Passenger facilities shall be configured so that a train operator will have unobstructed views of the full length of the platform and all adjacent walkways.

B. Passenger station platforms and other areas shall be able to accommodate the peak hour passenger volumes.

C. Platforms shall be long enough to accommodate the longest scheduled train anticipated for revenue service.

D. Where possible, pedestrian grade crossing should be combined with vehicle crossings. Pedestrian grade crossing shall be situated so that it is not blocked by the berthing of a passenger train at a station.

E. Passenger stations shall be equipped with a means of communicating directly with the OCC for use by passengers and staff. Platforms shall also be equipped with public address systems and variable message signage for train service information.

F. Passenger station platforms shall be designed to accommodate level boarding for mobility impaired passengers. Stations shall be "Accessible" as defined by the American's Disability Act and local codes and ordinances.

2.6.8 Track Designations

A. All mainline tracks shall be named in the predominant geographic direction of travel. (i.e. NB or SB, EB or WB)

B. Protocol for milepost numbering shall be shown in the respective Operations and Maintenance Plan.

C. Tracks within an O&M Facility shall have a separate convention. Details shall be found in the Operations Plan.

Yard tracks	Y1, Y2, etc.
Shop tracks	S1, S2, etc.

2.7 TERMINAL FACILITIES

A. Each permanent station terminal shall have as a minimum the following facilities:

1. Train Operating Supervisor's booth at platform level at the outbound end of the platform.

2. Booth shall be glass-enclosed, furnished with telephone, public address system, writing surface, secure drawer files, air conditioning and heat, and a train radio.

3. At least one unisex toilet for train operators shall be provided at either track or platform level. Preferably, the toilet will be located adjacent to the supervisor's booth.

2.8 TRACTION POWER SECTIONALIZATION

A. The overhead contact system shall be designed to enable sections of the catenary to be de-energized, while other sections remain energized. The design providing this capability is referred to as traction power sectionalization.

B. Operational requirements for the sectionalization include:

1. General:

a. Means of energizing and de-energizing traction power from the overhead catenary system (OCS) shall be provided at the Operations Control Center (OCC) and at the local traction power sub-stations.

b. Sectionalization design shall allow trains to operate between interlockings within the energized section.

c. This section shall have sufficient energized OCS to allow trains to turnback within the energized section.

d. Means shall also be provided for sectionalizing the OCS on either track using motorized disconnect switches.

e. Sectionalization shall be provided in shop and yard tracks so as to minimize disruption to operation and maintenance functionality.

END CHAPTER 2

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3. ENVIRONMENTAL

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3. ENVIRONMENTAL

3.1 ENVIRONMENTAL REVIEW PROCESS

The environmental review for a project under the National Environmental Policy Act (NEPA) and/or State Environmental Policy Act (SEPA) is typically completed during the preliminary engineering phase of the project. The environmental review is documented in a report or study, typically an Environmental Impact Statement (EIS), Environmental Assessment (EA) or Environmental Checklist. The Central Link light rail (Link) Transit Project completed a Final Environmental Impact Statement (FEIS), dated November 1999. Airport Link issued an Environmental Assessment (EA) updating the 1999 FEIS on May 2005. The North Link project is preparing a supplemental EIS that is planned to be complete late 2005. The 1999 FEIS, Airport Link EA, and North Link Supplemental EIS contain detailed information on the anticipated environmental consequences of the light rail line. These documents also identify potential mitigation measures and actions, which are intended to reduce the level of adverse effects resulting from implementation of the Projects.

3.2 ENVIRONMENTAL MITIGATION COMMITMENTS

The mitigation measures and actions that are committed to as part of the Project are incorporated in the environmental determination or commitment list for the project. This environmental determination is normally a Record of Decision (ROD) or Finding of No Significant Impact (FONSI) under NEPA or commitment list if only SEPA review is required. The Federal Transit Administration (FTA) issued ROD for Airport Link on September 13, 2005 and is expected to issue a ROD for North Link in early 2006. The ROD will detail all of the agreed upon environmental mitigation measures and the means to monitor environmental compliance. All design related mitigation measures contained in the ROD shall be incorporated into the design criteria by reference. Copies of the ROD's for North Link and Airport shall be obtained by the final design team after they are issued by the FTA. Mitigation commitments include actions that may affect the following design criteria:

1. General
2. Civil work
3. Utilities
4. Structural
5. Landscaping

6. Traffic control

3.3 NOISE AND VIBRATION

3.3.1 Introduction

A. The introduction of the light rail system may result in the potential for increased airborne noise and ground-borne noise and vibration. This may be particularly true in the areas where residences exist within 50 feet of the light rail operations or other sensitive receivers such as theaters, recording studios, or research facilities are near. The environmental mitigation commitments identify areas where noise and vibration mitigation will be implemented based on evaluation of the existing environment and the projected future environment. During final design, the analysis of noise, ground-borne noise, and vibration in the environmental documentation shall be refined to provide specific definition of the mitigation measures to be included in the final design. This includes updating the affected receivers and light rail trackway horizontal alignment and vertical profile at both the 60 percent and 90 percent stages of final design. This chapter defines limits of acceptable noise and vibration for the operation of the light rail system.

B. The limits are based on the noise and vibration criteria established in the Federal Transit Administration guidelines in Transit Noise and Vibration Impact Assessment, April 1995, and from state and local noise regulations. Where these noise and vibration criteria do not set a limit, then limits are used that have been found acceptable in previous rail projects. Whenever projections of noise and vibration indicate that the goals established in this document will be exceeded, special noise and vibration control measures shall be implemented to meet the Project environmental commitments, FTA guidelines, or local regulations.

3.3.2 Criteria for Wayside Noise

A. A wayside community noise impact criterion provides a basis to determine whether noise mitigation measures will be required to avoid annoyance in the community. The wayside noise criteria must be related to the type of activities taking place in the building or community and levels of the ambient noise, levels without the transit system noise. A train passby noise of the same level would be more objectionable in a quiet residential area at night than in a busy commercial area during the day.

B. The Link Light Rail criteria for wayside noise is based on the FTA Noise Impact Criteria, which groups noise-sensitive land uses into the following three use categories:

Category 1: Buildings or parks where quiet is an essential element of their purpose.

Category 2: Residences and buildings where people normally sleep. This includes residences, hospitals, and hotels where nighttime sensitivity is assumed to be of utmost importance.

Category 3: Institutional land uses with primarily daytime and evening use. This category includes schools, libraries, churches, office buildings, parks, certain historical sites, recreational facilities, and other commercial and industrial land use.

C. The day/night sound level (L_{dn}) is used to characterize noise exposure for residential areas (Category 2), and the maximum 1-hour L_{eq} during the period that the facility is in use is used for other noise sensitive land uses such as schools and churches (Categories 1 and 3). The existing ambient noise levels, measured as part of the Environmental Document, are at representative locations within each of the effected communities or neighborhoods over a continuous 24-hour period for residential areas, and a 1-hour period representative of the highest noise level period for commercial or institutional areas where there is no nighttime occupancy. The predicted change in the existing ambient noise levels with the transit system in operation will determine the extent of the noise impact and the need for mitigation measures.

3.3.3 Airborne Noise from Above-Ground Train Operations

A. The design criteria for above ground train operations are based on the existing ambient noise level of the effected community. The noise level of train passbys and the frequency of operations are used to determine the cumulative noise level with the transit system in operation over the time period appropriate to the land use affected. A 24-hour period would be used for residential areas and 1-hour period representative of the highest noise level hour would be used for commercial and institutional areas where there is no nighttime occupancy.

B. The noise impact criteria for transit operations are summarized in Table 3-1 for the different land use categories. The first column shows the existing noise exposure, and the remaining columns show how much additional noise exposure from the transit project is necessary to cause either a moderate or severe impact. The future noise exposure would be the combination of the existing noise exposure and the additional noise exposure caused by the transit project. As the existing noise exposure increases, the amount of allowable increase in the noise created by the project decreases.

Future project noise levels that exceed the criteria will require noise mitigation. The application of a moderate and severe impact to the project design is summarized below:

1. ***Moderate Impact:*** In this range, other project-specific factors must be considered to determine the magnitude of the impact and the need for mitigation. These other factors can include: the predicted increase over existing noise levels; the types and number of noise-sensitive land uses affected; existing outdoor-indoor sound insulation; and the cost-effectiveness of mitigating noise to more acceptable levels.

2. ***Severe Impact:*** Severe noise impacts are considered "significant", as this term is used in the National Environmental Policy Act (NEPA) and implementing regulations. Noise mitigation normally must be specified for "severe impact" areas, unless there is no practical method of mitigating the noise.

Table 3-1
Wayside Noise Level Criteria

Existing Noise Exposure Leq or Ldn	Project Noise Exposure Impact Thresholds, Ldn. or Leq[1] (All Noise Levels in dBA)			
	Category 1 or 2 Sites[2]		Category 3 Sites[2]	
	Moderate Impact	Severe Impact	Moderate Impact	Severe Impact
<43	Ambient + 10	Ambient + 15	Ambient + 15	Ambient + 20
43-44	52	<58	57	<63
45	52	<58	57	<63
46-47	53	<59	58	<64
48	53	<59	58	<64
49-50	54	<59	59	<64
51	54	<60	59	<65
52-53	55	<60	60	<65
54	55	<61	60	<66
55	56	<61	61	<66
56	56	<62	61	<67
57-58	57	<62	62	<67
59-60	58	<63	63	<68
61-62	59	<64	64	<69
63	60	<65	65	<70
64	61	<65	66	<70
65	61	<66	66	<71
66	62	<67	67	<72
67	63	<67	68	<72
68	63	<68	68	<73
69	64	<69	69	<74

70	65	<69	70	<74
71	66	<70	71	<75
72-73	66	<71	71	<76
74	66	<72	71	<77
75	66	<73	71	<78
76-77	66	<74	71	<79
>77	66	<75	71	<80

Notes:
[1] L_{dn} is used for land uses where nighttime sensitivity is a factor; Daytime L_{eq} is used for land use involving only daytime activities.
[2] Category Definitions:
Category 1: Buildings or parks, where quiet is an essential element of their purpose.
Category 2: Residences and buildings, where people normally sleep. This includes residences, hospitals and hotels, where nighttime sensitivity is assumed to be of utmost importance.
Category 3: Institutional land uses with primarily daytime and evening use. This category includes: schools, libraries, and churches.

Source: FTA Guidance Manual for Transit Noise and Vibration Impact Assessment, 1995.

3.3.4 Wheel Squeal

A. Sections of track with tight curves may potentially create a nuisance noise condition referred to as wheel squeal. The sliding or rubbing of the steel wheels of the LRT cars across the head of the steel rail causes wheel squeal. Wheel squeal may occur along tight curves in the track with radii of less than 400 feet. Other factors that may affect the potential for wheel squeal include: speed of the LRT train; rail vehicle truck geometry and rigidity; the conditions of the wheels and tracks; wheel damping technology; and contact-surface frictional characteristics.

B. The potential for wheel squeal shall be identified at locations where tight-radius curve trackwork is in close proximity to residential buildings. Since it is only possible to anticipate, but not to predict the occurrence of wheel squeal, mitigation measures shall be made available to treat a potential problem as soon as pre-revenue system operations begin. During pre-revenue testing of LRT operations, wayside noise levels shall be measured at the nearest residential building to these tight-radius curve locations. These measurements shall be compared to measurements taken along tangent sections of trackwork, at the same operating speed and distance to the track, to determine if the tight-radius curves may be increasing the wayside noise levels. If audible wheel squeal or higher noise levels are present, then either of the following measures, whichever is more appropriate, may be implemented before the start of revenue service.

1. ***Dry-stick friction modifiers:*** Apply friction modifiers on the wheel tread or directly on the running surface of the rail.

2. ***Lubrication:*** Wayside lubrication applied to the rail gauge face and wheel flange.

C. If the wheel squeal remains after these measures have been implemented, then sound insulation of residential buildings may be considered to reduce the interior noise levels. The sound insulation measures may consist of providing air-conditioning, double-paned windows, and adding insulation to the walls and ceiling of each residential building.

3.3.5 Roadway Traffic Noise

Traffic noise is also a potential impact when a project realigns or widens a highway, potentially moving it closer to sensitive receptors such as residences, schools, churches, and libraries. The criterion used to evaluate these impacts is taken from FHWA guidance, with additional guidance from WSDOT. The WSDOT criterion applicable to sensitive receptors is an exterior equivalent noise level (L_{eq}) from the project exceeding 66 dBA. The criterion for most other developed lands is 71 dBA. WSDOT also considers a traffic noise impact to occur when projected noise levels increase existing levels by 10 dBA or more.

3.3.6 Noise Mitigation Measures

Sound Transit requires that mitigation measures be reasonable as defined by the Link Noise Mitigation Policy, adopted by Sound Transit Board Motion No. M2004-08.

3.3.7 Ground-Borne Vibration Criteria

Ground-borne noise and vibration are exactly the same phenomena, up to the point of perception at the dwelling. Ground-borne vibration describes waves in the ground, which can be measured using vibration pickups mounted on side-walks, foundations, basement walls, or stakes in the ground and which can be perceived as mechanical motion. Ground-borne noise describes sound generated when the same waves in the ground reach room surfaces in the buildings, causing them to vibrate and radiate sound waves into the room.

3.3.7.1 Ground-Borne Noise from Train Operations

Table 3-2 presents the criteria to be used for maximum ground-borne noise due to train operations for different categories of land uses. As with airborne noise, there are some types of buildings for which specific design criteria should be applied, regardless of area category. Table 3-3 presents the design criteria for transient ground-borne noise levels to be used for occupied spaces of various types of buildings and rooms.

3.3.7.2 Ground-Borne Vibration from Train Operations

A. Table 3-2 presents the criteria to be used for maximum ground vibration for different categories of land uses. The criteria apply to measurements of vertical vibration of floor surfaces within the buildings.

B. As with ground-borne noise, there are some types of buildings for which specific design criteria for ground-borne vibration should be applied, regardless of area category. Table 3-3 presents the design criteria for ground-borne vibration levels to be used for occupied spaces of various types of buildings and rooms. Any other structures shall be evaluated on a site-specific basis.

C. Ground-borne vibration meeting the design criteria listed in Tables 3-2 and 3-3 may not be imperceptible in all cases. The criteria are based on minimizing the occurrence of any significant intrusion or annoyance. In most cases, there will be vibration from street traffic, other occupants of a building, or other sources that will create intrusion that is equal to or greater in level than the vibration from the transit trains.

Table 3-2
Maximum Ground Borne Noise and Vibration Criteria

Land Use Category	Ground-Borne Vibration Impact Levels (VdB re: 1 micro inch/sec)		Ground-Borne Noise Impact Levels (dB re: 20 micro Pascals)	
	Frequent Events[1]	Infrequent Events[2]	Frequent Events[1]	Infrequent Events[2]
Category 1: Buildings where low ambient vibration is essential for interior operations.	65VdB[3]	65VdB[3]	See Note 4	See Note 4
Category 2: Residences and buildings where people normally sleep.	72 VdB	80 VdB	35 dBA	43 dBA
Category 3: Institutional land uses with primarily daytime use.	75 VdB	83 VdB	40 dBA	48 dBA

Notes:
1 "Frequent Events" is defined as more than 70 vibration events per day.
2 "Infrequent Events" is defined as fewer than 70 vibration events per day.
3 This criterion is based on levels that are acceptable for most moderately sensitive equipment, such as optical microscopes. Vibration sensitive manufacturing or research would require detailed evaluation to define the acceptable vibration levels. Ensuring lower vibration levels in a building often requires special design of the HVAC system and stiffened floors.
4 Vibration-sensitive equipment is not sensitive to ground-borne noise.

Source: Transit Noise and Vibration Impact Assessment, FTA, April 1995.

Table 3-3 Maximum Ground-Borne Noise and Vibration Criteria for Special Buildings				
Type of Building or Room	Ground-Borne Vibration Impact Levels (VdB re: 1 micro inch/sec)		Ground-Borne Noise Impact Levels (dB re: 20 micro Pascals)	
	Frequent Events[1]	Infrequent Events[2]	Frequent Events[1]	Infrequent Events[2]
Concert Halls, TV Studios, Recording Studios	65 VdB	65 VdB	25 dBA	25 dBA
Auditorium	72 VdB	80 VdB	30 dBA	38 dBA
Theaters	72 VdB	80 VdB	35 dBA	43 dBA

Notes:
1 "Frequent Events" is defined as more than 70 vibration events per day.
2 "Infrequent Events" is defined as fewer than 70 vibration events per day. This category includes most commuter rail systems.

Source: Transit Noise and Vibration Impact Assessment, FTA, April 1995.

3.3.8 Ancillary Equipment Noise

A. Power substations, ventilation fans, vent shafts, and other mechanical equipment required for a rail transit system can all be intrusive sources of noise. In some cases, the noise is particularly intrusive because of its tonal character. Table 3-4 presents the design goals for community noise attributable to all ancillary equipment. The noise limits shall be reduced by 5 dBA if the noise has pure tones or contains an audible screech, whine, or hum, or contains information content such as music or public address system announcements.

B. In areas where the existing noise level (Leq) is greater than the limits in Table 3-4 for continuous noise, higher noise limits can be applied. Intermittent noise is defined as a noise that lasts for a cumulative period of less than 10 minutes every hour. In no case shall the noise from the ancillary equipment result in an increase in the existing Ldn of more than 3 dBA.

Table 3-4 Noise From Transit System Ancillary Facilities – Leq (dBA)			
District of Sound Source	**District of Receiving Property Within the City of Seattle**		
	Residential (dBA)	Commercial (dBA)	Industrial (dBA)
Residential	55/45	57/47	60/50
Commercial	57/47	60/50	65/55
Industrial	60/50	65/55	70/60

Note:
[1] The noise level limits are presented for (daytime)/ (nighttime). Daytime is 7 a.m. to 10 p.m. and nighttime 10 p.m. to 7 a.m.
[2] For intermittent noise sources add 10 dB.

3.3.9 Yard and Shop Noise

A. The storage and inspection yards and maintenance shops shall be designed such that the noise level at the property boundary does not exceed the limits shown in Table 3-4. The applicable limit is based on the zoning of the affected property. The limits of Table 3-4 shall be reduced by 5 dBA for any noise such as wheel squeal that has an audible screech, whine or hum, or contains information content such as music or yard intercom announcements.

B. Allowance should be made for areas with high existing noise. In areas where the existing Ldn is greater than 60 to 65 dBA, the Ldn due to the Yards and Shops noise shall be less than or equal to the existing Ldn. This is equivalent to specifying that the introduction of this additional noise source shall not increase the existing Ldn by more than 3 dBA.

C. Much of the equipment use in maintenance facilities has the potential of creating loud noise. To avoid excessive noise exposure of the employees, and to comply with existing and proposed standards of the Occupational Safety and Health Administration, shop equipment shall not exceed 85 dBA at operator stations and 90 dBA at any point 3 feet from the equipment. In areas where these limits cannot be complied with, hearing protection for the employees shall be required.

3.3.10 Park-and-Ride Noise Levels

Potential noise impacts that may be associated with park-and-ride facilities and is generally associated with noise form bus traffic on the park-and-ride site. The park-and-ride shall be designed in accordance with the guidance provided by the FTA *Transit Noise and Vibration Impact Assessment* report such that the noise level at the property boundary does not exceed the limits of Table 3-1. The principal noise control

measure is the use of barriers when the location of bus traffic is close enough to sensitive receivers that it exceeds the applicable limit.

3.3.11 Station Noise Control

Providing a comfortable acoustical environment for patrons requires careful attention to the use of acoustical absorption materials in any enclosed areas, control of noise from any mechanical equipment associated with the station, avoiding excessive noise as trains enter and leave the station and protection of public areas from external noise sources such as traffic and railroads. The criteria for station acoustics include maximum noise level limits for public areas and reverberation time goals for enclosed areas. In addition to presenting the noise and reverberation criteria, this chapter provides some general guidelines on the use of acoustically absorptive treatments in enclosed spaces.

3.3.11.1 Design Goals

A. The design goals for station noise have been set at levels that will provide a comfortable acoustical environment for the patrons. It should be possible to achieve these limits without extraordinary noise control measures.

B. Table 3-5 summarizes the noise limits for various station noises. The limits on train noise are largely dependent on the noise emission characteristics of the transit vehicle. Assuming that the delivered vehicle is in compliance with noise specifications, and the station design has acoustical absorption treatment consistent with the guidelines of section 3.3.13, the limits on train noise in Table 3-5 will be achieved. These limits do not apply to equipment rooms that will not contain noisy equipment, are not near public spaces, or do not require extensive maintenance.

C. The public spaces of unenclosed stations are sometimes exposed to noise from external sources such as freeway traffic and railroad trains. There are relatively few options available for reducing noise from external sources once the basic station layout and design have been developed. The principal noise control measure is the use of barriers or partial enclosures to block the line-of-sight path of the sound. In some cases, careful placement of acoustical absorption treatment will help reduce noise exposure.

D. The traffic noise limit of a maximum hourly L_{eq}[1] of 72 dBA is consistent with the FHWA guidelines for maximum acceptable traffic noise in commercial areas and should be used as a goal. At this noise level, it is possible to hold a conversation at a distance of 2 to 4 feet with a normal voice level.

Table 3-5
Design Criteria for Patron Noise Exposure in Stations

CONDITION	Lmax (dBA)
ON PLATFORM, TRAINS ENTERING AND LEAVING	
Subway	80
At-grade/above ground, tie and ballast track	80
At-grade/above ground, concrete trackbed	83
ON PLATFORM, TRAINS STATIONARY	
Subway	68
At-grade/above ground	68
ON PLATFORM OR IN ENCLOSED PUBLIC AREAS	
Ancillary Systems Operating	55[1]
Emergency Ventilation Systems operating	70 – 75[1]
ESCALATORS	
5 feet above tread, at entrance combs	55
ELEVATORS	
In cab, 5 feet above floor, 1 foot or more from wall, continuous noise	55
In cab, 5 feet above floor, 1 foot or more from wall, intermittent noise, peak	60[2]
3 feet or more from elevator equipment, continuous noise	55
3 feet or more from elevator equipment, intermittent noise	60[2]
Door operation, 3 feet or more from door	60[2]
CONDITION	
NOISE FROM OTHER EXTERNAL SOURCES (Without Train Passby)	
Street and freeway traffic	Leq = 72[3]

[1] L_{eq} is the energy average of a fluctuating sound averaged over a given time period.

Other intermittent sources	Leq = 75
NOISE IN MECHANICAL EQUIPMENT ROOMS	Lmax = 85[2]

Note:
[1] Community noise from station ancillary systems is covered in sub-chapter 3.3.4.
[2] Maximum level using the Slow Meter setting on a standard sound level meter.
[3] Highest traffic noise hourly L_{eq}. Traffic noise can be predicted using "FHWA Traffic Noise Model (TNM)," published by US DOT/FHWA, Office of Research, Office of Environmental Policy, Washington, D.C.

3.3.12 Reverberation Time Limits

A. Reverberation refers to the persistence of a sound in an enclosed space, as a result of multiple reflections, after the sound source has stopped. The more reverberant a space is, the more prone the area will be to acoustical energy building up in the space. A classic example is a subway station with almost all-hard, acoustically reflective surfaces. In such a space, the reflected sound will build up and can result in very high noise in a subway station. Controlling reverberation in the subway station and any other enclosed or partially enclosed public area is necessary in order to control crowd, train, and mechanical equipment noise. It is also required for audibility of public address systems.

B. "Reverberation time" is defined as the time that it takes a sound to decay 60 dB once the sound is suddenly interrupted. It is a measure of the persistence of an impulsive sound and the amount of acoustical absorption in the room. Table 3-6 presents the reverberation time goals for the Link light rail Transit Project stations. All enclosed public spaces should be designed to meet these limits on reverberation time.

C. The reverberation time of a space is dependent on the amount of acoustical absorption in the space. As the room size increases, the design goal reverberation time increases. The increase is approximately 0.1 seconds for each doubling of the room volume. As indicated in Table 3-6, the design goal reverberation time for a large space such as a subway station platform is 1.2 seconds. For a smaller enclosed space such as a mezzanine or passageway, the design reverberation time is reduced to 1.0 seconds.

D. Table 3-6 gives the design reverberation times at 500 Hz. Reverberation at other frequencies is equally important; however, with the acoustical materials meeting the criteria of section 3.3.13, the reverberation at other frequencies will be satisfactory.

Table 3-6 Reverberation Time Criteria (500 Hz)		
AREA	**MAXIMUM**	**GOAL**
Station platform areas, subway, at-grade, and above ground	1.5 seconds	1.2 seconds
Enclosed public spaces	1.2 seconds	1.0 second

3.3.13 Acoustical Absorption Treatments

Areas that will require acoustical absorption treatment are enclosed platform areas, enclosed passageways, enclosed mezzanines, mechanical and electrical equipment rooms, and ventilation shafts and plenums. At-grade and above-ground stations that are only partially enclosed will not generally require acoustical treatment.

3.3.13.1 Acoustical Absorption Materials

Acoustical materials shall be noncombustible, non-fibrous, non-asbestos, nonwicking, able to withstand heavy pressure water washing, suitable for exterior weather exposure, and shall be selected in accordance with the criteria set forth in Chapter 18, Fire/Life Safety. If located in public areas, they shall be out of reach of the public. If mechanical protection is to be provided with perforated panels, a minimum open area of 30 percent shall be maintained.

3.3.13.2 Required Amounts of Treatment

A. The required amount of treatment is dependent on the characteristics of the material used. It is recommended that a material with a Noise Reduction Coefficient (NRC) of at least 0.6 be used. In the station area and mechanical ventilation shafts, an additional requirement is that the treatment shall have minimum sound absorption coefficients of 0.26 at 125Hz, 0.6 at 250 Hz, and 0.8 at 500 Hz.

B. Following is a summary of recommended acoustical treatments for enclosed station spaces:

   1. ***Enclosed platforms:*** Treatments covering a minimum of 35 percent of the total wall and ceiling area. This shall include at least 50 percent of the ceiling area.

2. ***Other Enclosed Spaces:*** Treatment shall cover a minimum of 35 percent of the wall and ceiling area. This shall include at least 50 percent of the ceiling area.

3.3.14 Noise in Subway Tunnels

A. The noise levels inside the Link vehicle while it is in subway tunnel will be a function of the sound transmission loss characteristics of the transit vehicle, the acoustical absorption characteristics of the tunnel walls, and the noise emission characteristics of the vehicle. The goal for the noise level inside the car while operating at 40 mph in tunnel shall be 80 dBA.

B. Meeting the 80 dBA limit will require the Link vehicle to have effective sound isolating characteristics or the use of a sound absorption system on the tunnel walls and ceiling. Tunnel sound absorption treatment can reduce the car interior noise by as much as 5 dBA.

C. Vibration Isolation of Subway Structures

1. The subway structure shall never be in direct contact with a building structure or foundation. No less than 2 feet of intervening soil shall be provided between the subway structure and any existing building structure or foundation.

2. Whenever there is less than 2 feet of intervening soil between a building and the subway structure, an elastomer element shall be placed between the building and the subway structure. This will prevent direct transmission of noise and vibration to the building.

3. The elastomer element shall consist of a closed-cell neoprene pad selected to give proper support of hydraulic and structural loads. The deflection of the elastomer pad shall not exceed 20 percent of the pad thickness. The pad shall be at least 1 inch thick.

3.3.15 Noise and Vibration Characteristics of the Light Rail Vehicle

The noise and vibration design criteria for the light rail vehicle are provided in Chapter 12, Light Rail Vehicle, section 12.7.4, Noise and section 12.7.5, Shock and Vibration.

Table 3-7
NOISE EMISSION CHARACTERISTICS FOR Light Rail Transit Vehicles

INTERIOR NOISE	
Car stationary, all auxiliary equipment operating, normal conditions	72 dBA
Any one system of equipment operating	68 dBA
WAYSIDE NOISE (50 FEET FROM CAR)	
Vehicle stationary, empty	68 dBA
Vehicle moving (40 mph, tangent track)	75 dBA
Dynamic braking from 40 mph	75 dBA
EQUIPMENT NOISE, PRIOR TO INSTALLATION	
Each truck's traction motors, 16 feet from center of motor, in any direction, at all speeds from zero to the equivalent of 55 mph.	93 dBA
Each propulsion gear system and couplings at 16 feet from geometric center of the gearbox, in any direction, at all speeds from zero to the equivalent of 55 mph.	85 dBA
Noise produced by undercar or roof-mounted equipment, 16 feet from center of equipment, normal conditions and loads.	80 dBA
Air conditioning equipment in simulated enclosure, anywhere inside the enclosure.	68 dBA
EQUIPMENT NOISE AFTER INSTALLATION ON CAR	
Traction motors and gear sets of complete truck, no load conditions, wheels spinning at speeds equivalent to 0 to 55 mph, 16 feet from center of truck.	93 dBA
Individual operation of under car and roof mounted equipment, 16 feet car centerline, normal conditions. (Traction motors, gears, and equipment that operate occasionally are excepted.)	67 dBA
EQUIPMENT NOISE AFTER INSTALLATION ON CAR	
Individual operation of under car and hood-mounted equipment that operates, 16 feet from car centerline.	100 dBA
Air conditioning equipment in conjunction with operating static inverter, anywhere inside car with doors closed.	68 dBA

END CHAPTER 3

4. TRACK ALIGNMENT & VEHICLE CLEARANCES

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4. TRACK ALIGNMENT & VEHICLE CLEARANCES

4.1 INTRODUCTION

A. The criteria set forth in this chapter for the design of Link light rail Transit Project (Link) system alignments have been established to allow the provision of comfortable, economical, and efficient transportation for passengers while maintaining adequate factors of safety with respect to overall operation, maintenance, and vehicle stability. They have been developed by utilizing accepted engineering practices and the experiences of currently operating rail transit and railroad systems.

B. This chapter includes criteria for the design of Link horizontal track alignments, vertical track alignments, alignments through areas of special trackwork, and horizontal and vertical clearance requirements.

4.2 LIGHT RAIL TRANSIT TRACK ALIGNMENT AND CLEARANCES

4.2.1 General

A. Except for areas where Link operates within or adjacent to surface streets, the track alignment shall be designed to accommodate the maximum design speed of 55 miles per hour (mph). Physical constraints along various portions of the system, together with other design limitations, may preclude achievement of this objective. Where Link operates within or adjacent to surface streets, the maximum design speed for the track alignment shall be limited to the legal speed of the parallel street traffic. In all areas, the civil design speed shall be coordinated with the normal operating speeds as provided on the train performance simulation program speed-distance profiles.

B. Engineering stationing shall generally progress from the Downtown Seattle Transit Tunnel, increasing in an outbound direction. Stationing protocol shall remain independent of any mileposting system which may be instituted for operational purposes and which may actually run in the opposite direction from the engineering stationing.

C. When viewing the Link alignment looking ahead station (outbound), the track on the viewer's right shall be designated as the Control Track. Stationing shall be continuous along the length of the Control Track and this track shall be the basis of control for locating all other system facilities along the route. Independent stationing shall be required for all other tracks when tracks are neither parallel nor concentric, where widened track centers are required around curves,

where parallel tracks have independent profiles, or where tracks are in separate structures. All centerline stationing shall bear a prefix indicating the normal direction of LRV travel, i.e., NB, SB, EB, WB. Where curvature results in different stationing at the end of a curve, non-control track stationing shall be equated to the Control Track stationing at the spiral to tangent (ST) point of whichever track has the spiral that extends the farthest ahead station. Geometrics shall be developed for all tracks.

D. Where the Link system includes at-grade portions where light rail vehicles will operate in mixed traffic with rubber-tired vehicles in surface streets, the applicable geometric design criteria of the local municipality for such streets shall be met in the design of the track alignment.

E. Coordination of horizontal and vertical alignment shall avoid a combination of minimum radius, maximum grade, and maximum unbalanced superelevation.

4.2.2 Horizontal Alignment

The horizontal alignment of mainline tracks shall consist of a series of tangents joined to circular curves by means of spiral transition curves. Superelevation shall be used to maximize running speeds where it does not interfere with pavement grades in areas of mixed traffic operation. The nomenclature used to describe horizontal alignments shall be consistent with that illustrated in Figure 4.1.

4.2.3 Tangent Alignment

A. The minimum length of tangent track between curved sections of track shall be as follows:

Condition	Tangent Length
Desirable Minimum	200 feet
Minimum	100 feet, or three times the design speed (in mph), whichever is greater
Absolute Minimum (not to be reduced without Sound Transit approval)	40 feet

B. If adjacent curves in the same direction, which are in close proximity to one another, cannot be replaced by a single simple curve due to geometric constraints, a series of compound curves joined by means of spiral transition curves shall be the preferred arrangement. Broken back curves, (e.g., short tangents between curves in the same direction) shall be avoided.

C. At station platforms, the horizontal alignment shall be tangent throughout the entire length of the platform. The tangent shall be extended beyond both ends of the platform as follows:

Condition	Tangent Length
Desirable Minimum	75 feet
Minimum	60 feet
Absolute Minimum (not to be reduced without Sound Transit approval	45 feet

D. All special trackwork shall be located on horizontal tangents. Refer to Chapter 5, Trackwork, Section 5.24, Special Trackwork, for minimum tangent length criteria in areas of special trackwork.

4.2.4 Curved Alignment

A. Types of Curves

Intersections of horizontal tangents shall be connected by circular curves. The curves may be either simple or spiraled and may include superelevation, as required by this criteria.

B. Circular Curves

Circular curves shall be specified by their radius. Degree of curvature, where required for calculation purposes, shall be defined by the arc definition of curvature as determined by the following formula:

$$D = \frac{5729.578}{R}$$

Where,

D = degree of curvature

R = radius of curvature, in feet

1. The minimum radii for mainline tracks shall be as follows:

Location	Minimum Radius
Aerial structures	500 feet*
At-grade ballasted	300 feet*
Subway section	250 feet*
In-street	100 feet*
*Not to be reduced without Sound Transit approval **Requires a posted speed reduction	

2. The minimum radii for yard and service tracks shall be as follows:

Location	Minimum Radius
Yard and service tracks	100 feet*
*Not to be reduced without Sound Transit approval	

3. The desirable minimum circular curve length shall be determined by the following formula:

$$L = 3V$$

Where,

L = minimum length of curve, in feet

V = design speed through the curve, in mph

C. For spiraled circular curves, the length in feet of the circular curve added to the sum of one half the length of both spirals shall be an acceptable method of determining compliance with the desirable minimum length criteria. The absolute minimum length of a superelevated circular curve shall be 45 feet.

D. Curves that include no actual circular curve segment (e.g., double-spiraled curves) shall be permitted in areas of extremely restricted geometry provided no actual superelevation (Ea) is used and Sound Transit approval has been obtained.

E. The design speed for a given horizontal curve shall be based on its radius, length of spiral transition, and actual and unbalanced superelevation through the curve as described in the following sections.

F. Superelevation

1. Mainline tracks shall be designed with superelevation so as to permit desired design speeds to be achieved without resorting to excessively large radii of curvature. Note that due to local constraints, the design speed may be less than either the system maximum speed or the maximum possible speed for a curve of a given radius. The design speed criteria stated herein are based on a maximum lateral acceleration of the passenger of 0.1 g.

2. Equilibrium superelevation is the amount of superelevation that would be required so that the resultant force from the center of gravity of the light rail vehicle will be perpendicular to the plane of the two rails and halfway in between them at a given speed. If a curved track is superelevated so as to achieve equilibrium at a given speed, a light rail vehicle passenger would experience no centrifugal force through the curve at that speed. Equilibrium superelevation shall be determined by either of the following equations:

$$Eq = Ea + Eu = 3.96 \left(\frac{V^2}{R} \right)$$

Or

$$Eq = 0.00069\, V^2\, D$$

Where Eq = equilibrium superelevation, in inches

Ea = actual track superelevation to be constructed, in inches

Eu = unbalanced superelevation, in inches

V = design speed through the curve, in mph

R = radius of curve, in feet

D = degree of curve, in degrees (arc definition)

3. In practice, the full equilibrium superelevation (Eq) is rarely installed in track as doing so would require excessively long spiral transition curves. It could also produce passenger discomfort on board a train that is moving much slower than the design speed or stopped in the middle of a steeply superelevated curve. Therefore, only a portion of the calculated Eq, the actual superelevation Ea, shall be applied. The difference between the equilibrium superelevation and the actual superelevation is called the unbalance, and is designated as Eu.

4. Desirable values of actual superelevation (Ea) to be applied shall be determined by the following formula:

$$Ea = 2.64 \left(\frac{V^2}{R} \right) - 0.66$$

5. The desirable Ea value is derived based on the following relationship between Ea and Eu:

$$Eu - \left(\frac{Ea}{2} \right) = 1$$

6. The use of these equations will result in the gradual introduction of both actual and unbalanced superelevation and avoid unnecessary lateral acceleration of light rail vehicles and their passengers. Calculated values for actual superelevation shall be rounded to the nearest 1/4 inch. For an equilibrium superelevation (Ea + Eu) of 1 inch or less, no actual superelevation (Ea) shall be applied. In specific cases where physical constraints limit the amount of Ea which can be introduced, a maximum of 1-1/2 inches of Eu shall be permitted without introduction of Ea.

7. Actual superelevation (Ea) shall be attained and removed linearly throughout the full length of the spiral transition curve by raising the outside rail while maintaining the inside rail at the profile grade.

8. In extraordinary cases, Sound Transit may grant approval for the introduction of superelevation in a curve with no spirals. In such cases, superelevation shall be developed along the tangent immediately preceding the point of curvature (PC), and shall be run out in the tangent immediately beyond the point of tangency (PT). The transition length is then determined from the minimum spiral length formulae of this section. The maximum amount of superelevation, which may be run out in tangent track, shall be 1-1/2 inches.

9. The maximum values for actual and unbalanced superelevation shall be as follows:

Superelevation	Maximum Value
Ea =	4 inches desirable *
	6 inches absolute
Eu =	3 inches desirable *
	4.5 inches absolute
* Not to be exceeded without approval of Sound Transit	

10. Ea shall be set so that trains will have a positive Eu on curves where speed is likely to vary.

11. Figure 4.2 provides desirable values of actual superelevation to be provided in Link alignment calculations. Other combinations of Ea and Eu may be used where physical restrictions make the use of Figure 4.2 prohibitive or impractical.

G. Spiral Transitions

1. Spiral transition curves shall be used to develop the superelevation of the track and limit lateral acceleration during the horizontal transition of the light rail vehicle as it enters the curve. Spiral transition curves shall be clothoid spirals as depicted in Figure 4.1 and as defined by Hickerson[1]. Spirals shall be required on all mainline track horizontal curves with a radius less than 10,000 feet.

2. The minimum length of spiral shall be the greater of the lengths determined from the following formulae (rounded off to the next largest 10 feet), but preferably not less than 60 feet:

$$Ls = 31\ Ea$$

$$Ls = 0.82\ Ea\ V$$

$$Ls = 1.10\ Eu\ V$$

Where,

Ls = minimum length of spiral, in feet.

3. Where geometric conditions are extremely restricted, the spiral length may be reduced to the absolute minimum of 30 feet. Spiral lengths of less than 30 feet may be used provided that Sound Transit approval has been obtained.

4. A spiral is preferred, but not required for yard and secondary tracks where design speeds are less than 10 mph. Yard and secondary tracks, which have design speeds greater than 10 mph, shall have spirals. Superelevation is required when at all feasible.

5. Figure 4.2 provides minimum spiral lengths for various combinations of design speed, radius of curvature, and desirable actual superelevation.

[1]Thomas F. Hickerson, *Route Location Design*, 5th ed (New York: McGraw-Hill, 1964), pp. 168-171, 374-375.

H. Compound Circular Curves

1. Where compound curves are used, they shall be connected by a spiral transition curve. The absolute minimum spiral length shall be the greater of the lengths as determined by the following (rounded off to the next largest 10 feet):

$$Ls = 31\ (Ea_2 - Ea_1)$$

$$Ls = 0.82\ (Ea_2 - Ea_1)\ V$$

$$Ls = 1.10\ (Eu_2 - Eu_1)\ V$$

Where Ls = minimum length of spiral, in feet.

Ea_1 = actual superelevation of the first circular curve, in inches

Ea_2 = actual superelevation of the second circular curve, in inches

Eu_1 = unbalanced superelevation of the first circular curve, in inches

Eu_2 = unbalanced superelevation of the second circular curve, in inches

V = design speed through the circular curves, in mph

2. Spiral transition curves connecting compound curves are not required when both (Ea_2 - Ea_1) and (Eu_2 - Eu_1) are less than 1 inch. For compound circular curves without a spiral, the change in superelevation shall be run out entirely within the curve of the larger radius.

I. Reverse Curves

1. Where extremely restrictive horizontal geometrics make it impossible to provide sufficient tangent length between reversed superelevated curves, the curves may meet at a point of reverse spiral upon approval from Sound Transit. The reverse spirals shall be designed so that:

$$Ls_1 \times Ea_2 = Ls_2 \times Ea_1$$

Where Ea_1 = actual superelevation applied to the first curve

Ea_2 = actual superelevation of second circular curve, (inches)

Ls_1 = the length of the spiral leaving the first curve

Ls_2 = the length of the spiral entering the second curve

2. A maximum tangent length of 3 feet between the spirals is acceptable in lieu of meeting at a point.

3. The superelevation transition between reversed spirals shall be accomplished by sloping both rails of the track throughout the entire transition spiral as shown on Figure 4.3. Note that through the entire transition, both rails will be at an elevation above the theoretical profile grade line. Actual superelevation applied on the left and right rail will be equal at the point of reverse spiral. This method of superelevation transition creates additional design considerations including an increased ballast section width at the point of reverse spiral and possible increased clearances. Such issues shall be investigated in detail and all impacts identified in the exception application to Sound Transit.

4.2.5 Vertical Alignment

4.2.5.1 General

A. The vertical alignment shall be composed of constant grade tangent segments connected at their intersection by parabolic curves having a constant rate of change in grade. The nomenclature used to describe vertical alignments shall be consistent with that illustrated in Figure 4.4.

B. The profile grade line in tangent track shall be along the centerline of track between the two running rails and in the plane defined by the top of the two rails. In curved track, the inside rail of the curve shall remain at the profile grade line and superelevation achieved by raising the outer rail above the inner rail.

C. In areas of horizontal curvature where the profile is given for the right track only, the top of rail elevation of the left track shall be adjusted uniformly throughout the curve to compensate for the difference in horizontal curve lengths.

4.2.5.2 Vertical Grades

The following profile grade limitations shall apply:

MAINLINE TRACKS	
Maximum (sustained grade unlimited length)	4.00%
Maximum (sustained grade with up to 2500 feet between PVIs of vertical curves)	6.00%
Maximum (short sustained grade with no more than 500 feet between PVIs of vertical curves)	7.00%
Minimum (for drainage on direct fixation track) including stations	0.20%
YARD TRACK & POCKET TRACKS	
Desirable	0.00%
Preferred Maximum	1.00%
Absolute Maximum	2.00% *

* Not to be exceeded without Sound Transit approval.

A. No minimum grade is specified at passenger stations provided adequate track drainage can be maintained. In CBD areas, the existing street profile may govern the profile grade within the station. In this case, the profile grade may exceed 2.0 percent, but shall be restricted to a maximum of 3.5 percent.

B. All tracks entering the yard shall either be level, sloped downward away from the mainline, or dished to prevent rail vehicles rolling from the yard onto the mainline. For yard secondary tracks, it is desirable to have a slight grade, maximum 1.0 percent and minimum 0.35 percent, to achieve good track drainage at the subballast level.

C. Through storage tracks shall have a sag in the middle of their profile to prevent rail vehicles from rolling to either end. It is desirable that the profile grade of a stub end storage track descend toward the stub end, and, if adjacent to a mainline or secondary track, be curved away from that track at its stub end. If it is necessary for the profile grade of a storage track to slope up toward the stub end, it is desirable that the grade shall not exceed 0.2 percent.

D. Tracks located within maintenance shop buildings shall be level.

4.2.5.3 Vertical Tangents

A. The minimum length of constant profile grade between vertical curves shall be as follows:

Condition	Length
Desirable Minimum	100 feet or 3 times the design speed (in mph), whichever is greater
Minimum	40 feet

B. In CBD areas, where the need to conform to existing street profiles makes compliance with the above criteria economically unfeasible, the above requirement may be waived with approval from Sound Transit. In such cases, consideration shall be given to reverse or compound vertical curves, so as to avoid abrupt changes in vertical acceleration which could result in both passenger ride discomfort and excessive vehicle suspension system wear and tear.

C. The profile at stations shall be on a vertical tangent that extends 40 feet beyond each end of the platform. Special trackwork shall be located on vertical tangents. Refer to Chapter 5, Trackwork, section 5.24, Special Trackwork for minimum vertical tangent length criteria in areas of special trackwork.

4.2.5.4 Vertical Curves

A. All changes in grade shall be connected by vertical curves. Vertical curves shall be defined by parabolic curves having a constant rate of change in grade.

1. Vertical Curve Lengths

a. The minimum length of vertical curves shall be determined as follows:

Desirable length	LVC = 200A
Preferred minimum length	LVC = 100A

b. Absolute minimum vertical curve length shall be the longer vertical curve length determined by the formula below:

Crest curves $LVC = \frac{AV^2}{25}$ or $LVC = .01\ RvcA$

Sag curves $LVC = \frac{AV^2}{45}$ or $LVC = .01\ RvsA$

Where LVC = length of vertical curve, in feet

A = (G2 - G1) = algebraic difference in gradients connected by the vertical curve, in percent.

G1 = percent grade of approaching tangent

G2 = percent grade of departing tangent

V = design speed, in mph

Rvc = 820 feet, minimum equivalent radius, crest

Rvs = 1150 feet, minimum equivalent radius, sag

c. Both sag and crest vertical curves shall have the maximum possible length, especially if approach and departure tangents are long. Vertical broken back curves and short horizontal curves at sags and crest of vertical curves shall be avoided.

d. Minimum vertical curve length and/or design speed may be governed by the overhead contact system (OCS) due to the maximum permissible rate of separation or convergence between the track grade and the contact wire grade. Coordination with the OCS designer shall be required to ensure compliance with this limitation.

2. Compound Vertical Curves

Compound and unsymmetrical vertical curves shall be permitted provided each curve conforms to the requirements stated in section 4.2.5.4, and Sound Transit approval has been obtained.

3. Combined Vertical and Horizontal Curvature

Where possible, areas of combined vertical and horizontal curvature shall be avoided. Where areas of combined vertical and horizontal curvature cannot be avoided, the geometrics shall not be more restrictive than a 100-foot radius horizontal curve combined with an 820-foot equivalent radius vertical crest curve.

4.2.6 Vehicle Clearances

4.2.6.1 General

This section establishes the minimum dimensions required to ensure proper clearances between the light rail vehicles or transit structures, and the obstructions involved. All designs shall meet or exceed the minimum clearance criteria as specified herein. Since the provision of adequate clearances for the safe passage of light rail vehicles is one of the most fundamental concerns inherent in the design of the system, it shall be rigorously monitored during both the design and construction phases.

4.2.6.2 Clearance Envelope

A. The Clearance Envelope (CE) is defined as the space occupied by the Vehicle Dynamic Envelope (VDE) plus the effects of other wayside factors (OWF) including construction and maintenance tolerances for track and various facilities, plus running clearances (RC). This relationship can be expressed as follows:

$$CE = VDE + OWF + RC$$

B. The Clearance Envelope represents the space into which no physical part of the system (other than the light rail vehicle) shall be placed, constructed or protrude. The Clearance Envelope shall be referenced from the centerline of track at the top of rail.

C. The following factors shall be considered in developing the Clearance Envelope.

1. Vehicle Dynamic Envelope – Considerations for Determination

   Determination of the Vehicle Dynamic Envelope begins with the cross sectional outline of the static vehicle. The dynamic outline of the vehicle is then developed by making allowances for the car body movements that occur when the vehicle is operating on level, tangent track. In addition to car body movements on level, tangent track, the effects of track curvature and superelevation must also be considered to allow additional room for vehicle overhang on curves and for vehicle lean when the curves are superelevated.

2. Static Vehicle Outline

   Design of the project is typically initiated prior to the specific dimensional characteristics of the light rail vehicle being known. In order to allow design of fixed facilities to proceed, a composite design vehicle concept has been employed which incorporates the most critical dimensions and operational characteristics of the light rail vehicles considered for the project. For simplicity, the composite light rail vehicle is referred to in this section as the Sound Transit-LRV. The points that define the static outline of the Sound Transit-LRV are tabulated in Figure 4.11.

3. Dynamic Vehicle Outline

   The dynamic outline of the vehicle shall be defined as the extreme car body displacement that can occur for any combination of rotational, lateral and vertical car body movements that occur when the vehicle is operating on level, tangent track. These car body movements are due to truck suspension movements, spring action, allowable wheel and rail wear, and permitted tolerances in vehicle and track construction. The car body movements included in the dynamic vehicle outline are defined in Figure 4.10.

4. Superelevation Effects

   The effect of superelevation shall also be taken into account in developing the Vehicle Dynamic Envelope. Superelevation effects shall be limited to the vehicle lean induced by a specified difference in elevation between the two rails of a track and shall be considered independently of other effects on the dynamic outline. In determining the superelevation effects, the shape of the dynamic outline shall not be altered. Rather, the dynamic outline shall be rotated about the centerline of the top of low rail an amount equal to the actual track superelevation.

D. Vehicle Dynamic Envelope

With the dynamic vehicle outline developed and the effects of track curvature and superelevation determined, the Vehicle Dynamic Envelope (VDE) can be calculated. Tables 4-1A through 4-14B provide the calculated VDE dimensions in tabular form for representative locations on the light rail vehicle cross-section. These tables include values of Tt (dynamic half width of vehicle toward the center of curve), and Ta (dynamic half width of vehicle away from the center of curve). They are tabulated as a function of radius of curve (82 feet to tangent), amount of actual superelevation (0-inch to 6 inches), and

amount of track cross level variation (0.5-inch for paved/direct fixation (DF) track, or 1.0-inch for ballasted track). The values of Tt and Ta to be used in track spacing calculations have been highlighted for ease of use. For intermediate curve radii or superelevation values not listed in these tables, straight line interpolation between adjacent values may be used.

1. Carbody Effect

   The tables do not include values for carbody point $B3_{out}$ with roll to the left or carbody point $B3_{in}$ with roll to the right. If required, these values shall be calculated manually and taken into consideration when calculating the required clearance envelope.

2. Curves Effect

   a. When calculating the Vehicle Dynamic Envelope for horizontal curves with spirals, the tangent Clearance Envelope shall end 50 feet before the tangent to spiral (TS) and 50 feet beyond the spiral to tangent (ST) point. The full curvature Clearance Envelope shall begin 25 feet prior to the spiral to curve (SC) point and end 25 feet beyond the curve to spiral (CS) point. The horizontal component of the Vehicle Dynamic Envelope between these two offset points (i.e., 50 feet before the TS and 25 feet before the SC) shall be considered to vary linearly with distance between the two points. Horizontal offsets at intermediate locations shall be calculated by linear interpolation. For simple circular curves, the full curvature Clearance Envelope shall begin 50 feet prior to the point of curvature (PC) and end 50 feet beyond the point of tangency (PT).

   b. The Clearance Envelope through turnouts shall be calculated based on the centerline radius of the turnout.

E. Other Wayside Factors

1. Other wayside factors (OWF) is the second component of the Clearance Envelope. OWF is the sum of certain construction and maintenance tolerances (CMT) plus a chorded wall construction factor (CW) to account for the effects of chorded wall construction, all where applicable. This relationship can be expressed as follows:

$$OWF = CMT + CW$$

2. The following define other wayside factors and are applicable to and shall be included in the horizontal component of the Clearance Envelope.

Construction and Maintenance Tolerances (CMT)	
Construction Tolerance Along Proposed Soldier Pile and Lagging Wall	6 inches
Construction Tolerance Along Platform Canopy Structures	1.0 inch
Construction Tolerance Along All Other Proposed Structures	2 inches
Construction Tolerance at Poles or Signal Equipment	1.5 inches
Track Construction and Maintenance Tolerance for Embedded or Direct Fixation Track	0.5 inch
Track Construction and Maintenance Tolerance for Mainline, Ballasted Track	2.5 inches
Track Construction and Maintenance Tolerance Yard Tracks	1 inch
Allowance for Acoustical Treatment, Where Required	3 inches
Construction Tolerance Along Tunnel Cast-in-Place Walkways	0 inches

Chorded Wall Construction Factor (CW):	
Additional Width for Chorded Construction of Walls to be Added on the Outside of Curves Only	See Figures 4.7 and 4.8

F. Running Clearances

In addition to the Vehicle Dynamic Envelope and other wayside factors, the Clearance Envelope includes an allowance for running clearance (RC). The following define the running clearances to be included in the horizontal component of the Clearance Envelope. Clearances for the

OCS components are described in Chapter 13, Traction Electrification.

To provide clear passage for a LRV, which has moved to the extreme position within the Dynamic Outline, the minimum horizontal clearance to any structure, or part of a structure, shall always include a horizontal running clearance.

Running Clearances (RC)	
Running Clearance at OCS Poles, Signals, Signs and Other Non-Structural Members	2 inches
Running Clearance along Soldier Pile and Lagging Walls and Other Structures which are normally constructed with liberal construction tolerances.	6 inches
Running Clearance along cast in-place, precast, and masonry walls and other structures which are normally constructed with strict construction tolerances.	2 inches
Running Clearance for Adjacent Light Rail Vehicles (Total between vehicles)	2 inches

1. The above dimensions are design values, the applicability of which depends on the type of track construction, as well as on the type of structure that the vehicle must clear. The following is a description of the applicability and rationale of these values.

2. Track Construction and Maintenance Tolerances

   The combination of several factors such as track misalignment and wheel and track gauge tolerances create the need for this tolerance. Ballasted track demands a greater track misalignment tolerance than either direct fixation or embedded track would require. Furthermore, a distinction is also made between primary tracks and yard tracks for safety reasons.

3. Construction Tolerances Along Proposed Structures

   Where the facility adjacent to the trackway is a structure, or part of a structure, the minimum horizontal construction tolerance shall be provided on the assumption that the structure, or part thereof, may be misplaced during construction by a dimension of that magnitude. It is emphasized that the term ¨structure¨ as used in this

section applies to any facility to be constructed alongside the Link system and above the top of rail.

4. Acoustical Treatment

The need for this allowance shall be investigated in cases where noise produced from the Link system operations may be found in excess of tolerable limits for a given area. The need for acoustical treatment shall be determined in accordance with the requirements specified in Chapter 3, Environmental.

4.2.6.3 Special Clearance Situations

A. In addition to the Clearance Envelope requirements described above, there are several special clearance situations warranting further definition. These special situations include the vehicle interface at station platforms, retaining walls in both cut and fill sections, through girder bridges, and maintenance and emergency evacuation paths.

B. All structures installed above the top of the nearest rail must be set either at, or beyond, the offsets shown in Figure 4.9, with the following exclusions:

1. Vehicle Interface at Station Platforms

At passenger stations, the distance from the centerline of the track to the edge of platform shall be 55.25 inches with a tolerance of +0.25 inch and -0.0 inch.

2. Retaining Walls

Where retaining walls are used, they shall comply with the following:

a. Cut Sections

In those cases where a retaining wall along the Link System is in a cut section, the preferred minimum clearance from the centerline of track to the near face of a retaining wall shall be 9 feet 0 inch. If a maintenance and emergency evacuation pathway is provided adjacent to the retaining wall. The absolute minimum clearance from the centerline of track to the near face of a retaining wall shall be no less than that required to clear the Clearance Envelope plus the emergency exiting width.

b. Fill Sections

In retained fill sections, the top of a retaining wall shall be 6 inches above the required elevation of the top of ballast adjacent to the wall, and the preferred minimum distance from the centerline of track to any fencing or hand railing on top of the wall shall be a minimum of 9 feet 0 inch, if a maintenance and emergency evacuation path is provided adjacent to a curb or retaining wall.

3. Through Girder Bridges

The lateral distance from a centerline of track to the nearest point on the girder of a through girder bridge shall be a minimum of 9 feet 0 inch.

4.2.6.4 Vertical Clearances to Overhead Structures

A. Since the Link system will draw electric traction power from an overhead contact wire system, the following vertical clearances from the top of the high rail along any given section of track to the soffit of any overhead structure, within the horizontal limits of the Clearance Envelope shall be provided as a minimum:

Location	Minimum Vertical Clearance
At Overhead Bridges	21 feet 6 inches, preferred minimum 15 feet 0 inches, desired minimum 14 feet 7 inches, absolute minimum
Link Structures over roadways	16 feet 6 inches, desired minimum

B. Absolute minimum vertical clearances will be coordinated with Sound Transit and the OCS designer as required to identify specific local conditions that may affect the clearance. In semi-exclusive or mixed traffic rights-of-way, vertical clearance over intersecting roadways and restrictions on OCS gradient may increase vertical clearance requirements for structures over the roadway. These should be evaluated on a case-by-case basis.

4.2.7 Track Spacing

A. The minimum allowable spacing between two exclusive Link mainline tracks, with equal superelevation and no OCS support poles between them, shall be determined from the following formula:

$$d = \frac{T_t + T_a + 2(OWF) + RC}{12}$$

Where,

d = minimum allowable spacing between track centerlines, in feet.

T_t = dynamic half width of vehicle towards curve center, in inches

T_a = dynamic half width of vehicle away from curve center, in inches

OWF = other wayside factors, in inches

RC = running clearance, in inches

B. Along sections where OCS poles are located between track centerlines, the minimum track spacing shall be determined from the following formula:

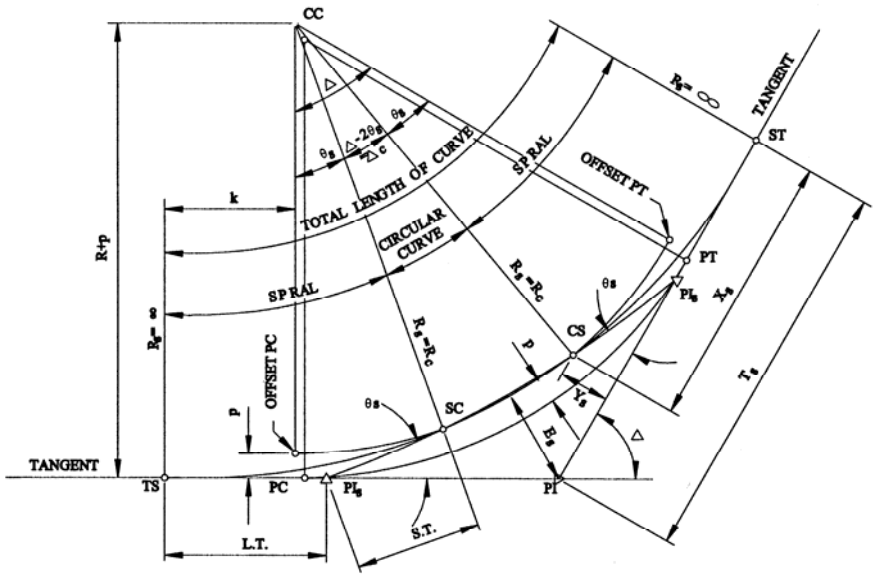
$$d = \frac{T_t + T_a + 2(OWF + RC) + P}{12}$$

Where,

P = maximum allowable OCS pole diameter (including deflection of 14 inches

C. The absolute minimum track spacing to be used along tangent ballasted track with center OCS support poles shall be 14 feet 0 inch. The absolute minimum track spacing to be used along tangent ballasted track without center OCS support poles shall be 12 feet 0 inch. Tangent embedded and direct fixation tracks without center OCS support poles shall have absolute minimum track centers of 12 feet 0 inches.

D. Where Link tracks are parallel to commuter rail, AMTRAK, or freight; the minimum track centers shall be the greater of the minimum track centers for the interfacing rail lines plus 30 inches.



NOTATIONS

CC = CENTER OF CIRCULAR CURVE

CS = POINT OF CHANGE FROM CIRCULAR CURVE TO SPIRAL

D_C = DEGREE OF CIRCULAR CURVE, ARC DEFINITION

E_s = TOTAL EXTERNAL DISTANCE OF A SPIRALIZED CURVE

k = TANGENT DISTANCE FROM TS OR ST TO PC OR PT OF THE SHIFTED CIRCULAR CURVE

L_C = TOTAL LENGTH OF CIRCULAR CURVE ARC

L_s = TOTAL LENGTH OF SPIRAL

L.T. = LONG TANGENT OF SPIRAL

p = OFFSET FROM THE MAIN TANGENT TO THE PC OR PT OF THE SHIFTED CIRCULAR CURVE

PC = POINT OF CHANGE FROM TANGENT TO CIRCULAR CURVE

PI = POINT OF INTERSECTION OF MAIN TANGENTS

PI_s = POINT OF INTERSECTION OF MAIN TANGENT WITH TANGENT THROUGH SC OR CS POINT

PT = POINT OF CHANGE FROM CIRCULAR CURVE TO TANGENT

R = RADIUS OF CIRCULAR CURVE

SC = POINT OF CHANGE FROM SPIRAL TO CIRCULAR CURVE

ST = POINT OF CHANGE FROM SPIRAL TO TANGENT

S.T. = SHORT TANGENT OF SPIRAL

T_s = TOTAL TANGENT DISTANCE FROM TS OR ST TO PI

TS = POINT OF CHANGE FROM TANGENT TO SPIRAL

X_s = TANGENT DISTANCE FROM TS TO SC OR ST TO CS

Y_s = TANGENT OFFSET AT SC OR CS

Δ = TOTAL CENTRAL ANGLE OF SPIRAL AND CIRCULAR CURVES

Δ_c = CENTRAL ANGLE OF THE CIRCULAR CURVE

θ_s = CENTRAL ANGLE OF SPIRAL

CURVE FORMULAS

$$D_C = \frac{5729.578}{R}$$

$$T_s = (R+p)\tan\frac{\Delta}{2} + k$$

$$E_s = (R+p)\left(\frac{1}{\cos\frac{\Delta}{2}} - 1\right) + p$$

$$L_C = \frac{\Delta_c}{D_C} \times 100 = \frac{\Delta - 2\theta_s}{D_C} \times 100$$

SPIRAL FORMULAS

θ_s IN RADIANS

$$X_s = L_s\left(1 - \frac{\theta_s^2}{10} + \frac{\theta_s^4}{216} - \frac{\theta_s^6}{9360} \cdots\right)$$

$$Y_s = L_s\left(\frac{\theta_s}{3} - \frac{\theta_s^3}{42} + \frac{\theta_s^5}{1320} - \frac{\theta_s^7}{75600} \cdots\right)$$

$$k = L_s\left(\frac{1}{2} - \frac{\theta_s^2}{60} + \frac{\theta_s^4}{2160} - \frac{\theta_s^6}{131040} \cdots\right)$$

$$p = L_s\left(\frac{\theta_s}{12} - \frac{\theta_s^3}{336} + \frac{\theta_s^5}{15840} \cdots\right)$$

$$L_s = 2R\theta_s$$

$$f_s = \frac{1}{2}\frac{L_s}{R}$$

$$L.T. = X_s - \frac{Y_s}{\tan\theta_s}$$

$$S.T. = \frac{Y_s}{\sin\theta_s}$$

Figure 4.1
Horizontal Curve and Spiral Nomenclature

VEL	RAD	82	85	100	115	130	150	175	200	250	300	350	400	450	500	600	700	800	900	1000	1100	1200	1300	1400	1500	1600	1700
10	Ea	2.5	2.5	2.0	1.8	1.3	1.0	0.8	0.8	*	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Ls	80	80	70	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
15	Ea	MIN.		5.3	4.5	4.0	3.3	2.8	2.3	1.8	1.3	1.0	0.8	0.8	*	*	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Ls	R=90'		170	140	130	110	90	70	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
20	Ea							5.3	4.5	3.5	2.8	2.3	2.0	1.8	1.5	1.0	0.8	0.8	*	*	*	*	*	0.0	0.0	0.0	0.0
	Ls			MIN. R=159'				170	140	110	90	70	70	60	60	60	60	60	60	60	60	60	60	60	60	60	60
25	Ea									6.0	4.8	4.0	3.5	3.0	2.8	2.0	1.8	1.5	1.3	1.0	0.8	0.8	*	*	*	*	*
	Ls							MIN. R=248'		190	150	130	110	100	90	70	60	60	60	60	60	60	60	60	60	60	60
30	Ea												5.3	4.5	4.0	3.3	2.8	2.3	2.0	1.8	1.5	1.3	1.3	1.0	1.0	0.8	0.8
	Ls										MIN. R=357'		180	150	140	110	100	80	70	60	60	60	60	60	60	60	60
35	Ea														5.8	4.8	4.0	3.5	3.0	2.5	2.3	2.0	1.8	1.8	1.5	1.3	1.3
	Ls											MIN. R=486'			230	190	160	140	120	100	90	80	70	70	60	60	60
40	Ea																5.3	4.5	4.0	3.5	3.3	2.8	2.5	2.3	2.3	2.0	1.8
	Ls														MIN. R=635'		240	200	180	160	150	130	110	100	100	90	80
45	Ea																	6.0	5.3	4.8	4.3	3.8	3.5	3.3	3.0	2.8	2.5
	Ls															MIN. R=803'		300	260	240	220	190	180	170	150	140	130
50	Ea																			6.0	5.3	4.8	4.5	4.0	3.8	3.5	3.3
	Ls																MIN. R=991'			330	290	270	250	220	210	200	180
55	Ea																					6.0	5.5	5.0	4.8	4.3	4.0
	Ls																		MIN. R=1200'			370	340	310	290	260	250

Figure 4.2a
Desirable LRT Superelevation and Spiral Curve Lengths

VEL	RAD	1800	1900	2000	2100	2200	2300	2400	2500	2600	2700	2800	2900	3000	3100	3200	3300	3400	3500	3600	3700	3800	3900	4000	4100
10	Ea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Ls	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
15	Ea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Ls	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
20	Ea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Ls	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
25	Ea	*	*	*	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Ls	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
30	Ea	0.8	*	*	*	*	*	*	*	*	*	*	*	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Ls	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
35	Ea	1.3	1.0	1.0	1.0	0.8	0.8	0.8	0.8	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*	*
	Ls	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
40	Ea	1.8	1.5	1.5	1.3	1.3	1.3	1.0	1.0	1.0	1.0	0.8	0.8	0.8	0.8	0.8	*	*	*	*	*	*	*	*	*
	Ls	80	70	70	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60
45	Ea	2.3	2.3	2.0	2.0	1.8	1.8	1.5	1.5	1.5	1.3	1.3	1.3	1.0	1.0	1.0	1.0	1.0	0.8	0.8	0.8	0.8	0.8	0.8	0.8
	Ls	120	120	100	100	90	90	80	80	80	70	70	70	60	60	60	60	60	60	60	60	60	60	60	60
50	Ea	3.0	2.8	2.8	2.5	2.3	2.3	2.0	2.0	2.0	1.8	1.8	1.5	1.5	1.5	1.5	1.3	1.3	1.3	1.3	1.0	1.0	1.0	1.0	1.0
	Ls	170	160	160	140	130	130	110	110	110	100	100	90	90	90	90	70	70	70	70	60	60	60	60	60
55	Ea	3.8	3.5	3.3	3.3	3.0	2.8	2.8	2.5	2.5	2.3	2.3	2.0	2.0	2.0	1.8	1.8	1.8	1.5	1.5	1.5	1.5	1.5	1.3	1.3
	Ls	230	220	200	200	190	170	170	160	160	140	140	130	130	130	110	110	110	100	100	100	100	100	80	80

Figure 4.2b
Desirable LRT Superelevation and Spiral Curve Lengths

VEL	RAD	4200	4300	4400	4500	4600	4700	4800	4900	5000	5500	6000	6500	7000	7500	8000	8500	9000	9500	10000	10500	11000	11500	12000
	Ea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
10	Ls	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	0	0	0	0	0
	Ea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
15	Ls	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	0	0	0	0	0
	Ea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
20	Ls	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	0	0	0	0	0
	Ea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
25	Ls	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	0	0	0	0	0
	Ea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
30	Ls	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	0	0	0	0	0
	Ea	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
35	Ls	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	0	0	0	0	0
	Ea	*	*	*	*	*	*	*	*	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
40	Ls	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	0	0	0	0	0
	Ea	*	*	*	*	*	*	*	*	*	*	*	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
45	Ls	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	0	0	0	0	0
	Ea	1.0	0.8	0.8	0.8	0.8	0.8	0.8	0.8	0.8	*	*	*	*	*	*	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
50	Ls	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	60	0	0	0	0	0
	Ea	1.3	1.3	1.3	1.0	1.0	1.0	1.0	1.0	1.0	0.8	0.8	*	*	*	*	*	*	*	*	0.0	0.0	0.0	0.0
55	Ls	80	80	80	70	70	70	70	70	70	60	60	60	60	60	60	60	60	60	0	0	0	0	0

Figure 4.2c
Desirable LRT Superelevation and Spiral Curve Lengths

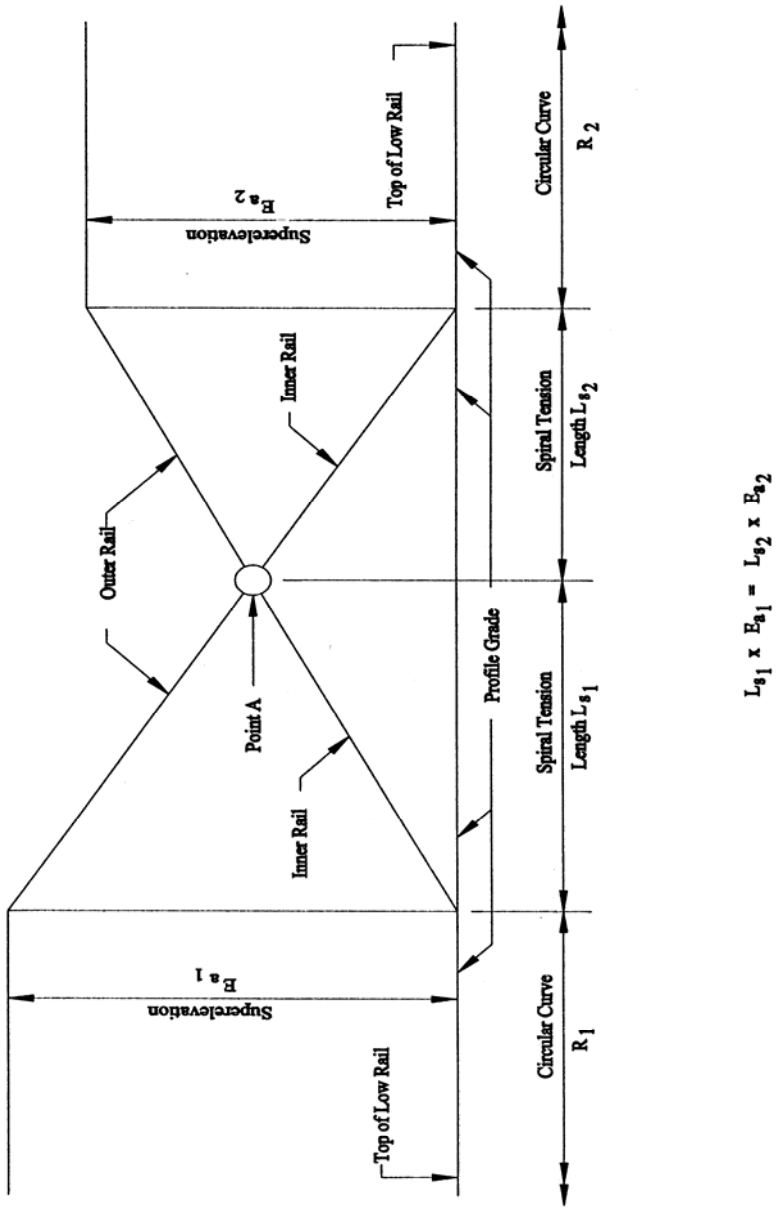
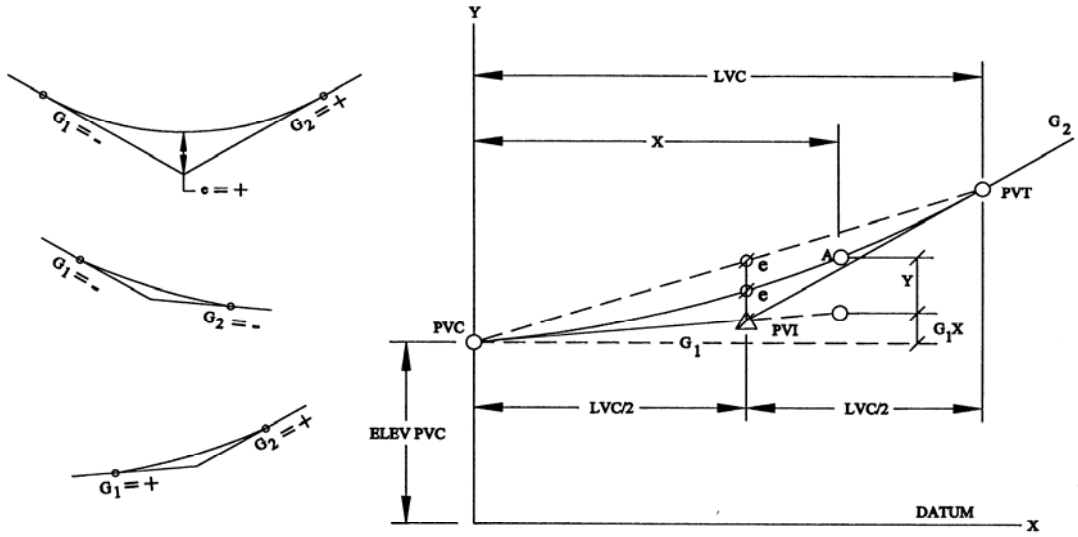
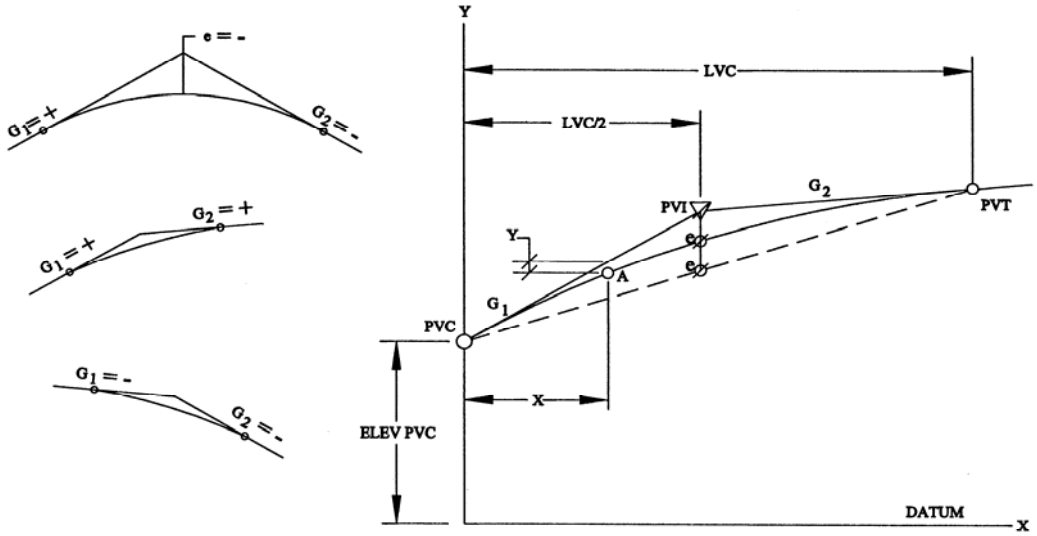


Figure 4.3
Superelevation Transitions for Reverse Curves



SAG VERTICAL CURVES



CREST VERTICAL CURVES

PARABOLIC VERTICAL CURVE FORMULAS:

$$e = \left(\frac{G_2 - G_1}{8}\right) LVC = \frac{1}{8} \quad A\,(LVC); \qquad r = \left(\frac{G_2 - G_1}{LVC}\right) = \text{RATE OF CHANGE IN GRADE}$$

$$y = \frac{1}{2}\left(\frac{G_2 - G_1}{LVC}\right) X^2 = \frac{1}{2}\, rX^2$$

$$\text{ELEV A} = \left(\frac{r}{2}\right) X^2 + XG_1 + \text{ELEV PVC}$$

Figure 4.4
Standard Vertical Curves

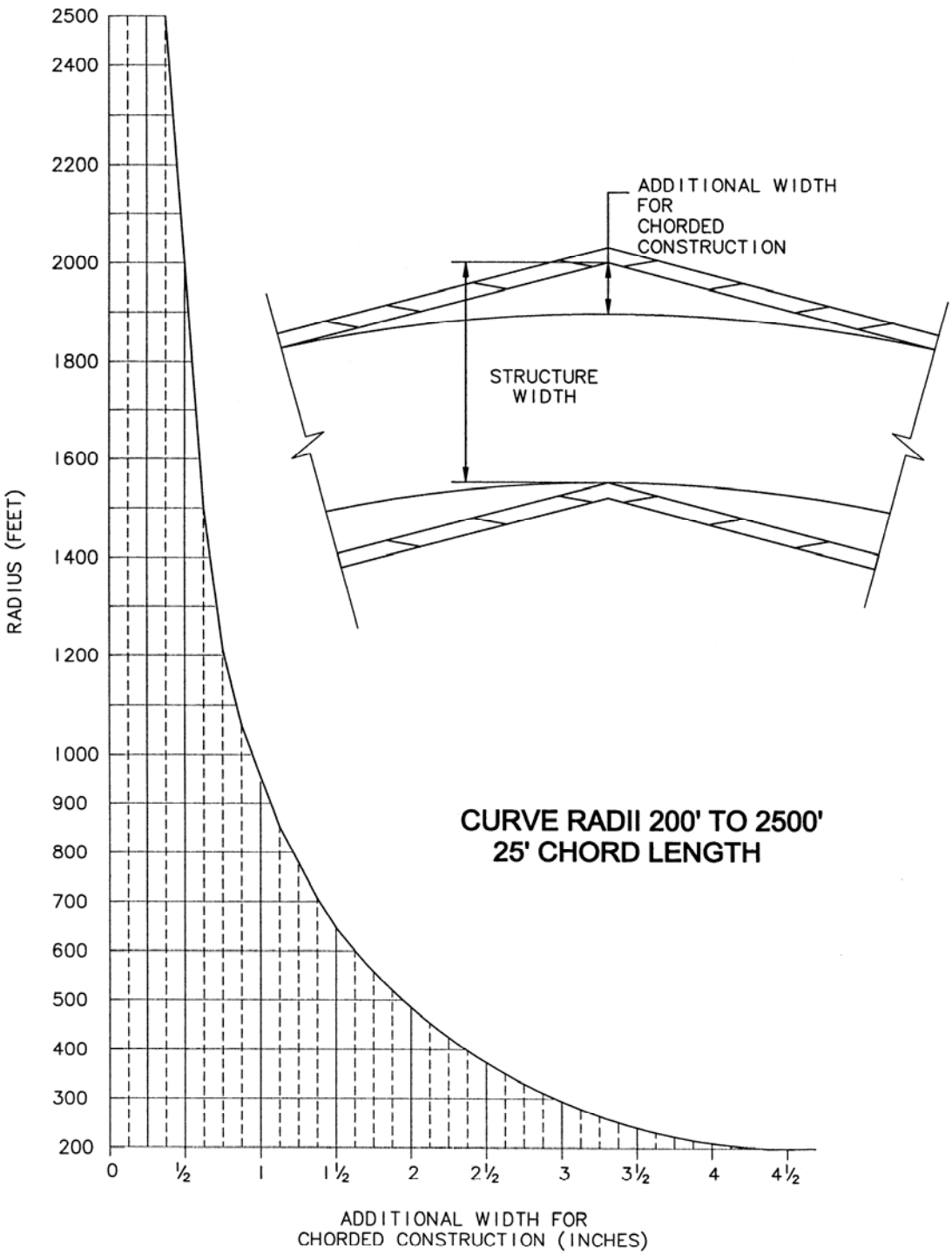


Figure 4.7
Additional Width for Chorded Construction 25' Chord Length

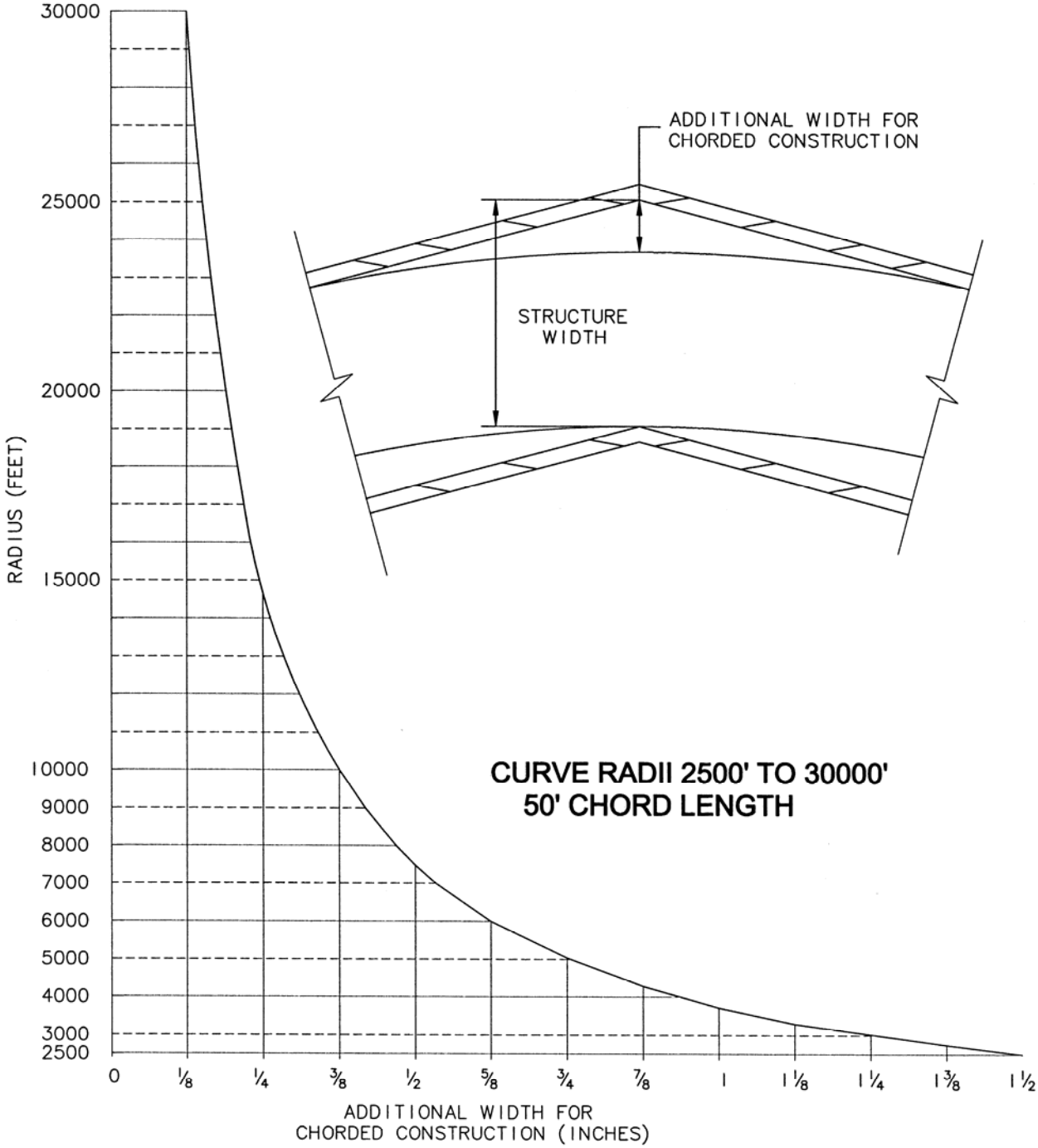
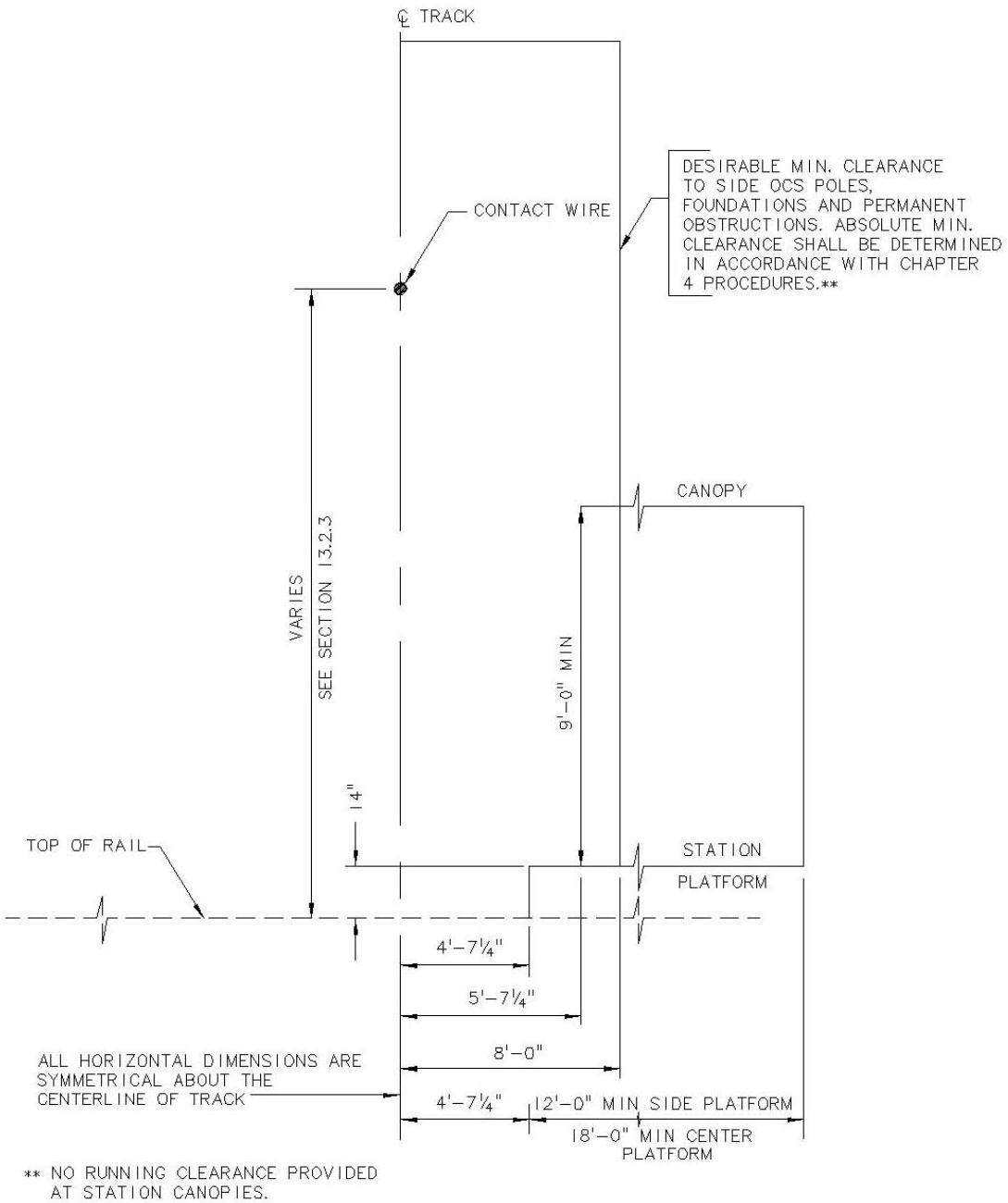


Figure 4.8
Additional Width for Chorded Construction 50' Chord Length



MAIN LINE - TANGENT TRACK

NTS

Figure 4.9
Light Rail Clearance Diagram

SOUND TRANSIT PROPOSED LRV — VEHICLE DYNAMIC ENVELOPE — FIG 4.10

VEHICLE DYNAMIC ENVELOPE CLEARANCE PROGRAM - HORIZONTAL OFFSETS & DISPLACEMENTS

Agency Name:	SOUND TRANSIT
City:	SEATTLE
State:	WASHINGTON

LRV Type:	DOUBLE ARTICULATED
LRV Manufacturer:	?
Pantograph Type:	?
Mirror:	None

File Name:	ST-W-NM-3-13.5a.xls
Revision By:	wrw
Revision Date:	24-Nov-99

DATA INPUT

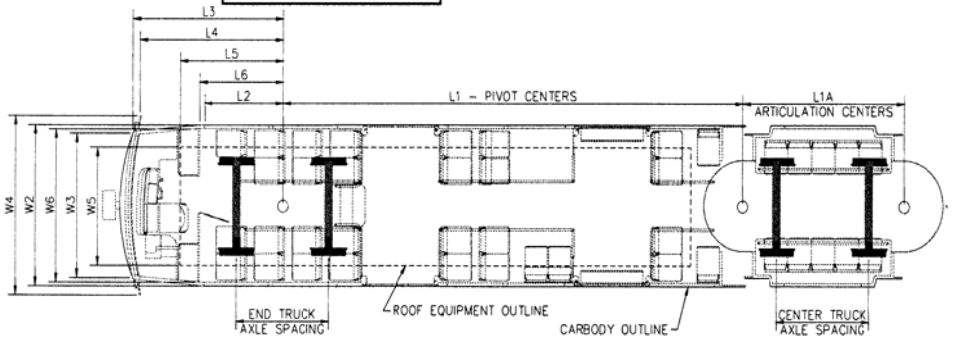
End Truck Axle Spacing:	70.87	in
Center Truck Axle Spacing:	70.87	in
L1 - Pivot Centers Spacing:	351.97	in
L1A - Articulation Centers	124.02	in
L2 - Body Corner Location:	60.79	in
L3 - Front End Location:	113.94	in
L4 - Mirror Location:		in
L5 - Roof Equipment Location:	78.74	in
L6 - Roof Shroud Location:	60.79	in
W2 - Body Corner Width:	104.49	in
W3 - Front End Width:	96.06	in
W4 - Out to Out Mirror Width:	96.06	in
W5 - Roof Equipment Width:	76.77	in
W6 - Roof Shroud Width:	96.61	in
Pantograph Sway (total)	2.99	in

LATERAL MOTION

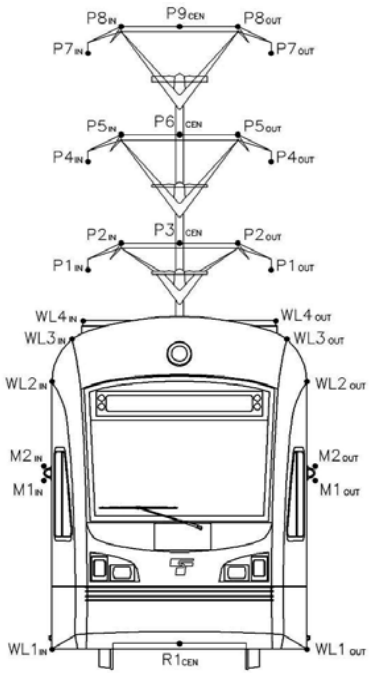
Wheel wear:	0.315	in
Rail wear:	0.512	in
Rail gauge tolerance (half):	0.118	in
Wheel gauge tolerance (half):	0.039	in
Nominal sideplay (half):	0.394	in
Lateral suspension motion:	1.339	in
Total:	2.717	in

SKEW

Lateral Motion:	2.717	in
D2 - Body Corner Skew:	3.655	in
D3 - Front End Skew:	4.475	in
D4 - Mirror Skew:		in
D5 - Roof Equipment Skew:	3.932	in
D6 - Roof Shroud:	3.655	in



SOUND TRANSIT LRV — VEHICLE DYNAMIC ENVELOPE — FIG 4.11



B# = LRV Body Points
M# = LRV Mirror Points
P# = LRV Pantograph Points
R# = LRV Roll Center Point

STATIC ROLL CENTER

	X	Y
	in	in
R1	0.00	15.00

STATIC PANTOGRAPH POINTS

	X	Y		X	Y
	in	in		in	in
$P1_{OUT}$	39.42	152.00	$P1_{IN}$	-39.42	152.00
$P2_{OUT}$	31.50	162.00	$P2_{IN}$	-31.50	162.00
$P3_{CEN}$	0.00	162.00			
$P4_{OUT}$	39.42	206.00	$P4_{IN}$	-39.42	206.00
$P5_{OUT}$	31.50	216.00	$P5_{IN}$	-31.50	216.00
$P6_{CEN}$	0.00	216.00			
$P7_{OUT}$	39.42	266.00	$P7_{IN}$	-39.42	266.00
$P8_{OUT}$	31.50	276.00	$P8_{IN}$	-31.50	276.00
$P9_{CEN}$	0.00	276.00			

STATIC BODY POINTS

	X	Y		X	Y
	in	in		in	in
$WL1_{OUT}$	52.24	8.66	$WL1_{IN}$	-52.24	8.66
$WL2_{OUT}$	52.24	126.00	$WL2_{IN}$	-52.24	126.00
$WL3_{OUT}$	48.31	140.35	$WL3_{IN}$	-48.31	140.35
$WL4_{OUT}$	38.39	148.82	$WL4_{IN}$	-38.39	148.82
$WL5_{OUT}$	0.00	0.00	$WL5_{IN}$	0.00	0.00
$WL6_{OUT}$	0.00	0.00	$WL6_{IN}$	0.00	0.00

STATIC MIRROR POINTS

	X	Y		X	Y
	in	in		in	in
$M1_{OUT}$	55.59	85.00	$M1_{IN}$	-55.59	85.00
$M2_{OUT}$	55.59	87.00	$M2_{IN}$	-55.59	87.00

SKEW

Lateral Motion:	2.717	in
WL1 Corner Skew:	3.656	in
WL1 End Skew:	4.476	in
WL2 Corner Skew:	3.656	in
WL2 End Skew:	4.476	in
WL3 Corner Skew:	3.656	in
WL3 End Skew:	4.414	in
WL4 Corner Skew:	3.933	in
WL4 End Skew:	3.933	in
WL5 Corner Skew:	2.717	in
WL5 End Skew:	2.717	in
WL6 Corner Skew:	2.717	in
WL6 End Skew:	2.717	in
Mirror Skew:	3.646	in

NOTES APPLICABLE TO ALL TABLES

- Coordinates shown are in standard units.
- All coordinates shown are referenced from a point located at ½ track gauge and top of rail (0.0).
- Superelevation is applied relative to top of low rail.
- Points $R1_{CEN}$, $P3_{CEN}$, $P6_{CEN}$, and $P9_{CEN}$ are not specific to either Outside or Inside of curve.

TABLE 1A - VEHICLE DYNAMIC ENVELOPE - OUTSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 0.5 in
Superelevation = 0.0 in

Radius:	$WL1_{OUT}$		$WL2_{OUT}$		$WL3_{OUT}$		$WL4_{OUT}$		$WL5_{OUT}$		$WL6_{OUT}$		$M1_{OUT}$		$M2_{OUT}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	76.38	5.25	82.80	122.37	78.95	136.93	65.36	151.15	0.00	0.00	0.00	0.00	73.64	81.24	73.76	90.49
100	72.48	5.25	78.90	122.37	75.20	136.93	62.89	151.15	0.00	0.00	0.00	0.00	72.04	81.24	72.16	90.49
150	66.28	5.25	72.70	122.37	69.23	136.93	58.96	151.15	0.00	0.00	0.00	0.00	69.42	81.24	69.54	90.49
200	63.05	5.25	69.47	122.37	66.13	136.93	56.92	151.15	0.00	0.00	0.00	0.00	68.03	81.24	68.15	90.49
300	59.73	5.25	66.15	122.37	62.95	136.93	54.83	151.15	0.00	0.00	0.00	0.00	66.58	81.24	66.70	90.49
400	58.60	5.25	65.02	122.37	61.97	136.93	53.77	151.15	0.00	0.00	0.00	0.00	65.83	81.24	65.96	90.49
500	58.14	5.25	64.56	122.37	61.51	136.93	53.12	151.15	0.00	0.00	0.00	0.00	65.38	81.24	65.50	90.49
600	57.83	5.25	64.25	122.37	61.20	136.93	52.69	151.15	0.00	0.00	0.00	0.00	65.08	81.24	65.20	90.49
700	57.61	5.25	64.03	122.37	60.98	136.93	52.38	151.15	0.00	0.00	0.00	0.00	64.86	81.24	64.98	90.49
800	57.44	5.25	63.86	122.37	60.81	136.93	52.15	151.15	0.00	0.00	0.00	0.00	64.69	81.24	64.81	90.49
900	57.31	5.25	63.73	122.37	60.68	136.93	51.97	151.15	0.00	0.00	0.00	0.00	64.56	81.24	64.68	90.49
1000	57.21	5.25	63.63	122.37	60.57	136.93	51.82	151.15	0.00	0.00	0.00	0.00	64.46	81.24	64.58	90.49
1200	57.05	5.25	63.47	122.37	60.41	136.93	51.60	151.15	0.00	0.00	0.00	0.00	64.30	81.24	64.42	90.49
1500	56.89	5.25	63.31	122.37	60.26	136.93	51.39	151.15	0.00	0.00	0.00	0.00	64.15	81.24	64.27	90.49
2000	56.73	5.25	63.15	122.37	60.10	136.93	51.17	151.15	0.00	0.00	0.00	0.00	63.99	81.24	64.11	90.49
5000	56.44	5.25	62.86	122.37	59.81	136.93	50.77	151.15	0.00	0.00	0.00	0.00	63.71	81.24	63.83	90.49
10000	56.35	5.25	62.77	122.37	59.71	136.93	50.64	151.15	0.00	0.00	0.00	0.00	63.61	81.24	63.73	90.49
50000	56.27	5.25	62.69	122.37	59.64	136.93	50.53	151.15	0.00	0.00	0.00	0.00	63.53	81.24	63.66	90.49
Tangent	56.25	5.25	62.67	122.37	59.62	136.93	50.51	151.15	0.00	0.00	0.00	0.00	63.51	81.24	63.64	90.49

Radius:	$P1_{OUT}$		$P2_{OUT}$		$P4_{OUT}$		$P5_{OUT}$		$P7_{OUT}$		$P8_{OUT}$		$R1_{CEN}$		$P3_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	52.02	149.10	44.72	163.89	55.30	203.00	48.00	217.79	58.94	262.89	51.65	277.68	-0.13	15.25	-13.28	162.24
100	52.02	149.10	44.72	163.89	55.30	203.00	48.00	217.79	58.94	262.89	51.65	277.68	-0.13	15.25	-13.28	162.24
150	52.02	149.10	44.72	163.89	55.30	203.00	48.00	217.79	58.94	262.89	51.65	277.68	-0.13	15.25	-13.28	162.24
200	52.02	149.10	44.72	163.89	55.30	203.00	48.00	217.79	58.94	262.89	51.65	277.68	-0.13	15.25	-13.28	162.24
300	52.02	149.10	44.72	163.89	55.30	203.00	48.00	217.79	58.94	262.89	51.65	277.68	-0.13	15.25	-13.28	162.24
400	52.02	149.10	44.72	163.89	55.30	203.00	48.00	217.79	58.94	262.89	51.65	277.68	-0.13	15.25	-13.28	162.24
500	52.02	149.10	44.72	163.89	55.30	203.00	48.00	217.79	58.94	262.89	51.65	277.68	-0.13	15.25	-13.28	162.24
600	52.02	149.10	44.72	163.89	55.30	203.00	48.00	217.79	58.94	262.89	51.65	277.68	-0.13	15.25	-13.28	162.24
700	52.02	149.10	44.72	163.89	55.30	203.00	48.00	217.79	58.94	262.89	51.65	277.68	-0.13	15.25	-13.28	162.24
800	52.02	149.10	44.72	163.89	55.30	203.00	48.00	217.79	58.94	262.89	51.65	277.68	-0.13	15.25	-13.28	162.24
900	52.02	149.10	44.72	163.89	55.30	203.00	48.00	217.79	58.94	262.89	51.65	277.68	-0.13	15.25	-13.28	162.24
1000	52.02	149.10	44.72	163.89	55.30	203.00	48.00	217.79	58.94	262.89	51.65	277.68	-0.13	15.25	-13.28	162.24
1200	52.02	149.10	44.72	163.89	55.30	203.00	48.00	217.79	58.94	262.89	51.65	277.68	-0.13	15.25	-13.28	162.24
1500	52.02	149.10	44.72	163.89	55.30	203.00	48.00	217.79	58.94	262.89	51.65	277.68	-0.13	15.25	-13.28	162.24
2000	52.02	149.10	44.72	163.89	55.30	203.00	48.00	217.79	58.94	262.89	51.65	277.68	-0.13	15.25	-13.28	162.24
5000	52.02	149.10	44.72	163.89	55.30	203.00	48.00	217.79	58.94	262.89	51.65	277.68	-0.13	15.25	-13.28	162.24
10000	52.02	149.10	44.72	163.89	55.30	203.00	48.00	217.79	58.94	262.89	51.65	277.68	-0.13	15.25	-13.28	162.24
50000	52.02	149.10	44.72	163.89	55.30	203.00	48.00	217.79	58.94	262.89	51.65	277.68	-0.13	15.25	-13.28	162.24
Tangent	52.02	149.10	44.72	163.89	55.30	203.00	48.00	217.79	58.94	262.89	51.65	277.68	-0.13	15.25	-13.28	162.24

TABLE 1B - VEHICLE DYNAMIC ENVELOPE - INSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 0.5 in
Superelevation = 0.0 in

Radius:	$WL1_{IN}$		$WL2_{IN}$		$WL3_{IN}$		$WL4_{IN}$		$WL5_{IN}$		$WL6_{IN}$		$M1_{IN}$		$M2_{IN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	-70.86	5.25	-77.29	122.37	-74.23	136.93	-64.84	151.15	0.00	0.00	0.00	0.00	-50.35	81.24	-50.47	90.49
100	-68.03	5.25	-74.45	122.37	-71.40	136.93	-62.01	151.15	0.00	0.00	0.00	0.00	-52.95	81.24	-53.07	90.49
150	-63.77	5.25	-70.19	122.37	-67.13	136.93	-57.75	151.15	0.00	0.00	0.00	0.00	-56.70	81.24	-56.82	90.49
200	-61.65	5.25	-68.07	122.37	-65.01	136.93	-55.62	151.15	0.00	0.00	0.00	0.00	-58.49	81.24	-58.61	90.49
300	-59.53	5.25	-65.95	122.37	-62.90	136.93	-53.51	151.15	0.00	0.00	0.00	0.00	-60.22	81.24	-60.34	90.49
400	-58.48	5.25	-64.90	122.37	-61.84	136.93	-52.45	151.15	0.00	0.00	0.00	0.00	-61.07	81.24	-61.19	90.49
500	-57.84	5.25	-64.26	122.37	-61.21	136.93	-51.82	151.15	0.00	0.00	0.00	0.00	-61.57	81.24	-61.69	90.49
600	-57.42	5.25	-63.84	122.37	-60.79	136.93	-51.40	151.15	0.00	0.00	0.00	0.00	-61.90	81.24	-62.02	90.49
700	-57.12	5.25	-63.54	122.37	-60.49	136.93	-51.10	151.15	0.00	0.00	0.00	0.00	-62.13	81.24	-62.25	90.49
800	-56.89	5.25	-63.31	122.37	-60.26	136.93	-50.87	151.15	0.00	0.00	0.00	0.00	-62.31	81.24	-62.43	90.49
900	-56.72	5.25	-63.14	122.37	-60.08	136.93	-50.70	151.15	0.00	0.00	0.00	0.00	-62.44	81.24	-62.56	90.49
1000	-56.58	5.25	-63.00	122.37	-59.94	136.93	-50.56	151.15	0.00	0.00	0.00	0.00	-62.55	81.24	-62.67	90.49
1200	-56.37	5.25	-62.79	122.37	-59.73	136.93	-50.34	151.15	0.00	0.00	0.00	0.00	-62.71	81.24	-62.83	90.49
1500	-56.16	5.25	-62.58	122.37	-59.52	136.93	-50.13	151.15	0.00	0.00	0.00	0.00	-62.87	81.24	-63.00	90.49
2000	-55.95	5.25	-62.37	122.37	-59.31	136.93	-49.92	151.15	0.00	0.00	0.00	0.00	-63.04	81.24	-63.16	90.49
5000	-56.06	5.25	-62.48	122.37	-59.42	136.93	-50.24	151.15	0.00	0.00	0.00	0.00	-63.32	81.24	-63.45	90.49
10000	-56.15	5.25	-62.58	122.37	-59.52	136.93	-50.37	151.15	0.00	0.00	0.00	0.00	-63.42	81.24	-63.54	90.49
50000	-56.23	5.25	-62.65	122.37	-59.60	136.93	-50.48	151.15	0.00	0.00	0.00	0.00	-63.50	81.24	-63.62	90.49
Tangent	-56.25	5.25	-62.67	122.37	-59.62	136.93	-50.51	151.15	0.00	0.00	0.00	0.00	-63.51	81.24	-63.64	90.49

Radius:	$P1_{IN}$		$P2_{IN}$		$P4_{IN}$		$P5_{IN}$		$P7_{IN}$		$P8_{IN}$		$P6_{CEN}$		$P9_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	-52.02	149.10	-44.72	163.89	-55.30	203.00	-48.00	217.79	-58.94	262.89	-51.65	277.68	-16.56	216.24	-20.20	276.24
100	-52.02	149.10	-44.72	163.89	-55.30	203.00	-48.00	217.79	-58.94	262.89	-51.65	277.68	-16.56	216.24	-20.20	276.24
150	-52.02	149.10	-44.72	163.89	-55.30	203.00	-48.00	217.79	-58.94	262.89	-51.65	277.68	-16.56	216.24	-20.20	276.24
200	-52.02	149.10	-44.72	163.89	-55.30	203.00	-48.00	217.79	-58.94	262.89	-51.65	277.68	-16.56	216.24	-20.20	276.24
300	-52.02	149.10	-44.72	163.89	-55.30	203.00	-48.00	217.79	-58.94	262.89	-51.65	277.68	-16.56	216.24	-20.20	276.24
400	-52.02	149.10	-44.72	163.89	-55.30	203.00	-48.00	217.79	-58.94	262.89	-51.65	277.68	-16.56	216.24	-20.20	276.24
500	-52.02	149.10	-44.72	163.89	-55.30	203.00	-48.00	217.79	-58.94	262.89	-51.65	277.68	-16.56	216.24	-20.20	276.24
600	-52.02	149.10	-44.72	163.89	-55.30	203.00	-48.00	217.79	-58.94	262.89	-51.65	277.68	-16.56	216.24	-20.20	276.24
700	-52.02	149.10	-44.72	163.89	-55.30	203.00	-48.00	217.79	-58.94	262.89	-51.65	277.68	-16.56	216.24	-20.20	276.24
800	-52.02	149.10	-44.72	163.89	-55.30	203.00	-48.00	217.79	-58.94	262.89	-51.65	277.68	-16.56	216.24	-20.20	276.24
900	-52.02	149.10	-44.72	163.89	-55.30	203.00	-48.00	217.79	-58.94	262.89	-51.65	277.68	-16.56	216.24	-20.20	276.24
1000	-52.02	149.10	-44.72	163.89	-55.30	203.00	-48.00	217.79	-58.94	262.89	-51.65	277.68	-16.56	216.24	-20.20	276.24
1200	-52.02	149.10	-44.72	163.89	-55.30	203.00	-48.00	217.79	-58.94	262.89	-51.65	277.68	-16.56	216.24	-20.20	276.24
1500	-52.02	149.10	-44.72	163.89	-55.30	203.00	-48.00	217.79	-58.94	262.89	-51.65	277.68	-16.56	216.24	-20.20	276.24
2000	-52.02	149.10	-44.72	163.89	-55.30	203.00	-48.00	217.79	-58.94	262.89	-51.65	277.68	-16.56	216.24	-20.20	276.24
5000	-52.02	149.10	-44.72	163.89	-55.30	203.00	-48.00	217.79	-58.94	262.89	-51.65	277.68	-16.56	216.24	-20.20	276.24
10000	-52.02	149.10	-44.72	163.89	-55.30	203.00	-48.00	217.79	-58.94	262.89	-51.65	277.68	-16.56	216.24	-20.20	276.24
50000	-52.02	149.10	-44.72	163.89	-55.30	203.00	-48.00	217.79	-58.94	262.89	-51.65	277.68	-16.56	216.24	-20.20	276.24
Tangent	-52.02	149.10	-44.72	163.89	-55.30	203.00	-48.00	217.79	-58.94	262.89	-51.65	277.68	-16.56	216.24	-20.20	276.24

TABLE 2A - VEHICLE DYNAMIC ENVELOPE - OUTSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll

Cross Level Variation = 0.5 in

Superelevation = 1.0 in

Radius:	$WL1_{OUT}$		$WL2_{OUT}$		$WL3_{OUT}$		$WL4_{OUT}$		$WL5_{OUT}$		$WL6_{OUT}$		$M1_{OUT}$		$M2_{OUT}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	76.18	6.62	80.72	123.85	76.63	138.36	62.89	152.14	0.00	0.00	0.00	0.00	72.26	82.74	72.35	91.84
100	72.29	6.62	76.83	123.85	72.87	138.36	60.41	152.14	0.00	0.00	0.00	0.00	70.65	82.74	70.74	91.84
150	66.09	6.62	70.62	123.85	66.90	138.36	56.48	152.14	0.00	0.00	0.00	0.00	68.03	82.74	68.12	91.84
200	62.86	6.62	67.39	123.85	63.80	138.36	54.44	152.14	0.00	0.00	0.00	0.00	66.64	82.74	66.73	91.84
300	59.54	6.62	64.07	123.85	60.62	138.36	52.35	152.14	0.00	0.00	0.00	0.00	65.20	82.74	65.28	91.84
400	58.41	6.62	62.95	123.85	59.65	138.36	51.29	152.14	0.00	0.00	0.00	0.00	64.45	82.74	64.54	91.84
500	57.95	6.62	62.48	123.85	59.19	138.36	50.65	152.14	0.00	0.00	0.00	0.00	64.00	82.74	64.08	91.84
600	57.64	6.62	62.17	123.85	58.88	138.36	50.21	152.14	0.00	0.00	0.00	0.00	63.69	82.74	63.78	91.84
700	57.42	6.62	61.95	123.85	58.65	138.36	49.91	152.14	0.00	0.00	0.00	0.00	63.47	82.74	63.56	91.84
800	57.25	6.62	61.78	123.85	58.48	138.36	49.67	152.14	0.00	0.00	0.00	0.00	63.31	82.74	63.39	91.84
900	57.12	6.62	61.65	123.85	58.35	138.36	49.49	152.14	0.00	0.00	0.00	0.00	63.18	82.74	63.27	91.84
1000	57.01	6.62	61.55	123.85	58.25	138.36	49.35	152.14	0.00	0.00	0.00	0.00	63.07	82.74	63.16	91.84
1200	56.86	6.62	61.39	123.85	58.09	138.36	49.13	152.14	0.00	0.00	0.00	0.00	62.92	82.74	63.01	91.84
1500	56.70	6.62	61.23	123.85	57.93	138.36	48.91	152.14	0.00	0.00	0.00	0.00	62.76	82.74	62.85	91.84
2000	56.54	6.62	61.07	123.85	57.77	138.36	48.69	152.14	0.00	0.00	0.00	0.00	62.60	82.74	62.69	91.84
5000	56.25	6.62	60.79	123.85	57.48	138.36	48.29	152.14	0.00	0.00	0.00	0.00	62.32	82.74	62.41	91.84
10000	56.16	6.62	60.69	123.85	57.39	138.36	48.16	152.14	0.00	0.00	0.00	0.00	62.23	82.74	62.31	91.84
50000	56.08	6.62	60.61	123.85	57.31	138.36	48.06	152.14	0.00	0.00	0.00	0.00	62.15	82.74	62.24	91.84
Tangent	56.06	6.62	60.59	123.85	57.29	138.36	48.03	152.14	0.00	0.00	0.00	0.00	62.13	82.74	62.22	91.84

Radius:	$P1_{OUT}$		$P2_{OUT}$		$P4_{OUT}$		$P5_{OUT}$		$P7_{OUT}$		$P8_{OUT}$		$R1_{CEN}$		$P3_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	49.49	150.39	42.01	164.75	51.86	204.33	44.39	218.58	54.49	264.28	47.02	278.40	-0.39	15.75	-16.01	162.74
100	49.49	150.39	42.01	164.75	51.86	204.33	44.39	218.58	54.49	264.28	47.02	278.40	-0.39	15.75	-16.01	162.74
150	49.49	150.39	42.01	164.75	51.86	204.33	44.39	218.58	54.49	264.28	47.02	278.40	-0.39	15.75	-16.01	162.74
200	49.49	150.39	42.01	164.75	51.86	204.33	44.39	218.58	54.49	264.28	47.02	278.40	-0.39	15.75	-16.01	162.74
300	49.49	150.39	42.01	164.75	51.86	204.33	44.39	218.58	54.49	264.28	47.02	278.40	-0.39	15.75	-16.01	162.74
400	49.49	150.39	42.01	164.75	51.86	204.33	44.39	218.58	54.49	264.28	47.02	278.40	-0.39	15.75	-16.01	162.74
500	49.49	150.39	42.01	164.75	51.86	204.33	44.39	218.58	54.49	264.28	47.02	278.40	-0.39	15.75	-16.01	162.74
600	49.49	150.39	42.01	164.75	51.86	204.33	44.39	218.58	54.49	264.28	47.02	278.40	-0.39	15.75	-16.01	162.74
700	49.49	150.39	42.01	164.75	51.86	204.33	44.39	218.58	54.49	264.28	47.02	278.40	-0.39	15.75	-16.01	162.74
800	49.49	150.39	42.01	164.75	51.86	204.33	44.39	218.58	54.49	264.28	47.02	278.40	-0.39	15.75	-16.01	162.74
900	49.49	150.39	42.01	164.75	51.86	204.33	44.39	218.58	54.49	264.28	47.02	278.40	-0.39	15.75	-16.01	162.74
1000	49.49	150.39	42.01	164.75	51.86	204.33	44.39	218.58	54.49	264.28	47.02	278.40	-0.39	15.75	-16.01	162.74
1200	49.49	150.39	42.01	164.75	51.86	204.33	44.39	218.58	54.49	264.28	47.02	278.40	-0.39	15.75	-16.01	162.74
1500	49.49	150.39	42.01	164.75	51.86	204.33	44.39	218.58	54.49	264.28	47.02	278.40	-0.39	15.75	-16.01	162.74
2000	49.49	150.39	42.01	164.75	51.86	204.33	44.39	218.58	54.49	264.28	47.02	278.40	-0.39	15.75	-16.01	162.74
5000	49.49	150.39	42.01	164.75	51.86	204.33	44.39	218.58	54.49	264.28	47.02	278.40	-0.39	15.75	-16.01	162.74
10000	49.49	150.39	42.01	164.75	51.86	204.33	44.39	218.58	54.49	264.28	47.02	278.40	-0.39	15.75	-16.01	162.74
50000	49.49	150.39	42.01	164.75	51.86	204.33	44.39	218.58	54.49	264.28	47.02	278.40	-0.39	15.75	-16.01	162.74
Tangent	49.49	150.39	42.01	164.75	51.86	204.33	44.39	218.58	54.49	264.28	47.02	278.40	-0.39	15.75	-16.01	162.74

TABLE 2B - VEHICLE DYNAMIC ENVELOPE - INSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 0.5 in
Superelevation = 1.0 in

Radius:	$WL1_{IN}$		$WL2_{IN}$		$WL3_{IN}$		$WL4_{IN}$		$WL5_{IN}$		$WL6_{IN}$		$M1_{IN}$		$M2_{IN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	-71.05	4.87	-79.36	121.86	-76.55	136.47	-67.31	151.13	0.00	0.00	0.00	0.00	-51.73	80.72	-51.88	90.12
100	-68.22	4.87	-76.52	121.86	-73.71	136.47	-64.48	151.13	0.00	0.00	0.00	0.00	-54.32	80.72	-54.48	90.12
150	-63.95	4.87	-72.26	121.86	-69.45	136.47	-60.22	151.13	0.00	0.00	0.00	0.00	-58.07	80.72	-58.23	90.12
200	-61.83	4.87	-70.14	121.86	-67.33	136.47	-58.10	151.13	0.00	0.00	0.00	0.00	-59.86	80.72	-60.02	90.12
300	-59.72	4.87	-68.02	121.86	-65.21	136.47	-55.98	151.13	0.00	0.00	0.00	0.00	-61.60	80.72	-61.75	90.12
400	-58.66	4.87	-66.97	121.86	-64.16	136.47	-54.93	151.13	0.00	0.00	0.00	0.00	-62.44	80.72	-62.60	90.12
500	-58.03	4.87	-66.33	121.86	-63.53	136.47	-54.29	151.13	0.00	0.00	0.00	0.00	-62.94	80.72	-63.10	90.12
600	-57.61	4.87	-65.91	121.86	-63.10	136.47	-53.87	151.13	0.00	0.00	0.00	0.00	-63.27	80.72	-63.43	90.12
700	-57.31	4.87	-65.61	121.86	-62.80	136.47	-53.57	151.13	0.00	0.00	0.00	0.00	-63.51	80.72	-63.66	90.12
800	-57.08	4.87	-65.39	121.86	-62.58	136.47	-53.34	151.13	0.00	0.00	0.00	0.00	-63.68	80.72	-63.84	90.12
900	-56.90	4.87	-65.21	121.86	-62.40	136.47	-53.17	151.13	0.00	0.00	0.00	0.00	-63.82	80.72	-63.97	90.12
1000	-56.76	4.87	-65.07	121.86	-62.26	136.47	-53.03	151.13	0.00	0.00	0.00	0.00	-63.93	80.72	-64.08	90.12
1200	-56.55	4.87	-64.86	121.86	-62.05	136.47	-52.82	151.13	0.00	0.00	0.00	0.00	-64.09	80.72	-64.24	90.12
1500	-56.34	4.87	-64.65	121.86	-61.84	136.47	-52.60	151.13	0.00	0.00	0.00	0.00	-64.25	80.72	-64.41	90.12
2000	-56.13	4.87	-64.44	121.86	-61.63	136.47	-52.39	151.13	0.00	0.00	0.00	0.00	-64.41	80.72	-64.57	90.12
5000	-56.24	4.87	-64.55	121.86	-61.74	136.47	-52.71	151.13	0.00	0.00	0.00	0.00	-64.70	80.72	-64.85	90.12
10000	-56.34	4.87	-64.65	121.86	-61.84	136.47	-52.84	151.13	0.00	0.00	0.00	0.00	-64.80	80.72	-64.95	90.12
50000	-56.42	4.87	-64.72	121.86	-61.91	136.47	-52.95	151.13	0.00	0.00	0.00	0.00	-64.87	80.72	-65.03	90.12
Tangent	-56.44	4.87	-64.74	121.86	-61.93	136.47	-52.98	151.13	0.00	0.00	0.00	0.00	-64.89	80.72	-65.05	90.12

Radius:	$P1_{IN}$		$P2_{IN}$		$P4_{IN}$		$P5_{IN}$		$P7_{IN}$		$P8_{IN}$		$P6_{CEN}$		$P9_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	-54.54	148.77	-47.42	163.99	-58.73	202.61	-51.61	217.94	-63.39	262.43	-56.27	277.88	-20.21	216.74	-24.86	276.74
100	-54.54	148.77	-47.42	163.99	-58.73	202.61	-51.61	217.94	-63.39	262.43	-56.27	277.88	-20.21	216.74	-24.86	276.74
150	-54.54	148.77	-47.42	163.99	-58.73	202.61	-51.61	217.94	-63.39	262.43	-56.27	277.88	-20.21	216.74	-24.86	276.74
200	-54.54	148.77	-47.42	163.99	-58.73	202.61	-51.61	217.94	-63.39	262.43	-56.27	277.88	-20.21	216.74	-24.86	276.74
300	-54.54	148.77	-47.42	163.99	-58.73	202.61	-51.61	217.94	-63.39	262.43	-56.27	277.88	-20.21	216.74	-24.86	276.74
400	-54.54	148.77	-47.42	163.99	-58.73	202.61	-51.61	217.94	-63.39	262.43	-56.27	277.88	-20.21	216.74	-24.86	276.74
500	-54.54	148.77	-47.42	163.99	-58.73	202.61	-51.61	217.94	-63.39	262.43	-56.27	277.88	-20.21	216.74	-24.86	276.74
600	-54.54	148.77	-47.42	163.99	-58.73	202.61	-51.61	217.94	-63.39	262.43	-56.27	277.88	-20.21	216.74	-24.86	276.74
700	-54.54	148.77	-47.42	163.99	-58.73	202.61	-51.61	217.94	-63.39	262.43	-56.27	277.88	-20.21	216.74	-24.86	276.74
800	-54.54	148.77	-47.42	163.99	-58.73	202.61	-51.61	217.94	-63.39	262.43	-56.27	277.88	-20.21	216.74	-24.86	276.74
900	-54.54	148.77	-47.42	163.99	-58.73	202.61	-51.61	217.94	-63.39	262.43	-56.27	277.88	-20.21	216.74	-24.86	276.74
1000	-54.54	148.77	-47.42	163.99	-58.73	202.61	-51.61	217.94	-63.39	262.43	-56.27	277.88	-20.21	216.74	-24.86	276.74
1200	-54.54	148.77	-47.42	163.99	-58.73	202.61	-51.61	217.94	-63.39	262.43	-56.27	277.88	-20.21	216.74	-24.86	276.74
1500	-54.54	148.77	-47.42	163.99	-58.73	202.61	-51.61	217.94	-63.39	262.43	-56.27	277.88	-20.21	216.74	-24.86	276.74
2000	-54.54	148.77	-47.42	163.99	-58.73	202.61	-51.61	217.94	-63.39	262.43	-56.27	277.88	-20.21	216.74	-24.86	276.74
5000	-54.54	148.77	-47.42	163.99	-58.73	202.61	-51.61	217.94	-63.39	262.43	-56.27	277.88	-20.21	216.74	-24.86	276.74
10000	-54.54	148.77	-47.42	163.99	-58.73	202.61	-51.61	217.94	-63.39	262.43	-56.27	277.88	-20.21	216.74	-24.86	276.74
50000	-54.54	148.77	-47.42	163.99	-58.73	202.61	-51.61	217.94	-63.39	262.43	-56.27	277.88	-20.21	216.74	-24.86	276.74
Tangent	-54.54	148.77	-47.42	163.99	-58.73	202.61	-51.61	217.94	-63.39	262.43	-56.27	277.88	-20.21	216.74	-24.86	276.74

TABLE 3A - VEHICLE DYNAMIC ENVELOPE - OUTSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 0.5 in
Superelevation = 2.0 in

Radius:	$WL1_{OUT}$		$WL2_{OUT}$		$WL3_{OUT}$		$WL4_{OUT}$		$WL5_{OUT}$		$WL6_{OUT}$		$M1_{OUT}$		$M2_{OUT}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	75.97	7.99	78.62	125.29	74.28	139.74	60.39	153.08	0.00	0.00	0.00	0.00	70.85	84.22	70.90	93.16
100	72.08	7.99	74.72	125.29	70.53	139.74	57.92	153.08	0.00	0.00	0.00	0.00	69.24	84.22	69.30	93.16
150	65.87	7.99	68.52	125.29	64.56	139.74	53.99	153.08	0.00	0.00	0.00	0.00	66.63	84.22	66.68	93.16
200	62.64	7.99	65.29	125.29	61.45	139.74	51.95	153.08	0.00	0.00	0.00	0.00	65.23	84.22	65.29	93.16
300	59.32	7.99	61.97	125.29	58.28	139.74	49.86	153.08	0.00	0.00	0.00	0.00	63.79	84.22	63.84	93.16
400	58.20	7.99	60.84	125.29	57.30	139.74	48.79	153.08	0.00	0.00	0.00	0.00	63.04	84.22	63.10	93.16
500	57.73	7.99	60.38	125.29	56.84	139.74	48.15	153.08	0.00	0.00	0.00	0.00	62.59	84.22	62.64	93.16
600	57.42	7.99	60.07	125.29	56.53	139.74	47.72	153.08	0.00	0.00	0.00	0.00	62.28	84.22	62.34	93.16
700	57.20	7.99	59.85	125.29	56.31	139.74	47.41	153.08	0.00	0.00	0.00	0.00	62.06	84.22	62.12	93.16
800	57.03	7.99	59.68	125.29	56.14	139.74	47.18	153.08	0.00	0.00	0.00	0.00	61.90	84.22	61.95	93.16
900	56.90	7.99	59.55	125.29	56.01	139.74	47.00	153.08	0.00	0.00	0.00	0.00	61.77	84.22	61.82	93.16
1000	56.80	7.99	59.45	125.29	55.90	139.74	46.85	153.08	0.00	0.00	0.00	0.00	61.67	84.22	61.72	93.16
1200	56.64	7.99	59.29	125.29	55.74	139.74	46.63	153.08	0.00	0.00	0.00	0.00	61.51	84.22	61.56	93.16
1500	56.48	7.99	59.13	125.29	55.58	139.74	46.41	153.08	0.00	0.00	0.00	0.00	61.35	84.22	61.41	93.16
2000	56.32	7.99	58.97	125.29	55.43	139.74	46.20	153.08	0.00	0.00	0.00	0.00	61.20	84.22	61.25	93.16
5000	56.04	7.99	58.68	125.29	55.14	139.74	45.80	153.08	0.00	0.00	0.00	0.00	60.91	84.22	60.97	93.16
10000	55.94	7.99	58.59	125.29	55.04	139.74	45.67	153.08	0.00	0.00	0.00	0.00	60.82	84.22	60.87	93.16
50000	55.86	7.99	58.51	125.29	54.96	139.74	45.56	153.08	0.00	0.00	0.00	0.00	60.74	84.22	60.79	93.16
Tangent	55.84	7.99	58.49	125.29	54.95	139.74	45.54	153.08	0.00	0.00	0.00	0.00	60.72	84.22	60.78	93.16

Radius:	$P1_{OUT}$		$P2_{OUT}$		$P4_{OUT}$		$P5_{OUT}$		$P7_{OUT}$		$P8_{OUT}$		$R1_{CEN}$		$P3_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	46.94	151.63	39.29	165.55	48.40	205.61	40.75	219.31	50.02	265.59	42.38	279.04	-0.66	16.24	-18.76	163.23
100	46.94	151.63	39.29	165.55	48.40	205.61	40.75	219.31	50.02	265.59	42.38	279.04	-0.66	16.24	-18.76	163.23
150	46.94	151.63	39.29	165.55	48.40	205.61	40.75	219.31	50.02	265.59	42.38	279.04	-0.66	16.24	-18.76	163.23
200	46.94	151.63	39.29	165.55	48.40	205.61	40.75	219.31	50.02	265.59	42.38	279.04	-0.66	16.24	-18.76	163.23
300	46.94	151.63	39.29	165.55	48.40	205.61	40.75	219.31	50.02	265.59	42.38	279.04	-0.66	16.24	-18.76	163.23
400	46.94	151.63	39.29	165.55	48.40	205.61	40.75	219.31	50.02	265.59	42.38	279.04	-0.66	16.24	-18.76	163.23
500	46.94	151.63	39.29	165.55	48.40	205.61	40.75	219.31	50.02	265.59	42.38	279.04	-0.66	16.24	-18.76	163.23
600	46.94	151.63	39.29	165.55	48.40	205.61	40.75	219.31	50.02	265.59	42.38	279.04	-0.66	16.24	-18.76	163.23
700	46.94	151.63	39.29	165.55	48.40	205.61	40.75	219.31	50.02	265.59	42.38	279.04	-0.66	16.24	-18.76	163.23
800	46.94	151.63	39.29	165.55	48.40	205.61	40.75	219.31	50.02	265.59	42.38	279.04	-0.66	16.24	-18.76	163.23
900	46.94	151.63	39.29	165.55	48.40	205.61	40.75	219.31	50.02	265.59	42.38	279.04	-0.66	16.24	-18.76	163.23
1000	46.94	151.63	39.29	165.55	48.40	205.61	40.75	219.31	50.02	265.59	42.38	279.04	-0.66	16.24	-18.76	163.23
1200	46.94	151.63	39.29	165.55	48.40	205.61	40.75	219.31	50.02	265.59	42.38	279.04	-0.66	16.24	-18.76	163.23
1500	46.94	151.63	39.29	165.55	48.40	205.61	40.75	219.31	50.02	265.59	42.38	279.04	-0.66	16.24	-18.76	163.23
2000	46.94	151.63	39.29	165.55	48.40	205.61	40.75	219.31	50.02	265.59	42.38	279.04	-0.66	16.24	-18.76	163.23
5000	46.94	151.63	39.29	165.55	48.40	205.61	40.75	219.31	50.02	265.59	42.38	279.04	-0.66	16.24	-18.76	163.23
10000	46.94	151.63	39.29	165.55	48.40	205.61	40.75	219.31	50.02	265.59	42.38	279.04	-0.66	16.24	-18.76	163.23
50000	46.94	151.63	39.29	165.55	48.40	205.61	40.75	219.31	50.02	265.59	42.38	279.04	-0.66	16.24	-18.76	163.23
Tangent	46.94	151.63	39.29	165.55	48.40	205.61	40.75	219.31	50.02	265.59	42.38	279.04	-0.66	16.24	-18.76	163.23

TABLE 3B - VEHICLE DYNAMIC ENVELOPE - INSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 0.5 in
Superelevation = 2.0 in

Radius:	$WL1_{IN}$		$WL2_{IN}$		$WL3_{IN}$		$WL4_{IN}$		$WL5_{IN}$		$WL6_{IN}$		$M1_{IN}$		$M2_{IN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	-71.23	4.49	-81.42	121.31	-78.85	135.96	-69.78	151.05	0.00	0.00	0.00	0.00	-53.09	80.17	-53.28	89.72
100	-68.40	4.49	-78.58	121.31	-76.02	135.96	-66.94	151.05	0.00	0.00	0.00	0.00	-55.69	80.17	-55.88	89.72
150	-64.13	4.49	-74.32	121.31	-71.76	135.96	-62.68	151.05	0.00	0.00	0.00	0.00	-59.44	80.17	-59.63	89.72
200	-62.01	4.49	-72.20	121.31	-69.64	135.96	-60.56	151.05	0.00	0.00	0.00	0.00	-61.23	80.17	-61.42	89.72
300	-59.90	4.49	-70.08	121.31	-67.52	135.96	-58.45	151.05	0.00	0.00	0.00	0.00	-62.96	80.17	-63.15	89.72
400	-58.84	4.49	-69.03	121.31	-66.47	135.96	-57.39	151.05	0.00	0.00	0.00	0.00	-63.81	80.17	-64.00	89.72
500	-58.21	4.49	-68.39	121.31	-65.83	135.96	-56.76	151.05	0.00	0.00	0.00	0.00	-64.31	80.17	-64.50	89.72
600	-57.79	4.49	-67.97	121.31	-65.41	135.96	-56.33	151.05	0.00	0.00	0.00	0.00	-64.64	80.17	-64.83	89.72
700	-57.49	4.49	-67.67	121.31	-65.11	135.96	-56.03	151.05	0.00	0.00	0.00	0.00	-64.87	80.17	-65.06	89.72
800	-57.26	4.49	-67.45	121.31	-64.88	135.96	-55.81	151.05	0.00	0.00	0.00	0.00	-65.05	80.17	-65.24	89.72
900	-57.08	4.49	-67.27	121.31	-64.71	135.96	-55.63	151.05	0.00	0.00	0.00	0.00	-65.18	80.17	-65.37	89.72
1000	-56.94	4.49	-67.13	121.31	-64.57	135.96	-55.49	151.05	0.00	0.00	0.00	0.00	-65.29	80.17	-65.48	89.72
1200	-56.73	4.49	-66.92	121.31	-64.36	135.96	-55.28	151.05	0.00	0.00	0.00	0.00	-65.45	80.17	-65.64	89.72
1500	-56.52	4.49	-66.71	121.31	-64.14	135.96	-55.07	151.05	0.00	0.00	0.00	0.00	-65.62	80.17	-65.81	89.72
2000	-56.31	4.49	-66.50	121.31	-63.93	135.96	-54.86	151.05	0.00	0.00	0.00	0.00	-65.78	80.17	-65.97	89.72
5000	-56.42	4.49	-66.61	121.31	-64.05	135.96	-55.18	151.05	0.00	0.00	0.00	0.00	-66.07	80.17	-66.25	89.72
10000	-56.52	4.49	-66.71	121.31	-64.14	135.96	-55.31	151.05	0.00	0.00	0.00	0.00	-66.16	80.17	-66.35	89.72
50000	-56.60	4.49	-66.78	121.31	-64.22	135.96	-55.41	151.05	0.00	0.00	0.00	0.00	-66.24	80.17	-66.43	89.72
Tangent	-56.62	4.49	-66.80	121.31	-64.24	135.96	-55.44	151.05	0.00	0.00	0.00	0.00	-66.26	80.17	-66.45	89.72

Radius:	$P1_{IN}$		$P2_{IN}$		$P4_{IN}$		$P5_{IN}$		$P7_{IN}$		$P8_{IN}$		$P6_{CEN}$		$P9_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	-57.06	148.40	-50.12	164.04	-62.15	202.16	-55.21	218.02	-67.82	261.89	-60.88	278.00	-23.85	217.23	-29.52	277.22
100	-57.06	148.40	-50.12	164.04	-62.15	202.16	-55.21	218.02	-67.82	261.89	-60.88	278.00	-23.85	217.23	-29.52	277.22
150	-57.06	148.40	-50.12	164.04	-62.15	202.16	-55.21	218.02	-67.82	261.89	-60.88	278.00	-23.85	217.23	-29.52	277.22
200	-57.06	148.40	-50.12	164.04	-62.15	202.16	-55.21	218.02	-67.82	261.89	-60.88	278.00	-23.85	217.23	-29.52	277.22
300	-57.06	148.40	-50.12	164.04	-62.15	202.16	-55.21	218.02	-67.82	261.89	-60.88	278.00	-23.85	217.23	-29.52	277.22
400	-57.06	148.40	-50.12	164.04	-62.15	202.16	-55.21	218.02	-67.82	261.89	-60.88	278.00	-23.85	217.23	-29.52	277.22
500	-57.06	148.40	-50.12	164.04	-62.15	202.16	-55.21	218.02	-67.82	261.89	-60.88	278.00	-23.85	217.23	-29.52	277.22
600	-57.06	148.40	-50.12	164.04	-62.15	202.16	-55.21	218.02	-67.82	261.89	-60.88	278.00	-23.85	217.23	-29.52	277.22
700	-57.06	148.40	-50.12	164.04	-62.15	202.16	-55.21	218.02	-67.82	261.89	-60.88	278.00	-23.85	217.23	-29.52	277.22
800	-57.06	148.40	-50.12	164.04	-62.15	202.16	-55.21	218.02	-67.82	261.89	-60.88	278.00	-23.85	217.23	-29.52	277.22
900	-57.06	148.40	-50.12	164.04	-62.15	202.16	-55.21	218.02	-67.82	261.89	-60.88	278.00	-23.85	217.23	-29.52	277.22
1000	-57.06	148.40	-50.12	164.04	-62.15	202.16	-55.21	218.02	-67.82	261.89	-60.88	278.00	-23.85	217.23	-29.52	277.22
1200	-57.06	148.40	-50.12	164.04	-62.15	202.16	-55.21	218.02	-67.82	261.89	-60.88	278.00	-23.85	217.23	-29.52	277.22
1500	-57.06	148.40	-50.12	164.04	-62.15	202.16	-55.21	218.02	-67.82	261.89	-60.88	278.00	-23.85	217.23	-29.52	277.22
2000	-57.06	148.40	-50.12	164.04	-62.15	202.16	-55.21	218.02	-67.82	261.89	-60.88	278.00	-23.85	217.23	-29.52	277.22
5000	-57.06	148.40	-50.12	164.04	-62.15	202.16	-55.21	218.02	-67.82	261.89	-60.88	278.00	-23.85	217.23	-29.52	277.22
10000	-57.06	148.40	-50.12	164.04	-62.15	202.16	-55.21	218.02	-67.82	261.89	-60.88	278.00	-23.85	217.23	-29.52	277.22
50000	-57.06	148.40	-50.12	164.04	-62.15	202.16	-55.21	218.02	-67.82	261.89	-60.88	278.00	-23.85	217.23	-29.52	277.22
Tangent	-57.06	148.40	-50.12	164.04	-62.15	202.16	-55.21	218.02	-67.82	261.89	-60.88	278.00	-23.85	217.23	-29.52	277.22

TABLE 4A - VEHICLE DYNAMIC ENVELOPE - OUTSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 0.5 in
Superelevation = 3.0 in

Radius:	$WL1_{OUT}$		$WL2_{OUT}$		$WL3_{OUT}$		$WL4_{OUT}$		$WL5_{OUT}$		$WL6_{OUT}$		$M1_{OUT}$		$M2_{OUT}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	75.73	9.36	76.49	126.70	71.92	141.09	57.88	153.98	0.00	0.00	0.00	0.00	69.42	85.67	69.44	94.46
100	71.84	9.36	72.60	126.70	68.16	141.09	55.40	153.98	0.00	0.00	0.00	0.00	67.81	85.67	67.83	94.46
150	65.63	9.36	66.39	126.70	62.19	141.09	51.47	153.98	0.00	0.00	0.00	0.00	65.19	85.67	65.21	94.46
200	62.40	9.36	63.16	126.70	59.09	141.09	49.43	153.98	0.00	0.00	0.00	0.00	63.80	85.67	63.82	94.46
300	59.09	9.36	59.85	126.70	55.91	141.09	47.34	153.98	0.00	0.00	0.00	0.00	62.35	85.67	62.38	94.46
400	57.96	9.36	58.72	126.70	54.94	141.09	46.28	153.98	0.00	0.00	0.00	0.00	61.61	85.67	61.63	94.46
500	57.50	9.36	58.26	126.70	54.47	141.09	45.64	153.98	0.00	0.00	0.00	0.00	61.16	85.67	61.18	94.46
600	57.19	9.36	57.95	126.70	54.16	141.09	45.21	153.98	0.00	0.00	0.00	0.00	60.85	85.67	60.87	94.46
700	56.96	9.36	57.73	126.70	53.94	141.09	44.90	153.98	0.00	0.00	0.00	0.00	60.63	85.67	60.65	94.46
800	56.80	9.36	57.56	126.70	53.77	141.09	44.67	153.98	0.00	0.00	0.00	0.00	60.47	85.67	60.49	94.46
900	56.66	9.36	57.43	126.70	53.64	141.09	44.48	153.98	0.00	0.00	0.00	0.00	60.34	85.67	60.36	94.46
1000	56.56	9.36	57.32	126.70	53.53	141.09	44.34	153.98	0.00	0.00	0.00	0.00	60.23	85.67	60.25	94.46
1200	56.40	9.36	57.16	126.70	53.38	141.09	44.12	153.98	0.00	0.00	0.00	0.00	60.08	85.67	60.10	94.46
1500	56.24	9.36	57.01	126.70	53.22	141.09	43.90	153.98	0.00	0.00	0.00	0.00	59.92	85.67	59.94	94.46
2000	56.08	9.36	56.85	126.70	53.06	141.09	43.68	153.98	0.00	0.00	0.00	0.00	59.76	85.67	59.78	94.46
5000	55.80	9.36	56.56	126.70	52.77	141.09	43.29	153.98	0.00	0.00	0.00	0.00	59.48	85.67	59.50	94.46
10000	55.70	9.36	56.46	126.70	52.67	141.09	43.15	153.98	0.00	0.00	0.00	0.00	59.39	85.67	59.41	94.46
50000	55.62	9.36	56.39	126.70	52.60	141.09	43.05	153.98	0.00	0.00	0.00	0.00	59.31	85.67	59.33	94.46
Tangent	55.60	9.36	56.37	126.70	52.58	141.09	43.02	153.98	0.00	0.00	0.00	0.00	59.29	85.67	59.31	94.46

Radius:	$P1_{OUT}$		$P2_{OUT}$		$P4_{OUT}$		$P5_{OUT}$		$P7_{OUT}$		$P8_{OUT}$		$R1_{CEN}$		$P3_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	44.37	152.83	36.56	166.31	44.92	206.82	37.11	219.98	45.54	266.82	37.72	279.61	-0.94	16.73	-21.50	163.73
100	44.37	152.83	36.56	166.31	44.92	206.82	37.11	219.98	45.54	266.82	37.72	279.61	-0.94	16.73	-21.50	163.73
150	44.37	152.83	36.56	166.31	44.92	206.82	37.11	219.98	45.54	266.82	37.72	279.61	-0.94	16.73	-21.50	163.73
200	44.37	152.83	36.56	166.31	44.92	206.82	37.11	219.98	45.54	266.82	37.72	279.61	-0.94	16.73	-21.50	163.73
300	44.37	152.83	36.56	166.31	44.92	206.82	37.11	219.98	45.54	266.82	37.72	279.61	-0.94	16.73	-21.50	163.73
400	44.37	152.83	36.56	166.31	44.92	206.82	37.11	219.98	45.54	266.82	37.72	279.61	-0.94	16.73	-21.50	163.73
500	44.37	152.83	36.56	166.31	44.92	206.82	37.11	219.98	45.54	266.82	37.72	279.61	-0.94	16.73	-21.50	163.73
600	44.37	152.83	36.56	166.31	44.92	206.82	37.11	219.98	45.54	266.82	37.72	279.61	-0.94	16.73	-21.50	163.73
700	44.37	152.83	36.56	166.31	44.92	206.82	37.11	219.98	45.54	266.82	37.72	279.61	-0.94	16.73	-21.50	163.73
800	44.37	152.83	36.56	166.31	44.92	206.82	37.11	219.98	45.54	266.82	37.72	279.61	-0.94	16.73	-21.50	163.73
900	44.37	152.83	36.56	166.31	44.92	206.82	37.11	219.98	45.54	266.82	37.72	279.61	-0.94	16.73	-21.50	163.73
1000	44.37	152.83	36.56	166.31	44.92	206.82	37.11	219.98	45.54	266.82	37.72	279.61	-0.94	16.73	-21.50	163.73
1200	44.37	152.83	36.56	166.31	44.92	206.82	37.11	219.98	45.54	266.82	37.72	279.61	-0.94	16.73	-21.50	163.73
1500	44.37	152.83	36.56	166.31	44.92	206.82	37.11	219.98	45.54	266.82	37.72	279.61	-0.94	16.73	-21.50	163.73
2000	44.37	152.83	36.56	166.31	44.92	206.82	37.11	219.98	45.54	266.82	37.72	279.61	-0.94	16.73	-21.50	163.73
5000	44.37	152.83	36.56	166.31	44.92	206.82	37.11	219.98	45.54	266.82	37.72	279.61	-0.94	16.73	-21.50	163.73
10000	44.37	152.83	36.56	166.31	44.92	206.82	37.11	219.98	45.54	266.82	37.72	279.61	-0.94	16.73	-21.50	163.73
50000	44.37	152.83	36.56	166.31	44.92	206.82	37.11	219.98	45.54	266.82	37.72	279.61	-0.94	16.73	-21.50	163.73
Tangent	44.37	152.83	36.56	166.31	44.92	206.82	37.11	219.98	45.54	266.82	37.72	279.61	-0.94	16.73	-21.50	163.73

TABLE 4B - VEHICLE DYNAMIC ENVELOPE - INSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 0.5 in
Superelevation = 3.0 in

Radius:	$WL1_{IN}$		$WL2_{IN}$		$WL3_{IN}$		$WL4_{IN}$		$WL5_{IN}$		$WL6_{IN}$		$M1_{IN}$		$M2_{IN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	-71.40	4.11	-83.46	120.72	-81.15	135.42	-72.23	150.94	0.00	0.00	0.00	0.00	-54.45	79.61	-54.67	89.30
100	-68.57	4.11	-80.63	120.72	-78.32	135.42	-69.40	150.94	0.00	0.00	0.00	0.00	-57.04	79.61	-57.27	89.30
150	-64.31	4.11	-76.37	120.72	-74.05	135.42	-65.13	150.94	0.00	0.00	0.00	0.00	-60.80	79.61	-61.02	89.30
200	-62.18	4.11	-74.25	120.72	-71.93	135.42	-63.01	150.94	0.00	0.00	0.00	0.00	-62.59	79.61	-62.81	89.30
300	-60.07	4.11	-72.13	120.72	-69.82	135.42	-60.90	150.94	0.00	0.00	0.00	0.00	-64.32	79.61	-64.54	89.30
400	-59.01	4.11	-71.08	120.72	-68.76	135.42	-59.84	150.94	0.00	0.00	0.00	0.00	-65.16	79.61	-65.39	89.30
500	-58.38	4.11	-70.44	120.72	-68.13	135.42	-59.21	150.94	0.00	0.00	0.00	0.00	-65.66	79.61	-65.89	89.30
600	-57.96	4.11	-70.02	120.72	-67.71	135.42	-58.79	150.94	0.00	0.00	0.00	0.00	-65.99	79.61	-66.22	89.30
700	-57.66	4.11	-69.72	120.72	-67.40	135.42	-58.49	150.94	0.00	0.00	0.00	0.00	-66.23	79.61	-66.45	89.30
800	-57.43	4.11	-69.49	120.72	-67.18	135.42	-58.26	150.94	0.00	0.00	0.00	0.00	-66.40	79.61	-66.63	89.30
900	-57.26	4.11	-69.32	120.72	-67.00	135.42	-58.09	150.94	0.00	0.00	0.00	0.00	-66.54	79.61	-66.76	89.30
1000	-57.12	4.11	-69.18	120.72	-66.86	135.42	-57.95	150.94	0.00	0.00	0.00	0.00	-66.65	79.61	-66.87	89.30
1200	-56.90	4.11	-68.97	120.72	-66.65	135.42	-57.73	150.94	0.00	0.00	0.00	0.00	-66.81	79.61	-67.03	89.30
1500	-56.69	4.11	-68.76	120.72	-66.44	135.42	-57.52	150.94	0.00	0.00	0.00	0.00	-66.97	79.61	-67.19	89.30
2000	-56.48	4.11	-68.54	120.72	-66.23	135.42	-57.31	150.94	0.00	0.00	0.00	0.00	-67.13	79.61	-67.35	89.30
5000	-56.60	4.11	-68.66	120.72	-66.34	135.42	-57.63	150.94	0.00	0.00	0.00	0.00	-67.42	79.61	-67.64	89.30
10000	-56.69	4.11	-68.75	120.72	-66.44	135.42	-57.76	150.94	0.00	0.00	0.00	0.00	-67.52	79.61	-67.74	89.30
50000	-56.77	4.11	-68.83	120.72	-66.52	135.42	-57.87	150.94	0.00	0.00	0.00	0.00	-67.59	79.61	-67.81	89.30
Tangent	-56.79	4.11	-68.85	120.72	-66.54	135.42	-57.90	150.94	0.00	0.00	0.00	0.00	-67.61	79.61	-67.83	89.30

Radius:	$P1_{IN}$		$P2_{IN}$		$P4_{IN}$		$P5_{IN}$		$P7_{IN}$		$P8_{IN}$		$P6_{CEN}$		$P9_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	-59.56	147.99	-52.80	164.05	-65.57	201.65	-58.81	218.05	-72.24	261.28	-65.48	278.04	-27.50	217.72	-34.17	277.72
100	-59.56	147.99	-52.80	164.05	-65.57	201.65	-58.81	218.05	-72.24	261.28	-65.48	278.04	-27.50	217.72	-34.17	277.72
150	-59.56	147.99	-52.80	164.05	-65.57	201.65	-58.81	218.05	-72.24	261.28	-65.48	278.04	-27.50	217.72	-34.17	277.72
200	-59.56	147.99	-52.80	164.05	-65.57	201.65	-58.81	218.05	-72.24	261.28	-65.48	278.04	-27.50	217.72	-34.17	277.72
300	-59.56	147.99	-52.80	164.05	-65.57	201.65	-58.81	218.05	-72.24	261.28	-65.48	278.04	-27.50	217.72	-34.17	277.72
400	-59.56	147.99	-52.80	164.05	-65.57	201.65	-58.81	218.05	-72.24	261.28	-65.48	278.04	-27.50	217.72	-34.17	277.72
500	-59.56	147.99	-52.80	164.05	-65.57	201.65	-58.81	218.05	-72.24	261.28	-65.48	278.04	-27.50	217.72	-34.17	277.72
600	-59.56	147.99	-52.80	164.05	-65.57	201.65	-58.81	218.05	-72.24	261.28	-65.48	278.04	-27.50	217.72	-34.17	277.72
700	-59.56	147.99	-52.80	164.05	-65.57	201.65	-58.81	218.05	-72.24	261.28	-65.48	278.04	-27.50	217.72	-34.17	277.72
800	-59.56	147.99	-52.80	164.05	-65.57	201.65	-58.81	218.05	-72.24	261.28	-65.48	278.04	-27.50	217.72	-34.17	277.72
900	-59.56	147.99	-52.80	164.05	-65.57	201.65	-58.81	218.05	-72.24	261.28	-65.48	278.04	-27.50	217.72	-34.17	277.72
1000	-59.56	147.99	-52.80	164.05	-65.57	201.65	-58.81	218.05	-72.24	261.28	-65.48	278.04	-27.50	217.72	-34.17	277.72
1200	-59.56	147.99	-52.80	164.05	-65.57	201.65	-58.81	218.05	-72.24	261.28	-65.48	278.04	-27.50	217.72	-34.17	277.72
1500	-59.56	147.99	-52.80	164.05	-65.57	201.65	-58.81	218.05	-72.24	261.28	-65.48	278.04	-27.50	217.72	-34.17	277.72
2000	-59.56	147.99	-52.80	164.05	-65.57	201.65	-58.81	218.05	-72.24	261.28	-65.48	278.04	-27.50	217.72	-34.17	277.72
5000	-59.56	147.99	-52.80	164.05	-65.57	201.65	-58.81	218.05	-72.24	261.28	-65.48	278.04	-27.50	217.72	-34.17	277.72
10000	-59.56	147.99	-52.80	164.05	-65.57	201.65	-58.81	218.05	-72.24	261.28	-65.48	278.04	-27.50	217.72	-34.17	277.72
50000	-59.56	147.99	-52.80	164.05	-65.57	201.65	-58.81	218.05	-72.24	261.28	-65.48	278.04	-27.50	217.72	-34.17	277.72
Tangent	-59.56	147.99	-52.80	164.05	-65.57	201.65	-58.81	218.05	-72.24	261.28	-65.48	278.04	-27.50	217.72	-34.17	277.72

TABLE 5A - VEHICLE DYNAMIC ENVELOPE - OUTSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 0.5 in
Superelevation = 4.0 in

Radius:	$WL1_{OUT}$		$WL2_{OUT}$		$WL3_{OUT}$		$WL4_{OUT}$		$WL5_{OUT}$		$WL6_{OUT}$		$M1_{OUT}$		$M2_{OUT}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	75.47	10.73	74.35	128.06	69.53	142.39	55.35	154.83	0.00	0.00	0.00	0.00	67.96	87.09	67.95	95.72
100	71.57	10.73	70.46	128.06	65.77	142.39	52.87	154.83	0.00	0.00	0.00	0.00	66.36	87.09	66.35	95.72
150	65.37	10.73	64.25	128.06	59.80	142.39	48.95	154.83	0.00	0.00	0.00	0.00	63.74	87.09	63.73	95.72
200	62.14	10.73	61.02	128.06	56.70	142.39	46.91	154.83	0.00	0.00	0.00	0.00	62.35	87.09	62.34	95.72
300	58.82	10.73	57.71	128.06	53.52	142.39	44.82	154.83	0.00	0.00	0.00	0.00	60.90	87.09	60.89	95.72
400	57.69	10.73	56.58	128.06	52.55	142.39	43.75	154.83	0.00	0.00	0.00	0.00	60.16	87.09	60.14	95.72
500	57.23	10.73	56.12	128.06	52.09	142.39	43.11	154.83	0.00	0.00	0.00	0.00	59.70	87.09	59.69	95.72
600	56.92	10.73	55.81	128.06	51.78	142.39	42.68	154.83	0.00	0.00	0.00	0.00	59.40	87.09	59.38	95.72
700	56.70	10.73	55.58	128.06	51.55	142.39	42.37	154.83	0.00	0.00	0.00	0.00	59.18	87.09	59.16	95.72
800	56.53	10.73	55.41	128.06	51.39	142.39	42.14	154.83	0.00	0.00	0.00	0.00	59.01	87.09	59.00	95.72
900	56.40	10.73	55.28	128.06	51.25	142.39	41.96	154.83	0.00	0.00	0.00	0.00	58.88	87.09	58.87	95.72
1000	56.30	10.73	55.18	128.06	51.15	142.39	41.81	154.83	0.00	0.00	0.00	0.00	58.78	87.09	58.77	95.72
1200	56.14	10.73	55.02	128.06	50.99	142.39	41.59	154.83	0.00	0.00	0.00	0.00	58.62	87.09	58.61	95.72
1500	55.98	10.73	54.86	128.06	50.83	142.39	41.37	154.83	0.00	0.00	0.00	0.00	58.47	87.09	58.45	95.72
2000	55.82	10.73	54.70	128.06	50.67	142.39	41.15	154.83	0.00	0.00	0.00	0.00	58.31	87.09	58.30	95.72
5000	55.54	10.73	54.42	128.06	50.39	142.39	40.76	154.83	0.00	0.00	0.00	0.00	58.03	87.09	58.01	95.72
10000	55.44	10.73	54.32	128.06	50.29	142.39	40.63	154.83	0.00	0.00	0.00	0.00	57.93	87.09	57.92	95.72
50000	55.36	10.73	54.24	128.06	50.21	142.39	40.52	154.83	0.00	0.00	0.00	0.00	57.86	87.09	57.84	95.72
Tangent	55.34	10.73	54.22	128.06	50.19	142.39	40.49	154.83	0.00	0.00	0.00	0.00	57.84	87.09	57.82	95.72

Radius:	$P1_{OUT}$		$P2_{OUT}$		$P4_{OUT}$		$P5_{OUT}$		$P7_{OUT}$		$P8_{OUT}$		$R1_{CEN}$		$P3_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	41.79	153.98	33.81	167.02	41.43	207.98	33.45	220.58	41.04	267.98	33.05	280.10	-1.22	17.22	-24.24	164.22
100	41.79	153.98	33.81	167.02	41.43	207.98	33.45	220.58	41.04	267.98	33.05	280.10	-1.22	17.22	-24.24	164.22
150	41.79	153.98	33.81	167.02	41.43	207.98	33.45	220.58	41.04	267.98	33.05	280.10	-1.22	17.22	-24.24	164.22
200	41.79	153.98	33.81	167.02	41.43	207.98	33.45	220.58	41.04	267.98	33.05	280.10	-1.22	17.22	-24.24	164.22
300	41.79	153.98	33.81	167.02	41.43	207.98	33.45	220.58	41.04	267.98	33.05	280.10	-1.22	17.22	-24.24	164.22
400	41.79	153.98	33.81	167.02	41.43	207.98	33.45	220.58	41.04	267.98	33.05	280.10	-1.22	17.22	-24.24	164.22
500	41.79	153.98	33.81	167.02	41.43	207.98	33.45	220.58	41.04	267.98	33.05	280.10	-1.22	17.22	-24.24	164.22
600	41.79	153.98	33.81	167.02	41.43	207.98	33.45	220.58	41.04	267.98	33.05	280.10	-1.22	17.22	-24.24	164.22
700	41.79	153.98	33.81	167.02	41.43	207.98	33.45	220.58	41.04	267.98	33.05	280.10	-1.22	17.22	-24.24	164.22
800	41.79	153.98	33.81	167.02	41.43	207.98	33.45	220.58	41.04	267.98	33.05	280.10	-1.22	17.22	-24.24	164.22
900	41.79	153.98	33.81	167.02	41.43	207.98	33.45	220.58	41.04	267.98	33.05	280.10	-1.22	17.22	-24.24	164.22
1000	41.79	153.98	33.81	167.02	41.43	207.98	33.45	220.58	41.04	267.98	33.05	280.10	-1.22	17.22	-24.24	164.22
1200	41.79	153.98	33.81	167.02	41.43	207.98	33.45	220.58	41.04	267.98	33.05	280.10	-1.22	17.22	-24.24	164.22
1500	41.79	153.98	33.81	167.02	41.43	207.98	33.45	220.58	41.04	267.98	33.05	280.10	-1.22	17.22	-24.24	164.22
2000	41.79	153.98	33.81	167.02	41.43	207.98	33.45	220.58	41.04	267.98	33.05	280.10	-1.22	17.22	-24.24	164.22
5000	41.79	153.98	33.81	167.02	41.43	207.98	33.45	220.58	41.04	267.98	33.05	280.10	-1.22	17.22	-24.24	164.22
10000	41.79	153.98	33.81	167.02	41.43	207.98	33.45	220.58	41.04	267.98	33.05	280.10	-1.22	17.22	-24.24	164.22
50000	41.79	153.98	33.81	167.02	41.43	207.98	33.45	220.58	41.04	267.98	33.05	280.10	-1.22	17.22	-24.24	164.22
Tangent	41.79	153.98	33.81	167.02	41.43	207.98	33.45	220.58	41.04	267.98	33.05	280.10	-1.22	17.22	-24.24	164.22

TABLE 5B - VEHICLE DYNAMIC ENVELOPE - INSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 0.5 in
Superelevation = 4.0 in

Radius:	$WL1_{IN}$		$WL2_{IN}$		$WL3_{IN}$		$WL4_{IN}$		$WL5_{IN}$		$WL6_{IN}$		$M1_{IN}$		$M2_{IN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	-71.57	3.73	-85.50	120.11	-83.43	134.84	-74.68	150.78	0.00	0.00	0.00	0.00	-55.79	79.02	-56.05	88.85
100	-68.74	3.73	-82.67	120.11	-80.60	134.84	-71.84	150.78	0.00	0.00	0.00	0.00	-58.39	79.02	-58.64	88.85
150	-64.47	3.73	-78.40	120.11	-76.33	134.84	-67.58	150.78	0.00	0.00	0.00	0.00	-62.14	79.02	-62.39	88.85
200	-62.35	3.73	-76.28	120.11	-74.21	134.84	-65.46	150.78	0.00	0.00	0.00	0.00	-63.93	79.02	-64.18	88.85
300	-60.24	3.73	-74.17	120.11	-72.10	134.84	-63.34	150.78	0.00	0.00	0.00	0.00	-65.66	79.02	-65.92	88.85
400	-59.18	3.73	-73.11	120.11	-71.04	134.84	-62.29	150.78	0.00	0.00	0.00	0.00	-66.51	79.02	-66.76	88.85
500	-58.55	3.73	-72.48	120.11	-70.41	134.84	-61.65	150.78	0.00	0.00	0.00	0.00	-67.01	79.02	-67.26	88.85
600	-58.12	3.73	-72.06	120.11	-69.99	134.84	-61.23	150.78	0.00	0.00	0.00	0.00	-67.34	79.02	-67.59	88.85
700	-57.82	3.73	-71.75	120.11	-69.69	134.84	-60.93	150.78	0.00	0.00	0.00	0.00	-67.57	79.02	-67.83	88.85
800	-57.60	3.73	-71.53	120.11	-69.46	134.84	-60.71	150.78	0.00	0.00	0.00	0.00	-67.75	79.02	-68.00	88.85
900	-57.42	3.73	-71.35	120.11	-69.29	134.84	-60.53	150.78	0.00	0.00	0.00	0.00	-67.88	79.02	-68.14	88.85
1000	-57.28	3.73	-71.21	120.11	-69.14	134.84	-60.39	150.78	0.00	0.00	0.00	0.00	-67.99	79.02	-68.25	88.85
1200	-57.07	3.73	-71.00	120.11	-68.93	134.84	-60.18	150.78	0.00	0.00	0.00	0.00	-68.15	79.02	-68.41	88.85
1500	-56.86	3.73	-70.79	120.11	-68.72	134.84	-59.97	150.78	0.00	0.00	0.00	0.00	-68.31	79.02	-68.57	88.85
2000	-56.65	3.73	-70.58	120.11	-68.51	134.84	-59.76	150.78	0.00	0.00	0.00	0.00	-68.48	79.02	-68.73	88.85
5000	-56.76	3.73	-70.69	120.11	-68.62	134.84	-60.07	150.78	0.00	0.00	0.00	0.00	-68.76	79.02	-69.02	88.85
10000	-56.86	3.73	-70.79	120.11	-68.72	134.84	-60.21	150.78	0.00	0.00	0.00	0.00	-68.86	79.02	-69.12	88.85
50000	-56.94	3.73	-70.87	120.11	-68.80	134.84	-60.31	150.78	0.00	0.00	0.00	0.00	-68.94	79.02	-69.19	88.85
Tangent	-56.95	3.73	-70.89	120.11	-68.82	134.84	-60.34	150.78	0.00	0.00	0.00	0.00	-68.95	79.02	-69.21	88.85

Radius:	$P1_{IN}$		$P2_{IN}$		$P4_{IN}$		$P5_{IN}$		$P7_{IN}$		$P8_{IN}$		$P6_{CEN}$		$P9_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	-62.06	147.54	-55.48	164.01	-68.96	201.09	-62.39	218.01	-76.64	260.60	-70.06	278.00	-31.15	218.22	-38.82	278.21
100	-62.06	147.54	-55.48	164.01	-68.96	201.09	-62.39	218.01	-76.64	260.60	-70.06	278.00	-31.15	218.22	-38.82	278.21
150	-62.06	147.54	-55.48	164.01	-68.96	201.09	-62.39	218.01	-76.64	260.60	-70.06	278.00	-31.15	218.22	-38.82	278.21
200	-62.06	147.54	-55.48	164.01	-68.96	201.09	-62.39	218.01	-76.64	260.60	-70.06	278.00	-31.15	218.22	-38.82	278.21
300	-62.06	147.54	-55.48	164.01	-68.96	201.09	-62.39	218.01	-76.64	260.60	-70.06	278.00	-31.15	218.22	-38.82	278.21
400	-62.06	147.54	-55.48	164.01	-68.96	201.09	-62.39	218.01	-76.64	260.60	-70.06	278.00	-31.15	218.22	-38.82	278.21
500	-62.06	147.54	-55.48	164.01	-68.96	201.09	-62.39	218.01	-76.64	260.60	-70.06	278.00	-31.15	218.22	-38.82	278.21
600	-62.06	147.54	-55.48	164.01	-68.96	201.09	-62.39	218.01	-76.64	260.60	-70.06	278.00	-31.15	218.22	-38.82	278.21
700	-62.06	147.54	-55.48	164.01	-68.96	201.09	-62.39	218.01	-76.64	260.60	-70.06	278.00	-31.15	218.22	-38.82	278.21
800	-62.06	147.54	-55.48	164.01	-68.96	201.09	-62.39	218.01	-76.64	260.60	-70.06	278.00	-31.15	218.22	-38.82	278.21
900	-62.06	147.54	-55.48	164.01	-68.96	201.09	-62.39	218.01	-76.64	260.60	-70.06	278.00	-31.15	218.22	-38.82	278.21
1000	-62.06	147.54	-55.48	164.01	-68.96	201.09	-62.39	218.01	-76.64	260.60	-70.06	278.00	-31.15	218.22	-38.82	278.21
1200	-62.06	147.54	-55.48	164.01	-68.96	201.09	-62.39	218.01	-76.64	260.60	-70.06	278.00	-31.15	218.22	-38.82	278.21
1500	-62.06	147.54	-55.48	164.01	-68.96	201.09	-62.39	218.01	-76.64	260.60	-70.06	278.00	-31.15	218.22	-38.82	278.21
2000	-62.06	147.54	-55.48	164.01	-68.96	201.09	-62.39	218.01	-76.64	260.60	-70.06	278.00	-31.15	218.22	-38.82	278.21
5000	-62.06	147.54	-55.48	164.01	-68.96	201.09	-62.39	218.01	-76.64	260.60	-70.06	278.00	-31.15	218.22	-38.82	278.21
10000	-62.06	147.54	-55.48	164.01	-68.96	201.09	-62.39	218.01	-76.64	260.60	-70.06	278.00	-31.15	218.22	-38.82	278.21
50000	-62.06	147.54	-55.48	164.01	-68.96	201.09	-62.39	218.01	-76.64	260.60	-70.06	278.00	-31.15	218.22	-38.82	278.21
Tangent	-62.06	147.54	-55.48	164.01	-68.96	201.09	-62.39	218.01	-76.64	260.60	-70.06	278.00	-31.15	218.22	-38.82	278.21

TABLE 6A - VEHICLE DYNAMIC ENVELOPE - OUTSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 0.5 in
Superelevation = 5.0 in

Radius:	$WL1_{OUT}$		$WL2_{OUT}$		$WL3_{OUT}$		$WL4_{OUT}$		$WL5_{OUT}$		$WL6_{OUT}$		$M1_{OUT}$		$M2_{OUT}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	75.18	12.08	72.19	129.39	67.13	143.65	52.81	155.64	0.00	0.00	0.00	0.00	66.49	88.48	66.44	96.95
100	71.29	12.08	68.29	129.39	63.37	143.65	50.33	155.64	0.00	0.00	0.00	0.00	64.88	88.48	64.84	96.95
150	65.09	12.08	62.09	129.39	57.40	143.65	46.40	155.64	0.00	0.00	0.00	0.00	62.27	88.48	62.22	96.95
200	61.86	12.08	58.86	129.39	54.30	143.65	44.36	155.64	0.00	0.00	0.00	0.00	60.88	88.48	60.83	96.95
300	58.54	12.08	55.54	129.39	51.12	143.65	42.28	155.64	0.00	0.00	0.00	0.00	59.43	88.48	59.38	96.95
400	57.41	12.08	54.41	129.39	50.15	143.65	41.21	155.64	0.00	0.00	0.00	0.00	58.68	88.48	58.64	96.95
500	56.95	12.08	53.95	129.39	49.69	143.65	40.57	155.64	0.00	0.00	0.00	0.00	58.23	88.48	58.18	96.95
600	56.64	12.08	53.64	129.39	49.38	143.65	40.14	155.64	0.00	0.00	0.00	0.00	57.92	88.48	57.88	96.95
700	56.42	12.08	53.42	129.39	49.15	143.65	39.83	155.64	0.00	0.00	0.00	0.00	57.70	88.48	57.66	96.95
800	56.25	12.08	53.25	129.39	48.98	143.65	39.60	155.64	0.00	0.00	0.00	0.00	57.54	88.48	57.49	96.95
900	56.12	12.08	53.12	129.39	48.85	143.65	39.42	155.64	0.00	0.00	0.00	0.00	57.41	88.48	57.36	96.95
1000	56.01	12.08	53.02	129.39	48.75	143.65	39.27	155.64	0.00	0.00	0.00	0.00	57.31	88.48	57.26	96.95
1200	55.86	12.08	52.86	129.39	48.59	143.65	39.05	155.64	0.00	0.00	0.00	0.00	57.15	88.48	57.10	96.95
1500	55.70	12.08	52.70	129.39	48.43	143.65	38.83	155.64	0.00	0.00	0.00	0.00	56.99	88.48	56.95	96.95
2000	55.54	12.08	52.54	129.39	48.27	143.65	38.61	155.64	0.00	0.00	0.00	0.00	56.84	88.48	56.79	96.95
5000	55.25	12.08	52.25	129.39	47.98	143.65	38.22	155.64	0.00	0.00	0.00	0.00	56.55	88.48	56.51	96.95
10000	55.16	12.08	52.16	129.39	47.89	143.65	38.09	155.64	0.00	0.00	0.00	0.00	56.46	88.48	56.41	96.95
50000	55.08	12.08	52.08	129.39	47.81	143.65	37.98	155.64	0.00	0.00	0.00	0.00	56.38	88.48	56.33	96.95
Tangent	55.06	12.08	52.06	129.39	47.79	143.65	37.95	155.64	0.00	0.00	0.00	0.00	56.36	88.48	56.32	96.95

Radius:	$P1_{OUT}$		$P2_{OUT}$		$P4_{OUT}$		$P5_{OUT}$		$P7_{OUT}$		$P8_{OUT}$		$R1_{CEN}$		$P3_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	39.20	155.08	31.05	167.69	37.93	209.07	29.78	221.12	36.53	269.05	28.38	280.58	-1.52	17.70	-26.98	164.66
100	39.20	155.08	31.05	167.69	37.93	209.07	29.78	221.12	36.53	269.05	28.38	280.58	-1.52	17.70	-26.98	164.66
150	39.20	155.08	31.05	167.69	37.93	209.07	29.78	221.12	36.53	269.05	28.38	280.58	-1.52	17.70	-26.98	164.66
200	39.20	155.08	31.05	167.69	37.93	209.07	29.78	221.12	36.53	269.05	28.38	280.58	-1.52	17.70	-26.98	164.66
300	39.20	155.08	31.05	167.69	37.93	209.07	29.78	221.12	36.53	269.05	28.38	280.58	-1.52	17.70	-26.98	164.66
400	39.20	155.08	31.05	167.69	37.93	209.07	29.78	221.12	36.53	269.05	28.38	280.58	-1.52	17.70	-26.98	164.66
500	39.20	155.08	31.05	167.69	37.93	209.07	29.78	221.12	36.53	269.05	28.38	280.58	-1.52	17.70	-26.98	164.66
600	39.20	155.08	31.05	167.69	37.93	209.07	29.78	221.12	36.53	269.05	28.38	280.58	-1.52	17.70	-26.98	164.66
700	39.20	155.08	31.05	167.69	37.93	209.07	29.78	221.12	36.53	269.05	28.38	280.58	-1.52	17.70	-26.98	164.66
800	39.20	155.08	31.05	167.69	37.93	209.07	29.78	221.12	36.53	269.05	28.38	280.58	-1.52	17.70	-26.98	164.66
900	39.20	155.08	31.05	167.69	37.93	209.07	29.78	221.12	36.53	269.05	28.38	280.58	-1.52	17.70	-26.98	164.66
1000	39.20	155.08	31.05	167.69	37.93	209.07	29.78	221.12	36.53	269.05	28.38	280.58	-1.52	17.70	-26.98	164.66
1200	39.20	155.08	31.05	167.69	37.93	209.07	29.78	221.12	36.53	269.05	28.38	280.58	-1.52	17.70	-26.98	164.66
1500	39.20	155.08	31.05	167.69	37.93	209.07	29.78	221.12	36.53	269.05	28.38	280.58	-1.52	17.70	-26.98	164.66
2000	39.20	155.08	31.05	167.69	37.93	209.07	29.78	221.12	36.53	269.05	28.38	280.58	-1.52	17.70	-26.98	164.66
5000	39.20	155.08	31.05	167.69	37.93	209.07	29.78	221.12	36.53	269.05	28.38	280.58	-1.52	17.70	-26.98	164.66
10000	39.20	155.08	31.05	167.69	37.93	209.07	29.78	221.12	36.53	269.05	28.38	280.58	-1.52	17.70	-26.98	164.66
50000	39.20	155.08	31.05	167.69	37.93	209.07	29.78	221.12	36.53	269.05	28.38	280.58	-1.52	17.70	-26.98	164.66
Tangent	39.20	155.08	31.05	167.69	37.93	209.07	29.78	221.12	36.53	269.05	28.38	280.58	-1.52	17.70	-26.98	164.66

TABLE 6B - VEHICLE DYNAMIC ENVELOPE - INSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 0.5 in
Superelevation = 5.0 in

Radius:	$WL1_{IN}$		$WL2_{IN}$		$WL3_{IN}$		$WL4_{IN}$		$WL5_{IN}$		$WL6_{IN}$		$M1_{IN}$		$M2_{IN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	-71.73	3.35	-87.52	119.46	-85.70	134.23	-77.11	150.58	0.00	0.00	0.00	0.00	-57.12	78.41	-57.41	88.38
100	-68.89	3.35	-84.69	119.46	-82.87	134.23	-74.27	150.58	0.00	0.00	0.00	0.00	-59.72	78.41	-60.00	88.38
150	-64.63	3.35	-80.42	119.46	-78.60	134.23	-70.01	150.58	0.00	0.00	0.00	0.00	-63.47	78.41	-63.76	88.38
200	-62.51	3.35	-78.30	119.46	-76.48	134.23	-67.89	150.58	0.00	0.00	0.00	0.00	-65.26	78.41	-65.55	88.38
300	-60.39	3.35	-76.19	119.46	-74.37	134.23	-65.77	150.58	0.00	0.00	0.00	0.00	-66.99	78.41	-67.28	88.38
400	-59.34	3.35	-75.13	119.46	-73.31	134.23	-64.72	150.58	0.00	0.00	0.00	0.00	-67.84	78.41	-68.13	88.38
500	-58.71	3.35	-74.50	119.46	-72.68	134.23	-64.09	150.58	0.00	0.00	0.00	0.00	-68.34	78.41	-68.63	88.38
600	-58.28	3.35	-74.08	119.46	-72.26	134.23	-63.66	150.58	0.00	0.00	0.00	0.00	-68.67	78.41	-68.96	88.38
700	-57.98	3.35	-73.77	119.46	-71.95	134.23	-63.36	150.58	0.00	0.00	0.00	0.00	-68.90	78.41	-69.19	88.38
800	-57.76	3.35	-73.55	119.46	-71.73	134.23	-63.14	150.58	0.00	0.00	0.00	0.00	-69.08	78.41	-69.37	88.38
900	-57.58	3.35	-73.37	119.46	-71.55	134.23	-62.96	150.58	0.00	0.00	0.00	0.00	-69.21	78.41	-69.50	88.38
1000	-57.44	3.35	-73.23	119.46	-71.41	134.23	-62.82	150.58	0.00	0.00	0.00	0.00	-69.32	78.41	-69.61	88.38
1200	-57.23	3.35	-73.02	119.46	-71.20	134.23	-62.61	150.58	0.00	0.00	0.00	0.00	-69.48	78.41	-69.77	88.38
1500	-57.02	3.35	-72.81	119.46	-70.99	134.23	-62.40	150.58	0.00	0.00	0.00	0.00	-69.64	78.41	-69.93	88.38
2000	-56.81	3.35	-72.60	119.46	-70.78	134.23	-62.19	150.58	0.00	0.00	0.00	0.00	-69.81	78.41	-70.09	88.38
5000	-56.92	3.35	-72.71	119.46	-70.89	134.23	-62.51	150.58	0.00	0.00	0.00	0.00	-70.09	78.41	-70.38	88.38
10000	-57.02	3.35	-72.81	119.46	-70.99	134.23	-62.64	150.58	0.00	0.00	0.00	0.00	-70.19	78.41	-70.48	88.38
50000	-57.09	3.35	-72.89	119.46	-71.07	134.23	-62.74	150.58	0.00	0.00	0.00	0.00	-70.27	78.41	-70.55	88.38
Tangent	-57.11	3.35	-72.90	119.46	-71.08	134.23	-62.77	150.58	0.00	0.00	0.00	0.00	-70.28	78.41	-70.57	88.38

Radius:	$P1_{IN}$		$P2_{IN}$		$P4_{IN}$		$P5_{IN}$		$P7_{IN}$		$P8_{IN}$		$P6_{CEN}$		$P9_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	-64.54	147.04	-58.15	163.92	-72.34	200.47	-65.95	217.91	-81.01	259.84	-74.62	277.89	-34.78	218.64	-43.45	278.63
100	-64.54	147.04	-58.15	163.92	-72.34	200.47	-65.95	217.91	-81.01	259.84	-74.62	277.89	-34.78	218.64	-43.45	278.63
150	-64.54	147.04	-58.15	163.92	-72.34	200.47	-65.95	217.91	-81.01	259.84	-74.62	277.89	-34.78	218.64	-43.45	278.63
200	-64.54	147.04	-58.15	163.92	-72.34	200.47	-65.95	217.91	-81.01	259.84	-74.62	277.89	-34.78	218.64	-43.45	278.63
300	-64.54	147.04	-58.15	163.92	-72.34	200.47	-65.95	217.91	-81.01	259.84	-74.62	277.89	-34.78	218.64	-43.45	278.63
400	-64.54	147.04	-58.15	163.92	-72.34	200.47	-65.95	217.91	-81.01	259.84	-74.62	277.89	-34.78	218.64	-43.45	278.63
500	-64.54	147.04	-58.15	163.92	-72.34	200.47	-65.95	217.91	-81.01	259.84	-74.62	277.89	-34.78	218.64	-43.45	278.63
600	-64.54	147.04	-58.15	163.92	-72.34	200.47	-65.95	217.91	-81.01	259.84	-74.62	277.89	-34.78	218.64	-43.45	278.63
700	-64.54	147.04	-58.15	163.92	-72.34	200.47	-65.95	217.91	-81.01	259.84	-74.62	277.89	-34.78	218.64	-43.45	278.63
800	-64.54	147.04	-58.15	163.92	-72.34	200.47	-65.95	217.91	-81.01	259.84	-74.62	277.89	-34.78	218.64	-43.45	278.63
900	-64.54	147.04	-58.15	163.92	-72.34	200.47	-65.95	217.91	-81.01	259.84	-74.62	277.89	-34.78	218.64	-43.45	278.63
1000	-64.54	147.04	-58.15	163.92	-72.34	200.47	-65.95	217.91	-81.01	259.84	-74.62	277.89	-34.78	218.64	-43.45	278.63
1200	-64.54	147.04	-58.15	163.92	-72.34	200.47	-65.95	217.91	-81.01	259.84	-74.62	277.89	-34.78	218.64	-43.45	278.63
1500	-64.54	147.04	-58.15	163.92	-72.34	200.47	-65.95	217.91	-81.01	259.84	-74.62	277.89	-34.78	218.64	-43.45	278.63
2000	-64.54	147.04	-58.15	163.92	-72.34	200.47	-65.95	217.91	-81.01	259.84	-74.62	277.89	-34.78	218.64	-43.45	278.63
5000	-64.54	147.04	-58.15	163.92	-72.34	200.47	-65.95	217.91	-81.01	259.84	-74.62	277.89	-34.78	218.64	-43.45	278.63
10000	-64.54	147.04	-58.15	163.92	-72.34	200.47	-65.95	217.91	-81.01	259.84	-74.62	277.89	-34.78	218.64	-43.45	278.63
50000	-64.54	147.04	-58.15	163.92	-72.34	200.47	-65.95	217.91	-81.01	259.84	-74.62	277.89	-34.78	218.64	-43.45	278.63
Tangent	-64.54	147.04	-58.15	163.92	-72.34	200.47	-65.95	217.91	-81.01	259.84	-74.62	277.89	-34.78	218.64	-43.45	278.63

TABLE 7A - VEHICLE DYNAMIC ENVELOPE - OUTSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 0.5 in
Superelevation = 6.0 in

Radius:	$WL1_{OUT}$		$WL2_{OUT}$		$WL3_{OUT}$		$WL4_{OUT}$		$WL5_{OUT}$		$WL6_{OUT}$		$M1_{OUT}$		$M2_{OUT}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	74.88	13.43	70.01	130.68	64.71	144.86	50.26	156.40	0.00	0.00	0.00	0.00	65.00	89.85	64.92	98.16
100	70.99	13.43	66.12	130.68	60.96	144.86	47.78	156.40	0.00	0.00	0.00	0.00	63.39	89.85	63.31	98.16
150	64.78	13.43	59.91	130.68	54.99	144.86	43.85	156.40	0.00	0.00	0.00	0.00	60.77	89.85	60.69	98.16
200	61.55	13.43	56.68	130.68	51.89	144.86	41.81	156.40	0.00	0.00	0.00	0.00	59.38	89.85	59.30	98.16
300	58.23	13.43	53.37	130.68	48.71	144.86	39.72	156.40	0.00	0.00	0.00	0.00	57.93	89.85	57.85	98.16
400	57.11	13.43	52.24	130.68	47.73	144.86	38.66	156.40	0.00	0.00	0.00	0.00	57.19	89.85	57.11	98.16
500	56.64	13.43	51.78	130.68	47.27	144.86	38.02	156.40	0.00	0.00	0.00	0.00	56.74	89.85	56.66	98.16
600	56.33	13.43	51.47	130.68	46.96	144.86	37.59	156.40	0.00	0.00	0.00	0.00	56.43	89.85	56.35	98.16
700	56.11	13.43	51.24	130.68	46.74	144.86	37.28	156.40	0.00	0.00	0.00	0.00	56.21	89.85	56.13	98.16
800	55.94	13.43	51.08	130.68	46.57	144.86	37.04	156.40	0.00	0.00	0.00	0.00	56.05	89.85	55.97	98.16
900	55.81	13.43	50.95	130.68	46.44	144.86	36.86	156.40	0.00	0.00	0.00	0.00	55.92	89.85	55.84	98.16
1000	55.71	13.43	50.84	130.68	46.33	144.86	36.72	156.40	0.00	0.00	0.00	0.00	55.81	89.85	55.73	98.16
1200	55.55	13.43	50.68	130.68	46.18	144.86	36.50	156.40	0.00	0.00	0.00	0.00	55.66	89.85	55.58	98.16
1500	55.39	13.43	50.52	130.68	46.02	144.86	36.28	156.40	0.00	0.00	0.00	0.00	55.50	89.85	55.42	98.16
2000	55.23	13.43	50.37	130.68	45.86	144.86	36.06	156.40	0.00	0.00	0.00	0.00	55.34	89.85	55.26	98.16
5000	54.95	13.43	50.08	130.68	45.57	144.86	35.67	156.40	0.00	0.00	0.00	0.00	55.06	89.85	54.98	98.16
10000	54.85	13.43	49.98	130.68	45.47	144.86	35.53	156.40	0.00	0.00	0.00	0.00	54.97	89.85	54.88	98.16
50000	54.77	13.43	49.90	130.68	45.40	144.86	35.43	156.40	0.00	0.00	0.00	0.00	54.89	89.85	54.81	98.16
Tangent	54.75	13.43	49.89	130.68	45.38	144.86	35.40	156.40	0.00	0.00	0.00	0.00	54.87	89.85	54.79	98.16

Radius:	$P1_{OUT}$		$P2_{OUT}$		$P4_{OUT}$		$P5_{OUT}$		$P7_{OUT}$		$P8_{OUT}$		$R1_{CEN}$		$P3_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	36.59	156.14	28.28	168.30	34.42	210.10	26.11	221.61	32.01	270.05	23.70	281.02	-1.82	18.17	-29.71	165.05
100	36.59	156.14	28.28	168.30	34.42	210.10	26.11	221.61	32.01	270.05	23.70	281.02	-1.82	18.17	-29.71	165.05
150	36.59	156.14	28.28	168.30	34.42	210.10	26.11	221.61	32.01	270.05	23.70	281.02	-1.82	18.17	-29.71	165.05
200	36.59	156.14	28.28	168.30	34.42	210.10	26.11	221.61	32.01	270.05	23.70	281.02	-1.82	18.17	-29.71	165.05
300	36.59	156.14	28.28	168.30	34.42	210.10	26.11	221.61	32.01	270.05	23.70	281.02	-1.82	18.17	-29.71	165.05
400	36.59	156.14	28.28	168.30	34.42	210.10	26.11	221.61	32.01	270.05	23.70	281.02	-1.82	18.17	-29.71	165.05
500	36.59	156.14	28.28	168.30	34.42	210.10	26.11	221.61	32.01	270.05	23.70	281.02	-1.82	18.17	-29.71	165.05
600	36.59	156.14	28.28	168.30	34.42	210.10	26.11	221.61	32.01	270.05	23.70	281.02	-1.82	18.17	-29.71	165.05
700	36.59	156.14	28.28	168.30	34.42	210.10	26.11	221.61	32.01	270.05	23.70	281.02	-1.82	18.17	-29.71	165.05
800	36.59	156.14	28.28	168.30	34.42	210.10	26.11	221.61	32.01	270.05	23.70	281.02	-1.82	18.17	-29.71	165.05
900	36.59	156.14	28.28	168.30	34.42	210.10	26.11	221.61	32.01	270.05	23.70	281.02	-1.82	18.17	-29.71	165.05
1000	36.59	156.14	28.28	168.30	34.42	210.10	26.11	221.61	32.01	270.05	23.70	281.02	-1.82	18.17	-29.71	165.05
1200	36.59	156.14	28.28	168.30	34.42	210.10	26.11	221.61	32.01	270.05	23.70	281.02	-1.82	18.17	-29.71	165.05
1500	36.59	156.14	28.28	168.30	34.42	210.10	26.11	221.61	32.01	270.05	23.70	281.02	-1.82	18.17	-29.71	165.05
2000	36.59	156.14	28.28	168.30	34.42	210.10	26.11	221.61	32.01	270.05	23.70	281.02	-1.82	18.17	-29.71	165.05
5000	36.59	156.14	28.28	168.30	34.42	210.10	26.11	221.61	32.01	270.05	23.70	281.02	-1.82	18.17	-29.71	165.05
10000	36.59	156.14	28.28	168.30	34.42	210.10	26.11	221.61	32.01	270.05	23.70	281.02	-1.82	18.17	-29.71	165.05
50000	36.59	156.14	28.28	168.30	34.42	210.10	26.11	221.61	32.01	270.05	23.70	281.02	-1.82	18.17	-29.71	165.05
Tangent	36.59	156.14	28.28	168.30	34.42	210.10	26.11	221.61	32.01	270.05	23.70	281.02	-1.82	18.17	-29.71	165.05

TABLE 7B - VEHICLE DYNAMIC ENVELOPE - INSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 0.5 in
Superelevation = 6.0 in

Radius:	$WL1_{IN}$		$WL2_{IN}$		$WL3_{IN}$		$WL4_{IN}$		$WL5_{IN}$		$WL6_{IN}$		$M1_{IN}$		$M2_{IN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	-71.88	2.97	-89.52	118.78	-87.95	133.58	-79.52	150.34	0.00	0.00	0.00	0.00	-58.44	77.78	-58.76	87.88
100	-69.05	2.97	-86.69	118.78	-85.12	133.58	-76.69	150.34	0.00	0.00	0.00	0.00	-61.03	77.78	-61.35	87.88
150	-64.78	2.97	-82.42	118.78	-80.85	133.58	-72.43	150.34	0.00	0.00	0.00	0.00	-64.78	77.78	-65.11	87.88
200	-62.66	2.97	-80.30	118.78	-78.73	133.58	-70.30	150.34	0.00	0.00	0.00	0.00	-66.57	77.78	-66.90	87.88
300	-60.55	2.97	-78.19	118.78	-76.62	133.58	-68.19	150.34	0.00	0.00	0.00	0.00	-68.31	77.78	-68.63	87.88
400	-59.49	2.97	-77.13	118.78	-75.56	133.58	-67.13	150.34	0.00	0.00	0.00	0.00	-69.15	77.78	-69.47	87.88
500	-58.86	2.97	-76.50	118.78	-74.93	133.58	-66.50	150.34	0.00	0.00	0.00	0.00	-69.65	77.78	-69.97	87.88
600	-58.43	2.97	-76.08	118.78	-74.51	133.58	-66.08	150.34	0.00	0.00	0.00	0.00	-69.98	77.78	-70.30	87.88
700	-58.13	2.97	-75.78	118.78	-74.20	133.58	-65.78	150.34	0.00	0.00	0.00	0.00	-70.22	77.78	-70.54	87.88
800	-57.91	2.97	-75.55	118.78	-73.98	133.58	-65.55	150.34	0.00	0.00	0.00	0.00	-70.39	77.78	-70.71	87.88
900	-57.73	2.97	-75.37	118.78	-73.80	133.58	-65.38	150.34	0.00	0.00	0.00	0.00	-70.53	77.78	-70.85	87.88
1000	-57.59	2.97	-75.23	118.78	-73.66	133.58	-65.24	150.34	0.00	0.00	0.00	0.00	-70.64	77.78	-70.96	87.88
1200	-57.38	2.97	-75.02	118.78	-73.45	133.58	-65.02	150.34	0.00	0.00	0.00	0.00	-70.80	77.78	-71.12	87.88
1500	-57.17	2.97	-74.81	118.78	-73.24	133.58	-64.81	150.34	0.00	0.00	0.00	0.00	-70.96	77.78	-71.28	87.88
2000	-56.96	2.97	-74.60	118.78	-73.03	133.58	-64.60	150.34	0.00	0.00	0.00	0.00	-71.12	77.78	-71.44	87.88
5000	-57.07	2.97	-74.71	118.78	-73.14	133.58	-64.92	150.34	0.00	0.00	0.00	0.00	-71.41	77.78	-71.73	87.88
10000	-57.17	2.97	-74.81	118.78	-73.24	133.58	-65.05	150.34	0.00	0.00	0.00	0.00	-71.50	77.78	-71.83	87.88
50000	-57.24	2.97	-74.89	118.78	-73.32	133.58	-65.16	150.34	0.00	0.00	0.00	0.00	-71.58	77.78	-71.90	87.88
Tangent	-57.26	2.97	-74.91	118.78	-73.33	133.58	-65.19	150.34	0.00	0.00	0.00	0.00	-71.60	77.78	-71.92	87.88

Radius:	$P1_{IN}$		$P2_{IN}$		$P4_{IN}$		$P5_{IN}$		$P7_{IN}$		$P8_{IN}$		$P6_{CEN}$		$P9_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	-67.00	146.51	-60.80	163.79	-75.70	199.80	-69.50	217.74	-85.37	259.02	-79.16	277.70	-38.41	219.01	-48.07	278.96
100	-67.00	146.51	-60.80	163.79	-75.70	199.80	-69.50	217.74	-85.37	259.02	-79.16	277.70	-38.41	219.01	-48.07	278.96
150	-67.00	146.51	-60.80	163.79	-75.70	199.80	-69.50	217.74	-85.37	259.02	-79.16	277.70	-38.41	219.01	-48.07	278.96
200	-67.00	146.51	-60.80	163.79	-75.70	199.80	-69.50	217.74	-85.37	259.02	-79.16	277.70	-38.41	219.01	-48.07	278.96
300	-67.00	146.51	-60.80	163.79	-75.70	199.80	-69.50	217.74	-85.37	259.02	-79.16	277.70	-38.41	219.01	-48.07	278.96
400	-67.00	146.51	-60.80	163.79	-75.70	199.80	-69.50	217.74	-85.37	259.02	-79.16	277.70	-38.41	219.01	-48.07	278.96
500	-67.00	146.51	-60.80	163.79	-75.70	199.80	-69.50	217.74	-85.37	259.02	-79.16	277.70	-38.41	219.01	-48.07	278.96
600	-67.00	146.51	-60.80	163.79	-75.70	199.80	-69.50	217.74	-85.37	259.02	-79.16	277.70	-38.41	219.01	-48.07	278.96
700	-67.00	146.51	-60.80	163.79	-75.70	199.80	-69.50	217.74	-85.37	259.02	-79.16	277.70	-38.41	219.01	-48.07	278.96
800	-67.00	146.51	-60.80	163.79	-75.70	199.80	-69.50	217.74	-85.37	259.02	-79.16	277.70	-38.41	219.01	-48.07	278.96
900	-67.00	146.51	-60.80	163.79	-75.70	199.80	-69.50	217.74	-85.37	259.02	-79.16	277.70	-38.41	219.01	-48.07	278.96
1000	-67.00	146.51	-60.80	163.79	-75.70	199.80	-69.50	217.74	-85.37	259.02	-79.16	277.70	-38.41	219.01	-48.07	278.96
1200	-67.00	146.51	-60.80	163.79	-75.70	199.80	-69.50	217.74	-85.37	259.02	-79.16	277.70	-38.41	219.01	-48.07	278.96
1500	-67.00	146.51	-60.80	163.79	-75.70	199.80	-69.50	217.74	-85.37	259.02	-79.16	277.70	-38.41	219.01	-48.07	278.96
2000	-67.00	146.51	-60.80	163.79	-75.70	199.80	-69.50	217.74	-85.37	259.02	-79.16	277.70	-38.41	219.01	-48.07	278.96
5000	-67.00	146.51	-60.80	163.79	-75.70	199.80	-69.50	217.74	-85.37	259.02	-79.16	277.70	-38.41	219.01	-48.07	278.96
10000	-67.00	146.51	-60.80	163.79	-75.70	199.80	-69.50	217.74	-85.37	259.02	-79.16	277.70	-38.41	219.01	-48.07	278.96
50000	-67.00	146.51	-60.80	163.79	-75.70	199.80	-69.50	217.74	-85.37	259.02	-79.16	277.70	-38.41	219.01	-48.07	278.96
Tangent	-67.00	146.51	-60.80	163.79	-75.70	199.80	-69.50	217.74	-85.37	259.02	-79.16	277.70	-38.41	219.01	-48.07	278.96

TABLE 8A - VEHICLE DYNAMIC ENVELOPE - OUTSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 1.0 in
Superelevation = 0.0 in

Radius:	$WL1_{OUT}$		$WL2_{OUT}$		$WL3_{OUT}$		$WL4_{OUT}$		$WL5_{OUT}$		$WL6_{OUT}$		$M1_{OUT}$		$M2_{OUT}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	76.47	4.56	83.83	121.62	80.11	136.21	66.60	151.65	0.00	0.00	0.00	0.00	74.33	80.48	74.47	91.17
100	72.58	4.56	79.94	121.62	76.36	136.21	64.12	151.65	0.00	0.00	0.00	0.00	72.73	80.48	72.86	91.17
150	66.37	4.56	73.74	121.62	70.39	136.21	60.19	151.65	0.00	0.00	0.00	0.00	70.11	80.48	70.25	91.17
200	63.14	4.56	70.50	121.62	67.28	136.21	58.15	151.65	0.00	0.00	0.00	0.00	68.72	80.48	68.85	91.17
300	59.83	4.56	67.19	121.62	64.11	136.21	56.06	151.65	0.00	0.00	0.00	0.00	67.27	80.48	67.41	91.17
400	58.70	4.56	66.06	121.62	63.13	136.21	55.00	151.65	0.00	0.00	0.00	0.00	66.52	80.48	66.66	91.17
500	58.24	4.56	65.60	121.62	62.67	136.21	54.36	151.65	0.00	0.00	0.00	0.00	66.07	80.48	66.21	91.17
600	57.93	4.56	65.29	121.62	62.36	136.21	53.93	151.65	0.00	0.00	0.00	0.00	65.76	80.48	65.90	91.17
700	57.70	4.56	65.07	121.62	62.14	136.21	53.62	151.65	0.00	0.00	0.00	0.00	65.55	80.48	65.68	91.17
800	57.54	4.56	64.90	121.62	61.97	136.21	53.38	151.65	0.00	0.00	0.00	0.00	65.38	80.48	65.52	91.17
900	57.41	4.56	64.77	121.62	61.84	136.21	53.20	151.65	0.00	0.00	0.00	0.00	65.25	80.48	65.39	91.17
1000	57.30	4.56	64.66	121.62	61.73	136.21	53.06	151.65	0.00	0.00	0.00	0.00	65.15	80.48	65.29	91.17
1200	57.14	4.56	64.51	121.62	61.57	136.21	52.84	151.65	0.00	0.00	0.00	0.00	64.99	80.48	65.13	91.17
1500	56.98	4.56	64.35	121.62	61.41	136.21	52.62	151.65	0.00	0.00	0.00	0.00	64.83	80.48	64.97	91.17
2000	56.83	4.56	64.19	121.62	61.26	136.21	52.40	151.65	0.00	0.00	0.00	0.00	64.68	80.48	64.82	91.17
5000	56.54	4.56	63.90	121.62	60.97	136.21	52.01	151.65	0.00	0.00	0.00	0.00	64.39	80.48	64.53	91.17
10000	56.44	4.56	63.80	121.62	60.87	136.21	51.87	151.65	0.00	0.00	0.00	0.00	64.30	80.48	64.44	91.17
50000	56.36	4.56	63.73	121.62	60.79	136.21	51.77	151.65	0.00	0.00	0.00	0.00	64.22	80.48	64.36	91.17
Tangent	56.34	4.56	63.71	121.62	60.78	136.21	51.74	151.65	0.00	0.00	0.00	0.00	64.20	80.48	64.34	91.17

Radius:	$P1_{OUT}$		$P2_{OUT}$		$P4_{OUT}$		$P5_{OUT}$		$P7_{OUT}$		$P8_{OUT}$		$R1_{CEN}$		$P3_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	53.28	148.44	46.07	164.32	57.02	202.31	49.81	218.20	61.17	262.17	53.96	278.05	-0.26	15.50	-14.65	162.48
100	53.28	148.44	46.07	164.32	57.02	202.31	49.81	218.20	61.17	262.17	53.96	278.05	-0.26	15.50	-14.65	162.48
150	53.28	148.44	46.07	164.32	57.02	202.31	49.81	218.20	61.17	262.17	53.96	278.05	-0.26	15.50	-14.65	162.48
200	53.28	148.44	46.07	164.32	57.02	202.31	49.81	218.20	61.17	262.17	53.96	278.05	-0.26	15.50	-14.65	162.48
300	53.28	148.44	46.07	164.32	57.02	202.31	49.81	218.20	61.17	262.17	53.96	278.05	-0.26	15.50	-14.65	162.48
400	53.28	148.44	46.07	164.32	57.02	202.31	49.81	218.20	61.17	262.17	53.96	278.05	-0.26	15.50	-14.65	162.48
500	53.28	148.44	46.07	164.32	57.02	202.31	49.81	218.20	61.17	262.17	53.96	278.05	-0.26	15.50	-14.65	162.48
600	53.28	148.44	46.07	164.32	57.02	202.31	49.81	218.20	61.17	262.17	53.96	278.05	-0.26	15.50	-14.65	162.48
700	53.28	148.44	46.07	164.32	57.02	202.31	49.81	218.20	61.17	262.17	53.96	278.05	-0.26	15.50	-14.65	162.48
800	53.28	148.44	46.07	164.32	57.02	202.31	49.81	218.20	61.17	262.17	53.96	278.05	-0.26	15.50	-14.65	162.48
900	53.28	148.44	46.07	164.32	57.02	202.31	49.81	218.20	61.17	262.17	53.96	278.05	-0.26	15.50	-14.65	162.48
1000	53.28	148.44	46.07	164.32	57.02	202.31	49.81	218.20	61.17	262.17	53.96	278.05	-0.26	15.50	-14.65	162.48
1200	53.28	148.44	46.07	164.32	57.02	202.31	49.81	218.20	61.17	262.17	53.96	278.05	-0.26	15.50	-14.65	162.48
1500	53.28	148.44	46.07	164.32	57.02	202.31	49.81	218.20	61.17	262.17	53.96	278.05	-0.26	15.50	-14.65	162.48
2000	53.28	148.44	46.07	164.32	57.02	202.31	49.81	218.20	61.17	262.17	53.96	278.05	-0.26	15.50	-14.65	162.48
5000	53.28	148.44	46.07	164.32	57.02	202.31	49.81	218.20	61.17	262.17	53.96	278.05	-0.26	15.50	-14.65	162.48
10000	53.28	148.44	46.07	164.32	57.02	202.31	49.81	218.20	61.17	262.17	53.96	278.05	-0.26	15.50	-14.65	162.48
50000	53.28	148.44	46.07	164.32	57.02	202.31	49.81	218.20	61.17	262.17	53.96	278.05	-0.26	15.50	-14.65	162.48
Tangent	53.28	148.44	46.07	164.32	57.02	202.31	49.81	218.20	61.17	262.17	53.96	278.05	-0.26	15.50	-14.65	162.48

TABLE 8B - VEHICLE DYNAMIC ENVELOPE - INSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 1.0 in
Superelevation = 0.0 in

Radius:	$WL1_{IN}$		$WL2_{IN}$		$WL3_{IN}$		$WL4_{IN}$		$WL5_{IN}$		$WL6_{IN}$		$M1_{IN}$		$M2_{IN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	-70.96	4.56	-78.32	121.62	-75.39	136.21	-66.08	151.65	0.00	0.00	0.00	0.00	-51.04	80.48	-51.18	91.17
100	-68.13	4.56	-75.49	121.62	-72.56	136.21	-63.25	151.65	0.00	0.00	0.00	0.00	-53.64	80.48	-53.77	91.17
150	-63.86	4.56	-71.22	121.62	-68.29	136.21	-58.98	151.65	0.00	0.00	0.00	0.00	-57.39	80.48	-57.53	91.17
200	-61.74	4.56	-69.10	121.62	-66.17	136.21	-56.86	151.65	0.00	0.00	0.00	0.00	-59.18	80.48	-59.32	91.17
300	-59.63	4.56	-66.99	121.62	-64.06	136.21	-54.75	151.65	0.00	0.00	0.00	0.00	-60.91	80.48	-61.05	91.17
400	-58.57	4.56	-65.93	121.62	-63.00	136.21	-53.69	151.65	0.00	0.00	0.00	0.00	-61.76	80.48	-61.89	91.17
500	-57.94	4.56	-65.30	121.62	-62.37	136.21	-53.06	151.65	0.00	0.00	0.00	0.00	-62.26	80.48	-62.39	91.17
600	-57.52	4.56	-64.88	121.62	-61.95	136.21	-52.64	151.65	0.00	0.00	0.00	0.00	-62.59	80.48	-62.72	91.17
700	-57.21	4.56	-64.58	121.62	-61.64	136.21	-52.33	151.65	0.00	0.00	0.00	0.00	-62.82	80.48	-62.96	91.17
800	-56.99	4.56	-64.35	121.62	-61.42	136.21	-52.11	151.65	0.00	0.00	0.00	0.00	-63.00	80.48	-63.13	91.17
900	-56.81	4.56	-64.18	121.62	-61.24	136.21	-51.93	151.65	0.00	0.00	0.00	0.00	-63.13	80.48	-63.27	91.17
1000	-56.67	4.56	-64.03	121.62	-61.10	136.21	-51.79	151.65	0.00	0.00	0.00	0.00	-63.24	80.48	-63.38	91.17
1200	-56.46	4.56	-63.82	121.62	-60.89	136.21	-51.58	151.65	0.00	0.00	0.00	0.00	-63.40	80.48	-63.54	91.17
1500	-56.25	4.56	-63.61	121.62	-60.68	136.21	-51.37	151.65	0.00	0.00	0.00	0.00	-63.56	80.48	-63.70	91.17
2000	-56.04	4.56	-63.40	121.62	-60.47	136.21	-51.16	151.65	0.00	0.00	0.00	0.00	-63.72	80.48	-63.86	91.17
5000	-56.15	4.56	-63.51	121.62	-60.58	136.21	-51.48	151.65	0.00	0.00	0.00	0.00	-64.01	80.48	-64.15	91.17
10000	-56.25	4.56	-63.61	121.62	-60.68	136.21	-51.61	151.65	0.00	0.00	0.00	0.00	-64.11	80.48	-64.25	91.17
50000	-56.33	4.56	-63.69	121.62	-60.76	136.21	-51.72	151.65	0.00	0.00	0.00	0.00	-64.18	80.48	-64.32	91.17
Tangent	-56.34	4.56	-63.71	121.62	-60.78	136.21	-51.74	151.65	0.00	0.00	0.00	0.00	-64.20	80.48	-64.34	91.17

Radius:	$P1_{IN}$		$P2_{IN}$		$P4_{IN}$		$P5_{IN}$		$P7_{IN}$		$P8_{IN}$		$P6_{CEN}$		$P9_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	-53.28	148.44	-46.07	164.32	-57.02	202.31	-49.81	218.20	-61.17	262.17	-53.96	278.05	-18.38	216.47	-22.53	276.46
100	-53.28	148.44	-46.07	164.32	-57.02	202.31	-49.81	218.20	-61.17	262.17	-53.96	278.05	-18.38	216.47	-22.53	276.46
150	-53.28	148.44	-46.07	164.32	-57.02	202.31	-49.81	218.20	-61.17	262.17	-53.96	278.05	-18.38	216.47	-22.53	276.46
200	-53.28	148.44	-46.07	164.32	-57.02	202.31	-49.81	218.20	-61.17	262.17	-53.96	278.05	-18.38	216.47	-22.53	276.46
300	-53.28	148.44	-46.07	164.32	-57.02	202.31	-49.81	218.20	-61.17	262.17	-53.96	278.05	-18.38	216.47	-22.53	276.46
400	-53.28	148.44	-46.07	164.32	-57.02	202.31	-49.81	218.20	-61.17	262.17	-53.96	278.05	-18.38	216.47	-22.53	276.46
500	-53.28	148.44	-46.07	164.32	-57.02	202.31	-49.81	218.20	-61.17	262.17	-53.96	278.05	-18.38	216.47	-22.53	276.46
600	-53.28	148.44	-46.07	164.32	-57.02	202.31	-49.81	218.20	-61.17	262.17	-53.96	278.05	-18.38	216.47	-22.53	276.46
700	-53.28	148.44	-46.07	164.32	-57.02	202.31	-49.81	218.20	-61.17	262.17	-53.96	278.05	-18.38	216.47	-22.53	276.46
800	-53.28	148.44	-46.07	164.32	-57.02	202.31	-49.81	218.20	-61.17	262.17	-53.96	278.05	-18.38	216.47	-22.53	276.46
900	-53.28	148.44	-46.07	164.32	-57.02	202.31	-49.81	218.20	-61.17	262.17	-53.96	278.05	-18.38	216.47	-22.53	276.46
1000	-53.28	148.44	-46.07	164.32	-57.02	202.31	-49.81	218.20	-61.17	262.17	-53.96	278.05	-18.38	216.47	-22.53	276.46
1200	-53.28	148.44	-46.07	164.32	-57.02	202.31	-49.81	218.20	-61.17	262.17	-53.96	278.05	-18.38	216.47	-22.53	276.46
1500	-53.28	148.44	-46.07	164.32	-57.02	202.31	-49.81	218.20	-61.17	262.17	-53.96	278.05	-18.38	216.47	-22.53	276.46
2000	-53.28	148.44	-46.07	164.32	-57.02	202.31	-49.81	218.20	-61.17	262.17	-53.96	278.05	-18.38	216.47	-22.53	276.46
5000	-53.28	148.44	-46.07	164.32	-57.02	202.31	-49.81	218.20	-61.17	262.17	-53.96	278.05	-18.38	216.47	-22.53	276.46
10000	-53.28	148.44	-46.07	164.32	-57.02	202.31	-49.81	218.20	-61.17	262.17	-53.96	278.05	-18.38	216.47	-22.53	276.46
50000	-53.28	148.44	-46.07	164.32	-57.02	202.31	-49.81	218.20	-61.17	262.17	-53.96	278.05	-18.38	216.47	-22.53	276.46
Tangent	-53.28	148.44	-46.07	164.32	-57.02	202.31	-49.81	218.20	-61.17	262.17	-53.96	278.05	-18.38	216.47	-22.53	276.46

TABLE 9A - VEHICLE DYNAMIC ENVELOPE - OUTSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 1.0 in
Superelevation = 1.0 in

Radius:	$WL1_{OUT}$		$WL2_{OUT}$		$WL3_{OUT}$		$WL4_{OUT}$		$WL5_{OUT}$		$WL6_{OUT}$		$M1_{OUT}$		$M2_{OUT}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	76.29	5.93	81.77	123.11	77.80	137.65	64.13	152.62	0.00	0.00	0.00	0.00	72.96	81.99	73.06	92.51
100	72.40	5.93	77.87	123.11	74.04	137.65	61.66	152.62	0.00	0.00	0.00	0.00	71.35	81.99	71.46	92.51
150	66.19	5.93	71.67	123.11	68.07	137.65	57.73	152.62	0.00	0.00	0.00	0.00	68.74	81.99	68.84	92.51
200	62.96	5.93	68.44	123.11	64.97	137.65	55.69	152.62	0.00	0.00	0.00	0.00	67.34	81.99	67.45	92.51
300	59.65	5.93	65.12	123.11	61.79	137.65	53.60	152.62	0.00	0.00	0.00	0.00	65.90	81.99	66.00	92.51
400	58.52	5.93	63.99	123.11	60.82	137.65	52.54	152.62	0.00	0.00	0.00	0.00	65.15	81.99	65.26	92.51
500	58.06	5.93	63.53	123.11	60.36	137.65	51.89	152.62	0.00	0.00	0.00	0.00	64.70	81.99	64.80	92.51
600	57.75	5.93	63.22	123.11	60.05	137.65	51.46	152.62	0.00	0.00	0.00	0.00	64.39	81.99	64.50	92.51
700	57.52	5.93	63.00	123.11	59.82	137.65	51.15	152.62	0.00	0.00	0.00	0.00	64.17	81.99	64.28	92.51
800	57.36	5.93	62.83	123.11	59.66	137.65	50.92	152.62	0.00	0.00	0.00	0.00	64.01	81.99	64.11	92.51
900	57.22	5.93	62.70	123.11	59.52	137.65	50.74	152.62	0.00	0.00	0.00	0.00	63.88	81.99	63.98	92.51
1000	57.12	5.93	62.60	123.11	59.42	137.65	50.59	152.62	0.00	0.00	0.00	0.00	63.78	81.99	63.88	92.51
1200	56.96	5.93	62.44	123.11	59.26	137.65	50.38	152.62	0.00	0.00	0.00	0.00	63.62	81.99	63.72	92.51
1500	56.80	5.93	62.28	123.11	59.10	137.65	50.16	152.62	0.00	0.00	0.00	0.00	63.46	81.99	63.57	92.51
2000	56.64	5.93	62.12	123.11	58.94	137.65	49.94	152.62	0.00	0.00	0.00	0.00	63.31	81.99	63.41	92.51
5000	56.36	5.93	61.83	123.11	58.66	137.65	49.54	152.62	0.00	0.00	0.00	0.00	63.02	81.99	63.13	92.51
10000	56.26	5.93	61.74	123.11	58.56	137.65	49.41	152.62	0.00	0.00	0.00	0.00	62.93	81.99	63.03	92.51
50000	56.18	5.93	61.66	123.11	58.48	137.65	49.30	152.62	0.00	0.00	0.00	0.00	62.85	81.99	62.96	92.51
Tangent	56.16	5.93	61.64	123.11	58.46	137.65	49.28	152.62	0.00	0.00	0.00	0.00	62.83	81.99	62.94	92.51

Radius:	$P1_{OUT}$		$P2_{OUT}$		$P4_{OUT}$		$P5_{OUT}$		$P7_{OUT}$		$P8_{OUT}$		$R1_{CEN}$		$P3_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	50.76	149.75	43.38	165.16	53.59	203.68	46.20	218.96	56.73	263.59	49.34	278.73	-0.52	16.00	-17.39	163.00
100	50.76	149.75	43.38	165.16	53.59	203.68	46.20	218.96	56.73	263.59	49.34	278.73	-0.52	16.00	-17.39	163.00
150	50.76	149.75	43.38	165.16	53.59	203.68	46.20	218.96	56.73	263.59	49.34	278.73	-0.52	16.00	-17.39	163.00
200	50.76	149.75	43.38	165.16	53.59	203.68	46.20	218.96	56.73	263.59	49.34	278.73	-0.52	16.00	-17.39	163.00
300	50.76	149.75	43.38	165.16	53.59	203.68	46.20	218.96	56.73	263.59	49.34	278.73	-0.52	16.00	-17.39	163.00
400	50.76	149.75	43.38	165.16	53.59	203.68	46.20	218.96	56.73	263.59	49.34	278.73	-0.52	16.00	-17.39	163.00
500	50.76	149.75	43.38	165.16	53.59	203.68	46.20	218.96	56.73	263.59	49.34	278.73	-0.52	16.00	-17.39	163.00
600	50.76	149.75	43.38	165.16	53.59	203.68	46.20	218.96	56.73	263.59	49.34	278.73	-0.52	16.00	-17.39	163.00
700	50.76	149.75	43.38	165.16	53.59	203.68	46.20	218.96	56.73	263.59	49.34	278.73	-0.52	16.00	-17.39	163.00
800	50.76	149.75	43.38	165.16	53.59	203.68	46.20	218.96	56.73	263.59	49.34	278.73	-0.52	16.00	-17.39	163.00
900	50.76	149.75	43.38	165.16	53.59	203.68	46.20	218.96	56.73	263.59	49.34	278.73	-0.52	16.00	-17.39	163.00
1000	50.76	149.75	43.38	165.16	53.59	203.68	46.20	218.96	56.73	263.59	49.34	278.73	-0.52	16.00	-17.39	163.00
1200	50.76	149.75	43.38	165.16	53.59	203.68	46.20	218.96	56.73	263.59	49.34	278.73	-0.52	16.00	-17.39	163.00
1500	50.76	149.75	43.38	165.16	53.59	203.68	46.20	218.96	56.73	263.59	49.34	278.73	-0.52	16.00	-17.39	163.00
2000	50.76	149.75	43.38	165.16	53.59	203.68	46.20	218.96	56.73	263.59	49.34	278.73	-0.52	16.00	-17.39	163.00
5000	50.76	149.75	43.38	165.16	53.59	203.68	46.20	218.96	56.73	263.59	49.34	278.73	-0.52	16.00	-17.39	163.00
10000	50.76	149.75	43.38	165.16	53.59	203.68	46.20	218.96	56.73	263.59	49.34	278.73	-0.52	16.00	-17.39	163.00
50000	50.76	149.75	43.38	165.16	53.59	203.68	46.20	218.96	56.73	263.59	49.34	278.73	-0.52	16.00	-17.39	163.00
Tangent	50.76	149.75	43.38	165.16	53.59	203.68	46.20	218.96	56.73	263.59	49.34	278.73	-0.52	16.00	-17.39	163.00

TABLE 9B - VEHICLE DYNAMIC ENVELOPE - INSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 1.0 in
Superelevation = 1.0 in

Radius:	$WL1_{IN}$		$WL2_{IN}$		$WL3_{IN}$		$WL4_{IN}$		$WL5_{IN}$		$WL6_{IN}$		$M1_{IN}$		$M2_{IN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	-71.14	4.18	-80.39	121.09	-77.70	135.72	-68.55	151.65	0.00	0.00	0.00	0.00	-52.41	79.95	-52.58	90.81
100	-68.31	4.18	-77.55	121.09	-74.87	135.72	-65.71	151.65	0.00	0.00	0.00	0.00	-55.01	79.95	-55.18	90.81
150	-64.04	4.18	-73.29	121.09	-70.60	135.72	-61.45	151.65	0.00	0.00	0.00	0.00	-58.76	79.95	-58.93	90.81
200	-61.92	4.18	-71.17	121.09	-68.48	135.72	-59.33	151.65	0.00	0.00	0.00	0.00	-60.55	79.95	-60.72	90.81
300	-59.81	4.18	-69.06	121.09	-66.37	135.72	-57.21	151.65	0.00	0.00	0.00	0.00	-62.28	79.95	-62.45	90.81
400	-58.75	4.18	-68.00	121.09	-65.31	135.72	-56.16	151.65	0.00	0.00	0.00	0.00	-63.13	79.95	-63.30	90.81
500	-58.12	4.18	-67.37	121.09	-64.68	135.72	-55.53	151.65	0.00	0.00	0.00	0.00	-63.63	79.95	-63.80	90.81
600	-57.70	4.18	-66.94	121.09	-64.26	135.72	-55.10	151.65	0.00	0.00	0.00	0.00	-63.96	79.95	-64.13	90.81
700	-57.40	4.18	-66.64	121.09	-63.96	135.72	-54.80	151.65	0.00	0.00	0.00	0.00	-64.19	79.95	-64.36	90.81
800	-57.17	4.18	-66.42	121.09	-63.73	135.72	-54.58	151.65	0.00	0.00	0.00	0.00	-64.37	79.95	-64.54	90.81
900	-57.00	4.18	-66.24	121.09	-63.56	135.72	-54.40	151.65	0.00	0.00	0.00	0.00	-64.50	79.95	-64.67	90.81
1000	-56.85	4.18	-66.10	121.09	-63.41	135.72	-54.26	151.65	0.00	0.00	0.00	0.00	-64.61	79.95	-64.78	90.81
1200	-56.64	4.18	-65.89	121.09	-63.20	135.72	-54.05	151.65	0.00	0.00	0.00	0.00	-64.77	79.95	-64.95	90.81
1500	-56.43	4.18	-65.68	121.09	-62.99	135.72	-53.84	151.65	0.00	0.00	0.00	0.00	-64.93	79.95	-65.11	90.81
2000	-56.22	4.18	-65.47	121.09	-62.78	135.72	-53.63	151.65	0.00	0.00	0.00	0.00	-65.10	79.95	-65.27	90.81
5000	-56.33	4.18	-65.58	121.09	-62.89	135.72	-53.94	151.65	0.00	0.00	0.00	0.00	-65.38	79.95	-65.56	90.81
10000	-56.43	4.18	-65.68	121.09	-62.99	135.72	-54.08	151.65	0.00	0.00	0.00	0.00	-65.48	79.95	-65.65	90.81
50000	-56.51	4.18	-65.75	121.09	-63.07	135.72	-54.18	151.65	0.00	0.00	0.00	0.00	-65.56	79.95	-65.73	90.81
Tangent	-56.53	4.18	-65.77	121.09	-63.09	135.72	-54.21	151.65	0.00	0.00	0.00	0.00	-65.58	79.95	-65.75	90.81

Radius:	$P1_{IN}$		$P2_{IN}$		$P4_{IN}$		$P5_{IN}$		$P7_{IN}$		$P8_{IN}$		$P6_{CEN}$		$P9_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	-55.80	148.09	-48.77	164.45	-60.44	201.89	-53.41	218.37	-65.61	261.67	-58.58	278.29	-22.03	217.00	-27.19	277.00
100	-55.80	148.09	-48.77	164.45	-60.44	201.89	-53.41	218.37	-65.61	261.67	-58.58	278.29	-22.03	217.00	-27.19	277.00
150	-55.80	148.09	-48.77	164.45	-60.44	201.89	-53.41	218.37	-65.61	261.67	-58.58	278.29	-22.03	217.00	-27.19	277.00
200	-55.80	148.09	-48.77	164.45	-60.44	201.89	-53.41	218.37	-65.61	261.67	-58.58	278.29	-22.03	217.00	-27.19	277.00
300	-55.80	148.09	-48.77	164.45	-60.44	201.89	-53.41	218.37	-65.61	261.67	-58.58	278.29	-22.03	217.00	-27.19	277.00
400	-55.80	148.09	-48.77	164.45	-60.44	201.89	-53.41	218.37	-65.61	261.67	-58.58	278.29	-22.03	217.00	-27.19	277.00
500	-55.80	148.09	-48.77	164.45	-60.44	201.89	-53.41	218.37	-65.61	261.67	-58.58	278.29	-22.03	217.00	-27.19	277.00
600	-55.80	148.09	-48.77	164.45	-60.44	201.89	-53.41	218.37	-65.61	261.67	-58.58	278.29	-22.03	217.00	-27.19	277.00
700	-55.80	148.09	-48.77	164.45	-60.44	201.89	-53.41	218.37	-65.61	261.67	-58.58	278.29	-22.03	217.00	-27.19	277.00
800	-55.80	148.09	-48.77	164.45	-60.44	201.89	-53.41	218.37	-65.61	261.67	-58.58	278.29	-22.03	217.00	-27.19	277.00
900	-55.80	148.09	-48.77	164.45	-60.44	201.89	-53.41	218.37	-65.61	261.67	-58.58	278.29	-22.03	217.00	-27.19	277.00
1000	-55.80	148.09	-48.77	164.45	-60.44	201.89	-53.41	218.37	-65.61	261.67	-58.58	278.29	-22.03	217.00	-27.19	277.00
1200	-55.80	148.09	-48.77	164.45	-60.44	201.89	-53.41	218.37	-65.61	261.67	-58.58	278.29	-22.03	217.00	-27.19	277.00
1500	-55.80	148.09	-48.77	164.45	-60.44	201.89	-53.41	218.37	-65.61	261.67	-58.58	278.29	-22.03	217.00	-27.19	277.00
2000	-55.80	148.09	-48.77	164.45	-60.44	201.89	-53.41	218.37	-65.61	261.67	-58.58	278.29	-22.03	217.00	-27.19	277.00
5000	-55.80	148.09	-48.77	164.45	-60.44	201.89	-53.41	218.37	-65.61	261.67	-58.58	278.29	-22.03	217.00	-27.19	277.00
10000	-55.80	148.09	-48.77	164.45	-60.44	201.89	-53.41	218.37	-65.61	261.67	-58.58	278.29	-22.03	217.00	-27.19	277.00
50000	-55.80	148.09	-48.77	164.45	-60.44	201.89	-53.41	218.37	-65.61	261.67	-58.58	278.29	-22.03	217.00	-27.19	277.00
Tangent	-55.80	148.09	-48.77	164.45	-60.44	201.89	-53.41	218.37	-65.61	261.67	-58.58	278.29	-22.03	217.00	-27.19	277.00

TABLE 10A - VEHICLE DYNAMIC ENVELOPE - OUTSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 1.0 in
Superelevation = 2.0 in

Radius:	$WL1_{OUT}$		$WL2_{OUT}$		$WL3_{OUT}$		$WL4_{OUT}$		$WL5_{OUT}$		$WL6_{OUT}$		$M1_{OUT}$		$M2_{OUT}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	76.09	7.31	79.68	124.57	75.47	139.05	61.65	153.54	0.00	0.00	0.00	0.00	71.56	83.48	71.63	93.81
100	72.19	7.31	75.78	124.57	71.71	139.05	59.17	153.54	0.00	0.00	0.00	0.00	69.96	83.48	70.03	93.81
150	65.99	7.31	69.58	124.57	65.74	139.05	55.24	153.54	0.00	0.00	0.00	0.00	67.34	83.48	67.41	93.81
200	62.76	7.31	66.35	124.57	62.64	139.05	53.20	153.54	0.00	0.00	0.00	0.00	65.95	83.48	66.02	93.81
300	59.44	7.31	63.03	124.57	59.46	139.05	51.11	153.54	0.00	0.00	0.00	0.00	64.50	83.48	64.57	93.81
400	58.31	7.31	61.90	124.57	58.49	139.05	50.05	153.54	0.00	0.00	0.00	0.00	63.76	83.48	63.83	93.81
500	57.85	7.31	61.44	124.57	58.02	139.05	49.41	153.54	0.00	0.00	0.00	0.00	63.30	83.48	63.37	93.81
600	57.54	7.31	61.13	124.57	57.71	139.05	48.98	153.54	0.00	0.00	0.00	0.00	63.00	83.48	63.07	93.81
700	57.32	7.31	60.91	124.57	57.49	139.05	48.67	153.54	0.00	0.00	0.00	0.00	62.78	83.48	62.85	93.81
800	57.15	7.31	60.74	124.57	57.32	139.05	48.44	153.54	0.00	0.00	0.00	0.00	62.61	83.48	62.68	93.81
900	57.02	7.31	60.61	124.57	57.19	139.05	48.25	153.54	0.00	0.00	0.00	0.00	62.48	83.48	62.55	93.81
1000	56.92	7.31	60.51	124.57	57.08	139.05	48.11	153.54	0.00	0.00	0.00	0.00	62.38	83.48	62.45	93.81
1200	56.76	7.31	60.35	124.57	56.93	139.05	47.89	153.54	0.00	0.00	0.00	0.00	62.22	83.48	62.29	93.81
1500	56.60	7.31	60.19	124.57	56.77	139.05	47.67	153.54	0.00	0.00	0.00	0.00	62.07	83.48	62.14	93.81
2000	56.44	7.31	60.03	124.57	56.61	139.05	47.45	153.54	0.00	0.00	0.00	0.00	61.91	83.48	61.98	93.81
5000	56.15	7.31	59.74	124.57	56.32	139.05	47.06	153.54	0.00	0.00	0.00	0.00	61.63	83.48	61.70	93.81
10000	56.06	7.31	59.65	124.57	56.22	139.05	46.92	153.54	0.00	0.00	0.00	0.00	61.53	83.48	61.60	93.81
50000	55.98	7.31	59.57	124.57	56.15	139.05	46.82	153.54	0.00	0.00	0.00	0.00	61.45	83.48	61.53	93.81
Tangent	55.96	7.31	59.55	124.57	56.13	139.05	46.79	153.54	0.00	0.00	0.00	0.00	61.44	83.48	61.51	93.81

Radius:	$P1_{OUT}$		$P2_{OUT}$		$P4_{OUT}$		$P5_{OUT}$		$P7_{OUT}$		$P8_{OUT}$		$R1_{CEN}$		$P3_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	48.22	151.01	40.66	165.94	50.14	204.98	42.58	219.65	52.27	264.94	44.71	279.34	-0.80	16.50	-20.13	163.48
100	48.22	151.01	40.66	165.94	50.14	204.98	42.58	219.65	52.27	264.94	44.71	279.34	-0.80	16.50	-20.13	163.48
150	48.22	151.01	40.66	165.94	50.14	204.98	42.58	219.65	52.27	264.94	44.71	279.34	-0.80	16.50	-20.13	163.48
200	48.22	151.01	40.66	165.94	50.14	204.98	42.58	219.65	52.27	264.94	44.71	279.34	-0.80	16.50	-20.13	163.48
300	48.22	151.01	40.66	165.94	50.14	204.98	42.58	219.65	52.27	264.94	44.71	279.34	-0.80	16.50	-20.13	163.48
400	48.22	151.01	40.66	165.94	50.14	204.98	42.58	219.65	52.27	264.94	44.71	279.34	-0.80	16.50	-20.13	163.48
500	48.22	151.01	40.66	165.94	50.14	204.98	42.58	219.65	52.27	264.94	44.71	279.34	-0.80	16.50	-20.13	163.48
600	48.22	151.01	40.66	165.94	50.14	204.98	42.58	219.65	52.27	264.94	44.71	279.34	-0.80	16.50	-20.13	163.48
700	48.22	151.01	40.66	165.94	50.14	204.98	42.58	219.65	52.27	264.94	44.71	279.34	-0.80	16.50	-20.13	163.48
800	48.22	151.01	40.66	165.94	50.14	204.98	42.58	219.65	52.27	264.94	44.71	279.34	-0.80	16.50	-20.13	163.48
900	48.22	151.01	40.66	165.94	50.14	204.98	42.58	219.65	52.27	264.94	44.71	279.34	-0.80	16.50	-20.13	163.48
1000	48.22	151.01	40.66	165.94	50.14	204.98	42.58	219.65	52.27	264.94	44.71	279.34	-0.80	16.50	-20.13	163.48
1200	48.22	151.01	40.66	165.94	50.14	204.98	42.58	219.65	52.27	264.94	44.71	279.34	-0.80	16.50	-20.13	163.48
1500	48.22	151.01	40.66	165.94	50.14	204.98	42.58	219.65	52.27	264.94	44.71	279.34	-0.80	16.50	-20.13	163.48
2000	48.22	151.01	40.66	165.94	50.14	204.98	42.58	219.65	52.27	264.94	44.71	279.34	-0.80	16.50	-20.13	163.48
5000	48.22	151.01	40.66	165.94	50.14	204.98	42.58	219.65	52.27	264.94	44.71	279.34	-0.80	16.50	-20.13	163.48
10000	48.22	151.01	40.66	165.94	50.14	204.98	42.58	219.65	52.27	264.94	44.71	279.34	-0.80	16.50	-20.13	163.48
50000	48.22	151.01	40.66	165.94	50.14	204.98	42.58	219.65	52.27	264.94	44.71	279.34	-0.80	16.50	-20.13	163.48
Tangent	48.22	151.01	40.66	165.94	50.14	204.98	42.58	219.65	52.27	264.94	44.71	279.34	-0.80	16.50	-20.13	163.48

TABLE 10B - VEHICLE DYNAMIC ENVELOPE - INSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 1.0 in
Superelevation = 2.0 in

Radius:	$WL1_{IN}$		$WL2_{IN}$		$WL3_{IN}$		$WL4_{IN}$		$WL5_{IN}$		$WL6_{IN}$		$M1_{IN}$		$M2_{IN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	-71.32	3.80	-82.44	120.52	-80.00	135.20	-71.01	151.59	0.00	0.00	0.00	0.00	-53.77	79.39	-53.98	90.42
100	-68.48	3.80	-79.61	120.52	-77.17	135.20	-68.18	151.59	0.00	0.00	0.00	0.00	-56.37	79.39	-56.57	90.42
150	-64.22	3.80	-75.35	120.52	-72.91	135.20	-63.91	151.59	0.00	0.00	0.00	0.00	-60.12	79.39	-60.33	90.42
200	-62.10	3.80	-73.23	120.52	-70.79	135.20	-61.79	151.59	0.00	0.00	0.00	0.00	-61.91	79.39	-62.12	90.42
300	-59.99	3.80	-71.11	120.52	-68.67	135.20	-59.68	151.59	0.00	0.00	0.00	0.00	-63.64	79.39	-63.85	90.42
400	-58.93	3.80	-70.05	120.52	-67.62	135.20	-58.62	151.59	0.00	0.00	0.00	0.00	-64.49	79.39	-64.69	90.42
500	-58.30	3.80	-69.42	120.52	-66.98	135.20	-57.99	151.59	0.00	0.00	0.00	0.00	-64.99	79.39	-65.19	90.42
600	-57.87	3.80	-69.00	120.52	-66.56	135.20	-57.56	151.59	0.00	0.00	0.00	0.00	-65.32	79.39	-65.52	90.42
700	-57.57	3.80	-68.70	120.52	-66.26	135.20	-57.26	151.59	0.00	0.00	0.00	0.00	-65.55	79.39	-65.76	90.42
800	-57.35	3.80	-68.47	120.52	-66.03	135.20	-57.04	151.59	0.00	0.00	0.00	0.00	-65.73	79.39	-65.93	90.42
900	-57.17	3.80	-68.30	120.52	-65.86	135.20	-56.86	151.59	0.00	0.00	0.00	0.00	-65.86	79.39	-66.07	90.42
1000	-57.03	3.80	-68.16	120.52	-65.72	135.20	-56.72	151.59	0.00	0.00	0.00	0.00	-65.97	79.39	-66.18	90.42
1200	-56.82	3.80	-67.95	120.52	-65.51	135.20	-56.51	151.59	0.00	0.00	0.00	0.00	-66.13	79.39	-66.34	90.42
1500	-56.61	3.80	-67.73	120.52	-65.30	135.20	-56.30	151.59	0.00	0.00	0.00	0.00	-66.30	79.39	-66.50	90.42
2000	-56.40	3.80	-67.52	120.52	-65.08	135.20	-56.09	151.59	0.00	0.00	0.00	0.00	-66.46	79.39	-66.66	90.42
5000	-56.51	3.80	-67.64	120.52	-65.20	135.20	-56.41	151.59	0.00	0.00	0.00	0.00	-66.75	79.39	-66.95	90.42
10000	-56.61	3.80	-67.73	120.52	-65.29	135.20	-56.54	151.59	0.00	0.00	0.00	0.00	-66.84	79.39	-67.05	90.42
50000	-56.68	3.80	-67.81	120.52	-65.37	135.20	-56.64	151.59	0.00	0.00	0.00	0.00	-66.92	79.39	-67.12	90.42
Tangent	-56.70	3.80	-67.83	120.52	-65.39	135.20	-56.67	151.59	0.00	0.00	0.00	0.00	-66.94	79.39	-67.14	90.42

Radius:	$P1_{IN}$		$P2_{IN}$		$P4_{IN}$		$P5_{IN}$		$P7_{IN}$		$P8_{IN}$		$P6_{CEN}$		$P9_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	-58.31	147.70	-51.46	164.52	-63.86	201.41	-57.01	218.49	-70.03	261.10	-63.18	278.45	-25.68	217.48	-31.85	277.48
100	-58.31	147.70	-51.46	164.52	-63.86	201.41	-57.01	218.49	-70.03	261.10	-63.18	278.45	-25.68	217.48	-31.85	277.48
150	-58.31	147.70	-51.46	164.52	-63.86	201.41	-57.01	218.49	-70.03	261.10	-63.18	278.45	-25.68	217.48	-31.85	277.48
200	-58.31	147.70	-51.46	164.52	-63.86	201.41	-57.01	218.49	-70.03	261.10	-63.18	278.45	-25.68	217.48	-31.85	277.48
300	-58.31	147.70	-51.46	164.52	-63.86	201.41	-57.01	218.49	-70.03	261.10	-63.18	278.45	-25.68	217.48	-31.85	277.48
400	-58.31	147.70	-51.46	164.52	-63.86	201.41	-57.01	218.49	-70.03	261.10	-63.18	278.45	-25.68	217.48	-31.85	277.48
500	-58.31	147.70	-51.46	164.52	-63.86	201.41	-57.01	218.49	-70.03	261.10	-63.18	278.45	-25.68	217.48	-31.85	277.48
600	-58.31	147.70	-51.46	164.52	-63.86	201.41	-57.01	218.49	-70.03	261.10	-63.18	278.45	-25.68	217.48	-31.85	277.48
700	-58.31	147.70	-51.46	164.52	-63.86	201.41	-57.01	218.49	-70.03	261.10	-63.18	278.45	-25.68	217.48	-31.85	277.48
800	-58.31	147.70	-51.46	164.52	-63.86	201.41	-57.01	218.49	-70.03	261.10	-63.18	278.45	-25.68	217.48	-31.85	277.48
900	-58.31	147.70	-51.46	164.52	-63.86	201.41	-57.01	218.49	-70.03	261.10	-63.18	278.45	-25.68	217.48	-31.85	277.48
1000	-58.31	147.70	-51.46	164.52	-63.86	201.41	-57.01	218.49	-70.03	261.10	-63.18	278.45	-25.68	217.48	-31.85	277.48
1200	-58.31	147.70	-51.46	164.52	-63.86	201.41	-57.01	218.49	-70.03	261.10	-63.18	278.45	-25.68	217.48	-31.85	277.48
1500	-58.31	147.70	-51.46	164.52	-63.86	201.41	-57.01	218.49	-70.03	261.10	-63.18	278.45	-25.68	217.48	-31.85	277.48
2000	-58.31	147.70	-51.46	164.52	-63.86	201.41	-57.01	218.49	-70.03	261.10	-63.18	278.45	-25.68	217.48	-31.85	277.48
5000	-58.31	147.70	-51.46	164.52	-63.86	201.41	-57.01	218.49	-70.03	261.10	-63.18	278.45	-25.68	217.48	-31.85	277.48
10000	-58.31	147.70	-51.46	164.52	-63.86	201.41	-57.01	218.49	-70.03	261.10	-63.18	278.45	-25.68	217.48	-31.85	277.48
50000	-58.31	147.70	-51.46	164.52	-63.86	201.41	-57.01	218.49	-70.03	261.10	-63.18	278.45	-25.68	217.48	-31.85	277.48
Tangent	-58.31	147.70	-51.46	164.52	-63.86	201.41	-57.01	218.49	-70.03	261.10	-63.18	278.45	-25.68	217.48	-31.85	277.48

TABLE 11A - VEHICLE DYNAMIC ENVELOPE - OUTSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 1.0 in
Superelevation = 3.0 in

Radius:	$WL1_{OUT}$		$WL2_{OUT}$		$WL3_{OUT}$		$WL4_{OUT}$		$WL5_{OUT}$		$WL6_{OUT}$		$M1_{OUT}$		$M2_{OUT}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	75.86	8.68	77.57	126.00	73.11	140.42	59.15	154.41	0.00	0.00	0.00	0.00	70.14	84.94	70.18	95.09
100	71.97	8.68	73.67	126.00	69.35	140.42	56.67	154.41	0.00	0.00	0.00	0.00	68.54	84.94	68.58	95.09
150	65.76	8.68	67.47	126.00	63.38	140.42	52.74	154.41	0.00	0.00	0.00	0.00	65.92	84.94	65.96	95.09
200	62.53	8.68	64.24	126.00	60.28	140.42	50.70	154.41	0.00	0.00	0.00	0.00	64.53	84.94	64.57	95.09
300	59.21	8.68	60.92	126.00	57.10	140.42	48.61	154.41	0.00	0.00	0.00	0.00	63.08	84.94	63.12	95.09
400	58.09	8.68	59.79	126.00	56.13	140.42	47.55	154.41	0.00	0.00	0.00	0.00	62.34	84.94	62.37	95.09
500	57.62	8.68	59.33	126.00	55.67	140.42	46.91	154.41	0.00	0.00	0.00	0.00	61.88	84.94	61.92	95.09
600	57.31	8.68	59.02	126.00	55.36	140.42	46.47	154.41	0.00	0.00	0.00	0.00	61.58	84.94	61.61	95.09
700	57.09	8.68	58.80	126.00	55.13	140.42	46.16	154.41	0.00	0.00	0.00	0.00	61.36	84.94	61.39	95.09
800	56.92	8.68	58.63	126.00	54.97	140.42	45.93	154.41	0.00	0.00	0.00	0.00	61.19	84.94	61.23	95.09
900	56.79	8.68	58.50	126.00	54.83	140.42	45.75	154.41	0.00	0.00	0.00	0.00	61.06	84.94	61.10	95.09
1000	56.69	8.68	58.40	126.00	54.73	140.42	45.61	154.41	0.00	0.00	0.00	0.00	60.96	84.94	61.00	95.09
1200	56.53	8.68	58.24	126.00	54.57	140.42	45.39	154.41	0.00	0.00	0.00	0.00	60.80	84.94	60.84	95.09
1500	56.37	8.68	58.08	126.00	54.41	140.42	45.17	154.41	0.00	0.00	0.00	0.00	60.65	84.94	60.68	95.09
2000	56.21	8.68	57.92	126.00	54.25	140.42	44.95	154.41	0.00	0.00	0.00	0.00	60.49	84.94	60.53	95.09
5000	55.93	8.68	57.63	126.00	53.97	140.42	44.55	154.41	0.00	0.00	0.00	0.00	60.21	84.94	60.24	95.09
10000	55.83	8.68	57.54	126.00	53.87	140.42	44.42	154.41	0.00	0.00	0.00	0.00	60.11	84.94	60.15	95.09
50000	55.75	8.68	57.46	126.00	53.79	140.42	44.32	154.41	0.00	0.00	0.00	0.00	60.04	84.94	60.07	95.09
Tangent	55.73	8.68	57.44	126.00	53.77	140.42	44.29	154.41	0.00	0.00	0.00	0.00	60.02	84.94	60.05	95.09

Radius:	$P1_{OUT}$		$P2_{OUT}$		$P4_{OUT}$		$P5_{OUT}$		$P7_{OUT}$		$P8_{OUT}$		$R1_{CEN}$		$P3_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	45.67	152.23	37.94	166.67	46.67	206.22	38.94	220.29	47.79	266.21	40.06	279.86	-1.08	16.99	-22.87	163.96
100	45.67	152.23	37.94	166.67	46.67	206.22	38.94	220.29	47.79	266.21	40.06	279.86	-1.08	16.99	-22.87	163.96
150	45.67	152.23	37.94	166.67	46.67	206.22	38.94	220.29	47.79	266.21	40.06	279.86	-1.08	16.99	-22.87	163.96
200	45.67	152.23	37.94	166.67	46.67	206.22	38.94	220.29	47.79	266.21	40.06	279.86	-1.08	16.99	-22.87	163.96
300	45.67	152.23	37.94	166.67	46.67	206.22	38.94	220.29	47.79	266.21	40.06	279.86	-1.08	16.99	-22.87	163.96
400	45.67	152.23	37.94	166.67	46.67	206.22	38.94	220.29	47.79	266.21	40.06	279.86	-1.08	16.99	-22.87	163.96
500	45.67	152.23	37.94	166.67	46.67	206.22	38.94	220.29	47.79	266.21	40.06	279.86	-1.08	16.99	-22.87	163.96
600	45.67	152.23	37.94	166.67	46.67	206.22	38.94	220.29	47.79	266.21	40.06	279.86	-1.08	16.99	-22.87	163.96
700	45.67	152.23	37.94	166.67	46.67	206.22	38.94	220.29	47.79	266.21	40.06	279.86	-1.08	16.99	-22.87	163.96
800	45.67	152.23	37.94	166.67	46.67	206.22	38.94	220.29	47.79	266.21	40.06	279.86	-1.08	16.99	-22.87	163.96
900	45.67	152.23	37.94	166.67	46.67	206.22	38.94	220.29	47.79	266.21	40.06	279.86	-1.08	16.99	-22.87	163.96
1000	45.67	152.23	37.94	166.67	46.67	206.22	38.94	220.29	47.79	266.21	40.06	279.86	-1.08	16.99	-22.87	163.96
1200	45.67	152.23	37.94	166.67	46.67	206.22	38.94	220.29	47.79	266.21	40.06	279.86	-1.08	16.99	-22.87	163.96
1500	45.67	152.23	37.94	166.67	46.67	206.22	38.94	220.29	47.79	266.21	40.06	279.86	-1.08	16.99	-22.87	163.96
2000	45.67	152.23	37.94	166.67	46.67	206.22	38.94	220.29	47.79	266.21	40.06	279.86	-1.08	16.99	-22.87	163.96
5000	45.67	152.23	37.94	166.67	46.67	206.22	38.94	220.29	47.79	266.21	40.06	279.86	-1.08	16.99	-22.87	163.96
10000	45.67	152.23	37.94	166.67	46.67	206.22	38.94	220.29	47.79	266.21	40.06	279.86	-1.08	16.99	-22.87	163.96
50000	45.67	152.23	37.94	166.67	46.67	206.22	38.94	220.29	47.79	266.21	40.06	279.86	-1.08	16.99	-22.87	163.96
Tangent	45.67	152.23	37.94	166.67	46.67	206.22	38.94	220.29	47.79	266.21	40.06	279.86	-1.08	16.99	-22.87	163.96

TABLE 11B - VEHICLE DYNAMIC ENVELOPE - INSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 1.0 in
Superelevation = 3.0 in

Radius:	$WL1_{IN}$		$WL2_{IN}$		$WL3_{IN}$		$WL4_{IN}$		$WL5_{IN}$		$WL6_{IN}$		$M1_{IN}$		$M2_{IN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	-71.49	3.42	-84.49	119.92	-82.30	134.64	-73.46	151.50	0.00	0.00	0.00	0.00	-55.12	78.81	-55.36	90.01
100	-68.65	3.42	-81.65	119.92	-79.46	134.64	-70.63	151.50	0.00	0.00	0.00	0.00	-57.72	78.81	-57.96	90.01
150	-64.39	3.42	-77.39	119.92	-75.20	134.64	-66.36	151.50	0.00	0.00	0.00	0.00	-61.47	78.81	-61.71	90.01
200	-62.27	3.42	-75.27	119.92	-73.08	134.64	-64.24	151.50	0.00	0.00	0.00	0.00	-63.26	78.81	-63.50	90.01
300	-60.15	3.42	-73.15	119.92	-70.96	134.64	-62.13	151.50	0.00	0.00	0.00	0.00	-64.99	78.81	-65.23	90.01
400	-59.10	3.42	-72.10	119.92	-69.91	134.64	-61.07	151.50	0.00	0.00	0.00	0.00	-65.84	78.81	-66.08	90.01
500	-58.47	3.42	-71.46	119.92	-69.27	134.64	-60.44	151.50	0.00	0.00	0.00	0.00	-66.34	78.81	-66.58	90.01
600	-58.04	3.42	-71.04	119.92	-68.85	134.64	-60.02	151.50	0.00	0.00	0.00	0.00	-66.67	78.81	-66.91	90.01
700	-57.74	3.42	-70.74	119.92	-68.55	134.64	-59.71	151.50	0.00	0.00	0.00	0.00	-66.90	78.81	-67.14	90.01
800	-57.52	3.42	-70.52	119.92	-68.32	134.64	-59.49	151.50	0.00	0.00	0.00	0.00	-67.08	78.81	-67.32	90.01
900	-57.34	3.42	-70.34	119.92	-68.15	134.64	-59.31	151.50	0.00	0.00	0.00	0.00	-67.21	78.81	-67.45	90.01
1000	-57.20	3.42	-70.20	119.92	-68.01	134.64	-59.17	151.50	0.00	0.00	0.00	0.00	-67.32	78.81	-67.56	90.01
1200	-56.99	3.42	-69.99	119.92	-67.80	134.64	-58.96	151.50	0.00	0.00	0.00	0.00	-67.48	78.81	-67.72	90.01
1500	-56.78	3.42	-69.78	119.92	-67.59	134.64	-58.75	151.50	0.00	0.00	0.00	0.00	-67.65	78.81	-67.89	90.01
2000	-56.57	3.42	-69.57	119.92	-67.38	134.64	-58.54	151.50	0.00	0.00	0.00	0.00	-67.81	78.81	-68.05	90.01
5000	-56.68	3.42	-69.68	119.92	-67.49	134.64	-58.86	151.50	0.00	0.00	0.00	0.00	-68.10	78.81	-68.33	90.01
10000	-56.78	3.42	-69.78	119.92	-67.58	134.64	-58.99	151.50	0.00	0.00	0.00	0.00	-68.19	78.81	-68.43	90.01
50000	-56.85	3.42	-69.85	119.92	-67.66	134.64	-59.10	151.50	0.00	0.00	0.00	0.00	-68.27	78.81	-68.51	90.01
Tangent	-56.87	3.42	-69.87	119.92	-67.68	134.64	-59.12	151.50	0.00	0.00	0.00	0.00	-68.29	78.81	-68.53	90.01

Radius:	$P1_{IN}$		$P2_{IN}$		$P4_{IN}$		$P5_{IN}$		$P7_{IN}$		$P8_{IN}$		$P6_{CEN}$		$P9_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	-60.81	147.27	-54.15	164.55	-67.27	200.88	-60.60	218.54	-74.45	260.45	-67.78	278.53	-29.33	217.96	-36.50	277.94
100	-60.81	147.27	-54.15	164.55	-67.27	200.88	-60.60	218.54	-74.45	260.45	-67.78	278.53	-29.33	217.96	-36.50	277.94
150	-60.81	147.27	-54.15	164.55	-67.27	200.88	-60.60	218.54	-74.45	260.45	-67.78	278.53	-29.33	217.96	-36.50	277.94
200	-60.81	147.27	-54.15	164.55	-67.27	200.88	-60.60	218.54	-74.45	260.45	-67.78	278.53	-29.33	217.96	-36.50	277.94
300	-60.81	147.27	-54.15	164.55	-67.27	200.88	-60.60	218.54	-74.45	260.45	-67.78	278.53	-29.33	217.96	-36.50	277.94
400	-60.81	147.27	-54.15	164.55	-67.27	200.88	-60.60	218.54	-74.45	260.45	-67.78	278.53	-29.33	217.96	-36.50	277.94
500	-60.81	147.27	-54.15	164.55	-67.27	200.88	-60.60	218.54	-74.45	260.45	-67.78	278.53	-29.33	217.96	-36.50	277.94
600	-60.81	147.27	-54.15	164.55	-67.27	200.88	-60.60	218.54	-74.45	260.45	-67.78	278.53	-29.33	217.96	-36.50	277.94
700	-60.81	147.27	-54.15	164.55	-67.27	200.88	-60.60	218.54	-74.45	260.45	-67.78	278.53	-29.33	217.96	-36.50	277.94
800	-60.81	147.27	-54.15	164.55	-67.27	200.88	-60.60	218.54	-74.45	260.45	-67.78	278.53	-29.33	217.96	-36.50	277.94
900	-60.81	147.27	-54.15	164.55	-67.27	200.88	-60.60	218.54	-74.45	260.45	-67.78	278.53	-29.33	217.96	-36.50	277.94
1000	-60.81	147.27	-54.15	164.55	-67.27	200.88	-60.60	218.54	-74.45	260.45	-67.78	278.53	-29.33	217.96	-36.50	277.94
1200	-60.81	147.27	-54.15	164.55	-67.27	200.88	-60.60	218.54	-74.45	260.45	-67.78	278.53	-29.33	217.96	-36.50	277.94
1500	-60.81	147.27	-54.15	164.55	-67.27	200.88	-60.60	218.54	-74.45	260.45	-67.78	278.53	-29.33	217.96	-36.50	277.94
2000	-60.81	147.27	-54.15	164.55	-67.27	200.88	-60.60	218.54	-74.45	260.45	-67.78	278.53	-29.33	217.96	-36.50	277.94
5000	-60.81	147.27	-54.15	164.55	-67.27	200.88	-60.60	218.54	-74.45	260.45	-67.78	278.53	-29.33	217.96	-36.50	277.94
10000	-60.81	147.27	-54.15	164.55	-67.27	200.88	-60.60	218.54	-74.45	260.45	-67.78	278.53	-29.33	217.96	-36.50	277.94
50000	-60.81	147.27	-54.15	164.55	-67.27	200.88	-60.60	218.54	-74.45	260.45	-67.78	278.53	-29.33	217.96	-36.50	277.94
Tangent	-60.81	147.27	-54.15	164.55	-67.27	200.88	-60.60	218.54	-74.45	260.45	-67.78	278.53	-29.33	217.96	-36.50	277.94

TABLE 12A - VEHICLE DYNAMIC ENVELOPE - OUTSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 1.0 in
Superelevation = 4.0 in

Radius:	$WL1_{OUT}$		$WL2_{OUT}$		$WL3_{OUT}$		$WL4_{OUT}$		$WL5_{OUT}$		$WL6_{OUT}$		$M1_{OUT}$		$M2_{OUT}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	75.61	10.04	75.43	127.38	70.74	141.74	56.63	155.24	0.00	0.00	0.00	0.00	68.70	86.38	68.71	96.34
100	71.72	10.04	71.54	127.38	66.98	141.74	54.15	155.24	0.00	0.00	0.00	0.00	67.10	86.38	67.10	96.34
150	65.51	10.04	65.34	127.38	61.01	141.74	50.22	155.24	0.00	0.00	0.00	0.00	64.48	86.38	64.48	96.34
200	62.28	10.04	62.10	127.38	57.91	141.74	48.18	155.24	0.00	0.00	0.00	0.00	63.09	86.38	63.09	96.34
300	58.96	10.04	58.79	127.38	54.73	141.74	46.09	155.24	0.00	0.00	0.00	0.00	61.64	86.38	61.64	96.34
400	57.84	10.04	57.66	127.38	53.76	141.74	45.03	155.24	0.00	0.00	0.00	0.00	60.89	86.38	60.90	96.34
500	57.37	10.04	57.20	127.38	53.29	141.74	44.39	155.24	0.00	0.00	0.00	0.00	60.44	86.38	60.44	96.34
600	57.06	10.04	56.89	127.38	52.98	141.74	43.96	155.24	0.00	0.00	0.00	0.00	60.14	86.38	60.14	96.34
700	56.84	10.04	56.67	127.38	52.76	141.74	43.65	155.24	0.00	0.00	0.00	0.00	59.92	86.38	59.92	96.34
800	56.67	10.04	56.50	127.38	52.59	141.74	43.41	155.24	0.00	0.00	0.00	0.00	59.75	86.38	59.75	96.34
900	56.54	10.04	56.37	127.38	52.46	141.74	43.23	155.24	0.00	0.00	0.00	0.00	59.62	86.38	59.63	96.34
1000	56.44	10.04	56.26	127.38	52.36	141.74	43.09	155.24	0.00	0.00	0.00	0.00	59.52	86.38	59.52	96.34
1200	56.28	10.04	56.11	127.38	52.20	141.74	42.87	155.24	0.00	0.00	0.00	0.00	59.36	86.38	59.37	96.34
1500	56.12	10.04	55.95	127.38	52.04	141.74	42.65	155.24	0.00	0.00	0.00	0.00	59.21	86.38	59.21	96.34
2000	55.96	10.04	55.79	127.38	51.88	141.74	42.43	155.24	0.00	0.00	0.00	0.00	59.05	86.38	59.05	96.34
5000	55.68	10.04	55.50	127.38	51.59	141.74	42.04	155.24	0.00	0.00	0.00	0.00	58.77	86.38	58.77	96.34
10000	55.58	10.04	55.40	127.38	51.50	141.74	41.90	155.24	0.00	0.00	0.00	0.00	58.67	86.38	58.67	96.34
50000	55.50	10.04	55.33	127.38	51.42	141.74	41.80	155.24	0.00	0.00	0.00	0.00	58.59	86.38	58.60	96.34
Tangent	55.48	10.04	55.31	127.38	51.40	141.74	41.77	155.24	0.00	0.00	0.00	0.00	58.57	86.38	58.58	96.34

Radius:	$P1_{OUT}$		$P2_{OUT}$		$P4_{OUT}$		$P5_{OUT}$		$P7_{OUT}$		$P8_{OUT}$		$R1_{CEN}$		$P3_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	43.10	153.41	35.19	167.36	43.19	207.41	35.29	220.86	43.30	267.41	35.40	280.33	-1.37	17.48	-25.62	164.48
100	43.10	153.41	35.19	167.36	43.19	207.41	35.29	220.86	43.30	267.41	35.40	280.33	-1.37	17.48	-25.62	164.48
150	43.10	153.41	35.19	167.36	43.19	207.41	35.29	220.86	43.30	267.41	35.40	280.33	-1.37	17.48	-25.62	164.48
200	43.10	153.41	35.19	167.36	43.19	207.41	35.29	220.86	43.30	267.41	35.40	280.33	-1.37	17.48	-25.62	164.48
300	43.10	153.41	35.19	167.36	43.19	207.41	35.29	220.86	43.30	267.41	35.40	280.33	-1.37	17.48	-25.62	164.48
400	43.10	153.41	35.19	167.36	43.19	207.41	35.29	220.86	43.30	267.41	35.40	280.33	-1.37	17.48	-25.62	164.48
500	43.10	153.41	35.19	167.36	43.19	207.41	35.29	220.86	43.30	267.41	35.40	280.33	-1.37	17.48	-25.62	164.48
600	43.10	153.41	35.19	167.36	43.19	207.41	35.29	220.86	43.30	267.41	35.40	280.33	-1.37	17.48	-25.62	164.48
700	43.10	153.41	35.19	167.36	43.19	207.41	35.29	220.86	43.30	267.41	35.40	280.33	-1.37	17.48	-25.62	164.48
800	43.10	153.41	35.19	167.36	43.19	207.41	35.29	220.86	43.30	267.41	35.40	280.33	-1.37	17.48	-25.62	164.48
900	43.10	153.41	35.19	167.36	43.19	207.41	35.29	220.86	43.30	267.41	35.40	280.33	-1.37	17.48	-25.62	164.48
1000	43.10	153.41	35.19	167.36	43.19	207.41	35.29	220.86	43.30	267.41	35.40	280.33	-1.37	17.48	-25.62	164.48
1200	43.10	153.41	35.19	167.36	43.19	207.41	35.29	220.86	43.30	267.41	35.40	280.33	-1.37	17.48	-25.62	164.48
1500	43.10	153.41	35.19	167.36	43.19	207.41	35.29	220.86	43.30	267.41	35.40	280.33	-1.37	17.48	-25.62	164.48
2000	43.10	153.41	35.19	167.36	43.19	207.41	35.29	220.86	43.30	267.41	35.40	280.33	-1.37	17.48	-25.62	164.48
5000	43.10	153.41	35.19	167.36	43.19	207.41	35.29	220.86	43.30	267.41	35.40	280.33	-1.37	17.48	-25.62	164.48
10000	43.10	153.41	35.19	167.36	43.19	207.41	35.29	220.86	43.30	267.41	35.40	280.33	-1.37	17.48	-25.62	164.48
50000	43.10	153.41	35.19	167.36	43.19	207.41	35.29	220.86	43.30	267.41	35.40	280.33	-1.37	17.48	-25.62	164.48
Tangent	43.10	153.41	35.19	167.36	43.19	207.41	35.29	220.86	43.30	267.41	35.40	280.33	-1.37	17.48	-25.62	164.48

TABLE 12B - VEHICLE DYNAMIC ENVELOPE - INSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 1.0 in
Superelevation = 4.0 in

Radius:	$WL1_{IN}$		$WL2_{IN}$		$WL3_{IN}$		$WL4_{IN}$		$WL5_{IN}$		$WL6_{IN}$		$M1_{IN}$		$M2_{IN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	-71.65	3.04	-86.52	119.29	-84.57	134.04	-75.90	151.37	0.00	0.00	0.00	0.00	-56.46	78.21	-56.73	89.58
100	-68.82	3.04	-83.68	119.29	-81.74	134.04	-73.07	151.37	0.00	0.00	0.00	0.00	-59.06	78.21	-59.33	89.58
150	-64.55	3.04	-79.42	119.29	-77.48	134.04	-68.80	151.37	0.00	0.00	0.00	0.00	-62.81	78.21	-63.08	89.58
200	-62.43	3.04	-77.30	119.29	-75.35	134.04	-66.68	151.37	0.00	0.00	0.00	0.00	-64.60	78.21	-64.87	89.58
300	-60.32	3.04	-75.18	119.29	-73.24	134.04	-64.57	151.37	0.00	0.00	0.00	0.00	-66.33	78.21	-66.60	89.58
400	-59.26	3.04	-74.13	119.29	-72.18	134.04	-63.51	151.37	0.00	0.00	0.00	0.00	-67.18	78.21	-67.45	89.58
500	-58.63	3.04	-73.49	119.29	-71.55	134.04	-62.88	151.37	0.00	0.00	0.00	0.00	-67.68	78.21	-67.95	89.58
600	-58.21	3.04	-73.07	119.29	-71.13	134.04	-62.46	151.37	0.00	0.00	0.00	0.00	-68.01	78.21	-68.28	89.58
700	-57.90	3.04	-72.77	119.29	-70.83	134.04	-62.15	151.37	0.00	0.00	0.00	0.00	-68.24	78.21	-68.51	89.58
800	-57.68	3.04	-72.55	119.29	-70.60	134.04	-61.93	151.37	0.00	0.00	0.00	0.00	-68.42	78.21	-68.69	89.58
900	-57.50	3.04	-72.37	119.29	-70.43	134.04	-61.75	151.37	0.00	0.00	0.00	0.00	-68.55	78.21	-68.82	89.58
1000	-57.36	3.04	-72.23	119.29	-70.29	134.04	-61.61	151.37	0.00	0.00	0.00	0.00	-68.66	78.21	-68.93	89.58
1200	-57.15	3.04	-72.02	119.29	-70.07	134.04	-61.40	151.37	0.00	0.00	0.00	0.00	-68.82	78.21	-69.10	89.58
1500	-56.94	3.04	-71.81	119.29	-69.86	134.04	-61.19	151.37	0.00	0.00	0.00	0.00	-68.98	78.21	-69.26	89.58
2000	-56.73	3.04	-71.60	119.29	-69.65	134.04	-60.98	151.37	0.00	0.00	0.00	0.00	-69.15	78.21	-69.42	89.58
5000	-56.84	3.04	-71.71	119.29	-69.77	134.04	-61.30	151.37	0.00	0.00	0.00	0.00	-69.43	78.21	-69.71	89.58
10000	-56.94	3.04	-71.81	119.29	-69.86	134.04	-61.43	151.37	0.00	0.00	0.00	0.00	-69.53	78.21	-69.80	89.58
50000	-57.02	3.04	-71.88	119.29	-69.94	134.04	-61.54	151.37	0.00	0.00	0.00	0.00	-69.61	78.21	-69.88	89.58
Tangent	-57.03	3.04	-71.90	119.29	-69.96	134.04	-61.56	151.37	0.00	0.00	0.00	0.00	-69.62	78.21	-69.90	89.58

Radius:	$P1_{IN}$		$P2_{IN}$		$P4_{IN}$		$P5_{IN}$		$P7_{IN}$		$P8_{IN}$		$P6_{CEN}$		$P9_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	-63.31	146.79	-56.82	164.53	-70.66	200.29	-64.18	218.53	-78.84	259.73	-72.36	278.53	-32.97	218.48	-41.15	278.48
100	-63.31	146.79	-56.82	164.53	-70.66	200.29	-64.18	218.53	-78.84	259.73	-72.36	278.53	-32.97	218.48	-41.15	278.48
150	-63.31	146.79	-56.82	164.53	-70.66	200.29	-64.18	218.53	-78.84	259.73	-72.36	278.53	-32.97	218.48	-41.15	278.48
200	-63.31	146.79	-56.82	164.53	-70.66	200.29	-64.18	218.53	-78.84	259.73	-72.36	278.53	-32.97	218.48	-41.15	278.48
300	-63.31	146.79	-56.82	164.53	-70.66	200.29	-64.18	218.53	-78.84	259.73	-72.36	278.53	-32.97	218.48	-41.15	278.48
400	-63.31	146.79	-56.82	164.53	-70.66	200.29	-64.18	218.53	-78.84	259.73	-72.36	278.53	-32.97	218.48	-41.15	278.48
500	-63.31	146.79	-56.82	164.53	-70.66	200.29	-64.18	218.53	-78.84	259.73	-72.36	278.53	-32.97	218.48	-41.15	278.48
600	-63.31	146.79	-56.82	164.53	-70.66	200.29	-64.18	218.53	-78.84	259.73	-72.36	278.53	-32.97	218.48	-41.15	278.48
700	-63.31	146.79	-56.82	164.53	-70.66	200.29	-64.18	218.53	-78.84	259.73	-72.36	278.53	-32.97	218.48	-41.15	278.48
800	-63.31	146.79	-56.82	164.53	-70.66	200.29	-64.18	218.53	-78.84	259.73	-72.36	278.53	-32.97	218.48	-41.15	278.48
900	-63.31	146.79	-56.82	164.53	-70.66	200.29	-64.18	218.53	-78.84	259.73	-72.36	278.53	-32.97	218.48	-41.15	278.48
1000	-63.31	146.79	-56.82	164.53	-70.66	200.29	-64.18	218.53	-78.84	259.73	-72.36	278.53	-32.97	218.48	-41.15	278.48
1200	-63.31	146.79	-56.82	164.53	-70.66	200.29	-64.18	218.53	-78.84	259.73	-72.36	278.53	-32.97	218.48	-41.15	278.48
1500	-63.31	146.79	-56.82	164.53	-70.66	200.29	-64.18	218.53	-78.84	259.73	-72.36	278.53	-32.97	218.48	-41.15	278.48
2000	-63.31	146.79	-56.82	164.53	-70.66	200.29	-64.18	218.53	-78.84	259.73	-72.36	278.53	-32.97	218.48	-41.15	278.48
5000	-63.31	146.79	-56.82	164.53	-70.66	200.29	-64.18	218.53	-78.84	259.73	-72.36	278.53	-32.97	218.48	-41.15	278.48
10000	-63.31	146.79	-56.82	164.53	-70.66	200.29	-64.18	218.53	-78.84	259.73	-72.36	278.53	-32.97	218.48	-41.15	278.48
50000	-63.31	146.79	-56.82	164.53	-70.66	200.29	-64.18	218.53	-78.84	259.73	-72.36	278.53	-32.97	218.48	-41.15	278.48
Tangent	-63.31	146.79	-56.82	164.53	-70.66	200.29	-64.18	218.53	-78.84	259.73	-72.36	278.53	-32.97	218.48	-41.15	278.48

TABLE 13A - VEHICLE DYNAMIC ENVELOPE - OUTSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 1.0 in
Superelevation = 5.0 in

Radius:	$WL1_{OUT}$		$WL2_{OUT}$		$WL3_{OUT}$		$WL4_{OUT}$		$WL5_{OUT}$		$WL6_{OUT}$		$M1_{OUT}$		$M2_{OUT}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	75.34	11.40	73.28	128.73	68.35	143.02	54.10	156.03	0.00	0.00	0.00	0.00	67.24	87.78	67.21	97.56
100	71.44	11.40	69.39	128.73	64.59	143.02	51.62	156.03	0.00	0.00	0.00	0.00	65.63	87.78	65.61	97.56
150	65.24	11.40	63.19	128.73	58.62	143.02	47.69	156.03	0.00	0.00	0.00	0.00	63.02	87.78	62.99	97.56
200	62.01	11.40	59.95	128.73	55.52	143.02	45.65	156.03	0.00	0.00	0.00	0.00	61.63	87.78	61.60	97.56
300	58.69	11.40	56.64	128.73	52.34	143.02	43.56	156.03	0.00	0.00	0.00	0.00	60.18	87.78	60.15	97.56
400	57.56	11.40	55.51	128.73	51.37	143.02	42.50	156.03	0.00	0.00	0.00	0.00	59.43	87.78	59.40	97.56
500	57.10	11.40	55.05	128.73	50.90	143.02	41.86	156.03	0.00	0.00	0.00	0.00	58.98	87.78	58.95	97.56
600	56.79	11.40	54.74	128.73	50.59	143.02	41.42	156.03	0.00	0.00	0.00	0.00	58.67	87.78	58.64	97.56
700	56.57	11.40	54.52	128.73	50.37	143.02	41.12	156.03	0.00	0.00	0.00	0.00	58.45	87.78	58.42	97.56
800	56.40	11.40	54.35	128.73	50.20	143.02	40.88	156.03	0.00	0.00	0.00	0.00	58.29	87.78	58.26	97.56
900	56.27	11.40	54.22	128.73	50.07	143.02	40.70	156.03	0.00	0.00	0.00	0.00	58.16	87.78	58.13	97.56
1000	56.17	11.40	54.11	128.73	49.96	143.02	40.56	156.03	0.00	0.00	0.00	0.00	58.06	87.78	58.03	97.56
1200	56.01	11.40	53.96	128.73	49.81	143.02	40.34	156.03	0.00	0.00	0.00	0.00	57.90	87.78	57.87	97.56
1500	55.85	11.40	53.80	128.73	49.65	143.02	40.12	156.03	0.00	0.00	0.00	0.00	57.74	87.78	57.71	97.56
2000	55.69	11.40	53.64	128.73	49.49	143.02	39.90	156.03	0.00	0.00	0.00	0.00	57.59	87.78	57.56	97.56
5000	55.40	11.40	53.35	128.73	49.20	143.02	39.50	156.03	0.00	0.00	0.00	0.00	57.30	87.78	57.27	97.56
10000	55.31	11.40	53.25	128.73	49.10	143.02	39.37	156.03	0.00	0.00	0.00	0.00	57.21	87.78	57.18	97.56
50000	55.23	11.40	53.18	128.73	49.03	143.02	39.27	156.03	0.00	0.00	0.00	0.00	57.13	87.78	57.10	97.56
Tangent	55.21	11.40	53.16	128.73	49.01	143.02	39.24	156.03	0.00	0.00	0.00	0.00	57.11	87.78	57.08	97.56

Radius:	$P1_{OUT}$		$P2_{OUT}$		$P4_{OUT}$		$P5_{OUT}$		$P7_{OUT}$		$P8_{OUT}$		$R1_{CEN}$		$P3_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	40.51	154.53	32.44	168.00	39.70	208.53	31.63	221.37	38.80	268.52	30.73	280.85	-1.67	17.96	-28.35	164.94
100	40.51	154.53	32.44	168.00	39.70	208.53	31.63	221.37	38.80	268.52	30.73	280.85	-1.67	17.96	-28.35	164.94
150	40.51	154.53	32.44	168.00	39.70	208.53	31.63	221.37	38.80	268.52	30.73	280.85	-1.67	17.96	-28.35	164.94
200	40.51	154.53	32.44	168.00	39.70	208.53	31.63	221.37	38.80	268.52	30.73	280.85	-1.67	17.96	-28.35	164.94
300	40.51	154.53	32.44	168.00	39.70	208.53	31.63	221.37	38.80	268.52	30.73	280.85	-1.67	17.96	-28.35	164.94
400	40.51	154.53	32.44	168.00	39.70	208.53	31.63	221.37	38.80	268.52	30.73	280.85	-1.67	17.96	-28.35	164.94
500	40.51	154.53	32.44	168.00	39.70	208.53	31.63	221.37	38.80	268.52	30.73	280.85	-1.67	17.96	-28.35	164.94
600	40.51	154.53	32.44	168.00	39.70	208.53	31.63	221.37	38.80	268.52	30.73	280.85	-1.67	17.96	-28.35	164.94
700	40.51	154.53	32.44	168.00	39.70	208.53	31.63	221.37	38.80	268.52	30.73	280.85	-1.67	17.96	-28.35	164.94
800	40.51	154.53	32.44	168.00	39.70	208.53	31.63	221.37	38.80	268.52	30.73	280.85	-1.67	17.96	-28.35	164.94
900	40.51	154.53	32.44	168.00	39.70	208.53	31.63	221.37	38.80	268.52	30.73	280.85	-1.67	17.96	-28.35	164.94
1000	40.51	154.53	32.44	168.00	39.70	208.53	31.63	221.37	38.80	268.52	30.73	280.85	-1.67	17.96	-28.35	164.94
1200	40.51	154.53	32.44	168.00	39.70	208.53	31.63	221.37	38.80	268.52	30.73	280.85	-1.67	17.96	-28.35	164.94
1500	40.51	154.53	32.44	168.00	39.70	208.53	31.63	221.37	38.80	268.52	30.73	280.85	-1.67	17.96	-28.35	164.94
2000	40.51	154.53	32.44	168.00	39.70	208.53	31.63	221.37	38.80	268.52	30.73	280.85	-1.67	17.96	-28.35	164.94
5000	40.51	154.53	32.44	168.00	39.70	208.53	31.63	221.37	38.80	268.52	30.73	280.85	-1.67	17.96	-28.35	164.94
10000	40.51	154.53	32.44	168.00	39.70	208.53	31.63	221.37	38.80	268.52	30.73	280.85	-1.67	17.96	-28.35	164.94
50000	40.51	154.53	32.44	168.00	39.70	208.53	31.63	221.37	38.80	268.52	30.73	280.85	-1.67	17.96	-28.35	164.94
Tangent	40.51	154.53	32.44	168.00	39.70	208.53	31.63	221.37	38.80	268.52	30.73	280.85	-1.67	17.96	-28.35	164.94

TABLE 13B - VEHICLE DYNAMIC ENVELOPE - INSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 1.0 in
Superelevation = 5.0 in

Radius:	$WL1_{IN}$		$WL2_{IN}$		$WL3_{IN}$		$WL4_{IN}$		$WL5_{IN}$		$WL6_{IN}$		$M1_{IN}$		$M2_{IN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	-71.80	2.66	-88.53	118.62	-86.83	133.40	-78.33	151.19	0.00	0.00	0.00	0.00	-57.79	77.59	-58.09	89.12
100	-68.97	2.66	-85.70	118.62	-84.00	133.40	-75.49	151.19	0.00	0.00	0.00	0.00	-60.38	77.59	-60.69	89.12
150	-64.71	2.66	-81.43	118.62	-79.74	133.40	-71.23	151.19	0.00	0.00	0.00	0.00	-64.13	77.59	-64.44	89.12
200	-62.59	2.66	-79.31	118.62	-77.62	133.40	-69.11	151.19	0.00	0.00	0.00	0.00	-65.92	77.59	-66.23	89.12
300	-60.47	2.66	-77.20	118.62	-75.50	133.40	-66.99	151.19	0.00	0.00	0.00	0.00	-67.66	77.59	-67.96	89.12
400	-59.42	2.66	-76.14	118.62	-74.45	133.40	-65.94	151.19	0.00	0.00	0.00	0.00	-68.50	77.59	-68.81	89.12
500	-58.78	2.66	-75.51	118.62	-73.81	133.40	-65.30	151.19	0.00	0.00	0.00	0.00	-69.00	77.59	-69.31	89.12
600	-58.36	2.66	-75.09	118.62	-73.39	133.40	-64.88	151.19	0.00	0.00	0.00	0.00	-69.33	77.59	-69.64	89.12
700	-58.06	2.66	-74.79	118.62	-73.09	133.40	-64.58	151.19	0.00	0.00	0.00	0.00	-69.57	77.59	-69.87	89.12
800	-57.83	2.66	-74.56	118.62	-72.86	133.40	-64.36	151.19	0.00	0.00	0.00	0.00	-69.74	77.59	-70.05	89.12
900	-57.66	2.66	-74.38	118.62	-72.69	133.40	-64.18	151.19	0.00	0.00	0.00	0.00	-69.88	77.59	-70.18	89.12
1000	-57.52	2.66	-74.24	118.62	-72.55	133.40	-64.04	151.19	0.00	0.00	0.00	0.00	-69.99	77.59	-70.29	89.12
1200	-57.31	2.66	-74.03	118.62	-72.34	133.40	-63.83	151.19	0.00	0.00	0.00	0.00	-70.15	77.59	-70.45	89.12
1500	-57.09	2.66	-73.82	118.62	-72.13	133.40	-63.62	151.19	0.00	0.00	0.00	0.00	-70.31	77.59	-70.61	89.12
2000	-56.88	2.66	-73.61	118.62	-71.91	133.40	-63.41	151.19	0.00	0.00	0.00	0.00	-70.47	77.59	-70.78	89.12
5000	-57.00	2.66	-73.72	118.62	-72.03	133.40	-63.72	151.19	0.00	0.00	0.00	0.00	-70.76	77.59	-71.06	89.12
10000	-57.09	2.66	-73.82	118.62	-72.12	133.40	-63.86	151.19	0.00	0.00	0.00	0.00	-70.85	77.59	-71.16	89.12
50000	-57.17	2.66	-73.90	118.62	-72.20	133.40	-63.96	151.19	0.00	0.00	0.00	0.00	-70.93	77.59	-71.24	89.12
Tangent	-57.19	2.66	-73.92	118.62	-72.22	133.40	-63.99	151.19	0.00	0.00	0.00	0.00	-70.95	77.59	-71.26	89.12

Radius:	$P1_{IN}$		$P2_{IN}$		$P4_{IN}$		$P5_{IN}$		$P7_{IN}$		$P8_{IN}$		$P6_{CEN}$		$P9_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	-65.78	146.28	-59.48	164.47	-74.04	199.64	-67.74	218.46	-83.21	258.94	-76.91	278.46	-36.61	218.94	-45.78	278.93
100	-65.78	146.28	-59.48	164.47	-74.04	199.64	-67.74	218.46	-83.21	258.94	-76.91	278.46	-36.61	218.94	-45.78	278.93
150	-65.78	146.28	-59.48	164.47	-74.04	199.64	-67.74	218.46	-83.21	258.94	-76.91	278.46	-36.61	218.94	-45.78	278.93
200	-65.78	146.28	-59.48	164.47	-74.04	199.64	-67.74	218.46	-83.21	258.94	-76.91	278.46	-36.61	218.94	-45.78	278.93
300	-65.78	146.28	-59.48	164.47	-74.04	199.64	-67.74	218.46	-83.21	258.94	-76.91	278.46	-36.61	218.94	-45.78	278.93
400	-65.78	146.28	-59.48	164.47	-74.04	199.64	-67.74	218.46	-83.21	258.94	-76.91	278.46	-36.61	218.94	-45.78	278.93
500	-65.78	146.28	-59.48	164.47	-74.04	199.64	-67.74	218.46	-83.21	258.94	-76.91	278.46	-36.61	218.94	-45.78	278.93
600	-65.78	146.28	-59.48	164.47	-74.04	199.64	-67.74	218.46	-83.21	258.94	-76.91	278.46	-36.61	218.94	-45.78	278.93
700	-65.78	146.28	-59.48	164.47	-74.04	199.64	-67.74	218.46	-83.21	258.94	-76.91	278.46	-36.61	218.94	-45.78	278.93
800	-65.78	146.28	-59.48	164.47	-74.04	199.64	-67.74	218.46	-83.21	258.94	-76.91	278.46	-36.61	218.94	-45.78	278.93
900	-65.78	146.28	-59.48	164.47	-74.04	199.64	-67.74	218.46	-83.21	258.94	-76.91	278.46	-36.61	218.94	-45.78	278.93
1000	-65.78	146.28	-59.48	164.47	-74.04	199.64	-67.74	218.46	-83.21	258.94	-76.91	278.46	-36.61	218.94	-45.78	278.93
1200	-65.78	146.28	-59.48	164.47	-74.04	199.64	-67.74	218.46	-83.21	258.94	-76.91	278.46	-36.61	218.94	-45.78	278.93
1500	-65.78	146.28	-59.48	164.47	-74.04	199.64	-67.74	218.46	-83.21	258.94	-76.91	278.46	-36.61	218.94	-45.78	278.93
2000	-65.78	146.28	-59.48	164.47	-74.04	199.64	-67.74	218.46	-83.21	258.94	-76.91	278.46	-36.61	218.94	-45.78	278.93
5000	-65.78	146.28	-59.48	164.47	-74.04	199.64	-67.74	218.46	-83.21	258.94	-76.91	278.46	-36.61	218.94	-45.78	278.93
10000	-65.78	146.28	-59.48	164.47	-74.04	199.64	-67.74	218.46	-83.21	258.94	-76.91	278.46	-36.61	218.94	-45.78	278.93
50000	-65.78	146.28	-59.48	164.47	-74.04	199.64	-67.74	218.46	-83.21	258.94	-76.91	278.46	-36.61	218.94	-45.78	278.93
Tangent	-65.78	146.28	-59.48	164.47	-74.04	199.64	-67.74	218.46	-83.21	258.94	-76.91	278.46	-36.61	218.94	-45.78	278.93

TABLE 14A - VEHICLE DYNAMIC ENVELOPE - OUTSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 1.0 in
Superelevation = 6.0 in

Radius:	$WL1_{OUT}$		$WL2_{OUT}$		$WL3_{OUT}$		$WL4_{OUT}$		$WL5_{OUT}$		$WL6_{OUT}$		$M1_{OUT}$		$M2_{OUT}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	75.04	12.75	71.12	130.04	65.94	144.25	51.55	156.77	0.00	0.00	0.00	0.00	65.76	89.16	65.70	98.75
100	71.15	12.75	67.22	130.04	62.19	144.25	49.08	156.77	0.00	0.00	0.00	0.00	64.15	89.16	64.09	98.75
150	64.94	12.75	61.02	130.04	56.22	144.25	45.15	156.77	0.00	0.00	0.00	0.00	61.54	89.16	61.47	98.75
200	61.71	12.75	57.79	130.04	53.11	144.25	43.11	156.77	0.00	0.00	0.00	0.00	60.14	89.16	60.08	98.75
300	58.40	12.75	54.47	130.04	49.94	144.25	41.02	156.77	0.00	0.00	0.00	0.00	58.70	89.16	58.63	98.75
400	57.27	12.75	53.34	130.04	48.96	144.25	39.96	156.77	0.00	0.00	0.00	0.00	57.95	89.16	57.89	98.75
500	56.81	12.75	52.88	130.04	48.50	144.25	39.31	156.77	0.00	0.00	0.00	0.00	57.50	89.16	57.43	98.75
600	56.50	12.75	52.57	130.04	48.19	144.25	38.88	156.77	0.00	0.00	0.00	0.00	57.19	89.16	57.13	98.75
700	56.28	12.75	52.35	130.04	47.96	144.25	38.57	156.77	0.00	0.00	0.00	0.00	56.97	89.16	56.91	98.75
800	56.11	12.75	52.18	130.04	47.80	144.25	38.34	156.77	0.00	0.00	0.00	0.00	56.81	89.16	56.74	98.75
900	55.98	12.75	52.05	130.04	47.67	144.25	38.16	156.77	0.00	0.00	0.00	0.00	56.68	89.16	56.62	98.75
1000	55.87	12.75	51.95	130.04	47.56	144.25	38.01	156.77	0.00	0.00	0.00	0.00	56.58	89.16	56.51	98.75
1200	55.71	12.75	51.79	130.04	47.40	144.25	37.80	156.77	0.00	0.00	0.00	0.00	56.42	89.16	56.36	98.75
1500	55.56	12.75	51.63	130.04	47.24	144.25	37.58	156.77	0.00	0.00	0.00	0.00	56.26	89.16	56.20	98.75
2000	55.40	12.75	51.47	130.04	47.08	144.25	37.36	156.77	0.00	0.00	0.00	0.00	56.11	89.16	56.04	98.75
5000	55.11	12.75	51.18	130.04	46.80	144.25	36.96	156.77	0.00	0.00	0.00	0.00	55.82	89.16	55.76	98.75
10000	55.01	12.75	51.09	130.04	46.70	144.25	36.83	156.77	0.00	0.00	0.00	0.00	55.73	89.16	55.66	98.75
50000	54.94	12.75	51.01	130.04	46.62	144.25	36.72	156.77	0.00	0.00	0.00	0.00	55.65	89.16	55.59	98.75
Tangent	54.92	12.75	50.99	130.04	46.60	144.25	36.70	156.77	0.00	0.00	0.00	0.00	55.63	89.16	55.57	98.75

Radius:	$P1_{OUT}$		$P2_{OUT}$		$P4_{OUT}$		$P5_{OUT}$		$P7_{OUT}$		$P8_{OUT}$		$R1_{CEN}$		$P3_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	37.92	155.62	29.68	168.59	36.20	209.59	27.97	221.85	34.30	269.56	26.07	281.29	-1.97	18.43	-31.09	165.36
100	37.92	155.62	29.68	168.59	36.20	209.59	27.97	221.85	34.30	269.56	26.07	281.29	-1.97	18.43	-31.09	165.36
150	37.92	155.62	29.68	168.59	36.20	209.59	27.97	221.85	34.30	269.56	26.07	281.29	-1.97	18.43	-31.09	165.36
200	37.92	155.62	29.68	168.59	36.20	209.59	27.97	221.85	34.30	269.56	26.07	281.29	-1.97	18.43	-31.09	165.36
300	37.92	155.62	29.68	168.59	36.20	209.59	27.97	221.85	34.30	269.56	26.07	281.29	-1.97	18.43	-31.09	165.36
400	37.92	155.62	29.68	168.59	36.20	209.59	27.97	221.85	34.30	269.56	26.07	281.29	-1.97	18.43	-31.09	165.36
500	37.92	155.62	29.68	168.59	36.20	209.59	27.97	221.85	34.30	269.56	26.07	281.29	-1.97	18.43	-31.09	165.36
600	37.92	155.62	29.68	168.59	36.20	209.59	27.97	221.85	34.30	269.56	26.07	281.29	-1.97	18.43	-31.09	165.36
700	37.92	155.62	29.68	168.59	36.20	209.59	27.97	221.85	34.30	269.56	26.07	281.29	-1.97	18.43	-31.09	165.36
800	37.92	155.62	29.68	168.59	36.20	209.59	27.97	221.85	34.30	269.56	26.07	281.29	-1.97	18.43	-31.09	165.36
900	37.92	155.62	29.68	168.59	36.20	209.59	27.97	221.85	34.30	269.56	26.07	281.29	-1.97	18.43	-31.09	165.36
1000	37.92	155.62	29.68	168.59	36.20	209.59	27.97	221.85	34.30	269.56	26.07	281.29	-1.97	18.43	-31.09	165.36
1200	37.92	155.62	29.68	168.59	36.20	209.59	27.97	221.85	34.30	269.56	26.07	281.29	-1.97	18.43	-31.09	165.36
1500	37.92	155.62	29.68	168.59	36.20	209.59	27.97	221.85	34.30	269.56	26.07	281.29	-1.97	18.43	-31.09	165.36
2000	37.92	155.62	29.68	168.59	36.20	209.59	27.97	221.85	34.30	269.56	26.07	281.29	-1.97	18.43	-31.09	165.36
5000	37.92	155.62	29.68	168.59	36.20	209.59	27.97	221.85	34.30	269.56	26.07	281.29	-1.97	18.43	-31.09	165.36
10000	37.92	155.62	29.68	168.59	36.20	209.59	27.97	221.85	34.30	269.56	26.07	281.29	-1.97	18.43	-31.09	165.36
50000	37.92	155.62	29.68	168.59	36.20	209.59	27.97	221.85	34.30	269.56	26.07	281.29	-1.97	18.43	-31.09	165.36
Tangent	37.92	155.62	29.68	168.59	36.20	209.59	27.97	221.85	34.30	269.56	26.07	281.29	-1.97	18.43	-31.09	165.36

TABLE 14B - VEHICLE DYNAMIC ENVELOPE - INSIDE OF CURVE

Design Criteria

Condition: Camera---3 degree roll
Cross Level Variation = 1.0 in
Superelevation = 6.0 in

Radius:	$WL1_{IN}$		$WL2_{IN}$		$WL3_{IN}$		$WL4_{IN}$		$WL5_{IN}$		$WL6_{IN}$		$M1_{IN}$		$M2_{IN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}
82	-71.95	2.28	-90.53	117.92	-89.08	132.73	-80.74	150.97	0.00	0.00	0.00	0.00	-59.10	76.95	-59.43	88.63
100	-69.12	2.28	-87.69	117.92	-86.25	132.73	-77.90	150.97	0.00	0.00	0.00	0.00	-61.69	76.95	-62.03	88.63
150	-64.85	2.28	-83.43	117.92	-81.98	132.73	-73.64	150.97	0.00	0.00	0.00	0.00	-65.44	76.95	-65.78	88.63
200	-62.73	2.28	-81.31	117.92	-79.86	132.73	-71.52	150.97	0.00	0.00	0.00	0.00	-67.23	76.95	-67.57	88.63
300	-60.62	2.28	-79.19	117.92	-77.75	132.73	-69.40	150.97	0.00	0.00	0.00	0.00	-68.97	76.95	-69.31	88.63
400	-59.56	2.28	-78.14	117.92	-76.69	132.73	-68.35	150.97	0.00	0.00	0.00	0.00	-69.81	76.95	-70.15	88.63
500	-58.93	2.28	-77.51	117.92	-76.06	132.73	-67.72	150.97	0.00	0.00	0.00	0.00	-70.31	76.95	-70.65	88.63
600	-58.51	2.28	-77.08	117.92	-75.64	132.73	-67.29	150.97	0.00	0.00	0.00	0.00	-70.64	76.95	-70.98	88.63
700	-58.21	2.28	-76.78	117.92	-75.33	132.73	-66.99	150.97	0.00	0.00	0.00	0.00	-70.88	76.95	-71.22	88.63
800	-57.98	2.28	-76.56	117.92	-75.11	132.73	-66.77	150.97	0.00	0.00	0.00	0.00	-71.05	76.95	-71.39	88.63
900	-57.81	2.28	-76.38	117.92	-74.93	132.73	-66.59	150.97	0.00	0.00	0.00	0.00	-71.19	76.95	-71.53	88.63
1000	-57.66	2.28	-76.24	117.92	-74.79	132.73	-66.45	150.97	0.00	0.00	0.00	0.00	-71.30	76.95	-71.63	88.63
1200	-57.45	2.28	-76.03	117.92	-74.58	132.73	-66.24	150.97	0.00	0.00	0.00	0.00	-71.46	76.95	-71.80	88.63
1500	-57.24	2.28	-75.82	117.92	-74.37	132.73	-66.03	150.97	0.00	0.00	0.00	0.00	-71.62	76.95	-71.96	88.63
2000	-57.03	2.28	-75.61	117.92	-74.16	132.73	-65.82	150.97	0.00	0.00	0.00	0.00	-71.78	76.95	-72.12	88.63
5000	-57.14	2.28	-75.72	117.92	-74.27	132.73	-66.14	150.97	0.00	0.00	0.00	0.00	-72.07	76.95	-72.41	88.63
10000	-57.24	2.28	-75.82	117.92	-74.37	132.73	-66.27	150.97	0.00	0.00	0.00	0.00	-72.16	76.95	-72.50	88.63
50000	-57.32	2.28	-75.89	117.92	-74.45	132.73	-66.37	150.97	0.00	0.00	0.00	0.00	-72.24	76.95	-72.58	88.63
Tangent	-57.34	2.28	-75.91	117.92	-74.47	132.73	-66.40	150.97	0.00	0.00	0.00	0.00	-72.26	76.95	-72.60	88.63

Radius:	$P1_{IN}$		$P2_{IN}$		$P4_{IN}$		$P5_{IN}$		$P7_{IN}$		$P8_{IN}$		$P6_{CEN}$		$P9_{CEN}$	
(feet)	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MIN}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}	X_{MAX}	Y_{MAX}
82	-68.24	145.72	-62.13	164.36	-77.39	198.94	-71.28	218.33	-87.55	258.07	-81.44	278.30	-40.23	219.33	-50.40	279.30
100	-68.24	145.72	-62.13	164.36	-77.39	198.94	-71.28	218.33	-87.55	258.07	-81.44	278.30	-40.23	219.33	-50.40	279.30
150	-68.24	145.72	-62.13	164.36	-77.39	198.94	-71.28	218.33	-87.55	258.07	-81.44	278.30	-40.23	219.33	-50.40	279.30
200	-68.24	145.72	-62.13	164.36	-77.39	198.94	-71.28	218.33	-87.55	258.07	-81.44	278.30	-40.23	219.33	-50.40	279.30
300	-68.24	145.72	-62.13	164.36	-77.39	198.94	-71.28	218.33	-87.55	258.07	-81.44	278.30	-40.23	219.33	-50.40	279.30
400	-68.24	145.72	-62.13	164.36	-77.39	198.94	-71.28	218.33	-87.55	258.07	-81.44	278.30	-40.23	219.33	-50.40	279.30
500	-68.24	145.72	-62.13	164.36	-77.39	198.94	-71.28	218.33	-87.55	258.07	-81.44	278.30	-40.23	219.33	-50.40	279.30
600	-68.24	145.72	-62.13	164.36	-77.39	198.94	-71.28	218.33	-87.55	258.07	-81.44	278.30	-40.23	219.33	-50.40	279.30
700	-68.24	145.72	-62.13	164.36	-77.39	198.94	-71.28	218.33	-87.55	258.07	-81.44	278.30	-40.23	219.33	-50.40	279.30
800	-68.24	145.72	-62.13	164.36	-77.39	198.94	-71.28	218.33	-87.55	258.07	-81.44	278.30	-40.23	219.33	-50.40	279.30
900	-68.24	145.72	-62.13	164.36	-77.39	198.94	-71.28	218.33	-87.55	258.07	-81.44	278.30	-40.23	219.33	-50.40	279.30
1000	-68.24	145.72	-62.13	164.36	-77.39	198.94	-71.28	218.33	-87.55	258.07	-81.44	278.30	-40.23	219.33	-50.40	279.30
1200	-68.24	145.72	-62.13	164.36	-77.39	198.94	-71.28	218.33	-87.55	258.07	-81.44	278.30	-40.23	219.33	-50.40	279.30
1500	-68.24	145.72	-62.13	164.36	-77.39	198.94	-71.28	218.33	-87.55	258.07	-81.44	278.30	-40.23	219.33	-50.40	279.30
2000	-68.24	145.72	-62.13	164.36	-77.39	198.94	-71.28	218.33	-87.55	258.07	-81.44	278.30	-40.23	219.33	-50.40	279.30
5000	-68.24	145.72	-62.13	164.36	-77.39	198.94	-71.28	218.33	-87.55	258.07	-81.44	278.30	-40.23	219.33	-50.40	279.30
10000	-68.24	145.72	-62.13	164.36	-77.39	198.94	-71.28	218.33	-87.55	258.07	-81.44	278.30	-40.23	219.33	-50.40	279.30
50000	-68.24	145.72	-62.13	164.36	-77.39	198.94	-71.28	218.33	-87.55	258.07	-81.44	278.30	-40.23	219.33	-50.40	279.30
Tangent	-68.24	145.72	-62.13	164.36	-77.39	198.94	-71.28	218.33	-87.55	258.07	-81.44	278.30	-40.23	219.33	-50.40	279.30

END CHAPTER 4

5. TRACKWORK

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5. TRACKWORK

5.1 INTRODUCTION

A. This chapter sets forth standards and design policies to govern the detailed engineering, materials, and construction standards for trackwork and its interface with other elements on the Link light rail transit (Link) project. Limits of work covered by this chapter are the top of trackway as defined herein to top of rail and the necessary interfaces of trackwork with other elements.

B. All track material, special trackwork, and practices described herein shall govern the design of track for the Link system and include the required interfacing of trackwork with other elements of the system such as tie and ballast and embedded trackway, subway, aerial guideway, bridges, track slabs, transition slabs, electrification system, signal system, drainage, etc. Construction plans and specifications shall comply with these criteria and Standard/Directive Drawings based on the current requirements of the:

1. Link light rail transit project including Link Project Rail Operations where appropriate

2. WSDOT - Washington State Department of Transportation

3. AREMA - American Railroad Engineering and Maintenance-of-Way Association

4. AAR - Association of American Railroads

5. Local Jurisdictions

5.2 TRACK SYSTEM

A. Trackwork systems are composed of a number of elements, each of which has a definite interaction with the elements of the system. Because of this interaction, the design criteria for trackwork must be undertaken as a systems approach with a cause and effects analysis being undertaken on each of the elements. In performing this trackwork design, consideration of allied factors such as safety, stray current, ride comfort, noise, and vibration must not be overlooked. In addition, the relationship of trackwork design to the design of other elements of the system, such as train control, drainage, and type of vehicle must be recognized and accommodated early in the design process.

B. Three distinct types of primary track construction may be encountered in the Link system: ballasted, direct fixation, and embedded. The design of the trackwork varies to some degree within these types of construction. The essential elements of trackwork are:

1. Roadbed and Ballast
2. Embedded Structure
3. Direct Fixation Structure
4. Rail
5. Crossties
   a. Concrete For Primary Track
   b. Timber For Yard Secondary Track
   c. Timber For Special Trackwork
6. Other Track Materials (OTM)
7. Fastening System
8. Special Trackwork

C. Development of the track requirements includes consideration of maintainability, reliability, parts standardization, capital costs, and maintenance costs. Maintainability and reliability are of particular importance since train frequencies make it difficult to maintain track during normal operating hours. Parts standardization is also important in that it allows inventories to be minimized and promotes mass production by suppliers, thereby reducing unit costs and enabling transit systems to buy "off the shelf" items.

5.3 TRACKWORK CLASSIFICATION

A. The tracks to be constructed under this project can be classified as follows:

1. Link Primary Track
2. Link Yard and Secondary Track

B. Typical trackwork sections of ballasted, direct fixation, embedded, and open deck bridge track construction are shown in the trackwork standard/directive drawings.

5.4 TRACK CONSTRUCTION TYPES

A. Trackwork shall be divided into four types of construction, which are:

1. Ballasted Track - Link Only

2. Embedded Track

3. Direct Fixation Track

4. Shop Track

B. Any one of these types of track except bridge structure may, in addition, be classified as guarded track and as special trackwork, as specified elsewhere in these criteria.

C. Embedded track using 115 RE rail shall be the standard used where the Link system shares the trackway with rubber-tired vehicles either in mixed traffic or in locations where only emergency vehicles will be permitted to travel along the trackway. Details of embedment and fixation of rail onto track slab shall be developed during detail design to suit site specific situations.

D. Direct fixation track construction in all types of guideway configuration shall be designed to utilize a second pour plinth concrete pad method of construction. Details of tunnel, underpass and at-grade direct fixation, and track slab alternatives shall be developed during detail design to suit site specific situations. Direct fixation aerial structures shall be protected from the large longitudinal forces, which may exist in CWR. CWR shall preferably not be terminated on aerial structure. The rail shall extend beyond the bridge structure such that a minimum of 110 rail fastenings or ties are engaged. Any reduction of this number of fasteners will require special anchorage devices. Direct fixation track shall be the standard used for trackwork constructed:

1. On aerial structures.

2. In exclusive Link use on aerial guideways, in underpasses, and in tunnels. Dual block tie track construction may be used as an alternative trackwork for the tunnel structures.

3. In at-grade primary tracks, which have grades in excess of 6 percent, radii less than 300 feet, or where limited right-of-way width exists and these restricting segments either exceed 350 feet in length or are adjacent to other segments of direct fixation or embedded track. It shall also be used in at-grade sections of less than 350 feet in length, which are bounded on each end by either direct fixation track or embedded track.

E. Termination as used above means absolute termination. The placement of a turnout or crossover between ends of continuous welded rail does not necessarily result in absolute termination of the rail. The continuous welded rail is not considered to be terminated if the rail joints are bonded or welded such that rail forces can be transmitted through the special trackwork. Special trackwork locations on aerial direct fixation shall be designed independently to suit specific design condition that may result from anchoring the rail.

F. Shop trackwork shall be installed within the limits of the maintenance shop building. Except in pit areas, this type of installation is similar to the embedded trackwork. In pit areas, welded 115 RE rail shall be supported by steel girders installed longitudinally beneath the rail and fastened to the steel girders with crane rail clamps or similar rail fasteners.

G. Transition ties and approach slabs as shown on the standard drawings shall be installed at interfaces between ballasted track and:

1. direct fixation track

2. embedded track

H. The crosstie spacing shall be adjusted to account for the difference in track modulus between the more rigid track and the adjoining ballasted track. The minimum ballast depth above a transition slab measured from bottom of tie varies from 10 to 12 inches.

5.5 TRACK GAUGE

5.5.1 Standard Gauge

Track gauge shall be the standard gauge of 4 feet 8-1/2 inches, measured between the inner (gauge) sides of the heads of the rails at a distance of 5/8 inch (16mm) below the top of rails.

5.5.2 Gauge Widening

Gauge widening shall be at a transition rate of not more than 1/4 inch in a distance of 31 feet. Full gauge widening shall be accomplished on the tangent in approach to the point of curve and removed following the point of tangent in simple curves. In spiraled curves, gauge widening shall be applied and removed within the length of the spirals. If the spiral is too short for full gauge widening to be accomplished without the rate exceeding 1/4 inch in 31 feet, sufficient gauge widening shall be placed in the approach tangents to meet the rate of 1/4 inch in 31 feet. If adjacent curves, both requiring widening, are too close together to allow run out of the gauge widening, the widened gauge shall be maintained between the curves.

5.5.3 Special Trackwork

Gauge through guardrails in special trackwork shall conform to AREMA Plan basic number 790. Flangeway dimensions shall in general conform to AREMA Plan basic number 791. Flangeway dimensions for sharper radii than are indicated on the AREMA plan shall be developed during design utilizing data concerning the actual wheel contour and diameter employed on the light rail vehicles.

5.6 TRACK CONSTRUCTION TOLERANCES

Track construction tolerances are determined by taking into consideration safety, speed of operation, and the type of service to be provided. The track construction tolerances are indicated in the Standard Specifications and Trackwork Standard Drawings. Deviation from specified tolerances to suit site specific situations shall be investigated in detail and all impacts shall be identified in the exception application to Sound Transit.

5.7 TRACTION POWER - IMPACT ON TRACK

5.7.1 Coordination

The relationship of trackwork design to the design of other elements of the system, such as train control, electrification, civil-structural works, drainage, and the Light Rail Vehicle (LRV) must be included in the total design process. The design selected for these other elements will affect the design parameters for trackwork so it is vital for the trackwork designer to know how the other elements will affect the design of the track structure.

5.7.2 Power Distribution

A. The purpose of the power distribution system is to conduct current between the substation and the train. The positive side of the power distribution system includes all positive power cable, overhead contact system, and various disconnecting devices, all located outside of the substation. The track system forms the return side of this circuit back to the substation. The negative return system usually consists of both running rails, supplemented by means of negative paralleling cables, if required.

B. The traction power design requires that ductwork, manholes, handholes, and pull boxes, etc., be incorporated into aerial structures, tunnels, and street sections. Niches may also be required to house traction power disconnect switch boxes in underground sections. Reference Systems and Structural Chapters for specific criteria.

5.7.3 Continuity

A. Bolted joints in negative return rail segments shall be electrically bonded across the joint bars with high conductivity bonds. The negative return rails of parallel tracks shall be cross-bonded frequently to equalize the currents that traverse them. In segments that use both running rails for return, all rails of parallel tracks shall be crossbonded. Crossbonding locations will be identified by the Systems Designers.

B. All rail joints and electrical track connections must be electrically "bonded". With the exception of any temporary connections, an exothermic process (Cadweld or Thermoweld) shall be used.

C. Appropriate measures shall be taken during the design of all types of trackwork, including embedded track and highway grade crossings, to minimize the leakage of stray current from the track structure to the ground. This work shall be consistent with system corrosion control requirements determined for each type of track construction. Reference Chapter 17 for corrosion control. Embedded track shall be protected as shown in the standard drawings.

5.8 SIGNALING AND TRAIN CONTROL - IMPACT ON TRACK

5.8.1 Coordination

A. Although train control design will not affect the selected trackwork design concept, it can affect specific parts of the design. The prime example of this interrelationship is the need for the location of insulated joints in the running rails to accommodate train control requirements. Such joints are normally required at the extremities of interlocking, within individual turnouts and crossovers, at each end of station platforms, and at other locations to be determined by the train control design.

B. The Link signaling system may include both track circuits and wayside magnetic loop detector signal systems to suit both ballasted and embedded track zones respectively. Impedance bond installation areas and requirements must be coordinated with track structure. Insulated joints at limits of track circuits will be determined by the Systems Engineer to facilitate underground ducting and traction crossbonding.

5.8.2 Embedded Track

Design of embedded track shall accommodate requirements for track circuit connections to the rails, and allowance for embedded wayside equipment, which may include switch machines and impedance bonds.

5.8.3 Cables

Signal and communication cables will require conduits, hand holes, and pull boxes. Niches may be required to house signaling equipment in underground segments. Reference Systems and Structural Chapters for specific criteria.

5.9 BALLAST, SUB-BALLAST, AND SUBGRADE

5.9.1 Coordination

A. Proper design of the roadbed and ballast elements of the track structure is very important to provide an adequate foundation and to minimize the maintenance requirements of the transit system. Roadbed and ballast sections shall be designed and analyzed to minimize the overall ROW width required while providing a uniform, well-drained foundation for the track structure. Rail support track modulus shall be designed in accordance with the AREMA Manual, Chapter1-Part 2. The roadbed includes the subgrade, sub-ballast, ties, and rail with associated other track materials.

B. Access to the track shall be provided for maintenance and emergency work. This requires provision for highway vehicles and for vehicles equipped with flanged wheels to drive onto the track at strategic locations. Where practicable, a service road on the ROW and paralleling the track shall be provided with adequate turn-around facilities where the road is not continuous.

5.9.2 Existing Ballasted Tracks

A. Existing track bed should be evaluated prior to civil and track design to determine if subgrade conditions are adequate for reuse or if remedial measures will be necessary. In some cases, sub-ballast and ballast depths may be reduced based on the existing conditions.

B. In locations where the Link track will be constructed upon existing ballast from an abandoned track, the existing ballast may eliminate the need for sub-ballast. In these locations, additional aggregate shall be mixed with existing ballast to improve the gradation and bring the ballast to the specified sub-ballast quality. Moreover, the use of geotextile fabric between the leveled and compacted existing ballast and the new track ballast is recommended. A 16-oz geotextile shall be included in the design as well as a minimum of 10 inches of new ballast under the ties at the low rail location.

C. Materials

1. ***Subgrade:*** The subgrade is the finished surface of the roadbed below the sub-ballast, supporting the loads transmitted through the rails, ties, and ballast. The subgrade shall be analyzed to determine whether it has both uniform stability and the strength to carry the track loadings expected. AREMA recommends that, for most soils, pressure on subgrade be lower than 25 psi to maintain subgrade integrity. Uniformity is important because it is differential settlement rather than total settlement that leads to unsatisfactory track alignment. The use of geotextiles or geogrids between the subgrade and sub-ballast can be advantageous under some conditions.

2. ***Sub-ballast:*** The sub-ballast for all tracks shall consist of a uniform layer placed and compacted over the entire width of the subgrade following the profile and cross section thereof. The minimum depth of sub-ballast measured from the top of the subgrade shall be 6 inches in new track embankments. Additional depth shall be used when necessary to decrease subgrade pressure. Where widened shoulder service roads are provided, the full depth of the sub-ballast shall be extended across the full width of the service road. Sub-ballast shall be crushed stone gradation in accordance with ASTM C29, C136, D15, and site specific additional design requirements.

3. ***Ballast:*** Ballast is a selected crushed and graded hard aggregate material placed upon the sub-ballast for the purpose of providing support for the rail and ties and distribution of the track loadings to the subgrade. AREMA states that ballast (plus sub-ballast) must be of sufficient depth to distribute pressure between tie and subgrade. The ballast must sustain and transmit static and dynamic loads in three directions (transverse, vertical, and longitudinal) and distribute those loads uniformly over the subgrade. The prime functions of the ballast is to drain the track system, distribute the rail vehicle loads to the subgrade, and hold the track in proper alignment, cross level and grade. It can also cushion the ride and isolate from ground any vibrations that originate at the rail - wheel interface. It also permits relatively easy adjustment of the track alignment. The gradation must provide the means to develop the stability and density requirements for the ballast section and provide the void space necessary to allow proper run off of precipitation. Ballast gradations smaller than AREMA size No. 4 shall not be used on tracks constructed with concrete crossties. Ballast gradation conforming to AREMA size No. 4 shall be used in main tracks with concrete ties. Ballast for concrete ties must be limited to either crushed granites, traprocks, or quartzites. AREMA size No. 5

shall be used in yards, industry tracks, and other non-main line tracks using timber ties. For simplicity and uniformity, the same material quality specification, except for gradation, should be considered for all ballast installations. The final top of ballast elevation shall be 1 inch below the top of tie, when compacted.

a. For main tracks, the minimum depth of ballast measured from the top of sub-ballast to the underside of track tie shall be 12 inches except for transition areas where the ballast depth varies from 10 to 12 inches. In curved track, the minimum depth of ballast shall be 12 inches measured under the low rail of the inside track. In dual track sections, the inside track establishes the top of sub-ballast.

b. For yard tracks, a minimum depth of 8 inches of ballast shall be used between the bottom of timber tie and the top of sub-ballast. The top of ballast elevation shall be at least 1 inch below the base of rail and the ballast shoulder shall extend level beyond the ends of the ties to form a suitable walking surface.

c. Crushed slag ballast will not be permitted.

5.10 CROSSTIES AND SWITCH TIES

5.10.1 Coordination

A. Due to specific requirements for both timber track ties and concrete track ties, this portion of the design criteria is provided to conform to the specific type of track tie selected.

B. All timber crossties shall be 8 feet - 0 inches long, 6-inch grade conforming to AREMA specifications.

C. Monoblock concrete ties are the preferred concrete tie system. Procurement specifications for them shall provide design requirements for fastener inserts for rail, restraining rail, and tie reinforcement. Rail pads shall be designed to prevent excessive flexure and fatigue of the rail hold down element and rail seat abrasion, while still providing the desired noise attenuation and electrical resistivity. Monoblock concrete ties with lateral resistance patterns on the sides of the tie are recommended. The concrete crosstie shall provide for a rail seat with a 40:1 cant. The track construction specifications shall include emphasis on construction methods for laying concrete ties on an initial ballast layer that will prevent centerbinding and other problems that could cause cracking during subsequent construction operations. Standard concrete ties shall be required for:

1. Mainline track consisting of two running rails

2. Mainline track consisting of two running rails and either restraining rail or emergency guardrail

D. Install guardrail ties to support emergency guardrails or restraining rails that will include insulated threaded inserts to which these items can be attached. The special concrete ties shall be designed so as to accommodate additional protection rails within a single tie design.

E. Special trackwork switch ties shall be hardwood timber produced from 100 percent oak. The timber sizes shall be 7 inches by 9 inches with lengths varying from 9 feet to 16 feet at 1-foot intervals. Special timber ties, 9 inches by 9 inches, may be required if the switch machine specified requires that the head block ties be dapped. Extra long (22 feet or greater, as required) switch timbers shall be specified for crossover locations to provide continuous support throughout the track crossing. Switch timber lengths shall be sufficient to ensure that no ties need be spiked within 12 inches of either end.

F. Tie spacing shall be set to provide sufficient lateral, longitudinal, and vertical restraint for each type of track. Ties shall have the following minimum longitudinal spacing:

1. Main line track consisting of concrete ties with “spring” fasteners: ties shall be spaced at 30-inch centers.

2. Yard track consisting of timber ties with insulated spring fasteners: ties shall be spaced at 26-inch centers, except at braced and guarded track where spacing shall be 24-inch centers.

3. Special trackwork tie spacing shall be in accordance to AREMA standard plans or as specified otherwise on Standard Drawings.

5.11 TEE RAIL AND GIRDER RAIL

5.11.1 Running Rail

A. New 115 RE section rail shall be used for all primary ballasted track embedded track in semi-exclusive configuration and direct fixation track on the Link system. Relay rail of other weights and sections that are in acceptable condition may be used in the yards and other tracks as described in these criteria, with Sound Transit approval. All new tee rail shall conform to the current AREMA "Specification for Steel Rails" and Link Project approved contract procurement specifications.

B. Rail for embedded track at road crossings and mixed traffic in surface streets shall be 115RE rail section. Rail for embedded track in

existing Downtown Seattle Transit Tunnel (DSTT) shall be Ri-52N. Girder rails shall be manufactured in accordance with prevailing European standard specifications and ASTM A2 as applicable.

5.11.2 High Strength Rail

A. High strength rail shall be used at station areas, other areas of frequent starting and stopping, on grades of 5 percent or greater, curves with radius equal to or less than 500 feet, and in areas where high wear rates or internal rail stresses are anticipated. Seldom-used secondary, emergency, or storage tracks with sharp curvatures and grades shall not be provided with high-strength rail. High strength rail shall also be used throughout all special trackwork.

B. Where high strength rail is used in curves, it shall extend into tangent track on the approach and departure ends of the curve a minimum distance of 10 feet but not more than 20 feet. When two sections of high strength rail are fairly close together and conformance to the above criterion would result in an intermediate segment of standard hardness rail less than 156 (2x78) feet in length, the high strength rail shall be made continuous through all three segments.

C. High strength rail shall extend at least 100 feet beyond the ends of the platform.

5.11.3 Rail Grinding

Prior to Link primary tracks being opened for revenue service, their running rails shall be surface ground to remove surface imperfections and mill scale, the rail wheel interface contact area optimized, and traction power return and signal shunting facilitated. Requirements for grinding rail in secondary Link tracks will be evaluated during design. Grinding of rail in embedded track shall be evaluated separately and provisions for grinding the railhead without damaging the surrounding surface must be considered. Rail grinding patterns shall be designed in conjunction with consideration of alternative LRV wheel contours.

5.11.4 Rail Fastening

All running rails shall be continuously flash butt welded into the longest lengths feasible for installation. Field welds should be used to join the lengths of shop welded rail. Embedded track within Central Business Districts may be considered for total field weld installation. Where joint bars or insulated joints are required in CWR, they shall be epoxy bonded to reduce noise and relative movement of the joint components.

5.11.5 Radius

A. Rails with short radius curves shall be precurved using standard roller bending method. Specifications for horizontally curved shop curved rail shall require that the rail base lie flat after bending. Inside and outside rail shall be precurved under the following circumstances:

1. Tee rail and restraining rail in CWR primary track horizontal curves of R= 500 feet or less.

2. Tee rail and restraining rail in either embedded track or bolted yard track curves of R = 500 feet or less.

3. Tee rails and restraining rail with vertical curve radius sharper than 1000 feet.

4. Girder rails with horizontal radius less than 500 feet or vertical curvature with a radius sharper than 1500 feet.

5.12 USE OF RAILS AND OTHER TRACK MATERIAL FROM EXISTING TRACKS

Relay track materials may be used for Link yard storage tracks and railroad relocations, as well as for emergency guardrails. Such materials shall be specified to be in acceptable condition as appropriate.

5.13 RESTRAINING GUARD RAIL FOR CURVED TRACK

A. Tracks having a centerline radius of less than or equal to 500 feet and other specific locations where restraining rail would prove to be beneficial shall have restraining rail added to the inside running rail. All track having a centerline radius less than or equal to 100 feet may require both running rails guarded. Such locations shall be analyzed and recommendations made to Sound Transit.

B. Restraining rail design shall have inner 115 RE inner guardrails mounted adjacent to the low rail in accordance with AREMA plans and specifications. The restraining rail shall be fastened to either the concrete crossties or the direct fixation track second pour plinth as applicable. The flangeway shall be determined by the selected design LRV wheel flange. Where restraining rail is required within a special trackwork layout, it may be fabricated from either vertically mounted 115 RE rail or another fabricator's design approved by Sound Transit.

C. The restraining rail assembly shall extend beyond each end of a guarded simple curve (no spirals) a minimum distance of 13 feet. Where the track geometrics include a spiral, the curve guarding shall end at the spiral to tangent point.

5.14 EMERGENCY GUARD RAIL

A. Emergency guardrail shall be used to limit the lateral movement of the trucks of derailed rail vehicles on aerial structures.

B. Emergency guardrail shall be fabricated from second hand 115 RE rail and installed in accordance with the Standard Drawings. As an alternate, a concrete parapet barrier can be provided subject to the approval of Sound Transit. For double tracks with a hazard on each side, one guardrail is required on each track and shall be located inside the running rail farthest from the hazard. On multiple tracks areas where the hazard is located on one side only, only the track closest to the hazard shall be equipped with emergency guardrail installed inside the running rail that is farthest from the hazard. On primary tracks, emergency guardrail shall extend 100 feet ahead of the beginning of the area being protected on the approach end, and 50 feet beyond the end of the protected area on the departure end. Bi-directional tracks shall be protected for 100 feet beyond each end of the hazard. Emergency guardrail extensions beyond the hazard may be one-half these distances on tracks operated at 20 miles per hour (mph) or less.

C. Emergency guardrail shall be positioned approximately 10 inches from the gauge side of the running rail. Emergency guardrail end sections shall be curved toward the track centerline and provided with vertical taper.

5.15 TIE PLATES FOR TIMBER TIES

A. The standard rail fastening for timber ties in Link track shall consist of steel tie plates with the spring clip type rail fastenings, which are fastened to the crossties with lag screws or lock spikes. Special provisions for control of stray current leakage at the tie plate must be considered and insulating design provided.

B. The standard rail fastening for timber ties in railroad only track shall be conventional double shoulder tie plates with cut spikes and rail anchors, all in accordance with the AREMA Manual and Portfolio of Trackwork Plans and the standards of the operating railroad involved. All standard tie fastening devices for timber ties shall have a 40:1 cant.

5.16 SPECIAL TRACKWORK PLATES FOR TIMBER SWITCH TIES

A. Ballasted special trackwork for mainline shall use resilient clips and insulated plates to provide stray current protection in accordance with the criteria determined by the traction power and corrosion control designers.

B. Ballasted special trackwork for maintenance yard track shall be of similar design to the resilient clip insulated plate design used on the main line.

5.17 DIRECT FIXATION RAIL FASTENERS

A. Direct fixation rail fasteners for aerial, tunnel, and direct fixation slab track shall provide the required lateral and longitudinal restraint for continuous welded rail and the electrical insulation required for the negative return current and the proper operation of track signal circuits. Direct fixation rail fasteners shall have the following longitudinal spacing:

Table 5-1
Trackwork

Trackwork	Spacing
Tangent or curved track with radius greater than 500 feet	30-inch centers
Curved track with radius 500 feet or less and greater than 300 feet	27-inch centers
Curved track with radius 300 feet or less	24-inch centers

B. Direct fixation rail fasteners shall provide a longitudinal restraint force of 2,500 pounds per fastener and restrain a broken rail gap to less than 2 inches wide. On aerial structures, low restraint fasteners may be required to allow the structure to expand and contract without overstressing the rail. Direct fixation rail fasteners used with Tee rail shall provide a 40:1 cant of the rail.

5.18 DIRECT FIXATION SPECIAL TRACKWORK

Rail fasteners for use in direct fixation special trackwork shall be of a design compatible with the standard fastener used in conventional special trackwork on timber ties and shall be spaced as shown on the Trackwork Standard Drawings.

5.19 INSULATED JOINT BARS

5.19.1 Types

A. Insulated joint bars of the epoxy-bonded type shall be used in CWR wherever it is necessary to electrically isolate contiguous rails from each other in order to comply with track signaling or traction power criteria. Track bolts shall be equipped with self-locking nuts. Insulated joint bars shall also comply with the physical parameters listed in section 5.21 of these criteria. Insulated joint bars shall be the "D" type section providing clearance for modified spring clip type rail fastenings or the “Fastclip” type rail fastening.

B. Wherever insulated joint bars are required in track constructed with jointed rail, they shall be either polyurethane encapsulated or

laminated fiberglass reinforced bolted insulated joint bars, except that the fiberglass type shall not be used in either curved rail or tracks that carry railroad traffic. All insulated joints should be located as suspended joints to obviate the need for insulated tie plates. Special modified spring clips may be required at insulated joint locations within the special trackwork.

5.20 BONDED JOINT BARS

A. Except in those tracks designated as being constructed with jointed rail, bolted joints shall only be used between welded rail strings of different chemical compositions or metallurgy. These joints shall be of the epoxy-bonded type and shall be fastened with high-strength pin type bolts. Rail at such joints shall be electrically bonded to provide a continuous path for traction power negative return current and signal circuits. They shall comply with the following parameters:

   1. Identical rail drilling pattern as standard joint bar.

   2. Compatible with the standard rail fasteners used on the Link project.

   3. Comply with the current AREMA "Specifications for Quenched Carbon Steel Joint Bars and Forged Compromise Joint Bars" and "Rail Drillings & Bar Punchings".

B. Flash butt welds shall be used wherever possible to join rail of different chemical composition or metallurgy.

5.21 JOINT BARS

The use of bolted joints shall be minimized during design except in those locations where the use of jointed rail is specified. The joint bars in exclusive Link track may be the lightweight design in accordance with former AREMA standards. Joint bars in joint use track shall be the heavy design in accordance with current AREMA standards. In either case, joint bars shall be 36-inch six-hole bars conforming to AREMA standard punching patterns. Track bolts, nuts, and lock washers shall conform to AREMA standards.

5.22 COMPROMISE RAILS AND JOINT BARS

Compromise joint bars shall be used to connect rails of dissimilar section wherever field welding is unfeasible or where the connection is temporary in nature. Wherever possible, however, field welds of the thermit type shall be used for permanent connections between dissimilar rail sections. Forged compromise rails may be used if available for the rail sections involved. Compromise rail shall have similar mechanical properties as high strength rail. Compromise joints,

welds, or rails shall not be located within special trackwork units or within 30 feet of the toe end of any turnout stock rail.

5.23 DERAILS

A. Either sliding or split switch point derails shall be used to prevent out-of-control rail vehicles from fouling adjoining or adjacent tracks. Derails shall be installed on the downgrade end of yard and secondary track normally used for the storage of unattended light rail vehicles if this track is directly connected to the main line track and if its prevailing grade is descending toward the main line track. Derails shall be placed at the clearance point (centers to be determined) of all railroad industrial tracks that connect to either a Link joint use track or to a railroad main track. Derails shall be used at other track locations where they would be likely to prevent or minimize injury to passengers and personnel, and/or damage to equipment.

B. Derail shall be located so as to derail equipment in the direction away from the main track. Refer to Trackwork Standard Drawings for typical locations of derails.

5.24 SPECIAL TRACKWORK

5.24.1 Definition

The term "special trackwork" designates the trackwork units necessary where tracks converge, diverge, or cross one another. Special trackwork includes turnouts, crossings, and crossovers. All special work design shall be based on AREMA standards except as modified to meet the special conditions of the Link system. Special trackwork, which conforms to European standards, may be considered depending on the type of special trackwork required and specialization of the item.

5.24.2 Uses

A. Special trackwork on the Link system will consist of ballasted, direct fixation, and embedded trackwork. Ballasted special trackwork shall be constructed on conventional timber switch ties using insulated rail fasteners. Embedded special trackwork shall consist of curved split switch inside a turnout housing, frogs, and track crossings. Direct fixation turnouts will be similar to ballasted track turnouts except that the rails, switches, and frogs will be fastened to a second pour concrete slab using insulated resilient rail fasteners. As it will be less costly than other types, the design should utilize ballasted special trackwork whenever possible.

1. All special trackwork shall be designed and constructed in strict accordance with the Sound Transit project Standard and Directive

Drawings. Turnouts and crossovers shall be located in ballasted track wherever possible.

2. Embedded special trackwork shall be designed to suit the restricted street and tunnel/aerial structures configurations. Standard components shall be used whenever feasible. The designer shall look for opportunities to make multiple use of custom embedded and DF special trackwork components, such as curved frogs of a particular radius.

5.24.3 Embedded Track

Embedded turnouts may vary in design sizes from conventional railroad designs. Generally, embedded turnouts with curved switches enclosed in a metal box housing and frogs embedded in an insulated concrete bathtub track slab and stem walls. The lateral and/or equilateral number 10, 8, and 5 turnouts may be used in the Link embedded special trackwork where appropriate.

5.24.4 Location

A. Special trackwork shall be located so as to reduce the exposure of pedestrians to the operating or movable mechanisms and to minimize requirements for special catenary and signal structures. Special trackwork shall not be located in areas designated for pedestrian crosswalks. Where this objective proves to be difficult to achieve, crosswalks may be located between the switch and the frog provided that pedestrians are nowhere exposed to a metallic walking surface or flangeway wider than would occur if the pedestrian crossing were located away from the special trackwork unit.

B. The limits of any trackwork design or construction contract shall not be located within a special trackwork unit or superelevated curve. Special trackwork shall be located in horizontal and vertical tangent track, unless otherwise approved by Sound Transit. There shall be no actual superelevation (E_a) in any special trackwork units. All special trackwork shall be located on tangent vertical profile grades.

C. The minimum length of horizontal tangent track between any point of switch and the end of a station platform shall be as specified in Chapter 4, Track Alignment and Vehicle Clearances, section 4.2.3, Tangent Alignment.

D. Tangent distances between turnout point of intersection and the beginning of horizontal or vertical curve shall be in accordance with directive drawings and were developed based on the following criteria:

1. Minimum distances are obtained by locating the beginning of horizontal or vertical curves at a point that is 35 feet from point of switch or point of frog.

2. Desirable distances are obtained by locating the beginning of horizontal or vertical curves ahead of a turnout at a point that is either 45 feet (approximately the length of one articulated LRV car body section) from the point of switch or 45 feet following a turnout beyond the last long switch tie. Curves following a turnout are set beyond the last long switch tie.

3. Absolute minimum distances are obtained by locating the beginning of horizontal or vertical curves 20 feet ahead of the point of switch. Non-superelevated horizontal curves may begin beyond the farthest end of the joint bars connecting the running rail to the heel of the frog. Vertical curves and superelevated horizontal curves following a turnout shall not begin until after the last long switch.

E. Turnouts are set to provide connections to branch lines, storage tracks, and industrial sidetracks and to merge two main tracks into a single track at the end of a double track segment. Crossovers consist of two turnouts located to allow traffic to cross over from one track to another, both tracks usually being in parallel. Where a pair of crossovers are required, one right-hand and the other left-hand, it is desirable that they be located as two single crossovers. If this is not possible, or if extraordinary site conditions make it more economical, a double crossover may be used. The size of turnout or crossover selected depends upon its purpose, desired design speeds, and local geometric constraints. The normal and maximum operating speeds through the various turnouts designated for use on the Link system are shown in Table 5-2.

Table 5-2
Turnout Operating Speeds (mph)

Turnout No.	Maximum Speed (U=3")	Normal Speed (U=1-1/2")
5	12	5
6	15	10
8	20	15
10	25	20
15	38	30
5 EQL	17	10
8 EQL	28	20
10 EQL	35	30
The usual application of turnouts is given in Table 5-3		

Table 5-3
Application of Turnouts – Turnout - Ballast/Direct Fixation

Frog No.	Curved Switch	Service
5	13'-0"	Link Yard Tracks only
5 EQL	13’-0”	For Pocket Tracks only
6	13’-0”	Absolute minimum main track turnout
8	19'-6"	Preferred main track turnout. Emergency crossovers, connection to yard, etc., also in yard leads.
10	19'-6"	Preferred main track turnout and use for permanent turnbacks

F. The separation distances required between points of intersection of various combinations and directions of turnouts are shown in Figures 5.1 through 5.4.

G As all special trackwork is a source of noise and vibration, its proposed location shall be determined with due consideration given to those factors.

H. All joints in primary track special trackwork shall be welded except at insulated joint locations.

I. Frogs in primary track turnouts shall be designed to eliminate all bolted joints in running surfaces. The running surface supporting the tread of wheel shall be treated to provide a minimum hardness of Brinell 360 for a minimum penetration of 1/2 inch.

J. Provisions shall be made during the design of special trackwork for the installation of switch heaters. All switches shall be designed to accommodate switch heaters regardless of the location of the specific installation within the system or the need for switch heaters at that location.

K. Where circumstances suggest that turnouts of non-standard design be considered, they shall conform to the criteria above, and shall be used only upon the approval of Sound Transit.

L. All Link special trackwork shall be designed to match 115 RE rail.

M. Elaborate special trackwork such as slip switches, double crossovers, movable point crossings, or lap turnouts may be considered in the design layout only with the approval of Sound Transit.

5.25 SWITCH MACHINES - POWER OPERATED AND MANUAL

Switches may be operated by power operated switch and lock movements, electrically locked hand-operated machines, or hand-operated trailable switch stands, depending on the location and purpose of the switch. Selection of a switch operating device and the space requirements for such devices shall be coordinated with design of the train control system and Chapter 14, Signaling. Switch machines for railroad use shall conform to the standards of the railroad involved.

5.26 AT-GRADE HIGHWAY CROSSINGS

Due to stray current concerns, the design of all at-grade crossings in primary track shall be of the embedded track design. The design of at-grade crossings of Link yard and ballasted primary track shall be based upon the use of the conventional railroad grade crossing materials, including proprietary design, modular concrete, rubber, and timber panels. At-grade highway crossings of relocated railroad tracks shall conform to the standards of the railroad company involved.

5.27 MISCELLANEOUS TRACK APPURTENANCES

A. Track bumping posts shall be designated to engage the anticlimber of the Link vehicle. They shall be installed at the ends of all stub-end tracks. Sand pits beyond the end of track or energy absorbing “skate” bumping posts may also be considered at specific locations with prior approval of Sound Transit.

B. The flangeways provided for the Link vehicle wheels in embedded track form natural conduits for storm water runoff. To prevent the formation of ponds and icing at low points of sag vertical curves, embedded track drains of the type shown on the Trackwork Standard Drawings shall be used. Such drains shall also be placed at appropriate intervals along grades to prevent the flangeways from overflowing. A track drain shall be placed on the downgrade end of embedded track segments, which adjoin ballasted or direct fixation track, to minimize fouling of track ballast and accumulation of silt and debris upon track slabs. Other locations where the use of track drains may be appropriate shall be reviewed during final design.

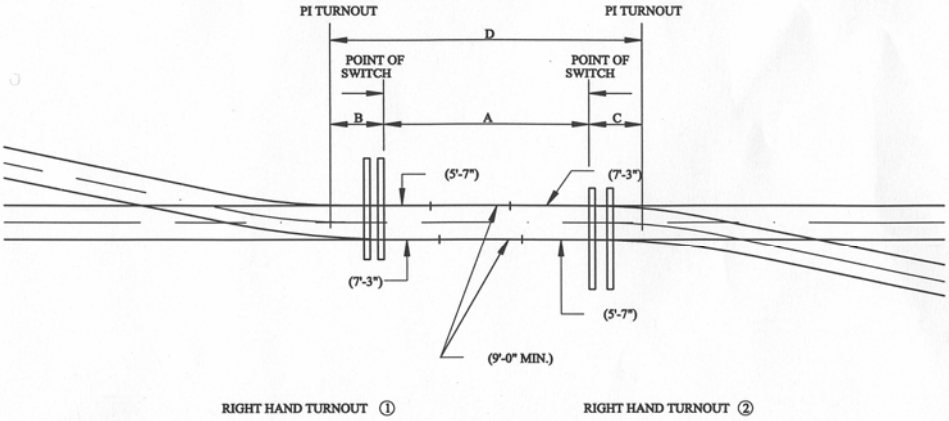
5.28 TRACK VIBRATION ISOLATION

A. Vibration isolation on direct fixation track can be achieved by floating slab design or resilient fasteners design.

1. Floating slab construction can be used where a high level of vibration isolation of the track from the invert is needed. In floating slab designs, the invert is depressed a depth sufficient to permit construction of an isolated slab that rests on elastomeric pads in the recess. Both cast-in-place and precast methods can be used to construct floating slabs.

2. Vibration isolation can also be achieved by using high-resilience fasteners between the invert slab and the rail. High-resilience fasteners should provide the same longitudinal restraint force as the standard direct fixation fasteners specified in section 5.17. These fasteners provide less attenuation than the floating slab construction.

Figure 5-1
Point of Switch to Point of Switch (Similar hand Turnouts)



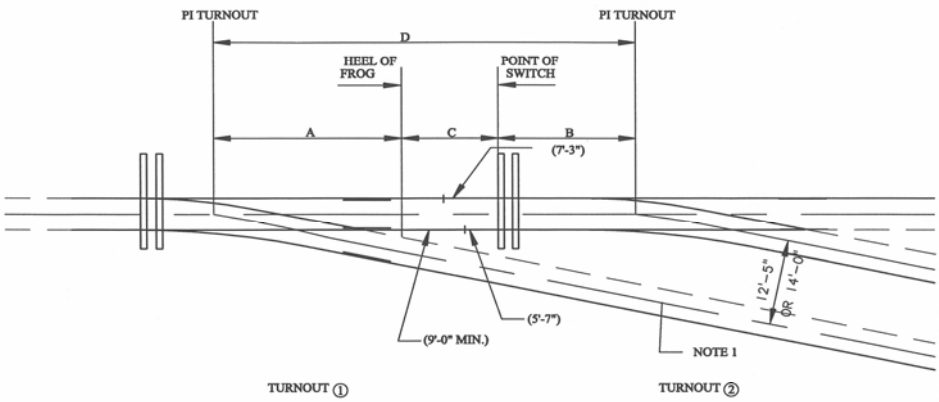
TURNOUTS		DIMENSIONS			
①	②	A	B	C	D
NO. 5 TO NO. 5		22' ABS. MIN. 35' DESIRABLE	20'-9 1/2"	20'-9 1/2"	63'-7" ABS. MIN. 76'-7" DESIRABLE
NO. 8(MODIFIED) TO NO. 8(MODIFIED)		29' ABS. MIN. 39' DESIRABLE	33'-7 3/4"	33'-7 3/4"	96'-3 1/2" ABS. MIN. 106'-3 1/2" DESIRABLE
NO. 8 TO NO. 8		29' ABS. MIN. 39' DESIRABLE	31'-0"	31'-0"	91'-0" ABS. MIN. 101'-0" DESIRABLE
NO. 8 TO NO. 10		29' ABS. MIN. 39' DESIRABLE	31'-0"	31'-5"	91'-5" ABS. MIN. 101'-5" DESIRABLE
NO. 10 TO NO. 10		29 ABS. MIN. 39' DESIRABLE	31'-5"	31'-5"	91'-10" ABS. MIN. 101'-10" DESIRABLE

NOTES:
(1) THE ABOVE FIGURES ARE BASED ON 32' TRUCK CENTERS AND 7' AXLE CENTERS
(2) DISTANCE "A" SUBJECT TO CHANGE BASED ON ACTUAL VEHICLE DIMENSIONS.

NO. 8 (MODIFIED) = NO. 8 TURNOUT WITH LATERAL SWITCH AND FROG CURVED WITH 645' RADIUS.

LINK LIGHT RAIL TRANSIT PROJECT	PSTC Puget Sound Transit Consultants	Point of Switch To Point of Switch	Figure No. 5.1	Rev. No. Page No.

Figure 5-2
Heel of Frog to Point of Switch (Similar Hand Turnouts)

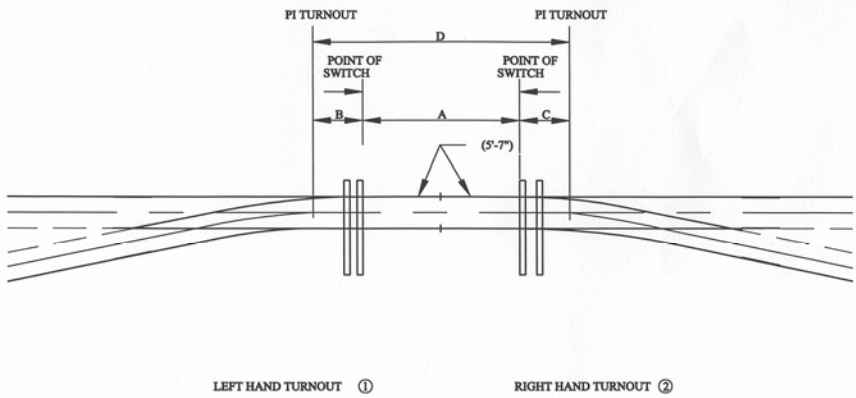


TURNOUTS		DISTANCES				DESIGNS REMARKS
①	②	A	B	C	D	
NO. 5 TO NO. 5		29'-2 1/2"	20'-9 1/2"	12.7083'	62.7100'	11°25'16" LADDER TRACK FOR 12'-5" TRACK CENTERS.
NO. 5 TO NO. 5		29'-2 1/2"	20'-9 1/2"	20.6979'	70.6991'	11°25'16" LADDER TRACK FOR 14'-0" TRACK CENTERS.
NO. 5 TO NO. 5		29'-2 1/2"	20'-9 1/2"	14.7291'	64.7303'	MINIMUM 9'-0" RAIL PLUS THERMITE WELDS-HEEL OF FROG TO END OF STOCK RAIL.
NO. 8(MODIFIED) TO NO. 8(MODIFIED)		49'-3 1/2"	33'-9 3/4"	14.7291'	97.6666'	
NO. 8 TO NO. 8		47'-5"	31'-0"	14.7291'	93.1458'	
NO. 8 TO NO. 10		47'-5"	31'-5"	14.7291'	93.5625'	
NO. 10 TO NO. 8		58'-10"	31'-0"	14.7291'	104.5625'	
NO. 10 TO NO. 10		58'-10"	31'-5"	14.7291'	104.9791'	

NOTES: (1) TURNOUT ① TRACK MUST CURVE AWAY FROM TURNOUT ② LATRERAL TRACK.
NO. 8 (MODIFIED) = NO. 8 TURNOUT WITH LATERAL SWITCH AND FROG CURVED WITH 645' RADIUS.

LINK LIGHT RAIL TRANSIT PROJECT	PSTC Puget Sound Transit Consultants	Heel of Frog To Point of Switch (Similar Hand Turnouts)	Figure No. 5.2	Rev. No. / Page No.

Figure 5-3
Point of Switch to Point of Switch (Opposite Hand Turnouts)



TURNOUTS		DIMENSIONS			
①	②	A	B	C	D
NO. 5 TO NO. 5		11'-3" ABS. MIN. (1) 35' DESIRABLE	20'-9 1/2"	20'-9 1/2"	52'-10" ABS. MIN. 76'-7" DESIRABLE
NO. 8(MODIFIED) TO NO. 8(MODIFIED)		29' ABS. MIN. 39' DESIRABLE	33'-7 3/4"	33'-7 3/4"	96'-3 1/2" ABS. MIN. 106'-3 1/2"DESIRABLE
NO. 8 TO NO. 8		29' ABS. MIN. 39' DESIRABLE	31'-0"	31'-0"	91'-0" ABS. MIN. 101'-0" DESIRABLE
NO. 8 TO NO. 10		29' ABS. MIN. 39' DESIRABLE	31'-0"	31'-5"	91'-5" ABS. MIN. 101'-5" DESIRABLE
NO. 10 TO NO. 10		29' ABS. MIN. 39' DESIRABLE	31'-5"	31'-5"	91'-10" ABS. MIN. 101'-5" DESIRABLE

NOTES:

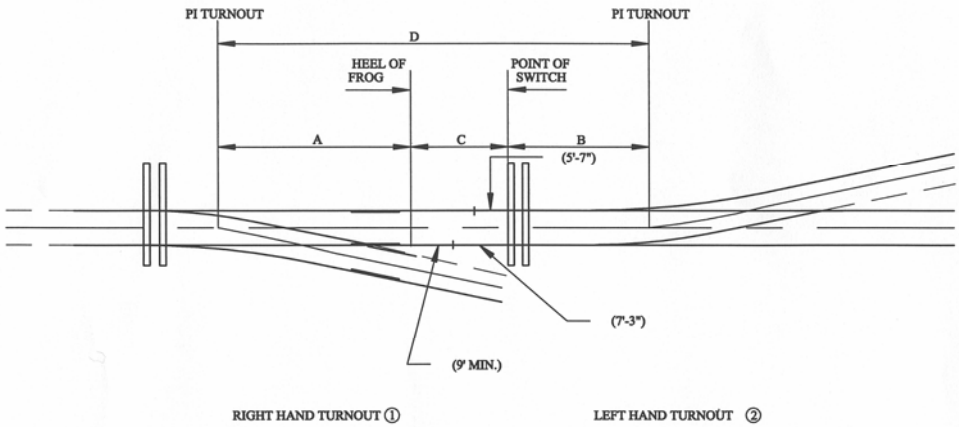
(1) BUTTING STOCK RAILS PLUS THERMITE WELD.

(2) THE ABOVE FIGURES ARE BASED ON 32' TRUCK CENTERS AND 7' AXLE CENTERS DISTANCE "A" SUBJECT TO CHANGE BASED ON ACTUAL VEHICLE DIMENSIONS.

NO. 8 (MODIFIED) = NO. 8 TURNOUT WITH LATERAL SWITCH AND FROG CURVED WITH 645' RADIUS.

LINK LIGHT RAIL TRANSIT PROJECT	PSTC Puget Sound Transit Consultants	Point of Switch To Point of Switch (Opposite Hand Turnouts)	Figure No. 5.3	Rev. No. Page No.

Figure 5-4
Point of Switch to Point of Switch (Opposite hand Turnouts)



TURNOUTS		DISTANCES				DESIGNS REMARKS
①	②	A	B	C	D	
NO. 5 TO NO. 5		29'-2 1/2"	20'-9 1/2"	16.3958'	66.3975'	MINIMUM 9'-0" RAIL PLUS THERMITE WELDS-HEEL OF FROG TO END OF STOCK RAIL.
NO. 8(MODIFIED) TO NO. 8(MODIFIED)		49'-3 1/2"	33'-7 3/4"	16.3958'	99.3333'	
NO. 8 TO NO. 8		47'-5"	31'-0"	16.3958'	94.8125'	
NO. 8 TO NO. 10		47'-5"	31'-5"	16.3958'	95.2292'	
NO. 10 TO NO.8		58'-10"	31'-0"	16.3958'	106.2292'	
NO. 10 TO NO. 10		58'-10"	31'-5"	16.3958'	106.6458'	

NO. 8 (MODIFIED) = NO. 8 TURNOUT WITH LATERAL SWITCH AND FROG CURVED WITH 645' RADIUS.

LINK LIGHT RAIL TRANSIT PROJECT	PSTC Puget Sound Transit Consultants	Heel of Frog To Point of Switch (Opposite Hand Turnouts)	Figure No. 5.4	Rev. No. / Page No.

END CHAPTER 5

6. CIVIL WORK

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6. CIVIL WORK

6.1 INTRODUCTION

This chapter establishes the basic civil engineering criteria to be used in design of the Link light rail Transit (Link) system. It includes criteria for the design of grading, roads/paving, fencing, drainage, surveying/mapping, and the definition of right-of-way (ROW). The criteria relating to storm water drainage shall meet the requirements of specifications and design guidelines of the local agency having jurisdiction for the drainage area under consideration. Refer to Chapter 9, Stations, for kiss-and-ride and park-and-ride facilities design criteria. Refer to Chapter 11, Traffic Control, for traffic signals, signs, and pavement markings design criteria. Refer to Chapter 18, Fire/Life Safety, for Fire Department access road design criteria to maintenance base and other Sound Transit facilities.

6.2 GRADING

All unpaved areas of proposed construction shall be cleared and grubbed, including the removal of unsuitable material. Cut and fill slopes along the Link system shall be two horizontal to one vertical (2:1) or as recommended by the geotechnical consultant or as required by the affected jurisdictions. Along roadway areas, cut slopes shall generally be 2:1 maximum or flatter as required for sight distance around curved alignments. Roadway fill slopes shall be 2:1 maximum, but shall be flattened to 4:1 where possible to eliminate guardrail.

6.3 ROADS AND PAVING

6.3.1 General

A. Roadway design in public ROW shall be in conformance with the specifications and design guidelines of the local agency having jurisdiction. Pavement structural cross section for Sound Transit facilities shall be designed for a 20 year life to support the anticipated traffic use.

B. Road and parking surfaces shall be either portland cement or asphalt concrete. The criteria set forth in this chapter are applicable to the design of alterations of existing streets, new streets, park-and-ride lots and access roads.

C. Replacement of streets and facilities maintained by forces other than Sound Transit shall be essentially replaced in kind. However, new facilities maintained by others shall be designed in conformance with published standard of the agency having jurisdiction.

6.3.2 Applicable Standards

A. Unless otherwise stated, roadway design shall be in accordance with the Washington State Department of Transportation (WSDOT) Design Manual except for design of new facilities or alterations to existing facilities to be owned or maintained by others. Those designs shall be in conformance with the current version of published standards and details of the local agency having jurisdiction.

B. The current versions of the WSDOT and Municipal documents refered to in Chapter 1, General, section 1.3, Reference Documents, are incorporated into these design criteria by reference and shall be adhered to wherever possible in the design of roads, parking, and related traffic control.

6.3.3 Roadway Geometrics

A. Design of Sound Transit roadways and parking lots shall be in accordance with WSDOT's Roadway Design Manual and A Policy on Geometric Design of Highways and Streets, of the American Association of State Highway and Transportation Officials (AASHTO), and as listed below in these criteria. New facilities and replacement of streets and facilities to be owned and/or maintained by entities other than Sound Transit shall be designed or replaced in accordance with the current standards of the agency having jurisdiction.

B. For motorized and non-motorized access to stations, refer to Chapter 9, Stations.

C. Number of Traffic Lanes

The number of traffic lanes and type of lanes (i.e. through, right, or left) shall be determined in consultation with the local jurisdictions, generally based on a traffic analysis that considers projected traffic volumes, light rail vehicle (LRV) intersection crossings, critical traffic movements, and geometric configurations.

D. Parking Lanes

Parking locations shall be determined in consultation with the local jurisdictions based on traffic analysis, safety considerations, and demand for on-street parking. Twenty-four hour parking prohibition shall be recommended at those locations (i.e., near intersections and at Link stations) where roadway width is not adequate to provide the necessary number of through lanes. Peak hour parking prohibition shall be recommended at those locations where traffic analysis shows that the capacity of the traveled way without the parking lane will not provide level of service E or better.

E. Normal Cross Slopes

The following criteria indicate the desirable cross slopes to be provided in non-superelevated pavement areas. New roadways shall be superelevated in accordance with local agency requirements wherever practical.

Non-Superelevated Pavement Areas	Cross Slope
Portland cement concrete and asphalt concrete pavement roads	2 percent
Gravel surface	3 percent
Paved parking areas	2 percent min * 5 percent max
Shoulders	5 percent
* 0.5 percent minimum with approval from Sound Transit	

F. Clearances

The minimum vertical clearance above the traffic lanes and shoulders on all roadways shall be 16 feet 6 inches except where greater clearance is required by the agency having jurisdiction. The clearance shall apply over the entire vehicle roadway width including any contiguous auxiliary (turning) lanes, parking lanes, and shoulders.

6.3.4 Curbs, Curb Ramps and Curb Cuts

A. Concrete curbs shall be installed along all new, widened, or reconstructed streets or access roads to be owned or maintained by Sound Transit or the applicable municipal jurisdiction. Concrete curb shall also be installed around the perimeter and islands of new park-and-ride lots constructed at Link stations. Extruded curb may be constructed in shoulder sections where required for storm runoff.

B. When new curb is constructed, the height of the vertical curb face above the finished pavement elevation shall be 6 inches. The curb face may be decreased to no less than 4 inches along existing streets and sidewalks to minimize areas of sidewalk reconstruction and impacts to adjacent properties, subject to the approval of the local governing jurisdiction.

C. Refer to Chapter 4, Track Alignment and Vehicle Clearances, for horizontal clearance from track centerline.

D. Curb ramps shall be provided to meet ADA standards in accordance with the following:

1. Restore or replace all existing non-conforming ramps.

2. Provide new ramps at intersections where sidewalk exists and the curb returns are modified as part of this project. It is not necessary to provide curb ramps where no sidewalk exists.

3. Provide curb ramps at intersections or mid-block locations where new curb and crosswalk will be constructed as part of this project.

E. The design and location of curb ramps shall be in accordance with the applicable provisions of the local governing jurisdiction, WSDOT's Design Manual, and the USDOT's Standards for Accessible Transportation Facilities to comply with the Americans with Disabilities Act (ADA).

6.3.5 Sidewalks

Sidewalks shall be in compliance with the standards of the applicable municipal jurisdiction. At a minimum, all sidewalks must have at least 5 feet in clear width. Cross slopes on sidewalks shall be 2 percent maximum. Existing sidewalks impacted by the project shall be repaired or replaced in kind where practical. New sidewalks shall only be provided upon request of the agency having jurisdictional responsibility and with Sound Transit's direction.

6.3.6 Driveways

Driveway pavement types and minimum widths shall be in accordance with municipal standards, depending on the applicable jurisdiction. In general, all existing driveways impacted by the project shall be replaced in kind where practical. Driveway closings required to facilitate Link operations or construction must be approved by the local agency having jurisdiction.

6.3.7 Bus Loading Zones

Bus loading zone designs in order of preference are parallel, sawtooth, and recessed in relation to the curb. Dimensions, arrangements, and locations for bus loading zones shall be determined in coordination with the transit agency having jurisdiction either King County, King County Metro Bus Operations Division, or Pierce Transit.

6.3.8 Paving

A. Restored or widened pavements shall be of similar materials existing prior to Link construction, except that if an existing street other than in

an Historic District is found to be based on obsolete paving materials, such as brick or cobblestone, replacements of base materials will not be in kind, but current specifications and practices will control.

B. New pavements shall be of materials conforming to the latest standards of the agency having jurisdiction and maintenance responsibility.

6.3.9 Traffic Maintenance and Protection

A. The design drawings shall be in accordance with the Manual of Uniform Traffic Control Devices (MUTCD) or the requirements of the applicable jurisdiction and shall include traffic staging and detour plans submitted to and approved by local agencies. The maintenance and protection of vehicular, bicycle, and pedestrian traffic including ADA access must be addressed as well as construction work crews, and emergency and enforcement personnel. Traffic control and staging plans shall include:

1. The number of lanes that must remain open.

2. Hours of allowable closure by day of week.

3. General impacts such as driveway access and the need for night time work.

4. Consideration of special events such as SeaFair and emergency services.

5. Needs for public information.

6.4 DRAINAGE

6.4.1 General

A. The design of drainage systems using the criteria contained herein is to protect the trackway and facilities from storm-runoff damage, and to protect Sound Transit from liability for damage to property from resulting storm-runoff either passing through or caused by Link construction. The design of Sound Transit drainage facilities, such as maintenance bases and parking lots within Sound Transit ROW, shall be in accordance with the criteria listed in the WSDOT Hydraulics Manual or the local jurisdiction.

B. Design of drainage facilities belonging to another agency, which are relocated or modified because of Link construction, and which do not cross or parallel rail system facilities or trackbeds, shall conform to the design criteria and standards of that agency. In general, required

relocation of existing drainage facilities shall be "replacement-in-kind" or "equal construction." Outside of Sound Transit ROW, design of drainage facilities shall conform to the requirements of the local jurisdiction.

C. Drainage structures within the embedded trackway and aerial structures shall be designed in accordance with the Preliminary Hydraulics Report and the Standard Drawings.

6.4.2 Submittals

Drainage designs of facilities requiring review and approval of jurisdictional agencies shall be submitted in accordance with the procedures established by the respective agencies. Agencies having jurisdiction may include WSDOT, Cities of Seattle, Tacoma, Tukwila, SeaTac, and Port of Seattle. All construction, relocation, and restoration of storm sewers and drainage facilities and maintenance of existing facilities during construction shall conform to the design standards of those agencies.

6.4.3 Link Drainage

A. Link drainage criteria apply only to design of drainage facilities under the jurisdiction of Sound Transit. Drainage of other facilities and connections to other drainage systems shall be designed in accordance with the criteria of the respective agency having jurisdiction.

B. Invert elevations and location of drainage facilities at the ends of contract design segments shall be coordinated with adjacent segments.

C. As far as practicable, drainage shall be by gravity flow. Where sections are below discharge points or in a tunnel where gravity outfalls cannot be provided, pumping stations shall be installed. No sanitary sewer discharge shall be permitted to enter the Link drainage system.

6.4.4 Hydrology and Hydraulics

A. The following procedures shall be used in preparing hydrologic computations:

1. Hydrologic and hydraulic design shall be in accordance Washington State Department of Ecology, the WSDOT Hydraulics Manual, the AREMA Manual for Railway Engineering, and the applicable local jurisdiction procedures.

2. The hydraulic capacity of open channels, swales, gutters, storm sewer pipe systems, and culverts shall be determined using the Manning equation. Pipe flow velocities shall range from 3 to 10 feet per second where possible.

3. Storm Frequency

B. The following facilities shall be designed/protected by accommodating the storm frequency listed:

Facility	**Design Strom Frequency**
All culverts and drainage facilities crossing the Link system where flooding could damage the system	100-year
Track roadbed (to top of subballast)	25-year
Longitudinal storm drains in roadways	25-year
Parking lot storm sewer systems	25-year
All longitudinal drains or subdrains at low points that could flood roadways or track roadbed	25-year

The frequencies shall be modified if the local jurisdictional agency has a more conservative standard. Wherever feasible, the top of rail elevation shall be a minimum of 1 foot above the 100-year flood elevation.

6.4.5 Selection of Drainage Structures

Sound Transit-maintained drainage structures within the trackway shall be in accordance with the Standard Drawings. Drainage structures located within maintenance base sites and parking lots shall be selected from WSDOT standard plans or the local jurisdictions. When conditions occur for which the standard drainage structures are not suitable, the engineer will be required to modify these structures or to design special structures that satisfy the conditions.

6.4.6 Pipe Materials

All underground storm drains maintained by Sound Transit may be HDPE, reinforced concrete pipe, minimum class V, Wall B, with gasketed joints, or ductile iron pipe. Underdrains may be PVC, HDPE, or non-reinforced concrete pipe. All pipe materials designed for other facilities shall conform to the requirements of the local jurisdictional agency.

6.4.7 Location of Drains

A. In the Link track sections, placement of drainage structures shall be in consideration of hydraulic requirements, economy, low points, and precede crosswalks and intersections. In general, placement of

drainage structures shall be every 300 feet to 400 feet for at-grade track sections and every 400 feet to 750 feet for aerial guideway. Special installation of drainage structures shall be evaluated by the final designer on a case-by-case basis.

B. Drainage structures shall be provided at changes in pipe slope, alignment and size, and at multiple-pipe intersections.

C. Underdrain cleanouts shall be provided at maximum 1,000-foot centers along all Link drainage lines.

D. All storm drain piping crossing beneath the track will have 4 feet 0 inches clearance from the top of rail to the top of piping, unless otherwise approved by Sound Transit.

E. Track drains with lateral piping across the track shall have a clearance in accordance with the Standard Drawings.

F. In general, drainage facilities shall be located to prevent sheet flow across at-grade track.

6.4.8 Parking Lots

Parking lots shall be designed so that storm water is removed by overland flow, to a gutter or curb and gutter, then to an inlet where the water will enter either a closed drainage system or an open ditch. Overland flow shall be on at least a 2.0 percent grade wherever possible. The maximum permissible spread for gutter flow shall be 6 feet.

6.4.9 Stormwater Management Facilities

Design shall be prepared in accordance with the standards and specifications of the local jurisdiction and the Washington State Department of Ecology.

6.4.10 Construction within the Flood Plain

Design of facilities to be constructed within the 100-year flood plain shall conform to the agencies having jurisdiction including the Corps of Engineers, the Federal Emergency Management Agency, the Department of Ecology, and the local jurisdiction.

6.4.11 Erosion Control

All areas disturbed by construction shall have erosion control plans. Temporary Erosion and Sedimentation Control Plans shall be prepared for use during construction, and permanent erosion control plans shall be prepared for post-construction conditions. Erosion control methods shall

include Best Management Practices established by Washington State Department of Ecology and local jurisdictions.

6.5 SURVEYING AND MAPPING

6.5.1 Survey Control System

A. Horizontal Control

1. All horizontal controls shall be based on the Washington State Plane Coordinate System, NAD '83/'91 in the appropriate zone.

2. The precision of all Secondary horizontal ground control surveys shall be, as a minimum, 1:50,000, Second Order, Class I as defined by the Federal Geodetic Control Committee and published under the title, "Standards and Specifications for Geodetic Control Networks," authored by the Federal Geodetic Control Committee in September 1984.

3. All subsequent horizontal surveys shall, as a minimum, have a precision of 1:20,000, Second Order, Class II as defined by the Federal Geodetic Control Committee and published under the title "Standards and Specifications for Geodetic Control Networks," authored by the Federal Geodetic Control Committee in September 1984.

B. Vertical Control

1. Vertical control for this project shall be based on the NAVD88.

2. The precision of the vertical ground control and of supporting vertical ground surveys shall be at least Second Order, Class II, as defined by the Federal Geodetic Control Committee and published under the title "Standards and Specifications for Geodetic Control Networks," authored by the Federal Geodetic Control Committee in September 1984.

6.6 RIGHT-OF-WAY (ROW)

6.6.1 General

A. ROW is the composite total of all real property interests and uses required to construct, maintain, protect, and operate the Link system. Certain ROW requirements are temporary and reversionary in nature, while others are permanent. Permanent requirements are dictated by operating needs. The intent is to acquire the minimum ROW required by the system and observe good ROW practices.

B. ROW plans are used as a basis for acquisition of property. All interests and uses required shall be shown on the ROW plans together with the detailed property dispositions.

6.6.2 Sound Transit Types of ROW

A. Fee Simple

Full ownership of property extending radically from the center of the earth outward through specified lateral limits on the surface of the earth to the sky. Fee ownership should be considered first for all transit facilities.

B. Easement

A non-possessing interest held by one party in land of another whereby the first party is accorded partial use of such land for a specific purpose.

1. Permanent Surface Easement

An easement that provides space for the transit facility when it is not practical or advisable to acquire a fee interest. This easement shall have the same parameters as fee ownership. Vertical limits shall be described only where passing under an existing structure.

2. Permanent Underground Easement

An easement that encompasses the total transit facility located beneath the surface of the ground. This easement shall have definite vertical and lateral limits. Lower limits shall be described only where special limiting features exist.

3. Permanent Aerial/Guideway Easement

An easement that encompasses the aerial portion of the transit facility. This easement shall have definite vertical and lateral limits. Vertical limits shall be described only where special limiting features exist. Support elements must be considered and may require special treatment. This easement will include vegetation clear zone. See Figures 6-1, 6-2, 6-3 and 6-4.

4. Temporary Construction Easement

An easement, temporary in nature but with a definite duration, that provides sufficient space to allow for the use of property by the contractor during construction, e.g., reconnection of driveways and staging areas.

5. Utility Easements

An easement that encompasses utility facilities that will be controlled by outside agencies. This easement is permanent in nature and shall be in accordance with local and utility regulations.

6.6.3 ROW Definition Criteria

A. This chapter provides criteria to be used as guidelines for defining the limits of ROW. The dimensions given are for minimum conditions and must be modified where engineering or real estate requirements dictate additional needs.

B. ROW Limits

All ROW limits shall be vertical or horizontal planes and incorporate the basic track width, drainage requirements, supporting slopes and structures, utilities, construction techniques, operation, protection, maintenance of the transit system, and the overall effect on the affected property. The limits of permanent ROW shall be defined using simple curves and tangents. Spiral curves will not be used in defining ROW limits. Chords may be used in lieu of curves under special conditions approved by Sound Transit.

1. At-Grade Construction

a. Upper Vertical limit:

Normally, a upper vertical limit is not required. When a upper vertical limit is required, the limit shall be described by the elevations of sloping planes, horizontal planes, stepped as required and co-locating the steps with existing property lines or prominent suitable topographical features. Refer to Chapter 4, Track Alignment and Vertical Clearances for vertical distance for upper limit.

b. Lateral Limit:

1) On exclusive ROW, the minimum allowable distance from the centerline of the nearest track to the limit of the ROW is 12 feet.

2) Additional distances, when drainage ditches and supporting slopes are required, shall be added to the above.

3) In retained cuts or on retained fills at least 2 feet of ROW shall be taken from the outside edge of the retaining wall

footings. Allowances shall be made for pile or anchor tie encroachments.

c. Lower Vertical Limit:

1) When required, the lower vertical limit shall be defined in a manner similar to that for the upper vertical limit.

2. Aerial Construction

a. Upper limit:, where required by local conditions, the upper vertical limit is delineated by elevations of sloping planes, horizontal planes, stepped as required, co-locating the steps with existing property lines or prominent suitable topographical features. The minimum required vertical distance from top of catenary support structure to the horizontal plane is 2 feet.

b. Lateral limit to a minimum of 2 feet (5 feet desirable) beyond the limit of structures. Additional easements shall be required for maintenance of and repairs to structures.

c. Lower vertical limit, where required by local conditions and/or specifically directed by Sound Transit shall be the ground level with specified use restrictions, except where crossing other ROW. For aerial support structure, lower vertical limit shall include support foundation.

3. Stations

a. ROW required for stations shall include space needed for platforms, fare collection, waiting areas, stations ancillary facilities, and the structure.

b. In addition to the structural, mechanical, and electrical requirements for space, the requirements for pedestrian and vehicular circulation space shall be observed.

4. Roadway Construction

a. In sidewalk sections, easements (construction or permanent) beyond ROW may be required due to grade difference, retaining walls, etc., between sidewalk and private property.

b. At intersections, additional ROW may be required behind the sidewalk for placement of signal poles, controller cabinets, and bus stop shelters.

6.7 FENCING

A. Fencing may be required in certain areas to provide security and/or ensure safety. Fencing shall be parallel to the track, forming an open-ended envelope and allowing unrestricted LRV movement. Fencing shall generally be provided along areas of exclusive Link right-of-way and operation. Fencing is not generally required in public ROW where Link operations occur within the street pavement; exceptions to this are where pedestrian movements across the Link tracks are restricted to certain areas for safety reasons.

B. Vehicle service, maintenance and storage areas shall be secured by perimeter fencing. Fence locations shall be subject to all clearance requirements indicated in Chapter 4, Track Alignment and Vehicle Clearances. Fencing may be installed along new or existing bridges that pass over the Link track and are used by pedestrians. Fencing discourages dropping or throwing objects onto the Link ROW. The fencing installation will be discussed with the agency having jurisdiction over the bridge.

C. Fencing on bridges overpassing Link tracks shall have a curved top. Other types or heights of fencing, such as wrought iron or ornamental steel, may be considered in some areas for aesthetic reasons in coordination with Sound Transit and the local municipality.

Figure 6-1

Aerial Guideway Structure Typical Right-of-Way Requirements – at Columns Drilled Shaft

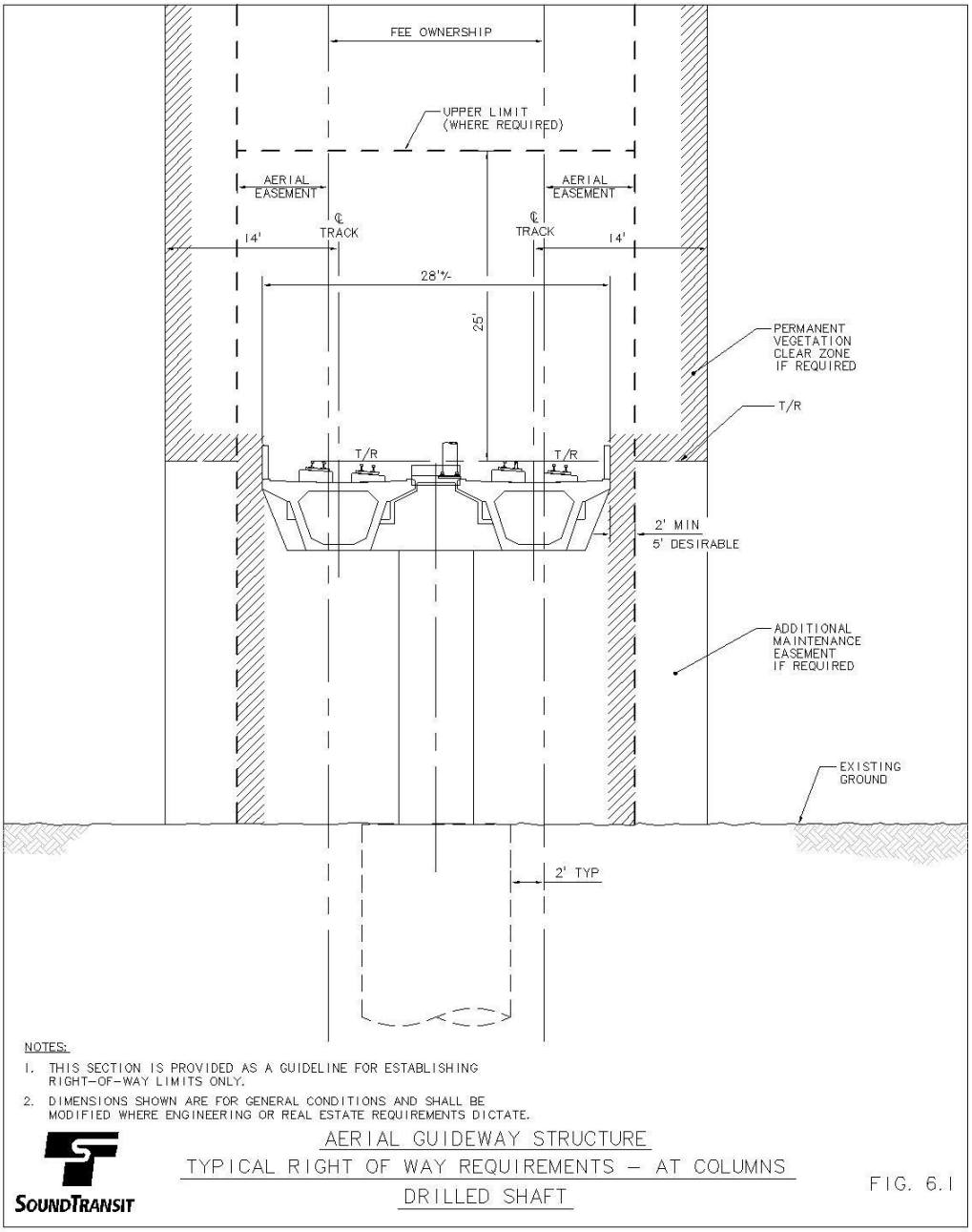


Figure 6-2

Aerial Guideway Structure Typical Right-Of-Way Requirements – at Columns Spread or Pile Foundation

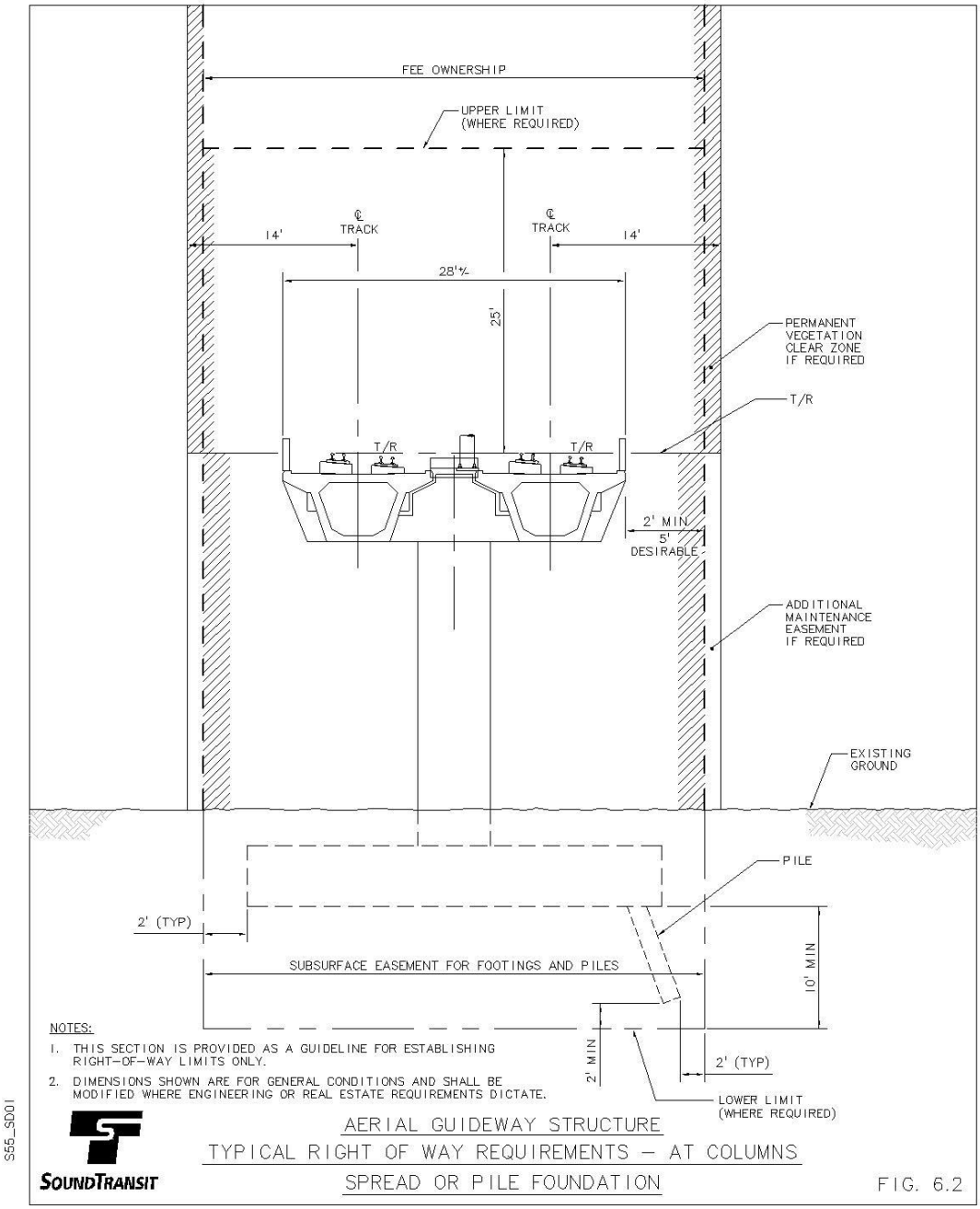


Figure 6-3

Aerial Guideway Structure Typical Right-Of-Way Requirements Between Columns

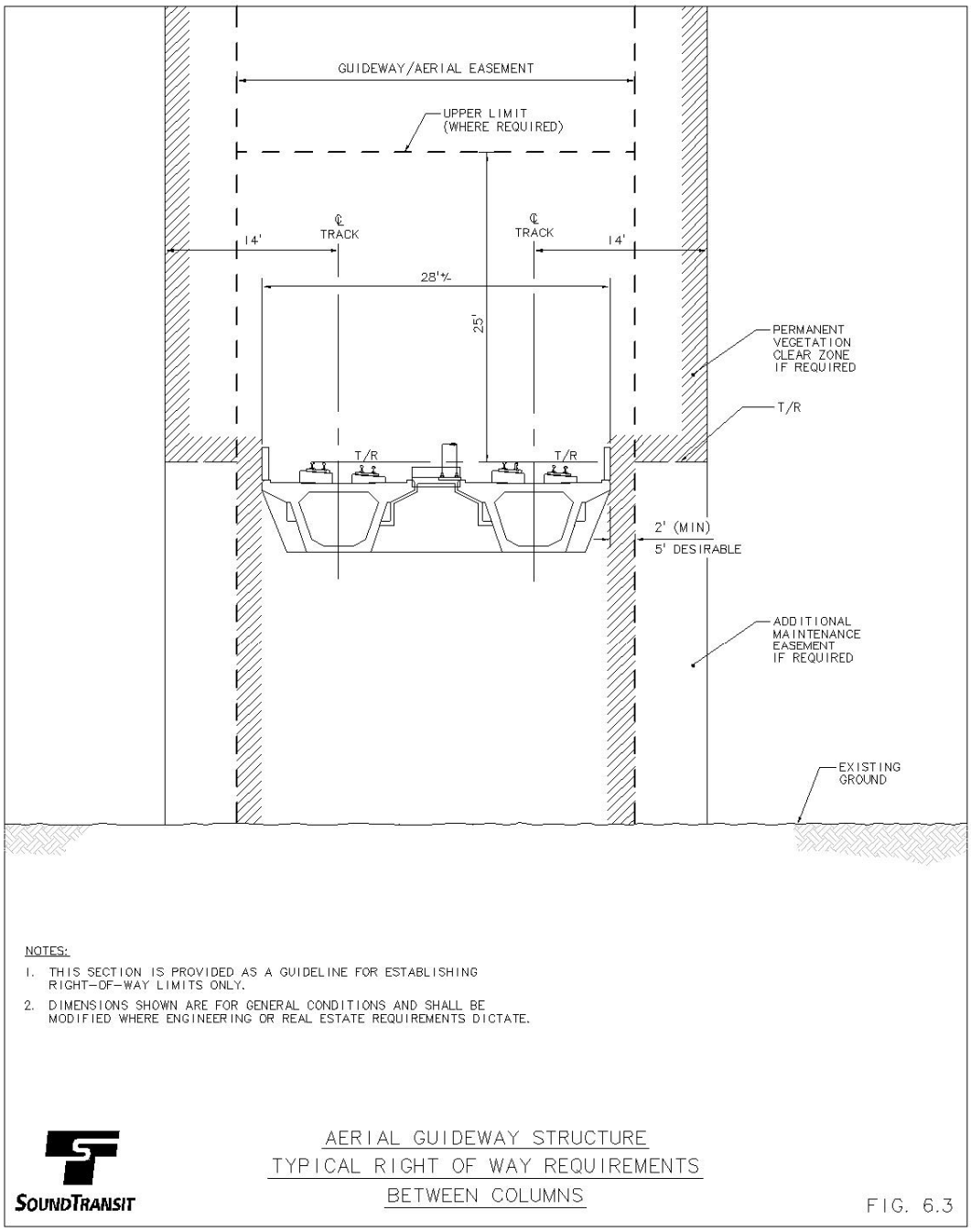
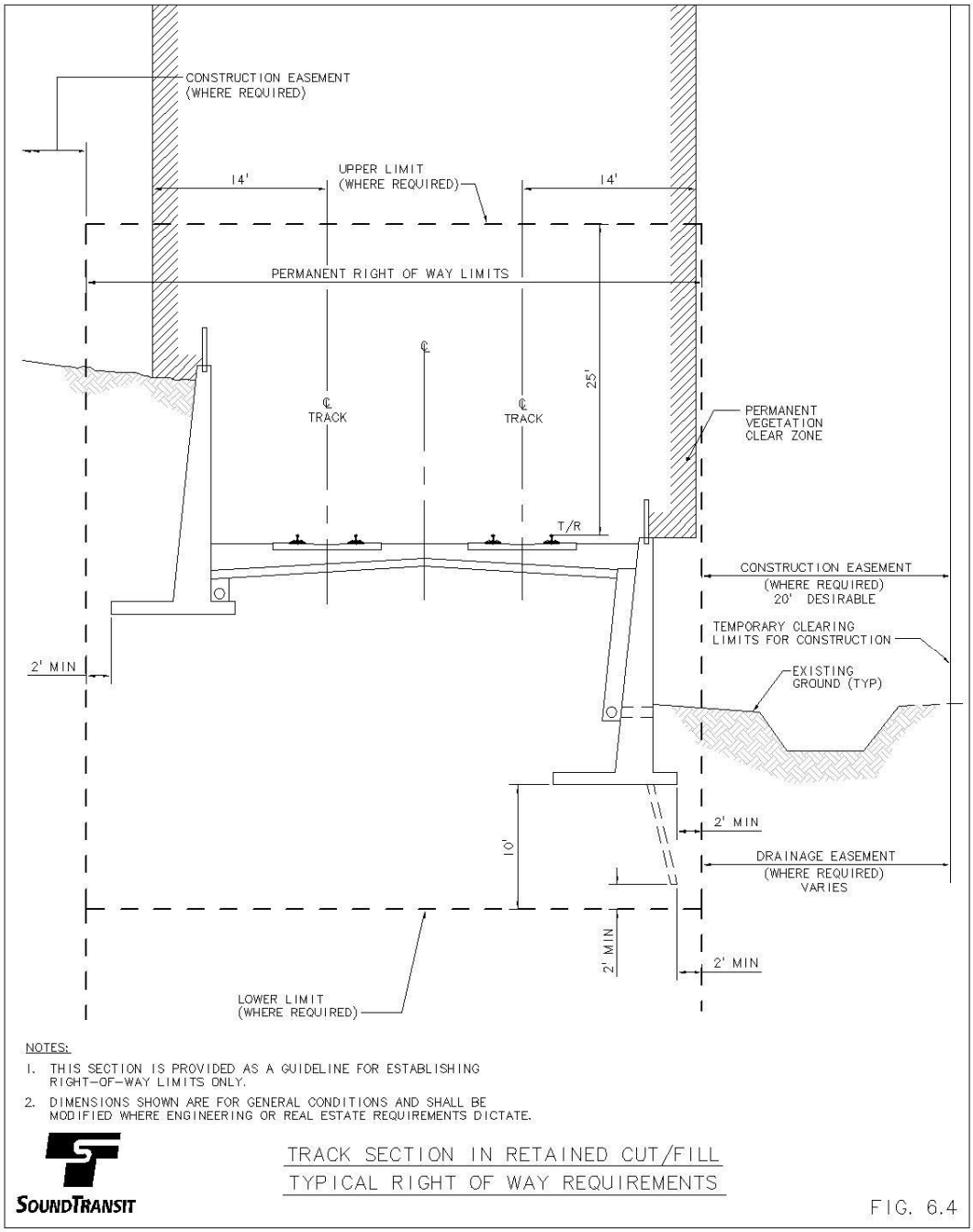


Figure 6-4

Track Section In Retained Cut/Fill Typical Right-Of-Way Requirements



END CHAPTER 6

7. UTILITIES

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7. UTILITIES

7.1 INTRODUCTION

These procedures and design criteria shall govern new utility construction outside of buildings, and the support, maintenance, relocation, and restoration of utilities encountered or affected by the Link Light Rail Transit (Link) system construction. Consideration shall be given to the needs of the Link system, the requirements and obligations of the public and private utility owners, and the utility service needs of adjacent properties. Link will follow the standards of the affected utility companies for relocations and new installation. Utility work occurring in public ROW will be coordinated with the local jurisdiction in accordance with local permits and franchise requirements.

7.2 PRECONSTRUCTION

7.2.1 Purpose

A. The objective of preconstruction activities is to ensure that pertinent utility information is obtained, properly incorporated into the design process, and shown on construction plans. Information to be acquired includes owner, type, size, material, location, and existing right-of-way (ROW) and easements of all existing and proposed utility facilities affected by Link construction, and the disposition of existing and proposed facilities within the area to be acquired by Sound Transit.

B. The following information shall be clearly and correctly identified on the final construction drawings.

1. Utilities supported and maintained complete in place during construction and continued in service following construction of the Link system.

2. Utilities reconstructed, supported, and maintained complete in place.

3. Utilities temporarily relocated and maintained then restored upon completion of the transit system.

4. Utilities permanently relocated beyond the immediate limits of transit construction.

5. Utilities that have been abandoned in place, or are to be abandoned and removed.

6. All rights-of-way, existing and proposed, and all easements, existing and proposed.

C. Interruption of existing utility service shall be minimized. If temporarily relocated, utilities shall be restored upon completion of work. Replacements for existing utilities shall be designed to provide service essentially equal to that offered by the existing installations. Designers must bring all proposals for betterment to the attention of Sound Transit at an early stage of the design. No betterments shall be included unless specifically approved by the utility owner or public agency, and Sound Transit prior to final design.

7.2.2 Procedure

A. The horizontal and vertical alignments, ROW and construction easements of the Link system and affected roadways, and the necessary property lines adjacent to the ROW shall be indicated in the final contract documents. As the design is developed, the affected utility companies will be furnished with preliminary plans and specifications and requested to verify their existing facility types, sizes, and locations. Each utility company or public agency will be requested to return within a certain period, marked-up plans or prints of Sound Transit's plan sets reflecting the necessary information. The design consultant shall then prepare drawings reflecting all assembled information and latest plan developments. Plans shall be in sufficient detail to evaluate conflicts and develop proposed utility relocations, or to prepare alternative relocation schemes to accommodate the transit project. Critical utility elevations and locations shall be determined and checked by field survey. Where existing utility locations are critical to Link design, potholes shall be dug at such locations as recommended by the designers and approved by Sound Transit. Coordination between the design consultant and the utility agencies shall be a continuing activity during the design phase. Design consultant shall notify Sound Transit in writing of key issues or decisions made.

B. After the Utility agency/owner reviews and comments upon the designer's utility rearrangement recommendations, the design consultant and Sound Transit will conduct its review and direct the coordination of proposals to achieve a satisfactory resolution of the utility impacts and rearrangements. Transit alignment changes to alleviate possibly costly or difficult utility relocations will be investigated. Questions arising from proposed relocations shall be discussed in detail at meetings between the design consultant, Sound Transit, and the affected utility agencies.

Potential right-of-way/easement required for utilities shall be identified as early in the design phase as possible to allow adequate time for acquisition. As Sound Transit approves adjustments or relocations, the utility agency shall be notified, and the design consultant shall include these relocations on the construction plans. The disposition of existing utilities within the ROW shall be indicated by labeling those to be removed, abandoned, maintained in place, or relocated in accordance with the utility standard drawings.

C. A final meeting shall be conducted between Sound Transit, the design consultant, and utility representatives to agree upon the selected recommendation to be implemented. Cost estimates for relocations, betterments, material delivery, scheduling for construction, occupancy, and the items of work to be performed by the utility agency shall be prepared and reviewed at this time. All additional ROW acquisitions should be decided at this time to provide Sound Transit with information to acquire additional ROW or easements.

D. When it is agreed by all entities involved, that no major design changes are contemplated, the latest utility information, as verified at the final utility-design meeting, shall be incorporated into the Link design documents. Prints of the updated design documents shall then be forwarded to each utility agency, including bridge plans for those utilities having bridge occupancy, indicating method of attachment, and noting all special requirements or restrictions. Requests for final cost estimates to clear the construction area shall be made at this time. If design changes are required, additional meetings shall be scheduled to resolve these issues.

E. Memorandum of Understanding, Memorandum of Agreement, or utility relocation agreements will be executed by Sound Transit and utility jurisdictions to clarify responsibility for utility relocation, design, construction, and reimbursement.

F. The design consultant shall request that the utility company prepare a cost estimate for work to be performed by utility forces and reimbursed by Sound Transit according to the Memorandum of Understanding/Memorandum of Agreement/utility relocation agreement. The design consultant shall review the cost estimate and determine whether the estimate conforms to the Memorandum of Understanding/Memorandum of Agreement, prepare the Work Authorization, recommend approval, and submit it to Sound Transit for its approval and issuance to the utility company. Final engineering design for utilities shall be completed by the design consultant, utility company, or designated consultants. Design drawings prepared for utilities by others will be reviewed and approved by the utility owners. Design drawings prepared by the utility company will be reviewed and approved by Sound Transit and the design consultant. The review

shall consider space reservations for utility work to be completed during final transit system restoration work. The utility company design drawings shall be consistent with the work authorization estimate and compatible with the work of other utility agencies. Pertinent utility elevations and locations shall be checked by field survey. Plans being developed by others in adjoining areas shall be checked to ensure that the overall utilities systems will be comparable to those existing before start of construction and that they will be compatible with the transit system.

G. The design consultant shall complete a risk assessment on all critical utilities under or within the influence zone of the trackbed. The risk assessment will evaluate potential impact of normal maintenance or utility failure on Sound Transit operations and identify a range of appropriate actions to mitigate risk.

H. The design consultant or others shall contact local utilities during the design phase regarding the need for spare ducts/casings for future service.

I. New construction and the support, maintenance, restoration, rearrangement, and relocation of utilities shall be in strict conformance with the latest technical specifications and practices of the governing utilities or public agencies. Standard specifications and standard utility drawings for the various utilities shall be incorporated into the Contract Documents as required. In the event that there are no standards, final design shall be in accordance with the current design criteria and engineering practices for the particular utility agency involved. Satisfactory completion of the work and its acceptance shall be signified through sign-off by the responsible utility or agency.

7.3 GAS LINES

A. Permanently relocated gas lines shall be designed, installed, and tested in accordance with the current standards of Puget Sound Energy, Northwest Natural Gas Company, or other owner utility companies and:

1. "Minimum Federal Safety Standards for Gas Lines, Title 49 Code of Federal Regulations, Part 192".

2. "ASME" Guide for Gas Transmission and Distribution Piping Systems" of the American Society of Mechanical Engineers Gas Piping Standards Committee.

3. “Manual for Railways Engineering”, Chapter 5, American Railway Engineering and Maintenance-of-Way association (AREMA).

4. Gas mains shall be encased at light rail crossings.

7.4 SANITARY, STORM AND COMBINED SEWERS

7.4.1 General Design Guidelines

A. Schematic design of sewer relocations shall be completed by the Civil Design Consultant and approved by the appropriate city, county, or utility agency. Final design of sewer locations shall be done either by the responsible city, county, or utility agency or completed by Sound Transit's Civil Design Consultant and approved by the appropriate city, county, or utility agency.

B. Service to adjoining properties shall be maintained by either supporting in place, providing alternate temporary facilities, or by diverting to other points. Necessary replacements of existing sewers and appurtenances shall provide services equivalent to those existing facilities.

C. Minimum pipe diameter sizes for public sanitary sewers shall be 8 inches.

D. All sanitary sewers shall be designed to give mean velocities, when flowing full, of not less than 2.0 fps based on the following formula:

$$V = 1.486\, n r^{2/3} s^{1/2}$$

Where:

V = Velocity of flow (fps)
r = Hydraulic radius (ft)
s = Slope of total head line (ft/ft)
n = Manning roughness coefficient

E. The Final Design Consultant shall coordinate requirements for service to vacant property with Sound Transit and the utility agency. Cost reimbursement must be resolved prior to incorporating provision for future utility service in the construction documents.

F. Sound Transit will coordinate with the utility owner to establish the agency that will have maintenance responsibility for the facilities. The utility agency may have special requirements for manhole lids depending on which agency is responsible for facility maintenance.

7.4.2 Sanitary Sewers

Relocations, replacements or extensions of existing sanitary sewer systems serving other than transit facilities shall comply with all state and local standards; shall be approved by the governing municipality/agency; and shall be designed to the criteria of those governing municipalities' agencies.

7.4.3 Storm Sewers

Design of replacement, relocation, or extension of existing storm sewers shall follow the design criteria for computing runoff quantities as indicated in Chapter 6, Civil Work, as well as the local municipality's design criteria, whichever is more restrictive. Surface drains from adjoining areas shall not be connected to the Link system track drains.

7.4.4 Combined Sewers

The City of Seattle system includes both a separate and combined drainage facilities. The replacements shall be designed as separate systems when it is less costly to provide separated systems or at the specific direction of the City of Seattle. The replacement sanitary sewer shall be designed in accordance with sections 7.4.1 and 7.4.2. The local municipality shall provide the sanitary sewer and storm sewer flow quantities for new facilities; otherwise the Final Design Consultant shall assume replacement in kind. The replacement storm sewer shall be designed in accordance with Chapter 6, Civil Work and the standards of the local municipality/agency.

7.5 ELECTRICAL POWER FACILITIES

All support, maintenance, relocation, and restoration of existing overhead and underground electric lines throughout the Link system shall be in strict conformance with: current practices of Seattle City Light, Puget Sound Energy, Tacoma Public Utilities, and King County Metro; the requirements of the Electrical Code of the responsible jurisdictions and agencies; and, the National Electric Safety Code. New service will be coordinated with the utility by the Sound Transit Link Systems division. Relocation of existing utility infrastructure will be coordinated with the utility by the Sound Transit Link Civil division. Local jurisdictions may require undergrounding of electrical facilities impacted by Link construction.

7.6 TELEPHONE FACILITIES AND CABLE COMMUNICATION

A. Maintenance, relocation, and support of existing telephone and cable communication lines within Sound Transit or street ROW shall be in strict conformance with the current practices of:

1. Qwest Communications
2. Western Union Telegraph Company
3. General Telephone Company (GTE)
4. American Telephone and Telegraph Company (AT&T)
5. U.S. Sprint Communications
6. MCI World Com
7. AT&T Broadband
8. Other agencies having jurisdiction

B. The design shall indicate telephone lines to be maintained complete in place, ducts to be removed, cables maintained and supported, and upon completion of Sound Transit's work, replaced by a new system of split ducts or new ducts and replacement cable; and all relocation or new telephone line construction. Abandoned lines or those to be abandoned shall also be indicated on the plans.

C. Construction of permanent relocations and temporarily relocated and restored telephone facilities may be completed by the utility owner or by Sound Transit's construction contractor. Splicing, where required, will be completed by the utility owner. Other requirements for telephone rearrangements will be established by the utility owner and may be incorporated in a utility relocation agreement.

7.7 WATER MAINS

A. Relocations and rearrangements of existing water mains impacted by Link construction shall comply with applicable regulations of federal, state and the governing municipality/agency. They shall be designed to the criteria of the governing municipality, utility owner, and AWWA.

B. Construction of permanent relocations, temporarily relocated and restored water pipelines, and water service connections may be completed by the owners or by Sound Transit's construction contractor. Those lines requiring support and maintenance in place shall be the responsibility of the

construction contractor; work shall be completed in accordance with practices of the utility owner.

C. Refer to Chapter 18, Fire/Life Safety for water supply and fire hydrant requirements on the maintenance base and other facilities.

7.8 LIQUID-PETROLEUM PIPELINES

A. Each new liquid-petroleum-products pipeline system and each pipeline in which pipe has been relocated or replaced, or the part of a pipeline system that has been relocated within Sound Transit's or street ROW, shall be designed, installed, and tested in accordance with applicable federal, state and local standards and applicable chapters of the following:

1. "ANSI Standard for Liquid-Petroleum-Transportation Piping Systems Part B31.4".

2. "API Recommended Practice for Crossing Highways and Railroads".

3. US Department of Transportation "49 CFR Part 195 of Government Requirements for Transportation of Liquids by Pipeline."

B. Construction of permanent relocations and temporarily relocated and restored liquid-petroleum lines will be completed by the owner. Those lines requiring support and maintenance in place shall be the responsibility of the construction contractor, and work shall be completed in accordance with practices of the owner.

7.9 FIRE ALARM AND POLICE COMMUNICATIONS SYSTEMS

A. Maintenance, relocation, and support of the existing Fire Alarm and Police Communication Systems within Sound Transit or street ROW shall be in strict conformance with the current standards of the agency having jurisdiction.

B. Design shall indicate which emergency communication facilities are to be maintained complete in place, which are to be removed, which are to be supported in place and maintained, and which are to be temporarily relocated and replaced after Sound Transit's work is completed. The lines to be abandoned, or that are already abandoned, shall also be indicated.

C. The contractor shall install ducts and manholes. The owner will be responsible for the performance of all cable work, including removal of existing cable unless otherwise specified.

7.10 STREET LIGHTS AND TRAFFIC SIGNALS

A. All relocations, temporary or permanent, and maintenance of municipal street lights, video surveillance equipment and traffic signal equipment shall be in accordance with the requirements of the governing owner agency and/or municipality.

B. The street and traffic lights are usually either served by cables located in ducts, municipally owned, or wires on poles of the owner utility company.

C. The contractor shall maintain the street lights, video surveillance equipment, and traffic signal equipment during construction. The contractor shall install, maintain and remove conduits and pedestal supports for temporary traffic signals, which may be required as a result of Link construction operations.

7.11 PARKING METERS

A. The contractor shall remove, store, and reinstall posts and meters after completion of Sound Transit's construction.

7.12 VAULTS

A. Remodeling, abandonment, or other work involving existing private vaults extending from adjoining buildings into public space shall be in strict accordance with rules, regulations, and practices of governing municipality, which shall include currently applicable Building Codes, Electrical Codes, Plumbing Codes, and the National Electrical Safety Code.

B. The designer shall determine which vaults will be affected by Link construction. Details shall show the portion of each vault to be excavated; new walls required to permit continued use of vaults outside of construction limits; new walls to accomplish complete abandonment of vaults, where required; work required to restore vaults, including delivery chutes and freight elevators; and the area available for permanent occupancy by the original owner upon completion of transit facilities.

C. The designer shall also determine what goods or facilities including utility services are to be removed from the vault, how deliveries will be made to properties when existing vault entrances are required to be abandoned, and the construction time required to make alterations and occupy the vault. Sound Transit will arrange for permission to occupy the vault and make the necessary alterations after receiving the necessary information. Information shall be developed at the earliest practicable date in order that Sound Transit may take prompt action to avoid delaying construction.

7.13 OVERHEAD UTILITY LINES

A. Abandonment, relocation, restoration, maintenance, and extension of existing overhead utility lines, poles and appurtenances, including service lines to adjoining properties, will be performed by the utility owners in accordance with laws and regulations of the appropriate jurisdiction, utility owners' standards, the National Electrical Safety Code, appropriate railroad overhead wire standards and the appropriate owner utility company. Final designer shall verify requirements to underground relocated overhead utility lines with the local jurisdiction.

B. Protection and support of overhead utility lines, including poles, equipment, appurtenances, and services, that may exist upon completion of the work, shall be provided by the Sound Transit contractor during Sound Transit's construction.

C. Poles supporting overhead facilities may be owned by one party and shared with or rented to others under mutual agreement. Utilities in this common use arrangement are:

1. Electric Cables
2. Telephone Cables
3. Cable Television
4. Western Union Lines
5. King County Metro - TRANSIT
6. Police, Fire Alarm, and other Government Lines
7. Street Lights and Traffic Signals
8. Security Firms
9. Others

D. The designers shall coordinate their efforts with those of the owners to ensure that Sound Transit plans include designs mutually acceptable to the owners and Sound Transit.

E. Memorandum of Understanding/Memorandum of Agreement negotiated by Sound Transit will address design responsibilities and allocation of costs associated with protection/relocation of utilities.

F. Plans shall denote the general type of service provided by overhead lines in accordance with the symbols of Utility Standard Drawing "Utility Standard Abbreviations Symbols and General Notes¨.

G. Certain jurisdictions may restrict the use of overhead lines in some areas. The designer shall reflect these requirements in the project design.

H. Clearances shall be in accordance with the standards adopted by the utilities involved, and those specified in the National Electrical Safety Code shall be considered the minimum requirements with respect to Sound Transit's ROW crossings, catenary system, and structures.

I. The designer shall evaluate the need for relocation of existing overhead high-voltage electric lines, including transmission lines, due to hazards from Sound Transit's construction, catenary system, train control, or train operations. Findings and recommendations shall be developed and submitted to the appropriate utility agency for consideration and inclusion in Contract Documents.

7.14 UTILITY MARKERS

A. Utility markers will be placed if so required by the utility. In the case of hazardous liquids pipelines, one-call markers must be replaced.

B. The Sound Transit construction manager will provide half-size prints of as-built utility drawings for use by Sound Transit maintenance forces and the utility companies.

7.15 UTILITY CROSSINGS OF LINK SYSTEM AT-GRADE

Generally, utility lines crossing beneath the rail system trackway at-grade shall conform to the following Sound Transit utility relocation guidelines:

A. Depth of cover under the light rail transit structure within the street shall be as shown in Figure 7-1, unless otherwise approved by Sound Transit.

B. Specifications and design standards of the various utilities shall be made available for reference through Sound Transit.

C. Utilities include facilities belonging to governmental agencies, public utility corporations, special service districts, private parties (including service lines to adjoining properties), and Link utilities.

D. Utilities encountered or located close enough to be affected by transit construction shall be either:

1. Supported and maintained in place and in operation during construction;

2. Temporarily relocated and maintained, then, upon completion of transit facilities, replaced by a new utility; or

3. Permanently relocated to a new location beyond the immediate limits of transit construction, preferably prior to Link construction.

E. Interruptions of utility service to abutting property shall be minimized.

F. Replacements for all existing utilities, including governmental facilities and pavements, shall be designed to provide service equal to that offered by the existing installations. No betterments shall be included, unless specifically approved by Sound Transit.

G. Utilities cross light rail tracks shall be relocated/protected as follows:

1. New pipelines, 2 inches and over, crossing the light rail tracks and carrying water, oil, HP gas, or other highly flammable, volatile, or pressurized substance shall be encased in a larger casing pipe or conduit.

2. New gas mains 2 inches and over shall be cased if located in Zone 2 (see Figures 7-1 and 7-2).

3. All other new or existing pipes passing beneath the trackbed will be relocated/protected in consultation with the agency or utility company and Sound Transit.

4. Casing pipes shall be designed to withstand Link loadings.

H. Where possible, all utilities shall cross beneath the Link right-of-way at 90 degrees to the Link centerline.

I. Relocated utilities that run longitudinally adjacent to the Link right-of-way shall be relocated or protected. See Figure 7-1 and Figure 7-2 for typical cross-sections.

J. All abandoned pipes beneath the trackbed shall be plugged and filled unless an exception is provided by Sound Transit, based on diameter, material, or other factors. In the case of hazardous liquid pipelines, in addition to purging, filling, and flagging the lines, the pipes shall be disconnected from all sources of the transported liquid, such as other pipelines, meter stations, control lines, and other appurtenances consistent with CFR Part 195.402.

7.16 CORROSION MITIGATION

See Chapter 17, Corrosion Control, for guidelines for the mitigation of corrosion of underground utilities.

7.17 UTILITY PLANS

A. Composite utility drawings for coordination with utility companies or agencies shall be prepared by the designer at 1 inch = 20 feet scale, (or as determined by the Civil Engineering Manager), with sufficient planimetric data as background to show the street and property patterns of the area. The drawings shall include:

1. Rail system structure outline and horizontal alignment.

2. Existing and proposed utilities crossing or adjacent to construction. The information will indicate utility status including:

   a. Abandoned (when of record), existing, to be abandoned, maintained, supported, restored, diverted, and proposed.

   b. Vaults, pipelines, tunnels, other surface and subsurface features.

   c. Size and identification of underground utilities that may be affected by construction.

   d. Overhead lines that may be affected by construction.

   e. Service lines between utilities and adjoining properties must be investigated for maintenance of service and shall be shown on the drawings by the Final Designer. It should be noted on the drawings that service connections must be maintained by the contractor.

   f. Separate utility plans (and profiles if applicable) shall be prepared for proposed utility relocations of affected utility.

   g. Detailed dimensions and elevations of roofs and floors of vaults affected by construction shall be shown on an appropriate utility plan.

   h. Utility depth shall be shown on the drawings in plan view at pothole locations.

   i. The drawings shall not include utility work beyond the immediate limits of construction. If the need for such work develops as in the case of rerouting, the matter shall be discussed with the design consultant and included with the approval of Sound Transit. Major utility work beyond the limits of construction, unless otherwise directed by Sound Transit, will be handled by the utility company concerned.

B. The design consultant shall consult and coordinate with the appropriate utilities and governmental agencies at all stages of planning and design, and shall reach agreement with the respective owners before detailing drawings. Where designs are prepared by utility owners, the design consultant shall ascertain that work is compatible with the rail system and shall include the

work on Sound Transit plans, appropriately labeled. The design consultant shall cooperate with all utility owners to ensure a fully coordinated utilities installation.

C. It is the responsibility of the design consultant to submit plans and specifications at various stages of completion for review to the respective utility owners, including government agencies, and to secure and file with the Design Consultant and Sound Transit letters of acceptance and approval by the owners. Upon completing design, the Design Consultant shall submit a list of betterments to Sound Transit and shall secure from each affected owner a firm estimate of work to be undertaken by the utility.

D. Where applicable, utility work shall conform to the standards of each utility owner and to the policies established, or to be established by Sound Transit.

E. In the preparation of designs, the design consultant shall consider the various ways in which utilities may be handled and the effect of these alternatives on the overall costs or other aspects of the project.

F. To the fullest extent practicable and economical, existing utilities shall be maintained complete in place. All facilities maintained in place, restored, and new are to be supported on undisturbed material or well-compacted backfill.

G. In addition to existing building and curb lines, miscellaneous structures, vaults, and trees, plan sheets shall show centerline track stationing as well as the pipes, ducts, and facilities pertaining to the particular utility relocation. Track profiles shall show all major crossing utilities and interferences as well as Sound Transit structures. Utility profiles shall be prepared for utility main relocation parallel to the proposed Link alignment. Profiles should also show top and bottom envelope or cross-section of all utilities, all drawn to scale.

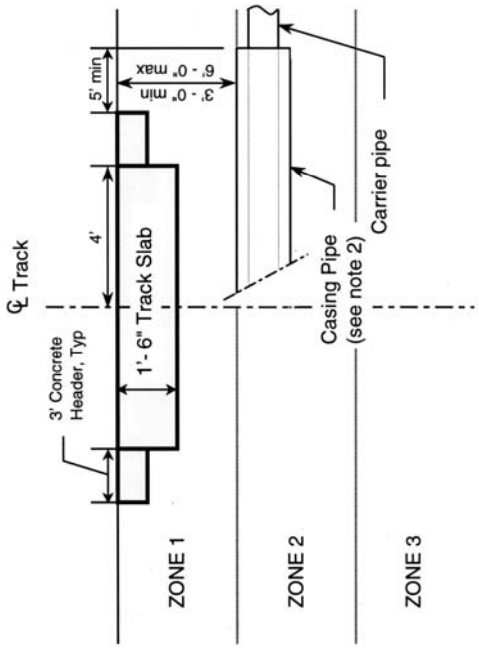
H. In non-congested utility areas, profiles for water and gas mains may be replaced by a note stipulating the depth at which the lines are to be placed.

I. When work shown on the drawings is to be done by others, the plans shall indicate if it is to be executed before, during, or after Sound Transit construction, and if the work is to be supported during construction. Final Designer shall provide a general note on the drawing cross-referencing all special construction/protection.

J. The final design consultant shall prepare design review coordination drawings that include all proposed construction to check conflicts between each discipline.

7.17.1 Utilities – Cross-Sections

Major crossing utilities shall be shown on the track profiles. Sections of existing utilities shall be provided on an as-needed basis. As a minimum, longitudinal sections of existing utilities shall be drawn at every intersection.



Utility Main Crossing
(Single Track Configuration Shown)

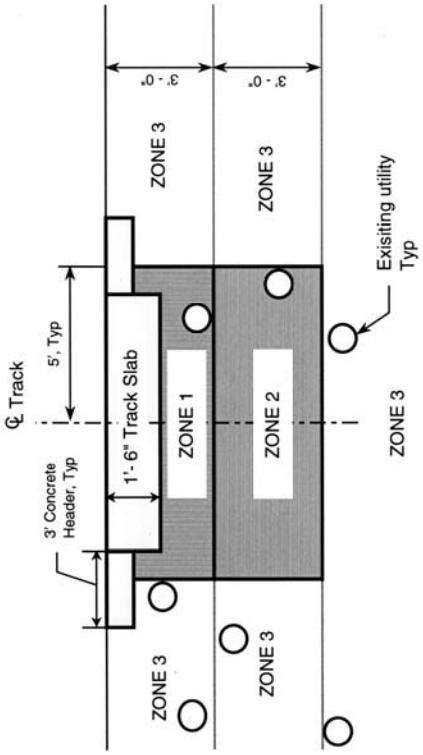
Zone	Depth of Cover	Preferred Configuration (See note 1)	Alternative Configuration
1	< 3' - 0"	Relocate utility	Provide structural protection
2	3' - 0 " to 6' - 0"	Relocate utility or provide structural protection. (See Note 2)	Provide structural protection
3	> 6' - 0"	No upgrade required unless special concern due to age, condition, replacement frequency or risk.	No upgrade required unless special concern due to age, condition, replacement frequency or risk.

Notes:
1. Exceptional circumstances may justify variance from preferred utility configuration
2. Structural protection may include installation of casing or concrete cover slab

Utility Relocation Guidelines
Not to Scale

Rev. 9/28/99

Figure 7-1



Utility Main - Parallel
(Single Track Configuration Shown)

Zone	Preferred Configuration (See note 1)	Alternative Configuration
1	Relocate utility	Provide structural protection
2	Relocate utility or provide structural protection. (See Note 2)	Provide structural protection
3	No upgrade/protection required unless special concern due to age, condition, replacement frequency or risk.	No upgrade/protection required unless special concern due to age, condition, replacement frequency or risk.

Notes:
1. Exceptional circumstances may justify variance from preferred utility configuration
2. Structural protection may include installation of casing or concrete cover slab

Utility Relocation Guidelines
Not to Scale

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Figure 7-2

END CHAPTER 7

8. STRUCTURAL

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8. STRUCTURAL

8.1 INTRODUCTION

8.1.1 Scope

The basic design criteria for structures on Link light rail Transit Projects (Link) are established in this chapter. Items in this category include aerial structures, bridges, cut-and-cover line structures, tunnels, stations, retaining walls, buildings, construction structures, and miscellaneous structures. Where there are cases of special designs encountered that are not specifically covered by these criteria, the designer shall bring them to the attention of Sound Transit to determine the technical source for the design criteria to be used.

8.1.2 Design Codes, Manuals, and Specifications

A. The structural design shall meet all applicable portions of the current editions of the codes, manuals, or specifications identified in this chapter.

B. Unless specifically noted otherwise in these criteria, the latest edition of the code, regulation and standard that is applicable at the time the design is initiated shall be used. If a new edition or amendment to a code, regulation or standard is issued before the design is completed, the design shall conform to the new requirement(s) to the extent practical or required by the agency enforcing the code, regulation or standard changed, and as agreed to by Sound Transit.

8.1.2.1 OSHA

For buildings, stations, elevators, escalators, lines and shafts the design shall meet all Occupational Safety and Health Act (OSHA) standards.

8.1.2.2 References

A. (AASHTO) Standard Specifications for Highway Bridges, adopted by the American Association of State Highway and Transportation Officials, including interim specifications.

B. (ACI) Building Code Requirements for Reinforced Concrete, reported by the American Concrete Institute Committee 318.

C. (AISC) Manual of Steel Construction, by the American Institute of Steel Construction, Inc. Use Allowable Stress Design (ASD) unless Sound Transit approves the use of Load and Resistance Factor Design (LRFD).

D. (AREMA) Manual for Railway Engineering, by the American Railway Engineering and Maintenance of Way Association, including manual updates.

E. (ASTM) American Society for Testing and Materials, by the American Society for Testing Materials.

F. (AWS) Structural Welding Code - Steel and the Bridge Welding Code, by the American Welding Society.

G. (DCM) North Link and Airport Link Design Criteria Manual – Link light rail Transit Systems, prepared for Sound Transit.

H. (PCI) PCI Design Handbook Precast and Prestressed Concrete, by the Prestressed Concrete Institute.

I. (IBC) International Building Code, by the International Code Council, Inc.

J. (AASHTO) Specifications for Structural Supports for Highway Signs, Luminaries and Traffic Signals, adopted by the American Association of State Highway and Transportation Officials, including interim specifications.

K. (WSDOT) Bridge Design Manual Volumes 1 and 2, by the Washington State Department of Transportation including latest revisions.

L. (SSIM) Seattle Street Improvement Manual, by the Engineering Department and Department of Construction and Land Use of the City of Seattle.

M. (SSC) Standard Specifications for Facilities Construction – Link light rail Transit Project, prepared for Sound Transit.

N. (NDSWC) National Design Specifications for Wood Construction, by the American Forest and Paper Association.

O. (WAC) Washington Administrative Code 51-40.

P. (ADA) Americans with Disabilities Act, including U.S. Department of Transportation, Final Rule – Transportation for Individuals with Disabilities.

Q. Infrastructure Design and Construction Standards, by the City of Tukwila.

R. FEMA-302 NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures, 1997 Edition, Part 1 – Provisions (BSSC, 1997a).

S. FEMA-303 NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures, 1997 Edition Part 2 – Commentary (BSSC, 1997b).

T. AISC Seismic Provisions for Structural Steel Buildings, April 15, 1997, (AISC, 1997) including Supplement No. 1, February 15, 1999 (AISC, 1999).

8.1.2.3 Design Codes and Specifications

The following Link structures shall be designed using the current edition of the listed codes. The tabulation of these codes has been arranged in order of precedence. If a conflict exists between the designated codes, the requirements of the first code shall apply, unless otherwise directed by Sound Transit.

A. Concrete Buildings and Miscellaneous Structures

1. DCM
2. IBC
3. ACI
4. AASHTO

B. Steel Buildings and Miscellaneous Structures

1. DCM
2. IBC
3. AISC
4. AASHTO

C. Timber Buildings and Miscellaneous Structures

1. DCM
2. IBC

3. NDSWC

D. Concrete and Steel Link Bridges

1. DCM
2. AASHTO
3. WSDOT – Bridge Design Manuals

E. At-Grade Track Structures

1. DCM
2. AASHTO

F. Underground Tunnels

1. DCM
2. AASHTO
3. ACI

G. Stations

1. DCM
2. IBC

H. Private Facilities

1. Privately owned structures shall be designed using codes that are specifically prescribed by the individual owners. In all cases, privately owned structures will meet the requirements stipulated by the International Building Code, (IBC).

I. Structures owned and operated by local agencies (WSDOT, cities and counties) shall be designed by the codes adopted by the local agency and jurisdiction.

8.2 LOADS AND CONDITIONS

A. All rail transit structures shall be designed to sustain the maximum dead and live loads to which they may be subject, including erection loads occurring during construction if directed by Sound Transit and the following other loads and forces:

1. Dead loads (DL)
2. Live loads (LL)
3. Weight of Rail Vehicle (LRV)
4. Derailment loads (DR)
5. Earthquake force (EQ)
6. Vertical Impact (IV), Horizontal Impact (IH)
7. Centrifugal force (CF)
8. Longitudinal force (LF)
9. Earth pressure (E)
10. Hydrostatic pressure and buoyancy (B)
11. Wind load on structure (W)
12. Wind load on live load (WL)
13. Stream flow pressure and flooding (SF)
14. Shrinkage and creep forces (S)
15. Thermal force (T)
16. Differential Settlement (DS)
17. Collision Loads (CL)

B. The loading criteria to which the structures are designed shall appear on the structural drawings. When required by design conditions, concrete placing sequence shall be indicated on the plans or in the supplementary conditions. Construction sequencing shall be clearly shown on all design plans for all structures. Some of the structures may have less elaborate construction sequencing requirements. If approved in writing by Sound Transit, prior to the start of the design, the sequencing requirement will be left to construction contractors as part of the working drawings.

8.2.1 Dead Loads (DL)

The dead loads consist of the actual weight of the structure and include permanently installed trackwork, partitions, service walks, pipes, conduits, cables, utilities, services, and all other permanent construction and fixtures. The dead load shall be computed from the weights of the

materials composing the structure and its permanent fixtures. The approximate unit weights of materials normally used in construction are shown in Table 8-1. A specific check shall be made as to the actual weight where a variation might affect the adequacy of the design or where the construction may vary from the normal practice. Dead weight of catenary support for electrification shall be determined by the catenary consultant.

8.2.1.1 Structures Constructed by Cut-and-Cover Methods

A. The dead load for structures constructed by cut-and-cover methods shall consist of the weight of the basic structure, the weight of secondary elements permanently supported by the structure, and the weight of the earth cover supported by the top of the structure and acting as a simple gravity load.

B. The dead load shall be applied in stages to realistically represent the lift history of the designed structure. For example, removal of the earth cover from a pre-stressed concrete span at some future date may create a serious upward deflection problem and should, therefore, be analyzed as a separate loading case.

C. The design unit weight of earth, both above and below the groundwater table shall not be less than 130 pcf for the analysis of the structural frame unless specified otherwise by the Geotechnical Consultant. In making calculations with regard to dead weight resisting flotation of the structure, the actual unit weight of backfill placed over the structure shall be used, but in no case shall be taken as greater than 120 pcf. Where full hydrostatic pressure below the groundwater table is used as a design load, a submerged design unit weight of not less than 68 pcf shall be used for earth below the groundwater table.

8.2.1.2. Minimum Earth Cover for Design

All underground rail transit structures in the public right-of-way shall be designed for actual cover depth or for an assumed minimum cover depth of 8'-0" when the actual cover depth is less than 8'-0".

Table 8-1
Weights of Materials

MATERIAL	WEIGHT (PSF)
Aluminum alloys	175 pcf
Asphalt mastic, bituminous macadam	150 pcf
Ballast, crushed stone	120 pcf
Ceilings, plaster board, unplastered	3 psf
Gypsum, ceiling tile, 2”, unplastered	9 psf
Pressed steel	2 psf
Ceramic glazed structural facing tile, 4”	33 psf
Concrete	160 pcf
Floors, gypsum floor slab, per inch	5 psf

MATERIAL	WEIGHT PSF)
Asphalt mastic	5 psf
Ceramic tile, on 1” mortar bed	23 psf
Terrazzo, 1” on 1/2” mortar bed	18 psf
Marble, 1” on 1/2” mortar bed	20 psf
Linoleum, 1/4”	2 psf
Maple, 7/8” on sheathing, 2” cinder fill, no ceiling	18 psf
Oak, 7/8” on sheathing, wood joists at 16” centers, no ceiling	11 psf
Glass	160 pcf
Gravel, sand	120 pcf
Iron, cast	450 pcf
Partitions, plaster, 2”, channel stud, metal lath	20 psf
Plaster, 4”, channel stud, metal lath	32 psf
Hollow plaster, 4” metal lath	22 psf
Gypsum block, solid, 3” – both sides plastered	19 psf
Gypsum block, hollow, 5” – both sides plastered	22 psf
Marble wainscoting, 1”	15 psf
Steel partitions	4 psf
Ceramic glazed structural tile, 4”	33 psf
Rails and fastenings, per track (2 rails)	200 plf

Roofs, roofing felt, 3-ply and gravel	5.5 psf
Roofing felt, 5-ply	6.5 psf
Sheathing, 3/4” thick	3.5 psf
Steel	490 pcf
Timber, untreated	48 pcf
Timber, treated	60 pcf
Walls, brick solid, per inch	10 psf
(Terra cotta tile 4”) – plastering - add 5 psf per side	25 psf
(Terra cotta tile 8”)	33 psf
(Terra cotta tile 12”)	45 psf
Glass, structural, per inch	15 psf
Windows, frame, glass, sash	8 psf
Stone, 4”	55 psf
Steel sheet, 14 gage	3 psf
Catenary support system	As provided to designer

8.2.1.3 Loads from Adjacent Existing Building Foundations or Other Existing Structures

A. The designer shall determine the need for all permanent underpinning of buildings or structures. The underground structures shall be designed for loading from existing adjacent buildings or structures. Consideration shall be given to the maximum and minimum loads that can be transferred to the design structure. Design loads shall be assumed to be the same as those for which the adjacent structure was designed. However, in the absence of this information, loads based on provisions in the applicable building code or the actual weights and the heaviest occupancy for which the building is suitable shall be used.

B. Horizontal and vertical distribution of loads from foundations of existing buildings shall be determined by the designer in consultation with Sound Transit’s Geotechnical Consultant.

8.2.1.4 Miscellaneous Loads

Provisions of agreements with property owners, railroads, and other agencies regarding special loading for portions of structures that pass beneath or adjacent to their properties or

facilities shall be considered in establishing the loading conditions for such structures. Attention shall be paid to proposed future constructions.

8.2.2 Live Loads (LL)

A. Light Rail Projects utilizing light rail technology shall normally operate trains consisting of 1, 2, 3, or 4 articulated cars. Normally, the light rail cars are approximately 90 feet in length and are equipped with 3 trucks of 2 axles each making a total of 6 axles.

B. Under some abnormal operating conditions, one train will be used to push or pull a failed train. This procedure will result in two of the maximum length trains being operated over a portion of a line. Both trains may be carrying passenger loads until the next station is reached before passengers on board the failed train can be off-loaded.

C. Structure subjected to train loads shall be designed for all combination of train lengths, loads, and forces which produce the most critical condition.

D. If live loads or vehicles not included in these criteria are proposed to be applied to the structure, the structural live loads produced by their axle loads/configuration shall not exceed the live loads as now specified.

8.2.2.1 Light Rail Vehicle (LRV)

Car dimensions and weights of Light Rail Vehicle (LRV) are shown on Figure 8-1.

8.2.2.2 Roadway

A. Roadway LL for rail transit structures shall be based on the HS 25 loading. Design HS-25 loading by multiplying AASHTO HS-20-44 loads by 1.25.

B. The following revisions to AASHTO and HS-25 loading shall apply to underground rail transit structures.

1. When the depth of soil cover is 2 feet or less, the live load shall be distributed as concentrated loads applied directly to the top of the underground structure.

2. For fill heights greater than 2 feet up to 8 feet, concentrated live loads shall be distributed over a square, the sides of which shall equal 1.75 times the depth of the fill.

3. For fill heights greater than 8 feet, concentrated live loads shall be distributed over a square, the sides of which shall be equal to 2.5 times the depth of the fill.

4. All underground structures having less than 8 feet of earth cover shall be designed for the following two conditions and the more severe of these shall govern:

   a. The actual depth of cover plus superimposed HS 25 wheel load distributed in accordance with the above requirements.

   b. An assumed future soil cover of 8 feet plus a uniform LL of 300 psf.

8.2.2.3 Pedestrian Areas

A. Station platforms, pedestrian ramps, mezzanines, and other pedestrian areas shall be designed for a uniform LL of 100 psf.

B. Stairways shall be designed for a uniform LL of 100 psf or a concentrated load of 300 lbs. on the center of stair treads, whichever is critical.

8.2.2.4 Storage Space and Machinery Rooms

A. Electrical equipment rooms, pump rooms, service rooms, storage space, and machinery rooms shall be designed for uniform LL of 250 psf, to be increased if storage or machinery loads so dictate.

B. Fan rooms and battery rooms shall be designed for uniform loads of 350 psf, to be increased if storage or machinery loads so dictate.

8.2.2.5. Elevators, Escalators, and Passenger Conveyors

Structures supporting elevators, escalators or passenger conveyors shall be designed for the maximum reactions from any of the manufactured units considered for use in the system.

8.2.2.6 Railings, Screening and Fences

A. Opening where there is a vertical step of more than 30 inches shall be guarded by railing. As a minimum, the railing, its components, supports and connections shall be designed according to the following:

1. Railing in areas with public occupancy of 50 people or greater, including station platforms, station mezzanines, and station service walkways, shall conform to IBC in terms of geometry and configurations. Load for these types of railings shall be 50 pounds per lineal foot (plf) applied horizontally and vertically to the top of the railing. An additional load of 25 pounds per square foot (psf) acting horizontally over the entire tributary area including openings shall be applied simultaneously with the load on the top rail.

2. Railing in public areas with occupancies less than 50 people shall conform to IBC in terms of geometry and configurations. Load for these type of railings shall be 20 plf applied horizontally and vertically to the top of the railing. Components shall be designed for 25 psf acting horizontally applied over the entire tributary area including openings. This 25 psf load need not be applied simultaneously with the load on the top rail.

3. Railings in equipment and maintenance areas not accessible to the public shall conform to OSHA in terms of geometry and configuration including toeboards. Loading for these railings shall be a 200 pound point load acting in any direction at any point on the railing.

4. Railing for aerial structures and for Light Rail Transit structures away from platforms and away from public areas shall conform to AASHTO in terms of geometry and configuration. Loading for these railings shall include 50 plf both transversely and vertically acting simultaneously on each longitudinal element. Components and connections shall be capable of sustaining a 200-pound load at any point and in any direction applied on the top rail. The 200-pound load need not act simultaneously with the 50 plf loads for each longitudinal element.

B. Vertical barriers that provide separation between spaces that have vertical steps less than 30 inches may be designed as a Screen or Fence. Screens or Fences imply open latticework and may have similar configuration to railing. The minimum live load for Screens and Fences is 15 psf acting perpendicular to the entire surface including openings. Screens and Fences shall also meet the applicable IBC environmental loads and combinations including wind and seismic.

8.2.2.7 Gratings

A. Gratings in areas that are subject to loading from vehicles shall be designed to carry HS 25 loading in accordance with AASHTO.

B. Gratings in sidewalks and in areas protected from vehicular traffic shall be designed for a uniform LL of 100 psf.

8.2.2.8 Service and Emergency Walks

Service and emergency walks shall be designed for a uniform LL of 85 psf of walkway area.

8.2.2.9 Underground Tunnel Walls, Doors, and Dampers

These items are subject to air pressure from the running trains. Details are covered in section 8.14.5.

8.2.3 Derailment Loads (DR)

8.2.3.1 Vertical

A. Vertical derailment load shall be that produced by fully loaded LRV vehicles (Fig. 8-1), placed with their longitudinal axes parallel to the track.

B. Lateral vehicle excursion shall vary as follows:

1. For tangent track and curved track with radii greater than 5,000 feet, vehicle excursions shall vary from a minimum 4 inches to a maximum of 3’-0”.

2. For tracks with 5,000 feet radii or smaller the minimum excursion is 4 inches. The maximum excursion is either 3’-0” or 8 inches from the traffic face or the nearest barrier if any, or the edge of deck, whichever is less.

3. Where devices to limit derail excursions, such as guardrails in Chapter 5, Trackwork, Section 5.14, Emergency Guard Rail, are provided, the maximum derail excursion need not exceed the limit provided by the device. Even where derail excursion-limiting devices are used, one truck (two axles) shall have the maximum excursions given in subparagraphs 1 and 2 above. This truck shall be selected and placed to result in the critical loading.

C. A vertical impact factor of 100 percent of vehicle weight shall be applied in computing the equivalent static derailment load. This shall be in lieu of the vertical impact provided in section 8.2.5.

D. The decks shall be designed for 100 percent vertical impact from one truck (two axles) located anywhere on the deck. The truck shall be selected to give the critical loading.

E. When checking any component of superstructure or substructure that supports two or more tracks, only one train on one track shall be considered to have derailed, with the other track being loaded with a stationary train.

F. All elements of the structure shall be checked assuming simultaneous application of all derailed wheel loads. However, the reduction of positive moment in continuous slabs due to derailed wheel loads in adjacent spans shall not be allowed.

8.2.3.2 Horizontal

For cross-sections having clearance between vehicle and barrier wall of 6 inches to 3'-0", the force due to horizontal DR shall be taken as 40 percent of a single fully loaded vehicle acting 2 feet above top of rail and normal to the barrier wall for a distance of 10 feet along the wall.

8.2.4 Earthquake Forces (EQ)

A. Two levels of earthquake are considered. A Maximum Design Earthquake (MDE) has a high intensity and a low probability of occurrence over the life of the structure. An Operating Design Earthquake (ODE) has a lower intensity but a higher probability that it will occur at least once during the service life of the structure. The underlying concept is that a structure should be able to experience the lower without disruption to service, and should be able to survive the higher without collapse. The base acceleration and design parameters and requirements for each earthquake level will be detailed in Chapter 8A, Seismic Design.

B. All aerial structures and bridges shall be designed to resist earthquake motions in accordance with Chapter 8A, Seismic Design.

C. Structures and structural elements not subject to rail transit loading, including stations, buildings, and building-like structures shall be designed to resist earthquake motions in accordance with applicable codes of section 8.1.2.3. The design shall be in accordance with Chapter 8A, Seismic Design.

D. Underground structures subject to earthquake motions shall be designed in accordance with Chapter 8A, Seismic Design.

E. Earth retaining structures shall be designed to resist lateral earth pressure induced by earthquakes as recommended by Sound Transit's Geotechnical Consultant.

F. All other structures shall be designed to resist earthquake motions in accordance with applicable building codes.

8.2.5 Impact (I)

A. Impact loads are statically equivalent dynamic loads resulting from vertical and horizontal acceleration of the LL.

B. Impact considerations for aerial structures supporting rail transit loading shall meet the following requirements:

1. Impact shall be applied to the superstructure and generally to those members of the structure that extend down to the main footings. The portion above the ground line of concrete or steel piles rigidly connected to the superstructure as in rigid frame or continuous design is included. Impact shall not be considered for abutments, retaining walls, wall-type piers, embedded piles, footings, and service walks.

2. Vertical impact (IV) allowance for aerial structures shall be 30 percent of LL.

3. In addition to the vertical impact provided above, a horizontal impact (IH) equal to 10 percent of LL shall be applied. This force shall be equally distributed to the individual axles of the vehicle and shall be assumed to act in either direction transverse to the track through a point at 3.5 feet above the top of the low rail. The horizontal force component transmitted to the rails and supporting structure by an axle shall be concentrated at the rail having direct wheel flange to rail head contact.

C. Design of the top slab of underground structures supporting highway loading shall conform to the following:

0'-0" to 1'-0" earth cover IV	=	30 percent (LL)
1'-1" to 2'-0" earth cover IV	=	20 percent (LL)
2'-1" to 3'-0" earth cover IV	=	10 percent (LL)
Greater than 3'-0" earth cover IV	=	0 percent (LL)

The depth of cover shall be measured from the top of ground or paving to the top of the underground structure.

D. Structures supporting special vehicles, such as moving equipment or other dynamic loadings that cause significant impact, shall conform to the local building code or, if not covered by code, shall be considered individually using the best technical information available.

E. Impact shall not be considered for stairways, mezzanines, station platforms, or other pedestrian areas.

8.2.6 Centrifugal Force (CF)

A. Structures on curves shall be designed for a horizontal radial force (CF, equal to the following percentage of the LL, without impact, in all trackways:

$C = 0.00117S^2 D = 6.68S^2/R$

where:

C = the CF in percent of the LL, without impact

S = the design speed in miles per hour

D = the degree of curve of the track centerline

R = the radius of the curve of the track centerline, in feet.

B. The centrifugal force shall be applied 4 feet above the top of low rail, on all tracks.

8.2.7 Longitudinal Force (LF)

8.2.7.1 Due to Acceleration and Deceleration

A. Provision shall be made for the longitudinal force, LF, due to train acceleration and deceleration. The magnitude of the longitudinal force shall be computed as follows:

1. For decelerating trains, LF shall be equal to 28 percent of LL without impact.

2. For accelerating trains, LF shall be equal to 14 percent of LL without impact.

B. This force shall be applied to the rails and supporting structure as uniformly distributed load over the length of the train in a horizontal plane at the top of low rail. Consideration shall be given to various combinations of acceleration and deceleration forces where more than one track is carried by the structure.

8.2.7.2 Due to Restraint of Continuous Welded Rail (CWR)

A. Whenever a continuous welded rail is terminated, provisions shall be made to restrict fully its end from movement. This restraint will introduce a significant longitudinal force. The continuous welded rail shall not be terminated on the aerial structure unless the structure is designed to withstand the imposed loads.

B. Chapter 8A, Seismic Design, section 8A.13, References, and section 8.15 of this chapter include references and design aids that are suitable guidelines for performing the interactive rail force analysis.

8.2.7.3 Due to Rail Bumping Posts

A. A rail-mounted vehicles' retarding device in the form of bumper posts shall be used on stub-end tracks located in yards, on main lines, or on sidings. This device shall limit movement by absorbing vehicle energy. It shall include an anti-climbing feature. Should conditions warrant, an additional hydraulic car-retarder or sand box shall be provided.

B. The transfer of loads due to collision between any number of rail transit cars, traveling at the design speed, and any structure-mounted rail bumping post shall be limited to 200 kips including impact. The bumping post shall be attached only to the rail it protects and shall transfer load to the structure only through rail seat assemblies. The structure shall be designed for the loads transmitted through the rail seat assemblies for only one bumping post being activated at one time.

C. To further protect the structure, the post shall be designed with a flexible mounting so that excess loads will either deform or shear off the bumping post. As an alternative to a

frangible mounting, the design shall preclude any device that would cause the loads to be transferred to exceed 200 kips.

D. For structural design, the bumping post load shall be evenly divided between the two rails to which it is attached. Structures shall be designed to resist the lesser of 200 kips or the total available restraint provided by the rail seal assemblies on the structure supporting the rails and the bumping post in question.

8.2.8 Earth Pressure (E)

A. The designer shall be responsible for reviewing all soils information from the soils boring program formulated by Sound Transit's Geotechnical Consultant. In the event of changes in design or construction concepts between preliminary and final design phases, Sound Transit's Geotechnical Consultant will be kept informed and their recommendations shall be obtained.

B. Structures that retain earth shall be designed for side pressure due to earth abutting the structure and load surcharges resting on abutting earth. Allowances shall be made for both dry and submerged earth pressure and for hydrostatic pressure. Consideration shall be given to multi-layered effects where substantial differences in soil properties occur over the depth of the structures. The effects of specified construction procedures (e.g., "inverted" construction, rigid bulkheads, or cut-off walls) on the development of lateral pressures shall be considered.

1. Rail transit loading may be assumed as a uniform surcharge equal to 3 additional feet of earth.

2. LL and DL from adjacent foundations of structures shall be considered in computing horizontal pressures.

3. Where railroad loading occurs, the surcharge shall be determined as specified in the AREMA Manual, Chapter 8, Part 5, subsection 5.3.1.

4. The rock-earth pressures to be used in design shall be established in consultation with Sound Transit's Geotechnical Consultant.

8.2.9 Hydrostatic Pressure and Buoyancy (B)

The effects of hydrostatic pressure and buoyancy shall be considered whenever the presence of groundwater is indicated. The possibility of future major changes in groundwater elevation shall be considered. The elevation of groundwater shall be controlled so that the calculated total

weight of structure and backfill shall always exceed the calculated uplift due to buoyancy by 10 percent. The design shall take into account the effect of hydrostatic pressures pertaining to construction sequence. The backfill shall be considered as the volume contained within vertical planes defined by the outside limits of the structure. No value shall be assigned to contact soil friction.

8.2.10 Wind Load on Structure (W)

The aerial structures shall be designed to withstand wind loads of uniform pressure acting upon the superstructure, substructure, and live load (see section 8.2.11 for wind on live load).

8.2.10.1 Wind Load on Superstructure

A horizontal uniform wind load of the intensities given by AASHTO shall be applied simultaneously at the centroid of all exposed areas. In addition to the horizontal wind loads, an upward load shall be applied at the windward quarter point of the transverse width of the superstructure. This vertical load shall be as specified by AASHTO. Wind loading on catenary shall be considered in the design of both superstructure and substructure elements. Loads (magnitude and location) shall be determined by the catenary design consultant.

8.2.10.2 Wind Load on Substructure

The substructure shall be designed to withstand the preceding loads applied to the superstructure as they are transmitted to the substructure. In addition, a horizontal wind load of magnitude specified by AASHTO in any direction shall be applied simultaneously at the centroid of the exposed substructure area.

8.2.11 Wind Load on Live Load (WL)

A. For trains operating on aerial structures with the underside of the main girders not more than 40 feet above the mean retarding surface, wind on live load, WL, shall consist of a transverse wind load of 200 plf of train and a longitudinal wind load of 40 plf of train. These loads shall be applied simultaneously. The transverse force shall be applied to the rail and superstructure as loads concentrated at the axle locations, and in plane 6'-4" above the top of the lower rail. The longitudinal force shall be applied to the rails and superstructure as a load uniformly distributed over the length of the train in a horizontal plane 6'-4" above the top of the lower rail.

B. For aerial structures higher than 40 feet above the mean retarding surface, the values of WL in the transverse and longitudinal directions shall be as follows:

Transverse wind pressure = 300 plf

Longitudinal wind pressure = 60 plf

C. These loads apply to the design of substructure elements supporting a single track. For the design of substructure elements supporting two tracks, these loads shall be increased by 30 percent when both tracks are loaded; this factor accounts fully for shielding effect of vehicle-on-vehicle as the two trains run alongside each other.

8.2.12 Stream Flow Pressure and Flooding (SF)

Local flooding may add load to structures in the flood plain. Design of the structures shall make allowance for this loading, as required by the particular type of structure and the conditions affecting each location. Anticipated flood elevations shall be determined by a study of official flood records. SF shall be included in the design of aerial structures where applicable. All piers and other portions of structures that are subject to flood forces shall be designed in accordance with sound engineering practice.

8.2.13 Shrinkage and Creep Forces (S)

Stresses and movements resulting from concrete shrinkage and creep shall be incorporated into the design of the structures.

8.2.14 Thermal Force (T)

A. Provision shall be made for stresses and deformations resulting from temperature changes above or below the normal temperature of 64°F. Operational temperature ranges and thermal coefficients for various materials are as follows:

1. Concrete

   a. Temperature 0 - 100°F

   b. Coefficient of expansion .0000060 inch/inch/°F.

2. Steel

   a. Temperature 0 - 120°F

   b. Coefficient of expansion .0000065 inch/inch/°F.

B. Provisions shall be made for transverse (radial) and longitudinal rail/structure interaction forces due to temperature variations in the continuous welded rail. Base the transverse and longitudinal forces in continuously welded rail on temperature changes that include a temperature drop of 75°F, and a temperature rise to 60°F. These forces shall be applied in a horizontal plane at the top of low rail as follows:

1. Transverse Force:

   a. The transverse force shall be applied in each direction. Its magnitude per linear foot of the structure per rail shall be determined by the designer.

   b. The magnitude of the transverse rail forces, particularly in curved structures, shall be determined by a rigorous analysis of the total structural system including rails, rail fasteners, girders, bearings, and substructures.

2. Longitudinal Force

   a. The magnitude of the longitudinal rail forces shall be determined by a rigorous analysis of the total structural system including rails, rail fasteners, girders, bearings, and substructure.

   b. Section 8.15 includes references and design aids that are suitable guidelines for performing the interactive rail force analysis.

   c. Aerial structures shall be designed to accommodate the temporary loads associated with rail break and rail replacement. In addition, the Link aerial structures shall be capable of adequately maintaining a broken rail with not more than a 2-inch gap at any one rail supported by the structure.

   d. Specify that the rail installation temperature for zero thermal stress to be between 60°F and 75°F.

C. Thermal forces resulting from the temperature variations in the overhead contact system shall be considered. Loads shall be determined by the catenary design consultant.

8.2.15 Differential Settlement (DS)

Load(s) induced on the structures by tolerable differential settlement shall be considered in the loading combination. The tolerable differential settlement shall be established in accordance with section 8.5.7.

8.2.16 Collision Loads (CL)

Piers or other guideway support elements that are situated less than 10 feet from the edge of an adjacent street or highway shall be designed to withstand a horizontal static force of 225 kips, unless protected with suitable barriers. This force is to be applied on the support element at an angle of 10 degrees from the direction of the road traffic and at a height of 4 feet above ground level. This condition occurs with the dead load of the structure but need not be applied concurrently with other applied loadings.

8.3 UNDERGROUND STRUCTURES

All underground structures shall be classified in one of the categories listed below. For each of these structures, the following assumptions shall be made:

8.3.1 Flexible Earth-Tunnel Sections

8.3.1.1 General Requirements

A. These design criteria apply to flexible and semi-flexible precast concrete segmental tunnel liners or cast-in-place concrete liners.

B. The liners may be bolted or unbolted on their longitudinal and circumferential joints.

C. In appropriate circumstances, the liners may be expanded against the ground. More generally, the annulus between the liner and the ground shall be completely filled with cement grout.

D. Tapered liner rings shall be used to negotiate curves and correct vertical and horizontal alignment.

E. In tunneled sections below the water table, the liners shall be capable of being made watertight by means of rubber sealing gaskets and/or caulking and bolt grommets.

F. No steel ring - timber spacer tunnel liners shall be used.

G. Threaded inserts shall be cast in all precast and cast-in-place tunnel liners for equipment mounting.

8.3.1.2 Design of the Liners

A. The liners shall be designed to sustain all the loads to which they will be subjected with minimum factor of safety of two. Such loads shall include:

1. Handling loads as determined by the transport and handling system.

2. Shield thrust ram loads as determined by the shield propulsion system.

3. Erection loads including external grouting loads.

4. Earth pressure shall be calculated using 2D finite element analysis methods based on best available geotechnical data. In lieu of this computer analysis, no less than full overburden shall be used.

5. Hydrostatic pressure

6. Self-weight of the tunnel structure

7. Loads due to imperfect liner erection, but not less than 0.5 percent diametrical distortion.

8. Additional loads due to the driving of adjacent tunnels

9. Effects of tunnel breakouts at cross-passages, portals, and shafts

10. Live loads of vehicles moving in the tunnel or on the surface above it

11. Surcharge loads due to adjacent buildings

12. Seismic loads as indicated in Chapter 8A, Seismic Design

B. Provisions shall be made in the liner segments for corrosion prevention and the elimination of stray currents from the surrounding ground area.

C. Provisions for ground structure interaction and lateral support of surrounding ground shall be included.

8.3.2 Rock Tunnel Liners

8.3.2.1 General Requirements

A. These design criteria apply to cast-in-place concrete liners and flexible or semi-flexible precast concrete segmental liners erected directly behind the tunneling machine.

B. For the cast-in-place concrete liners, temporary support may be required during the excavation phase of the tunneling process. This temporary support, in general, will be provided by steel arch ribs at centers to suit rock conditions. When and if rock conditions permit, these may be replaced by resin-anchored rock bolts at centers to suit rock conditions, shotcrete applied to the rock surface, or combinations of the above.

C. The precast concrete segmental liners may be bolted or unbolted on their longitudinal and circumferential joints.

D. In appropriate circumstances, the segmental liners may be expanded against the ground. More generally, the annulus between the liner and the ground shall be completely filled with cement grout.

E. Tapered segmental liner rings shall be used to negotiate curves and correct vertical and horizontal alignment.

F. In tunneled sections below the water table, the liners must be capable of being made watertight by means of sealing gaskets, duct sealants, caulking, or rock grouting or designed to incorporate a drainage system to relieve hydrostatic pressures behind the liner to drain to an invert drain in the tunnels.

G. No steel ring - timber spacer tunnel liners shall be used.

H. Threaded inserts shall be cast in all precast and cast-in-place tunnel liners for equipment mounting.

8.3.2.2 Design of the Liners

A. The temporary support systems shall be designed to sustain all the loads to which they will be subjected with minimum factor of safety of two. Such loads shall include:

1. Rock load shall be calculated using 2D finite element analysis methods based on best available geotechnical

data. In lieu of this computer analysis, no less than the weight of two diameters of rock overburden shall be used.

2. Self-weight

3. Additional loads due to the driving of adjacent tunnels.

B. The cast-in-place liners shall be designed to sustain all the loads to which they will be subjected with minimum factor of safety of two without beneficial effects from the initial support system. Such loads shall include:

1. Rock load shall be calculated using 2D finite element analysis methods based on best available geotechnical data. In lieu of this computer analysis, no less than the weight of two diameters of rock overburden shall be used.

2. Hydrostatic pressure either total or residual.

3. Additional loads due to the driving of adjacent tunnels (if applicable).

4. Live loads of vehicles moving in the tunnel

5. Seismic loads as indicated in Chapter 8A, Seismic Design.

C. The precast segmental liners shall be designed to sustain all the loads to which they will be subjected with adequate factors of safety. Such loads shall include:

1. Handling loads as determined by the transport and handling system.

2. Shield thrust ram loads if applicable as determined by the shield propulsion system.

3. Erection loads including external grouting loads.

4. Rock loads based on considerations of rock condition.

5. Hydrostatic pressure either total or residual.

6. Self-weight of the tunnel structure.

7. Loads due to imperfect liner erection.

8. Additional loads due to the driving of adjacent tunnels.

9. Live loads of vehicles moving in the tunnel.

10. Seismic loads as indicated in Chapter 8A, Seismic Design.

8.3.3 Shafts

8.3.3.1 The permanent shaft wall shall be in either precast segmental liner rings or reinforced concrete (cast-in-place or shotcrete). Loading imposed on the shaft by the surrounding ground shall be determined by the Designer in accordance with the subsurface investigations and consistent with the shaft configuration. Shafts inclined more than 45 degrees from the vertical shall be designed for tunnel design pressures.

8.3.3.2 Design of Shaft Lining

A. The shaft linings shall be designed to sustain all the loads to which they will be subjected with minimum factor of safety of two. Such loads shall include:

1. Erection loads including external grouting loads

2. Earth pressure shall be calculated using full overburden pressure multiplied by the effective at-rest lateral stress coefficient (K_O)

3. Hydrostatic pressure

4. Effects of tunnel breakouts, niches, and adits.

5. Live loads of vehicles moving on the ground surface adjacent to the shaft multiplied by the effective at-rest lateral stress coefficient (K_O)

6. Surcharge loads due to adjacent buildings or known future construction

7. Seismic loads as indicated in Chapter 8A, Seismic Design

B. Provisions shall be made in the liner segments for corrosion prevention and the elimination of stray currents from the surrounding ground area.

C. Provisions for ground structure interaction and lateral support of surrounding ground shall be included.

8.3.4 Tunnel Break-Outs

Permanent walls for tunnel breakouts in shafts, cross-passages, or any other location shall be in reinforced concrete. For tunnels lined with pre-cast segmental tunnel liners, requirements of specially segmented rings to suit break-out configurations shall be determined by the Designer. Crosspassages may be combined with other on-line structures such as pump and ventilation structures. Refer to NFPA 130, Fixed Guideway Transit Systems.

8.3.5 Reinforced Concrete Box Line and Station Section

A. These structures retain earth but do not permit the earth freedom to yield significantly. As a minimum, four basic loading cases shall be investigated. Values of loading shall be developed from applicable loads listed in section 8.2, in consultation with Sound Transit's Geotechnical Consultant. Additional permanent, temporary, and construction loading cases shall be investigated as required by particular circumstances.

Case I: Full vertical and long-term horizontal load.

Case II: Full vertical load, long-term horizontal load on one side and short-term horizontal load on the other.

B. In underground concrete box structures that could be subject to unequal lateral pressures, the structural analysis shall consider the top slab as both restrained and unrestrained against horizontal translation in arriving at maximum shears, thrusts, and moments. However, the ratio of horizontal displacement to height of the wall need not exceed 0.0005.

Case III: Full vertical load with short-term horizontal load neglecting hydrostatic pressure on both sides.

Case IV: Only dead vertical load with long-term horizontal load including hydrostatic pressure.

8.3.5.1 Foundation Pressures

A. Vertical pressure on foundation slabs may be divided into hydrostatic and earth pressure components. The hydrostatic component shall be distributed across the width of the foundation in proportion to the depth of each portion of the basic slab below the design groundwater table.

B. Distribution of the earth pressure moment shall be based on specified construction procedures, and shall include elastic foundation effects.

C. For design, the horizontal earth pressure distribution diagram for multiple braced flexible walls shall be the trapezoidal pressure diagram. Compression forces shall not be considered in shear design of the top and bottom slab in box sections.

D. In evaluating the design for temporary loadings produced by construction conditions such as the removal of horizontal struts, consideration shall be given to:

1. Allowable increase in stresses due to the temporary nature of the loading

2. Creep in the concrete

3. Effect of soil arching

4. Wall and slab flexibility

E. Where it is anticipated that restrutting will be proposed by the contractor due to the limitations inherent in the design of the permanent structure, the construction specifications are to stipulate that the working drawings, supporting computations, and order of procedure submitted for approval by the contractor must reflect proper consideration of such aspects as magnitude of preload in replacement struts, crushing of packing, and thermal-induced stress and deflection of the permanent structure. The contractor's proposal shall also detail the proposed instrumentation and monitoring thereof so as to ensure that the permanent structure will not be overstressed or otherwise damaged.

F. In all cases, the specifications for support of excavation must reflect all limitations inherent in the design of the permanent structure.

G. The grade slab and the exterior wall of the underground box structures shall be a minimum of 18 inches thick, unless special treatment of waterproofing is provided.

H. Provisions shall be made for corrosion control in accordance with Chapter 17, Corrosion Control, and in consultation with the corrosion consultant.

8.3.6 Reinforced Concrete Retaining Walls

These are structures that are free to yield to earth pressure. In retaining walls up to 20'-0" in height, the design earth pressure shall be computed in accordance with recommendations of the Geotechnical Consultant or

by the AREMA empirical method. Refer to Chapter 8, Part 5, Appendix C of the AREMA Manual. Retaining walls above 20'-0" in height shall be designed on the basis of specific soils information relating to the backfill material using an acceptable method in consultation with the Geotechnical Consultant.

8.3.7 Mined Caverns

8.3.7.1 Mined caverns consist of any underground spaces constructed by means other than a Tunnel Boring Machine. These structures include all components of mined stations, crossovers, and crosspassages. The final lining of all mined caverns shall be reinforced concrete, either cast-in-place, precast or shotcrete. If cast-in-place concrete or shotcrete is used, a waterproof membrane shall be used between the final lining and the initial support of excavation. If precast segments are used as the final lining, they shall be bolted and gasketed to provide water tightness.

8.3.7.2 Design of the Cavern Lining

Loadings imposed on the caverns by the surrounding medium and applicable surface loadings shall be determined by the designer in accordance with the subsurface investigations and shall be consistent with the cavern configuration and construction methods. The cavern linings shall be designed to sustain all the loads to which they will be subjected with minimum factor of safety of two. Such loads will include:

1. Erection loads including external grouting loads

2. Earth pressure acting on caverns in ground shall be calculated using 3D finite element analysis methods based on best available geotechnical data. In lieu of this computer analysis, no less than full overburden shall be used.

3. Rock pressure acting on caverns in rock shall be calculated using 3D finite element analysis methods based on best available geotechnical data. In lieu of this computer analysis, no less than the weight of two diameters rock overburden shall be used.

4. Hydrostatic pressure.

5. Effects of tunnel breakouts, niches, and, adits.

6. Live loads of vehicles moving on the ground surface above the cavern.

7. Surcharge loads due to adjacent buildings or known future construction.

8. Seismic loads as indicated in Chapter 8A, Seismic Design.

8.4 PORTALS AND U-SECTIONS

A. Tunnels and box section entrance portals shall be designed in a manner to minimize the rate-of-change of pressure on a train passing through the portal.

B. The pressure rise is a function of both the cross-sectional area of the portal entrance and the entrance speed of the train (see Figure 8-2).

8.4.1 Acceptable Design Methods

A. Provide the entrance with a flared transition so that the increase in cross-sectional area approximates the cross-section of 6-degree conical flare starting at the constant area section of the tunnel or box and extending to the portal opening. This flared transition can be formed using any combination of tapers on the top and sides, provided no plane or surface of the transition section is at an angle in excess of 6-degrees relative to the center line of the tunnel and provided the side tapers are symmetrical with the centerline. For the required length of the flared transition, see Figure 8-3 and for the required cross-sectional area at the portal, see Figure 8-4.

B. Design both the top and vertical sides of the entrance without a flare and provide a tapering slot in the top. From a one-foot minimum width at the constant area section, the slot should increase to a maximum at the portal at a taper rate of 12 feet per 100 feet of length. The slot opening should, therefore, be 13 feet wide at the portal for 100-foot long transition, or 7 feet wide at portal for 50-foot long transition. For the required length of transition, see Figure 8-3.

8.4.2 Exceptions

A. Exceptions that do not require special transition portal are:

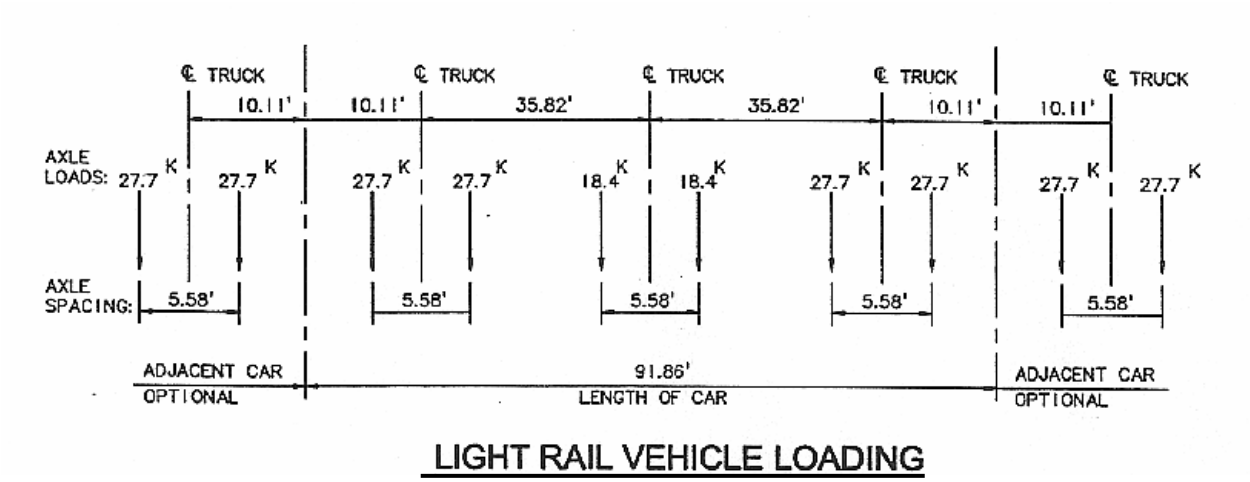
1. Tunnels of a length less than 200 feet

2. Single track horseshoe tunnels with design train speed of 45 mph or less

3. Box sections and single track circular tunnels with design train speed of 40 mph or less

4. Portals at underground stations

Figure 8-1
Light Rail Vehicle Design Load



NOTES :

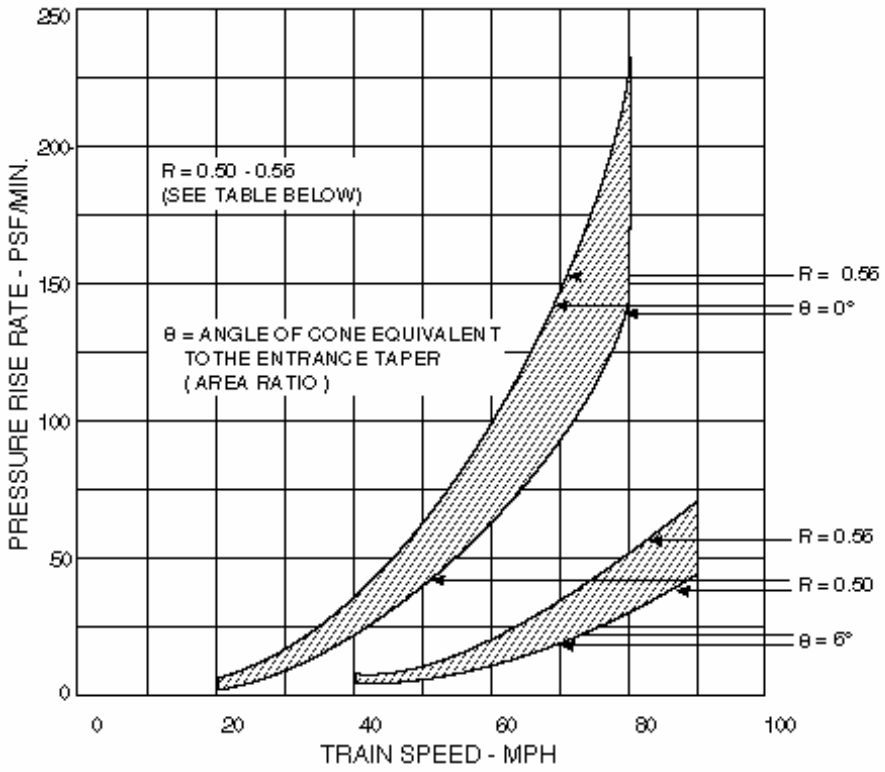
1. AXLE LOAD IN KIPS

2. THE TRAINS SHALL CONSIST OF ONE, TWO, THREE, OR FOUR CARS; WHICHEVER PRODUCES THE MAXIMUM LOAD FOR THE ELEMENT UNDER CONSIDERATION.

3. THIS LOADING CORRESPONDS TO AW4 IN SECTION 12.3.A. OBTAIN THE OTHER AW LOADING IN SECTION 12.3.A BY MULTIPLYING THE AXLE LOADS IN THE ABOVE FIGURE BY THE RATIO OF THE TOTAL WEIGHT FOR THE DESIRED AW LOAD TO THE TOTAL WEIGHT FOR THE AW4 LOADING GIVEN IN SECTION 12.3.A.

Figure 8-2

Pressure Rise Rate vs. Train Speed



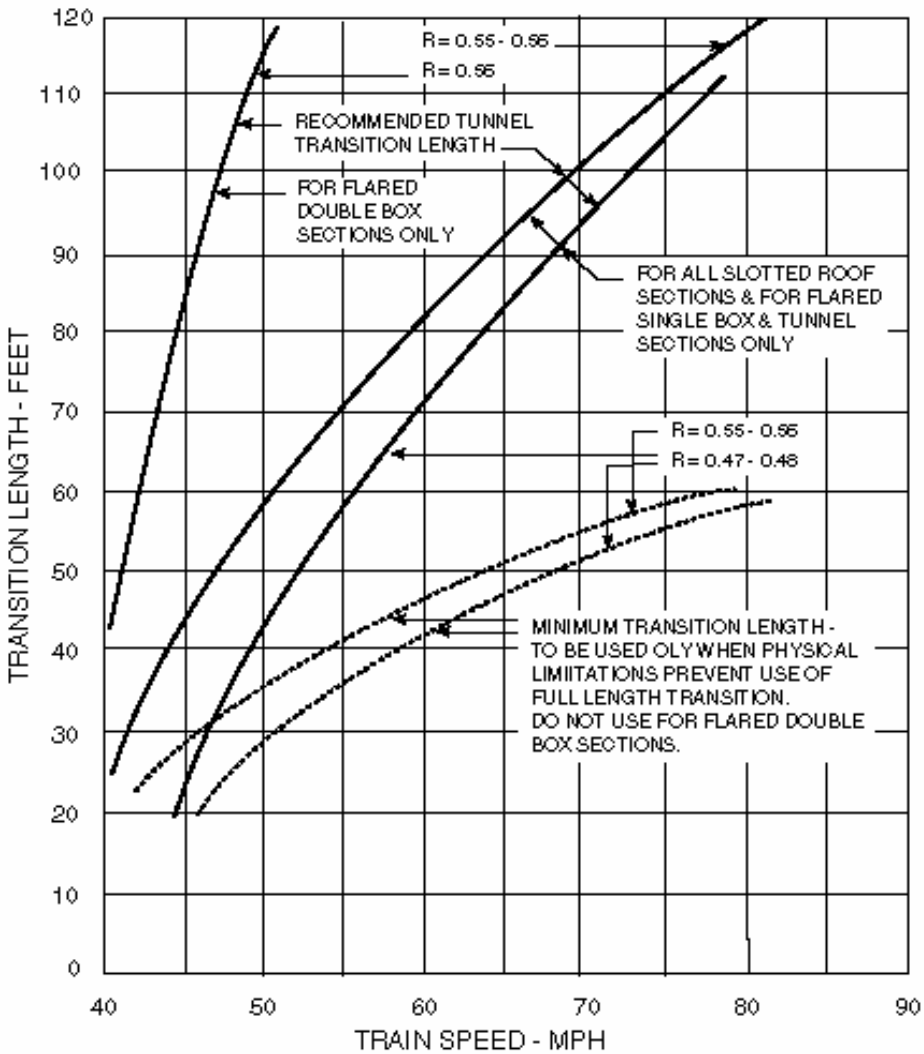
ESTIMATED PRESSURE RISE RATE VS. TRAIN SPEED FOR TUNNEL ENTRANCES WITH NO TAPER [θ = 0°] AND WITH 6° CONICAL TAPER [θ = 6°], OR EQUIVALENT.

TYPE OF TUNNEL	CROSS-SECTIONAL AREA	R
SINGLE BOX, CUT AND COVER	174 sq. ft.	.55
DOUBLE BOX, CUT AND COVERT	171	.56.
CIRCULAR EARTH TUNNEL	203	.47
HORSESHOE ROCK TUNNEL	180	.53

$$R = \frac{\text{CAR CROSS - SECTIONAL AREA}}{\text{TUNNEL CROSS - SECTIONAL AREA}}$$

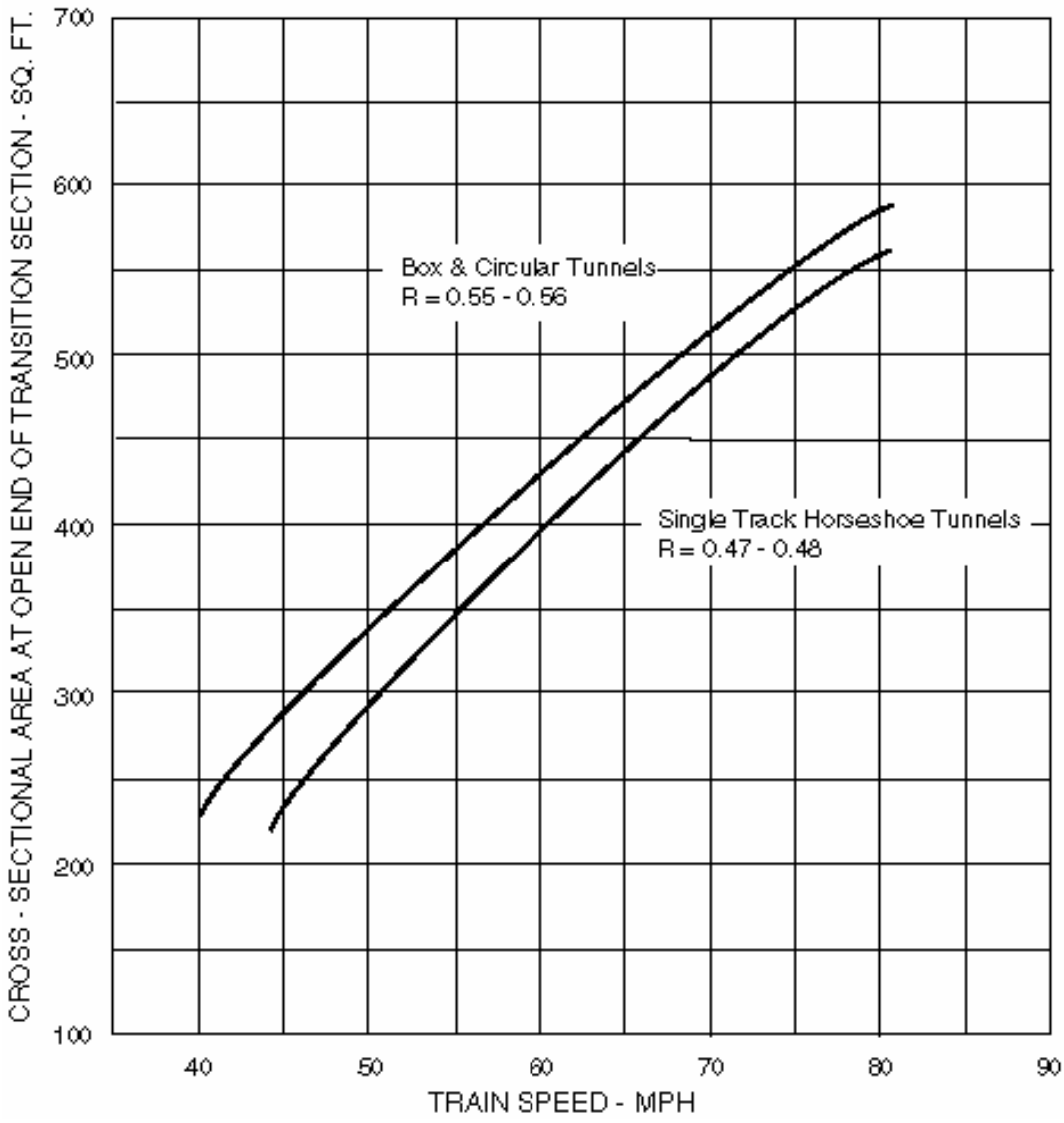
Figure 8-3

Tunnel Transition Length vs. Train Speed



RECOMMENDED LENGTH OF TUNNEL PORTAL TRANSITION AS A FUNCTION OF TRAINVELOCITY FOR SINGLE TRACK TUNNELS.

Figure 8-4
Recommended Area at Portal pf Tunnel or Box Section with Flared Transition



8.4.3 General Requirements

A. In locating portals and determining the ends of U-sections and walls, consideration shall be given to providing protection against flooding resulting from local storm runoff.

B. Adequate provision shall be made for resistance to hydrostatic uplift. Adequate provision shall be made for immediate and effective removal of water from rainfall, drainage, groundwater seepage, or any other source.

C. U-sections, with both walls continuous with a full-width base slab, shall be used for open-cut sections where the top of rail is less than 4 feet above the maximum groundwater table. Above that level, independent reinforced concrete cantilever retaining walls may be considered for design in accordance with the provisions of section 8.3.6.

D. U-sections may be analyzed as continuous structures on elastic foundations. If at any station the two walls are of unequal heights, then the factor of safety against sliding shall be a minimum of:

   1. 1.5 with no passive resistance of the soil.

   2. 2.0 with passive resistance of the soil.

E. Wall thickness for U-sections shall be designed by using:

   1. The geotechnical soils report recommendations for coefficient of lateral earth pressure, at-rest case.

   2. Hydrostatic pressure.

   3. Surcharge effects.

F. U-section grade slab design thickness shall be 6 inches greater than the wall thickness, with a minimum thickness of 24 inches. If the weight of the grade slab (in psf) is less than 40 percent of the hydrostatic head (in psf) as measured from the bottom of the grade slab, then the grade slab shall be designed for uplift pressure.

   If, at the last U-section segment away from the portals, the abutting at-grade trackway does not consist of a track slab, then a depressed approach slab shall be provided to permit the construction of tie-and-ballast trackbed up to the end of the U-section base slab that avoids a sharp break in support at that point.

8.5 AERIAL STRUCTURES

The criteria set forth in this chapter shall pertain specifically to the design of aerial line structures and bridges carrying rail transit loadings and aerial stations.

8.5.1 Design Specifications

A. For Seismic design, refer to Chapter 8A, Seismic Design.

B. Strength design method (load factor design method as per AASHTO) shall be used for the design of all structural components and connections. To ensure serviceability and durability, permanent deformations under overloads, live load deflections, and fatigue characteristics under service loadings shall be investigated.

8.5.2 Application of Loadings

Where applicable, loads and forces listed in section 8.2, shall be used for the design of rail transit aerial structures. For structures carrying rail transit loads, one train per track shall be applied for both strength and serviceability considerations in all materials.

8.5.3 Reduction in Load Intensity

For structures carrying rail transit loads, a track shall be treated as a traffic lane in applying the provisions of AASHTO Article 3.12.

8.5.4 Special Design Considerations

8.5.4.1 Vibration and Deflection Control

A. To limit vibrational amplification due to the dynamic interaction between the superstructure and the rail car, the first-mode natural frequency of flexural vibration of each simple span guideway should generally be not less than 2.5 hertz and no more than one span in a series of three consecutive spans should have a first-mode natural frequency of less than 3.0 hertz. Long simple spans having lower natural frequencies may be used, provided that due consideration is given to possible vibrational interactions between the structure and the rail car, and their effect on vertical impact loading.

B. To ensure rider comfort, the deflection of longitudinal girders under normal live load should not exceed 1/1000 of the span length. For main cantilever girders, the deflection under normal live load should not exceed 1/375 of the cantilever span.

C. A special analysis shall be conducted for any bridge or superstructures having a first mode of vertical vibration which is less than 2.5 hertz, or for the condition when more than one span in a series of three consecutive spans has the first mode of vibration which is less than 3.0 hertz.

D. This analysis shall model the proposed structure and the transit vehicle. The analysis shall contain a sufficient number of degrees of freedom to allow modeling of the structure, vehicle truck spacing, vehicle primary suspension, vehicle secondary suspension, and the car body. It shall make provision for the placement of the vehicle on the structure in various locations in order to model the passage of the transit vehicle. When the exact configuration of either the vehicle or the structure is not known, the study shall assume a reasonable range of parameters and shall model combinations of those parameters as deemed appropriate.

E. The analysis shall determine whether impact loads in excess of 30 percent of rail transit are required for the design of the structure. The analysis shall also determine whether certain operational considerations such as speed restriction or other provisions are required in order to ensure the safe operation of the rail transit over the structure.

8.5.4.2 Trackwork

Consideration shall be given to the thermal force interaction between the structural components and the trackwork system, as specified in section 8.2.14.

8.5.4.3 Fatigue

Consideration shall be given to the effect of change of stress levels caused by passage of rail trains over structures. Over the life of the structure, 3 million cycles of maximum stress shall be used in estimating the number of repetitive maximum stress cycles.

8.5.4.4 Uplift

Provision shall be made for adequate attachment of the superstructure to the substructure should any combination of loading produce uplift at any support. Where DL, E, or any other loadings tend to reduce the uplift effect, the corresponding load factors shall be taken as 0.9 for DL, 0.75 for E, and zero for other loadings.

8.5.4.5 Friction

Where applicable, friction shall be considered in the design.

8.5.4.6 Stray Current Provisions

Stray current provisions are detailed in Chapter 17, Corrosion Control.

8.5.4.7 Sound Barriers

Sound barriers, if required by the project, shall be considered in the design.

8.5.5 Reinforced and Prestressed Concrete Design.

Reinforced and prestressed concrete members for aerial structures shall conform to the requirements of section 8.9, except as modified below.

8.5.5.1 Camber and Deflections

As a guide in design, the total long-term predicted camber growth occurring after installation of the rails shall be limited to 1/2000 of the span length for unballasted, prestressed concrete aerial structures. The camber growth prior to trackwork construction shall be limited to 1/1600 of the span length, unless approved otherwise.

8.5.5.2 Live Load Deflections

A. Girders of simple or continuous spans shall be designed so that the deflections due to LL plus impact shall not exceed 1/1000 of the span length. The deflection of cantilever arms due to LL plus impact shall be limited to 1/375 of cantilever arm.

B. For deflection calculations only, normal loading of the transit vehicle (AW1 per section 12.3.A) may be considered. Live load shall consist of all tracks loaded as specified in section 8.2.2.

8.5.5.3 Longitudinal Tension Stresses in Prestressed Members

Longitudinal tension stresses shall not exceed the values permitted by AASHTO.

8.5.5.4 Shrinkage and Creep

Stresses and movements resulting from concrete shrinkage and creep shall be taken into account in the design of the structures in accordance with AASHTO.

8.5.5.5 Structure Deformations and Settlements

All structure deformations, including foundation settlement, shall be considered, not only for their effect on structural behavior, but also for their effect on trackwork. The control of deformations through proper structural design is of paramount importance in obtaining acceptable ride quality for the transit vehicles.

8.5.5.6 Crack Control

A. The provision for controlling flexural cracking described in ACI 318 shall apply to all structures. For prestressed concrete aerial structures, consideration shall be given to the effect of temporary loads imposed by sequence of construction stages, forming, falsework and construction equipment, as well as the stresses created by lifting or placing precast members, stress concentration (non-uniform bearing at the ends of precast beams), end block design and detailing, methods of erection, shrinkage and curing. The Designer is responsible to ensure that the structural design of all prestressed or reinforced concrete members is adequate and clear, and that precise specifications are prepared which are compatible with the design so that objectionable cracking does not occur in erection or service.

B. The use of large bars in the highly compressed anchorage area should be avoided.

8.5.6 Structural Steel Design

A. Structural steel and composite steel-concrete flexural members for aerial structures shall conform to the requirements of section 8.10.

B. The requirements governing LL deflections and structure deformations and settlements as outlined for reinforced and prestressed concrete design shall also apply to structural steel design.

8.5.7 Foundations

Under any service load combination, the foundation of the aerial structures shall be so designed that the calculated differential settlement

between adjacent piers shall not cause a gradient in the rail profile which exceeds 1/2400 of the sum of the lengths of any two adjacent spans. Differential settlement between any adjacent structural supports shall not exceed 1-1/2 inches, unless approved by Sound Transit.

8.5.7.1 Spread Footings

The design shall keep the maximum soil pressure for the various loading combinations within the design bearing capacity and soil pressures as nearly uniform as practicable. Spread footings shall be considered to be shallow foundations.

8.5.7.2 Pile Substructures

A. Pile substructures shall be designed so that the load on any pile does not exceed its design capacity. Design should allow for an accidental misplacement of the center of gravity of the substructure, 6 inches in any direction. Pile substructures shall be considered to be deep foundations.

B. For Group I loading, the uplift force on any friction pile shall not exceed 5 percent of its design capacity. For other group loadings, the uplift on any pile shall not exceed 50 percent of its design capacity. All proposed deviations shall be submitted to Sound Transit for prior approval.

C. Uplift shall not be permitted for bearing piles or combination bearing and friction piles.

8.5.7.3 Drilled Shafts

The design shall keep the soil pressure at the base of the shaft within its bearing limits. Design should allow for an accidental misplacement of the center of gravity of the substructure, 6 inches in any direction.

8.5.7.4 Lateral Resistance

A. Consideration shall be given to the ability of piles or drilled shafts to resist lateral loads. When the lateral resistance of the soil surrounding piles is inadequate to counteract the horizontal forces transmitted to the foundation or when increased rigidity of the entire structure is required, battered piles shall be used in a pile foundation. Battered piles shall have a slope not greater than one horizontal to three vertical. Where battered piles are to be used, consideration shall be given to the possibility of such battered piles encroaching on property outside the right-of-way lines. The connections of

battered piles to the pile cap shall be capable of sustaining load reversals and impact loading from seismic events.

B. The axial loads on piles and shafts shall be determined by static analysis of the moment resistant group, by the method of elastic center, or by any other satisfactory method. Each member, vertical or battered, in a pile or drilled shaft group may be assumed to have lateral resistance capacity, in addition to the horizontal component of the axial load on the battered members, equal to the least of the following values:

1. As recommended by the Geotechnical Consultant.

2. That of the pile or drilled shafts as a structural member.

3. Ten percent of the member's design compressive capacity perpendicular to the strong axis only.

C. Unless a pile or shaft is installed to a sufficient depth in competent material to develop fixity, it shall be assumed to have no capacity to resist lateral loads in bending.

D. The lateral resistance capacity of pile shafts shall be determined by the Geotechnical Consultant.

8.5.7.5 Selection of Foundation Types

A. A deep foundation shall be used when a shallow foundation cannot be designed to carry the applied loads or distortions safely and economically. It shall also be used where scour, erosion or settlement might occur, and the soil conditions permit its use, even though the bearing capacity of the soil is sufficient to make practical the use of shallow foundations.

B. It is the designer's responsibility to select a foundation type or types. Such selection shall be based upon conditions prevailing at the site, cost, availability, and the desire to stimulate competition among the suppliers of alternate materials.

8.5.8 Segmental Bridges

Design and construction of segmental bridges shall be to the requirements of AASHTO's Guide Specifications for the Design and Construction of Segmental Bridges.

8.5.9 Mechanically Stabilized Earth Walls (MSE)

Design and construction of mechanically stabilized earth walls, MSE, shall be in accordance with the requirement of FHWA, "Mechanically Stabilized Earth Walls and Reinforced Soil Slopes Design and Construction Guidelines", Publication No. FHWA-SA-96-071. Seismic requirements are in accordance with Chapter 8A, Seismic Design.

8.6 LOADING COMBINATIONS

The following groups represent various combinations of loads and forces to which a structure may be subjected. Each component of the structure shall be proportioned to withstand safely all group combinations of forces that are applicable to the particular site or type. Group loading combinations for Load Factor Design and Services Load Design are given in Table 8-2 and Table 8-3 respectively:

Table 8-2
Loading Combination Factors

Load Factor Design

GROUP		GAMMA FACTOR	BETA FACTORS												
		D	(LL+IV+IH)		CF	E	B	SF	W	WL	LF	Ps *	R+S+T	EQ	ICE
			LRV	DR											
IRV	1.30	βD	1.67	0	1	βE	1	1	0	0	1	0.77	0	0	0
II	1.30	βD	0	0	0	βE	1	1	1	0	0	0.77	0	0	0
III	1.30	βD	1	0	1	βE	1	1	0.3	1	1	0.77	0	0	0
IV	1.30	βD	1	0	1	βE	1	1	0	0	1	0.77	1	0	0
V	1.25	βD	0	0	0	βE	1	1	1	0	0	0.77	1	0	0
VI	1.25	βD	1	0	1	βE	1	1	0.3	1	1	0.80	1	0	0
VII **															
VIII	1.30	βD	1	0	1	βE	1	1	0	0	1	0.77	0	0	1
IX	1.20	βD	0	0	0	βE	1	1	1	0	0	0.83	0	0	1
X ***	1.30	βD	1.67	0	0	βE	0	0	0	0	0	0.77	0	0	0
XI	1.30	βD	1	0.77	1	βE	1	1	0	0	0	0.77	0	0	0

* Ps = Pre-stressing Force

other
** Group VII = See Section 8A.7.4

*** Applies only to culverts. Other groups do not apply to culverts.

(See Chapter 8A for Seismic Design)

βD = 0.75 when checking columns for maximum moment or maximum eccentricities and associated axial load and when Dead Load effects are opposite sign to the net effects of loads in a Group.

βD = 1.00 when columns for maximum axial load and associated moment.

βD = 1.00 for flexural and tension members and for culverts.

βE = 1.00 for vertical earth pressure and for rigid culverts.

βE = 1.30 for lateral earth pressure. (Not for culverts.)

βE = 0.50 for checking positive moments in rigid frames.

βE = 1.50 for flexible culverts.

Table 8-3
Factors for Service Load Design*

GROUP	GAMMA FACTOR	BETA FACTORS												
		D	LL+I	CF	E	B	S_F	W	WL	L_F	Ps	R+S+T	ICE	%
I	1.0	1	1	1	1	1	1	0	0	0	1	0	0	100
II	1.0	1	0	0	1	1	1	1	0	0	1	0	0	125
III	1.0	1	1	1	1	1	1	0.3	1	1	1	0	0	125
IV	1.0	1	1	1	1	1	1	0	0	0	1	1	0	125
V	1.0	1	0	0	1	1	1	1	0	0	1	1	0	140
VI	1.0	1	1	1	1	1	1	0.3	1	1	1	1	0	140
VIII	1.0	1	1	1	1	1	1	0	0	0	1	0	1	140
IX	1.0	1	0	0	1	1	1	1	0	0	1	0	1	150

* Not applicable for culvert design. Use Load Factor Design.

% Indicates percentage of basic unit stress.

No increase in allowable unit stresses shall be permitted for members or connection carrying wind loads only

When EQ loads are applied, Load Factor Design shall be used to analyze their effects.

LL includes LRV

I includes Iv and I_H

Ps is Pre-stressing Force

8.7 LOAD DISTRIBUTION

8.7.1 Distribution to Longitudinal Members

Live load shall be distributed in accordance with the provisions of AASHTO with the following modifications:

8.7.2 Distribution in Concrete Slabs

8.7.2.1 Ballasted Track

A. Axle loads may be assumed as uniformly distributed longitudinally over a length of 3 feet, plus the depth of ballast under the tie, plus twice the effective depth of slab, except as limited by axle spacing.

B. Wheel loads may be assumed to have uniform lateral distribution over a width equal to the length of the tie plus the depth of ballast under the tie, except as limited by the proximity of adjacent tracks or the extent of the structure.

8.7.2.2 Direct Fixation Track

A. Where wheel loads are transmitted to the deck slab through rail mountings placed directly on the slab, the wheel load shall be assumed as uniformly distributed over a length of 3 feet along the rail. This load may be distributed transversely (normal to the rail and centered on the rail) by the width of the rail fastener pad plus twice the depth of the deck and track concrete.

B. For derailment loads where the vehicle wheels bear directly on the slab, the wheel loads shall be assumed to be distributed over 3 feet of the slab in a direction perpendicular to the main reinforcement.

8.8 SOILS AND GEOLOGIC DATA

8.8.1 Geotechnical Reports

A. The Geotechnical Consultants will investigate the subsurface conditions, perform laboratory testing, describe the geologic features of the area, and make recommendations relative to geotechnical behavior to be considered for design and construction. These findings are given in the various Geotechnical Data, Baseline, Characterization and Engineering Recommendations Reports.

B. Earth, rock, and water pressures on the structures may vary considerably with geographic location. These pressures and other geotechnical parameters shall be determined by the designers through reference to the geotechnical reports and by consultation with the Geotechnical Consultants.

C. Design bearing and frictional values for foundations shall be determined by the designer through reference to the geotechnical reports and by consultation with the Geotechnical Consultant.

D. Based upon available existing soils and geologic data, on data obtained from the geotechnical investigation and on the professional judgment of the designer, the designer shall identify and recommend for further investigation all known or suspected areas of the alignments where unusual soils or geologic conditions exist.

E. For structures subject to the jurisdiction of local authorities, the design bearing and frictional values for foundations shall not exceed the limits given by the local building code, except for deviations as provided for in the code.

8.9 REINFORCED AND PRESTRESSED CONCRETE

8.9.1 Minimum Concrete Design Strengths

A. For all underground reinforced concrete cast-in-place structures including box lines and stations, abutments, retaining walls, shafts, cross-passageways, portals, U-sections, spread footings, piles, drilled-in caissons, and basement walls - f'_c = 4,000 psi.

B. For all aboveground reinforced concrete cast-in-place structures including columns, cap beams, and superstructure for aerial structures and bridges, columns, beams, slabs, foundations, and walls for buildings and Central Control Facility - f'_c = 4,000 psi.

C. For prestressed concrete - f'_c = 5,000 psi.

D. For precast prestressed members - f'_c = 5,000 psi.

E. For all building foundations, floor slabs, pits and other miscellaneous foundations at yards and shops, miscellaneous foundations other than those specified, and station platform foundations - f'_c = 3,000 psi.

F. In certain cases, strengths of concrete other than those specified above might be required. These cases will be as directed by Sound Transit.

8.9.2 Reinforcing and Prestressing Steel

A. Reinforcement resisting earthquake-induced flexural and axial forces in frame members and in wall boundary members shall comply with ASTM A706 and A615, Grades 60 and 40 for primary and secondary reinforcement respectively.

B. Prestressing steel shall conform to the following requirements:

1. Stress relieved steel wire ASTM A421 Grade 240

2. Stress relieved steel strand ASTM A416 Grade 270

3. High tensile steel bar ASTM A722 Grade 150

C. To the extent possible, main reinforcing bars shall be spaced at 6 inches, 9 inches, or 12 inches on center in elements of tunnels, cut-and-cover subway, retaining walls, bridge structures, and stations. Exceptions to this rule include columns, stairways, and thin slabs.

D. Standardization of spacing is intended to simplify design details, checking of bar placement, and field inspection. Spacing should also consider ease of concrete placement, room for embedded items, decrease in concrete coverage due to lapped splices, and the blockages that might occur by crossings of closely spaced reinforcement. Bar sizes should be selected to avoid crowding, particularly where larger size rebars are used. When bars are lap spliced, the spacing of the rebars must be such that a clear space of at least 3 inches is available between the lapped pairs to permit entry of vibrator.

8.9.3 Methods of Design

A. For all underground rail transit cast-in-place reinforced concrete structures including lines and stations, shafts, cross passageways, portals, and U-sections, the design shall be by the strength design method.

B. For all aboveground and aerial structures, the design shall be by strength design method or load factor design method.

C. Prestressed concrete design shall be designed by both allowable stress and load factor design in accordance with AASHTO.

8.9.4 Joints in Cut-and-Cover Structures

A. The following definitions are used to classify the three types of joints referred to in this chapter – expansion joints, contraction joints, and

construction joints. There are two broad classes of joints: movement joints that allow movement along the longitudinal member axis, and non-movement joints that do not allow movement. There are two general types of movement joints: expansion and contraction joints. Expansion joints can open and close. Under temperature drops and shrinkage, an expansion joint opens. Under a temperature rise, an expansion joint closes. An expansion joint is generally constructed with an open gap. Contraction joints are designed to only open. Contraction joints open under temperature drops and shrinkage. A contraction joint is generally constructed closed. Non-movement joints neither open nor close during temperature changes or shrinkage. A construction joint is a joint placed for the contractor's convenience in sequencing concrete placement. A construction joint can be either a movement or a non-movement joint.

B. To promote water tightness and structural integrity and in view of relatively uniform internal temperatures in the massive main members of subway structures, expansion joints need not be provided within the subway line or station structures, but construction and contraction joints shall be provided in accordance with provisions stipulated below. At locations of major change in structure section, e.g., from cut-and-cover line to station or from cut-and-cover structure to open-cut structure, construction joints shall be provided. Where a box line section meets a station section, the connection shall be designed either to absorb any differential movements or to transmit the forces that may occur under any design conditions. In all cases, thorough consideration shall be given to water-tightness.

C. To control shrinkage stresses in monolithically poured concrete slabs and walls and to minimize cracking, contraction joints shall be provided at spacings not exceeding 50 feet, and closer if appropriate to the framing construction. Joints shall have proportion reinforcing steel continuous across the joint, keys, roughened joints, or other positive means of shear transfer; in all exterior elements in contact with soil or rock, joints shall have nonmetallic water stops.

D. Temperature and shrinkage reinforcement, as provided for by applicable specifications and codes, shall be installed continuous in all walls and slabs of these underground structures.

8.9.5 Waterproofing

8.9.5.1 Stations and Crossovers

Membrane waterproofing shall be provided over entire mined and cut-and-cover station and crossover structures. Boundary condition details, such as reglets, flashing, and laps, shall be shown on the Contract Drawings.

8.9.5.2 Equipment Rooms

A. Train control rooms, electrical rooms, and auxiliary equipment spaces shall have those roofs and walls in contact with earth waterproofed by an external membrane. Where the base floor is subjected to hydrostatic pressure, it shall be sloped to drain and the equipment shall be installed on raised pads. The equipment should be located as to permit repair of leaks while the equipment is in operation.

B. Substations, switchgear, and similar rooms shall have roof surfaces waterproofed with an external membrane as previously described.

C. Line ventilation and sump pump rooms shall not be specially waterproofed, but shall be designed to prevent moisture intrusion into the equipment to the greatest extent possible.

D. Conduits leading from walls or roofs of any of the above spaces shall be so installed as to prevent water running in or along the conduit to the equipment.

8.9.5.3 Line Section

External waterproofing need not be applied to reinforced concrete cut-and-cover line sections above or below the water table, provided that the individual external elements roof, walls, base slab are 18 inches or more thick, except in areas where hazardous or toxic gases are anticipated to be encountered.

8.9.5.4 Repairs

A. Provision for injection sealing of leaks in walls and slabs shall be made for all underground reinforced concrete rail structures.

B. Special consideration shall be given to design details and construction sequences for reduction of cracking. Also, specifications shall have provisions that promote high concrete density and impermeability by controlling the water cement ratio, the proportions of cement and pozzolan materials, and the placement and curing temperature of the concrete.

C. Leaks shall be repaired in accordance with the Specifications.

8.9.6 Architectural Considerations

To ensure uniformity of structural concrete color in public areas of the stations, it will be necessary to standardize concrete mix and strength, the aggregate source, and the brand of cement to be used in any given area. This will apply to all concrete exposed to public view within the stations or to the concrete exposed to view from outside the stations.

8.10 STRUCTURAL STEEL

Consideration shall be limited to the following types of structural steel. Other types may be used only with the approval of Sound Transit.

8.10.1 Structural Steel

For normal use - ASTM A36.

8.10.2 High-Strength Structural Steel

For uses requiring higher-strength steels or where economically justifiable - ASTM A242, A441, A514, A572, and A588.

8.10.3 Connections

A. Shop connections as detailed by the designer shall be welded unless otherwise approved. Welding shall be in accordance with the current code or specifications of the American Welding Society, Inc., D1.1 Series, as applicable.

B. Field connections shall be designed for high-strength bolts or welding. High-strength bolts shall be ASTM A325 unless otherwise approved by Sound Transit.

8.11 SUPPORT AND UNDERPINNING OF EXISTING STRUCTURES

8.11.1 General

A. The designer, in consultation with the Geotechnical Consultant, shall investigate all structures to remain over, or adjacent to, the work, and shall prepare all necessary designs for their protection or permanent support and underpinning.

B. All buildings or structures to be considered shall include, but will not be limited to, the following:

1. Buildings or structures that extend over the transit structures to such an extent that they must be temporarily supported during construction and permanently underpinned.

2. Buildings or structures immediately adjacent to the transit structures that must be carried on underpinning. These are to be braced to act as retaining elements supporting the sides of the excavation.

3. Buildings or structures that may be affected by groundwater lowering. In certain areas, uncontrolled lowering of the groundwater for rail transit construction may cause settlements of buildings either adjacent to or some distance from the cut-and-cover or tunneled excavation.

4. Any other buildings or structures for which Sound Transit and the Geotechnical Consultant agree that it is appropriate for the designer to prepare designs.

C. Underpinning walls or piers supporting buildings or structures and forming a portion of the excavation support system shall be extended to a minimum depth of 2'-0" below subgrade elevation of the underground transit structure, or to sound bearing material, whichever is greater.

8.11.2 Methods

Methods used to underpin or protect these buildings or structures shall depend on local soil conditions and may include the following:

8.11.2.1 Pier, Pile, or Caisson Method of Underpinning

If soil conditions, structure size, and proximity to the underground light rail structure dictate underpinning piers, piles, or caissons, they shall, in general, extend below a sloped line drawn from the side of the excavation at a point 2'- 0" below subgrade elevation to the intersection with the vertical projection of the underpinned building foundation, or to sound bearing material whichever is greater. The slope of this line shall be established by the designer in consultation with the Geotechnical Consultant.

8.11.2.2 Protection Wall Method of Structure Protection

Under some soil conditions, the supporting system for the excavation will be sufficient to protect light structures. Under heavier loading conditions, a reinforced concrete cutoff wall, constructed in short clay-slurry-filled (slurry wall) trenches or bored pile sections (tangent or secant pile walls) braced with

preloaded struts, may be considered as an alternate to underpinning or to avoid settlement due to dewatering.

8.11.2.3 Stabilization of Soil

In general, techniques such as freezing and chemical injections for the stabilization of soil under buildings in lieu of underpinning shall not be specified in the design phase. However, after consultation with the Geotechnical Consultant, these techniques may be considered as alternatives to solve problems attendant to localized soils.

8.11.2.4 Temporary Bracing Systems

A tight bracing system is important to minimize temporary support movement underpinning and for protective wall support. In addition to the general requirements for support of excavation that are provided in the specifications, the designer shall indicate special requirements for the installation and removal of the temporary bracing systems that relate to the designs of underpinning and protection walls, such as the levels of bracing tiers, the maximum distances of excavation below an installed brace, and the amount of preloading. However, the detailed design of the temporary bracing system shall be the responsibility of the contractor based on the overall criteria given in the documents.

8.12 SUPPORT OF EXCAVATION STRUCTURES

A. Detailed design of the temporary decking, sheeting, and bracing shall be prepared by the contractor and reviewed by the designer, based upon criteria and design standards included in the Contract Drawings and Specifications.

B. The designer shall perform a conceptual/preliminary design of decking, sheeting, and bracing utilizing the criteria that will appear in the contract documents. The design shall be for the purposes of evaluating the support of excavation problems associated with the underground construction, of determining the need for supplementing or revising the criteria, and of arriving at a cost estimate for decking, sheeting, and bracing.

C. The designs shall not be shown in the Contract Drawings except to the extent necessary to clarify unique situations not adequately addressed by the written criteria. In any event, detail design of decking, sheeting, and bracing shall not be shown.

D. It shall be a requirement in the Contract Documents that the design of support of excavation structures be prepared and certified by a registered structural engineer in the State of Washington. The review and acceptance

of the designs submitted by the contractor shall be made by a registered structural engineer in the State of Washington.

8.13 SURFACE STATIONS AND BUILDINGS

8.13.1 Surface Stations

Surface stations are defined as those stations with platforms constructed at-grade (at grade stations) or above ground (aerial stations). Surface stations included in the Transit Projects shall be designed in accordance with section 8.1.2, and Chapter 9, Stations. Loads and forces shall be as specified in section 8.2.

8.13.2 Buildings

A. Buildings included in the Light Rail Projects shall be designed in accordance with the requirements of section 8.1.2 and section 8.2, and Chapter 19, Operations and Maintenance Facility. Wind loading on the building shall be based on a wind velocity of 85 miles per hour with Exposure A and/or B.

B. New building by private developers representing commercial interests or other public agencies that are planning pedestrian entrance access to Sound Transit facilities must have their designs reviewed by Sound Transit. This includes not only plans for physical attachment, but also all new construction within the influence zone of the existing facilities.

C. A lateral separation of 8 feet shall be maintained between the finished exterior walls and foundations of underground station facilities and those of new building construction if seismic isolation is to be assumed. Similarly, a vertical separation of 8 feet should be maintained between the finished exterior roofs of underground station facilities and the mat or spread footing foundations of new building construction. All new construction closer than this, the developers shall demonstrate seismic isolation by submitting calculations.

D. High-rise tubular buildings, that create large perimeter loads on their foundations during seismic events, shall be analyzed as special cases. This analysis shall demonstrate the pressures created by the building foundations do not exceed the design loads on the facilities using accepted geotechnical techniques of analysis.

E. Where joint development passageways interface directly with Transit station facilities, calculations shall be provided to demonstrate the new building elements have sufficient seismic and differential settlement ductility, as not to cause overstress to existing or new structural elements. The details shall be provided to demonstrate that

waterproof integrity of the new construction with the existing station structure can be maintained for its anticipated service life.

F. In areas where the geotechnical investigation for the Transit facilities, or that of the planned or joint development construction suggests a potential for the seismic consolidation or liquefaction of the soil, a special structural and geotechnical analysis of both designs shall be undertaken by the developers.

G. Temporary support of transit facilities during the adjacent excavation for new buildings will be such that at any level, the station shell static lateral displacement shall not exceed 0.0005 times its overall height above the bottom of the base slab. The lateral forces used for the design of temporary excavation support shall consider both the static and dynamic loads for which the facility was designed. Where temporary support elements are used, details shall be provided to demonstrate that membrane waterproofing shall not be damaged.

H. Subsurface areas of new buildings where the public has access or that cannot be guaranteed as a secure area, such as parking garages and commercial storage and warehousing, will be treated as areas of potential explosion. NFPA 130, Standard for Fixed Guideway Transit Systems, life safety separation criteria will be applied that assumes such spaces contain Class I flammable, or Class II or Class III combustible liquids. For structural and other considerations, separation and isolation for blast shall be treated the same as for seismic, and the more restrictive shall be applied.

I. All static, dynamic, and geotechnical zone of influence calculations provided in support of the above criteria, will be sealed by a structural engineer licensed in the State of Washington. Zone of influence calculation shall be based on intergranular soil pressures that consider the worst possible hydrostatic condition that might occur during the service life of the Transit facilities.

8.14 MISCELLANEOUS STRUCTURES

8.14.1 Gratings

The following grating types shall be adopted as standards for use in Light Rail Projects:

A. For Light Loading	**For general use not subject to vehicular loads**
Bearing bars	1-1/4" x 3/16" on 1-3/16" centers
Crossbars	4" centers
Maximum allowable deflection	1/200 span
Grating type	Rectangular serrated
Material	Steel, hot-dip galvanized
B. For Heavy Loading	**Grating subject to vehicle wheel loads**
Bearing bars	4" x 1/4" on 1-3/16" centers
Crossbars	4" centers
Design loading	AASHTO HS 25
Maximum allowable deflection	1/300 span
Grating type	Rectangular-plain
Material	steel, hot-dip galvanized
C. For Sidewalks	
Bearing Bars	2-1/2" x 3/16" on 15/32" centers
Crossbars	4" centers
Design Loading	100 psf
Maximum allowable deflection	1/300 span
Grating type	Rectangular-plain
Material	Steel, hot-dip galvanized

8.14.2 Emergency Access Shafts

A. Hatches on access shafts shall be readily unlatched from the inside of the subway by means of panic hardware and opened by means of a key-operated device from outside the subway in accordance with the Fire and Intrusion Alarm System. Continuous handrails shall be provided in access shaft passageways as well as on stairways.

B. Access hatches shall be protected from surface water. Allowances must be made to divert surface water to the drainage system, away from the hatches.

C. Where doors are required, they shall open in the exit direction at the subway level and at the surface level. Where locks are required, they shall be provided with panic hardware. Doors shall also meet the fire rating specified in the local codes.

D. All doors and hatches shall be provided with the means for future installation of intrusion detection systems.

8.14.3 Structures Supporting Pedestrian Traffic Only

To avoid the possibility of resonant vibrations induced by pedestrian traffic, the natural frequency of the unloaded structure shall be not less than 2.0 cycles per second. To avoid vibrations that might be objectionable to patrons, the calculated live load deflection, in inches, shall be limited to the span length, in feet, divided by 67, or 1 inch maximum.

8.14.4 Parapets

Where parapets are used, they shall be designed to withstand dead load, wind load, force due to thermal expansion and contraction, shrinkage force, and earthquake forces equal to the full dead load of the parapet acting at the center of mass of the component parts.

8.14.5 Underground Structures

Miscellaneous items in underground structures subject to air pressure caused by running trains including walls, ceilings, doors, and ductwork shall be designed to meet or exceed these pressures.

8.14.6 Elevators

The surface structure shall be designed for the loads described below:

A. Dead load of structure.

B. Live load of 100 plf applied at the free edges of the frame.

C. Wind load of 40 psf on windward side.

8.14.7 Escalators

The support elements shall be designed for the end reactions from the escalators.

8.15 REFERENCES

1. ***"Design Guideline for the Thermal Interactive Forces Between Continuously Welded Rail and the NJ TRANSIT LRT Aerial Structures";*** by Parsons Brinckerhoff Quade & Douglas, Inc., July 1995.

2. ***"Thermal Interaction Between Continuously Welded Rail and Elevated Transit Guideways";*** by Hid N. Grouni and Chris Sadler, Structural Office Ontario Ministry of Transportation and Communications.

3. ***"Continuous Welded Rail/Aerial Structure Interactive Behavior Report"***; prepared for Dallas Area Rapid Transit by Parson Brinckerhoff Centec, Inc. and DeLeuw Cather & Company, June 1988.

4. ***"Aerial Transit Structure Interaction Analysis"***; by American Transit Consultants, September 1990.

END CHAPTER 8

8A. SEISMIC DESIGN

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8A. SEISMIC DESIGN

8A.1 INTRODUCTION

8A.1.1 Scope

A. The seismic design criteria for structures on the North and Airport Link light rail Transit Project (Link) are established in this document. Items in this category include aerial structures, bridges, cut-and-cover line structures, tunnels, stations, retaining walls, surface buildings, miscellaneous permanent structures, and nonstructural components and equipment. Provisions of these criteria do not apply to at-grade ballasted track.

B. This document supplements Chapter 8, Structural – Link Systems (DCM), prepared for the Central Link Project. Except where modified or supplemented by this document, the structural design shall meet the requirements of Chapter 8, Structural of the Design Criteria Manual and applicable portions of the current editions of the design codes, manuals, and specifications listed in Chapter 8, Structural, Section 8.1.2.

C. This document has been written to address the general seismic design conditions that apply to the project. Where there are cases of special designs encountered that are not specifically covered by these criteria, the designer shall bring them to the attention of Sound Transit to determine the technical source for the design criteria to be used.

8A.2 DESIGN POLICY

A. Sound Transit has adopted a two-level earthquake hazard design approach for this project. The two earthquake hazard levels are the Operating Design Earthquake and the Maximum Design Earthquake.

B. The Operating Design Earthquake (ODE) is defined as an earthquake event that has a return period of 150 years. Such an event can reasonably be expected to occur during the 100-year facility design life. The probability of exceedance of this level of event is approximately 50 percent during the facility design life.

C. The Maximum Design Earthquake (MDE) is defined as an earthquake event that has a return period of 2,500 years. Such an event has a small probability of exceedance during the 100-year facility design life. The probability of exceedance for the MDE is approximately 4 percent during the facility design life.

8A.3 DESIGN OBJECTIVES

A. For the Operating Design Earthquake (ODE), which is likely to occur more than once during the normal life expectancy, the structure shall be designed to respond without significant structural damage, which can be repaired during normal operating hours.

B. For the Maximum Design Earthquake (MDE), which has a low probability of being exceeded during the normal life expectancy, the structure shall be designed to survive the deformation imposed on the structure, to avoid major failure, and to maintain life safety. The goal is to provide adequate strength and ductility to prevent collapse of the structure.

8A.4 DESIGN CODES, MANUALS, AND SPECIFICATIONS

The structural design for seismic loading shall meet applicable portions of the current editions of the codes, manual, or specifications identified in this supplemental specification, in accordance with the Design Criteria Manual –Link System (DCM).

8A.5 DESIGN EARTHQUAKE PARAMETERS

8A.5.1 Earthquake Sources

A. Based on regional tectonism and the local geological features, three types of seismic sources are recognized for seismic hazard evaluation purposes: (1) deep subcrustal (intraplate) earthquakes, (2) Cascadia subduction interface earthquakes, and (3) shallow crustal earthquakes. Historically, the significant events to affect the Seattle area were from the deep subcrustal sources. Since 1900, five subcrustal earthquakes of magnitude 6 or greater have occurred in the Puget Sound area, including the 1949 Olympia (M_s=7.1) and 1965 Seattle-Tacoma (M_s=6.5) events both known to have caused considerable damage in the area. Subcrustal earthquakes are deep (45 to 60 km below surface) and are believed to occur within the down-going portion of the subducted oceanic plate (Juan de Fuca Plate).

B. The Cascadia subduction interface earthquakes occur along the interface between the subducted oceanic crust and the overriding North American continental crustal plate. Despite the lack of regionally reported historical occurrence of such an earthquake, there is evidence of sudden subsidence of coastal marshes and turbidites (avalanche-like deposits of sand) on the deep sea floor triggered by ground shaking. Dating of buried marsh and forest soils suggests that events of magnitude of 8.5 or larger have occurred several times in the 3500 past years. The best evidence available suggests that on

the average these great earthquakes occur every 500 – 600 years, producing events as large as magnitude 9.0.

C. The shallow crustal earthquakes occur principally along crustal faults in the North American plate. The focal depths of these types of earthquakes are generally relatively shallow, in the range between 10 to 15 km. In the Puget Sound area, there are not many known crustal faults. The most prominent of the major known crustal faults is the Seattle thrust fault, which trends east-west through south downtown Seattle and crosses beneath one of the at-grade segments of the proposed Link Light Rail Transit line. Recent geological evidence indicates that the Seattle fault may have ruptured a little more than 1,000 years ago, producing an earthquake of magnitude on the order of 7.0.

D. Table 8A-1 summarizes some of the parameters associated with the three principal earthquake sources considered for this project.

Table 8A-1: Earthquake Sources

Earthquake Sources	Maximum Considered Moment Magnitude (Mw)	Focal Depth (km)	Rupture Distance to Project Site (km)
Shallow Crustal (Seattle Thrust Fault)	7.0 ~ 7.5	10 ~ 15	1 ~ 20
Deep Subcrustal (Intraplate)	7.5	45 ~ 60	45 ~ 60
Cascadia Subduction Interface	8.5 ~ 9.0	20 ~ 40	120 ~ 170

8A.5.2 Design Ground Motion Parameters

Unless explicitly noted in this document, the seismic design of the structures of the Link light rail Transit Project (Link) shall be based on the design ground motion parameters specified in this section.

8A.5.2.1 Design Acceleration Response Spectra

A. Design horizontal acceleration response spectra representing the MDE and ODE for rock sites are presented in Figure 8A.1. The MDE spectra correspond to a 2,500-year return period earthquake and the ODE spectra represent a 150-year return period event. These design rock acceleration spectra are for NEHRP B-C boundary subsurface conditions (i.e. rock characterized by a shear wave velocity of 2,500 feet per second) and are

based on the latest seismic hazard study conducted by the US Geological Survey (USGS, 1996) for the Seattle area. The horizontal spectra are applicable for the analysis of structures under seismic motions in any horizontal direction. The vertical acceleration response spectra shall be taken as two-thirds (2/3) of the horizontal spectral values.

B. The MDE ground motions are governed by the shallow crustal Seattle Fault earthquakes, due primarily to the short rupture distance to the project site. The corresponding design earthquake magnitude for the MDE level design is 7.5 (moment magnitude).

C. The ODE ground motions are governed by the deep subcrustal earthquakes because of the relatively short return period for their occurrence (see section 8A. 5.1.1). A moment magnitude of 7.5 shall be used for the ODE level design.

D. Table 8A-2 provides the definitions of various site classes. The horizontal acceleration response spectra for soil site Classes C and D for the MDE design and soil site Classes C, D and E for the ODE design, along with their respective rock site (Class B) spectra are shown in Figures 8A.2 and 8A.3 respectively. These soil spectra are derived in accordance with the 1997 Edition NEHRP's recommended procedure.

E. The site classes shall be determined by the Final Design Geotechnical Consultant using one of the following three methods with mean shear wave velocity ($\check{C}_s$), mean standard penetration testing blow count ($\check{N}$), and mean undrained shear strength $\check{S}_u$.

1. $\check{C}_s$ for the top 100 feet ($\check{C}_s$ method).

2. $\check{N}$ for the top 100 feet ($\check{N}$ method).

3. $\check{S}_u$ for cohesive soil layers (PI > 20) in the top 100 feet (S_u method) and $\check{N}_{ch}$ for cohesionless soil layers (PI < 20) in the top 100 feet. If the $\check{S}_u$ and $\check{N}_{ch}$ criteria differ, select the softer site class (e.g., use Site Class E instead of D).

F. Site class parameters $\check{C}_s$, $\check{N}$ and $\check{S}_u$ shall be determined in the upper 100 feet of the site soil. Profiles containing distinctly different soil layers shall be subdivided into those

layers designated by a number that ranges from 1 to n in the upper 100 feet. The definitions of $\check{C}_s$, $\check{N}$, $\check{N}_{ch}$ and $\check{S}_u$ are as follows:

$\check{C}_s = \Sigma_{(i=1:n)}\, d_i \,/\, \Sigma_{(i=1:n)}\, (d_i / C_{si})$

where: d_i = Thickness of any layer, i , between 0 and 100 feet.
C_{si} = shear wave velocity of layer i.
$\Sigma_{(i=1:n)}\, d_i$ = 100 feet.

$\check{N} = \Sigma_{(i=1:n)}\, d_i \,/\, \Sigma_{(i=1:n)}\, (d_i / N_i)$

where: d_i = Thickness of any layer, i , between 0 and 100 feet.
N_i = Standard Penetration Resistance (ASTM D1586-99), not to exceed 100 blows/foot as directly measured in the field without corrections.
$\Sigma_{(i=1:n)}\, d_i$ = 100 feet.

$\check{S}_u = d_c \,/\, \Sigma_{(i=1:k)}\, (d_i / S_{ui})$

$\check{N}_{ch} = d_s \,/\, \Sigma_{(i=1:m)}\, (d_i / N_i)$

where: S_{ui} = undrained shear strength, not to exceed 5 ksf.
d_i = Thickness of any layer, i , between 0 and 100 feet.
N_i = Standard Penetration Resistance (ASTM D1586-99), not to exceed 100 blows/foot as directly measured in the field without corrections.
d_i = thickness of layer i.
$d_c = \Sigma_{(i=1:k)}\, d_i$ = total thickness ($100-d_s$) of cohesive soil layers in the top 100 feet.
$d_s = \Sigma_{(i=1:m)}\, d_i$ = total thickness ($100-d_c$) of cohesionless soil layers in the top 100 feet.

G. The acceleration response spectra for various site classes are also presented in tabular form in Tables 8A.3 and 8A.4 for MDE and ODE respectively. For soil sites classified as Classes E and F, special investigation study shall be conducted to properly investigate the dynamic properties of the soils. Site-specific response analyses shall be performed for Site Classes E and F to obtain the site-specific design soil spectra.

Table 8A-2: Site Classes for Response Spectral (IBC, 1997, and NEHRP, 1997)

Site Class	Description	Mean Shear Wave Velocity Čs (ft/sec)	Mean Undrained Shear Strength Šu (ksf)	Mean Penetration Resistance Ň or Ňch
B (Rock)	Firm to Hard Rock	5,000 > Čs ≥ 2,500	-	
C (Soil)	Very Dense Soil and Soft Rock	2,500 > Čs ≥ 1,200	Šu ≥ 2.0	≥ 50
D (Soil)	Stiff Soils	1,200 > Čs ≥ 600	1.0 > Šu ≥ 2.0	15 to 50
E (Soil)	Soft Soils	600 > Čs (see Note 1)	1.0 > Šu	< 15
F (Soil)	Special-Investigation Soils	(see Note 2)		
Note 1: Soil Site Class E could also be any profile with more than 10 ft of soft clay defined as having Plasticity Index PI > 20, water content Wn > 40 percent, and undrained shear strength less than 0.5 ksf.				
Note 2: Special-Investigation Soils include the following: collapsible, liquefiable, highly sensitive soils; more than 10 ft of peat or highly organic soils; more than 25 ft of very high plasticity soils with PI > 75 percent; very thick (more than 120 ft) soft/medium clays.				

Table 8A-3: Spectral Acceleration Values for MDE Level Design

Period (sec)	Site Class B (Rock) (g)	Site Class C (Soil) (g)	Site Class D (Soil) (g)	Site Class E (Soil) (g)	Site Class F (Soil) (g)
0.0 (PGA*)	0.77	0.77	0.77	Need Site-Specific Study	Need Site-Specific Study
0.1	1.63	1.63	1.63		
0.3	1.63	1.63	1.63		
0.4	1.43	1.63	1.63		
0.6	0.95	1.24	1.43		
0.8	0.71	0.93	1.07		
1.0	0.57	0.74	0.86		
1.5	0.38	0.49	0.57		
2.0	0.28	0.37	0.43		
3.0	0.19	0.25	0.29		
4.0	0.14	0.19	0.21		

** PGA: Peak Ground Acceleration*

Table 8A-4: Spectral Acceleration Values for ODE Level Design

Period (sec)	Site Class B (Rock) (g)	Site Class C (Soil) (g)	Site Class D (Soil) (g)	Site Class E (Soil) (g)	Site Class F (Soil) (g)
0.0 (PGA*)	0.18	0.18	0.23	0.32	Need Site-Specific Study
0.1	0.38	0.46	0.57	0.80	
0.3	0.38	0.46	0.57	0.80	
0.4	0.30	0.46	0.57	0.80	
0.6	0.20	0.34	0.46	0.69	
0.8	0.15	0.26	0.35	0.52	
1.0	0.12	0.20	0.28	0.41	
1.5	0.08	0.14	0.19	0.28	
2.0	0.06	0.10	0.14	0.21	
3.0	0.04	0.07	0.09	0.14	
4.0	0.03	0.05	0.07	0.10	

** PGA: Peak Ground Acceleration*

8A.5.2.2 Design Peak Ground Motion Parameters

A. Peak ground motion values in terms of acceleration, velocity and displacement are presented in Table 8A.5 for rock site and in Table 8A.6 for stiff soil sites. For this purpose, stiff soils are defined as those having a shear wave velocity value greater than 1,000 ft/sec, and should include the glacially consolidated soils at the project site. The values of peak ground velocity and displacement of softer sites shall be determined by the Designer in consultation with the Final Design Geotechnical Consultant.

Table 8A-5: Design Peak Ground Motion Parameters in Rock

Design Earthquake	Peak Ground Motion Parameters in Rock					
	PGA (g)		PGV (ft/sec)		PGD (ft)	
	Horiz.	Vert.	Horiz.	Vert.	Horiz.	Vert.
MDE	0.77	0.5	2.5	1.6	1.1	0.7
ODE	0.18	0.12	0.45	0.3	0.14	0.1

PGA: Peak Ground Acceleration
PGV: Peak Ground Velocity
PGD: Peak Ground Displacement

Table 8A-6: Design Peak Ground Motion Parameters in Stiff Soils

Design Earthquake	Peak Ground Motion Parameters in Stiff Soils*					
	PGA (g)		PGV (ft/sec)		PGD (ft)	
	Horiz.	Vert.	Horiz.	Vert.	Horiz.	Vert.
MDE	0.77	0.5	3.5	2.3	2.2	1.5
ODE	0.18	0.12	0.6	0.4	0.24	0.16

* *Stiff soils include glacially over consolidated soils and stiff/dense soil deposits that have a shear wave velocity value greater than 1000 ft/sec.*

8A.6 UNDERGROUND STRUCTURES

A. The general procedure for seismic design of underground structures shall be based primarily on the ground deformation approach specified herein. During earthquakes, underground structures move together with the surrounding geologic media. The structures, therefore, shall be designed to accommodate the deformations imposed by the ground. The analysis of the structure response can be conducted first by ignoring the stiffness of the structure, leading to a conservative estimate of the ground deformations. This simplified procedure is generally applicable for structures embedded in rock or stiff/dense soil. In cases where the structure is stiff relative to the surrounding soil, the effects of soil-structure interaction shall be taken into consideration.

B. Underground tunnel structures undergo three primary modes of deformation during seismic shaking: ovaling/racking, axial, and curvature deformations (see Figures 8A.4 and 8A.5). The ovaling/racking deformation is caused primarily by seismic waves propagating perpendicular to the tunnel longitudinal axis. Vertically propagating shear waves are generally considered the most critical type of waves for this mode of deformation. The axial and curvature deformations are induced by components of seismic waves that propagate along the longitudinal axis.

8A.6.1 Bored Circular Tunnels

Bored circular tunnels include earth tunnel sections and rock tunnel sections, using either the precast concrete segmental lining or cast-in-place concrete lining. Design details for the seismic design of the reinforced concrete tunnel lining shall be in accordance with the provisions of ACI-318, and shall also comply with the requirements specified in Chapter 8, Structural.

8A.6.1.1 Seismic Loads due to Ovaling Deformations

A. Seismic ovaling loads for the lining of bored circular tunnels shall be defined in terms of change of tunnel diameter (ΔD_{EQ}) caused by the vertically propagating shear

waves of the MDE and ODE. ΔD_{EQ} can be considered as seismic ovaling deformation demand for the lining. The procedure for determining ΔD_{EQ} is summarized as follows:

1. Estimate the expected free-field ground strains caused by the vertically propagating shear waves of the design earthquakes, for both MDE and ODE. The free-field ground strains can be estimated using the following formula:

   $\gamma_{max} = V_s / C_{se}$

   where: γ_{max} = maximum free-field shear strain at the elevation of the tunnel

   V_s = design peak ground velocity as defined in section 8A. 5.2.2)

   C_{se} = effective shear wave velocity of the soil/rock medium surrounding the tunnel

   a. Alternatively, the maximum free-field shear strain can be estimated by a more refined free-field site response analysis (e.g., SHAKE 91, 1992).

   b. The effective shear wave velocity of the vertically propagating shear wave, C_{se} , shall be compatible with the level of the shear strain that may develop in the ground at the elevation of the tunnel under the design earthquake shaking. For rock, the ratio of C_{se} / C_s can be assumed equal to 1.0, where C_s is the low-strain shear wave velocity. For stiff to very stiff soil, C_{se} / C_s may range from 0.6 to 0.8 for MDE and from 0.7 to 0.9 for ODE. Alternatively, site-specific response analyses can be performed for estimating C_{se}. Site-specific response analyses shall be performed for estimating C_{se} for tunnels embedded in soft soils.

   c. The values of the low-strain shear wave velocity, C_s, and the effective shear wave velocity, C_{se}, for various soil/rock units shall be determined by the Designer in consultation with the Final Design Geotechnical Consultant.

2. By ignoring the stiffness of the tunnel, which is applicable for tunnels in rock or stiff/dense soils, the lining is assumed to conform to the distortion imposed

on it by the surrounding ground with the presence of a cavity in the ground due to the tunnel excavation. The resulting diameter change of the tunnel is estimated as follows:

$\Delta D_{EQ} = \pm 2\gamma_{max} (1-\nu_m)D$

where: ν_m = Poisson's ratio of the surrounding ground

D = diameter of the tunnel

3. If the structure is stiff relative to the surrounding soil, the effects of soil-structure interaction shall be taken into consideration. The relative stiffness of the lining is measured by the flexibility ratio, F, defined as follows:

$F = \{E_m (1-\nu_c^2) R^3 \}/ \{6 E_c I_c(1+\nu_m)\}$

Where: E_m = strain-compatible elastic modulus of the surrounding ground

E_c = elastic modulus of the concrete lining

R = nominal radius of the concrete lining

I_c = moment of inertia of the concrete lining (per unit width)

ν_c = Poisson's ratio of the concrete Lining

ν_m = Poisson's ratio of the surrounding ground

a. The strain-compatible elastic modulus of the surrounding ground E_m shall be derived using the strain-compatible shear modulus G_m corresponding to the effective shear wave propagating velocity C_{se}.

b. The moment of inertia of the concrete lining, I_c, shall be determined based on the expected behavior of the selected lining under the combined seismic and static loads, accounting for cracking and joints between segments and between rings as appropriate.

4. The diameter change, ΔD_{EQ} , accounting for the soil-structure interaction effects shall then be estimated using the following equation:

   $\Delta D_{EQ} = \pm 1/3 (K_1 F \gamma_{max} D)$

   where: K_1 = Seismic ovaling coefficient = $12(1-\nu_m) / (2F + 5 - 6\nu_m)$

5. The seismic ovaling coefficient curves are presented in Figures 8A.6 and 8A.7 (Wang, 1993).

6. The seismic ovaling deformation shall be combined with deformations resulting from non-seismic loads defined in Chapter 8, Structural, for the Central Link Project. For the ODE level design, the lining shall be designed to respond essentially in an elastic manner with no ductility demand. The material strains of the lining shall be checked not to exceed 0.001 for concrete and 0.002 for steel. For the MDE level design, inelastic deformations are allowed, but shall be kept to the acceptable levels: the material strains of the lining shall be checked not to exceed 0.002 for concrete and 0.006 for steel. For the MDE level design, the concrete strain may be allowed to exceed 0.002 but not to exceed 0.004 provided that the strain is predominantly in flexural mode.

7. The lining shall also be designed to satisfy the strength requirements for the ODE level design. The internal forces, EQ, associated with the seismic ovaling deformation ΔD_{EQ} shall be derived by elastic analysis using the effective I_c value. The loading combination shall be as follows:

   Group Load = 1.0 [D + LL+ B + E +EQ]

   where: D = Dead loads
   LL = Live loads
   B = Hydrostatic pressure and buoyancy
   E = Static Soil/Rock pressure on lining
   EQ = Elastic seismic force due to seismic ovaling deformation, ΔD_{EQ}

8. For lining that can be modeled with a uniform bending stiffness (EI), the internal seismic force EQ, expressed in terms of maximum bending moment, M_{max}, can be derived as follows:

$$M_{max} = \pm (1/6)\, k_1 \,[\, E_m /(1 + V_m)\,]\, R^2\, \gamma_{max}$$

where k_1, E_m, V_m, R, and γ_{max} are as defined in this subsection, above.

The internal seismic force, EQ, expressed in terms of maximum thrust, T_{max}, can be derived as follows:

$$T_{max} = \pm\, k_2 \,[\, E_m / 2(1 + V_m)\,]\, R\, \gamma_{max}$$

where: $k_2 = 1 + \{ F[(1 – 2V_m) – (1 – 2V_m)C] – ½ (1 - 2V_m)^2 + 2\} / \{ F[(3 – 2V_m) + (1 – 2V_m)C] + C[5/2 – 8V_m + 6V_m^2] + 6 – 8V_m \}$

F = flexibility ratio (defined above)

C = compressibility ratio = $[E_m (1 – V_c^2) R] / [E_c\, t (1 + V_m) (1 - 2V_m)]$

t = lining thickness

8A.6.1.2 Seismic Loads due to Axial and Curvature Deformations

A. Tunnel lining shall be designed to accommodate seismic strains caused by axial and curvature deformations for the ground. The strains due to combined axial and curvature deformations can be estimated by combining the longitudinal strains generated by axial and bending strains as follows:

$$\varepsilon_{EQ} = \pm \{V_s /(2C_{s,H}) + 0.35rA_s /(C_{s,H})^2 \}$$

Where: V_s = design peak ground velocity as defined in section 8A.5.2.2

A_s = design peak ground acceleration as defined in section 8A.5.2.2

$C_{s,H}$ = horizontally traveling shear wave velocity

r = radius of the tunnel lining

B. The horizontally traveling shear wave velocity, $C_{s,H}$, corresponds to the seismic shear wave propagation through the deeper rocks rather than to that of the shallower soils where the tunnel may be located. In general, this velocity value varies from about 2 to 4 km/sec. Due to the location of much of the alignment within the Seattle Basin, the velocities may vary from about 1.5 to 2.0 km/sec. $C_{s,H}$ shall be determined by the Designer in consultation with the Final Design Geotechnical Consultant.

C. For the ODE level design, the longitudinal strains, ε_{EQ} , due to the axial and curvature deformations shall be checked not to exceed 0.001 for concrete and 0.002 for steel. For the MDE level design, the allowable material strains are 0.002 for concrete and 0.006 for steel.

8A.6.1.3 Interface Joints

Interfaces between the bore tunnel structures and the more massive structures, such as the cut-and-cover structures, mined station sections, and ventilation/access structures, shall be designed as flexible joints to accommodate the differential movements. The design differential movements shall be determined by the Designer in consultation with the Final Design Geotechnical Consultant.

8A.6.2 Reinforced Concrete Box Structures

The reinforced concrete box (rectangular) structures include cut-and-cover structures and mined station sections that behave in similar manner as a rectangular structure during earthquake shaking. Design details for the seismic design of the reinforced concrete box structures shall be in accordance with the provisions of the ACI-318, and shall also comply with the requirements specified in Chapter8, Structural.

8A.6.2.1 Seismic Loads due to Racking Deformations and Vertical Motions

Seismic design of the transverse cross section of a structure shall consider two loading components: (1) the racking deformations due to the vertically propagating shear waves, which is similar to the ovaling deformations of a circular tunnel lining (see section 8A.6.1.1 and 8A6.1.12), inertia forces due to vertical seismic motions.

1. Loads due to Racking Deformations, Q_h . Racking deformations are defined as the differential sideways movements between the top and bottom elevations of the box structures, shown as "Δ_s" in Figure 8A.8. The internal forces, Q_h , associated with the seismic racking deformation, Δ_s , shall be derived by imposing the differential deformation on the structure in an elastic frame analysis. The procedure for determining Δ_s , for both MDE and ODE level design and with the consideration of soil-structure interaction effects, is as follows (Wang, 1993):

   a. Estimate the free-field ground strains γ_{max} (at the structure elevation) caused by the vertically propagating shear waves of the design earthquakes, see section 8A.6.1.1. Determine $\Delta_{free-field}$, the differential free-field relative displacements corresponding to the top and the bottom elevations of the box structure (see Figure 8A.8) by

      $$\Delta_{free-field} = h \bullet \gamma_{max}$$

      where: h = height of the box structure

   b. Determine the racking stiffness, K_s , of the proposed design of the box structure from a structural frame analysis. The racking stiffness shall be computed using the displacement of the roof subjected to a unit lateral force applied at the roof level, while the base of the structure is restrained against translation, but with the joints free to rotate. The ratio of the applied force to the resulting lateral displacement yields K_s . In performing the structural frame analysis, the gross moment of inertia, I_g , shall be used for slabs and half of the gross moment of inertia (0.5 I_g) shall be used for walls.

   c. Determine the flexibility ratio, F_{rec}, of the proposed design of the structure using the following equation:

Frec = (Gm / Ks) • (w/h)

Where: w = width of the box structure

G_m = average strain-compatible shear modulus of the soil/rock layer between the top and bottom elevation of the structure. The strain-compatible shear modulus shall be derived from the strain-compatible, effective shear wave velocity, C_{se} , see section 8A. 6.1.1. G_m shall be determined by the Designer in consultation with the Final Design Geotechnical Consultant.

d. Based on the flexibility ratio obtained form Step c above, determine the racking ratio, R, for the proposed structure using Figure 8A.9 (Wang, 1993).

e. Determine the racking deformation of the structure, Δ_s , using the following relationship:

$$\Delta_s = R \bullet \Delta_{free\text{-}field}$$

f. The seismic demand in terms of internal forces as well as material strains are calculated by imposing Δ_s upon the structure in a frame analysis as depicted in Figure 8A.10.

2. Loads due to Vertical Seismic Motions, Q_v . Loads due to vertical seismic motions on cut-and-cover structures are accounted for by applying a vertical static loading, equivalent to a fraction of the slab and the overburden materials (directed up or down, whichever results in a more critical load case):

$Q_v = 0.50\ (D + E_v)$ for MDE level design

$Q_v = 0.12\ (D + E_v)$ for ODE level design

Where: D = Dead loads

E_v = Loads due to weight of overburden materials for cut-and-cover structure

a. For Mined station sections, E_v corresponds to loads due to weight of the loosened zone above roof and shall be determined by the Final Designer in conjunction with their proposed construction methods and sequences.

b. Seismic loads due to racking deformations and vertical seismic motions shall be combined with non-seismic loads using the following loading combinations:

Group Load = 1.0 [D + LL+ B + E +EQ/2.0] for MDE level design

Group Load = 1.0 [D + LL+ B + E +EQ] for ODE level design

where: D = Dead loads

LL = Live loads

B = Hydrostatic pressure and buoyancy

E = Static earth pressure including vertical, horizontal effects of dry and saturated earth, and surcharge loading

EQ = Earthquake Loads (MDE or ODE, as applicable)

The earthquake loads, EQ, shall consider the following two cases:

$EQ_1 = Q_h \pm 0.3Q_v$

$EQ_2 = 0.3Q_h \pm Q_v$

c. In addition, the material strains of the main structural members shall be checked not to exceed the allowable values for both MDE and ODE level design. The allowable values specified in section 8A.6.1.1 shall be applied.

8A.6.2.2 Seismic Loads due to Axial and Curvature Deformations

The design and evaluation procedure specified in section 8A.6.1.2 shall be applied for cut-and-cover tunnel structures subject to axial and curvature deformations, except that the definition of "r" is changed to the following:

r = distance from the neutral axis of the tunnel cross section to the extreme fiber of the cross section.

8A.6.2.3 Interface Joints

Interfaces between the cut-and-cover structures and the more massive structures, such as the station sections and ventilation/access structures, shall be designed as flexible joints to accommodate the differential movements. The design differential movements shall be determined by the Designer in consultation with the Final Design Geotechnical Consultant.

8A.6.3 Ventilation/Access Shafts

A. Design Details for the reinforced concrete underground ventilation/access shaft structures shall be in accordance with the Provisions of the ACI-318, and shall also comply with the requirements specified in Chapter 8, Structural.

B. The seismic considerations for the design of vertical shaft structures are similar to those for the lined circular tunnel structure(see section 8A.6.1), except that ovaling and axial deformations in general do not govern the design. Considerations shall be given to the curvature strains and shear forces of the lining resulting from vertically propagating shear waves. Force and deformation demands may be considerable in cases where shafts are embedded in deep, soft deposits. In addition, potential stress concentrations at the following critical locations along the shaft shall be properly assessed and designed for: (1) abrupt change of the stiffness between two adjoining geologic layers, (2) shaft/tunnel or shaft/station interfaces, and (3) shaft/surface building interfaces. Flexible connections shall be used between any two structures with drastically different stiffness/mass in poor ground conditions.

8A.7 AERIAL STRUCTURES

Seismic design of aerial structures and bridges shall be in accordance with the provisions of Division IA – Seismic Design of the AASHTO Standard Specifications for Highway Bridges, except as supplemented or explicitly modified herein. The designers' attention is directed to the Commentary to Division IA – Seismic Design – Bridges, in the 1998 AASHTO Interim Specifications.

8A.7.1 Analysis Requirements

A. Four analysis procedures are described in Sub-section 4 of Division IA, AASHTO Standard Specifications (Ref. 1):

Procedure 1. Uniform Load Method (Equivalent Static Analysis)
Procedure 2. Single-Mode Spectral Method (Equivalent Static Analysis)
Procedure 3. Multi-mode Spectral Method (Elastic Dynamic Analysis)
Procedure 4. Time History Method (Inelastic Dynamic Analysis)

B. With the exception of single span bridges, Procedure 3 – Multi-mode Spectral Method shall be the minimum analysis requirement for all aerial structures and bridges. Structure response (member forces or displacements) shall be computed by combining the respective response quantities (e.g. force, displacement or relative displacement) from the individual modes by the Complete Quadratic Combination (CQC) method.

C. In addition to the multi-mode spectral analysis, either an inelastic static (push-over) analysis or inelastic dynamic (non-linear time history) analysis shall be performed to verify the deformation capacity of the structure for the Maximum Design Earthquake (MDE). Inelastic static analysis shall be performed in accordance with the procedures specified in Article 3.21.7, Inelastic Static Analysis, of ATC 32, Improved Seismic Design Criteria for California Bridges: Provisional Recommendations (Ref 3). If inelastic dynamic analysis is used, the analysis shall be performed in accordance with the procedures specified in Article 3.21.8, Inelastic Dynamic Analysis, of ATC 32.

D. Inelastic static analysis shall not be used as the basis for reducing design quantities required based on the multi-mode response spectrum analysis. Inelastic dynamic analysis may be used to refine design requirements determined from the multi-mode response spectrum analysis, except that design displacements, design forces, and quantities of transverse reinforcement shall not be less than 80 percent of the values required based on the multi-mode response spectrum analysis.

E. Member forces and flexural plastic hinge rotations computed using multi-mode response spectrum analysis, inelastic static analysis or inelastic dynamic analysis shall not exceed capacities calculated in accordance with the requirements of Division I and Sub-section 7 of Division IA – Seismic Design of the AASHTO Standard Specifications for Highway Bridges (Ref. 1), for Seismic Performance Category D, as modified by this criteria.

F. Except for cases where soil response spectra are derived by site-specific response analyses (e.g., for the "Special-Investigation Soil Sites"), the design response spectra presented in section 8A.5.2.1 (for both MDE and ODE) shall be used directly as the ground motion input for the response spectrum analysis in each orthogonal direction.

G. For long viaducts (greater than 1,500 feet) where intermediate hinges or joints are used, differential support displacements resulting from earthquake motions shall be considered in the design to account for non-uniform ground (support) motions. Differential support displacement effects shall be evaluated using appropriate methods, considering the behavior of the intermediate hinges and expansion joints.

H. The inertia effects of the Light Rail Vehicle (LRVi), without impact, acting on one track only shall be included in the dynamic analysis in deriving EQM (or EQF). The LRVi mass shall be the AW1 loading from sub-section 12.3.A.2 (see Figure 8A.1) and shall be considered acting along the centerline of track, at a height of 4'-0"above the top of the low rail. The dynamic characteristic of the suspension system of the Light Rail Vehicle shall be considered in deriving the inertia effects of the LRVi. To include this consideration in the dynamic analysis, the LRVi can be modeled as a mass supported by (or attached to) the superstructure through an equivalent spring representing the vibratory characteristics of the LRVi. Where appropriate, the effects of the following considerations shall be included: (1) the effects of continuous rails on distributing the longitudinal inertia force of the LRVi to multiple bents, and (2) the limiting transferable forces between the LRVi and the rails or between the rails and the superstructure.

I. For concrete columns, the effective (cracked) moment of inertia shall be used for both the ODE and MDE level analyses. It is recommended that the effective stiffness EI be based on evaluation of the moment-curvature curve for the particular column section under consideration. In lieu of a more accurate moment-curvature analysis, the effective moment of inertia for the ODE level event shall be taken as 60 percent of the gross column section, and for the MDE level event shall be determined using Figure 8A.11.

J. If transverse shear keys are used, they shall be included in the analytical model providing that they are designed to adequately resist the design force(s) for the level of earthquake under consideration (ODE or MDE).

K. The design for the ODE level earthquake shall not count on any stiffness contribution from the abutment backwall. For the MDE level earthquake, the stiffness contribution from the abutment backwall (compression only) may be included in the analytical model, providing the abutment backwall is suitably designed and detailed.

L. Soil-structure interaction effects shall be considered in the analysis. Soil structure interaction effects may be considered by including boundary (foundation) springs in the analytical model, by using an equivalent depth-of-fixity for the foundation elements, or other suitable method. If boundary springs are used, they should include three translational spring constants and three rotational spring constants (the diagonal terms of the stiffness matrix). Coupling (off-diagonal) terms shall be included in the foundation stiffness matrix if coupling effects are significant.

M. Structure/rail interactions effects shall be included in the global analysis. (see section 8A.7.10).

8A.7.2 Elastic Design Forces, Moments and Displacements

8A.7.2.1 Combination of Effects

A. Earthquake actions shall be determined for seismic input in three orthogonal directions; the horizontal longitudinal and transverse axis of the structure and the vertical axis. The longitudinal axis of a curved bridge should generally be represented by a chord connecting the two abutments.

B. For response spectrum analysis (Procedure 3), a combination of orthogonal forces shall be used to account for the directional uncertainty of earthquake motions and the simultaneous occurrences of earthquake forces in the three perpendicular directions. Elastic seismic forces, moments and displacements resulting from the analysis in the three perpendicular directions shall be combined to form three load cases as follows:

1. Seismic Load Case 1: Combine 100 percent of the absolute value of the forces, moments and displacements resulting from the longitudinal loading with 30 percent of the absolute value of the corresponding forces, moments and displacements

resulting from the analyses in the transverse and vertical directions.

2. Seismic Load Case 2: Combine 100 percent of the absolute value of the forces, moments and displacements resulting from the transverse loading with 30 percent of the absolute value of the corresponding forces, moments and displacements resulting from the analyses in the longitudinal and vertical directions.

3. Seismic Load Case 3: Combine 100 percent of the absolute value of the forces, moments and displacements resulting from the vertical loading with 30 percent of the absolute value of the corresponding forces, moments and displacements resulting from the analyses in the longitudinal and transverse directions.

C. When the forces for integral (moment-resisting) connections between superstructure and columns or columns and foundations are determined from plastic hinging of the columns (see section 8A.7.5), the resulting forces and moments need not be combined as specified above.

D. Where time-history analysis is used (Procedure 4), ground motions are typically input simultaneously in the two horizontal directions plus the vertical direction. This being the case, it will not be necessary to use the seismic load combination rules specified above.

8A.7.2.2 Design Displacements

A. It has been observed (Ref. 3) that, for short-period structures, linear-elastic response models tend to underestimate inelastic displacement amplitudes. In order to account for this phenomenon, horizontal displacements calculated from the elastic response spectrum analysis shall be multiplied by the factor R_d to obtain the design displacements.

$$R_d = [1 - 1/R\,]T^*/T + 1/R \geq 1.0$$

where: R_d = Amplification factor applied to elastic model spectral displacements to obtain design displacements
R = Response modification factor. R shall be taken as the maximum value of R used in design of that frame (i.e. use the maximum value for longitudinal / transverse analysis).

T = Fundamental period of vibration of the bridge/structure as a whole, seconds.
T* = Characteristic ground motion period (in seconds) corresponding to the peak of the energy input spectra. Values of T* are given in Table 8A-7 (adopted form reference 3).

B. If inelastic dynamic (non-linear time history) analysis is performed, displacements calculated from the inelastic analysis may be used directly in the design, but these displacements shall not be taken as less than 80 percent of the adjusted design displacements, calculated as described above.

Table 8A-7: Values of Characteristic Ground Motion Period, T*

	Values of T* (in seconds)											
	M = 6.5 ± 0.25				**M = 7.25 ± 0.25**				**M = 8.0 ± 0.25**			
PGA (g)	Class B	Class C	Class D	Class E	Class B	Class C	Class D	Class E	Class B	Class C	Class D	Class E
0.1	0.32	0.45	0.46	0.44	0.41	0.53	0.56	0.56	0.51	0.69	0.71	0.71
0.2	0.37	0.44	0.49	0.64	0.42	0.53	0.55	0.74	0.47	0.61	0.65	0.85
0.3	0.35	0.43	0.50	0.73	0.38	0.51	0.55	0.76	0.48	0.64	0.65	0.98
0.4	0.39	0.47	0.50	0.87	0.42	0.56	0.59	0.93	0.46	0.62	0.66	1.04
0.5	0.37	0.46	0.50	-	0.42	0.53	0.62	-	0.45	0.59	0.70	-
0.6	0.35	0.44	0.50	-	0.43	0.54	0.64	-	0.46	0.60	0.76	-
0.7	-	-	-	-	0.50	0.66	0.76	-	0.54	0.71	0.80	-

Refer to section 8A.5.2.1 for definitions of Site Classes B, C, D and E
M = Moment Magnitude

8A.7.3 Response Modification Factors

A. Seismic forces for individual members and connections shall be determined by dividing the elastic forces from the response spectrum analysis by the appropriate Response Modification Factor (R). The response modification factors for various bridge components are given in Table 8A.8, below.

Table 8A-8: Response Modification Factors

Substructure	ODE (150 year)	MDE (2500 year)
Wall-type pier [1]	1.0	2.0
Reinforced concrete pile bents		
a. Vertical piles only	1.0	3.0
b. One or more batter piles	1.0	2.0
Single Columns (reinforced concrete)	1.0	4.0
Steel or composite steel and concrete pile bents		
a. Vertical piles only	1.0	5.0
b. One or more batter piles	1.0	3.0
Multiple column bent (reinforced concrete)	1.0	5.0

Connections [2]	ODE (150 year)	MDE (2500 year)
Superstructure to Abutment [5]	1.0	1.04
Expansion joints within a span of the superstructure	1.0	1.0
Columns, piers or pile bents to capbeam or superstructure [3, 5]	1.0	1.0
Columns or piers to foundations [3]	1.0	1.0

[1] *A wall-type pier my be designed as a column in the weak direction of the pier provided all the provision for columns in Division IA – Seismic Design, Article 7.6, of the AASHTO Standard Specifications, (Seismic Performance Category D), as supplemented by the requirements herein, are satisfied. The R-factor for a single column may then be used.*

[2] *Connections are those mechanical devices which transfer shear and axial forces from one structural component to anther. They generally do not include moment connections, and thus comprise bearings and shear keys. The R-factors listed for connections in this table are applied to the elastic forces in the restrained directions only.*

[3] *It is recommended that integral (moment-resisting) connections of columns, piers or pile bents to capbeam or superstructure and columns or piers to foundations be designed for the maximum forces capable of being developed by plastic hinging of the column bent (see section 8A.7.5, Forces Resulting from Plastic Hinging in the Columns, Piers or Bents).*

[4] *Abutment transverse shear keys may be designed as a fuse, to withstand the full transverse shear force resulting from the ODE level event, and fail under the MDE level event (See section 8A. 7.7.7, Abutments).*

[5] *These connections shall include shear restriction devices, e.g., shear pins surrounded by compressible material connecting the superstructure to the substructure.*

B. Response modification factors greater than 1.0, as listed above, shall only be used when all of the design/detailing requirements for Seismic Performance Category (SPC) D of Division IA – Seismic Design Sub-section 7, of the AASHTO Standard Specifications (Ref. 1), as supplemented by the requirements herein, are satisfied. These design/detailing requirements are intended to ensure a ductile structural design, and the use of response modification factors greater than 1.0 is premised on the assumption that components are designed and detailed to provide adequate ductility.

C. Where post-tensioning tendons are the primary reinforcement, e.g. for pre-cast segmental column construction, the R-factor for design of the pier columns shall be determined based on a rigorous method of analysis. Such rigorous analysis shall address segment joint opening and spalling of concrete on both the inside and outside faces of the column walls, in order to reflect the lower curvature ductility capacity for a hollow concrete column section reinforced with high-strength post-tensioning steel.

8A.7.4 Modified Design Forces (Load Combinations)

Modified design forces shall be determined as specified in sections 8A.7.4.1 and 8A.7.4.2, below. Note that the seismic forces resulting from response spectrum analysis are absolute value, and therefore, for columns, maximum and minimum column force shall be calculated for each load case by taking the seismic axial force as positive and negative.

8A.7.4.1 Modified Design Forces for Structural Members and Connections

A. Seismic design forces specified in this sub-section shall apply to:

1. The superstructure, its expansion joints and the connections between the superstructure and the supporting substructure.

2. The supporting substructure down to the base of the columns and piers, but not including the footing, pile cap or piles.

3. Components connecting the superstructure to the abutment.

B. Seismic design forces for the above components shall be determined by dividing the elastic seismic forces obtained from Load case 1, Load Case 2 or Load Case 3, defined in section 8A.7.2.1, by the appropriate Response

Modification Factor, defined in section 8A.7.3. The modified seismic forces resulting from the three load cases shall then be combined independently with forces from other loads as specified in the following group loading combination for the components. Note that the seismic forces are reversible (positive and negative) and the maximum loading for each component shall be calculated as follows:

Group Load = 1.0 [D + LL+I + PS + B + SF + E +EQM]

where: D = Dead load

LL + I = Live load plus impact for the design Light Rail Vehicle (AW1 See sub-section 12.3.A and Chapter 8, Structural, Figure 8.1, Light Rail Vehicle Design Load), acting on one track only. The track which is considered to loaded with live load plus impact shall be selected so to produce the critical effect in the component under consideration.

PS = Pre-stressing load

B = Hydrostatic pressure and buoyancy

SF = Stream flow pressure and flooding

E = Earth pressure

EQM = Elastic seismic force (MDE and ODE) for either Load Case 1, Load Case 2 or Load Case 3, defined in section 8A.7.2.1, modified by dividing by the appropriate R-factor (see section 8A,7.3, section 8A.7.6). The inertial effects of the train live load (LRVi , see section 8A. 7.1) are included in this force.

C. Where post-tensioning tendons are the primary reinforcement, e.g. for pre-cast segmental column construction, the R-factor for design of the pier columns shall be as determined by rigorous analysis (see section 8A.7.3).

D. Each component of the structure shall be designed to withstand the forces resulting from each load combination according the requirements of Division I and Sub-section 7 of Division IA – Seismic Design of the AASHTO Standard Specifications (for Seismic Performance Category D), as supplemented by the requirements of this criteria. The above load combination shall be used in lieu of the Group VII loading combination listed in Chapter 8, Structural, Table 8.2, Loading Combination Factors.

8A.7.4.2 Modified Design Forces for Foundations

A. Seismic design forces for foundations, including footings, pile caps and piles, shall be the elastic seismic forces obtained from Load Case 1, Load Case 2 and Load Case 3, defined in section 8A.7.2.1, using a response modification factor of 1.0. These seismic forces shall then be combined independently with forces from other loads as specified in the following group loading combination to determine three alternative load combinations for the foundations.

Group Load = 1.0 [D + LL + PS + B + SF + E +EQF]

where: D = Dead load

LL = Live load for the design Light Rail Vehicle (LRV), acting on one track only. The track which is considered to loaded with live load shall be selected so to produce the critical effect in the component under consideration. (Live load impact shall be excluded for design of the footings and those portions below the ground line).

PS = Pre-stressing load

B = Hydrostatic pressure and buoyancy

SF = Stream flow pressure and flooding

E = Earth pressure

EQF = Elastic seismic force (MDE and ODE) for either Load Case 1, Load Case 2 or Load Case 3, defined in section 8A.7.2.1, divided by an R-factor equal to 1.0.

B. Each component of the foundation shall be designed to resist the forces resulting form each load combination according the requirements for Seismic Performance Category (SPC) D of Division I and sub-section 7.2.6 of Division IA – Seismic Design of the AASHTO Standard Specifications, as supplemented by the requirements of this criteria. The above load combination shall be used in lieu of the Group VII loading combination listed in Chapter 8, Structural, Table 8.2. Loading Combination Factors.

8A.7.5 Forces Resulting from Plastic Hinging in the Columns, Piers and Bents

A. The force resulting from plastic hinging at the top and/or bottom of the column shall be calculated after the preliminary design of the column is complete. The forces resulting from plastic hinging are recommended for determining design forces for most components for the Maximum Design Earthquake (MDE), as specified in section

8A.7.6, below. Modified elastic design forces are specified in the event forces resulting from plastic hinging are not calculated, or, as expected for the Operating Design Earthquake (ODE), for cases where they are less than the computed plastic hinging forces.

B. The procedures for calculating the plastic hinging forces for single columns and piers shall be as specified in sub-section 7.2.2(A) of Division IA – Seismic Design, of the AASHTO Standard Specifications (Ref. 1). For bents with two or more columns, the procedure shall be as specified in sub-section 7.2.2(B) of Division IA – Seismic Design of the AASHTO Standard Specifications.

8A.7.6 Component Design Forces

8A.7.6.1 Column and Pile Bent Design Forces

A. Design forces (MDE and ODE) for columns and pile bents shall be as follows:

1. ***Axial Forces:*** The minimum and maximum design forces shall be either the elastic design values determined as specified in section 8A.7.4.1, using an R-factor of 1.0, or the value corresponding to plastic hinging of the column, determined as specified in section 8A.7.5, above.

2. The modified design moments determined in accordance with section 8A.7.4.1.

3. ***Shear Force:*** Either the elastic design value determined as specified in section 8A.7.4.1, using an R-factor of 1.0, or the value corresponding to plastic hinging of the column, determined as specified in section 8A.7.5, above.

B. When forces due to plastic hinging are used, the combination of forces specified in section 8A.7.2.1 is not applicable.

8A.7.6.2 Wall-Type Pier Design Forces

A. The design forces for wall-type piers shall be the modified design values determined as specified in section 8A.7.4.1, except if the pier is designed as a column in the weak direction. If the pier is designed as a column, the forces in the weak direction shall be as specified in section 8A.7.6.1, above, and all of the design requirements for columns in Seismic Performance Category (SPC) D in Division IA –

Seismic Design, Article 7.6, of the AASHTO Standard Specifications (Ref. 1), as supplemented by the requirements herein, shall apply.

B. Note: When forces due to plastic hinging are used in the weak direction, the combination of forces specified in section 8A.7.2.1, is not applicable.

8A.7.6.3 Connection Design Forces

A. The design forces for piers shall be the modified design values determined as specified in section 8A.7.4.1, except that for integral (moment-resisting) connections of superstructure to columns and columns to cap beams or footings, the alternate forces specified in section 8A.7.6.3.1 are recommended for the MDE.

B. Design forces for longitudinal linkages and hold-down devices shall be determined as specified in Sub-section 7.2.5(A) and 7.2.5(B), respectively, of Division IA – Seismic Design, AASHTO Standard Specifications (Ref. 1). Where the Acceleration Coefficient is referred to in AASHTO, use A = 0.18 for the Operating Design Earthquake (ODE) and 0.77 for the Maximum Design Earthquake (MDE).

8A.7.6.3.1 Column and Pier Connections to Cap Beams and Footings (Integral)

A. For the MDE event, the recommended design forces for integral (moment-resisting) connections between the superstructure and columns, columns and cap beams, and columns and spread footings or pile caps are the forces developed at the top and bottom of the columns due to column plastic hinging, determined as specified in section 8A.7.5, above. Note that column plastic hinging forces should be calculated after the column design is completed and the column overstrength moment capacities are determined.

B. For the ODE event (as well as the MDE event), design forces for these integral (moment resisting) connections shall be taken as the smaller of the values due to column plastic hinging and the modified design forces specified in section 8A.7.4.1.

8A.7.6.4 Foundation Design Forces

A. The design forces for foundations, including spread footings, pile caps and piles, shall be either the modified design values determined as specified in section 8A.7.4.1, or the forces at the bottom of the columns resulting from column plastic hinging, determined as specified in section 8A.7.5, whichever is smaller.

B. When the columns of a bent have a common footing, the final force distribution at the base of the columns from Step 4 of Sub-section 7.2.2(B), Division IA – Seismic Design of the AASHTO Standard Specifications may be used for design of the footing in the plane of the bent. This force distribution produces lower shear forces and moments on the footing because one exterior column may be in tension and the other in compression due to the seismic overturning moment. This effectively increases the ultimate moments and shear forces on one column and reduces them on the other.

8A.7.7 Structural Design and Details

Except as supplemented or explicitly modified in this criteria, all components of the structure shall be designed and detailed to withstand the forces resulting from each of the load combinations specified in section 8A.7.4.1, or, where applicable, forces resulting from column plastic hinging, in accordance with the requirements of Division I and Sub-section 7 of Division IA – Seismic Design of the AASHTO Standard Specifications for Highway Bridges (Ref. 1), for Seismic Performance Category D. Additional design and detailing requirements for various components follow in this section.

8A.7.7.1 Reinforcing Steel

8A.7.7.1.1 General Reinforcement Requirements

A. All reinforcing steel for the substructures, including connection of the piers, columns or pile bents to the superstructure, cap beam and foundations, shall conform to ASTM A706, with a minimum yield strength of 60 ksi and a maximum yield strength of 78 ksi. A yield strength of 66 ksi shall be used for design (using A706 reinforcement only) unless otherwise restricted by ACI code requirements.

B. Reinforcing bar development lengths shall be in accordance with the AASHTO Standard Specifications (Sub-section 8 , Part D – Reinforcement and Division 1A – Seismic Design), with the supplemental requirements in the following subsection.

8A.7.7.1.2 Lateral Reinforcement

A. Lateral reinforcement for compression members shall consist of either spiral reinforcement, hoops, or a combination of lateral ties and cross ties. Ties shall only be used when it is not practical to provide spiral or hoop reinforcement. Where longitudinal bars are required outside the spiral or hoop reinforcement, they shall have lateral support provided by bars spaced and hooked as required by Division IA of the AASHTO Standard Specifications for SPC Category D) for cross-ties. The hooked bars shall be extended into the core of the spiral or hoop a full development length. Reinforcement used to satisfy this requirement may also be used to satisfy shear strength requirements of Sub-section 8.16.6.3 of the AASHTO Standard Specifications (Ref. 1).

B. Lateral reinforcement shall extend into the cap beams and footings at a transverse reinforcement ratio equal to that in the column, unless a higher ratio is required to satisfy the requirements of section 8A.7.7.4 and section 8A.7.7.5.

C. Lateral reinforcement for compression members constructed in monolithic form with the cap or footing shall be continued into the cap or footing for the full length of the straight main reinforcement from compression members, or for the entire straight portion of hooked reinforcement form compression members. This reinforcement may be in the form of hoops or spirals, and may be discontinuous at the bottom flexural reinforcement of the cap.

D. No reduction factors may be applied to the basic development length of a standard hook in tension. All other reinforcing bar development criteria and modification factors in Sub-section 8, Part D of the AASHTO Standard Specifications for straight or hooked bars shall be applicable. No. 18 bars shall not be hooked.

8A.7.7.2 Superstructure

8A.7.7.2.1 Superstructure Design Over Bent Cap

A. The superstructure in the area over the bent caps shall be designed (based on ultimate capacity) to resist the smaller of (1) Forces Resulting From Plastic Hinging in the Columns, Piers and Bents, determined in accordance with section 8A.7.5, above, and (2) The modified design forces specified in section 8A.7.4.1, using a response modification factor R=1.0 for both the ODE and MDE events. The effective superstructure width (transverse) on either side of the centerline of a column for resisting longitudinal seismic moments induced by column action shall be taken as one-half the column width plus the depth of the superstructure, as shown in Figure 8A.12, adopted from Reference 3.

B. When it is not possible place the required reinforcement within the area specified above, designers should consider such details as:

1. Using thicker soffits and/or top slabs
2. Widening the cap
3. Using a dropped cap

C. All top and bottom bent cap reinforcement should preferably be made continuous. If this is not physically possible, then at least 75 percent of the top and bottom bent cap reinforcement shall be continuous. There shall be no lap splices in the main bent cap reinforcement.

8A.7.7.2.2 Externally Post-tensioned Box Girders

For externally post-tensioned segmental box girders, the AASHTO Guide Specifications for Design and Construction of Segmental Concrete Bridges shall be supplemented with the following requirements to ensure adequate ductility and redundancy:

1. Sufficient internal pre-stressing tendons, bonded to the box girder section, shall be provided in each span at both positive and negative moment regions to resist the continuous span dead load and superimposed dead load moments using a load factor of 1.3. External, unbonded tendons may be used to resist live, impact and other loads, including seismic. If couplers are used to achieve continuity of internally bonded tendons, not more than 50 percent of these couplers shall be placed at the same cross section.

2. External unbonded tendons may be anchored in the end and pier segments. The requirement for a maximum of 50 percent couplers at the same cross section is not applicable at the end and pier segments, since in the area of negative moment regions the internal bonded pre-stressing will adequately resist the dead load moments.

8A.7.7.2.3 Skew

Skewed bridges are known to develop large displacements at their support due to the superstructure rotating about a vertical axis through the center of stiffness of the substructure. This has been observed in many earthquakes, and the relatively frequent occurrence of damaged and unseated skewed spans is attributed to the phenomenon. To avoid this phenomenon, the superstructure skew should be minimized to the extent possible.

8A.7.7.3 Columns

A. The columns shall be designed to remain fully elastic under the ODE level event, and shall be designed and detailed to ensure that plastic hinges occur at the top and/or bottom of the columns under the MDE level event. To transfer shear forces associated with column plastic hinging, the joint force transfer area and additional longitudinal and/or transverse reinforcement shall be designed in accordance with the requirements of section 8A.7.7.4.

B. The minimum area of longitudinal reinforcement for compression members shall not be less than 0.008 times the gross area (Ag) of the section. The maximum area of longitudinal reinforcement for compression members shall not exceed 0.04 times the gross area Ag of the section except at lap splices. However, it is recommended that the column reinforcement ratio be kept under 2.5 percent to reduce congestion due to added joint reinforcement at the joint force transfer areas. This will also help reduce the joint shear stresses.

C. For all reinforced concrete members under the ODE level event, and for other than ductile columns under the MDE event, the design flexural strength shall be considered to be reached when the extreme fiber compression strain is equal to 0.003.

D. For ductile columns under the MDE event only, the design flexural strength shall be considered to be reached when the extreme fiber compression strain is equal to 0.004.

E. For flared columns where the flare section is designed to be non-structural, vertical column steel outside the core, in the column flare section, shall be embedded not more than 6” in to the cap beam, so as not to increase the column plastic hinging moment.

F. Column deflection capacity, determined based on evaluation of the moment-curvature curve for the particular column section under consideration, must be larger than the displacement demand for the MDE level event. Inelastic static (push-over) analysis may be used to determine a more realistic displacement capacity for multiple-column bents in the transverse and/or longitudinal directions, as applicable. In evaluating displacement demands and capacities in the transverse and longitudinal

directions, the following interaction equation must be satisfied:

$$(\Delta_{DL} / \Delta_{CL})^2 + (\Delta_{DT} / \Delta_{CT})^2 \leq 1.0$$

where,

Δ_{DL} = Displacement demand in the longitudinal direction, determined from the elastic response spectrum analysis (including amplification factor R_d (see section 8A.7.2.2)

Δ_{DT} = Displacement demand in the transverse direction, determined from the elastic response spectrum analysis (including amplification factor R_d (see section 8A.7.2.2)

Δ_{CL} = Displacement capacity in the longitudinal direction

Δ_{CT} = Displacement capacity in the transverse direction

G. Amplification of displacement demands due to P-Delta effects must be considered, in accordance with the requirements of Sub-section 8.16.5 of the AASHTO Standard Specifications (Ref. 1).

H. Precast hollow-section pier columns constructed segmentally shall be designed to meet the following additional requirements:

1. Minimum transverse reinforcement in accordance with Sub-sections 7.6.2(C), 7.6.2(D) and 7.6.2(E) of Division IA –Seismic Design, AASHTO Standard Specifications, shall be placed at each side of segment joints. Transverse reinforcement shall be provided throughout the segment, on the inside and outside faces of the hollow-section, and the two layers of reinforcement shall be tied together.

2. Wall slenderness ratios (X_u/t) for the walls shall, as a minimum, be in accordance with the article Design Recommendations for Thin-Walled Box Piers and Pylons, by A.W. Taylor and J.E. Breen, Concrete International, December 1994 (Ref. 8). These requirements are summarized below:

a. The wall slenderness ratio of a hollow rectangular cross section, λ_w, is defined as follows (see Figure 8A.17):

$\lambda_w = X_u / t$

where: X_u = the clear length of the constant thickness portion of a wall between other walls or fillets between walls

t = thickness of wall

λ_w = wall slenderness ratio for hollow column

b. Wall slenderness ratios of a hollow cross rectangular cross section, λ_w, greater than 35.0 are not permitted, unless specific analytical and experimental evidence is submitted justifying such values. The equivalent rectangular stress block method shall not be employed in the design of hollow rectangular compression members with a wall slenderness ratio λ_w of 15 or greater. Where the wall slenderness ratio λ_w is less than 15, the rectangular stress block method may be used based on a compressive strain of 0.003.

c. If the wall slenderness ratio λ_w is 15 or greater, then the maximum usable strain at the extreme concrete compression fiber is equal to the computed local bucking strain of the widest flange in the cross section, or 0.003, whichever is less.

d. The local bucking strain of the widest flange in the cross section may be computed assuming simply supported boundary conditions on all four edges of the flange. Nonlinear material behavior shall be considered by incorporating the tangent material moduli of the concrete and reinforcing steel in computations of the local buckling strain.

e. In lieu of the provisions of c. and d., above, the following approximate method may be used to account for the strength reduction due to wall slenderness, where the wall slenderness ratio is less than or equal to 35.0:

f. The maximum usable strain at the extreme compression fiber shall be taken as 0.003 for all values of λ_w up to and including 35.0. A strength reduction of

factor, ϕ_w, shall be applied in addition to the usual strength reduction factor. The factor ϕ_w shall be taken as 1.0 for values of λ_w up to and including 15.0. For values of λ_w greater than 15.0 and less than or equal to 25.0, the reduction factor shall be taken as $\phi_w = 1.0 - 0.025(\lambda_w - 15)$. For values of λ_w greater than 25.0 and less than or equal to 35.0, ϕ_w shall be taken as 0.75.

g. Discontinuous, non-post-tensioned reinforcement in segmentally constructed hollow compression members shall be neglected in computations of member strength. Flexural resistance shall be calculated using the principles of Article 9.17, Flexural Strength (Prestressed Concrete), of the AASHTO Standard Specification for Highway Bridges (Ref. 1), applied with anticipated stress-strain curves for the types of material to be used.

8A.7.7.4 Moment-Resisting Connections Between Members (Column/Beam Joints and Column/ Footing Joints)

This section applies to integral (moment-resisting) connections of superstructure to columns and columns to cap beams or footings.

8A.7.7.4.1 Design Forces

Moment-resisting connections between members shall be designed to transmit the maximum forces applied by the connected members. For the MDE level event, it is recommended that the connection design forces be based on the maximum column plastic hinging moments, as defined in section 8A.7.5.

8A.7.7.4.2 Force Resisting Mechanisms

Forces acting on the boundaries of connections shall be considered to be transmitted by mechanisms involving appropriate contributions by concrete and reinforcement actions. Mechanisms shall be based on an analysis of force transfer within the connection, and shall be supported by relevant test results.

8A.7.7.4.3 Principal Stress in Connections

8A.7.7.4.3.1 Applied Stresses

Principal stresses in any vertical plane within a connection shall be calculated in accordance with the following equations.

Principal tension stress is given by:

$$p_{t_{1/2}} = (f_h + f_v)/2 - [\ ((f_h - f_v)/2)^2 + v_{hv}^2\ ]$$

Principal compression stress is given by:

$$p_{c_{1/2}} = (f_h + f_v)/2 + [\ ((f_h - f_v)/2)^2 + v_{hv}^2\ ]$$

where f_h and f_v are the average axial stresses in the horizontal and vertical directions within the plane of the connection under consideration (compression positive) and v_{hv} is the shear stress within that plane.

The joint shear stress can be estimated with adequate accuracy form the expression

$$v_{hv} = M_p / h_b h_c b_{je}$$

where M_p is the maximum plastic moment resulting from column hinging as determined as described in section 8A.7.5, above, h_b is the cap beam or footing depth, h_c is the column lateral dimension in the direction under consideration (i.e. h_c = D for a circular column) and b_{je} is the effective joint width, found using a 45-degree spread from the column boundaries. Figure 8A.13, adopted for Reference 3 (after Priestly, Seible and Calvi, Ref. 6),

clarifies the dimensions to be used for this calculation.

8A.7.7.4.3.2 Minimum Required Horizontal Reinforcement

When the principal tension stress is less than $p_t = 3.5\ (f'_c)^{1/2}$ psi, the minimum amount of horizontal joint shear reinforcement to be provided shall be capable of transferring 50 percent of the cracking stress resolved to the horizontal direction. For circular columns or columns with intersecting spirals, the volumetric ratio of transverse reinforcement in the form of spirals or circular hops to be continued in the cap beam or footing as required by section 8A.7.7.1.2, shall not be less than

$$p_s = 3.5\ (f'_c)^{1/2} / f_{yh} \qquad \text{(psi)}$$

where f_{yh} = Specified yield strength of transverse reinforcement.

8A.7.7.4.3.3 Maximum Allowable Compression Stress

The principal compression stress in a connection, p_c , calculated in accordance with the above equation, shall not exceed $p_c = 0.25f'_c$.

8A.7.7.5 Reinforcement for Joint Transfer

Where the magnitude of principal tension stress values, p_t , calculated in accordance with the above equation, exceed $p_t = 3.5\ (f'_c)^{1/2}$ psi, vertical and horizontal joint reinforcement, placed in accordance with the requirements of following sections 8A.7.7.5.1, 8A.7.7.5.2 and 8A.7.7.5.3, shall be deemed to satisfy sections 8A.7.7.4.1 and 8A.7.7.4.2, above.

8A.7.7.5.1 Vertical Joint Shear Reinforcement

A. On each side of the column or pier wall, the superstructure or footing that is subject to bending forces shall have vertical stirrups, with a total area A_{jv} = 0.16 A_{ST} located within a distance 0.5D or 0.5h from the column or pier wall face,

where: A_{jv} = Area of vertical stirrups required to provide tie force T_s resisting the vertical component of strut D_2 in Figure 8A.14 (adopted from Reference 3).
A_{ST} = Total area of column reinforcement anchored in the joint
D = Column diameter (for circular column), See Figure 8A.13.
h = Transverse column width (for rectangular column), See Figure 8A.13.

B. The allowable maximum outside dimensions of the surrounding area are twice the dimensions of the column. Reinforcement within overlaps of the two intersecting strips should be counted double to meet the A_{ST} criteria.

C. These vertical stirrups shall be distributed over a width not exceeding 2D. Figure 8A.15 shows the areas within which the vertical reinforcement A_{jv} must be placed.

D. Longitudinal reinforcement contributing to cap beam or footing flexural strength (i.e. superstructure top reinforcement, cap top reinforcement, footing bottom reinforcement) shall be clamped into the joint by vertical bars providing a total area of 0.08 A_{ST}. These bars shall be hooked around the restrained longitudinal reinforcement and extend into the joint a distance not less than 2/3 of the joint depth. If more than 50 percent of the superstructure moment capacity and/or cap beam moment capacity is provided by pre-stress, this reinforcement may be omitted,

unless needed for the orthogonal direction of response.

8A.7.7.5.2 Horizontal Joint Shear Reinforcement

Additional longitudinal reinforcement in the cap beam, superstructure and footing of total amount 0.08 A_{ST} over and above that required for flexural strength, shall be placed in the face adjacent to the column (i.e. bottom of cap beam or superstructure, top of footing), extending through the joint and for a sufficient distance to develop its yield strength at a distance of 0.5D from the column face, as shown in Figure 8A.16 (adopted from Reference 3).

8A.7.7.5.3 Hoop or Spiral Reinforcement

The volumetric ratio of column joint hoop or hoop spiral reinforcement to be carried into the cap beam or footing shall not be less than

$$\rho_s = 0.4A_{ST} / (l_{ac})^2$$

where: A_{ST} = Total area of column reinforcement anchored in the joint

l_{ac} = length of column bear embedded in to cap beam or footing

8A.7.7.5.4 Main Column Reinforcing Bars

A. Hooks on the main column bars may be turned inward to facilitate construction, if desired. Hooks on the main column bars are not required if sufficient depth is available in the structure above or below the column to accommodate required development length for the vertical bars.

B. Hooks on the main column bars are to be set on top of the bottom mat of footing reinforcement.

C. The use of bundled bars should be avoided if possible. If bundled bars are used, one of the hooks should turn inward and the other outward.

8A.7.7.6 Expansion Joints

A. In addition to meeting requirements of the AASHTO Standard Specifications, expansion joints and expansion joint gaps shall be designed according to the following criteria:

$MR = 2\Delta EQ_L + \Delta T/2$

$a = \Delta EQ_L - \Delta PS/2 + \Delta T/4$

where:

MR= Movement rating, defined as the total anticipated expansion joint movement from the widest opening to the narrowest opening (rounded up to the nearest ½ inch).

a = Expansion joint gap size at the time the joint is set, defined as the clear distance between the inside faces of the adjacent structure spans, i.e., the width of joint filler or compression seal (rounded up to the nearest ¼ inch).

ΔEQ_L = Design longitudinal displacement for the ODE level event (including amplification factor R_d (see section 8A.7.2.2). This is the anticipated on-direction earthquake displacement.

ΔT = Total design thermal displacement range.

ΔPS = Pre-stress shortening that is expected to occur after the expansion joint is set.

B. The above requirements for expansion joints are intended to prevent damage in the expansion joint area during the Operational Design Earthquake (ODE).

C. The above requirements need not apply at locations where relative movement between the superstructure and pier column are restricted by shear restriction devices (e.g., shear pins surrounded by a compressible material). For this case, the expansion joints shall be designed to accommodate the maximum movement permitted by the shear restriction devices.

8A.7.7.7 Abutments and Wingwalls

A. Abutments and wingwalls shall be designed in accordance with the requirements for Seismic Performance Category (SPC) D of sub-section 7.4.3 and 7.4.5 of Division IA,

Seismic Design, of the AASHTO Standard Specifications (Ref. 1), with the following supplemental requirements.

B. For the ODE level event, the design shall maintain an open gap between superstructure and the abutment backwall, and shall provide full transfer of transverse shear forces at the abutment.

C. For the MDE level event, the design may be based on engaging the stiffness contribution of the abutment backwall and approach slab in the longitudinal direction. In order to reduce transverse demands on the abutment foundation under the MDE level event, abutment transverse shear keys may be designed as a fuse, to withstand the full transverse shear force resulting from the ODE level event, and fail under the MDE level event.

D. The design procedure for the abutments is described below:

1. Design the abutment foundation and shear keys to carry the full transverse shear force for the ODE level event, using a response modification factor R = 1.0 (see section 8A.7.3), and size the gap at the abutment expansion joint to accommodate the full design longitudinal movement for the ODE event. If this is not feasible, increase the column stiffness/strength and repeat the design. The intent of this design procedure is to ensure that the transverse shear keys remain intact and there is no engagement of the abutment backwall (and approach slab) during the ODE level event.

2. In order to avoid excessive abutment damage during the MDE level event, an analysis is required to determine the maximum displacements and forces that may occur at the abutment. To control damage when the abutment backwall is engaged, longitudinal displacements shall be limited to 2.5 inches after gap closure occurs. If these limits are exceeded, the designer should increase the column stiffness/strength and repeat the analysis. Abutment transverse shear keys may be designed as a fuse, to fail under the MDE level event. The abutment foundation (i.e. piles) and wingwalls shall not exceed their ultimate capacities under the MDE event.

3. Expansion and deflection capacity shall be provided at abutment gaps for all system conduits in a manner consistent with the design of the structure. The design for all facilities shall accommodate the full expansion joint movement rating (MR) longitudinally (see section 8A.7.6,). If the abutment transverse shear keys are designed as a fuse, to withstand only the ODE level event, all facilities which are considered to be critical shall be designed to accommodate the anticipated transverse displacement under the MDE level event.

8A.7.7.8 Foundations

For both the ODE and MDE level events, footings shall be provided with sufficient vertical carrying capacity within a 45-degree cone directly under the column to carry the un-factored dead load reaction.

8A.7.8 Minimum Seat Width

A. Seismic design displacements for determination of seat width requirements shall be taken as the greater of the following:

1. Elastic displacements resulting from the elastic response spectrum analysis in the longitudinal, transverse and vertical directions, combined to form Seismic Load Cases 1, 2 and 3, multiplied by the amplification factor R_d, to obtain design displacements. (See sections 8A.7.2.1, and 8A.7.2.2).

2. The minimum support length requirements for Seismic Performance Category (SPC) D, in sub-section 7.3.1 of the AASHTO Standard Specifications.

B. If inelastic dynamic (non-linear time history) analysis is performed, displacements calculated from the inelastic analysis may be used in lieu of the adjusted elastic displacements, but these displacements shall not taken as less than 80 percent of the adjusted design displacements, calculated as described in section 8A.7.2.2.

8A.7.9 Cable Restrainers

The use of cable restrainers as a primary means of resisting seismic forces shall not be permitted.

8A.7.10 Structure / Rail Interaction

The seismic analysis shall include an evaluation of the interaction between the structural components and the trackwork above, with special

attention being paid to the expansion joints and abutments. During and following the Operating Design Earthquake (ODE), there shall be no damage to the trackwork and no transverse residual gaps between adjacent segments of rails.

8A.8 BUILDING STRUCTURES

A. Seismic design of surface, building like structures and/or nonbuilding surface structures other than aerial guideway structures shall be governed by the latest edition of the International Building Code (IBC).

B. Aerial stations and guideways which are planned to be built as a combined structural system, shall be designed as follows:

1. The combined frame of the station and Guideway shall be analyzed for the ODE, MDE and for IBC seismic events.

2. Structural components for the guideway shall be designed and detailed for the forces and deformations generated by the ODE and the MDE events in accordance with the provisions of section 8A.7.

3. Major structural components of the building shall be designed and detailed for the most stringent forces and deformations generated by the three events. Structural members not directly connected to the guideway shall be designed for the forces and deformations generated by IBC's seismic event.

4. Nonstructural components of the building shall be designed and detailed in accordance with section 8A.9.

8A.9 NONSTRUCTURAL COMPONENTS AND EQUIPMENT SUPPORTED BY STRUCTURES

Permanent nonstructural components and their attachments, and the attachments for permanent equipment (including mechanical/electrical systems) supported by a structure shall be designed in accordance with the International Building Code.

8A.10 RETAINING WALLS

A. Design details for seismic design of retaining walls shall be designed in accordance with the requirements for Seismic Performance Category (SPC) D of sub-section 7.4.3 and 7.4.5 of Division IA, Seismic Design, of the AASHTO Standard Specifications (Ref. 1).

B. For conventional reinforced concrete retaining walls and U-walls, seismic loads expressed in terms of dynamic earth pressures, as outlined in AASHTO

Specifications and FHWA Publication No. FHWA HI-99-012, shall be followed. Special considerations shall be directed to the yielding/non-yielding nature of the walls in determining the dynamic earth pressures. For retaining walls that are allowed to accommodate some limited deformations, depending on their functioning requirements during MDE and ODE, the dynamic earth pressures may be reduced by selecting a design seismic coefficient lower than the peak ground acceleration value (expressed in terms of percent gravity, g). The design seismic coefficients for both MDE and ODE shall be determined by the Designer in consultation with the Final Design Geotechnical Consultant, but the reduced seismic coefficient used for design shall not be less than 50 percent of the original value.

C. Seismic design of mechanically stabilized earth (MSE) walls shall be in accordance with FHWA-SA-96-071, "Mechanically Stabilized Earth Walls and Reinforced Soil Slopes - Design and Construction Guidelines", except that the design seismic coefficients shall be based on the project specific design earthquakes.

D. Seismic design of soil nail walls shall be in accordance with FHWA-SA-96-069, "Manual for Design and Construction Monitoring of Soil Nail Walls", except that the design seismic coefficients shall be based on the project specific design earthquakes.

8A.11 OTHER SEISMIC CONSIDERATIONS

8A.11.1 Liquefaction

A. Liquefaction and liquefaction-related ground instability shall be evaluated at relevant locations along the project alignments. Empirical procedures based on CPT data or SPT blowcounts may be used (NCEER, 1997). An initial screening study shall be conducted followed by more refined analyses and evaluation of its impact to the proposed facility. Special attention shall be paid to loose hydraulic fill, deltaic deposits and Holocene alluvium at the project site. The effects of liquefaction on the design of the foundations as well as structures shall be thoroughly investigated. These effects shall include, but not be limited to, the following: (1) downdrag and lateral/vertical resistance of deep foundation, (2) loss of bearing capacity and settlements of shallow footings, (3) post-liquefaction (post-earthquake) stability and deformations of embankments, (4) increased lateral pressures and buoyancy forces on walls and underground structures, and (5) lateral spreading along gentle slopes.

B. If the liquefaction impact analyses yield unacceptable performance of the structures, mitigation measures shall be incorporated into the design.

8A.11.2 Landslide

A. The potential for seismically induced landslides shall be identified along the proposed alignment, particularly in areas where existing slopes have displayed signs of movement under static conditions (e.g., at the portals of the Beacon Hill tunnel section). If pseudo-static seismic stability analyses indicate insufficient safety margin against the landslide movements, then an appropriate method of analysis, such as the Newmark time-history analysis, shall be used to estimate the movements. The impact of the potential slope movements on the affected structures shall be assessed. If the impact analyses yield unacceptable performance of the structures, mitigation measures shall be incorporated into the design.

B. If any reduction in existing safety margin of the slope could result from the proposed construction of the facility, the design shall incorporate appropriate remedial measures to prevent such reduction.

8A.12 CONSTRUCTION CONDITION AND TEMPORARY STRUCTURES

8A.12.1 Seismic Loading During Construction Condition

All aerial, stations, and surface structures shall be designed to resist an equivalent static load of 0.1g acting at the center of mass for configurations occurring under the assumed construction sequence. The structures should be designed to avoid collapse.

8A.12.2 Temporary Detail Aerial Structures

Temporary detour aerial structures which will be subjected to traffic shall be designed by response by response spectrum methods for motions corresponding to 75 percent of the design response spectra specified for the ODE in section 8A.5.2. Design procedure and parameters shall be as those for the ODE level earthquake.

8A.12.3 Temporary Support Structures for Surface Excavation

Seismic loading for temporary support structures for surface excavation shall be defined by dynamic earth pressure distributions. The dynamic earth pressure distributions shall be developed by the Designer's Geotechnical Consultant using Mononobe-Okabe method (as outlined in AASHTO Specifications and FHWA Publication No. FHWA-HI-99-012) with a horizontal seismic coefficient of 0.1. The effects of sloping backfill and surcharge load shall be considered in developing the dynamic earth pressure distributions. Other design requirements shall be in accordance with section 8A.10.

8A.12.4 Temporary Support Structures for Underground Excavation

These structures include, but are not limited to, initial ground supports for mined stations, caverns, crossovers, and mainline tunnels. The structures shall be designed to accommodate the ovaling/racking, axial, and curvature deformations (refer to section 8A.6) determined by using 50 percent of the design peak ground motion parameters (i.e., PGA, PGV, and PGD) specified for the ODE in section 8A.5.2.2.

8A.13 REFERENCES

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2. ***"International Building Code"***, by the International Conference of Building Official, 2003.

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5. "***Manual for Railway Engineering, sub-section 9 - Seismic Design for Railway Structures"***, by American Railway Engineering Association,

6. ***"Seismic Design and Retrofit of Bridges"***, by Priestly, Seible and Calvi, 1996.

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8. ***"Design Recommendations for Thin-Walled Box Piers and Pylons, Concrete International"***, Volume 16, Number 12, by Taylor, Andrew W. and Breen, John E., December 1994, pages 36-41.

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11. ***"NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures"***, Part 1 – Provisions, 1997 Edition, FEMA302, February, 1998

12. ***"Proceedings of the NCEER Workshop on Evaluation of Liquefaction Resistance of Soils"***, NCEER-97-0022, NCEER, by Youd, T. L., and Idriss, I. M., 1997.

13. ***"Geotechnical Earthquake Engineering – Reference Manual, Training Course in Geotechnical and Foundation Engineering"***, NHI Course No. 13239 – Module 9, FHWA HI-99-012, by U.S. Department of Transportation, Federal Highway Administration, 1998.

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15. ***"Manual for Design and Construction Monitoring of Soil Nail Walls"***, FHWA-SA-96-069, by U.S. Department of Transportation, Federal Highway Administration, 1997.

16. ***"Seismic Design of Tunnels – A Simple State-of-the-Art Design Approach",*** Monograph 7, 1991 William Barclay Parsons Fellowship, Parsons Brinckerhoff, 1993.

17. ***"Analysis and Design of Reinforced and Prestressed Concrete Guideway Structures"***, by American Concrete Institute, ACI 358.1R-92, 1992.

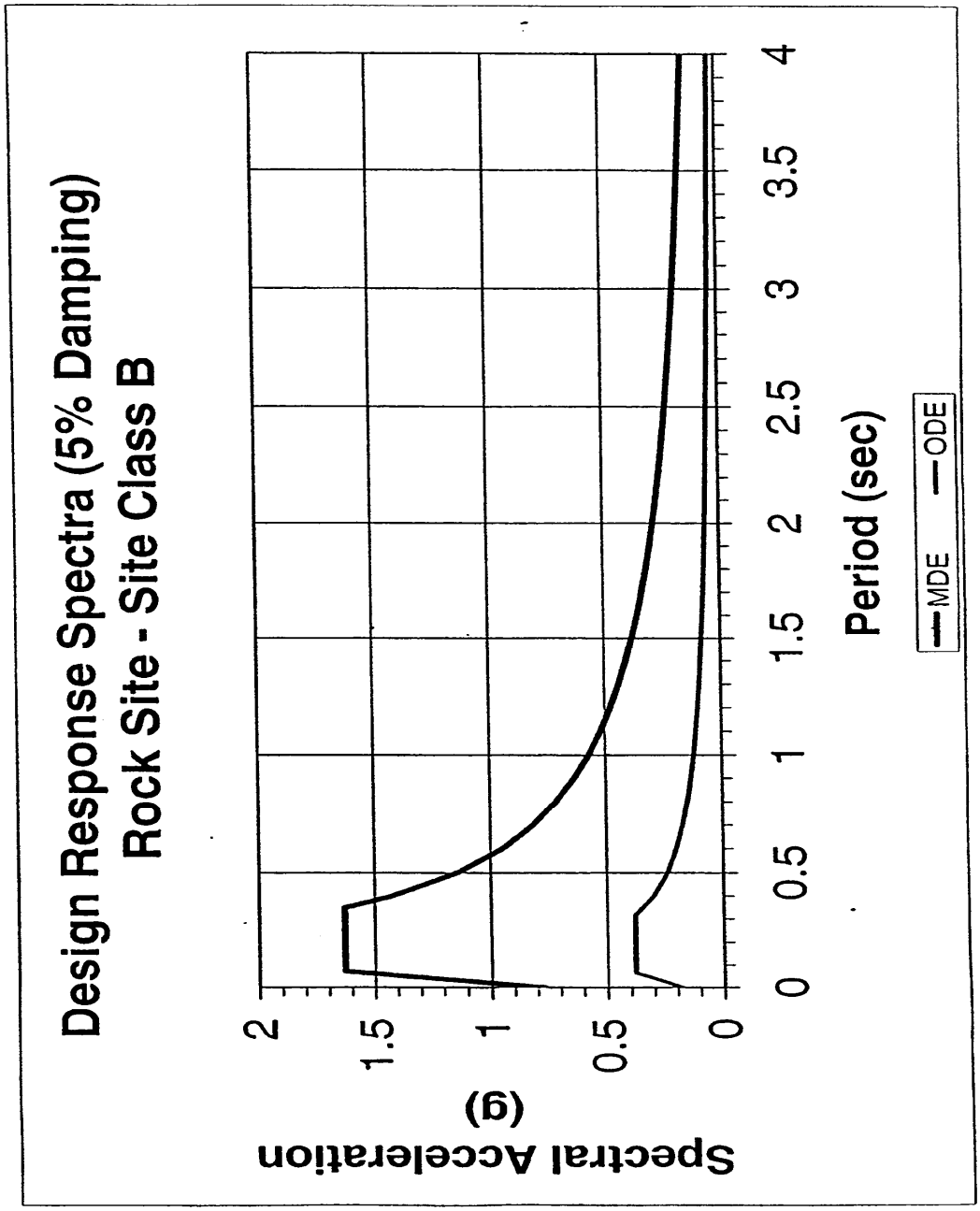


Figure 8A-1: Design Response Spectra (5 percent Damping) Rock Site – Site B

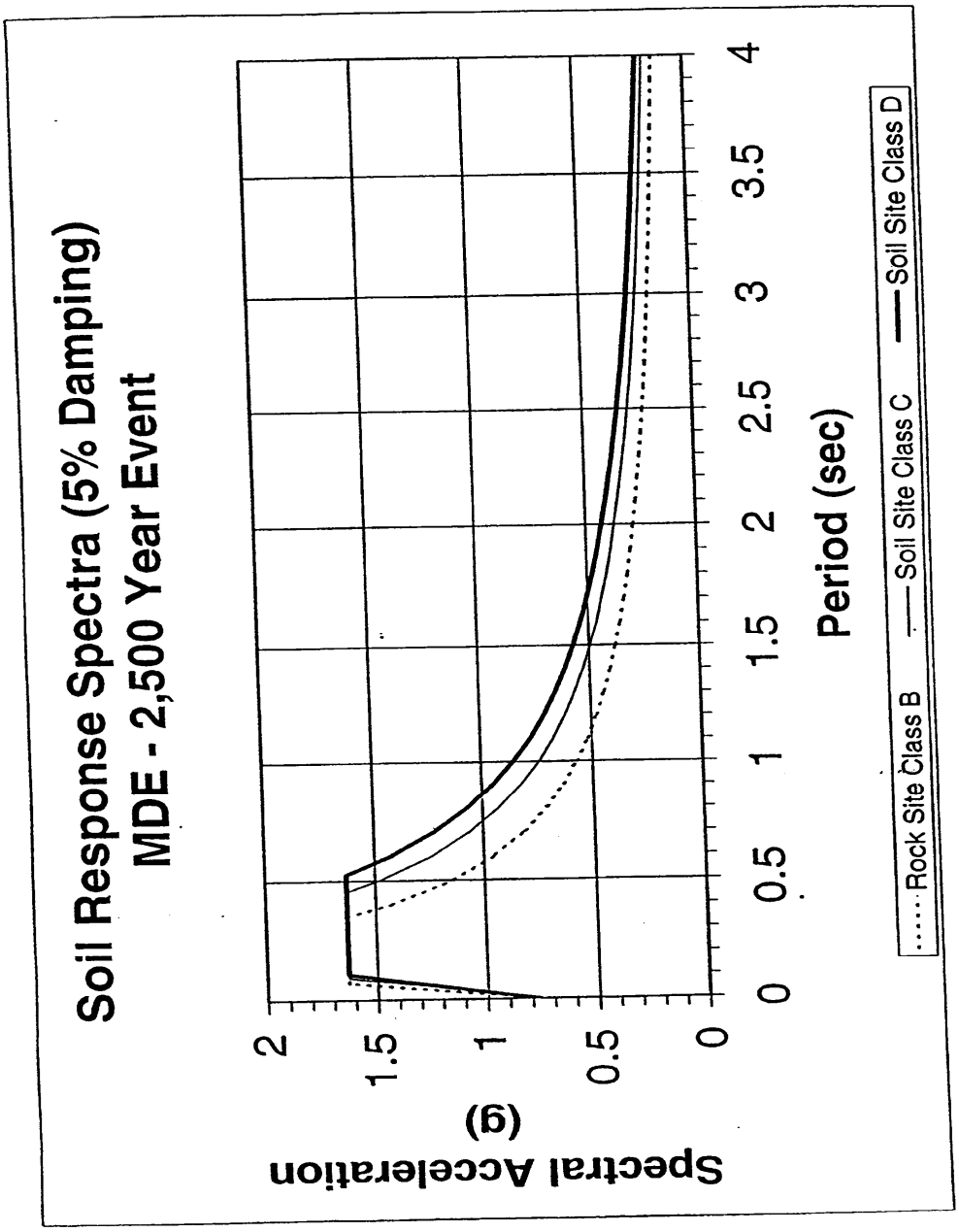


Figure 8A-2: Soil Response Spectra (5 percent Damping MDE – 2,500 Year Event

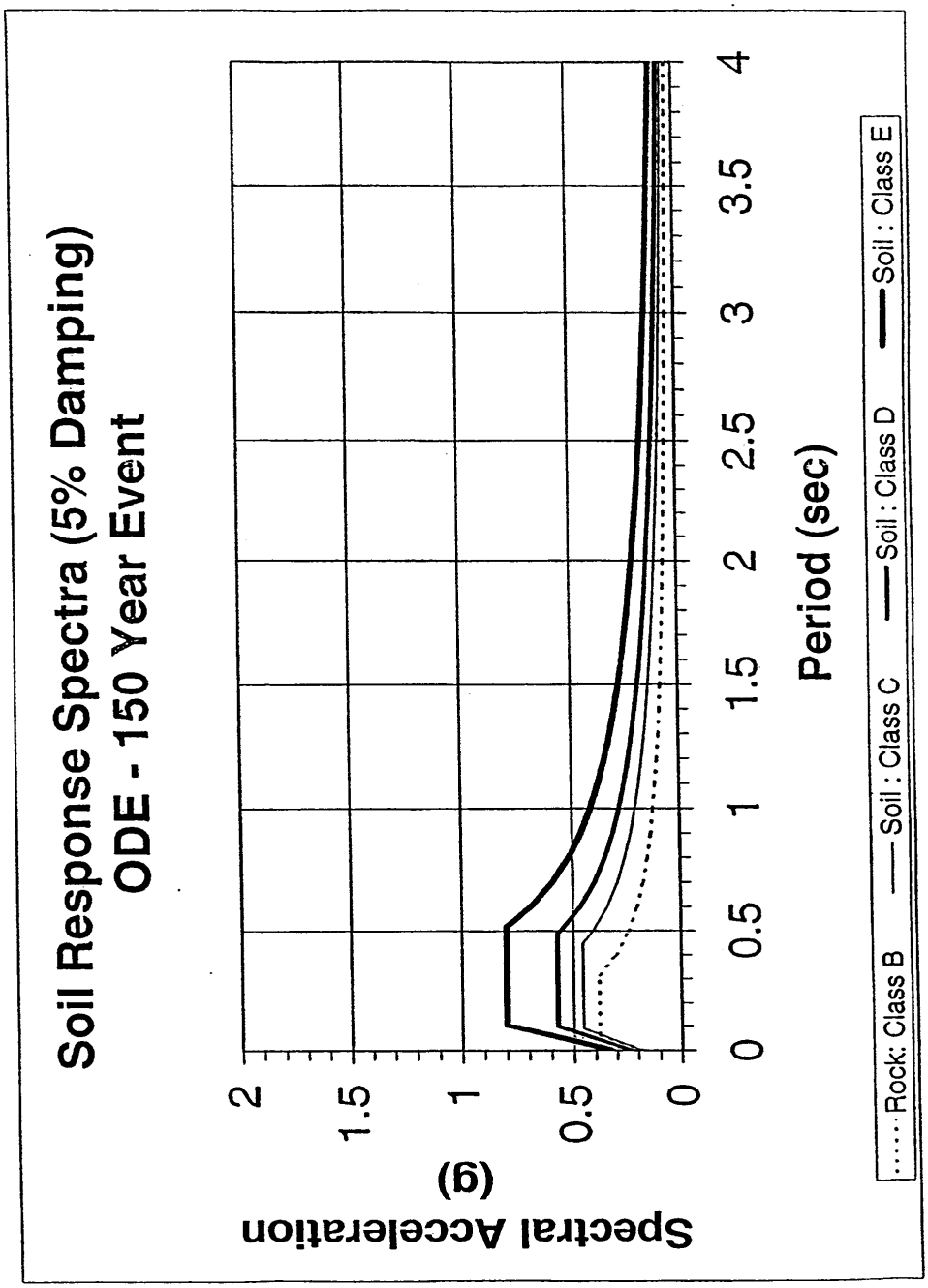
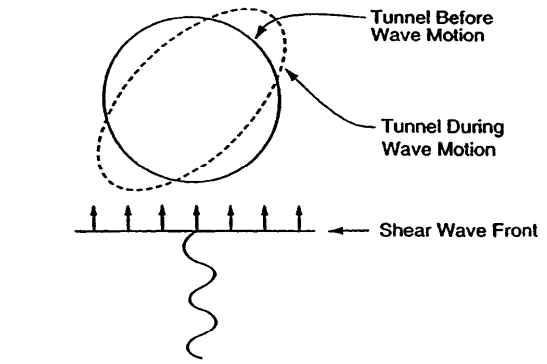
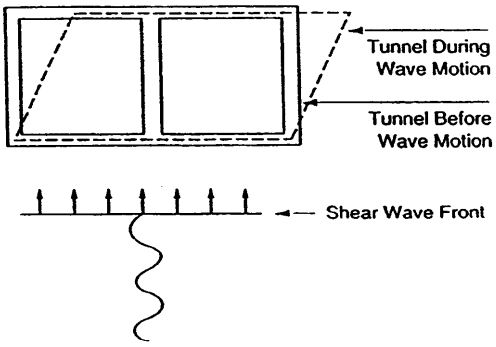


Figure 8A-3: Soil Response Spectra (5 percent AMPING ode – 150 Year Event



A. Ovaling Deformation of a Circular Cross Section



B. Racking Deformation of a Rectangular Cross Section

Figure 8A-4: Ovaling Deformation of Circular Section and Racking Deformation of Rectangular Section

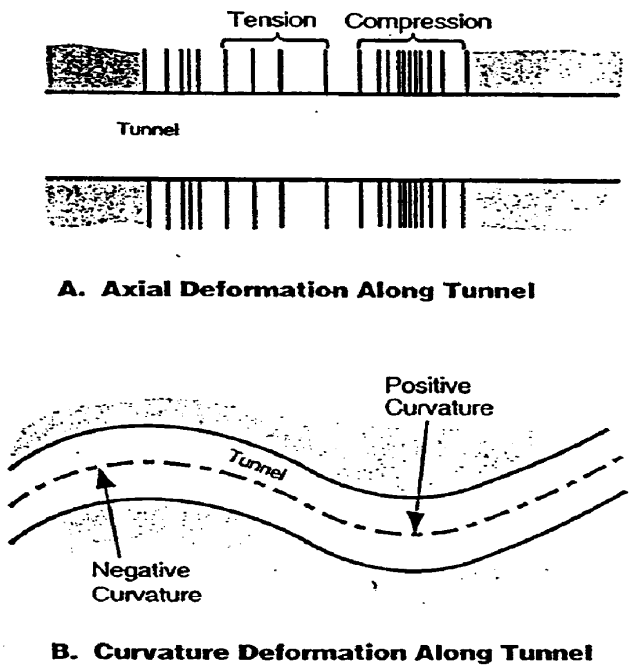


Figure 8A-5: Axial Deformation along Tunnel and Curvature Deformation along Tunnel

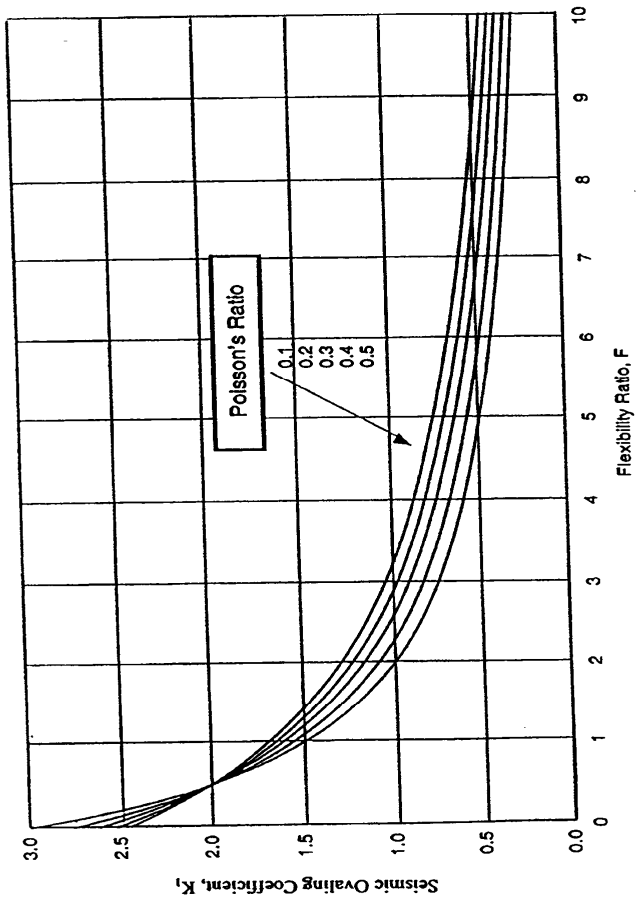


Figure 8A-6: Seismic Ovaling Coefficient, K1 (for F between 0 and 100)

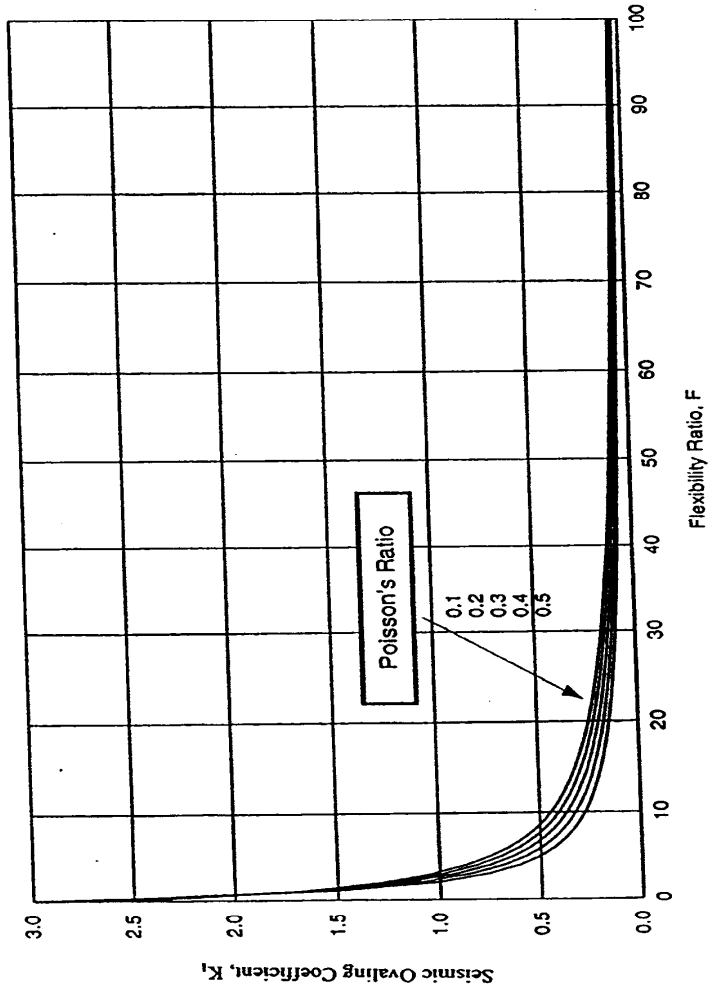


Figure 8A-7: Seismic Ovaling Coefficient, K1, (for F between 0 and 100)

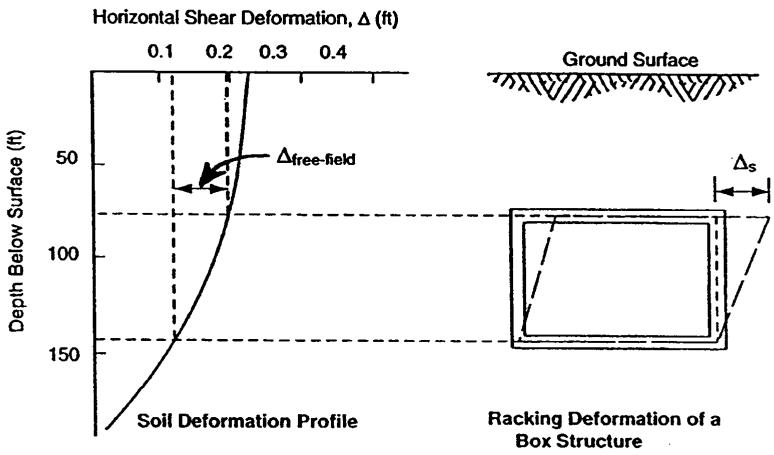


Figure 8A-8: Racking Deformation of Box Structure

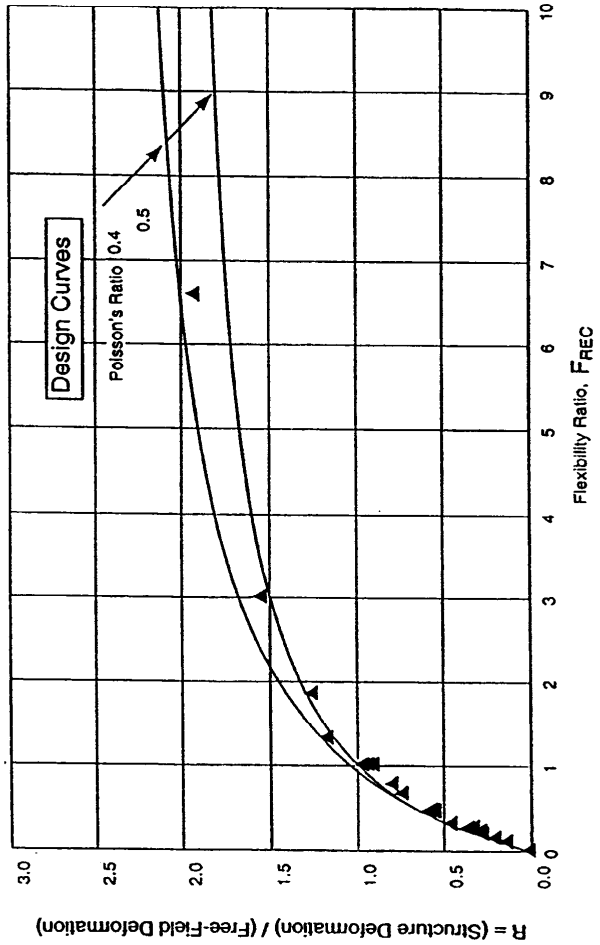
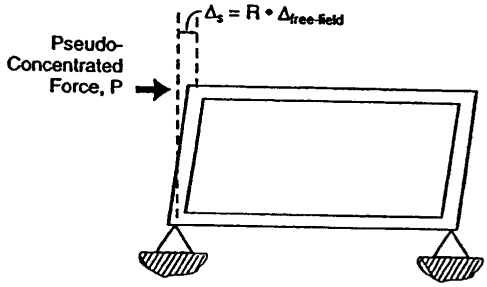
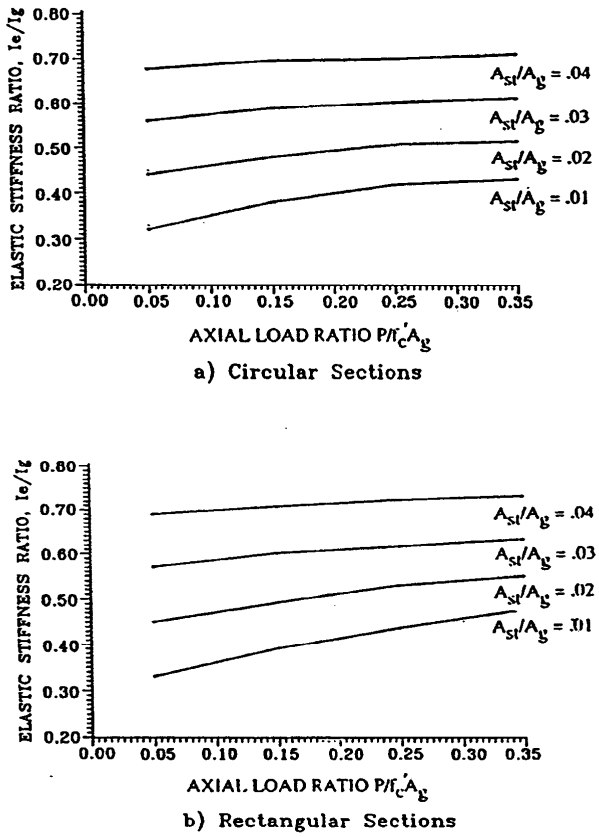


Figure 8A-9: Structure vs. Free Field Deformation



Frame Analysis Modeling of Racking Deformations

Figure 8A-10: Frame Analysis Modeling of Racking Deformation



Effective stiffness of cracked reinforced concrete sections [N4].

Figure 8A-11: Effective Stiffness of Cracked Reinforced Concrete Sections

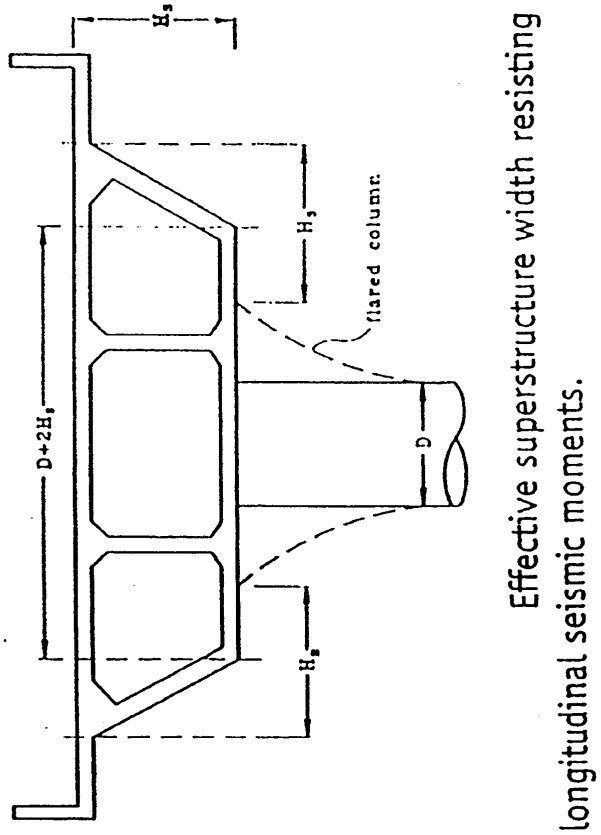
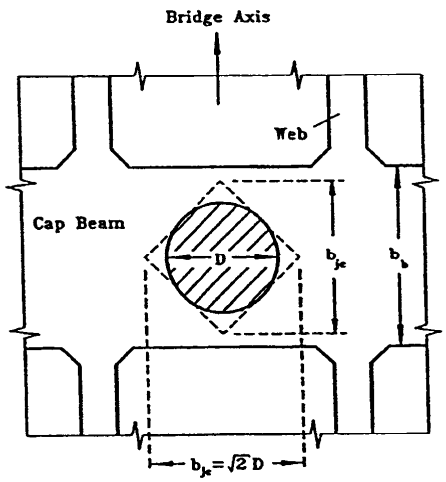
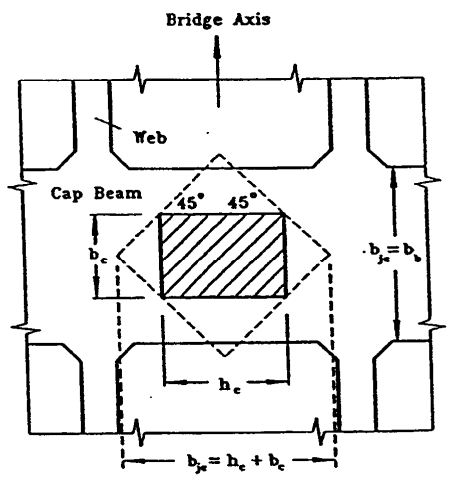


Figure 8A-12: Effective Superstructure Width Resisting Longitudinal Seismic Moments



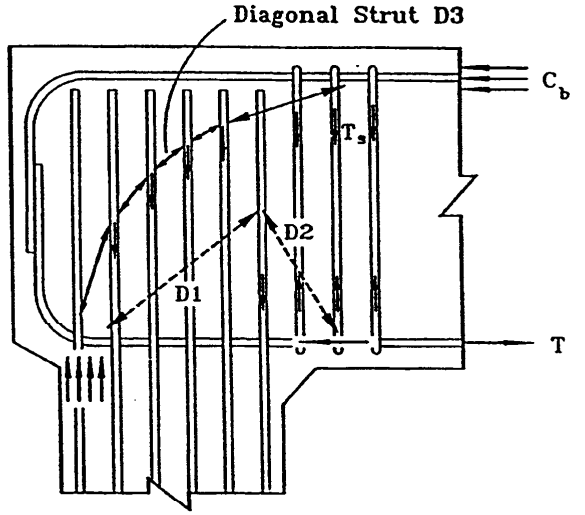
(a) Circular Column



(b) Rectangular Column

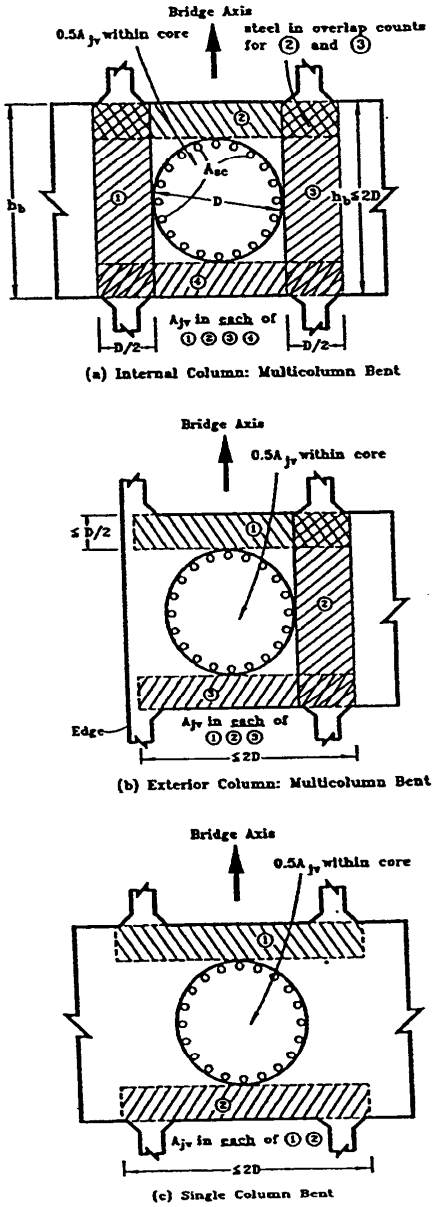
Effective joint width for shear stress calculations.

Figure 8A-13: Effective Joint Width for Shear Stress Calculations



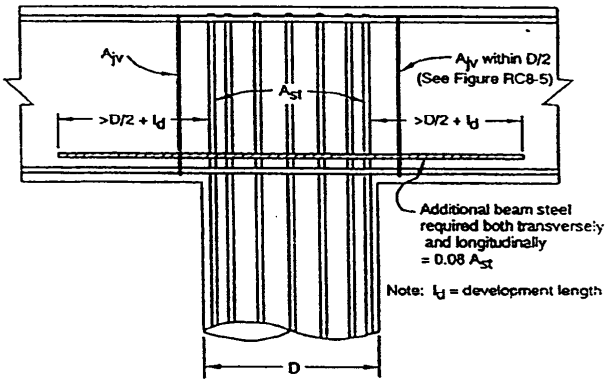
External vertical joint reinforcement for joint force transfer.

Figure 8A-14: External Vertical Joint Reinforcement for Joint Force Transfer



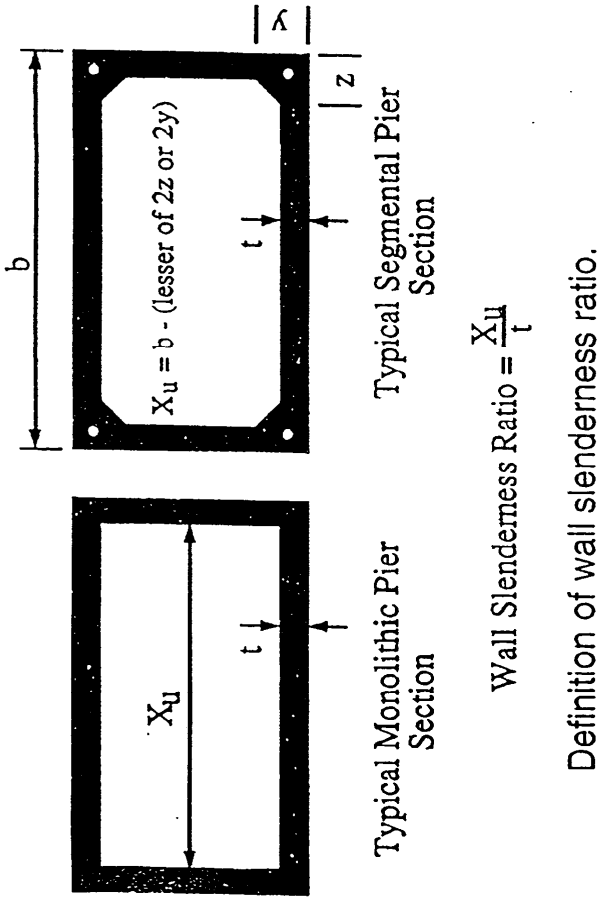
Locations for vertical joint reinforcement.

Figure 8A-15: Locations for Vertical Joint Reinforcement



Additional cap beam bottom reinforcement for joint force transfer.

Figure 8A-16: Additional Cap Beam Bottom Reinforcement for Joint Force Transfer



Wall Slenderness Ratio = $\frac{X_u}{t}$

Definition of wall slenderness ratio.

Figure 8A-17: Definition of Wall slenderness Ratio (Adopted from Reference 8)

END OF CHAPTER 8A

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9. STATIONS

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9. STATIONS

9.1 INTRODUCTION

A. This chapter establishes specific guidelines and standards for the design of stations. Chapter 1, General, shall be referred to for overall guidelines for the development of station design. Elements discussed in this chapter include the design of platforms, amenities, vertical circulation, and platform access; general guidelines for use in the design of bus access, kiss-and-ride, and park-and-ride facilities; and guidelines for the selection of materials. Reference should also be made to Chapter 3, Environmental; Chapter 6, Civil Work; Chapter 18, Fire/Life Safety, Chapter 21, Lighting; Chapter 27, ST*art*, Sound Transit Art Program; and Chapter 29, Security; for additional criteria.

B. The design of the stations shall provide a permanent civic architecture that contributes to its context. Each station's design should not only be a derivative of the transit system, but of the neighborhoods and community of which it is a part. Within this framework, the development of a family of parts for stations that are interchangeable and allow for the individual character of each neighborhood or community is an acceptable standardization practice.

C. Furthermore, the Sound Transit Board adopted resolutions with respect to the functioning and appearance of the Link light rail facilities, several of which will impact on the design of stations. Specific reference should be made to existing and future motions, including Resolution No. R98-1, and Motion Nos. M40 (1997), M98-58, M98-60, M98-64, M98-66, M98-67 and M98-78.

9.2 DEFINITIONS

A. As defined in Chapter 18, Fire/Life Safety, stations shall be designed to facilitate the movement of patrons in an efficient, safe, and secure manner.

B. Passenger Stations are defined as those facilities and their appurtenances used to load and unload passengers, and are located on exclusive, semi-exclusive, or open right-of-way, often with passenger access restricted by fences or other barriers.

C. This chapter is applicable to elevated, at-grade, and underground passenger stations.

TABLE 9-1

BOARD MOTIONS

Motion No.	SUBJECT
R98-1	Art Program
M98-58	Automated Teller Machines, Bicycles, Passenger Amenities, and Signage
M98-60	Architectural Expression, Vertical/Horizontal Circulation, Guideway Architecture, Overhead Catenary System, and Streetscape
M98-64	Security
M98-65	Advertising
M98-66	Concessions
M98-67	Public Restrooms and Drinking Fountains
M98-78	Bicycles

9.3 CODES AND STANDARDS

A. The linear nature of Link light rail (Link) causes its alignment to travel through numerous districts, cities, and counties. Each of these legally defined areas has different land use and development regulations and legislative procedures directly affecting station site planning and design. Each individual jurisdiction may have special amendments or supplements to codes and standards that apply on a statewide and national basis. In addition, transit companies (private and public) have Design Criteria and Standards for their facilities. Therefore, station designers shall:

B. Identify the governing jurisdiction for each site at every governmental level, as referenced in Chapter 1, General.

C. Locate jurisdictional boundaries

D. Review applicable adopted master plans, municipal codes, and standards

E. Use the latest edition of the following:

1. IBC, as adopted and amended by the State of Washington

2. NFPA – Fire protection codes

3. International Fire Code (IFC)

4. Americans with Disabilities Act (ADA)

5. Washington State Accessibility Standards

F. Where no provisions are made in the codes for particular features of the design, the best architectural practice shall be followed, with the prior approval of Sound Transit.

9.4 GENERAL DESIGN PARAMETERS

A. Stations must be able to handle patrons efficiently, economically, safely, conveniently, and comfortably. Stations and related facilities shall aesthetically support the use of proven modern technology while providing for the traditional requirements of public transit systems: identity in the neighborhood or downtown area as a location for public transit; shelter from severe weather; and cover and/or screening from average weather conditions.

B. In designing stations and related facilities, the anticipated growth and long-term life of the system shall be considered, not only for functional elements and materials, but also for visual quality. The quality of the designs shall have lasting character and shall utilize high quality, durable materials.

C. The design of transit stations must provide proper orientation for the patron. To a large extent, this orientation can be accomplished by simplifying how patrons use the system, which in turn can be measured in terms of the ease of patron access to and dispersal from stations/trains. The ease of patron access is best achieved by utilizing a common arrangement or organization of the functional spaces in stations. This level of commonality will make each station familiar to patrons and minimize the need to learn the system on a station-by-station basis.

D. The following general principles shall be employed for the basic organization of a station's public spaces:

1. Public access to the station should be restricted to designated public entrances only.

2. Fare collection and designation of Fare Paid Zones shall be positioned in a similar manner in all stations to the greatest extent possible.

3. The connection of major spatial elements shall minimize the number of decisions a patron must make at any one point and should be organized in a clear, logical, and sequential manner that reinforces patron flow.

4. The area of the Fare Paid Zone must be clear and obvious. Designation of the Fare Paid Zone will be an Operational decision.

5. Vertical circulation elements shall be located so as to be readily visible and identifiable as a means of direct access to the levels they are designated to interconnect.

6. Stairs and escalators shall be located so as to reinforce the direct straight line from entry to platform.

7. Elevator access shall be located in Fare Paid areas to the greatest extent possible.

8. Elevator landings shall be located so that users waiting for elevators do not impede general circulation, have adequate space for queuing, and are not hidden from view.

9. Stairs and escalators shall run in the same direction (be parallel) so that patron movement is simplified and logical

E. Sound transit approved standard elements, such as "furniture" (benches, trash receptacles, telephone housing, etc.), Sound Transit graphics/information signing systems, paving materials, glazing type, sizes and systems, and light fixture types shall be utilized to reduce inventory, maintenance and replacement costs.

F. In all segments, it is essential that great care be taken in coordinating final design with Sound Transit and the affected communities, adjacent property owners or developers, and other such public agencies or community groups as may have jurisdiction or significant interest in each segment or station.

G. All maintenance and performance criteria materials used shall recognize the vital role of durability, vandal-resistance, and maintenance needs of the particular station site. Materials shall be selected considering life cycle costs.

9.4.1 Station Art Program

Sound Transit has established an art program, entitled “ST*art*”, which is aimed at incorporating works of art in and adjacent to the Link light rail facilities. The ST*art* program takes into consideration that stations will be designed first and foremost, as functional facilities organized on established principles of pedestrian movement. Reference shall be made to Chapter 27, ST*art*, Sound Transit Art Program, for the guiding principles and goals for the Sound Transit art program. Basic guidelines related to incorporating art in the Link light rail stations are included herein:

9.4.1.1 Architectural Integration

Given the potential variety of character and size, art shall be compatible with the volumes of the interior or exterior spaces (where applicable) in which they are located, and shall in all

cases, be integrated with the architectural expression of individual stations that fits within the context of the surrounding areas.

9.4.1.2 Locational Criteria

A. The placement of art shall recognize the primary importance of the functional clarity of stations.

B. The location of art shall not impede patron circulation in passageways, circulation areas, surge areas, and platform areas, nor pose a safety hazard.

C. Art may support, but not compete with, essential system signing and information.

D. The location of art may conflict with the advertising program, should Sound Transit pursue such a program. A balance of all elements will be required, with priority given to art over advertising.

9.4.1.3 Maintenance and Performance Criteria

A. All materials used in the fabrication of artworks shall support the artistic concept developed for the station while recognizing the vital role of durability, vandal-resistance, and maintenance needs of the particular station site.

B. Artwork intended to be permanent shall incorporate materials, fabrication methods, and installation methods which are appropriate for its expected life.

C. Maintenance needs of artworks shall, in general, be consistent with the maintenance needs of the particular station and site.

D. Station artwork shall work with the existing ambient lighting of the stations wherever possible. Special lighting requirements shall be identified on a station-specific basis and shall be accommodated within the station planning as early as possible.

E. Other special needs shall be assessed on a station-specific basis and shall be identified within station planning as early as possible.

9.4.2 Pedestrian Criteria

A. The criteria listed in this chapter are minimum guidelines relevant to pedestrian circulation and should not supplant the logic of a better functional solution should it develop. Certain circulation elements can handle a definite number of people conveniently in a given period of time. There are three distinct groups that must be considered in the design of pedestrian circulation: regular commuters; infrequent users; and individuals with disabilities. The three groups move through the systems in varying ways: commuters move quickly with a minimum of guidance; infrequent users move easily with great reliance on signs for guidance; and individuals with disabilities move slowly with guidance required depending on the frequency of use and the degree of the disability. The following general principles shall be employed to accommodate these varying demands:

1. Right-hand flows are the norm, and therefore desirable.

2. Pedestrian flow will take the path-of-least-resistance, so stations shall be designed to directly and safely accommodate anticipated pedestrian movement.

3. Grade changes are to be minimized, and where they are necessary, they shall conform to slope criteria for individuals with disabilities access, or stair and ramp criteria as noted.

4. The patron should know where he/she is going at all times and the direction of circulation elements shall be as obvious as possible to aid recognition.

5. Circulation shall be designed to accommodate room for hesitation or slow passage so the individual with a disability, the infrequent user or waiting patron can pause adjacent to, but out of the mainstream of pedestrian flow, where practical.

6. Surge and queuing spaces shall be provided ahead of every barrier, change in circulation, direction or mode and in front of TVM, (ticket vending machine) installations.

7. No obstructions shall be within the main pedestrian flow as defined in section 9.7.5.

8. Enclosed shelter areas and circulation elements shall have sufficient transparency to give adequate visual surveillance of these spaces and to discourage vandalism.

9. Pedestrian access from bus, kiss-and-ride, park-and-ride areas, and neighborhood sidewalks and streets must be clear and as simple as possible.

10. Circulation elements shall use color, texture, and sight distances to best advantage to increase visual pleasure, guidance, patron safety, and security.

11. Circulation elements and station structures shall be designed using "Transit Security Design Considerations, FTA-TRI-MA-26-7085-05, November 2004", as noted in Appendix C.

9.4.3 Way Finding Provisions

Tactile Way Finding provisions in stations for people who are blind or have low vision shall consist of the following:

A. Tactile Path/Braid

1. The tactile path/braid shall begin at the entry to the station with a "knot" pattern. The path shall extend to fare vending/information areas and to the threshold of vertical circulation elements, (where applicable) at station entry levels. The path shall extend over to one TVM machine/information area at the station entry. Bump outs shall be provided to locate other important elements along the path such as additional information.
2. At platform level the tactile path/braid shall extend from the threshold of vertical circulation elements to the tactile train waiting/information areas.
3. The path/braid shall be 8 inches wide and typically located 4 feet back from the platform edge detectable warning surface.
4. Materials employed for the path/braid shall be of a contrasting color to field paving. Sound Transit standard is a white granite paver.

B. Tactile Training Waiting Area

1. Tactile train waiting areas shall identify the location of the two center-most sets of doors of a two-car train.
2. The waiting areas shall be 6 feet wide and extend the full depth of platforms, excluding platform edge detectable warning surfaces.
3. Pavers with raised ribs oriented parallel to the platform edge shall be used.
4. Pavers of the same materials and color as adjacent platform paving shall be used.

9.5 LEVEL-OF-SERVICE STANDARDS

A. Level-of-Service (LOS) performance standards represent a method for sizing circulation elements that responds to the demands of patron/pedestrian behavior. Safety codes address emergency conditions and permit a range of crowded conditions. LOS is a performance standard that assume a range of normally recurring conditions and apply a level-of-service in which patron movement may be restricted, but not crowded or uncomfortable.

B. The following minimum performance standards shall be used in the design of station public circulation elements. They permit relatively free circulation through concourse areas and a degree of restricted walking speed and circulation in queue situations.

9.5.1 Walkways and Concourse Connectors – LOS D

A. Average Pedestrian Area Occupancy - 10 to 15 square feet per person.

B. Average Flow Volume - 15 to 20 Pedestrians per foot width of walkway, per minute (PFM).

C. At walkway LOS D, the majority of persons would have their normal walking speeds restricted and reduced, due to difficulties in bypassing slower-moving pedestrians and avoiding conflicts. Designs at this LOS would be representative of the most crowded public areas, where it is necessary to continually alter walking stride and direction to maintain reasonable forward progress.

9.5.2 Concourse Area (Including Fare Vending) – LOS A

A. Average Pedestrian Area Occupancy - 13 square feet per person, or more.

B. Average Inter-person spacing - 4 feet, or more.

C. At LOS A, space is provided for standing and free circulation through the concourse area without disturbing others. Sufficient queuing space shall be provided at fare vending equipment to maintain free circulation in the concourse area, particularly between the station entrance and access to vertical circulation elements.

9.5.3 Platform Waiting Zones – LOS C

A. Average Pedestrian Area Occupancy - 7 to 10 square feet per person.

B. Average Inter-person spacing - 3 to 3-1/2 feet.

C. At queuing LOS C, space is provided for standing and restricted circulation through the queue without disturbing others.

9.5.4 Surge Areas – LOS D

A. Average Pedestrian Area Occupancy - 3 to 7 square feet per person.

B. Average Inter-person spacing - 2 to 3 feet.

C. At queuing LOS D, space is provided for standing without personal contact with others, but circulation through the queuing area is severely restricted, and forward movement is only possible as a group. Applications would include escalator queuing areas. This level of area occupancy is not recommended for long-term periods of waiting.

9.5.5 Stairways (Public) – LOS D

A. Average Pedestrian Area Occupancy - 7 to 10 square feet per person.

B. Average Flow Volume - 10 to 13 PFM.

C. At stairway LOS D, representing a space approximately three to four treads long and two to three feet wide, locomotion speeds are restricted slightly, due to the limited open tread space and an inability to bypass slower-moving pedestrians. Reverse flows would encounter significant difficulties and traffic conflicts.

9.5.6 Conventional Elevators, (Aerial & Shallow Tunnel Stations) – LOS D

A. Average Pedestrian Area Occupancy - 3 to 7 square feet per person.

B. Average Inter-person Spacing - 2 to 3 feet.

C. At queuing LOS D, space is provided for standing without personal contact with others.

9.5.7 High Speed Elevators (Deep Tunnel Stations) – LOS E

A. Average Pedestrian Area Occupancy - 2 to 3 square feet per person.

B. Average Inter-person Spacing - 2 feet or less.

C. At queuing LOS E, some personal contact.

9.6 ELEMENTS OF VERTICAL CIRCULATION

A. In general, the following guidelines shall be used to determine the vertical circulation elements in grade-separated stations:

1. Utilize stairs and ramps as the primary vertical circulation elements where the vertical rise between public circulation levels is 12 feet or less, unless high patron volumes warrant the use of escalators and elevators (over 5,000 patrons a day).

2. Utilize escalators in the up direction only, in addition to stairs and elevators, where the vertical rise between public levels exceeds 12 feet but does not exceed 25 feet, unless high patron volumes warrant otherwise (over 5,000 patrons a day).

3. Utilize escalators in both directions, in addition to elevators and stairs, when the vertical rise between the station entrance and platform levels exceeds 25 feet, and in heavily patronized stations (over 5,000 patrons a day).

4. Utilize high-speed elevators as the primary means of vertical transportation where the depth of a subway station exceeds 120 feet from entry level to platform level.

B. Exceptions to the above criteria must be reviewed and approved by Sound Transit prior to use in design.

9.6.1 Ramps

A. The number, width, and distribution of ramps shall be determined per Table 9.2, Patron/Lane Requirements. Ramps shall meet the requirements of ADA.

B. In general, sloping sidewalks are preferred over ramps, and shall be used whenever possible.

9.6.2 Stairs

A. The number, width, and distribution of stairs shall be determined in accordance with Table 9.1, Patron/Lane Requirements. In addition to meeting all applicable code requirements (IBC, ADA, etc.), the following shall be incorporated into the design of all public stairs:

1. Ideally, stairs adjacent to an escalator shall be parallel to the angle of inclination of the escalator (30 degrees). Treads for these stairs shall be 11.50 inches with 6.64 inches risers.

2. Minimum headroom clearance of 9 feet measured vertically from stair tread nosing.

3. Maximum riser height - 7 inches.

4. Minimum tread width – 11.50 inches.

5. A cleaning trough three inches wide flanking the stairs shall be provided on both sides.

6. The minimum clear width of stairs for public use shall be 48 inches between handrails unless local jurisdiction requires wider stairs. The minimum length of landing for straight-line stairs shall be 54 inches. Larger dimensions shall be provided where planning indicated that more space is needed.

7. Maximum height between landings shall be 12 feet in compliance with IBC.

8. A distinct visual contrast between tread edges and treads shall be maintained. Where this is not possible a visual contrast between treads and stringers shall be provided.

9. Treads shall be furnished with non-slip surface material.

10. Open risers are not permitted.

11. Tactile warning cues for the visually impaired shall be provided.

12. The upper approach and the lower tread of each stair shall be marked by a strip of clearly contrasting color at least 2 inches wide, placed parallel to and not more than 1 inch from the nose of the step or landing to alert the visually impaired. The strip shall be of material that is at least as slip-resistant as the other treads of the stair.

B. Lighting for stairs shall be easily accessible for maintenance by ladder or from above, such as from platform level.

9.6.3 Escalators

A. The necessity, direction and capacity of escalators are determined by a combination of factors including, rise, expected patronage, and available budget. In general, the greater the patronage and rise, the more "weight" is given to including escalators.

B. The necessity, direction, and capacity (width) of escalators shall be determined by the station patronage. Each entrance shall be considered separately. Designers shall recommend, and Sound Transit will determine, if the "optional" escalators are to be initially included as a result of available budget.

C. The design of the escalators shall incorporate the following:

1. Speed of 100 fpm;

2. Stop/start controls on site (inaccessible to public) and at the central control facility;

3. Public-accessible emergency stop buttons at top and bottom of escalators. Emergency stop buttons should cause an alarm at the central control facility when activated. See Chapter 25, Elevators and Escalators, for additional information;

4. Automatic stop mechanism tied to fire detection system when detection system is provided; and

5. Where feasible, escalator designs and specifications shall be in accordance with Sound Transit standards.

D. Lighting for escalators shall be easily accessible for maintenance by ladder or from above, such as from platform level.

9.6.4 Elevators

A. General

1. Each multilevel station shall be provided with an elevator(s) connecting entry level to all platforms and any intermediate public levels. Elevator cab equipment shall be designed for use by individuals with disabilities. Elevator machine rooms shall be located as near as possible to hoistways, but clear of public walking and landing areas.

2. Specific elevators in each station shall be designated for use by patrons with bicycles.

3. Elevators intended for use in moving equipment to and from equipment rooms shall be sized to accommodate the intended equipment.

4. All elevator installations shall comply with IBC, NFPA, IFC, ADA, and Washington State Accessibility Standards.

5. All metal cladding, floors, wall railings, and trim shall be stainless steel. Finish on floors to be integral one piece material that includes base at wall. Floors to slope to center to discourage people from urinating in the elevators and for ease of cleaning. Elevator pit walls shall be lined with a non-porous material and shall have a sump pump if gravity drains are not available.

B. Conventional Elevators (Aerial and Shallow Tunnel Stations)

1. The minimum cab size allowed shall allow a 27-inch by 42-inch wheelchair to execute a 180-degree turn within the cab or accommodate a standard 30-inch by 72-inch hospital rolling stretcher plus attendant, or whichever is greater.

2. Specific elevators in each station shall be designated for use by patrons with bicycles.

3. Both elevator cab and hoistway enclosure shall be constructed of glass to the maximum extent possible in above-grade stations to enhance both actual and perceived security of the elevator and passengers.

C. High Speed Elevators (Deep Tunnel Stations)

1. Elevators shall be sized to accommodate projected patronage for the peak 15 minutes with the peak hour at ultimate system build out.

2. The minimum cab size allowed shall accommodate two standard 30-inch by 72--nch hospital rolling stretchers, without turning, plus attendants.

3. A minimum of four elevators (two per entrance) shall be provided in a deep tunnel station.

4. Elevator doors shall be glazed to the maximum extent possible to enhance both actual and perceived security of the elevator and passengers. Glazing shall include a reflective interlayer on cab doors such that during the ride in the elevator shaft visibility of the shaft interior is limited.

9.7 PLATFORM GEOMETRICS

A. Dimensional requirements for station platforms are established by either the fire/life safety (F/LS) requirements, wayfinding provisions, or by the day-to-day patron requirements as established in this chapter. Where calculations under the two methods lead to different numbers, the more stringent shall control.

B. For day-to-day operations, the platform shall be sized to accommodate the expected patrons on the platform comfortably under normal operating conditions. Missed and/or delayed headways need not be considered. For fire/life safety requirements, missed headways and NFPA peak factors must be considered if the loading platform(s) are classified as a "Station" as defined in Chapter 18, Fire/Life Safety. Under severe site constraints, day-to-day patronage requirements can be reduced, as approved by Sound Transit, but fire/life safety requirements must be met.

9.7.1 Configuration and Access

A. Station platforms can either be of center or side platform type depending on station functional requirements, site constraints or traffic conditions.

B. The design approach to the functional configuration of stations shall be "operational" in bias in that there will be a need to link patronage forecasts and system characteristics to achieve maximum system efficiency. As the capacity of the system increases, so does the importance of the interrelationship between stations. The objective is to achieve balanced vehicle loading by balancing platform access points within the whole system. Balanced vehicle loading also has benefits in terms of patron comfort.

C. Freestanding columns that are within 10 feet of a platform edge shall be located so as not to coincide with the locations of vehicle doors during station stops to minimize congestion. Columns beyond 10 feet shall have no restrictions in their placement.

D. Elevator, escalator, and stair surge zones shall be free of any and all obstructions. The elevator surge zone is defined as a 10 feet by 10 feet area in front of the elevator door. Stair and/or escalator surge zones shall be 15 feet long (measured from end of handrail) and, where conditions permit, 5 feet wider in each direction than the stair and/or escalator.

E. Obstructions of passenger and CCTV camera sight lines shall be minimized.

9.7.2 Platform Area

The minimum platform area (excluding elevator, escalator, stair, surge zones at stairs/ escalators, and the 24-inch platform edge detectable warning surface should accommodate the peak 15-minute entraining load at 10 square feet per person or the peak 15-minute entraining and detraining loads at 7 square feet per person. Peak hour design headways shall be factored into area calculations.

9.7.3 Platform Length

The platform length available for boarding and alighting shall be 380 feet to accommodate a four-car consist.

9.7.4 Platform Height

The vertical distance between top of rail and finished platform floor shall be 14 inches. Refer to Chapter 28, System Safety, section 28.3.2, Station Features, for additional requirements.

9.7.5 Platform Width

A. Platform widths will vary based on patronage, wayfinding provisions, the configuration of vertical circulation elements (for below-grade and aerial stations) and station site considerations. For initial planning purposes, a minimum dimension of 8 feet shall be provided between the edge of platform and the outside face of either a wall, balustrade or railing of a vertical circulation element, seating, or any other station furnishing. This dimension is based on the 24-inch platform edge detectable warning surface plus 3 feet-4 inches (the minimum dimension to the tactile path/braid), plus the 8 inch wide tactile path/braid, plus one travel lane (measured to the center line of the tactile path/braid). This dimension is in addition to the dimension of the vertical circulation element with the widest dimension within the platform area, be it the elevator shaft, escalator or stairwell as plan layout dictates.

B. For center platforms at-grade, the minimum platform width shall be 18 feet.

C. For side platforms at-grade, the minimum width shall be 12 feet from edge of platform to the face of station wall or parapet railing.

9.7.6 Travel Lanes/Exit Lanes

A. To allow a patron to enter or exit a station within a reasonable amount of time, the minimum number of travel lanes for day-to-day operations shall be the total necessary to allow patrons, having already detrained, to be able to reach and descend (or ascend) the vertical circulation, or platform entry point, within 30 seconds of the time required to make the same journey if no other patrons were present.

B. There shall be a minimum of two travel lanes between the platform edge detectable warning surface and walls, tactile wayfinding braid, station furnishings and the balustrade or railing of the vertical elements in an aerial station.

C. There shall be a minimum of three travel lanes along the total length of an at-grade center and side platform.

D. The minimum exit provisions shall be as required by IBC, NFPA 130, or NFPA 101 as required by local jurisdictions. The factors indicated in Table 9-2, together with ADA requirements, shall be the basis for calculating normal patron travel. See Chapter 18, Fire/Life Safety for calculating exiting requirements.

TABLE 9-2

Patron/Lane Requirements

	EXIT LANES (1) For Emergency Conditions	TRAVEL LANES (for Planning Normal Conditions)
Physical Dimensions		
Capacity/Lane width	SEE NOTES (2) (3) (4)	28 inches
Capacity/Half lane width	SEE NOTES (2) (3) (4)	14 inches
Lane to platform edge	24 inches	24 inches
Lane to wall, furnishings, guardrail on stairs, ramps, and sloping sidewalks(>4% slope)	12 inches	12 inches(6)
Lane to column	0 inch	0 inch
Capacity/Lane Width for Escalators		
24-inch escalator	SEE NOTE (5)	1.0 lane
32-inch escalator	SEE NOTE (5)	1.5 lanes
48-inch escalator	SEE NOTE (5)	2.0 lanes
Travel Speed/Capacity		
Horizontal travel (<4%)	124 ft/min	40 ppm/lane
Ramps up (>4%)	40 ft/min	30 ppm/lane
Ramp down (>4%)	48 ft/min	35 ppm/lane
Up stairs and stopped escalator	40 ft/min	18 ppm/lane
Down stairs and stopped escalator	48 ft/min	22 ppm/lane
Up & down moving escalators (90 fpm)	N/A	30 ppm/lane
Elevators (6-foot doors)	N/A	2.0 lanes
Elevators (8-foot doors)	N/A	3.0 lanes
LRV doorways	100ppm**	100ppm**
Patron Speed		
Horizontal travel (<4%)	SEE ABOVE	150 fpm
Ramp up (>4%)	SEE ABOVE	120 fpm
Ramp down (>4%)	SEE ABOVE	120 fpm
Up stairs and stopped escalator	SEE ABOVE	25 fpm
Down stairs and stopped escalator	SEE ABOVE	35 fpm
Equipment Speed		
Up and down moving escalators	N/A	90 fpm/120 fpm
High-speed elevators	N/A	1000 fpm
Hydraulic elevators	N/A	50 fpm/150 fpm

** Determined by technology selected

Notes (for Table 9-2):

(1) In accordance with 2003 edition of NFPA 130, exiting capacity shall be based on persons per inch per minute (PIM).

(2) Capacity of stairs and ramps over 4 percent slope in the upward direction = 1.31 people/inch/minute.

(3) Capacity of stairs and ramps over 4 percent slope in the downward direction = 1.41 people/inch/minute.

(4) Capacity of platform lanes, corridors, doors and gates, and ramps of 4 percent slope or less = 2.98 people/inch/minute.

(5) For NFPA calculations stopped escalators shall be considered as stairs; one escalator cannot be considered in exit calculations.

(6) In addition, travel lanes shall not occupy 3 feet by 3 feet areas in front of ticket vending machines, patron assistance telephones, pay phones, and maps.

9.7.7 Vertical Clearances

A. Any station element that could be targeted for theft or vandalism (e.g., light fixtures, speakers, cameras, signs, etc.) shall be located a minimum of 9 feet above traveled pathways. The potential to use benches, trash receptacles, etc., to access these elements should also be considered in locating these elements. In addition, horizontal elements (e.g., canopy framework, sign units, etc.) that could lend themselves to climbing shall also be located above 9 feet. Vertical elements shall also be designed to minimize the ability to climb them.

B. Locate equipment and light fixtures above 9’-0” but within reach by maintenance crews using a 12’-0” ladder (16’-0” high). Design of elements above this reach zone shall be approved by Sound Transit based on station type and configuration. Where station structure, lighting or other elements are above 16’-0” high, such as tunnel stations, roofs, canopies and window walls, restraining systems shall be provided for maintenance crews to tie off to access these areas.

9.8 GENERAL STATION REQUIREMENTS

9.8.1 Weather Protection

A. Though the climate is relatively benign and allows for open stations, patron protection from the sun and rain warrant special consideration. At a minimum, protection from the rain shall be provided for the following:

1. Public stairs

2. Escalators and elevators

3. Fare vending equipment including, at a minimum, a 4-foot by 4-foot area in front of the equipment.

4. System map viewing areas and other patron facilities such as public and emergency telephones, etc.

5. Platform areas in accordance with section 9.8.17.

B. In general, canopy and rainscreen design shall assume that rain is falling at a 10-degree angle from vertical. However, the orientation of a station's platform areas will impact the effectiveness of canopies in providing shade and rain protection. Station orientation shall be considered in developing canopy and wind/rain screen concepts on a station-specific basis. Drip lines or gutters shall not be over travel pathways or platform edges.

C. To protect patrons from strong wind-blown rain, transparent windscreens shall be provided on the platforms for a minimum of approximately one-third of canopy coverage. At stand alone windscreens, provide a gap at the bottom of framing for ease of cleaning and visibility.

D. Canopy designs shall maintain Light Rail Vehicle (LRV) clearances, including the overhead contact wire system.

9.8.2 Station Furniture and Patron Conveniences

A. The minimum seating provided at platform level shall be a ratio of 1:15 of platform length and shall be distributed to two or more locations along platform areas. One bench shall be located near each public entry point to the station and arranged so that they do not interfere with patron circulation or emergency exiting. Where practical, seating areas shall be protected within areas covered by canopy.

B. Benches and/or seating units shall be of designs that will prevent individuals from lying down and/or sleeping. Benches and/or seating units shall conform to ADA requirements. Furniture shall be selected from Sound Transit approved family of furnishings, see section 9.11.11. Some portion of the platform seating shall be designed with backs and full-length armrests to facilitate use by individuals with disabilities.

C. On-site bus stops shall be provided with a minimum of 6 lineal feet of seating per bus stall. Seating and shelter for off-site bus stops (on public streets) will typically be provided by the local transit company(s).

D. Newspaper vending policies will be determined by Sound Transit.

E. Drinking fountains shall be provided at station locations with restrooms or as determined by Sound Transit policy.

9.8.3 Ancillary Spaces

A. Ancillary spaces (e.g., electrical, elevator machine room, train control and communications, janitor closets, and/or traction power rooms or buildings) may be required at certain stations. Specific requirements will be determined on a station-by-station basis during Preliminary Engineering. In addition to the mechanical and electrical requirements of each space, the following shall be incorporated into the design:

1. Specify Sound Transit standard doors, hardware, interior paints, and light fixtures.

2. Provide reasonable (less than 200 feet travel distance) access to a permanently maintained service vehicle parking stall wherever it is feasible.

3. Provide permanent vehicular access to the emergency generator hookup. As this access is required only in the emergency condition, access may be on and across walks, plazas, etc.

4. Provide bullet resistant construction (stop standard 38-caliber bullet) for train control and communications rooms. In addition, provide bullet resistant construction at portion of walls behind sensitive equipment in traction power rooms.

5. Design of ancillary spaces shall be compatible with station architectural scheme.

9.8.4 Restrooms

A. Staff toilets are to be provided at locations as determined by Sound Transit. Toilets shall have a commode and a urinal. Toilets, where provided, shall be able to accommodate disabled employees.

B. Public restrooms shall be provided at locations as determined by Sound Transit's restroom policy.

C. Provisions for future toilet installations shall be provided at stations that are identified by Sound Transit during final design as outlined by Sound Transit's restroom policy.

D. Each service shall have a main shut-off valve and backflow preventer of a double-check type immediately inside the structure wall. Chapter 24, Plumbing and Fire Protection Systems, section 24.5.2, Water Service, sets forth the minimum fixture service requirements.

E. Hot water shall be supplied to all toilet and cleaners' rooms. Hot water shall be supplied by instantaneous electric heaters.

F. Provide relief valves in accordance with code requirements. Relief valve shall be piped to indirect waste.

G. Hot water heaters shall be set to deliver 110° F water.

H. Thermostatically controlled electric heaters shall be provided to maintain an internal temperature of 55°F minimum.

I. Discharge a minimum of 2 cfm per square feet of air to an area such that patrons, nearby residents, and pedestrians will not be offended by odors.

J. Use stainless steel materials and the latest automatic control technologies on fixtures. Stainless steel will resist breaking and denting; it is fireproof and heatproof; it is unmarred by strong solvents; and can be easily cleaned including the removal of graffiti.

9.8.5 Advertising

Sound Transit is determining specific policies with respect to advertising in stations. Station design shall identify locations appropriate for advertising based on the following guidelines. (See Appendix A for policy language.) Advertising shall conform to local jurisdictional restrictions.

9.8.5.1 General

A. Advertising shall not conflict by placement or treatment with, or take priority over, system signing and information.

B. Advertising shall be carefully located so as not to obstruct, cause distraction or retard patron movement.

C. Advertising shall be located so as not to conflict with legibility of emergency exits or equipment, particularly at platform level.

D. Advertising shall be placed so that it cannot be easily defaced or damaged.

E. Advertising shall be carefully controlled on all electronic message units that are used for system signing and information.

F. Advertising shall be used as design elements rather than haphazard displays.

G. The format and size of advertising shall be compatible with the volumes of the interior or exterior spaces in which they are located, and shall in all cases be compatible with the architectural expression of the stations.

9.8.5.2 Locational Criteria

A. Station entrances are suitable for advertising as this location is usually free of safety concerns related to trains or vertical circulation. The placement of advertising in the concourse shall not conflict with ticketing and signing functions, or basic patron movement patterns.

B. The placement of advertising in vertical circulation spaces could constitute a distraction for the patron. Advertising shall not be located at the top and bottom landings of escalators and stairs.

C. ***Platform Level:*** Two-dimensional advertising would be appropriate in across-track locations. It shall not conflict with system signing and information.

9.8.5.3 Maintenance and Performance Criteria

A. All materials used in the fabrication of advertising panels shall be of a durable and vandal-resistant nature.

B. Advertising panels shall exhibit low maintenance characteristics.

C. Advertising shall be in conformance with all applicable codes.

D. In general, where advertising panels are provided, their framework shall be standardized for ease of maintenance and replacement of advertising media.

9.8.5.4 Lighting

Advertising shall work with the existing ambient lighting of the stations wherever possible. Special lighting requirements should be identified on a station-specific basis and accommodated within station planning as early as possible.

9.8.6 Trash Receptacles

A. Trash receptacles shall be provided on the platforms, at fare vending areas, and at bus/shuttle areas. Receptacles for the general site,

parking, or kiss-and-ride areas shall be determined on a site-specific basis.

B. Maximum travel distance to the nearest receptacle on the platform shall be 70 feet. A minimum of one receptacle per fare vending area shall be provided. Minimum capacity of combined fare vending and platform receptacles shall be 0.12 gallons times peak hour entraining and detraining load.

C. Trash receptacles shall be secured to avoid removal by unauthorized persons and shall be vandal resistant. Liners shall be standardized systemwide. Exterior design shall be compatible with station architectural character. See section 9.11.11.5 for type of Trash receptacles.

9.8.7 Hose Bibbs

Standard flush hose bibbs with lockable covers shall be provided to allow full coverage of the platform, shelter, fare vending area, etc., with a 75-foot hose. See Chapter 24, Plumbing and Fire Protection Systems, for additional information.

9.8.8 Electrical Convenience Outlets

A. 110V, 20 amp, single-phase electrical service in lockable receptacles shall be located to allow full coverage of the platform and vertical circulation elements with a 75-foot electrical cord. Mechanical and electrical rooms shall have coverage in accordance with code, manufacturers', and designers' recommendations. All outlets shall be provided with a lockable cover plate.

B. In addition, electrical convenience outlets for concessions may be required in station areas as determined by Sound Transit.

9.8.9 Patron Information Center

A. Ticket vending areas in each station shall be weather protected. These areas shall include, at a minimum, the following:

1. General information panel
2. System map, including transit connections
3. Neighborhood map
4. Two ticket vending machines
5. Passenger assistance phone

B. Fare vending equipment, information displays, and adequate queue space shall be located so as to not obstruct required travel lanes.

9.8.10 System Signage

A. Systemwide signage has been developed by Sound Transit. The following basic design guidelines are provided to facilitate station design during the Preliminary Engineering phase of the project.

1. Insofar as possible, architectural elements, landscaping, and other design features shall identify entrances, exits, traffic routes, etc. without signs.

2. The number of signs shall be kept close to the minimum necessary for passenger guidance.

3. Signs shall be located for maximum visibility at or before all decision points within facilities.

4. Signs shall be placed at frequent enough intervals so that the infrequent or new user can readily find his or her way without assistance.

5. The pattern of signs shall be predictable and therefore consistent from station to station.

6. Map space shall be provided immediately adjacent to fare collection equipment and at other decision points such as platform areas.

7. Walls at ends of passageways, opposite major entrances, or leading to exits, shall be kept free of miscellaneous doors and advertisements so that they may be used for information graphics.

8. Station name signs shall be located so they may be easily seen by passengers in transit cars, both sitting and standing.

9. Relate outbound passengers to the surrounding community with appropriate signage.

9.8.11 Public Telephone

A. Provisions for a minimum of two coin-operated telephones shall be provided in each station and at least one shall conform to ADA requirements.

B. Public telephones shall be located inside weather protected areas.

C. Public telephones shall be located in fare-vending areas.

9.8.12 Passenger Information Phones (PIP)

Passenger Information Phones shall be highly visible and accessible to individuals with disabilities. Passenger Information Phones shall be located as identified in Chapter 15, Communications and Central Control, section 15.5.10, Network Management System.

9.8.13 Passenger Emergency Telephone (PET)

Passenger Emergency Phones shall be highly visible and accessible to individuals with disabilities. Passenger Emergency Phones shall be located as identified in Chapter 15, Communications and Central Control, section 15.5.9, Passenger Emergency Telephone.

9.8.14 Emergency Phone System (EPS)

Emergency phone system shall be back up communications for the Fire Department and other emergency personnel. They shall be located per Chapter 15, Communications and Central Control, section 15.5.8, Emergency Telephone System.

9.8.15 Closed Circuit Television Cameras (CCTVs)

See Chapter 15, Communications and Central Controls, Call-for-Aid Station, and Chapter 29, Security, for requirements concerning closed circuit television cameras.

9.8.16 Emergency Management Panel (EMP)

An Emergency Management Panel will, typically, be provided at all grade separated stations. Panel location will be determined by the Fire/Life Safety Committee.

9.8.17 Platform Canopy

A. A minimum of 30 percent of platform areas shall be weather protected. This may be increased on a station-by-station basis as determined by Sound Transit to meet projected peak period patronage, according to M98-58.

B. A basic design module of 4 feet 0 inches o.c. shall be employed in the design of canopies and related structures to permit the consistent accommodation of signage, standardized glazing and station furnishings.

C. Platform canopies shall be supported by columns centered on the platform for center platform stations and supported at the platform edge opposite the trackway for side platform stations.

D. Canopy structures shall be designed to allow for future expansion. Canopies shall be composed of materials that are durable and economic to repair or replace.

E. The minimum acceptable vertical clearance under the canopy, or any signage or equipment attached to same, shall be 9 feet.

F. To maximize patron comfort, canopy coverage shall extend over the platform area and as close to the platform edge as permitted by the clearance envelope.

G. Canopy coverage shall be provided at all vehicle platform access areas for elevators, escalators and public stairs.

9.8.18 Windscreens

A. Transparent or semi-transparent windscreens shall be provided at platform levels at locations to be determined during preliminary design. A minimum of approximately one-third of canopy coverage shall be provided in accordance with section 9.8.1.C.

B. A basic planning module of 4 feet 0 inches o.c. shall be utilized. Glazing and other infill material sizes shall be standardized to the greatest extent possible to allow ease of replacement.

C. Windscreens shall be sufficiently transparent to allow clear surveillance of station areas for patron security and to discourage vandalism.

9.8.19 Track Crosswalks at At-grade Stations

A. Track crosswalks shall be provided at areas where pedestrians will be crossing mainline tracks. They shall be located on tangent track, if possible, and away from special trackwork areas.

B. Track crosswalks shall be prefabricated and made of materials sufficiently durable for pedestrian traffic and vehicular traffic if located directly adjacent to a street crossing. Track crosswalk panels shall be constructed with due regard to remove ability for track maintenance, to noninterference with electrical track circuits and rail fastenings and conform to track-to-earth and rail-to-rail resistance requirements. Special care shall be taken, to ensure a safe, slip resistant walking surface. Track crosswalks shall comply with the requirements of ADA.

9.8.20 Fare Vending Equipment

See Chapter 16, Fare Collection, for information on number, spacing, location, and other data on ticket vending machines and related facilities.

9.9 STATION AND STATION SITE LIGHTING

The lighting criteria contained herein are intended to provide the functional and aesthetic guidelines necessary to design lighting for site areas, passenger stations, and appropriate trackway sections. Conformance with these criteria will ensure adequate lighting levels for the system facilities, and provide intended maintenance quality, convenience, safety, and efficiency for the Link system.

9.9.1 Design Objectives

A. General objectives for station and station site lighting are as follows:

1. Promote safety and security by identifying and properly illuminating areas and elements of potential hazard;

2. Enhance the system's visual and functional clarity by differentiating between site circulation networks, station entrances, fare vending areas, and platform areas;

3. Provide consistent levels of lighting for main public passageways/walkways;

4. Reinforce the legibility and clarity of the signage system and other essential graphic messages;

5. Provide vandal resistant fixtures, and

6. Compliment and enhance station and station site architecture.

B. Reference should also be made to Appendix C, Transit Security Design Considerations, FTA-TRI-MA-26-7085-05, November 2004.

9.9.2 Performance Standards - Codes

Refer to Chapter 21, Lighting, for the appropriate lighting standards and codes.

9.9.3 Illumination Levels

A. Illumination levels shall define and differentiate between functional areas, decision and transition points, and areas of potential hazard. Illumination shall be designed to minimize glare and provide uniform distribution. Luminaries shall be selected, located, and/or aimed to

accomplish their primary purpose while producing a minimum of objectionable glare and/or interference with vehicular traffic, and neighboring areas. Use Link Facility Lighting Standards, see section 9.11.11.7.

B. Minimum general required illumination levels are provided in Chapter 21, Lighting.

C. Required illumination levels for system signing are provided in accordance with Chapter 21, Lighting.

D. To minimize maintenance costs, standardized lamps are listed in Chapter 21, Lighting, section 21.1.3, Standard Equipment. These lamps work with the Link Facility Lighting Standards.

9.10 GENERAL STATION SITE DESIGN GUIDELINES

9.10.1 Travel Modes

A. Patrons will arrive at or depart from typical light rail stations and stops, by the modes of travel listed below. The modes are listed in order of priority for providing convenience and directness of routing.

1. Pedestrian
2. Individual with disability - non-driver (Para-transit)
3. Bus or commuter rail
4. Individual with disability - self-driver (at park-and-ride facilities)
5. Bicycle
6. Kiss-and-ride (including non-driver individual with disability)
7. Taxi
8. Park-and-ride
9. Motorcycle

B. The layout of station sites, as well as associated access roadways, must ensure that provisions are made for access by patrons in all the above classifications where applicable.

9.10.2 Vehicular Entrances to Station Sites

A. The design of entrances for motor vehicles at station sites with bus interfaces and park/kiss-and-ride facilities shall take into consideration adjacent land uses and avoid large unplanted or paved areas that are

out of scale with those uses. Curb cuts shall be minimized, while fulfilling the following requirements:

1. Direct access from major highways or streets into a station site shall be minimized. Streets designated for service and minor non-residential streets shall be utilized.

2. Direct access from quiet residential streets shall be minimized.

3. Entrance roadways to station sites shall be designed to contain sufficient traffic storage capacity to meet expected transit patronage at peak times and to prevent traffic backing up into public streets.

4. Conflicts shall be avoided between entrance roadways, bicycle access, and pedestrian access points.

5. Access by motor vehicles into a station site with more than 1,000 spaces shall be from more than one street. Refer to Chapter 28, System Safety, section 28.3.1, Station and Entrance Site Layout, for additional requirements.

9.10.3 Vehicular Exits from Station Sites

For larger stations, more than one station exit to the local street system should be considered to reduce traffic delays.

9.10.4 Access Roadways

A. Roadways intended to provide access to parking stalls, bus zones, park-and-ride, and kiss-and-ride facilities, shall be designed in accordance with "AASHTO Policy on Geometric Design of Highways and Streets" as supplemented and modified in these criteria. One-way traffic operation on such roadways is preferred. Provisions for passing a stalled vehicle shall be made along roadways exiting from public streets. Separate site access for car and buses shall be provided if possible.

B. Major pedestrian movements shall be separated from bicycle and vehicle circulation to the greatest extent possible.

9.10.5 Kiss-and-Ride Facilities

A. On-street passenger loading zones or taxi drop-off shall be provided at specific station locations as determined by Sound Transit.

B. At specified station locations, provisions for kiss-and-ride, or short-term parking, in close proximity to the platform or station shall be provided.

C. For at-grade stations, the preferred location for kiss-and-ride facilities is within view of the platform(s) or entry points to the platform(s).

D. Convenient recirculation of kiss-and-ride vehicles shall be provided in the event that short-term parking spaces become filled.

E. Avoid routing kiss-and-ride vehicles through the park-and-ride areas.

F. Stalls and aisles for kiss-and-ride areas shall be larger than those in long-term parking areas due to the frequent use of short-term parking provided that the quantity of stalls is not reduced.

G. Preferred parking arrangements for kiss-and-ride areas are as follows:

1. Parallel to curb
2. 45 degrees to the aisle
3. 60 degrees to the aisle
4. 90 degrees to the aisle

H. Parking lanes parallel to the curb shall be 10 feet wide and 21 feet long except that beginning and ending stalls may be 20 feet. Parallel parking spaces shall maintain a minimum of 20 feet from pedestrian crosswalks.

I. Parking layouts shall be in compliance with local codes.

9.10.6 Park-and-Ride Facilities

A. Park-and-ride areas shall be provided at selected stations as determined by Sound Transit. Park-and-ride areas shall be designed to optimize site utilization by using the following criteria. Vehicular stalls shall be 8.5 feet wide and 18 feet deep, in 60-foot bays, unless otherwise dictated by governing entity/municipality. Stall depths shown may be reduced 2 feet when against a curb if required planting areas are not reduced. Designs utilizing stalls at 90 degrees to the aisle are preferred.

B. Parking layouts shall be verified with local jurisdictional requirements.

9.10.7 Self-Drive Accessible Parking Stalls

Accessible parking shall be provided at selected stations as determined by Sound Transit, where other parking facilities are provided. Accessible stalls shall be provided near station entrances and in conformance with the ADA requirements. Continuous smooth surface ramps without

vertical rises and maximum slope of 1:12 shall be provided from the accessible parking area to sidewalks and station entrances.

9.10.8 Motorcycle Parking

Motorcycle parking stalls may be provided at park-and-ride locations. Stall sizes shall be 4 feet by 8 feet.

9.10.9 Bicycle Facilities

A. Bicycle storage shall be provided at all station locations to the extent determined by Sound Transit. Reference should be made to Sound Transit Board Motion M98-78 (Appendix A) for overriding policies. Bicycle facilities shall conform to the following basic requirements:

1. Bicycle storage facilities shall be constructed on hard surfaces.

2. Storage facilities shall be located for easy access to station entrances and the street system.

3. Conflicts with pedestrians, station access/fare collection and bus loading shall be avoided.

4. Bicycle facilities shall be given preference over motorcycles as to location.

5. Provide a secure stanchion to allow bicycles to be locked and/or bicycle lockers for protection from vandalism.

6. Bicycle storage areas shall be properly lighted. See Chapter 21, Lighting.

9.10.10 Borders of Parking Areas

In general, parking lots shall be designed so as to avoid the use of earth retaining structures, and to keep all work within Sound Transit's ROW lines. Curbs shall be provided at all parking lot edges constructed on fills more than 5 feet high. Where fills higher than 10 feet are required, guard rail protection shall be considered. These borders should be wide enough for landscaping and planting. Local jurisdiction requirements for Stormwater management and critical areas may override guidelines.

9.10.11 Pedestrian Access

A. Pedestrian circulation routes shall provide direct and convenient approaches to station entrances from off the site and from individual section of park-and-ride lots.

B. Parking aisle in park-and-ride lots shall be oriented to consider pedestrian needs and safety, as well as lot capacity. Pedestrian movements within park-and-ride areas will normally occur within the driving aisles. However, pedestrian walkways may be required to minimize vehicular interference, to reduce the number of points where pedestrians cross aisles, or to shorten irregular routes through successive aisles.

C. Walkways shall be at least 5 feet wide. Walkways crossing rail tracks to reach station platform shall be level and with the top of rail at the outer edge and between rails, except for a maximum 2.5-inch gap on the inner edge of each rail to permit passage of wheel flanges.

D. The following additional design guidelines shall be adhered to:

1. Steps or abrupt changes in level in walkways shall be avoided. Layout of walkways shall provide maximum visibility of and by oncoming rail and vehicular traffic.

2. The recommended width of pedestrian walkways shall be as follows:

TABLE 9-3 Walkway Guidelines

	Preferred	Minimum
Walkways over at-grade tracks	15 feet	10 feet
Walkways through bus stop areas	12 feet	7 feet - 2 inches
Walkways adjacent to Long term parallel parking	8 feet	6 feet
Walkways adjacent to short term parallel parking	10 feet	7 feet - 2 inches
Crosswalks	12 feet	10 feet

3. Crosswalks shall be marked and be clearly visible to motorists. Warning signs or signals shall be provided at crossings of LRV and/or railroad tracks, as well as adjacent roadways in accordance with Chapter 11, Traffic Control.

4. Crosswalk materials shall be noticeably different color or texture to clearly indicate where crossing should occur.

5. Pedestrian walkways shall be adequately lighted for safety. See Chapter 21, Lighting.

9.10.12 Bus Service

A. Certain stations shall include bus service access. The layout of bus facilities shall be coordinated with the transit companies (private and public) that will service these stations and shall utilize their design criteria. The design of station sites shall address the potential for relocating bus zones, rerouting bus lines, and establishing new bus lines, and layover and turnback facilities.

B. Bus stops shall be placed to minimize patron travel time (bus and walk time). Typically, street curb service is preferred over on-site access, especially for "through" buses. Where buses will circulate within the site, curb radii, and other turning movement geometry shall conform to the bus operators design criteria.

C. The prominent display of schedule and route information is essential. Bus information at bus stops shall be in accordance with the transit operator(s)' criteria.

9.10.13 Shuttle Service and Para-Transit Service

Private or public shuttle services may serve specific stations. The physical requirements for these shuttles, which typically are large vans or small buses, shall be coordinated with the potential operators. These services typically do not use bus stops as they require longer load/unload time. Para-Transit stops with off street loading area shall be provided at all stations unless determined otherwise by Sound Transit. Shelters for Para-Transit waiting shall be provided where the site can accommodate the space needed. Provide space for one bench and one wheelchair.

9.10.14 Emergency Access

See Chapter 18, Fire/Life Safety, for access requirements for emergency response by Fire Department and paramedic equipment and personnel.

9.11 MATERIALS AND FINISHES GUIDELINES AND REQUIREMENTS

The following basic requirements and criteria have been established for finish material used in public and ancillary areas within the system. While convenience, comfort and attractiveness shall be considered in the selection and application of finishes, safety, durability, and economy are essential attributes that must be satisfied.

9.11.1 General Criteria

Finish materials shall meet the following general criteria:

A. Finish materials shall aid in the creation of a visually pleasing transit system.

B. Finish materials shall be easily maintainable and repairable.

C. Finish materials shall facilitate passenger guidance, information, safety, and security in an aesthetically pleasing manner.

D. Finish materials for floors, walls, and ceilings shall be considered with respect to the total acoustic environment, so as to minimize reverberation while meeting other design and performance criteria.

E. Finish materials shall be supportive of an efficient lighting system.

F. The quality of the materials and the workmanship of their application shall be of high standard.

G. Initial materials costs shall be weighted against long-term maintenance costs.

H. Finish materials by virtue of texture, composition, or application shall not pose safety hazards to patrons using the system.

I. All finish materials shall accommodate the specific needs of the mobility disadvantaged and the requirements of the Americans with Disabilities Act (ADA).

J. Floor finish patterns shall not create an environment that is “too busy” or disorienting to patron movement.

K. Floors in heavy wear areas shall have a wear surface separate from the structural slab to facilitate replacement.

L. The zone from floor level to 8 feet on vertical surfaces, called a contact zone “touch zone”, is subject to abuse and willful damage; therefore, finish materials in this area shall be especially resistant and capable of repair in a cost-effective manner.

M. Where appropriate, wall finishes shall be chosen with reference to the potential need for access to service ducts, etc.

N. Wall finish materials shall not pose safety hazards to patrons; for example, materials adjacent to escalators shall not have perforations capable of catching fingers.

O. Ceiling and canopy finishes/systems and their application shall allow for “fine tuning” and future retrofitting of subsystems such as CCTV and public address systems.

P. Ceiling finishes/systems offer an effective means of controlling noise levels within below-grade stations. Consideration shall be given to the use of ceiling materials designed for the attenuation of sound.

9.11.2 Safety

A. Fire resistance and smoke generation hazard from fire shall be reduced by using finish materials with minimum burning rates, smoke generation and toxicity characteristics consistent with Code requirements as noted in IBC, IFC NFPA 101, Life Safety Code.

B. Proper fasteners and adequate bond strength shall be used to minimize hazards from dislodgment due to temperature change, vibration, wind, vehicle movement through stations, seismic forces, aging, or other causes.

C. Floor materials with non-slip qualities shall be utilized to increase pedestrian safety and accommodate the needs of individuals with disabilities. Stairways, platform edge strips and areas around equipment shall have high non-slip properties.

D. The following static coefficient of friction as defined in ASTM C1028 shall be provided as a minimum:

TABLE 9-4

Walkway Surface Coefficients

Surfaces	**Coefficient of Friction**
Public horizontal surfaces	0.6 per ADA
Non-public horizontal surfaces, exterior	0.6
Non-public horizontal surfaces, interior	0.5
Platform edge detectable warning surface	Textured visually contrasting material conforming to ADA requirements
Stairs, ramps, sloping sidewalks	0.8 per ADA
Area around equipment	0.6

9.11.3 Durability

Materials with excellent wear, strength and weathering qualities shall be used with due regard for both initial and replacement costs. Materials must be colorfast and maintain their good appearance throughout their useful life.

9.11.4 Ease of Maintenance

9.11.4.1 Cleaning

Facilitate cleaning and reduce cleaning costs by the use of materials that do not soil or stain easily, which have surfaces that are easy to clean in a single operation using standard equipment and cleaning agents, and on which minor soiling is not apparent. Materials shall be cleanable with commonly used equipment and cleaning agents. Platform walking surfaces shall utilize materials that are not damaged by pressure washing. Station elements shall be detailed to minimize their use as roosting areas for birds.

9.11.4.2 Repair or Replacement

To reduce inventory and maintenance costs, materials shall be used that are readily available and can be easily repaired or replaced without undue cost or interference with the operation of the Link system. For example, hose bibs, electrical outlets, lighting fixtures and lamps, glass or plastic lights, etc., shall be standardized on commonly available sizes and finishes to ease inventory stocking or direct purchase. Spare quantities shall be provided for tile and other applied unit materials in an amount equal to approximately 0.5 percent of the total material used.

9.11.5 Resistance to Vandalism

A. Provide materials and details that do not encourage vandalism and that are difficult to deface, damage, or remove.

B. All surfaces exposed to the public shall be finished in such a manner that the results of casual vandalism can be readily removed with common maintenance techniques.

9.11.6 Color

Material colors shall be consistent with systemwide/line identity colors, compatible with the surrounding area and of sufficient contrast and accent to provide visual interest, warmth, and concealment of minor soiling.

9.11.7 Non-Proprietary Materials and Buy America Requirements

Non-proprietary items shall be used in the system wherever possible in order to obtain competitive bids and comply with federal regulations. Proprietary items shall be used only where it is established that no other materials exist which would meet the particular design requirements. Such items shall be specified on a "performance specification" basis only. All materials shall be manufactured and/or supplied from the USA to meet Buy America Requirements. No materials shall be used that do not meet Buy America provisions without prior approval of Sound Transit.

9.11.8 Unit Size

Units shall be large enough to reduce the number of joints yet small enough to facilitate replacement if damaged. Monolithic materials may be used if they can be easily repaired without the repair being noticeable.

9.11.9 Installation Standards

Materials shall be detailed and specified to be installed in accordance with industry standards and manufacturer's printed directions for long life, low maintenance, and compliance with warranty requirements.

9.11.10 List of Finish Materials

The list of materials that follows is general in nature and applies to all areas of public use and contact. Exceptions to the list must be reviewed and approved by Sound Transit prior to use in design. The use of items listed as "acceptable" is subject to location and environmental considerations.

9.11.10.1 Exterior Materials

Exterior materials generally refer to materials used to finish surfaces of a transit station that are directly exposed to the climatic environment including sun, wind, and rain. Materials should be selected that are highly resistant to vandalism, and retain their original appearance with a minimum amount of maintenance and repair.

9.11.10.2 Paving Materials

General site paving refers to the finish of areas exterior to the station proper (platform) and used as walking surfaces.

A. Acceptable

1. Granite (trim)

2. Concrete pavers (preferred) See section 9.11.11
3. Quarry tile (trim)
4. Brick pavers (trim)
5. Cast-In-Place Concrete – integral color or textured/sandblasted and sealed

B. Not Recommended

1. Bituminous toppings

9.11.10.3 Entry Forecourt Paving (grade-separated stations)

Entry forecourt paving refers to the finish of areas exterior to the station proper and directly adjacent to the concourse.

A. Acceptable

1. Granite
2. Quarry tile
3. Brick pavers
4. Concrete pavers
5. Cast-In-Place Concrete - integral color or textured/sandblasted and sealed

B. Not Recommended

1. Bituminous toppings
2. Synthetic resin toppings
3. Terrazzo
4. Marble

9.11.10.4 Solid Wall Materials

Solid wall elements refer to the finish of vertical wall surfaces that provide enclosure to areas of a station at platform, entry, and mezzanine levels.

A. Acceptable

1. Concrete – integral color and/or sandblasted and stained
2. Porcelain Enamel Metal wall panels
3. Brick
4. Concrete masonry units textured or glazed
5. Solid Glass block
6. Porcelain tile
7. Architectural Precast Concrete

B. Not Recommended

1. Stucco (three coat system)
2. Synthetic Stucco
3. Plastics
4. Wood

9.11.10.5 Open Wall Elements

"Open wall" elements refer to the finish of vertical wall surfaces that provide enclosure while permitting ventilation and/or views into and out of station areas.

A. Acceptable

1. Expanded metal
2. Perforated metal
3. Stainless steel railing system (Preferred)
4. Cables and turnbuckles as intermediates
5. Metal louver
6. Galvanized railing (back of house only)

B. Not Recommended

1. Galvanized painted

9.11.10.6 Canopy Materials

A. Acceptable

1. Laminated tempered glass (preferred). See section 9.11.11

2. Baked/coated steel roofing

3. Aluminum roofing

4. Structural steel with High Performance Coating

5. Translucent panels

6. Acceptable steel deck, factory finished baked enamel

B. Not Recommended

1. Tile roofing

2. Built-up roofing

9.11.10.7 Interior Materials

Interior materials generally refer to materials used to finish surfaces of a transit station that are not directly exposed to the climatic environment

9.11.10.8 Floor Materials

A. Acceptable

1. Granite

2. Porcelain tile

3. Brick pavers

B. Not Recommended

1. Rubber tiles

2. Vinyl composition tile

3. Glazed tile
4. Concrete-textured and sealed
5. Synthetic epoxy toppings

9.11.10.9 Wall Materials

A. Acceptable

1. Porcelain enamel steel panels
2. Baked/coated steel panels
3. Ceramic tile
4. Stone veneer system
5. Stone tile
6. Metal wall panels

B. Not Recommended

1. Stucco (3-coat system)
2. Synthetic stucco system
3. Concrete-textured and stained
4. Concrete-sealed
5. Concrete masonry units-sealed
6. Reinforced glass fiber panels

9.11.10.10 Ceiling Materials

A. Acceptable

1. Porcelain enamel steel panels (w/acoustical treatment)
2. Baked coated metal panels (w/acoustical treatment)
3. Expanded metal – painted or stainless steel (w/acoustical treatment)
4. Perforated metal – painted or stainless steel (w/acoustical treatment)

5. Metal ceiling system with rigid attachment (w/acoustical treatment)

6. Plaster (at interior locations only)

B. Not Recommended

1. Suspended metal louver ceiling systems

2. Sprayed acoustic materials

3. Stucco (three coat system)

4. Synthetic stucco system

5. Gypsum wall board/sheathing

6. Wood

7. Plastic

9.11.10.11 Metallic Surfaces and Fixtures:

Wall panels, railings, posts, columns, fences, miscellaneous metal.

A. Acceptable

1. Stainless steel (Areas of public use)

2. Painted galvanized steel (Back of the house use)

3. Porcelain enamel

4. Factory applied hard-baked enamel

5. Factory applied powder coating

6. Polyurethane (3-coat system)

B. Not Acceptable

1. Job site-painted metals

9.11.11 Link Required Materials and Families of Materials

The list of required materials that follows applies to all areas of the station. Public use and contact areas shall use the most durable

materials. Exceptions to the list must be reviewed and approved by Sound Transit prior to use in design.

9.11.11.1 Standardized structural grid

A. Use of a basic grid of 4 feet will accommodate standardized glazing. Spacing of 16'-0" will accommodate the standard platform edge light for at-grade and aerial stations.

9.11.11.2 Family of Pavers

A. For at grade stations use 24-inch by 24-inch nominal concrete pavers. Wausau Tile "Terra-Pavers" Type 3 Cotillio FDX or Abbotsdford Concrete Products Ltd. HydraPressed Paving Slabs for smooth and train waiting tactile pavers. Maximum of three colors to be used selected from the following approved colors:

1. FDX 2008 Wausau Light Gray
2. FDX 3008 Wausau Dark Gray
3. FDX 4008 Wausau Dark Red
4. FDX 5008 Wausau Dark Tan

B. For tunnel and aerial stations use 12-inch by 12-inch nominal unglazed porcelain ceramic tiles. Crossville Cross-slate, Graniti Fiandre Graniti Slate, or Leonardo 1502 Ceramica Struturato.

1. Crossville A 850 Graphite (Dark Gray)
2. Crossville A900 Mica (Light Gray)
3. Crossville A 790 Burgundy (Dark Red) with cross-sheen finish
4. Crossville A876 Truffle (Tan)

C. 2'-0" wide Link system-wide Platform Edge Detectable Warning Pavers shall be used at all stations. Domes shall be spaced in an orthogonal pattern. Standard color to be muted yellow to match all stations.

9.11.11.3 Standardized Glazing Type and Sizes

A. Windscreen Glazing shall be 1/4-inch clear heat treated tempered Float Glass. Sizes shall be limited to the following:

1. 2'-9" by 3'-11" actual glass size to fit in 2'-10" by 4'-0" grid.

2. 2'-9" by 2'-9" actual glass size to fit in 2'-10" by 2'-10" grid.

3. 3'-11" by 3'-11" actual glass size to fit in a 4'-0" by 4'-0" grid.

4. Windscreen glazing in the touch zone shall have anti-graffiti film or patterning to facilitate repair of graffiti.

B. Canopy Glazing shall be laminated glass with a 65 percent light transmittance translucent white interlayer and two lights of 1/4-inch clear glass. Sizes shall be limited to the following options:

1. 1'-11 ½" by 3'-11 ½" actual glass size to fit in 2'-0" by 4'-0" grid.

2. 2'-5 ½" by 3'-11 ½" actual glass size to fit in 2'-6" by 4'-0" grid.

3. 3'-11 ½" by 3'-11 ½" actual glass size to fit in a 4'-0" by 4'-0" grid.

C. Elevator glazing shall work with the standards whenever possible. Atypical glazing sizes may be used at elevator shafts to meet the dimensional criteria of the elevator.

9.11.11.4 Finishes and Color Palette

A. Finishing of steel shall be completed with Satin Finish, High Performance Coatings wherever possible. Finishing of steel in the field shall be minimized by designing structures that can be shop fabricated in sections, primed and finished in the shop and bolted together on site. Minimize on-site welding and touch up painting whenever possible.

B. Designer shall select from the following colors for painted finishes. All deviations from these colors shall be reviewed

and approved by ST prior to use. Link Standardized colors are:

1. Dark Blue - FED 25042 (Rodda #FS00D3196)
2. Charcoal Gray – FED 27038 (Rodda #FS00D3197
3. Light Gray – Rodda #FS00B2659
4. Ferrari Red – Rodda #FS03A482 (accent color)
5. Pencil Yellow – ICI MP#10YY 37/654 (accent color)

9.11.11.5 Furnishings

A. Designer shall choose from the following approved benches:

1. RS Public Seating by Forms and Surfaces - Aluminum modular bench system with intermediate arm rests, with and without backs, in manufacturer's standard black;
2. Petosky by Landscape Forms - Removable perforated metal bench with powdercoat finish in manufacturer's standard black, or
3. Presidio by Landscape Forms - Modular steel bench system with intermediate arm rests and powdercoat finish in manufacturer's standard black. Backless seat preferred. Seat with back can be large on platform.

B. Trash Receptacles and Ash Urns – Design shall provide for:

1. Petosky trash receptacle by Landscape Forms or approved. Ground mounted with hinged lid. Perforated metal with powdercoat finish in manufacturer's standard black. Thirty-gallon capacity liner.
2. Petosky ash urn by Landscape Forms or similar approved. Ground mounted. Perforated metal with powdercoat finish in manufacturer's standard black. Locate at station entry only.

C. Modular News racks – Design shall provide for Boulevard Modular by Kaspar Sho-Rack or similar approved. Powdercoat finish in manufacturer's standard black.

D. Bike racks and lockers – Design shall provide:

1. Cora Bike Rack Model Expo "W" Series or similar approved. Standard size to accommodate ten bicycles, or

2. Cycle-Safe Bike Lockers Model M/#DFR ProPark or similar approved. Two bicycles per locker unit.

9.11.11.6 Sound Transit Systemwide Signage

A. See Sound Transit Systemwide Signage Design Manual.

9.11.11.7 Sound Transit Link Facility Lighting Standards

A. See Link Light Rail Facility Lighting Standards.

B. Platform edge lights on aerial and at-grade stations shall be Kim 'STS' Small Structural fixture.

END CHAPTER 9

10. LANDSCAPING

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10. LANDSCAPING

10.1 INTRODUCTION

A. This chapter provides objectives, and design parameters for the landscaping of Link light rail Transit (Link) facilities. These include stations, park-and-ride lots, kiss-and-ride areas, traction power substations, communications/signal facilities/yards and shops, and Link right-of-way (ROW) line sections. Landscaping at these facilities encompasses and contains embankments and earthworks for the purpose of shape and drainage; view corridor and site line preservation; plantings for boundary treatment; the enhancement or screening for stations and ROW alignment; conservation of the indigenous flora and fauna and wetlands; ballast work; and footpaths.

B. Landscape final designers shall be responsible for preparing construction documents for the landscaping and irrigation of these facilities. Designs shall be consistent with the guidance provided in these criteria, in the preliminary design drawings, and in Link standard detail drawings. In addition, landscaping around stations and parking lots shall be coordinated with the communications systems designers to minimize impacts to sight lines of surveillance cameras. Exceptions may be desirable in some specific cases, and recommendations or discussions of deviations are encouraged where this might result in improved design. Deviations to the guidelines provided in these documents, however, must be approved in writing by the design consultant and Sound Transit.

C. Landscape final design shall also be designed using “Transit Security Design Considerations, FTA-TRI-MA-26-7085-05”, November 2004 as noted in Appendix C.

D. For projects within FAA jurisdiction, FAA wildlife hazard management requirements need to be met.

10.2 OBJECTIVES

A. The attainment of the following objectives shall not adversely affect the site distance of train operators and the public with respect to Link or other vehicular traffic.

1. Provide a landscape design responsive to and compatible with intended Link operations, station architecture, graphics, furniture, art, and lighting design.

2. Provide a safe, secure, comfortable, and attractive environment throughout the transit system, particularly at and along approaches to station entrances.

3. Control access to the system by reinforcing designated pedestrian and vehicular circulation system movement and creating barriers elsewhere along the ROW as required.

4. Provide a landscape design that is compatible with local climatic conditions and conserving of water resources. (See section 10.5)

5. Achieve a landscape design that is compatible with the regional aesthetic character and with the character, or envisioned character, of existing neighborhoods adjacent to the Link line.

6. Design a landscape that will require low maintenance in the short- and long-terms, and consider the long-term growth and health of the plantings.

7. Establish a recognizable visual character of the landscape design for all of the light rail stations through the use of paving, wayfinding, site amenities and planting styles, while maintaining compatibility with adjacent areas by adjusting the master plan design concept to fit each individual station.

8. Provide visual screening where necessary to buffer incompatible adjacent uses.

9. Protect, frame, and enhance existing views and vistas.

10. The use of plant materials around historic buildings shall be used in a manner to enhance the historic settings and characters of the buildings.

11. Protect significant existing plant material to the greatest extent possible to preserve a sense of scale and history.

12. Create a site grading plan that complements the use patterns of the site and coordinates with site elements.

13. Incorporate significant existing site features that complement the overall site design concept.

14. Emphasize preservation of existing vegetation (trees and shrubs) wherever possible.

10.2.1 Station Sites

A. Provide safe passenger waiting areas that have a comfortable human scale and provide protection from weather.

B. Highlight and clarify pedestrian circulation routes.

C. Establish a consistent visual identity for station areas.

D. Enhance pedestrian safety and security by providing adequate sight line distances from adjacent areas.

E. Provide visual screening where desirable.

F. Provide continuity and pleasing transitions between stations and adjacent areas while also maintaining clear identification and visibility of the station areas.

10.2.2 Trackway

A. Provide an attractive and unifying design concept within the Link corridor.

B. Prevent the accumulation of grass, leaves or other plant materials on the track and guideway.

10.2.3 Park-and-Ride Lots

A. Provide planting islands in parking lots to create visual interest and shade in large paved areas.

B. Enhance pedestrian safety and security by providing adequate sight line distances for both vehicles and pedestrians.

C. Provide attractive approaches to stations.

D. Establish visual screening of parking areas while allowing for surveillance.

E. Integrate design elements with adjacent areas.

F. Reinforce vehicular and pedestrian movement paths.

G. Landscaping in parking areas shall meet local jurisdictional codes.

10.3 CODES AND STANDARDS

A. All local codes shall be followed to ensure acceptance of landscape designs during jurisdictional design reviews. In addition, the following standards and guidelines should be referenced:

1. American Standard for Nursery Stock ANSI Z60.1, 1996 or later, as adopted by the American Association of Nurserymen, Inc.

2. Bailey's Standard Encyclopedia of Horticulture.

3. Standard Plant Names, American Joint Committee on Horticulture Nomenclature (AJCHN).

B. Consult with local authorities having jurisdiction to conform to policies and plans that are in existence.

10.4 SITE PREPARATION

10.4.1 Finish Grading

A. Finish grading should meet existing grades of adjacent areas where possible. Minimum depth of topsoil shall be 4 inches. Topsoil should be placed in a uniform depth to prevent uneven settlement. Coordinate topsoil requirements with the plant material to be installed.

B. In cut areas that are to be seeded or sodded, rock including shale, shall be covered with 12 inches of topsoil. Finished settled grade of topsoil in lawn areas shall be 1 to 1-1/2 and a half inches below adjacent hardscape. Topsoil shall not be stripped, placed, or worked while frozen or wet. Topsoil shall not be placed on untilled or unscarified surfaces. Walks or paving must provide positive drainage.

C. All surfaces, including planting areas, walks, and paving shall be graded to provide positive drainage. Water shall not drain across walkways.

D. Swales for surface drainage in lawn or planted areas shall have a shallow dished cross-section with a uniform longitudinal fall of 2 percent minimum - 6 percent maximum.

E. Seeded or sodded areas shall have a minimum slope of 2 percent (2 feet fall per 100 feet) and maximum slope of 1:3 (1 foot vertical change of grade per 3 feet of horizontal distance).

10.4.2 Slope Stabilization

A. Skillful grading and the incorporation of mounds and depressed areas shall be used where appropriate to control pedestrian movements, obscure objectionable views, and reduce objectionable noise.

1. All slopes shall be stabilized to prevent physical failure, erosion, and maintenance problems. See Chapter 6, Civil Work, section 6.2, Grading, for specifics.

2. Slopes that are to receive mowed turf or aggregate mulches shall not exceed 1 foot (vertical) to 3 feet (horizontal), (1 foot vertical to 4 feet horizontal on Seattle Parks property).

3. Slopes that are to receive non-mowed grass or ground covers shall not exceed 1 foot (vertical) to 3 feet (horizontal).

4. Open anchored matting shall be used to stabilize sodded or seeded slopes and swales (surface flow lines) exceeding 6 percent gradient.

5. Straw shall be used to stabilize seeded slope areas and all newly seeded grass areas. (Straw not to be used on Seattle Parks property).

6. Stable rock cut faces shall be left exposed.

7. Vertical transition curves, 6 feet to 20 feet as appropriate to scale of slope, shall be provided at top and bottom of slopes or mounds.

B. The following plants or materials are suitable for slope stabilization and erosion control:

Material	Slope (Maximum) (Horiz. On Vert.)
Turf, Mowed	1 on 3
Grass	1 on 2
Myrtle, pachysandra, etc.	1 on 2
Stone rip-rap	1 on 1 ½
Cut Stone	1 on 1
Brick Paving	1 on 1
Concrete block paving	1 on 1
Concrete paving	1 on 1

C. If new grading is properly blended with the existing grades, the need for retaining walls should be minimal. Where they are used, retaining walls shall be treated as an architectural element with consideration being given to scale, color, texture, contrast, and appropriate materials in relationship to both the transit facilities and adjacent neighborhoods.

10.5 PLANT MATERIALS

A. Plantings shall be used to enhance the visual quality of the station areas and to integrate them with their surrounding environment in a manner consistent with "Transit Security Design Considerations, FTA-TRI-MA-26-7085-05", November 2004 as noted in Appendix C.

B. Planting design should emphasize utilization of hardy, drought tolerant, low maintenance material that can exist without supplemental water in the local climate after a 3-year establishment period.

C. In planting areas without irrigation systems plant material shall be able to survive with natural rainfall. Planting areas, which contain less hardy plants, shall be used sparingly and shall be irrigated. See section 10.5.2.

D. All landscaping in the vicinity of historic buildings shall conform to the requirements of the Standards for Rehabilitation of the US Department of the Interior, latest edition.

E. Plant material used in the Link program shall all be rated hardy for use in USDA Zone 7, with the exception of seasonal ornamental planting areas.

10.5.1 Landscaping Considerations

A. Considerations for the selection of plant material include the following:

1. Initial cost
2. Mature height and spread
3. Growth rate
4. Seasonal form and color
5. Hardiness
6. Sun/shade preferences
7. Deciduous/Evergreen
8. Leaf size

9. Seed/fruit/bloom toxicity

10. Disease and pest resistance

11. Soil and drainage conditions

12. Tolerance to water/lack of water

13. Tolerance to wind, pollutants, and salt

14. Transplant tolerance

15. Availability

16. Maintenance requirements

10.5.2 Irrigation Requirements

A. Provide an automatic irrigation system for all planting areas at stations and station areas. Plantings with different water requirements shall be zoned separately to ensure adequate water supply to each plant type. The controller shall allow timed watering schedules, have the ability to alter the watering schedule seasonally, and have the capability to manually interrupt the schedule in times of unpredictable weather inconsistencies. The irrigation system shall be designed to address slope conditions and prevent run-off of irrigation water.

B. Yard hydrants shall be provided at station sites and in park-and-ride lots for general maintenance and for emergency and back-up irrigation. The locations shall be coordinated to permit site coverage with a 100-foot hose, except as approved in writing by Sound Transit.

C. Irrigation system shall provide ability for remote control access and systemwide compatibility.

D. Temporary irrigation designed to accommodate a 3-5 year life for specified areas where supplemental water is not needed after initial establishment shall be used wherever possible.

10.5.3 Trees, Shrubs, and Ground Covers

A. Mature, healthy existing trees of appropriate species shall be preserved where possible and shall be indicated in the contract documents with appropriate protection specified.

B. Proposed trees shall enhance an existing street tree pattern, if any, or shall be a part of a street tree pattern established by the local governmental authority for adjoining areas. Where no pattern exists, an orderly pattern shall be established.

C. Minimum caliper of trees located in paved pedestrian areas shall be 2-1/2 inches. Minimum caliper of trees in unpaved areas shall be 2 inches. Trees shall be spaced an appropriate distance apart depending on the species and design intent.

D. Tree location shall be adjusted to accommodate subsurface conditions such as utilities and vaults, as well as special conditions such as existing or proposed sidewalk canopies, awnings, and shelters.

E. Excavation for tree root balls shall be minimally two times wider and 6 inches deeper than the size of the ball.

F. A tree grate with minimum area of 24 square feet shall be provided to prevent compaction of the soil surface (5 feet by 5 feet pr 4 feet by 6 feet typical). Coordination with the municipality having jurisdiction is required to determine local requirements. Tree grates shall be designed to support the weight of one wheel of a service vehicle.

G. Steel tree guards shall be considered only where necessary at locations where tree trunks are likely to receive abuse from service vehicles, snow removal equipment, or pedestrians.

H. Trees in pedestrian areas shall be staked, using a standard staking detail or as approved by the design consultant and Sound Transit. For non-pedestrian areas, trees shall be staked or guyed. Trees shall be guyed only where necessary. No underground staking shall be allowed without prior approval.

I. Where shrubs are used, they shall be selected and grouped in a manner to minimize maintenance.

J. Ground cover shall be used in landscaped areas and slopes where pedestrian activity is to be discouraged.

K. Vines should be used selectively to landscape and soften vertical surfaces.

10.5.4 Herbicides/Fertilizers

A. Plant material shall be fertilized at the time of installation and a fertilization schedule should be established in the maintenance schedule.

B. Handweeding shall be the preferred method of weed removal. Products used shall be organic, when available, or a product that is proven to be non-persistent and non-damaging to the environment.

10.6 ADDITIONAL REQUIREMENTS

For additional requirements see Chapter 6, Civil Work, section 6.2, Grading.

END CHAPTER 10

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11. TRAFFIC CONTROL

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11. TRAFFIC CONTROL

11.1 INTRODUCTION

This chapter establishes the basis for engineering criteria to be used in the design of Link light rail (Link) Transit Project. It includes requirements for traffic control devices and criteria for the design of the traffic signal systems, signing and pavement marking as they apply to interfacing the Link lines with pedestrian and the street and highway network.

11.2 APPLICABLE STANDARDS

A. Traffic vehicle and pedestrian signals, signs and markings shall be in accordance with the practices of the counties and local jurisdictions in which the system will be constructed and with the Manual on Uniform Traffic Control Devices (MUTCD) published by the US Department of Transportation.

B. Design of pedestrian facilities shall be in accordance with the Draft Guidelines for Accessible Public Right-of-Way (June 17, 2002) as adopted by Sound Transit and The Americans with Disabilities Act Accessibility Guidelines for buildings and Facilities (ADAAG).

C. Materials and equipment used in each installation and/or modification of traffic signal systems, signing, and paving markings shall conform to the latest specifications contained in the standards of the agency having jurisdiction at the location of the installation.

11.3 GENERAL

11.3.1 Exclusive Right-of-Way

A. Where the Link LRT vehicles are operated on aerial structures in the center of a public street, left-turn access to or from driveways shall be prohibited. Left-turn access to or from side streets (non-signalized) shall be prohibited. Left-turn treatment at signalized intersections shall be evaluated on a case by case basis. Columns for the aerial structures shall be protected by barrier curbs.

B. Where the Link LRT vehicles are operated on aerial structures within the clear zone of a higher speed limited facility, columns for the aerial structures shall be protected by guard rail or other suitable barriers. The design of these barriers shall conform to agency design standards applicable at the location of their installation.

C. Fencing shall be installed where LRT vehicles are operated at grade in exclusive right-of-way to prevent trespass by pedestrians.

11.3.2 Semi-Exclusive Right-of-Way

A. At locations where Link LRT vehicles will operate on semi-exclusive right-of-way, but will cross a public street, traffic control shall be provided by vital train detection devices. Primarily, this control shall be by means of railroad-type flashers, bells, and gates. When LRT speeds are 35 mph or less, intersection-type traffic signals controlled by standard traffic signal controllers may be utilized in lieu of railroad-type devices. Interconnection with nearby traffic signals on the public street may be required. Where train speeds exceed 25 mph, curbs shall be provided as a barrier between the Link LRT vehicle and other vehicular traffic.

B. To deter motorists from driving around a lowered gate, a raised median shall be installed on each approach of a two-way street between the crossing and a point nominally 100 feet upstream. This median may be formed by placing back-to-back, two 10 inch-wide traffic curbs type A as specified in the WSDOT Standard Plans. Four-Quadrant Gate Systems may be installed to improve safety at highway/LRT grade crossings based on engineering study when less restrictive measures such as automatic gates and channelization devices are not effective.

C. At ungated public roadway and pedestrian crossings, which include an LRT trackway, and LRT speeds are 35 mph or less, standard highway type traffic signals shall be used to control vehicle and pedestrian traffic. These signals shall be installed in accordance with the MUTCD and standards of the agency having jurisdiction at the location of the installation.

D. Where Link LRT vehicles will be operated on a public street, but in exclusive lanes (semi-exclusive, right-of-way classification), a trackway at least as wide as the dynamic outline of the LRT vehicles shall be physically separated from parallel general traffic on that street.

E. Where Link LRT vehicles are operated at-grade on one side of the public street, full access restrictions shall be imposed (no left or right turns or through movements from driveways or side streets) on the side of the roadway with LRT operations. A trackway at least as wide as the dynamic outline of the LRT vehicles shall be physically separated from parallel general traffic on that street. Left or right turns across the Link tracks shall only be allowed at signalized crossings. A separate left turn lane with a separate protected left turn signal phase

shall be provided. Supplemental “Train Coming” signage shall be provided.

F. Physical separation may be accomplished by barriers and/or curbs to channelize vehicular traffic. The design of these barriers and curbs shall conform to design standards of the authority having jurisdiction.

G. Traffic turning movements across the track(s) from a parallel traffic lane shall be prohibited except at locations where these movements are controlled by railroad type gates or traffic signals. At traffic signal locations where such turns across the tracks must be allowed, a separate turn lane with a separate protected left turn signal phase shall be provided. Supplemental “Train Coming” signage shall be provided.

H. Pedestrian safety measures shall be incorporated into design as necessary to prevent LRT/pedestrian conflicts. Pedestrian pathways shall be clearly delineated to minimize trespassing onto tracks. Adequate pedestrian storage and queuing space shall be provided along streets and cross streets and station locations.

I. Trackways and passenger stations shall be designed so as not to create any unnecessary interference with pedestrian movements. Where pedestrians must cross Link tracks, appropriate control devices shall be provided. Where a pedestrian crossing is part of a signalized street intersection, control shall be provided by means of standard vehicle and/or pedestrian traffic signals. At locations, where justified by engineering study, these devices may be supplanted or supplemented by passive signs, active signs, flashing beacons, movable gates, or any combination thereof.

J. Accessible Pedestrian Signal Detectors shall be used at all signalized pedestrian crossings of the LRT trackway. The design of these detectors shall conform to agency design standards and policies applicable at the location of their installation.

11.3.3 Non-Exclusive Right-of-Way

A. Where the trackway is at grade in the street and is not physically separated from traffic lanes (non-exclusive, right-of-way classification with LRT speeds less that 25 mph), it shall be delineated by a paving material and texture and/or pavement markers suitable to alert the driver of encroachment onto the dynamic outline of the LRT vehicle. Delineation shall be provided by markings on the paving and/or by contrasting paving material. The width of the trackway shall include a buffer zone outside the dynamic envelope of the Link car suitable to the specific location.

11.4 CONTROL OF TRAIN INTERFACE WITH TRAFFIC

A. At intersections through which Link LRT Vehicles will operate, whether in mixed traffic or reserved lanes, special signals shall be provided to control their movement. These Link signals shall be physically separated from the traffic signals. They shall be designed to be in compliance with Chapter 10 of the MUTCD and consistent with the operation of other LRT signals deployed on Link facilities. Reference Chapter 14, Signaling.

B. The intersection Link signals may be operated by the same controller that operates the traffic signals or by a separate, but interconnected and compatible, controller. This control equipment shall be capable of allowing the LRT vehicles to travel between stations without stopping. This shall be accomplished by adding a separate phase for Link movement on either a pre-timed or a priority basis and shall also be capable of deleting such phases when not required. The equipment shall also be capable of coordinating signal operation at each intersection with any network of which it is a part.

C. Link crossings of non-public roadways are to be avoided, if possible. Elimination of such crossings by reconfiguring the private roadway so that traffic can use a nearby public roadway crossing should be a primary consideration. Where they are unavoidable, private crossing configurations may not conform to those of orthodox public roadway crossings and innovative warning and traffic control techniques could be required.

D. The method of detecting the approach or presence of Link LRT vehicles may be by means of railway track circuits where feasible. Where that method is not feasible, detection may be by a method not related to the rails, employing devices placed beneath the trackway, attached to the overhead contact system, carried aboard the vehicles, or some combination thereof. Coordination will be undertaken by Sound Transit, and the agencies responsible for operating and maintaining the roadway and traffic signals at each affected intersection or crossing to determine the type, location, phasing, and timing of the signals; the methods of detecting vehicle traffic, pedestrians and Link LRT vehicles and also of interfacing the control at each location with existing traffic signal systems.

E. Emergency vehicle preemption will be provided at all intersections controlled by a standard highway type traffic signal, which include a Link trackway. Preemption equipment will be Opticom or similar equipment compatible with equipment to be provided on emergency vehicles by the Authority Having Jurisdiction over the intersection. Crossings of the trackway at uncontrolled locations for emergency vehicles only may be provided if required by Authority Having Jurisdiction over the location.

F. When Link LRT vehicles share operating ROW with buses, bus signals shall be interlocked with train signals to provide priority for train movements.

11.5 SIGN DESIGN

Traffic signs related to the Link operation shall be installed in accordance with the MUTCD and standards of the agency having jurisdiction at the location of the installation. In situations where sign requirements are not addressed by these standards, special supplemental signing will be developed by Sound Transit in coordination with the agency having jurisdiction.

11.6 PAVEMENT MARKING DESIGN

Paving markings related to the Link operation shall be installed in accordance with the MUTCD and standards of the agency having jurisdiction at the location of the installation. Special markings where required to delineate the dynamic outline of the Link cars shall conform as is practical to the MUTCD. In situations where marking requirements are not addressed by these standards, appropriate designs will be developed by Sound Transit and in coordination with the agency having jurisdiction.

11.7 GENERAL OPERATIONS

A. Where LRVs operate mixed with general traffic or adjacent thereto without an intervening barrier or curb, they shall travel no faster than 25 mph.

B. Each LRV shall be equipped with a gong and a horn or whistle to warn motorists and pedestrians that are in potential conflict. The gong shall be used in residential and business districts where speeds are low. Use of the horn or whistle shall be reserved for locations where the LRVs operate above 40 mph, but should be used for emergencies at any location.

C. At signalized intersections where all movements are controlled by standard traffic signal controllers and at crossings not controlled by gates, LRVs shall approach at speeds that will permit them to stop short of the point of conflict if the roadway is already occupied and, in no case, at a speed higher than 35 mph.

END CHAPTER 11

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12. LIGHT RAIL VEHICLE

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12. LIGHT RAIL VEHICLE

12.1 INTRODUCTION

12.1.1 Vehicle Type

The light rail vehicles shall be low-alloy, high-tensile (LAHT) steel, with selected elements of stainless steel or fiberglass reinforced plastic (FRP), doubly-articulated, six-axle, partial (approximately 70 percent) low-floor vehicles. There shall be eight passenger doorways, four per side directly across from one another, all in the low floor section. Each end of the vehicle shall have a fully equipped operator's position. Vehicles shall be capable of normal, multiple unit operation in consists of up to four cars and emergency multiple unit operation in consists of up to eight cars. The anticipated service life of the vehicles is 30 years.

12.1.2 Seating Arrangement

Each vehicle shall have seating for a minimum of seventy-four passengers.

12.1.3 Elderly and Handicapped Accessibility

A. The vehicles shall be designed to provide full accessibility for elderly and handicapped persons, particularly non-ambulatory persons in wheelchairs. Passenger platforms will be low level, providing accessibility through all doors. The cars shall be equipped with automatic load leveling to meet the vehicle to wayside vertical gap requirement of Americans with Disabilities Act (ADA). Space shall be provided in each vehicle to accommodate four wheelchairs. The vehicles, in conjunction with coordinated platform configuration, shall comply with the ADA.

B. Bicycle and luggage space shall be provided on each vehicle with a maximum of up to two bicycles and an identified luggage space. Such space, if shared with the handicap provisions, shall be designed to facilitate the shared use.

12.1.4 Operator’s Cab, Controls, and Indicators

A. Each car shall be designed with identical operator's cabs at each end. The cab shall be designed for use by an operator in the size range of 5th female percentage to 95th male percentage of the general population, as defined by Humanscale 1/2/3 (The MIT Press, 1974.) The design shall utilize the principles of ergonomics in the

development of the cab and instrument layout. Standing space shall be provided in the cab for a second person to monitor and train the vehicle operator.

B. The operator's controls shall be arranged to facilitate ease of operation. There will be a master controller and a console for the various controls.

C. The master controller group shall consist of a Key Switch, Reverser Switch, and Master Controller and shall be supplied as a single integrated unit. A foldable armrest shall be provided for the operator's arm, usable when the operator is using the Master Controller handle.

D. Remotely controlled closed circuit television shall be provided to permit the operator to view conditions on both sides of the train at all doorways on tangent track and perform functions normally provided by side mirrors. Side mirrors shall not be provided.

E. Opening side windows shall be provided on both sides of each cab. They shall provide a clear view of conditions on each side of the train and shall be easily opened, closed, and latched, with sufficient open area to permit an operator to reach pole mounted control switches and also look back along the outside of the train when outside cameras are not working.

12.1.5 Signaling and Train-To-Wayside Communication

The vehicle contract shall require the car builder to provide carborne Automatic Train Protection (ATP) and train-to-wayside communications equipment.

12.1.6 Lighting

A. Interior and exterior lighting shall be provided for the vehicles. External lighting and emergency interior lighting shall be powered from the car battery.

B. Normal interior lighting shall be warm white fluorescent high efficiency electronic ballasts powered from the low voltage dc power supply. The light fixtures shall be dust and moisture proof and may be combined with the air diffusers

C. Exterior lights at each end shall include two dual beam halogen automotive level headlights, a dimable, variable intensity, single roof mounted sealed beam railroad headlight, upper marker lights, tail lights, , brake lights, and turn signals. Exterior lights on the car sides shall include door, brake, turn signals, and fault indicators. All exterior

lights, except for the headlights, shall be high intensity LED modules that comply with federal highway vehicle lighting requirements.

12.1.7 Heating, Ventilation, and Air Conditioning

A. The vehicle shall be provided with a heating, ventilating, and cooling (HVAC) system. The units shall be a completely self-contained, service-proven package. Cab heaters and defroster / demisters shall be provided in each cab.

B. The HVAC controls shall include control and monitoring via a car data bus to a vehicle monitor in the operating cab.

C. The HVAC system shall be designed to automatically provide control of vehicle interior temperatures with specified ambient temperatures equally distributed. Passenger compartment floor heating power shall be three-phase ac. Overhead heat shall be three-phase ac or 1,500 Vdc.

D. The interior temperature shall be maintained in the temperature range of 66°F to 72°F depending on the ambient temperature.

E. The refrigerant to be used shall be environmentally friendly in accordance with DOT 40 CFR-82. All heating, ventilating, and cooling apparatus and controls shall also meet the applicable requirements of UL Standard 465 and ASHRAE Standard 37.

12.1.8 Propulsion Equipment

The vehicle shall be provided with separate three-phase ac inverter propulsion systems for each powered truck. Inverter design shall be service-proven IGBT designs with at least 2 years successful service experience. Inverters shall be air-cooled. Traction motors shall be totally enclosed, forced-air cooled, or splash-proof self-ventilated. Bi-motor parallel drive power trucks shall be provided. Propulsion equipment shall be provided in a modular package.

12.1.9 Friction Brakes

The vehicle shall be equipped with separate electro-hydraulic brake systems for each truck. Brake discs shall be provided for each axle and each independent wheel. Parking brakes shall be provided on power trucks. Electromagnet track brakes shall be provided on each truck. Sanders shall be provided to dump sand ahead of each powered truck in each direction of travel. Friction brake equipment shall be provided with in modular packages with unitized hydraulic control units for each truck with an associated electronic control unit that includes all control logic for interface with car trainline controls and monitoring systems.

12.1.10 Event Recorder

An event recorder with non-volatile memory shall be provided to monitor and store train performance parameters needed for accident investigation. It shall be ruggedly constructed to survive a collision and securely constructed to prevent tampering.

12.1.11 Monitoring and Diagnostics Logic System

Monitoring and Diagnostic Logic (MDL) System on each vehicle shall be dedicated to monitoring all vehicle systems and record data that will be needed to troubleshoot and maintain the equipment on the vehicle and train. It shall communicate with other car equipment via the Vehicle Network Data Bus, and shall monitor the propulsion control data bus and discrete trainlines. It shall communicate with the operator and maintainers via the Train Operator's Display. It shall include a battery backed clock and sufficient non-volatile memory to store train faults and monitored data on TBD events. Interfaces shall be provided to download to a notebook PC, PCMCIA cards, or by using a Portable Test Unit (PTU). An interface shall be provided for PTU. Interfaces shall be provided to allow attachment of recorders and other test equipment for train performance testing and troubleshooting. The MDL system shall record and access sufficient car system information to permit a maintainer to troubleshoot to the line replacement unit level without the need to employ external test equipment. Data from the MDL will be stored for download via PTU and wireless method.

12.1.12 Car Network Controller

A Car Network Controller shall be provided to interface between the train network data trainlines and car systems within a vehicle. It shall also provide necessary decoding and translation between these trainlines and systems.

12.1.13 Trainlines

The vehicle shall be equipped with a combination of discrete battery level trainlines and bi-directional data bus trainlines.

A. Discrete battery level trainlines shall be provided for certain functions, including emergency brake control, brake release, door control, and similar safety related signals.

B. Tractive effort modulation control signals may be Type I, II, or III in accordance with IEEE Standard 1475. If Type III, redundant Trainlined Control Networks shall be provided to interconnect the master controller, cab signal, propulsion, and friction braking systems.

If Type III, it shall communicate with on-car equipment through the Vehicle Network Controller.

C. Local vehicle Network Data Bus networks shall interconnect car equipment and the Car Network Controller.

D. Digital Audio Trainlines shall be used to transmit audio messages between vehicle communications system equipment.

E. Battery positive and battery negative trainlines shall be provided.

12.1.14 Vehicle Communications and Passenger Information System

The vehicle shall be provided with an integrated audio communications and passenger information system. The system shall include manual controls to permit the train operator to make public address announcements and communicate with passengers by means of a passenger emergency intercom. Radio communications shall be provided by separate hardware. The system shall also include interior passenger information variable message signs with yellow alphanumeric characters and exterior destination signs. The equipment shall provide automated station announcements by means of the public address system and passenger information signs.

12.1.15 Car Interior Surveillance Equipment

The vehicle shall be provided with four closed circuit color television cameras to monitor the vehicle interior. A time-lapse recorder shall be provided to store the images. The recorder shall have the capacity to store 24 hours of data before over-writing old images when recording at a rate of four images per second per camera.

12.1.16 Automatic Passenger Counting Equipment

Automatic passenger counting equipment shall be provided on every third vehicle. Passenger data shall be stored on the vehicle for downloading via PTU and wireless method.

12.2 CRITICAL VEHICLE DIMENSIONS

12.2.1 Carbody Dimensions

Length of car over coupler faces:	90 ft (27,430 mm) to 96.5 ft (29,400 mm)
Length of car over anticlimbers:	88 ft (26,820 mm) to 94.5 ft (28,800 mm)
Width of car at widest point :	8.7 ft (2,650 mm) to 8.8 ft (2,682 mm)
Floor height above top-of-rail: Maximum - high floor section: Low floor section:	 39 in (990 mm) 14 in (356 mm)
Minimum interior ceiling height, finished floor to finished ceiling, on vehicle centerline:	6.7 ft (2,040 mm)
Side door minimum clear opening width with doors fully opened:	48 in (1,220 mm)
Minimum clear side door height from finished floor:	6.5 ft (1,980 mm)
Maximum door panel excursion during opening sequence:	2.2 in (56 mm)
Minimum aisle width:	25 in (635 mm)
Maximum roof-mounted equipment height, including shroud, exclusive of pantograph, above Top of Rail (TOR) with new wheels and car at AW0:	12.4 ft (3,780 mm)
Coupler vertical centerline height above TOR, car at AW0, with new wheels:	18.5 in (470 mm) to 26.6 in (676 mm)
Top of anticlimber height over TOR, car at AW0, with new wheels:	same as top of high floor
Minimum depth of interior step treads:	11 in (280 mm)
Maximum height of interior step risers:	9.85 in (250 mm)
Maximum low floor height variation above top of rail at doorways, with loads from AW0 to AW3 (sum of suspension tolerances and deflection, and car body and truck tolerances, and deflection):	±0.375 in (±9.5 mm)

12.2.2 Pantograph Dimensions

Maximum height above TOR of the highest point on the pantograph in the lockdown position, new wheels and car at AW0:	12.7ft (3,870 mm)
Pantograph operating height, dynamic conditions any car weight AW0 to AW4, and with new to fully worn wheels:	Max. 22.3 ft (6,800 mm) Min. 13.0 ft (3,960 mm)
Collector head width over horns:	75 in (1,905 mm)
Minimum collector head carbon shoe length:	47 in (1,194 mm)
Radius of curved collector head carbon shoe:	19.7 ft (6.0 m)
Maximum longitudinal distance from center truck pivot to center of pantograph shoe, locked down:	46 in (1,168 mm)
Pantograph uplift pressure:	Nominal 18 lbf (80 N) Adjustable: 14 to 25 lbf (62 to 111 N)

12.2.3 Wheel Dimensions

Profile: (Subject to review by the Wheel to Rail Interface Study.)	The wheel profile shall be as shown in Figure 12-1.
Diameter, motor truck: New, nominal: Minimum allowable wheel diameter wear:	 26 in (660 mm) to 28 in (711 mm) 2 in (51 mm)
Diameter, center truck: New, nominal: Minimum allowable wheel diameter wear:	 24 in (610 mm) to 26 in (660 mm) 2 in (51 mm)
Track gauge:	56.5 in (1435 mm)
Back-to-Back Dimension:	53.8 in (1,367 mm)

12.2.4 Truck Dimensions

Motor truck center to pivot center spacing:	Sufficient to comply with dynamic envelope.
Truck wheelbase (nominal), motor truck:	71 in (1,800 mm) to 75 in (1,900 mm)
Truck wheelbase (nominal), trailer truck:	67 in (1,700 mm) to 75 in (1,900 mm)

12.3 WEIGHT AND PASSENGER LOADING

A. The maximum weight of each Vehicle, including passengers (calculated at 154 lbs each), shall be defined as follows:

1. AW0	Empty vehicle operating weight:	110,000 lb (49,900 kg)
2. AW1	Full seated load of 75 persons (74 passengers plus operator), plus AW0:	121,600 lb (55,160 kg)
3. AW2	Standees at 4 persons per m^2 suitable standing space per passenger, 120 persons, plus AW1:	140,000 lb (63,500 kg)
4. AW3	Standees at 6 person per m^2 suitable standing space per passenger, 180 persons, plus AW1:	149,300 lb (67,700 kg)
5. AW4	Standees at 8 persons per m^2 suitable standing space per passenger, 240 persons, plus AW1:	158,500 lb (71,900 kg)

B. The car weight supported at the center truck shall be within the range of 25 percent to 40 percent of the total car weight from AW0 to AW2 (evenly distributed).

C. The difference in vehicle weight between the A-End and B-End trucks shall not exceed 2,000 lb (900 kg) for all loading conditions AW0 to AW3.

D. The lateral imbalance shall not exceed 25,000 in-lb (290 kg-m) for all loading conditions from AW0 to AW3.

12.4 CURVE AND GRADE OPERATIONS

A. The vehicle shall operate over:

Minimum horizontal curve radius	82 ft (25 m)
Minimum vertical curve radius, crest	820 ft (250 m)
Minimum vertical curve radius, sag	1,150 ft (350 m)
Maximum gradient	7 percent

12.5 DYNAMIC ENVELOPE

12.5.1 General

Maximum dynamic roll angle, failed suspension: 3 degrees

12.5.2 Tangent Track

The dynamic envelope of the vehicle at all speeds up to 55 mph shall be limited to that shown in Chapter 4, Track Alignment and Vehicle Clearances.

12.5.3 Curves

The maximum dynamic offset in curves shall be limited to that shown in Chapter 4, Track Alignment and Vehicle Clearances.

12.5.4 Undercar Clearances

Vertical undercar clearance is defined from TOR with the maximum suspension deflection and car body roll, minimum vertical curve radius, and fully worn wheels. Minimum vertical clearance shall be 2 inches (50 mm).

12.5.5 Station Platform Interface

Refer to Chapter 4, Track Alignment and Vehicle Clearances, section 4.2.6.3, Special Clearance Situations and Chapter 28, System Safety, section 28.3.2, Station Features, for passenger station platform interface.

12.5.6 Pantograph Sway

Maximum sway of pantograph head with 65 lbf (290 N) side load independent of car body: 1.5 inches (40 mm) at any extension.

12.5.7 Pantograph location

The pantograph shall be over or adjacent to the center truck.

12.6 PROPULSION/BRAKING PERFORMANCE

12.6.1 Acceleration

A. The following maximum acceleration requirements shall be met at vehicle loads from AW0 to AW2. At loads above AW2, the maximum rate may be reduced proportionally by the ratio of AW2 to the actual car weight.

B. Maximum acceleration rate 3.0 mphps (1.34 m/s^2) ±5 percent

C. Time to reach 25 mph (40 km/h), AW0 to AW2 ≤10 s

D. Time to reach 50 mph (80 km/h), AW0 to AW2 ≤35 s

E. Acceleration shall be continuously adjustable by the operator between 0.3 mphps (0.134 m/s^2) and maximum acceleration. These acceleration rates shall be within the speed range from 0 to 20 mph (32 km/h).

F. Initial acceleration rates shall be as commanded by the trainlines over a 900 Vdc to 1,900 Vdc range at the catenary except that the commanded initial rate for the speed range of 0 to 20 mph (32 km/h) need only be met at 1,500 Vdc and above. Below 1,500 Vdc the speed to which the initial acceleration rate is held may be decreased proportional to the catenary voltage.

G. The propulsion system shall linearly reduce the maximum line current as the line voltage decreases below 1,200 Vdc, with a setting of 100 percent at 1,200 Vdc and 40 percent at 900 Vdc. The settings shall be software adjustable.

12.6.2 Coast Requirements

A coast mode shall be provided with an acceleration rate sufficiently low to be perceived as a free running coast by the Operator. The Master Controller shall have a positively indicated coast position between the motoring and braking zones with a perceptible detent in the coast position.

12.6.3 Service Brake Requirements

A. The following deceleration requirements shall be met at vehicle loads from AW0 to AW3. At loads above AW3, the maximum rate may be reduced proportionally by the ratio of AW3 to the actual car weight.

1. Blended full service brake rate, for speeds from 45 mph (72 km/h) to dynamic brake fade speed: 3.0 mphps (1.34 m/s^2) $\pm$ 5 percent.

2. For speeds from 59 mph (95 km/h) to 45 mph (72 km/h) the blended full service brake average retardation rate shall be tapered from 2.0 mphps (0.9 m/s^2) $\pm$5 percent at 59 mph (95 km/h) to 3.0 mphps (1.34 m/s^2) $\pm$5 percent at 45 mph (72 km/h).

3. Braking shall be continuously adjustable by the Operator between 0.3 mphps (0.134 m/s^2) and full service brake.

4. Braking shall be provided by a combination of dynamic and disc braking. The dynamic brake shall be regenerative and rheostatic.

5. Dynamic brake fade shall not occur above 6 mph (9.7 km/h).

6. In the event of dynamic brake failure, maximum train speed shall be automatically limited to not less than 25mph (40 km/h). The disc brake shall be capable of providing the specified rate, with a ± 20 percent tolerance, without damage to any equipment or brake pads, for a complete round trip on the Sound Transit line.

7. Dynamic braking rates shall be independent of the catenary voltage and, once initiated, full dynamic braking capabilities shall be available without catenary voltage present. Regenerative brake shall be regulated to limit the catenary voltage rise to no greater than 1,800 Vdc, with rheostatic brake continuously blended in to dissipate the braking energy that cannot be consumed by other loads on the catenary system. Line gaps, regenerative braking energy from other propulsion packages, or other external disturbances shall not cause loss or instability of dynamic braking. The system shall function continuously to monitor the catenary voltage and current during a brake application to maximize the regenerative brake portion of dynamic braking.

8. A Safety Brake (SB) rate of 2.0 mphps (0.89 m/s^2) shall be available from 59 mph (95 km/h) to stop for use by the ATP and Deadman Systems. The blended brake tolerance shall be ±5 percent and the all friction rate shall be ±15 percent.

12.6.4 Emergency Braking Requirements

A. For brake entry speeds equal to or greater than 30 mph (48 km/h), the minimum emergency brake rate, at all weights up to AW3, shall meet or exceed the values calculated by the following equation:

1. R_{AV} [mphps] = -0.02v [mph] + 5.6 (USA)

2. R_{AV} [m/s^2] = -0.006v [km/h] + 2.5 (SI)

For vehicle weights greater than AW3, the minimum emergency brake rate may decrease linearly from AW3 to AW4 down to a value determined by the ratio of AW3 to AW4 times the required AW3 rate.

Where R_{AV} is the average emergency braking rate in mphps (m/s^2), and v is the brake entry speed in mph (km/h). The maximum emergency braking rate shall not exceed the minimum rates by more than 30 percent.

B. For brake entry speeds greater than 15 mph (24 km/h) and less than 30 mph (48 km/h), the average emergency brake rate shall be a minimum of 5.0 mphps (2.23 m/s^2) and shall not exceed this rate by more than 30 percent.

C. For brake entry speeds of less than 15 mph (24 km/h), the instantaneous emergency brake rate after the rate has built up shall be a minimum of 5.0 mphps (2.23 m/s^2) and the maximum rate shall follow the characteristics of the magnetic track brake.

12.6.5 Parking Brake

The parking brake system shall be capable of holding a vehicle at all weights up to AW4 on a 7 percent grade indefinitely. Manual means shall be provided on a per-car basis to release and reapply the parking brakes in the case of trainline control system failures, associated control valves and pumps shall be accessible inside the car.

12.6.6 Brake Cut-Out

Manual brake cut-out valves shall be provided for each truck, accessible from one side of the vehicle.

Electrically-operated remote release valves shall be provided for each truck, controlled individually by cab-mounted switches.

12.6.7 Continuous and Balancing Speed

Minimum balancing speed: (AW0 to AW2, tangent track)	55 mph (88 km/h)
Balancing speed on a 5 percent uphill grade: (AW0 to AW2, tangent track)	40 mph (64 km/h)
Maximum safe operating speed:	65 mph(105km/h)
The vehicle shall be capable of continuous operation at low speeds of 5 mph (8 km/h) or less.	

12.6.8 Mode Change Dead Times

Mode change dead time shall not exceed the following:

Power to Brake	300 ms
Power to Coast	300 ms
Coast to Brake	300 ms
Coast to Power	300 ms
Brake to Power - below 3 mph	300 ms
Brake to Power - above 3 mph	400 ms
Friction Brake	500 ms

12.6.9 Jerk Limits

A. In response to a step input command signal, the average rate of change of acceleration or deceleration in any brake or propulsion mode except emergency braking shall be the following:

Minimum	2.5 mphps^2 (1.1 m/s^3)
Maximum	3.0 mphps^2 (1.3 m/s^3)

B. Emergency brake applications shall not be jerk limited.

12.6.10 Spin/Slide Correction

A. A system shall be provided to detect and correct wheel spin and slide on each car whether random or synchronous on an individual truck basis both in acceleration and braking.

B. Efficiency at a coefficient of adhesion of 0.05 or greater shall be at least 90 percent in acceleration and in braking.

12.6.11 No-Motion Detection

Apparatus shall be provided to detect, in a safe manner, all vehicle motions down to and including 2 mph (3 km/h).

12.6.12 Duty Cycle Rating

A. The car shall be capable of continuous operation on the Sound Transit lines without exceeding the continuous rating of any equipment, under the following conditions:

1. A constant AW3 load
2. A dwell time of 20 seconds at each stop
3. Acceleration and braking at maximum service rates
4. Operation to and maintenance of maximum track speeds
5. A 120 seconds layover at each end of the line

B. In addition, one train with an AW3 load shall be capable of pushing or towing another train of equal length with an AW3 load from the point of failure to the next station, where passengers would be unloaded, and then continue with both trains at AW0 load to the end of the line, at reduced performance, without damage or reduction in equipment life. The point of failure shall be considered to be at the farthest location on the line from either end of the line such that the worst load

is imposed on the equipment. The train will be dispatched to the nearest end of the line. The train operating in this condition would be operated as a special equipment movement with no passenger station stops after the first and would slow down only as normally required by other traffic, signals, and civil requirements. Maximum speed permitted may be reduced, by rulebook, to not more than 25 mph (40 km/h).

12.6.13 Compensation For Car Load

Acceleration and braking tractive effort shall be automatically adjusted to compensate for car load so that the acceleration and braking rates specified in the prior parts of section 12.6 are maintained constant as the car load varies. The compensation scheme shall use load sensors on each truck to provide separate signals to the propulsion and brake systems that are proportional to the load on each truck. The failure mode will be to indicate AW0 car weight only for the truck with the failed sensor, the load indications on other trucks shall indicate the actual load for those trucks. The specified rate shall be provided when the car is operating on level, tangent track; there shall be no compensation for grade or curve resistance. Schemes that use rate feedback will not be allowed.

12.6.14 Sanding

A sanding system shall be provided that deposits sand immediately in front of each wheel of both motor trucks or in front of each leading wheel of both motor trucks. Sanding shall be automatically provided during emergency braking and after detection of spin and slide conditions.

12.6.15 Load Leveling

An air or hydraulic spring secondary suspension with leveling valves shall be provided to maintain a constant floor height above top-of-rail at all car loads from AW0 to AW3.

12.7 SYSTEM OPERATIONS

12.7.1 Overhead Voltage

A. The car shall be designed for the following overhead catenary system voltage conditions:

1. Nominal: 1,500 Vdc
2. Maximum sustained: 1,900 Vdc
3. Minimum sustained: 900 Vdc

4. DC derived from 12-pulse rectification

B. Equipment powered from the catenary system shall include apparatus to prevent damage to itself due to transient and sustained under- and over-voltage conditions. The equipment may stop functioning during sustained out-of-limit conditions, but shall automatically restart as soon as in-range conditions occur. Systems shall be able to sustain 1,900 Vdc indefinitely. The systems shall shut down at voltages above 1,900 V before any damage occurs and shall automatically restart as soon as the voltage decreases below 1,850 Vdc.

12.7.2 Vehicle Voltages

A. Low Voltage Power System: 28.5 Vdc or 37.5 Vdc

B. AC power supply: 208Y/120 Vac rms, 3-phase, 4-wire, 60 Hz and variable voltage variable frequency, 3-phase, 3-wire for specific motor loads with Sound Transit approval.

12.7.3 Electromagnetic Interference

A. Radiated Emission Limits

1. From 0.01 MHz to 30 MHz, the maximum permissible interference limit shall not exceed 20 dB above the limit of Figure 22 (RE05) of MIL-STD-461A.

2. From 30 MHz to 88 MHz, the maximum permissible interference limit shall be 58 dB above one V/m/MHz bandwidth.

3. From 88 MHz to 3,000 MHz, the maximum permissible interference limit shall be 68 dB above one V/m/MHz bandwidth.

B. Conductive Emission Limits

1. From 40 Hz to 120 Hz, 1 A maximum.

2. From 120 Hz to 320 Hz, 10 A maximum.

3. Above 320 Hz, the emissions limit then follows a smooth curve through 10 A at 320 Hz, 0.05 A at 2.34 kHz, 0.016 A at 4 kHz, and 0.0046 A at 7 kHz.

C. Inductive Emission Limits

The inductive emissions shall be limited to a maximum of 20 millivolts rms, rail-to-rail, at all frequencies between 20 Hz and 20 kHz.

12.7.4 Noise

A. Interior noise shall not exceed the following:

Vehicle stationary:	72 dBA
Vehicle operating (not in tunnel):	75 dBA
Vehicle operating (in tunnel):	80 dBA

B. Exterior noise, measured 50 feet from the centerline of the track, 5 feet above the ground, shall not exceed the following:

Vehicle stationary:	68 dBA
Vehicle accelerating/decelerating on tangent track at 40 mph (64 km/h):	75 dBA

12.7.5 Shock and Vibration

A. Vibrations anywhere on the vehicle floor, walls, ceiling panels, and seat frames shall not exceed the following:

Below 1.4 Hz: Maximum deflection (peak to peak)	0.10 in. (2.54 mm)
1.4 Hz to 20 Hz: Peak acceleration:	0.01 g. (0.10 m/s^2)
Above 20 Hz: Peak velocity:	0.03 in/s. (0.76mm/s)

B. All vehicle equipment shall operate without damage or degradation of performance when subjected to vibration and impact encountered during normal service, and shall be compliant with and tested in accordance with IEC 61373 standard, including all functional and durability requirements.

12.7.6 Ride Quality

The rms acceleration values shall not exceed the 4-hour, reduced comfort level (vertical)" and "2.5 hr, reduced comfort level (horizontal) boundaries derived from Figure 2a (vertical) and Figure 3a (horizontal) of ISO 2631 over the range of 1 Hz to 80 Hz, for all load conditions AW0 to AW3.

12.7.7 Flammability and Smoke Emission

A. All materials used in the construction of the car shall meet as a minimum the requirements of the U.S. Department of Transportation's Recommended Fire Safety Practices for Rail Passenger Car Materials Selection - January 1989 and NFPA 130.

B. The floor structural assembly shall meet a 30-minute minimum endurance rating if tested in accordance with ASTM E 119. The roof structural assembly shall meet a 15-minute minimum endurance rating if tested in accordance with ASTM E 119.

C. Total BTU content shall be no more than 90,000,000 BTU (95 GJ) per car. Heat release rate shall be no more than 45,000,000 BTU/hr (47.5 GJ/hr) per car.

12.8 RELIABILITY

A. The Mean Distance Between Failure (MDBF) of the vehicle, defined as total accumulated mileage divided by total number of relevant failures, shall be 20,000 miles.

B. Individual systems shall meet the following reliability requirements:

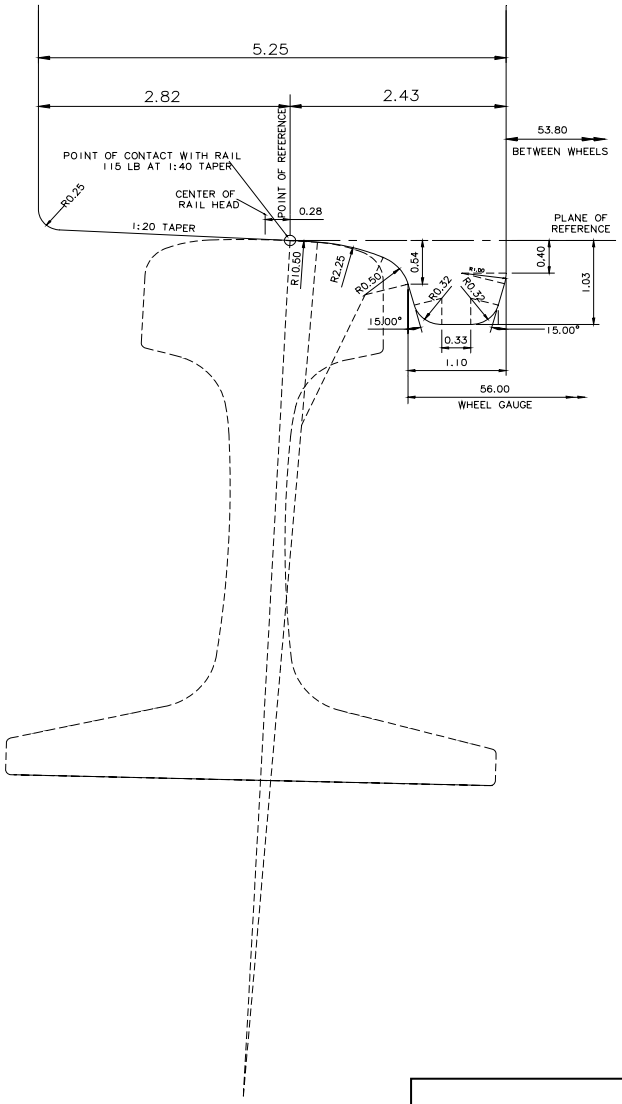
System	MDBF (mi)	MDBF (km)
Propulsion System	100,000	160,000
Friction Brake System	85,000	136,000
Communications, except Radio	200,000	320,000
Cab Signal System	200,000	320,000
TWC System	200,000	320,000
Car Body & Appointments	500,000	800,000
Side Doors & Controls	85,000	136,000
Lighting (except light bulbs)	500,000	800,000
General Electrical Apparatus	100,000	160,000
HVAC Equipment & Controls	150,000	240,000
Couplers & Draft Gear	250,000	400,000
Trucks & Suspension	250,000	400,000

12.9 MAINTAINABILITY

A. The vehicle shall be designed to minimize Mean Time To Repair (MTTR). The quantitative maintainability goal for the vehicle shall result in an overall MTTR of 1.8 hours. This shall be the weighted average of the MTTR of the key system elements as listed below. Diagnostic time shall be included in MTTR.

System Element	MTTR (hours)
Propulsion System	2.0
Friction Brake System	2.0
Communications, except radio	1.0
Side Doors & Controls	0.8
Lighting	0.5
General Electrical Apparatus	1.5
HVAC Equipment and Controls	2.1
Couplers & Draft Gear	2.6
Trucks & Suspension	1.6
Cab Signal System	1.0
Train-To-Wayside Communication	1.0
Car body and Appointments	2.1
Seat Cushion and Back (In vehicle replacement)	0.25
Side window replacement*	3.0

- To include remove old window glass, install and seal new window glass and for car to be ready to operate through the car wash without damage to the window and associated materials.



Units = Inches

Figure 12-1

LTK Engineering Services

***LINK* LRT Project**

SOUNDTRANSIT

Design Criteria	PROPOSED LRV PROFILE WITH 115 LB STANDARD RAIL

END CHAPTER 12

13. TRACTION ELECTRIFICATION

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13. TRACTION ELECTRIFICATION

13.1 INTRODUCTION

13.1.1 General

This chapter establishes the design criteria for the Traction Electrification System (TES), which includes traction power substations, the dc tie stations, the dc feeder system, and the overhead contact system (OCS).

13.1.2 Definitions

A. Traction power substations (TPSS) are located along the system route and connected to the local power utility company. They include all equipment necessary to transform and rectify ac three-phase voltage to dc electrification voltage.

B. Tie Stations (TS) are dc feeder circuit breakers located approximately mid-way between substations. They provide a means to parallel the OCS and provide additional protection for high-impedance faults.

C. The dc feeder system (DCFS) includes the ducts, cable and/or overhead connectors from the substations to the trackside disconnect switches and the track rails.

D. The OCS distributes power supplied from the TPSS to the vehicles. It includes messenger and contact wires and their physical support.

13.1.3 Codes and Standards

A. All design work and material selection shall conform to or exceed the requirements of the latest editions of standards and codes issued by the following organizations:

1. Association of American Railroads (AAR)
2. American Railway Engineering and Maintenance-of-Way Association (AREMA)
3. American National Standards Institute (ANSI)
4. American Society for Testing & Materials (ASTM)
5. Institute of Electrical & Electronics Engineers (IEEE)

6. National Electrical Manufacturers Association (NEMA)
7. Insulated Cable Engineers Association (ICEA)
8. American Society of Mechanical Engineers (ASME)
9. Underwriters Laboratories (UL)
10. National Fire Protection Association (NFPA)
11. National Electrical Testing Association (NETA)
12. National Electrical Code (NEC), where applicable
13. Applicable State, Local, and County Codes
14. National Electrical Safety Code (NESC)
15. Washington Utilities and Transportation Commission (WUTC)
16. Washington Industrial Safety and Health Act
17. Washington Administrative Code - WAC Title 296

13.2 SYSTEM DESIGN

13.2.1 System Description

A. The TES configuration shall be of the multiple feed type with dc electrical continuity between substations.

B. The light rail vehicles (LRVs) will collect power from the contact wire by means of pantographs and will return the power to the substations via running rails, except during regenerative braking when power will be placed back into the system via the vehicle pantograph to the OCS.

C. Mainline and yard tracks will be isolated from ground, as described in Chapter 17, Corrosion Control.

D. The Shop tracks will be solidly grounded.

E. The traction power supply system shall maintain the distribution system voltage above the minimum allowable value. The OCS shall be designed to allow the trains to operate with all pantographs in contact with the conductors up to the maximum allowable speed without excessive oscillations of the system and without pantograph bouncing or arcing.

F. Traction power and distribution system equipment shall be designed taking into account the effects of the harmonic content of the traction load, the highly fluctuating pattern of traction current, and system faults.

G. The TES shall be designed for a minimum functional life expectancy of 30 years.

13.2.2 System Load Flow Simulation

A. The design of the Traction Electrification System shall be based on a computer-aided load flow simulation. The trains shall be simulated to operate on the system for the following schedules:

1. Ultimate design capacity assuming the heaviest projected schedule as defined in Chapter 2, Operations, under normal and contingency conditions. The addition of future line extensions shall be considered in the design.

2. Minimum Signal System design headway under normal operation and contingency conditions.

13.2.3 Design Parameters

A. System Voltages

Substation dc 1 percent Full Load Voltage	1590 Vdc
Maximum Regeneration Voltage	1900 Vdc
Substation Voltage at Rated Power	1500 Vdc
Regulation	6%
Minimum System (Vehicle) Voltage	1050 Vdc

B. Distribution System dc Voltages)

Normal Minimum	1200 Vdc
Emergency Minimum	1050 Vdc

C. Maximum Rail-to-Ground Voltages

Normal Operation	50 V
Emergency Operation	60 V

D. Distribution and Return System

Average Contact Wire Wear for Electrical Load Flow Study (30 percent at spot locations)	20%
Running Rail Weight	115 lbs

E. Climatic Conditions

Maximum Ambient Temperature	40ºC
Minimum Ambient Temperature	-20ºC
Radial Ice Loading (Non Operating) Radial Ice Loading (Operating w/40 mph wind) Radial Ice Loading (Operating w/40 mph wind)	1/2” 1/2” messenger 1/4” contact wire
Maximum Wind Speed for Structural Design	70 MPH
Maximum Wind Speed for Train Operations	55 MPH

F. Conductor Material

Messenger Wire	HD Copper
Contact Wire	HD Copper

G. Factors of Safety - Conductors and Wires

Operating	2.0
Non-operating	1.6
Contact Wire Wear for Mechanical Design	30%

H. Factors of Safety - Hardware

Operating	2.5
Non-operating	2.0

I. Minimum Electrical Clearances

Static Clearance	5”
Passing Clearance	3” minimum

J. Minimum Contact Wire Height Above Top-of-Rail

Exclusive Right-of-Way, At-Grade	15’0”
In-Street System	20’6”
Road and Street Grade Crossings	20’6”
Railroad Crossings	22'6"
New Tunnels	14’0”
Existing Tunnels	13’0”

K. Maximum Contact Wire Gradients for design

Constant Gradient	1"
Gradient Change	1"

L. Pantograph Security

Minimum Pantograph Security	6"
Pantograph uplift allowance (4" electrical passing + 3" mechanical)	7"

M. Track Maintenance Tolerances

See Chapter 4, Track Alignment and Vehicle Clearances

N. Vehicle Clearances

See Chapter 4, Track Alignment and Vehicle Clearances

O. Vertical clearances at Overhead Bridges

See Chapter 4, Track Alignment and Vehicle Clearances

P. Pantograph and vehicle characteristics

See Chapter 12, Light Rail Vehicle

Q. Range for catenary Auto-Tensioning

Upper Limit of Auto-Tensioning	130°F
Lower Limit of Auto-Tensioning	5°F

13.3 TRACTION POWER SUBSTATIONS (TPSS)

13.3.1 Substation Description

The TPSS design shall include the following elements: substation housings, ac switchgear, transformer/rectifier units, dc switchgear assemblies, negative return system, protective systems, annunciation and

SCADA systems, fire alarm and intrusion detection systems (in accordance with Chapter 22, Fire Alarm Systems), auxiliary power supply systems, busbars, grounding systems, ventilation systems, batteries and chargers, lightning arresters, and metering equipment.

13.3.2 Substation Structure or Enclosure

A. The substation equipment shall be housed either in buildings, electrical equipment rooms, or in weatherproof factory-built packaged substation structures.

B. A paved or concrete sidewalk or ramp at ground level shall be provided outside the substation to allow removal and replacement of heavy equipment.

C. Substations shall have adequate area to accommodate all the electrical equipment and ancillary components.

D. Ceiling heights, structural openings, and door openings shall permit entry and removal of the largest components installed in the structure.

E. Substations below grade shall have equipment hatches or doors for removal and replacement of equipment from the substation.

F. Two exit doors with panic hardware, one at each end of the switchgear, shall be provided.

G. Insulation sufficient to prevent condensation, especially from the roof, shall be provided. Insulation may be fiberglass batt in the walls and solid insulation on the roof.

H. One and one half inches square framing channel shall be provided every 4 feet on center on the ceiling for support of lighting and equipment.

I. Portions of the substation building floor shall be coated with an epoxy material to insulate and electrically isolate the dc switchgear from any grounded objects.

J. Adequate space heating shall be provided to prevent condensation in electrical equipment. Minimum permissible inside temperature is 40°F.

K. Adequate ventilation shall be provided to prevent damage to the equipment. Maximum permissible inside temperature shall be 104° F. See Chapter 20, HVAC, for further information on HVAC for TPSS buildings and electrical rooms.

L. Lighting levels shall be designed for 50 to 70 foot-candles, average. Emergency lighting shall be provided.

M. Provide a distribution panelboard for installations that feed other buildings, rooms or a passenger station platform. Provide an ac panelboard for the substation auxiliary equipment, lighting, convenience receptacles, and HVAC. (See Chapter 23, Electrical Systems).

13.3.3 Substation Spacing and Location

A. The preferred location for traction power substations is at passenger stations, but final locations shall be based on the System Load Flow Study. Substations shall be located such that the following requirements are met:

1. Distribution system dc voltages do not drop below the minimum level required

2. Temperatures of distribution system conductors do not exceed the allowable maximum

3. Rail voltages do not exceed the maximum permissible values

4. Short circuit detection and protection can be accomplished

13.3.4 Substation Configurations

Substations shall have a minimum of four dc feeder breakers.

13.3.5 Substation Equipment Rating

A. The continuous rating of substation equipment such as the traction transformer, rectifier, circuit breakers, and cables shall be based on the System Load Flow Study.

B. Each mainline substation shall be capable of supplying the extra heavy-duty traction load cycle in accordance with NEMA RI-9.

13.3.6 Substation Incoming Service

Incoming primary ac power to the Traction Power Substations will be supplied by the local serving utility or from the tunnel electrical distribution system. If possible, adjacent traction substations should be supplied from separate utility substations or from different buses of the same utility substation.

13.3.7 AC Switchgear

A. The ac switchgear assembly shall be rated for the utility supplied voltage.

B. The assembly shall provide the means to deliver, control, and measure the substation power requirements.

C. The assembly shall be housed in dead-front enclosures containing ac circuit breaker, relaying, metering equipment, and auxiliary power supply.

13.3.8 Rectifier Transformer

A. The rectifier transformer shall be dry-type, self-cooled, with primary voltage to be consistent with utility supply, and equipped with appropriate taps. Provisions shall be included for future addition of fans for increasing the output above the specified base.

B. The transformer/rectifier shall have overall regulation not greater than 6 percent ± 0.5 percent between 1 percent rated load and 100 percent rated load.

13.3.9 Rectifier

A. The rectifier shall be natural convection-cooled. Provisions shall be included for future addition of fans for increasing the output above the specified base.

B. Each rectifier shall be a complete operative assembly consisting of the rectifier elements, heat sinks, internal buses, connections, fuses, and all other necessary components and accessories.

C. Rectifier shall consist of full wave bridges providing 12-pulse rectification.

D. Rectifier for the shop substation may be 6-pulse rectification.

13.3.10 DC Switchgear Assembly

A. The dc switchgear assembly shall form a lineup of dead-front metal enclosures.

B. The dc circuit breakers shall be stored energy, draw-out, single-pole units.

13.3.11 Negative Return

A. The negative return shall include negative disconnect switches, negative busbar, terminations for negative return cables and other associated equipment.

13.3.12 Protective Devices

A. Based on the magnitude of load, overload, and short circuit currents, a comprehensive protective scheme shall be designed to protect the substation equipment, the feeders, and the OCS, as well as provide back up for the transit vehicle protective devices.

B. Protective relays shall be high quality utility-type draw-out devices enclosed in rustproof, dust-proof, high-impact cases with test switches.

C. Protective relays shall be self-resetting and shall have seal-in, hand-resetting targets indicating relay operation.

D. Relays shall be arranged to be visible, accessible for maintenance, and logically grouped, with devices of related functions located in proximity to each other.

E. Programmable Logic Controllers (PLCs) may be considered as an alternative to the hard-wired auxiliary relays.

F. Transfer Tripping of substations adjacent to the section where a fault is detected shall be provided.

13.3.13 Emergency Trip Stations

A. Each substation shall be equipped with traction electrification emergency trip stations (ETS). One shall be mounted outside the entrance door and one shall be mounted inside near the exit.

B. Actuation of the ETS shall trip the incoming ac breaker and dc feeder breakers at the substation, and transfer trip and lock out the dc breakers at the adjacent substation for the line sections, thus completely isolating the sections. Activation of the ETS inside shall trip and lock out the incoming ac breaker and all dc feeder breakers but not initiate transfer trip.

13.3.14 Local and Remote Annunciation

A. Substations shall be equipped with a local annunciation system and provision for a remote annunciation system through SCADA.

B. The annunciation shall be of modular design, convection-cooled, and solid-state.

C. The annunciator shall include LED indicating lamps, audible alarm, test, silence, acknowledge and reset switches, as well as other associated equipment.

D. Alarm functions shall include unauthorized entry, fire, and smoke alarms.

13.3.15 SCADA Provisions

A. Substation equipment shall be designed for remote supervision from Central Control via a SCADA system in accordance with Chapter 15, Communications and Central Control.

B. Each substation shall be equipped with a SCADA interface.

C. A SCADA points list will be developed that includes alarms, status and supervisory control functions, and provided to the TES equipment supplier by specification. The points list shall include definitions of how information from each point shall be used by Central Control (e.g., stored as maintenance data, monitored, or alarmed).

D. Provisions for analog data shall be included.

E. Supervisory Control Lockout (local), to prevent remote operation of local equipment, shall be provided.

F. Equipment must be specified to accommodate SCADA functions desired.

G. Electrically operated circuit breakers shall be specified to accommodate SCADA monitoring and control.

13.3.16 Auxiliary Power

A. Each TPSS shall be furnished with a dc distribution panelboard, which shall supply all substation control power loads.

B. Secondary ac power may be supplied to both the substation facility loads and other Sound Transit loads at the building site. Separate ac panelboards shall be provided for substation facility loads and other loads.

C. The voltage for auxiliary equipment shall be either 120/240V, 1-phase or 208Y/120V, 3-phase and shall be the same throughout the project. Substations feeding nearby passenger station platform loads and the

system building loads shall be furnished with a 480Y277V 3-phase auxiliary transformer.

13.3.17 Busbars and Bus Connectors

A. Busbars and bus connections shall be designed to withstand the thermal and mechanical stresses occurring during the specified load cycle and the rated short circuit currents, without damage to the bus, bus supports, or enclosure.

B. Busbars shall be rigid, high electrically conductive copper.

C. Busbars shall be adequately insulated and braced with high-strength insulators.

D. Bus connections shall be bolted and furnished with silver-plated surfaces. Each joint shall have conductivity at least equal to that of the busbar.

13.3.18 Equipment Arrangement

A. Spacing and positioning of each item of equipment shall permit maintenance, removal, and replacement of any unit without the necessity of moving other units.

B. The arrangements of the equipment shall permit doors to be opened, panels to be removed, and breakers to be withdrawn without interference to other units.

C. Equipment shall be arranged to preserve the maximum amount of wall space for future growth.

13.3.19 Substation Grounding

A. Each traction power substation shall be provided with a ground mat.

B. The ground mats shall be constructed of bare copper or “Copperweld” conductors and ground rods exothermically welded together. Pressure connected joints will be considered for special applications.

C. Grounding connections shall carry the rated short circuit current. Minimum size of grounding conductors shall be 4/0.

D. Ground mat conductors shall be totally encased in native soil. If possible, a layer of coarse, clean, crushed gravel, free of fines, shall be placed over the soil. A surface layer over the gravel may be asphalt, masonry, or concrete.

E. The ground mat shall be designed to protect personnel from step and touch potentials, which may arise under substation fault conditions, and to meet the requirements of the IEEE Standard 80. The mat shall be used to solidly ground traction power transformer enclosures, auxiliary power transformer neutrals, building and doorframes, ac switchgear enclosure, and low voltage panels. The ground mat shall be extended 5 feet beyond equipment enclosures and/or metallic fences if provided.

F. The dc switchgear enclosure, including the rectifier and negative cubicles shall be connected to the substation ground through a high resistance ground relay.

G. The utility source feeders shall be grounded at the TPS station ground mat.

13.3.20 Underground Distribution Feeders

Underground distribution feeder cables shall be insulated to 2 kV minimum and sized according to the System Load Flow Study.

13.4 DOWNTOWN TUNNEL TRACTION ELECTRIFICATION SYSTEM

13.4.1 Tunnel Traction Power Substations (TPSS)

A. The following substations feed the Downtown Seattle Transit Tunnel (DSTT) and surface electric trolley bus (ETB) system:

1. International District Substation TPSS (IDS) feeds the DSTT tunnel. Power to the surface trolley bus system is fed from South Jackson substation located at IDS in a separate room.

2. University Substation TPSS, located at the University station, feeds the surface ETB system.

3. Pike Place TPSS feeds the DSTT tunnel. Power to the surface trolley bus system is fed from Olive substation located at Convention Place.

B. Trolley bus substations have the following characteristics:

1. 700 Vdc at 1 percent load

2. 672 Vdc at 100 percent load (4 percent regulation)

3. 850 Vdc (+20 percent) maximum regeneration voltage

4. 560 Vdc (-20 percent) minimum under normal condition

5. 490 Vdc (-30 percent) minimum under contingency condition

13.4.2 Primary Supply System

Two 26 kV feeders in conduit embedded in the tunnel floor feed the tunnel substations from two Seattle City Light (SCL) South Sub feeders.

13.4.3 Tunnel OCS Parallel Feeders

Four 1000 kcmil insulated parallel feeders are mounted in the soffit of the tunnel and jumpered to the contact wires approximately every 100 feet. Two 750 kcmil cables are also routed in conduit around each station.

13.5 DC FEEDER SYSTEM (DCFS)

The dc feeder subsystem shall include all feeder conductors, jumpers, cable ducts and raceways, and associated hardware that feed the dc power to the OCS, and the return current to the negative bus in the substation.

13.5.1 Feed/Return Cable

A. Dc feed and return cables shall be sized for the anticipated rms loads.

B. Each circuit shall consist of a number of 500 kcmil copper cables.

C. Cable insulation shall be rated 2 kV minimum.

D. Cable shall be Ethylene Propylene Rubber (EPR) insulated, non-shielded.

13.5.2 Cable Ducts and Raceways

A. Cable ducts and raceways for dc circuits shall consist of one or more PVC conduits, sized for the cables to be installed, protected by a poured concrete duct bank, as appropriate.

B. Conduit stub-ups, and stub-outs from concrete, shall be galvanized steel. Surface mounted conduits shall be galvanized steel.

C. Dc positive and dc negative traction power cables shall be installed in separate conduits and pull boxes.

13.6 OVERHEAD CONTACT SYSTEM (OCS)

13.6.1 System Description

A. The OCS consists of all equipment from the feeder cable terminations to the vehicle pantograph. The equipment shall include foundations,

poles, cantilevers, bridge arms, system conductors, parallel feeders, hangers, jumpers, guys, terminations, tensioning devices, sectioning equipment, and all other necessary equipment.

B. The overhead system shall be designed to be environmentally acceptable. Within the mechanical and structural design constraints, the system structures and associated equipment shall be as lightweight as possible and shall use components as visually non-intrusive as possible.

C. The messenger wire and the contact wire system shall be double insulated with each level of insulation compatible with the system insulation class.

13.6.2 Pantograph Clearance Envelope

A maximum pantograph clearance envelope shall be prepared.

13.6.3 Sectionalization

A. The OCS shall be electrically separated into discrete sections (sectionalized), and shall be designed for the following:

1. To enable the electrical protective relays to disconnect faulted sections of the distribution system and minimize disturbance to the remaining system

2. To perform planned maintenance

3. To achieve flexible operation during system emergencies

B. Mainline sectionalization shall be achieved by means of insulated overlaps whenever possible. Where physical constraints preclude the use of insulated overlaps, insulated air-breaks or section insulators may be used.

C. No-load disconnect switches shall be used to electrically connect and disconnect line sections. Disconnect switches shall be rated to withstand the system worst-case overload and short circuit conditions without overheating. Switches shall be no-load type.

D. To permit the OCS to be isolated from the substations, hand-operated disconnect switches shall be provided near each TPSS.

E. OCS sectionalizing switches for the mainline shall be located trackside and shall be hand-operated. They shall be pole-mounted at surface and aerial sections, or wall mounted in tunnels. Motor operated sectionalizing switches for remote operation shall be provided for special applications.

F. Enclosures containing switches shall not contain both positive and negative cables or equipment. Positive feeders, switches, and components shall be housed in isolated or insulated enclosures.

G. Provide traction power feeders to storage yards such that they afford operational flexibility permitting isolation of discrete sections by switching and circuit breakers. Incorporate switching from the wayside that will allow any exterior track to be powered from more than one circuit. Storage tracks will have individual isolation when feasible.

13.6.4 OCS Styles

A. Three styles of OCS shall be developed for use as required:

1. auto-tensioned simple catenary system;

2. low-profile simple catenary fixed termination system; and

3. auto-tensioned low profile simple catenary.

B. An auto-tensioned system shall be used along the open route sections.

C. A low-profile simple catenary fixed termination system shall be used in the tunnel sections.

D. A fixed termination single contact wire system shall be used at the Central Maintenance Facility yard.

E. In double-track areas, poles shall be located between the tracks wherever possible. Where necessary, poles located on the outer sides of the track or cross-span wire arrangements may be used.

13.6.5 Structure Spacing

A. Structure spacing for the overhead system shall be as long as practical and shall be based on pantograph security analysis.

B The structure spacing shall be selected so that the contact wire will remain on the pantograph head with the specified pantograph security.

13.6.6 Staggers

A. The contact wire shall be offset from the projected pantograph centerline to avoid uneven wear of the pantograph carbon running strip. This offset is referred to as stagger. The stagger shall alternate from center at each structure or point of support.

B. Staggers shall be designed to provide at least 10 pound radial load on the contact wire to prevent contact wire swivel clamp chatter, which can exacerbate wear.

C. Contact wire staggers of in-running contact wires shall be as large as practicable and still satisfy maximum stagger values on tangent tracks (alternating) and on curves (consistent one side of track centerline), and also be designed to meet mid-span offset criteria and stagger sweep criteria.

13.6.7 Stagger Sweep

The sweep of the contact wire shall not exceed 1-inch lateral in 10 running feet longitudinal on main line.

13.6.8 Tension Length Design

A. The OCS for each track shall include a sequence of overlapping tension sections. Each tension section shall be designed as long as possible considering the dimensional constraints of the system parameters, such as displacement of contact wire due to swinging cantilevers, tension loss along the system, counterweight travel, and manufacturing limits of conductor length.

B. The conductors of each tension section (wire run) shall be terminated at each end by auto-tensioning devices or fixed terminations, as applicable.

C. Half tension lengths, where one end of the length utilizes a fixed termination and the other end a counterweight, may also be used.

D. On steeply graded sections of track (over 4 percent gradient), half tension sections only shall be used with counterweights located at the downhill end.

13.6.9 Overlaps, Crossovers, and Turnouts

A. Overlaps shall be used between adjacent tension lengths to provide mechanical and electrical continuity of the overhead system.

B. All mainline crossovers and turnouts shall be of the same OCS style as the mainline.

C. The overlap, crossover, and turnout arrangements shall be designed considering the electrical sectionalization and mechanical properties of the overhead system.

D. At transitions, a smooth pantograph passage and good current collection without arcing shall be achieved as required under all operating conditions, unless ice is present.

E. At overlaps, a minimum 3-inch clearance shall be maintained between cantilevers and between the cantilever frames and adjacent conductors of different wire runs.

F. The overlap, crossover, and turnout arrangements shall be designed using poles with single or twin cantilevers.

G. In areas where center poles are used, the overlaps shall be staggered along the track to avoid having more than one counterweight assembly per anchor pole.

13.6.10 Foundations

A. Design of foundations for supporting structures and guy anchors shall be based on structure loading calculations and soil data.

B. Supporting structure foundations shall be designed to accept bolted base poles and shall have provision for feeder conduits and structure grounding as required. See Chapter 17, Corrosion Control, for further information on structure grounding.

13.6.11 Poles and Supporting Hardware

A. Poles shall be designed as free standing except for termination poles of auto-tensioned equipment.

B. For operations in paved track or street-running sections where aesthetics are important, tapered tubular steel poles, side-mounted, ranging from 9 inches to 17 inches in diameter shall be used. Wide flange beam poles may be used for specific applications.

C. For yards, tapered tabular poles shall be used for freedom of application of direction of cross-spans and terminations. Wide flange beam poles may be used for specific applications.

D. Structures shall be designed so that the normal operating across-track live load deflection of any structure shall not exceed 2-inches (i.e. 1-inch in either direction laterally) at contact wire level.

13.6.12 Cantilevers

A. Cantilevers shall be hinged at their pole clamps to accommodate conductor along-track movement.

B. Cantilevers shall be designed to either hold the conductors away from the pole (push-off) or to hold the conductors towards the pole (pull-off).

C. No parts of a cantilever, except the contact swivel clamp, shall intrude into the pantograph clearance envelope with the contact wire uplifted 7-inches.

13.6.13 Bridge Supports

A. Elastic arm-type OCS supports shall be used at bridges with insufficient clearance to accommodate cantilever-type assemblies.

B. Supports shall restrict uplift of the contact wire when subjected to pantograph pressure and shall be capable of providing vertical and across-track adjustment.

C. OCS bridge supports shall permit the longitudinal movement of contact wire.

13.6.14 Insulators

A. Insulators shall provide electrical insulation in accordance with the system insulation class and shall have the mechanical safety factors specified.

B. The insulators shall have resistance against deterioration from exposure to sunlight and airborne chemical pollution.

C. The insulators shall be a light gray, sky-tone color.

D. Insulator life expectancy shall be compatible with that of the rest of the equipment.

13.6.15 Conductors and Associated Items

A. Contact wire shall be solid, grooved, hard-drawn copper conductor.

B. Messenger wire shall be stranded, hard-drawn copper conductor.

C. Feeder jumpers shall be insulated, stranded copper conductors with sufficient flexibility to prevent fatigue failure of the cable due to movement and/or vibration of the overhead conductors. Feeder jumpers shall have two clamps when attached to contact wires and to messenger wires.

D. Conductor connections, attachments, hangers, and clamps shall be copper or bronze fittings and shall be designed for ease of replacement and maintenance.

E. Continuity and equalizing jumpers shall be flexible copper conductors.

F. Spacing of equalizing jumpers shall be based on required current conductivity, with a minimum of one jumper per 200 feet.

G. Continuity jumpers at overlaps and at crossovers shall have two clamps per conductor per clamped location when attached to contact wires and to messenger wires.

13.6.16 Terminations and Midpoint Anchors

A. Strain-type termination assemblies shall be lightweight and aesthetically pleasing. Wire wrap, straight line, cone, or wedge type designs are acceptable. Turnbuckles shall be included as appropriate and shall have adequate adjustability.

B. A mid-point anchor arrangement shall be used at or near the mid-point of each tension length of auto-tensioned equipment to restrict movement of the conductors at that point.

13.6.17 Tensioning Devices

A. Auto-tensioned system conductors shall be tensioned using cast iron or steel counterweights.

B. At wide flange beam poles, counterweights shall preferably be positioned between the flanges to be as unobtrusive as possible.

C. In areas frequented by passengers or pedestrians, counterweights shall be provided with protective shields.

D. At tubular poles, counterweights shall be outside of the poles. Counterweights shall be inside of the poles for special applications.

E. The tensioning devices shall accommodate conductor expansion and contraction and shall be provided with "broken wire" arrangements.

F. Operating cables shall be of flexible stainless steel wire.

G. Spring tensioning devices may be used for short tension lengths of catenary, such as at crossovers.

13.6.18 Lightning Arresters and Surge Arresters

A. Over-voltage protection for the overhead system shall be provided by lightning arresters and surge arresters.

B. Arresters shall be rated to withstand the maximum system voltage and anticipated voltages induced from paralleling high-voltage transmission lines.

C. Arresters shall be capable of discharging the energy resulting from lightning strikes.

D. At a minimum, lightning arresters or surge arresters shall be installed at feeder terminations located adjacent to each substation, each tie station, substation feeder switches, and in areas of reduced clearances, such as overhead bridges and tunnel portals. Surge arresters shall also be installed approximately 1.000-feet on each side of a feed point and between substations.

E. Surge arresters will be installed in all substations on each outgoing feeder.

13.6.19 Protective Screening

A. When Link is constructed below bridges, buildings, and structures, screening and fencing shall be erected on the structures and stairs so that catenary wires are separated at least 10 feet from where a person can stand.

13.6.20 North Link EMI Mitigation

A. In the tunnel segment under the University of Washington (UW), special electromagnetic interference (EMI) mitigation measures shall be installed to minimize the EMI propagation into sensitive UW facilities. The installation shall include a parallel positive feeder cable installed between the rails in each trackway. Riser cables shall be installed from the parallel positive feeder cables to the OCS at optimized spacing from the power supply to the OCS.

END CHAPTER 13

14. SIGNAL SYSTEM

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14. SIGNAL SYSTEM

14.1 INTRODUCTION

A. A Signal and Train Control system shall be applied to the North and Airport Link light rail lines to:

1. Enhance the safety of rail movements through interlockings;
2. Provide safe train separation for both normal and reverse traffic rail operations;
3. Interface with street traffic signal system in the street running sections to permit priority progression of the LRV trains in the peak direction;
4. Operate automatic highway crossing warning systems; and.
5. Provide an integrated signal system for joint bus / LRT operations in the DSTT.

14.2 AUTOMATIC TRAIN PROTECTION

A. The type of signaling applicable to the entire Link system to provide the desired Automatic Train Protection (ATP) is:

1. Bi-directional cab signal system with overspeed protection with wayside signals at interlockings.
2. ATP will not be used for street running portions of the system.

B. Automatic Train Protection (ATP) will permit higher operating speeds than are possible by relying on line-of-sight operation without signals. The ATP system will provide information to the train operators regarding conditions ahead, such as switch position and track occupancy.

14.3 INTERLOCKINGS

Interlockings shall be provided for all power switches and movable-point frogs. Interlocking signals shall be provided to govern train movements into and through interlocking limits.

14.3.1 Locking Functions

Locking functions shall be provided to prevent the unsafe operation of switches and to prevent the clearing of signals for opposing or conflicting routes. The types of locking to be provided are:

A. Approach locking shall lock the switches within a route governed by a cleared wayside signal. The logic shall be designed to prevent the clearing of wayside signals for opposing or conflicting routes when a cleared signal is set to stop and the train is closer than stopping distance from the signal.

B. Time locking shall lock the switches within a route governed by a cleared wayside signal. The logic shall be designed to prevent the clearing of wayside signals for opposing or conflicting routes when a cleared signal is set to stop.

C. Route locking shall lock the switches within a route after a train has accepted the wayside signal governing the entrance to the route and prevent the clearing of opposing or conflicting signals within the interlocking. Route locking shall remain in effect until the train has cleared the interlocking or satisfied sectional release, if sectional release is incorporated into the interlocking.

D. Sectional release shall unlock portion of the route as the train progresses through the interlocking. This will allow the clearing of different, non-conflicting route before the first train has cleared the entire interlocking. Interlocking track circuit configurations shall provide sectional release capability where required for headway purposes.

E. Detector locking shall lock the switches when the track over the switch is occupied or if there is occupancy of an interlocking track circuit, which indicates that clearance for an alternate route is not available. A vital timer shall be provided for 5-second loss of shunt protection within the interlocking.

F. Switches shall be locked by approach locking, time locking, route locking and detector locking. Switch locking shall be released only when approach locking, time locking, route locking, sectional release, and detector locking are all released.

G. Traffic locking shall prevent clearing signals into a section of track until traffic has been established for the direction of the movement. Individual traffic locking logic shall be provided for each section of track between interlockings. The direction of traffic on a section of track shall be locked when any track circuit within that track section is occupied, or when a route is requested into that track section, or when approach or route locking is in effect for the signal that has been cleared into that track

section. Five-second loss of shunt protection shall be provided for traffic locking. When traffic is not locked, the traffic logic shall maintain the direction of traffic until reverse traffic is called.

H. All non-conflicting train movements, through interlockings, shall be permitted simultaneously.

I. Logic shall permit trains in first track circuit outside interlocking to turn back into unoccupied traffic zone with full signal protection.

14.4 HIGHWAY GRADE CROSSING WARNING

Warning devices shall be installed at at-grade highway crossings, where such are deemed necessary. The design of the Automatic Highway Crossing Warning (AHCW) system shall be site specific and shall conform to the requirements of the Manual of Uniform Traffic Control Devices, as modified by the authority having jurisdiction, and the (AREMA) Communications and Signals Manual of Recommended Practices. Each crossing shall be equipped with automatic gates, flashing lights, bells, number-of-tracks signs, “In case of trouble, call Operations Control Center #…” signs, and crossbucks. The operation of AHCW system equipment shall be based on a design that includes approach and island track circuits and shall avoid unnecessary delays to motorists. Where at-grade crossings are in the proximity of signalized intersections, the operation of the AHCW system shall be coordinated with the traffic lights to avoid automobiles forming a queue across the tracks.

14.5 TRAIN-TO-WAYSIDE COMMUNICATIONS (TWC) SYSTEM

A. The TWC system shall be a 19-bit train 100 KHz frequency shift keyed system compatible with the Vetag system provided on the vehicles. It shall provide the following functions:

1. Route requests;
2. Yard switch movement requests;
3. AHCW system activation;
4. Train identification;
5. Vehicle identification;
6. Vehicle location and tracking; and
7. Motor vehicle traffic signal control interface.

14.6 CODES AND STANDARDS

The signal system shall be designed, constructed, and tested to the latest revision at the time of award of contract of the applicable portions of the following codes and standards:

A. American Railway Engineering and Maintenance of Way Association (AREMA):

   1. Communications and Signals Manual of Recommended Practice

   2. Typical Circuits Representing Current Practice for Railway Signaling

B. Rules and Regulations of the Washington State Department of Transportation and the Washington Utilities and Transportation Commission;

C. National Electrical Code (NEC);

D. National Electrical Safety Code (NESC);

E. Insulated Cable Engineers Association (ICEA);

F. American Society for Testing and Materials (ASTM);

G. American National Standards Institute, Inc. (ANSI);

H. Underwriters' Laboratories, Inc. (UL);

I. U.S. Department of Transportation, Federal Highway Administration, and Manual on Uniform Traffic Control Devices as modified for use by the Washington State Department of Transportation;

J. Institute of Electrical and Electronic Engineers (IEEE); and

K. Manual of Uniform Traffic Control Devices (MUTCD).

14.7 SAFETY DESIGN

A. Safety of rail movements shall be the prime consideration in the design of the signal system and in the selection of its components, including relays and other devices with moving parts, insulated wire, wire terminals, binding posts, housings, conduits, resistors, capacitors, transformers, inductors and other similar items. In the at-grade sections, safety of the train and other traffic shall be the primary consideration for design of the signal system. The entire signal system shall meet the requirements of this chapter.

B. Circuit design shall conform to the "Communications and Signals Manual of Recommended Practices" of the American Railway Engineering and Maintenance-of-Way Association (AREMA).

C. In this chapter, the terms "restrictive" and "permissive" are used in connection with the binary outputs of two-position components or subsystems and denote such alternatives as: stop and proceed, a lower speed and a higher speed, deceleration and acceleration, brakes applied and brakes released, actuation of alarm, and no actuation of alarm, respectively.

D. The following requirements shall govern the design of the portions of the system or a subsystem that affect train safety:

1. Only components that have high reliability and predictable failure modes and rates and that have been proven in conditions similar to the projected service shall be utilized.

2. Components shall be combined in a manner that ensures that a restrictive rather than a permissive condition will result from component failure.

3. All circuits that are not confined to one housing and that affect safety shall be double-wire, double-break, except signal and switch indicator light circuits.

4. The design shall be based on closed circuit principles.

5. Component or system failures shall cause a more restrictive signal indication than that permitted with no failure. The built-in fault detection and alarm generation capabilities are preferred.

6. System safety design shall be such that any single independent component or subsystem failure will result in a safe condition. Failures that are not independent (those failures that in turn always cause others) shall be considered in combination as a single failure and will not cause an unsafe condition.

7. Any latent failure of the equipment, that is a failure, which by itself does not result in an unsafe condition, but which in combination with a second or subsequent failures could result in an unsafe condition, must be detected and negated within a stipulated time period that will be determined contingent upon the location and operating conditions.

8. Electronic circuit design shall ensure that the following types of component failures have a restrictive rather than a permissive effect:

   a. Two terminal devices: open, short, partial open or short.

   b. Multi-terminal devices: combination of opens, shorts, partial opens and/or partial shorts.

   c. Redundant design by itself shall not be considered an acceptable method of achieving design safety.

d. Vital, safety-critical software (where employed) shall comply with recognized standards for critical high integrity systems.

14.8 HEADWAYS AND BLOCK LAYOUT

A. The design headway requirements and block layout shall be developed based on the system operating plan and the type of signaling to be employed for each area.

B. Criteria for design headways are as follows:

1. Operating area north of the yard entrance interlocking will have a 90 second design headway.

2. Operating area south of the yard entrance interlocking to Martin Luther King Boulevard (MLK) shall be designed for 120-second cab signal operating headway.

3. The operation in the street running area of MLK has no design headway since street running mode does not enforce train separation. The boundaries of the street running operation match both the north and south boundaries of the aerial to at grade street median construction.

4. Operating area south of MLK to S 200th will have a design headway of 150-seconds.

5. The headway in the joint operations between IDS and Pine Street Interlocking shall be designed for a future LRT only operation 90-second headway. However, the joint operations signal system shall have the headway as imposed by the Fire Department operating rules which require a separation of the transportation modes in the tunnel sections. The joint operations signal system shall use wayside signals for control and install only the track circuits necessary to provide the mode separation.

6. There is no design headway requirement for the reverse direction of travel.

C. The block design shall utilize the following eight cab signal speed code commands:

1. 55 mph – Code rate period 48 milliseconds

2. 45 mph – Code rate period 64 milliseconds

3. 40 mph – Code rate period 80 milliseconds

4. 35 mph – Code rate period 96 milliseconds

5. 30 mph – Code rate period 112 milliseconds

6. 20 mph– Code rate period 128 milliseconds

7. 10 mph– Code rate period 144 milliseconds

8. Street running (which shall be ATP limited to 35 mph) – Code rate period 160 milliseconds

D. Block layout in approach to curves shall slow normally operating trains to the design speed calculated in accordance with Chapter 4, Track Alignment and Vehicle Clearances of the Design Criteria. No train operating on Safe Braking Distance parameters shall exceed 4.5 inches of unbalanced superelevation.

1. A normally operating train is defined as performing in an average manner with respect to equipment and operator. Braking Distance calculations for the normally operating vehicle shall use the following formula:

$$BD = (V_{es} \times RT_{nom} \times 1.467) + ((V_{es}^2 - V_f^2) \times (0.7333/(0.22G + BR_{nom})$$

Where:

a. BD is the braking distance required, in approach to the spiral-to-curve point of a curve in feet.

b. V_{es} is the speed of the train as it enters the block and is assumed to be the cab speed.

c. RT_{nom} is the sum of the nominal reaction times from the time the train passes a cab signal change point until the brakes are applied and is 3.5 seconds.

d. V_f is the final target speed of the calculation. For approach to curves, it is the civil design speed of the curve the train is approaching.

e. G is the grade in percent.

f. BR_{nom} is the de-rated brake rate and is defined as 2.1 mphps.

14.9 SAFE BRAKING DISTANCE

Safe braking distances have been developed in coordination with the Link light rail vehicle design. Safe braking distance calculations shall take into account maximum train speeds, response times and track grades. The safety train model is the worst case braking model and shall be used to calculate safe braking distance (SBD) when trains are approaching an occupied block or red signal. SBD shall be calculated using the formula:

$$SBD=(V_{os} + RT_{max} \times 1.467) + ((V_{os}^2 \quad V_f^2) \times (0.7333/(0.22G + BR_{eff}))) * 1.35 + (2 * 7)$$

Where:

1. SBD is safe braking distance in feet.

2. V_{os} is the speed of the train (in mph) as it enters the block. This is defined as the cab signal command speed plus 4 mph.

3. RT_{max} is the sum of the worst case reaction times from the cab signal change point until the brakes are applied and is defined as 3.8 seconds. During this time, the train is assumed to have constant velocity V_{os}.

4. 1.467 and 0.7333 are standard conversion factors to convert from miles per hour to feet per second.

5. V_f is the final target speed of the train for this calculation. When calculating approach to an occupied block or red signal, V_f will always be zero.

6. G is the grade in percent.

7. 0.22 is the correction factor used to adjust braking distance for the effects of grade.

8. BR_{eff} is the de-rated brake rate and is 1.95 mphps.

9. 1.35 is the addition of a 35 percent safety factor and shall be applied on to the braking portion of the SBD calculation.

10. 2 x 7 accounts for the overhang of the vehicles and is assumed to be 7 feet per vehicle.

14.10 ENVIRONMENTAL CONSIDERATIONS

All equipment except batteries and UPS shall be designed to operate from a minimum temperature of -40°C (ambient) to a maximum temperature resulting from a combination of an ambient temperature, maximum sun loading, and maximum normal internal heat generation, of 55°C.

14.11 SERVICE PROVEN EQUIPMENT AND DESIGN

All signal equipment shall be proven in similar North American railroad or transit service. The signal system shall have an expected service life of 30 years at the specified level of service. Achievement of this useful life shall be through the use of off-the-shelf, proven hardware. Each major component shall incorporate provisions to allow for functional and physical interchangeability of replacement spare parts.

14.12 TRAIN DETECTION

A. Train detection methods shall use track circuits for train detection throughout the system. The technology of choice shall be audio frequency double rail jointless track circuits as the most economical method to provide detection and cab signal. Whenever special track work conditions or embedded track circuit conditions exist that make power frequency track circuits the most reliable or economical, then double or single rail track circuits shall be used.

B. Parameters for the design of track circuits include:

1. The design of the LRV propulsion and traction systems and selection of track circuit frequencies and modulation schemes shall preclude interference between the LRV and the signal system.

2. A shunt with a resistance of 0.2 ohm at any point between the two rails of any track circuit shall cause the track circuit to be de-energized. Voltage regulating transformers in the feed to the track may be used or additional track circuits may be installed, if necessary, to provide this shunting capability.

3. C-Bus Detection: Bus detection methods for the joint bus / LRT operating area are based on reading the unique cab number of the 128 bit Amtech radio tag mounted on the front of each bus. Logic shall use a check-in / check-out method for determining the occupancy of each bus zone between antennas for the length of the joint operation area.

14.13 SIGNALS AND SWITCH INDICATORS

14.13.1 Bus Color Light Signals

Bus signals in the bus / LRT joint operations area shall re-use the existing color light signals currently mounted in the bus tunnel. Aspect colors for bus control shall be compatible with the MUTCD.

14.13.2 Yard Switch Position Indicators

The yard switch position indications shall provide an alphanumeric indication of the aligned destination for the series of switches to reach a destination such as storage track, carwash, or mainline entrance. Switch alignment shall be requested via TWC requests from the LRV operators.

14.13.3 Signal Aspects

Signal aspects for both the street running areas and interlockings are bar signals in accordance with Part 10 of MUTCD for light rail systems using both position and color differential to assist in defining proceed and stop

conditions. Each signal shall have an indication (meaning), which is the same wherever it is displayed through out the Link system.

A. White vertical bar = Proceed straight ahead at the interlocking or street intersection.

B. White angled bar = Proceed on the diverging route indicated at the interlocking.

C. Amber horizontal bar = Stop.

14.13.4 Light-Out Protection

A wayside signal shall not display a more permissive aspect from that intended because of a burnt-out lamp or broken wire. A dark signal indicates the most restrictive signal aspect.

14.13.5 Signal Locations

LRT signals shall be placed as necessary to protect entrance into each interlocking. LRT signals for intersections at street running areas shall be duplicated on the near and far side of the intersection. Signals in the joint operations area shall be located to maintain the separation of transportation modes (bus or rail) in tunnel sections and control merge points of the modes. Location of the signals shall permit non-ambiguous indication to the operator as to which track is being controlled.

14.13.6 Signal Height

All signals shall be installed in accordance with recommended practices but shall be as close to the Train Operator's eye level as practicable. Signals installed within public rights-of-way shall conform to applicable codes with respect to clearances.

14.13.7 Signal Lighting

Signals shall be continuously illuminated. LED signals shall be the preferred signal type.

14.13.8 Signal Numbering

All wayside train signals shall be equipped with number plates to facilitate identification and simplify record keeping in accordance with Sound Transit provided numbering scheme.

14.14 MAINLINE TRACK SWITCHES

14.14.1 Track Switches in Open Track

A. Manual Track Switches

Manually operated switches in signaled territory shall be equipped with switch and lock movements with operating rods, lock rods and point detectors, and electric switch locks. Removing a padlock from the electric switch lock shall put neighboring signals to stop and shall start a timer to ensure clearance of trains that may have just passed the controlling signals. Expiration of the time shall permit the switches to be reversed.

B. Powered Track Switches

Powered switch machines shall be dual control (motor driven/manual). Power for the switch machines shall be from the signal bungalow Switch machines shall be equipped with operating rods, lock rods and point detectors.

14.14.2 Track Switches in Paved Track

Mainline switches shall be powered and capable to be remotely controlled by Central Control. They shall be equipped with point detection and shall allow for covered embedded track layout.

14.14.3 Powered Yard Switches

Powered yard switch operating mechanisms shall be dual-control (hand and motor), electrically operated, trailable devices.

14.15 CONTROL CIRCUITRY

The type of equipment to be used for signal control circuits shall be vital microprocessor. Relay logic may be used where special purposes or functions make it advisable.

14.16 SIGNAL POWER

The configuration of the signal power system shall be compatible with a combination cab signal system with TWC control in street running segments.

14.16.1 Power Line

Ac power will be provided from the most convenient source such as passenger station, traction power substation, or utility drop.

14.16.2 Batteries

Battery systems shall be used to provide backup to maintain normal operation of the signal system in the event of ac power system failure.

14.17 LOCAL CONTROL PANELS

A computer screen capable of performing local control panel functions shall be installed at all signal equipment rooms. The local control functions shall include track occupancies, switch condition (normal, reverse and locking) signal aspects, traffic direction status, operational blocks applied by OCC or the local control panel, grade crossing status, alarms, bus zone occupancies, and route requests. The local control functions shall also include the capability to initiate and cancel any request for signals, add or remove operational blocks, to position switches for routes, and capability to operate each power switch or crossover individually.

14.18 EVENT RECORDERS

A. Each signal equipment room shall be equipped to perform recording of events transpiring with the signal equipment. Events to be recorded shall include:
   1. Status of each track circuit (occupied or not)
   2. Status of each bus occupancy zone
   3. Switch status (locked, normal, reverse, or not in correspondence)
   4. Status of each signal
   5. Route requests
   6. Status of all alarms (including room power, grade crossing power, or equipment health)
   7. Status of grade crossing XR (energized or de-energized)
   8. Status of grade crossing gate arms (vertical, horizontal, or in transition)
   9. Status of operational track and signal blocks applied by OCC or the local control panel

14.19 SCADA INTERFACE

Each signal equipment room shall be equipped with a SCADA interface. SCADA information will include train positions, operating direction, interlocking status, alarm points, and signal system availability status, see Chapter 15, Communications and Central Control, section 15.5.2, Field Control System (FCS), formerly SCADA, for further information.

14.20 LIGHTNING AND TRANSIENT PROTECTION

A. Grounding electrodes shall be provided and installed in the signal rooms. Ground rods shall also be installed at all signal cases. All connections to grounding electrodes shall be by exothermic welding

B. All electronic and solid state devices shall have effective internal and separate external surge protection. High-voltage lightning arrestors shall be applied to commercial power connections.

14.21 WIRE AND CABLE

A. Room-to-room and room-to-wayside equipment signal wires shall not be combined with signal power wires in the same cable nor shall signal cable, power cable, or communication cable be run in the same conduit where duct bank is provided.

B. Case wiring shall be #16 AWG or larger as needed by the design requirements.

C. Wire and cable shall comply with all of the applicable sections of the AREMA Manuals – Signal Sections. A minimum of 10 percent, but not less than two spare conductors, shall be required in each cable.

14.22 LOCATION OF SIGNAL EQUIPMENT

A. Signal system equipment shall be located in wayside cases, houses, or special signal rooms provided in the tunnels and at stations in signaled territory. Signal cases shall be adequately ventilated. Signal houses and signal rooms shall be adequately climatized for winter and summer. Climatic conditions are described in Chapter 20, HVAC.

B. All signal equipment, including signals, switch machines, switch indicators, cases, and houses shall clear the LRV dynamic outline by a minimum of six inches. Exceptions to this may be allowed where right-of-way is restricted and vehicle speeds are minimal.

C. Doors of signal equipment cases and houses shall be restrained from opening to a position less than 6 inches from the LRV dynamic outline.

D. Equipment cases shall be located in such a way as to not obstruct the Train Operators' or motorists' (insofar as grade crossing warning equipment is concerned) view of the governing signal.

E. To the maximum extent possible, all signal control circuitry shall be located in central instrument locations (CIL) located near to the equipment being controlled and providing easy accessibility by maintenance forces.

14.23 SYSTEMS INTERFACES

A. The signal system shall interface with:

1. Link light rail vehicle
2. TES
3. OCS
4. Auxiliary electrical power system
5. SCADA system
6. Civil Provisions
   a. Trackwork
   b. Trackway
   c. Signal house sites
   d. Duct banks
   e. Traffic controllers
7. Architectural provisions
8. Mechanical provisions
9. Structural provisions

END CHAPTER 14

15. COMMUNICATIONS AND CENTRAL CONTROL

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15. COMMUNICATIONS AND CENTRAL CONTROL

15.1 INTRODUCTION

The Link Communication System shall be designed to transmit, receive, store, process, and display all non-vital voice, data, and video communications for the benefit of Link Operations, Link Maintenance, Link Security, Sound Transit Administration, customer service, the public, and other agencies as required. The System can be described as an integrated set of sub-systems connected as shown in Figure 15.1 and described as follows:

A. ***Central Control System (CCS):*** The hardware and software required to provide a data processing and Human Machine Interface system enabling the reliable operations of Link from central location(s). CCS is part of the voice, video, and data network located at the Link management center.

B. ***Field Control System (FCS), formerly SCADA:*** The hardware and software required to directly monitor and control specific remote hardware.

C. ***Communications Backbone (CB):*** The hardware and firmware required to provide highly available communications between remote facilities/equipment and the management center(s) of Link.

D. ***Public Address and Variable Message Signs (PA/VMS):*** The hardware and software required to provide the public and Link staff in key areas with ADA compliant information in a dynamic mode.

E. ***Radio System:*** The hardware and software required to provide mobile Link Staff, equipment, and emergency services such as Fire and Police, with reliable voice communications anywhere on Link.

F. ***Closed Circuit Television System (CCTV):*** The hardware and software required to record and transmit video images for Link Operations, emergency services and Link Security.

G. ***PABX Phone System (PABX):*** The hardware and firmware required to provide voice communications in specific locations for Link staff use. PABX is part of the voice, video, and data network located at the Link management center.

H. ***Emergency Telephone System (ETEL):*** The hardware and firmware required to provide Link staff and emergency services personnel, such

as Fire and Police, with back-up voice communications in key areas in the event of an emergency.

I. ***Passenger Emergency Telephone (PET):*** The hardware and firmware required to provide communications between distressed passengers and dedicated Link staff assigned to deal with passenger emergencies.

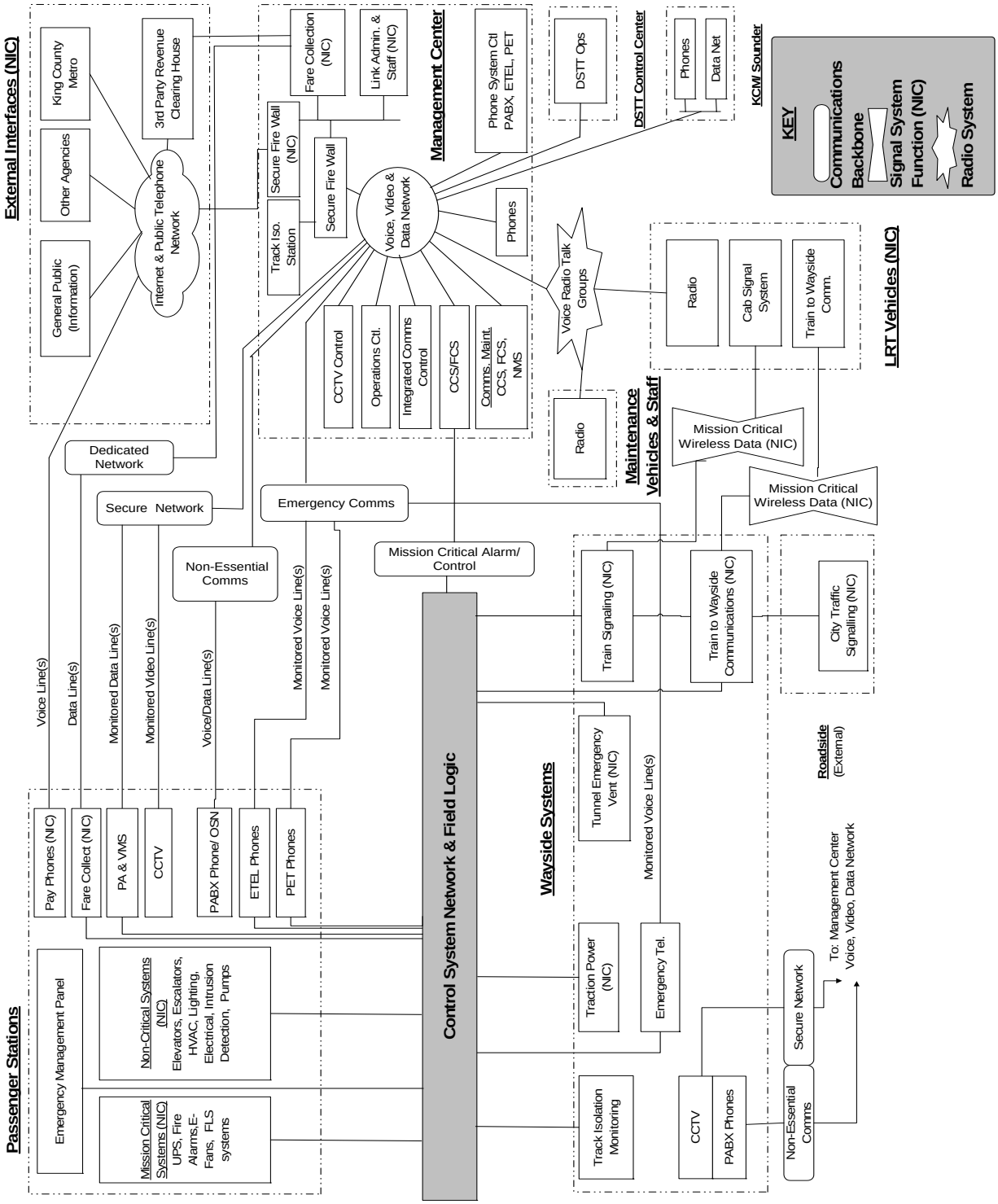
J. ***Network Management System (NMS):*** The hardware and software required to monitor, control, and configure the Communication System from a centralized location. NMS is part of the central maintenance function.

K. ***Emergency Management Panel (EMP):*** The hardware and software required to monitor and control the emergency facilities and systems designated in station(s) and on line sections in the event of an emergency.

L. ***Access Control System (ACS):*** The hardware and software required to provide intelligent key card access control and intrusion detection capability on Link.

M. ***Stray Current Testing System:*** The hardware provided to remote monitor and track the resistance of the return rail to ground at select locations. This system is part of the overall corrosion protection program.

Figure 15.1 Communications & Central Control System



15.2 CODES AND STANDARDS

A. The Communication System shall be designed to operate with the highest level of availability and safety reasonably practical. To verify this and ensure the future capability to do so, the Communication System, including the human interface elements, shall be designed using a Quantified Risk Assessment (QRA) in accordance with IEC 61508, and/or MIL STD 882D. The results of this analysis shall be used to validate design, construction, and integrated testing. The validated Communication System shall then form the baseline for future quantitative measurements of Availability and Safety.

B. In the design of the Human Machine Interface (HMI), all reasonable efforts shall be made to increase operating efficiency, reduce fatigue, and prevent injury to persons working with the Communications equipment. As such, a formal Ergonomic Study shall be prepared examining designs of other operating systems similar in function. The information gathered in this study shall be used to optimize the Link HMI to achieve an acceptable working environment for Link staff.

C. The Communication System shall be designed and constructed using the latest version of the following applicable codes and standards as a guide to best practices. In the event that any of these codes and standards conflict with each other, the more stringent requirements shall govern. In the event that the QRA or Ergonomic Study requires more stringent measures to guarantee reasonable availability and safety, such measures will govern the requirements.

1. American National Standards Institute (ANSI)
2. Americans with Disabilities Act (ADA)
3. Building Industry Consulting Service International (BICSI)
4. Electronic Industries Association (EIA)
5. Federal Communications Commission (FCC)
6. Underwriters Laboratories (UL)
7. Institute of Electrical and Electronic Engineers (IEEE)
8. International Electrotechnical Commission (IEC)
9. International Organization for Standardization (ISO)
10. International Telecommunications Union (ITU)
11. National Electrical Manufacturers Association (NEMA)

12. National Fire Protection Association (NFPA) Codes 70, 72, 130
13. Object Management Group (OMG)
14. Rural Utility Service (RUS)
15. Software Engineering Institute (SEI)
16. Telecommunications Industry Association (TIA)
17. Federal Highway Administration ITS Architecture and Standards (FHWA, DOT)
18. Federal Transit Administration National ITS Architecture on Transit Projects (FTA)

15.3 OPERATIONS AND MAINTENANCE FACILITY

15.3.1 General

Communications equipment will primarily be co-located with other equipment in or on a variety of locations, including but not limited to: cable raceways, equipment cabinets, electrical rooms, mechanical rooms, elevator shafts, escalator pits, station platforms, fare vending areas, ceilings, and lighting fixtures. Whenever possible, efforts shall be made to coordinate the location and aesthetic qualities of the communications equipment in public areas with the appropriate designer.

15.3.2 Stations

Specific provisions shall be made to accommodate collections of communications equipment as follows:

A. Underground and Aerial Stations

1. Communications Rooms or Buildings

Communications rooms and buildings at underground and aerial stations are designed to operate as primary communications nodes, which concentrate communications onto the Communications Backbone for transmission to the Communications Central Control and vice versa.

REQUIREMENT
270 SF (17'x16'x10') (LWH)
Within 200 LF of center of platform
30 kVA UPS; (4) quad socket 20A convenience outlets
2 grounds - 1 for power and 1 for signal
6) 4" to each interstation duct bank (3 each way); (2) 2" (ea) to traction power and signaling; connections as required to connect station
a nominal 5 tonnes of air conditioning to be provided, nominal heat load = 20,000 W; temp to be maintained 65-75 deg. F

2. Emergency Management Panels (Underground Stations Only)

   EMPs physically serve as the staging area for the fire department in the event of an emergency. All communication and control elements required to support their operations would be located in these panels. The physical location of the panel shall be coordinated with the Authority having jurisdiction and designing architect, but generally it shall be near the entrance to a station.

CRITERIA	REQUIREMENT
Size	64"x72"x 11.16" (WHD)
Location	Near Entrance of Station
Power	2.5 kVA UPS power, a single quad-socket 20A convenience outlet
Grounding	Per TIA/EIA - 607
Conduit Connections	(2) 3" conduits to Communications Room in station; (1) 2" conduit to interstation comm raceway
Special Conditions	Coordinate with AHJ; room temp not to exceed 90 deg. F

B. At-Grade Stations

1. Communications Cabinet

   The communications cabinet will serve as the secondary communications node concentrating communications for transmission to and from primary nodes.

Power	10 kVA UPS Power; a single quad-socket 20A convenience outlet
Grounding	2 grounds - 1 for power and 1 for signal
Conduit Connections	(4) 4" to interstation ductbank; (2) 2" (ea) to traction power and signalling; connections as required to connect station

NOTE: In the event that building, room, or cabinet is not within 200LF of center of platform, a 24 inch by 36 inch by 48 inch cabinet will be required near the centerline of platform.

15.3.3 Operations and Maintenance Facility

Specific provisions shall be made to accommodate collections of communications equipment as follows:

A. Operations Control Center (OCC)

OCC shall be the central control area for the centralized operations of Link and serve as the Central Supervising Station for Link meeting the intent of NFPA 72, Chapter 8, section 8.3 (2002 ed). As such, it shall need to be designed in conjunction with the Link Operations Plan. Spaces and equipment shall be optimized for the functions intended and coordinated with the ergonomic study (section 15.2.B).

CRITERIA	REQUIREMENT
Size	1660 SF
Location	Within 200 LF of Communication Center
Power	30 kVA UPS; 20 kVA standard
Grounding	2 grounds - 1 for power and 1 isolated and dedicated communications signal ground .
Conduit Connections	Equivalent of (8) 4" conduits to Communications Center
Special Features	12" raised computer floor; Access Control; adjustible lighting

B. Expansion Operations Control Center

Expansion space shall be added to accommodate future growth of Link and the OCC.

Power	30 kVA UPS; 20 kVA standard
Grounding	2 grounds - 1 for power and 1 isolated and dedicated communications signal ground .
Conduit Connections	Equivalent of (8) 4" conduits to Communications Center
Special Features	12" raised computer floor; Access Control; adjustible lighting

C. Central Communications Equipment Room (CCER)

CCER shall be the main communications and central control equipment room for Link. As such, it shall house the primary data servers, storage devices, recorders, and communications equipment that enable centralized operation of Link.

CRITERIA	REQUIREMENT
Size	980 SF
Location	Within 200 LF of Operations Control Center
Power	Contains building UPS rated at 100 kVA plus 50 kVA of 48 Vdc power back-up, and eight (8) quad convenience outlets
Grounding	2 grounds - 1 for power and 1 isolated and dedicated communications signal ground .
Conduit Connections	Equivalent of (8) 4" conduits to Operations Control Center and also to Communications Rooms
Special Features	FM 200 fire supression or equivalent; dust free, positive air pressure; 50 cd/ft lighting; Access Control

D. Communications Room

These rooms are located on each floor of the Central O&M facility and are for the localized distribution and concentration of communications.

CRITERIA	REQUIREMENT
Size	80 SF
Location	On each floor
Power	5 kVA UPS; (2) 20 A quad-socket convenience outlets
Grounding	2 grounds - 1 for power and 1 for signal
Conduit Connections	Equivalent of (8) 4" conduits to Communications Center; Conduits and cableways as required for distribution on floor
Special Features	No water pipes; 1st floor to have 6'x6'x6' vault and manhole below for building cable entry; Access Control

E. Communications Maintenance

Communications Maintenance shall serve as the primary office for all non-management communications maintenance staff. In this room communications staff will perform equipment status checks, pre-assemble equipment racks, test, and perform minor equipment repairs. Room shall be optimized for applications intended and flexibility. Staffing requirements for this room shall be designated in the Link Operations Plan.

CRITERIA	REQUIREMENT
Size	1086 SF
Location	Adjacent to Central Communications Equipment Room
Power	20 kVA UPS; 40 KVA standard
Grounding	2 grounds - 1 for power and 1 for signal
Conduit Connections	Equivalent of (8) 4" conduits to Communications Center
Special Features	30 cd/ft lighting; Access Control

F. Communications Storage

Communications Storage is for the storage of communications maintenance test equipment, drawings, manuals, and training equipment and shall be furnished with seismically braced shelving.

CRITERIA	REQUIREMENT
Size	518 SF
Location	Adjacent to Communication Center
Power	(1) 10A quad-socket convenience outlet
Grounding	None
Conduit Connections	None
Special Features	Access Control

15.4 GENERAL COMMUNICATIONS

15.4.1 Electrical Considerations

All grounds shall not exceed 5 ohms as measured by the IEEE-89 Fall of Potential Method at the ground bar provided in the communications facility or other source.

15.4.2 Environmental Considerations

Specifications and designs shall take into consideration the environment that equipment and/or software is to be located and ensure that all the elements of the Communication System shall have the maximum possible life and minimal disruption to other equipment in their respective locations once the system is built.

15.4.3 Commonality of Equipment

In as much as possible, designs should incorporate the same equipment for similar applications to reduce the different types of equipment. The goal is to reduce the number and cost of spares and the overall cost of training required for the Operations and Maintenance staff.

15.4.4 Test Access

Designs shall incorporate sufficient levels of testing capacity test ports to verify signal transmission levels, bit errors, data throughput, transmission protocols, and administrative data. This shall include but not be limited to automated loop backs, software-monitoring programs, monitor ports, fiber patch panels, and jackfields.

15.4.5 Maintainability

Designs shall strive for maximum maintainability. In consideration of this, designs shall evaluate and optimize access to equipment for replacement, lighting in and around equipment, weight of equipment, and lifting requirements. Additionally, in areas where significant communications wiring exists, designs shall include cable management systems. At a minimum, unique identification labels shall be provided for all devices, wires,

and assemblies. Labeling shall be coordinated with the Link Facilities and Numbering Standards Document.

15.4.6 Open Systems

Designs shall incorporate Open Systems standards in all equipment and systems to ensure long-term availability and flexibility of suitable equipment for use on Link.

15.4.7 Timing and Synchronization

Communication System shall incorporate timing and synchronization at various levels of the network for synchronous communications, system time, and correlation of events. Designs shall accommodate the delivery of Stratum Level 1 synchronization to all communications nodes, the correlation of events across Link to the nearest 0.1 second, and the delivery of clock time to every VMS, voice recorder, CCTV recorder, and OCC display.

15.4.8 Safety Related Systems

A. All life safety related communication subsystem shall meet NFPA 72 (2003 edition) section 6.9.4 – survivability from attack by fire by the following method:

1. Notification devices outside of the affected zone must not be affected.

2. Cable systems interconnecting devices shall be rated for 2 hours.

3. Notification zones shall be fed with redundant equipment.

4. All systems down to the device level shall be monitored at the OCC and also by maintenance.

5. Systems shall be supplied with at least 90 minutes of UPS.

6. Communications signals to/from OCC/NMS shall be via redundant paths with MTBF in excess of 100,000 hours.

15.5 SUB-SYSTEM SPECIFIC

15.5.1 Central Control System

A. CCS Software shall be designed using a formal, iterative, and structured software development process, such as Rational Unified Process. In this process, designs shall be expressed in Unified Modeling Language (UML).

B. CCS Software shall utilize common off-the-shelf software packages where applicable and practicable. Off-the-shelf software shall only be considered practicable if the development of said software follows a formal, iterative and structured software development process similar to the Rational Unified Process, has proven off-the-shelf availability with a network of independent developers and system integrators, and will have a technological life span of at least 10 years. Additionally, all interfaces and features shall be fully modeled and documented in UML.

C. CCS shall be able to detect, deter, and prevent intentional or unintentional breaches in system security or compromises in data integrity, in as much as reasonably practicable.

D. OCC shall include of displays, workstations, and servers required to process information in agreed HMI format.

E. OCC Consoles shall have separate displays and controls for communications and FCS functions. Firewalls shall be in place prior to interconnection to any non-CCS networks.

F. System Manager workstation shall be provided in Communications Maintenance Room.

G. Training/simulation console shall be provided in Expansion OCC.

H. CCS shall perform the following functions, at a minimum:

1. Transfer change-of-state statistics and events data to MMIS (Maintenance Management Information System) database for Electrification devices.

2. Monitor and report change-of-state for Signal Devices including track circuits, TWCs, interlockings, and switches.

3. Monitor and report change-of-state for Fire Alarms.

4. Monitor and report change-of-state for Ventilation equipment.

5. Monitor station and tunnel facilities such as elevators, escalators, and sump pumps for failure/trouble notification. Monitor additional location status for deep tunnel elevators used for emergency egress.

6. Monitor and report change-of-state for station normal and UPS power.

7. Manage both sensed and derived alarms. Generate alarms for detected and/or derived abnormal conditions. Alarm conditions may be indicated audibly, on a console display, and on a hard copy device. CCS maintains records of all alarms.

8. Keep current all displayed information on both Overview Display and console display.

9. Log, date, and time stamp events, alarms, and operator entered commands.

10. Provide Controller ability to control all standard functions associated with interlocking operations.

11. Provide capability for Train Controller to control (on/off) emergency ventilation equipment. The CCS provides the capability for issuance of commands for controlling the emergency ventilation system.

12. Monitor and report change-of-state for fare collection equipment.

13. Provide capability for Train Controller to control (turn-off/on) traction electrification at mainline. CCS provides commands to control: DC breakers, AC breakers, motor-operated disconnect switches.

14. Monitor and report change-of-state for intrusion detectors.

15. Logical train tracking, CCS tracks trains with train IDs in signaled and dark territories, and displays their locations.

16. Maintenance of track status, CCS provides the Train Controller with the capability to declare track status including closed and maintenance crew operating, for a section of the track. CCS displays status of track.

17. Receipt of operating schedules to track “on-time” performance.

18. Monitor and report off-hook conditions for emergency and passenger emergency telephones.

19. Capability for Train Controller to control fire suppression equipment. The CCS provides the capability for issuance of commands to control the fire suppression system at both OCC and at specific remote facilities.

20. CCTV images linked to specific Passenger Emergency Telephones in ‘off-hook’ condition for coverage in emergency. Operator will display both images and location of event with “quick view” capability.

21. The CCS monitors train ID and presence at selected locations and records actual time against scheduled time. This feature requires the CCS have the current schedule and be able to track trains with train ID at the selected locations.

22. CCS supports the generation of the following types of reports:
    a. Controller-Selected Output – display can be selected by a Controller to be routed to a printer for the production of a hard copy.
    b. Log Activity Report – the log data will be organized by location, type and time. The logged data can be selected for reporting with the selection of time period and type.

23 The CCS transfers performance to schedule data to another Link computer system. The train performance-to-schedule data (or log of train detected at selected locations) is transferred in machine-readable format to another Link computer where it is used to generate operating statistics.

24. The CCS monitors power consumption at the substation connection to the local power provider, between traction electrification and stations, and in supply to others. The collected data is stored for off-line processing by others.

25. The CCS provides the Train Controller with the capability to declare the storage of cars for a section of the track network. The declared status is displayed and remains until changed by a Train Controller.

26. The simulator allows training of CCS users, CCS validation, and testing. The simulator models the physical plant so as to present accurate representations of train movement, interlocking response, and traction electrification system response for the above purposes. The simulator is capable of simulating normal and abnormal equipment operation.

27. The CCS supports the remote testing of track leakage currents. The CCS controls the track measuring devices and monitors the test results for an initial line test section. The collected data is transferred to a maintenance management system for off-line processing by others.

28. Health status of monitored devices to be transferred to maintenance management system to be processed and analyzed off-line.

29. Monitoring of select equipment and facilities at the Yard Maintenance Facility.

30. CCS software required to handle at least twice the capacity of the starter system.

31. CCS actively monitors and reports health status of all safety related communications systems including Radio, PET, PA, VMS, Emergency Phones, and the EMP.

15.5.2 Field Control System (FCS), formerly SCADA

A. Field Control System shall be a distributed digital control system based upon open control system utilizing LonWorks technology. Devices and subsystems shall conform to at least one of the following interface standards:

1. LonMark interoperability including:

   a. LonMark OSI layer 1 through 6 interoperability guidelines

   b. LonMark OSI application layer interoperability guidelines

   c. LonTalk (NNSI/EIA 709.1-A, 1999) communications protocol

2. Relay based or analog discrete data points conforming to:

   a. Dry contacts rated at 125Vdc/10A

   b. Analog signals rated at 24Vac, 4-20 mA variable

3. TCP/IP Open Standards defined as:

   a. Having a communications protocol strictly following an openly published standard maintained by any of the following entities: IEEE, EIA, ASHRAE or ANSI

   b. Having a communications protocol transportable over the open standard protocol TCP/IP

   c. Having the ability to assign each device with an unique IP address

   d. Having all interface points within a device accessible through a unique memory address that is fully defined and documented

B. If not commercially available, a LonWorks based solution shall be used in all FCS applications, except as noted.

C. All devices shall be LonMark™ certified where applicable and feasible.

D. FCS shall interface with the following systems:

1. Traction Electrification

2. Train Signaling

3. 26 KV Electrical

4. UPS

5. Station Electrical
6. Emergency Ventilation
7. Station Ventilation/HVAC
8. Fire Alarm Control Panel
9. Elevators
10. Escalators
11. Station Lighting
12. Ticket Vending
13. Stray Current Testing System
14. Emergency Management Panel
15. Emergency Telephone System
16. Passenger Emergency Telephones
17. Radio System
18. Access Control Network
19. Misc. mechanical and electrical equipment such as sump pumps, shutter doors, cross passage doors, etc

E. FCS shall, at a minimum, provide hardware interface for the functionality of the CCS listed in section 15.5.1, Central Control System.

15.5.3 Communications Backbone

A. The CB will be based upon SONET and IP technologies conforming strictly to published industry standards for the protocols.

B. CB shall be primary communications backbone for all voice, data and video traffic.

C. CB shall provide connectivity to and between select Non- Link facilities as required.

D. CB Network shall be sized so that the maximum anticipated traffic load in 2020 shall not exceed 30 percent of the rated capacity of the Network.

E. CB Network shall be designed for the highest reasonable availability per IEC 61508 and/or MIL STD 882D. This includes designing in redundancy, selecting high MTBF equipment, implementing Quality of Service techniques, and designing system for maximum maintainability.

F. Fiber cables shall be designed to have 50 percent dark fibers for use in future expansions. Copper cable shall be designed to have 25 percent spares for use in future expansions.

G. Cables used on exterior right-of-ways shall be all-dialetric fiber optic cable.

H. Both fiber and copper cables shall be designed to minimize splicing, maximize protection, and use every means to extend cable life. This includes but is not limited to minimizing cable transitions, requiring special non-destructive cable installation methods, special protective jacketing or cable ways (innerduct), eliminating splices in right-of-way, and designing for the natural aging and signal loss in cables.

15.5.4 Public Address and Variable Message Signs

A. Public Address shall be provided in all pubic areas of all stations and on each floor of the Operations and Maintenance Facility.

B. Station PA and VMS Requirements:

1. PA in stations shall be divided into zones in all reasonable separable areas, such as fare vending, elevators, elevator lobbies, concourses, mezzanines, and platforms, in stations. A maximum of eight zones shall be used at each station.

2. Each zone shall be designed to support operating and emergency evacuation plans and procedures. As such, each PA zone shall be equipped with a redundant amplifier to meet NFPA 72 and NFPA 130 intent.

3. Variable Message Signs shall be provided in a clearly visible location.

4. PA and VMS messaging shall be designed to meet ADA requirements and support operations and emergency evacuation plans and procedures.

5. PA and VMS pre-recorded and ad hoc messages shall be deliverable from OCC.

6. PA and VMS pre-recorded messages shall be deliverable from the SFD staging area (typically at the EMP or FACP) for each passenger station. Ad hoc PA messaging shall also be available from this

location. A clear description of each pre-recorded message shall be provided at the EMP.

7. PA shall dynamically self-adjust volume to compensate for ambient noise. PA shall be designed for maximum intelligibility under all known conditions.

8. VMS shall be designed for two sides, two lines each side, twenty characters of text each line, clearly visible from all public areas within the station or designated facility by a person with 20/40 vision.

9. VMS display shall have self-adjusting light levels to compensate for ambient light levels.

10. Platform VMS display shall display current time.

11. PA and VMS shall be capable of automatically announcing train arrivals and other schedule based information. In areas without accurate signal information, this shall be based upon available information.

12. Health status of both PA and VMS shall be monitored by the NMS and reported to the CCS.

C. O&M Facility PA & VMS requirements:

1. PA shall be divided to allow for one zone per floor and shop floor as required.

2. PA shall be equipped with manually adjustable volume by zone to compensate for ambient noise. PA shall be designed for maximum intelligibility under all known conditions.

3. PA shall be operable from any PABX extension.

15.5.5 Radio System

A. Radio System shall be the primary means of voice communications for all Link mobile personnel and emergency services such as fire, police, and EMS.

B. Coverage in tunnel and underground areas shall be 90 percent of all spaces designed for human occupancy. In such areas that are critical to operations and emergency services coverage shall be 95 percent.

C. Radio System will record all talk groups at all times at OCC for event analysis.

D. Tunnel Radio shall be designed to accommodate the following talk groups:

1. Main Line Operations 1
2. Main Line Operations 2
3. Main Line Operations 3
4. Maintenance 1
5. Maintenance 2
6. Maintenance 3
7. Central Yard
8. Fare Inspection
9. Link Security 1
10. Link Security 2

E. Sufficient radios shall be supplied to accommodate, at a minimum, the following:

1. One dual headed mobile radio per train car
2. One portable per train operator
3. One base station at the Central O&M facility
4. Sufficient portables for maintenance and operational staff needs
5. 10 percent spares
6. Joint Operating Control Center to facilitate joint bus/rail control

15.5.6 Closed Circuit Television System

A. The following areas shall have CCTV coverage:

1. Elevator cabs
2. Elevator lobbies
3. Escalators and public stairwells
4. Platforms

5. Station entrances and exits

6. O&M Facility vehicle entrances, vehicle exits, passenger entrances, passenger exits, and staff parking lots

7. All yard tracks, leads, and vehicle storage areas

B. Cameras shall be color, vandal resistant, weather resistant, fixed position, and auto-focus. However, at least one pan-tilt-zoom camera shall be provided capable of viewing all incidents alarmed or otherwise identified in the public areas of stations.

C. Cameras shall be recorded continuously and indexed by time. Recordings shall be stored digitally for a period of 72 hours uncompressed and digitally compressed for a period of 30 days.

D. Recording method shall be an industry standard, non-proprietary format that includes the ability to digitally authenticate recording by an acceptable method to validate recording for use in a court of law. Digital authentication method may be proprietary.

E. CCTV images and time indexed recordings shall be available by query by CCTV operator, Train Controller, and designated security, fire/police, or operational personnel.

F. CCTV images within the applicable area shall be available by query from EMP (deep tunnel stations only).

15.5.7 PABX Phone System

A. PABX shall be the primary means for voice communications for fixed location Link staff.

B. PABX shall utilize both telephony and IP signaling for maximum efficiency.

C. PABX shall be compatible with and connect to other Sound Transit PABX systems located in Union Station.

D. PABX Phone functions shall include:

1. Dialing

2. Switching

3. Ringing

4. Tones

5. Intercept
6. Hunting
7. Recorded Announcements
8. Speed Call
9. Last number Redialing
10. Visual Displays
11. Hot Line
12. Caller ID
13. Distinctive Ring
14. Hands Free Answering
15. Call Forwarding
16. Call Transfer
17. Voice Mail
18. Busy Out
19. Multi-line Calling

E. PABX Network shall have the following features:

1. Capability to interface with all PSTN signaling and protocols
2. ISDN, Centrex, long distance trunk routing, and DID capability
3. Private Network Services such as numbering, centralized service attendant, call transfer, and DID
4. Automatic Route Selection
5. Restrict routes by ‘class of service’
6. Call Accounting

F. PABX Phones shall be located in the following types of locations:

1. Offices
2. Reception Areas
3. Conference Rooms
4. File Storage Rooms
5. First Aid Rooms
6. Incident Response Facilities including EMPs
7. Lobbies
8. Libraries
9. Lunch Rooms
10. Control Center(s)
11. Major Equipment Rooms including: electrical, mechanical, communications, train signaling, traction power, and UPS
12. Select Maintenance Shop Facilities

15.5.8 Emergency Telephone System (ETEL)

A. Emergency Telephone System shall be the back-up communications for the Fire Department and other emergency personnel reporting to the scene of an emergency as dictated by Link Emergency Procedures. It shall also serve as an emergency notification system for Link staff.

B. ETEL shall be installed in all areas required but not limited to NFPA 130 Section 11.4 (2003 ed.). Telephone sets shall be installed at the ends of station platforms, tunnel cross passages, emergency access points, and at traction power substations in accordance with NFPA 130 Section 6.1.4 (2003 ed.); inside the underground station access shaft stairways at all landings providing access to equipment room floor levels; in important ancillary rooms located in underground stations such as UPS, communications, emergency fan rooms, electrical switch gear, train control, sprinkler valve, and elevator machine rooms, etc.; at the elevator lobbies and in the elevator cars; and at all EMP locations and Fire Command Center rooms.

C. ETEL shall be divided into zones consisting of a particular station and the adjacent line sections to that station. EMP shall act as the central point in the ETEL network for a zone. Where a particular line section belongs to two or more stations, a clearly labeled switch shall enable the user to choose which station to connect.

D. ETEL zone shall operate as a 'party line' phone system with the capability for at least five (5) persons to participate in the conversation with the EMP and OCC. The connection with OCC shall be a two-way automatic ring down connection for any off-hook condition on any Emergency Phone. EMP shall be able to display any location of the 'off-hook' Emergency Phone within that zone. OCC shall be able to display to CCTV Operator the location of any 'off-hook' Emergency Phone and allow the Operator to 'patch' ETEL phone to any outside phone line.

E. All conversations on the ETEL shall be recorded at OCC.

F. EMP Emergency Phone shall be capable of connecting to EMPs at either adjacent station.

15.5.9 Passenger Emergency Telephone (PET)

PET system shall serve the function of an emergency notification system for use by passengers in the event of an emergency. The following shall govern the design of the PET:

A. Each PET shall be vandal resistant, clearly labeled and ADA compliant in message delivery.

B. The emergency function shall be the primary means for the public to notify Link Operations and staff of an emergency situation or passenger in distress per NFPA 130 Section 5.7.2.3 (2003 ed.).

C. Each PET shall operate as a two-way automatic ring down phone connected with the OCC staff, (and/or emergency services personnel at the EMP when in control). Upon instigation of an emergency call, OCC operator shall receive audible and visual indication of the situation, location information of the situation, and ability to view a 'live' video image of the caller and the surrounding area.

D. Each PET shall be automatically recorded for event analysis at OCC.

E. PET shall be located within 300 feet of any location in the public areas of grade separated or access restricted stations. Deep tunnel stations shall comply with NFPA 72, Chapter 5, Section 5.12 (2002 ed.) requirements locating PET within 200 feet of any location in the public areas and within 5 feet of any exit.

F. OCC/EMP design shall allow up to three PET calls on each console.

15.5.10 Network Management System (NMS)

A. NMS is the primary means for alarm notification, event notification, remote management, and remote configuration for the Communication System.

B. Primary users of the NMS shall be the Communications Maintenance staff.

C. NMS shall have the following functions but not be limited to:

1. Monitor and report change-of-state of all communications equipment, where applicable

2. Exchange information with the CCS in order to display status of devices that are safety related on the CCS

3. Remote device log-in and configuration capability, where feasible, for all communications equipment owned and maintained by Sound Transit Link

4. Graphical HMI for physical and logical configuration of system to enhance trouble shooting of the Communications System

5. Failure and maintenance recording with trend tracking and predictive failure analysis capability

6. Quick device and system recovery capability

7. Fully detailed on-line help feature including detailed procedures for trouble shooting, system recovery, and setting up individual device configurations

15.5.11 Emergency Management Panel (EMP)

A. EMP shall operate as the local Fire Control Center during emergencies dictated by the Link Emergency Procedures Manual.

B. Each underground station shall be equipped with an EMP located at or near the entrance of the station. This location shall be in the Fire Command Center Room, if applicable. EMP shall be protected from direct contact with inclement weather, but shall be capable of operating without failure when operated under severe weather conditions.

C. EMP shall display the following functions (as applicable) :

1. Schematic plans indicating the station floor plan, means of egress, fire protection systems, fire fighting equipment, fire department access, and Emergency Phone locations

2. Fire alarms

3. Status of all electrical systems including: Traction Electrification, station electrical, and UPS

4. Complete status of emergency ventilation fans, including health status, direction of air flow, and recommended tunnel vent scenarios

5. Location and status of cross-passage doors

6. Location (only to the degree of resolution of the signaling system) of trains in the tunnels

7. CCTV camera views of public areas (deep tunnel stations only)

8. Control status of fire and security elements

D. EMP shall be able to control the following (as applicable):

1. Unlock all emergency access or egress doors (deep tunnel stations only)

2. Functions available at the FACP

3. Emergency Ventilation System

4. Traction Electrification System (stop only)

E. Control of all other applicable equipment shall take place at the OCC.

F. The following ancillary equipment shall be located at EMP:

1. EPS

2. PABX

3. PA - ad hoc and pre-programmed messaging

4. VMS - pre-programmed messaging

5. CCTV Control, up to three simultaneous camera views with integrated controls at deep tunnel stations only

6. Laminated schematic maps of the station and entire system under control

7. Tagged keys for any doors or locked areas necessary

15.5.12 Access Control System

Access Control System (ACS) will consist of a network of devices designed to dynamically allow access through a controlled entry and to detect occupancy of select facilities or rooms for the purpose of determining unauthorized access. System will also provide the ability for a central operator to issue, revoke, or change access control to different secured facilities for Link personnel and authorized guests. Procedures for this shall be contained in the Sound Transit Security Manual.

A. ACS shall be designed to optimally utilize the existing Sound Transit investment in electronic key card access systems.

B. ACS shall utilize FCS Network for networking communications.

C. ACS shall be designed in conjunction with the System Safety Plan to ensure safe reliable operation.

15.5.13 Stray Current Testing System

A prototype remote stray current testing system test section shall be established to periodically monitor and test the stray current control mechanisms in place on Link. This system shall be fully compatible with the Field Control System which will collect raw data and port to a separate maintenance management system for results analysis. Design goals and testing parameters shall be established under Chapter 17, Corrosion Control, section 17.3, Stray Current Control.

15.6 INTERFACES

15.6.1 Internal Only System Interfaces

Communications and Central Control System shall be designed to facilitate operations, maintenance, and emergency operations by transmitting, receiving, processing and displaying all voice, video, and data information on Link. As such, the communication systems shall interface with all systems required by operations, maintenance, or emergency operations.

15.6.2 Internal-External System Interfaces

In order to facilitate Link operation's coordination with non-Link divisions of Sound Transit, external agencies and services, communication links shall be provided. This shall include communication links with the following:

A. Bus operations

B. Existing Sound Transit Information systems

C. Sounder cable connections to Union Station

D. Regional Intelligent Transportation Systems (ITS)

E. External fare collection services

F. Police, Fire, and other emergency services

G. Public exchange carrier(s)

15.6.3 External Only System Interfaces

The following communications related items shall be designed into the physical communication's requirements for Link. However, these systems do not directly interface with Link.

A. City of Seattle Traffic Signal Fiber Cable

B. King County Metro owned equipment and cables in the DSTT

C. Various equipment and systems required by police and fire departments

END CHAPTER 15

16. FARE COLLECTION

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16. FARE COLLECTION

16.1 INTRODUCTION

A. The Link fare collection system shall be a proof-of-payment (POP) system. POP is a barrier-free system, which does not employ fare gates. It instead utilizes roving fare inspectors to check fares on a percentage of light rail vehicles. Passengers will be expected to have valid proof-of-payment for the trip prior to boarding the train. Passengers, who are inspected and are unable to present a valid ticket, transfer, or pass for the trip they are taking may be cited under state code and required to pay a fine in court.

B. Ticket vending machines (TVMs) shall be located in the stations for passengers to purchase tickets or, if necessary due to fare policy, upgrade other pre-paid media. Some passengers entering the Link light rail system may already have valid proof-of-payment, which may be a pass, transfer, or other fare media. These passengers will be able to bypass the TVMs and proceed directly to the platform.

C. The Link fare collection system shall accommodate contactless smart card fare media if regional plans proceed. The Regional Fare Coordination System (RFCS) is a multi-agency project with the objective of introducing a smart card that is valid on each of the seven local transit agencies in the Central Puget Sound region, including Sound Transit, King County Metro, Pierce Transit, Community Transit (Snohomish County), Everett Transit (City of Everett), Kitsap Transit, and the Washington State Ferry system. As of November 2004, the project has reached the point at which the agencies have committed to its implementation. If the project proceeds as planned, the contactless smart card will be introduced region-wide in 2006. TVMs shall be capable of selling smart cards and adding value to previously purchased smart cards. Stand-Alone Fare Transactions Processors (SAFTPs) shall be installed at each station to validate stored-value smart cards for each trip. Portable Fare Transaction Processors (PFTPs) shall enable fare inspectors to interpret the smart card validation data for visual display to the inspector.

16.2 GENERAL REQUIREMENTS

The System design shall be guided by the following objectives:

1. Ensure that all passengers pay the appropriate fare.

2. Promote passenger convenience through ease of understanding and use.

3. Ensure the security and accountability of all revenues received.

4. Facilitate the continued safety of the riding public and personnel.

5. Operate efficiently, achieving fare policy objectives while minimizing the costs of operation and maintenance.

6. Operate reliably, incorporating proven design and components, and capable of operating under anticipated environmental conditions (specifics provided elsewhere in the design criteria document).

7. Resist vandalism, shocks, and misuse.

8. Operate dependably under the following environmental conditions:

Mean ambient temperature	Low 65°F High
Temperature Range	22°F - 99°F
Relative Humidity	5% to 100%
Maximum 24-hour rainfall	3 inches
Maximum 24-hour snowfall	24 inches
Ice	Infrequent measurable quantities
Prevailing average wind speed	9 mph
Maximum gust	70 mph

9. Conform to the ADA requirements for accessibility.

10. Utilize modular, state-of-the-art technology, facilitating periodic upgrades over the life of the equipment to remain current with region needs.

11. Accommodate “seamless” travel to/from other transit service in the region, including transfer to/from Sound Transit Regional Express, King County Metro, Pierce Transit, and Community Transit.

16.2.1 Components of the POP System

A. Passenger Station Equipment

1. Ticket Vending Machines (TVMs) with RFCS Smart Card Implementation

Self-service ticket vending machines shall sell tickets passes and sell upgrades to existing pre-purchased tickets and passes. The TVMs shall be capable of selling smart cards and of revaluing previously purchased RFCS Smart Cards for continued use.

2. Stand-Alone Fare Transaction Processors (SAFTP)

   Stand-alone Fare Transaction Processors shall be installed to validate stored-value RFCS Smart Cards for the customer's trip by deducting the appropriate value.

3. Fare Inspection Equipment – Portable Fare Transaction Processor (PFTP)

   Fare inspectors shall be equipped with handheld card readers, referred to as portable fare transaction processors, which will read electronic data on a RFCS Smart Card and display to the inspector for verification of validity.

B. Communications and Control

1. A Central Data Collection System (CDCS) at the Operations Control Center (OCC) shall monitor, control and collect data from fare collection equipment in the stations.

2. A control terminal at the OCC controller console shall provide specialized monitoring and control to OCC personnel.

3. A system administration terminal shall provide high-level access to the system for software maintenance and fare table modification for authorized personnel.

4. TVM alarms shall be transmitted directly to the SCADA system at the stations.

5. Authorized personnel (e.g., maintenance, revenue personnel) at Sound Transit offices shall have access to maintenance and revenue/sales.

C. Enforcement/Security

1. Station entry, mezzanine, and platform areas shall have signage, which indicates the need for possession of a valid ticket for entry into the paid area or vehicle. These signs shall be located before and at the point of differentiation, and within the paid areas so as to meet all legislative/legal requirements for effective enforcement.

2. Signs shall be conspicuous and easily understood by passengers and comply with legal requirements for such signage.

3. The location of the free to paid area line shall be clearly delineated by architectural features or signage to permit easy identification.

4. The interior of each car of all trains shall have signs, which indicate that on-board passengers must possess a valid ticket. These signs shall comply with all legislative/legal requirements for effective enforcement and be conspicuous and easily understood.

5. Fare Enforcement personnel shall be easily identified, assigned adequate enforcement authority, and meet state/local statutes or requirements.

6. Fare inspection shall be performed on light rail vehicles. Station design and TVM location shall not preclude the ability to perform inspections on station platforms.

7. TVMs shall be under CCTV surveillance.

D. Revenue Collection and Transport

1. Revenue in cash vaults and hoppers shall be transported from the TVMs via surface transport (i.e., armored truck) to a secure central facility within which the cash shall be processed and reported.

16.3 TICKET VENDING MACHINES

A. The TVMs shall have the following capabilities:

1. Accept as payment cash (valid US bills [$1, $5, $10 and $20] and coins [5¢, 10¢, 25¢, 50¢, $1] in general circulation), major credit cards (American Express, Discover, Master Card, and VISA) and bank-issued debit cards.

2. Issue tickets and passes from six types of loaded stock, including two types of stocks of paper fan-fold or roll fare cards and four stocks of plastic die-cut fare cards. Preliminary fares and fare media are as follows:

Fare Type	Fare Media
Single Ride (pk/off-pk, #zones)	Paper, print on issue
Single Ride Reduced (pk/off-pk, #zones)	Paper, print on issue
Zone upgrade	Paper, print on issue
Zone upgrade reduced	Paper, print on issue
Day Pass (#zones)	Paper, print on issue
Day Pass Reduced (#zones)	Paper, print on issue
Monthly Pass (#zones)	Plastic, print/encode on issue
Monthly Reduced (#zones)	Plastic, print/encode on issue
RFCS Smart Card (if implemented)	Plastic Smart Card
Parking Ticket	Paper, print on issue

3. Issue US coins as change.

4. Escrow inserted coins and bills during a transaction, returning same if transaction ends prior to completion.

5. Store inserted coin in a manner that enables its use as change in subsequent transactions (‘recycling’).

6. Store additional coin supply to dispense as change when recycled coin supply is depleted.

7. Automatically adjust fares in effect between peak and off-peak periods, based on preprogrammed criteria.

8. Continue in operation in degraded mode under certain failure conditions, with appropriate notice to customers. Examples: failure of note acceptor or coin validators, depletion of change or a supply of a particular fare card type, inability to authorize credit or debit cards.

9. Protect access to cash in the TVM when open for maintenance and repair.

10. Protect access to cash during revenue servicing, securing vaults, hoppers and drums transported to/from the TVMs.

11. Record and store all transaction data for transmission to the (CDCS) when polled.

12. Transmit alarms and changes in status to the (CDCS).

13. Respond to commands from the (CDCS) to either go into or out of service.

14. With loss of power, complete or cancel transaction in progress, transmit loss-of-power alarm to station controller prior to going out of service. (TVM memory to be retained for minimum of 10 days with backup power supply).

15. RFCS Smart Card Implementation

    a. Add value to inserted smart cards for payment tendered at the TVM.

    b. Add value to inserted smart cards for pre-paid amount (e.g., paid via website, subscription or transit benefits transfer) [“autoload”].

    c. Maintain in memory a registry of smart cards that are to be rejected for revaluing, provided by authorized personnel via the system network (‘hot list’ of bad cards).

B. The TVMs shall have the following characteristics:

1. Stainless Steel Construction

2. Color Flat-Panel Touch Screen; or ATM-style soft key buttons and flat-panel display, for fare selection

3. Large high-contrast raised letter graphics and instructions

4. 12-button ADA-compliant keypad for debit card PIN entry. Keypad must be capable of operating in both encrypted and clear modes

5. ADA-compliant raised alphabetic and Braille instructions and instructions path on TVM front panel

6. Audio instructions, activated by customer, with head-phone jack for optional use by customer

7. ADA-compliant accessibility for at least one TVM per array

8. Front access to internal components for maintenance and revenue servicing, restricted to authorized personnel via key, employee ID card and employee PIN

9. Secured access to cash-handling components, restricted to authorized revenue personnel via key

16.4 FARE TRANSACTION PROCESSOR (FTP)

A. FTPs shall be installed adjacent to each TVM array in the “free” area of the station. FTP shall be a contactless self-contained device post-mounted and free standing. This device shall permit the passengers to validate pre-purchased contactless RFCS Smart Cards.

B. One FTP shall be installed for each destination zone from the origin station. (Example: with two zones on the Link line, a minimum of two FTPs would be installed at each TVM array.) Each FTP shall be programmed to validate a smart card for a set number of zones from the origin station. Graphics shall be provided to indicate which FTP to use for a particular trip

C. Each FTP shall incorporate a contactless smart card interface (an antenna) and a display to provide passenger information. Audible tones and lights shall be provided to indicate to the passenger the completion of the transaction or if a problem exists.

D. Transaction records shall be stored for each card validation. Communication with the (CDCS) shall be provided independently or via the TVM for the transfer of maintenance, alarm, transactional and operational information. All

data shall be backed-up by battery in the event of a power failure for a period of not less than 21 days.

16.5 PORTABLE FARE TRANSACTION PROCESSOR (PFTP)

A. PFTPs shall be used for the on-board inspection of fares. These shall be operated by fare inspectors. The PFTPs shall incorporate an antenna similar to the FTP, and a display-to-display information to the inspector, such as amount remaining on the RFCS Smart Card. The PFTPs incorporate an internal battery.

B. The PFTPs shall provide verification that the fare media is valid or invalid.

C. Inspection data is stored for each card read. This data shall be transmitted to the (CDCS) via the recharging cradles interfaced to the (CDCS).

16.6 CENTRAL DATA COLLECTION SYSTEM (CDCS)

A. The (CDCS) shall provide transaction control, daily TVM, and FTP polling, event and machine status reporting. The (CDCS) shall store all data retrieved and make it available for the generation of user-definable reports. The data shall be stored in the primary data access location for a period of not less than 90 days and shall be immediately accessible during that time.

B. A control terminal shall be provided at the OCC control console to enable OCC personnel to monitor system status.

C. A system administration terminal shall be provided for authorized personnel to perform secure system software maintenance, including fare table updates.

D. Authorized personnel at Sound Transit shall have access to maintenance and revenue/sales data in a manner that protects the system from tampering with equipment status, transaction records and operating system.

E. The (CDCS) shall store the system configuration files, provide data editing capability, act as the repository of security and access information, provide backup of all system data and provide on-line monitoring for all fare collection equipment in addition to the polling requirements.

F. The (CDCS) shall provide for preparation of performance reports on a scheduled basis in order to identify those fare collection equipments that are not performing well.

G. The (CDCS) shall include the fare evader/repeat offender database, which shall be updated on a periodic basis.

H. The (CDCS) shall communicate with the financial clearinghouse for all credit and ATM card transactions that require authorization.

I. The (CDCS) shall communicate with the smart card clearinghouse to relay transaction data and provide for the encoding of RFCS Smart Cards.

16.7 LINK CONTROL CENTER

A. The Link Control Center shall contain equipment and systems that enable it to:

1. Monitor and control the status of fare collection equipment installed in stations.

2. Interpret the data stored on a Smart Card (if implemented), to diagnose and resolve a problem for a passenger.

3. Collect, process, store, display on a CRT, or print information obtained on command from fare collection equipment.

4. Receive alarms and provide immediate indication of each alarm to OCC personnel.

5. Collect and store data, prepare weekly and monthly reports, download changes in fare structure, transmit data and reports to computers at revenue processing facility, to a corporate computer and to the Regional Fare Collection Clearinghouse computer.

16.8 SIZING METHODOLOGY

16.8.1 Parameters and Overall Methodology

A. Enough ticket vending machines shall be provided at a station to process, within 15 minutes, all passengers entering at that station and requiring a ticket in the peak 15 minutes.

B. The number of ticket vending machines required is calculated for both the morning and evening peak hours. The greater of the two answers shall be used.

C. Ticket vending equipment is grouped by array. Each ticket-vending array is a grouping of ticket vending machines within a free area. Allocation of the total number of pieces of equipment to each array in a station is based on station configuration, and site-access-related factors.

16.8.2 Calculation Methodology

A. Enough ticket vending machines shall be provided at a station to process, within 15 minutes, all passengers entering at that station and requiring a ticket in the peak 15 minutes. Calculations shall be based on a 25-second transaction time for passengers purchasing tickets. The number of ticket vending machines required is calculated for both the morning and evening peak hours using the formula and factors given below. The greater of the two answers shall be used.

$$\text{No. TVMs} = \frac{PTxU}{36} + 1 \text{ or}$$

where **U** = proportion of arriving passengers using TVMs (use 0.40 for the AM peak and 0.35 for the PM peak). Assumes 35 percent of the passengers need to buy a ticket. Purchase on monthly passes has been allowed to some extent in the higher AM percentage and shall otherwise be excluded from these calculations.

PT = total passengers entering station in peak 15-minute period in AM or PM

B. If the calculated number of TVMs is less than two per array (on separate mezzanines), two TVMs shall be used.

C. All fractions of machines greater than or equal to 0.3 shall be rounded upward; fractions less than 0.3 shall be rounded downward. Numbers shall be rounded before spares are added.

D. Initial sizing shall be based on projected ridership approximately ten years after line opening. Space shall be provided for adding additional machines based on forecasted ridership a minimum of twenty years after line opening.

E. A minimum of 10 percent spare machines shall be provided.

END CHAPTER 16

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17. CORROSION CONTROL

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17. CORROSION CONTROL

17.1 INTRODUCTION

This chapter describes the design criteria for corrosion control. Corrosion control is required to prevent premature corrosion failures on transit system facilities and other underground structures. Such measures will also minimize stray current levels and their effects on underground and above-grade structures. Corrosion control systems should be economical to install, operate, and maintain.

17.1.1 Scope

A. Corrosion control design criteria encompass all engineering disciplines applied to the project.

B. The criteria are separated into three areas; soil corrosion, stray current corrosion, and atmospheric corrosion. The design criteria for each of these categories, and their implementation, shall meet the following objectives:

1. Realize the design life of system facilities by avoiding premature failure caused by corrosion;

2. Minimize annual operating and maintenance costs associated with material deterioration;

3. Provide continuity of operations by reducing or eliminating corrosion related failures of systems and subsystems; and

4. Minimize detrimental effects to facilities belonging to others as may be caused by stray earth currents from transit operations.

17.1.2 System Interfaces

Corrosion control engineering shall be coordinated with the other disciplines, including mechanical, utility, electrical, civil, structural, trackwork, electrification, signaling, and communications designs.

17.1.3 Codes and Standards

All design relating to implementation of the corrosion control requirements shall conform to or exceed the requirements of the latest versions of codes and standards identified in these criteria.

17.1.4 Requirements

A. Soil Corrosion Control

1. Criteria in this category apply to systems or measures installed to mitigate corrosion caused by soil/rock and groundwater.

2. Soil/rock samples should be obtained in conjunction with geotechnical testing in areas of extensive below-grade construction. The soil/rock samples should be analyzed for resistivity (or conductivity), moisture content, pH, chloride and sulfate ion concentrations, and for redox potentials.

3. Structures shall be protected against environmental conditions by system design, the use of coatings, isolation, cathodic protection, electrical continuity, or a combination of corrosion control measures, as appropriate.

B. Stray Current Corrosion Control

Criteria in this category apply to measures installed with the traction power system and trackwork to assure that stray earth traction currents do not exceed allowable levels. These criteria also apply to measures installed with fixed facilities, and to facilities belonging to others. They are based on anticipated stray earth traction current levels and the characteristics of fixed facilities and other buried structures.

C. Atmospheric Corrosion Control

Criteria in this category apply to systems or measures installed to mitigate corrosion caused by local climatological conditions and air pollutants.

17.2 SOIL CORROSION CONTROL

This chapter provides criteria for the design of systems and measures to prevent corrosion of transit system fixed facilities due to contact with area soil/rock and groundwater. Designs shall be based on achieving a minimum 50-year design life for buried structures, with exception of a 100-year design life for the Tunnel and stations through consideration of the factors given below.

17.2.1 Materials of Construction

A. All pressure and non-pressure piping and conduit in contact with soil shall be non-metallic, unless metallic materials are required for specific engineering purposes.

B. Aluminum and aluminum alloys shall not be used in direct burial applications.

C. Material for backfilling concrete or ferrous structure excavations shall meet the following criteria:

1. pH 6 to 8;

2. Maximum chloride ion concentration of 250 ppm; and

3. Maximum sulfate ion concentration of 200 ppm.

17.2.2 Location

Metallic piping and conduits serving tunnels and stations shall be routed inside the structure or embedded in the concrete. Where this is not practical, buried metallic pressure piping shall be coated and include provisions for cathodic protection, and non-pressure piping shall include corrosion control provisions.

17.2.3 Safety and Continuity of Operations

Corrosion control protection shall be required for those facilities where failure of such facilities caused by corrosion may affect the safety or interrupt the continuity of operations.

17.2.4 Accessibility of Installations

Permanent test facilities installed with certain corrosion control provisions shall be accessible after installation, allowing for periodic maintenance and monitoring.

17.2.5 Special Considerations

Soil corrosion control measures for facilities owned by others, but designed as part of the transit project, shall include the standards and practices of the facility owner. Where other facility owners plan to install or currently operate cathodic protection systems, the impact of such systems on Sound Transit facilities shall be assessed and any interference effects resolved to the satisfaction of both parties.

17.2.6 Materials and Methods

The following paragraphs establish the materials and methods to be used for soil corrosion control.

17.2.6.1 Coatings for Metallic Structures

A. Coatings specified for corrosion control of buried metallic facilities shall satisfy the following criteria:

1. Minimum volume resistivity of 10,000,000,000 ohm-centimeters ($1x10^{10}$ ohm-centimeters);

2. Minimum thickness as recommended for the specific system, but not less than 15 mils;

3. A chemical or mechanical bond to the metal surface. Pressure-sensitive systems are not acceptable; non-bonding systems may be used in special instances, after review and approval by Sound Transit;

4. Minimum 5-year performance record for the intended service;

5. Mill application wherever possible, with field application of a compatible paint or tape system; and

6. Mechanical characteristics capable of withstanding reasonable abuse during handling and earth pressure after installation for the design life of the system.

B. Generic coating systems include, but are not limited to, the following:

1. Extruded polyethylene/butyl based system;

2. 100 percent liquid epoxies (two component systems);

3. Polyethylene-backed butyl mastic tapes (cold applied);

4. Bituminous mastics (airless spray); and

5. Polyvinylchloride (PVC) coating for conduit.

17.2.6.2 Coatings for Concrete Structures

A. Evaluate the need for coatings as a measure of corrosion control for concrete structures in contact with soil or groundwater. Such structures may or may not realize significant benefit from the application of protective coatings. Such coatings would need to withstand the stresses (e.g., abrasion, impact, less than ideal application conditions, etc.) proposed installation techniques would impose.

B. Selection of coatings systems as corrosion protection for reinforced concrete structures must consider the intended purpose of the coating, the application options available based upon proposed construction techniques and performance history of both generic coating class (e.g., epoxy, epoxy-novolac, sealant/penetrant, etc.) and specific product.

C. Barrier coatings specified for corrosion control of concrete facilities shall satisfy the following criteria:

1. Minimum volume resistivity of 10,000,000,000 ohm-centimeters ($1x10^{10}$ ohm-centimeters);

2. Minimum thickness as recommended for the specific system;

3. A chemical and mechanical bond to the concrete surface;

4. Minimum 5-year performance record for the intended service;

5. Ability to perform when applied in the manner construction techniques will require (e.g., field application, uncontrolled atmosphere, etc.); and

6. Mechanical characteristics capable of withstanding reasonable abuse during handling and earth pressure after installation for the design life of the system.

17.2.6.3 Electrical Isolation of Piping

A. Devices used for electrical isolation of piping sections shall include non-metallic inserts, insulating flanges, couplings, unions, and/or concentric support spacers. Devices shall meet the following criteria:

1. A minimum resistance of 10 meg-ohms prior to installation.

2. Sufficient electrical resistance after insertion into the operating piping system such that no more than two percent of a test current applied across the device flows through the isolator, including flow through conductive fluids, if present.

3. Mechanical and temperature ratings equivalent to the structure in which they are installed.

4. Internal coating, except completely non-metallic units, with a polyamide epoxy for a distance on each side of the isolator equal to two times the diameter of the pipe in which they are used. Where conductive fluids with a resistivity of less than 2,000 ohm-centimeters are present, internal coating requirements shall be based on separate evaluation.

5. Devices (except non-metallic units) buried in soils shall be encased in a protective coating.

6. Devices (except non-metallic units) installed in chambers, or otherwise exposed to partial immersion or high humidity shall have a protective coating applied over all components.

7. Inaccessible insulating devices, such as buried or elevated isolators, shall be equipped with accessible permanent test facilities.

B. A minimum clearance of 12 inches shall be provided between new and existing metallic structures. When conditions do not allow a 12-inch clearance, the design shall include special provisions to prevent electrical contact with existing structures.

17.2.6.4 Electrical Continuity of Piping

A. Electrical continuity shall be provided for all non-welded metallic pipe joints. Pipelines with bonded joints shall be electrically insulated from existing metallic pipelines at the point of connection.

B. Use direct-burial, insulated, stranded, copper wire with the minimum length necessary to span the joint being bonded.

1. Wire size shall be based on the electrical characteristics of the structure and resulting electrical network to minimize attenuation and allow for cathodic protection.

2. Use a minimum of two wires per joint for redundancy.

3. Connect to the pipe with a thermite weld.

4. Repair damaged pipe coating.

5. Coat weld area and exposed conductor.

17.2.6.5 Cathodic Protection

A. Use sacrificial galvanic anodes for pipeline cathodic protection where soil conditions indicate that soil corrosion may reduce the service life of the facility below the design requirements. When galvanic cathodic protection is used for new facilities, the facilities shall be provided with a compatible coating system. Where galvanic anodes are in direct contact with soils or natural waters, they shall be connected to the facility by means of a cable attachment that permits the monitoring of anode

current discharge. Provision shall be made for the inclusion of stray dc current blocking diodes in the anode-to-facility connections.

B. Cathodic protection system design shall be based on theoretical calculations that include the following parameters:

1. Estimated percentage of bare surface area (minimum 1 percent);

2. Cathodic protection current density (minimum 1.0 ma/ft^2 of bare surface area);

3. Estimated current output per anode;

4. Estimated total number of anodes, size, and spacing;

5. Minimum anode life of 50 years (minimum 50 percent efficiency); and

6. Estimated anode-to-earth resistance.

C. Impressed current systems shall be used only when the use of sacrificial galvanic systems is not technically and/or economically feasible. Cathodic protection schemes that require connections to the transit system negative return system, instead of using a separate, isolated anode groundbed, are not permitted. Impressed current rectifier systems shall be designed using variable voltage and current output rectifiers. Rectifiers shall be rated at a minimum of 50 percent above calculated operating levels. Conditions, which may result in increased voltage and current requirements, shall be considered in the impressed current design system.

D. Test facilities shall be designed to permit initial and periodic testing of cathodic protection levels, interference currents, and system components (anodes, blocking diodes, reference electrodes, insulating devices, and continuity bonds). The designer shall specify the locations and types of test facilities for each cathodic protection system.

17.2.7 Structures and Facilities

The following paragraphs establish the protective measures to be considered for utilities and buried structures.

17.2.7.1 Ferrous Pressure Piping

All new buried cast iron, ductile iron and steel pressure piping shall satisfy the following minimum criteria:

A. Application of a protective coating to the external surface of the pipe (See section 17.2.6.1).

B. Electrical isolation of pipe from interconnecting pipes, other structures and segregation shall be designed into discrete electrically isolated sections depending upon the total length of piping. Electrical isolation fittings located with 50 feet of a rail shall be provided with galvanic grounding electrodes on both sides of the insulator and dc current blocking diodes. (See section 17.2.6.3).

C. Electrical continuity through the installation of copper wires across all mechanical pipe joints other than intended isolators (See section 17.2.6.4).

D. Permanent test/access facilities shall be installed at all insulated connections suitable for verification of electrical continuity, of electrical effectiveness of isolators, of stray current activity. Additional test/access facilities shall be installed at intermediate locations, either at intervals not greater than 500 feet, or at greater intervals determined on an individual structure basis.

E. A cathodic protection design if required shall be prepared for each individual structure.

F. For pressure piping entering Sound Transit facilities below grade, electrically insulate pipe shall be installed immediately inside of the wall penetration. For pressure piping entering Sound Transit facilities above grade, electrically insulate pipe immediately outside of the wall penetration. Pipe penetrations through the walls and floors shall be electrically isolated from building structural elements.

G. Piping encased in concrete including thrust blocks shall be provided with a coating material that extends a minimum of 6 inches beyond the concrete to soil interface.

17.2.7.2 Copper Piping

Buried copper pipe shall be electrically isolated from non-buried piping and from any ferrous piping, such as that contained in a station structure, through use of an accessible insulating union installed where the piping enters through a wall or floor. Pipe penetrations through the walls and floors shall be electrically isolated from building structural elements. The isolators should be located inside the structure and not buried.

17.2.7.3 Gravity Flow Piping (Non-Pressure)

A. Cast or ductile iron piping shall have:

1. An internal mortar lining with a bituminous coating on ductile iron pipe only (not required for cast iron soil pipe);

2. A bonded protective coating or unbonded dielectric encasement on the external surfaces in contact with soils (AWWA Standard C105); and

3. A bituminous mastic coating on the external surfaces of pipe six inches on each side of a concrete/soil interface.

B. Reinforced concrete non-pressure piping shall have:

1. Water/cement ratios meeting the minimum provisions of AWWA;

2. Minimum practical chloride concentration in the total concrete mix (mixing water, cement, admixture and aggregates); and

3. Use Type II cement as noted in Table 17-1.

17.2.7.4 Electrical Conduits

A. Buried metallic conduits shall have:

1. Galvanized steel with PVC or other coating acceptable for direct burial, including couplings and fittings. The PVC coating is not required when conduits are embedded in concrete; and

2. Electrical continuity through use of standard threaded joints or bond wires installed across non-threaded joints.

B. Buried non-metallic conduits shall be encased in concrete including couplings and fittings except at transitions where metallic materials are required (stub-ups, penetrations, etc.).

17.2.7.5 Hydraulic Elevator Cylinders

A. Steel hydraulic elevator cylinders shall be designed, fabricated and installed to meet the project design life. Unless the hydraulic elevator has a 100-year design life, the elevator design shall include the following criteria:

1. External protective coating (See section 17.2.6.1) resistant to deterioration by petroleum products (hydraulic fluid);

2. Outer concentric fiber glass reinforced plastic (FRP) casing. Casing shall be designed to prevent moisture intrusion (including the bottom) and to withstand the physical conditions;

3. Sand fill between the cylinder and FRP casing shall be installed and shall remain dry. Sand fill shall have a minimum resistivity of 25,000 ohm-centimeters, a pH between 6 and 8 and a maximum chloride content of 100 ppm;

4. Cathodic protection through the use of sacrificial anodes attached directly to the cylinder; and

5. Removable moisture-proof sealing lid installed on the top of the casing prior to installation of the cylinder. The top of the casing shall be permanently sealed against moisture intrusion after installation of the cylinder.

B. Hydraulic piping to elevator cylinders shall be placed in pipe chases or constructed of double wall pipe with provisions for leak detection. Connections to the cylinder and to the hydraulic fluid reserve tank shall use a dielectric isolator suitable for use with the hydraulic fluid and the design pressure of the cylinder. Where hydraulic piping must be placed in direct contact with soil or concrete, a barrier coating, dielectric isolation, and cathodic protection shall be included in the design.

17.2.7.6 Buried Concrete/Reinforced Concrete Structures

A. The design of cast-in-place concrete structures, precast utility structures, and precast tunnel liner segments, shall be based on the following criteria:

1. Use Type II cement as noted in Table 17-1. Use of a concrete mix with a cement type not specifically listed in Table 17-1 must be reviewed and approved by Sound Transit. ASTM C 452-75 and American Concrete Institute (ACI) Publication SP-77, “Sulfate Resistance of Concrete,” should be used as guidelines for evaluating the sulfate resistance of concrete mixes with non-standard cement types;

2. Water/cement ratio and air entrainment admixture in accordance with specifications presented in Chapter 8,

Structural, to establish a dense, low permeability concrete. Refer to applicable sections of ACI 201.2R, "Guide to Durable Concrete." Concrete to be in contact with soil or groundwater shall have a water/cement ratio of not greater than 0.45;

3. Chloride content of concrete shall be minimized. Mix components shall each be tested and those that contain more chloride than the practical minimum shall be rejected;

4. Concrete cover over reinforcing steel shall comply with ACI codes. Provide a minimum of three inches of cover on the soil/rock side of reinforcement when pouring within a form and when pouring directly against soil/rock or excavation support systems; and

5. The need for additional measures, as a result of localized special conditions, shall be determined on an individual basis. Additional measures may include application of protective coatings to concrete or reinforcing steel, or both.

17.2.7.7 Support Pilings

A. The following is applicable only to support piling systems that are to provide permanent support. Pilings used for temporary support do not require corrosion control provisions.

B. Designs based on the use of metallic supports exposed to the environment, such as H or solider piles, shall include the use of one or more of the following corrosion control methods:

1. Application of a barrier coating to the pile from the surface to a minimum of ten feet below the expected low groundwater level. The barrier coating shall conform to section 17.2.6.1 and include all exposed surfaces including splices.

2. Inclusion of additional wall thickness to the structural requirements for the pile. A minimum of 0.125 inch shall be included for each face or surface contacting the soil from the surface to a minimum of 10 feet below the expected low groundwater level.

3. The interior of open ended pipe piles shall be considered exposed to the soil and provided with a corrosion allowance of a minimum 0.125 inch. The interior of closed end pipe piles shall be considered as a surface contacting the soils unless filled with a cementacious mortar.

4. The need for special measures, such as cathodic protection, shall be determined on an individual basis, based on type of structure, analysis of soil borings for corrosive characteristics and the degree of anticipated structural deterioration caused by corrosion.

C. Reinforced concrete pilings, including fabrications with prestressed members, shall be designed to meet the following minimum criteria:

1. Concrete to be in contact with soil or groundwater shall have a water/cement ratio of not greater than 0.45.

2. Restrictions on chloride concentrations for concrete with non-prestressed members shall be in accordance with section 17.2.7.6.

3. Chloride content of concrete shall be minimized. Mix components shall each be tested and those that contain more chloride than the practical minimum shall be rejected.

4. A minimum of three inches of concrete cover over the outermost reinforcing steel, including prestressing wires, if present.

17.2.7.8 Reinforced Concrete Retaining Walls

A. Cast-in-place concrete retaining walls shall be in accordance with the requirements in section 17.2.7.6.

B. Modular-type retaining walls shall meet the requirements in section 17.2.7.6 and the following:

1. Steel reinforcement and embedded tie strip anchors of the modules shall be constructed without special provisions for establishing electrical continuity.

2. Steel reinforcement of adjacent modules shall not be electrically interconnected. The reinforcing strips shall be coated with a fluidized-bed epoxy resin system or liquid 100 percent epoxy system.

3. Tie strips shall be coated with a fluidized-bed epoxy resin system or coal-tar epoxy system prior to module construction.

4. Longitudinal reinforcing steel within precast concrete parapets and cast-in-place junction slabs shall not be made electrically continuous.

17.3 STRAY CURRENT CONTROL

A. This chapter provides criteria for designs to minimize the corrosive effect of stray current from transit operations on transit structures and adjacent structures and facilities owned by others, (such as underground pipelines).

B. Stray current control shall reduce or limit the level of stray currents at the source, under normal operating conditions, rather than trying to mitigate the corresponding effects (possibly detrimental), which may otherwise occur on transit facilities and other underground structures. The basic requirements for stray current control are as follows:

1. Operate the mainline system with no direct or indirect electrical connections between the positive and negative traction power distribution circuits and ground.

2. Minimize the electrical resistance of the negative return facilities.

17.3.1 Traction Power System

Traction power supply system shall be designed as a dedicated system, providing power solely to the light rail line. Joint use of traction power facilities, except for common civil structures, is not permitted. Individual traction power supply system for the light rail line shall be designed with electrically isolated, independent subsystems for mainline, yard, and shop.

17.3.1.1 Traction Power Substations (Mainline)

A. See Chapter 13, Traction Electrification, for Traction Power Substation requirements.

B. Substations shall be provided with cable connections to the dc negative bus for track-to-earth resistance and track-to-earth potential monitoring. Access shall be provided either inside through use of dedicated wall space, if available, or outside through the use of a lockable, weather-tight enclosure with an open conduit (minimum 1-inch diameter PVC) between the enclosure and the dc negative bus.

C. Provisions shall be included for monitoring track-to-earth resistance and track-to-earth potentials at intervals of approximately 1.0 to 1.5 miles. Monitoring facilities shall be located in the trackway near traction power substations and at

intermediate locations where necessary to maintain the required spacing.

D. An automated track isolation monitoring system shall be installed. The monitoring system shall comprise transducers, power supply, relays, data loggers and associated equipment. It shall be connected to a central monitoring location. The system shall include hardware and software to facilitate the scheduling and performance of testing from the central monitoring location.

17.3.1.2 Positive Distribution System

See Chapter 15, Communications and Central Control, section 15.5.2, Field Control System (FCS), formerly SCADA.

A. Mainline positive distribution system shall be normally operated as an electrically continuous bus, with no breaks, except during emergency or fault conditions. Intentional electrical segregation (sectionalizing) of mainline, yard, and shop positive distribution systems is the only type of segregation permitted.

B. Overhead contact systems (OCS) consisting primarily of support poles, the contact wire and, where applicable, the messenger wire, shall be designed to meet the following minimum requirements and include the following minimum provisions:

1. A maximum leakage current to ground of 2.5 milliamperes per mile of single-track OCS with 2,500 volts dc applied between the OCS and ground.

2. Discrete grounding of individual at-grade support poles, in lieu of interconnecting poles to each other or to a common ground electrode system. Such a system shall consist of one or more ground rods driven into the earth near or below the structure sufficient to dissipate anticipated stray current leakage or lightning induced voltages.

3. Common grounding of support poles on aerial structures through electrical connection to either bonded (welded) reinforcing steel in the deck or to each other through a dedicated grounding cable and a common ground electrode system. Establish electrical connections as described in section 17.3.2.3 for OCS poles on aerial structures.

17.3.1.3 Mainline Negative Return System

A. Running Rails

1. Mainline track (two rails), including special trackwork, grade crossings and all ancillary system connections, shall be designed to have the following minimum, uniformly distributed, in-service resistance.

   Direct fixation track and
   Concrete or Wood T&B
   (with insulated rails) .....500 ohms/1000 ft

   Embedded track.....200 ohms/1000 ft

2. Yard Track shall be designed to have the following minimum, uniformly distributed, in-service resistance:

   Tie and ballast track with
   Non-insulated rail fasteners.....085 ohms/1000 ft

3. The criteria shall be met through the use of appropriately designed insulating track fastening devices, such as insulated tie plates, insulated rail clips, direct fixation fasteners, rail encasement in dielectric materials or other approved methods.

4. Ballasted track construction shall use a hard rock, non-porous, well-drained ballast with a minimum one inch clearance between the ballast material and all metallic surfaces of the rail and metallic track components in electrical contact with the rail.

5. Embedded track shall meet the following minimum provisions:

   a. Rail support and fixation devices shall not damage the rail encasement.

   b. Track encasement material shall have a minimum resistivity value of 1×10^{12} ohms-cm.

   c. Reinforcing steel within the track slab shall be electrically continuous and provisions for maintaining electrical continuity across expansion and construction joints shall be included. The track slab reinforcing steel shall be electrically continuous for the entire length of embedded track.

d. Monitoring facilities shall be included that can used for measurement of stray current flow on the track slab reinforcing shall be installed at intervals of no more than 2,500 feet.

6. Mainline track shall be electrically insulated from foreign railroad connections (sidings) by use of insulating rail joints. Location of the insulating joints shall be chosen to reduce the possibility of a vehicle bridging the isolators for a time period longer than required to move onto or off the mainline.

B. Ancillary Systems

Switch machines, signaling devices, train communication systems, and other devices or systems that may contact the rails, shall be electrically isolated from earth. Electrical equipment in direct contact with track shall not be interconnected with power neutral grounds. Provisions for isolated grounds shall be made if the electrical equipment must be grounded. The criteria shall be met through the use of dielectric materials electrically separating the devices/systems from earth or solid state isolation devices designed specifically for the purpose, such that the criteria given in this chapter are met.

C. Electrical Continuity

The running rails shall be constructed as an electrically continuous power distribution circuit through use of either rail joint bonds, impedance bonds, continuously welded rail, or a combination of the three, except for the use of insulated rail joints at the locations noted in sections 17.3.1.3 and 17.3.1.4.

17.3.1.4 Maintenance Yard

A. Yard traction power shall be provided by a separate dedicated dc power supply electrically segregated from the shop traction power system and the mainline system in both the positive and negative dc power circuits.

B. Yard track shall be electrically isolated from mainline and shop track by the use of insulated rail joints. Actual locations of isolators shall ensure that parked vehicles can not electrically connect the shop track or mainline track to the yard track for periods of time longer than that required to move a vehicle into or out of the yard.

C. Yard track shall not be connected to any grounded structure and shall not be in contact with soil or water. Drainage provisions shall be as indicated in section 17.3.1.6.

D. Ballasted track construction shall meet the following minimum provisions:

1. Use of hard rock, non-porous, well drained ballast material; and

2. A minimum 1 inch clearance between the ballast material and all metallic surfaces of the rail and metallic track components in electrical contacted with the rail.

E. Operate the yard track with no direct or indirect electrical connections between the positive and negative traction power distribution circuits and ground. Switch machines, signaling devices, train communications systems, and other devices or systems that may contact the rails, shall be electrically isolated from earth. The criteria shall be met through the use of dielectric materials electrically separating the devices/systems from earth.

F. Provide multiple negative feeder cable connections throughout the yard spaced to minimize variations in track-to-earth voltage in the yard track system.

17.3.1.5 Maintenance Shop

A. Shop traction power shall be provided by a separate dedicated dc power supply electrically segregated from the yard traction power system and the mainline system in both the positive and negative dc power circuits.

B. Shop track shall be electrically connected to the shop building and shop grounding system.

C. Shop track shall be electrically insulated from yard track by the use of insulated rail joints. Actual locations of isolators shall ensure that parked vehicles will not electrically connect the shop track to the yard track for periods of time longer than that required to move a vehicle into or out of the shop.

D. Other electrically grounded track, such as blowdown pit tracks, car wash tracks and interconnecting switching tracks between these facilities, shall be electrically insulated from the yard tracks and powered from the shop traction power supply.

17.3.1.6 Water Drainage

A. Below grade and embedded track sections shall be designed to prevent water from dropping or running onto the negative rails and rail appurtenances and shall be designed to prevent the accumulation of freestanding water.

B. Water drainage systems for track sections exposed to the environment shall be designed to prevent water accumulation from contacting the rails and rail appurtenances.

17.3.2 Transit Fixed Facilities

17.3.2.1 Underground Trackway Structures

A. Reinforcing steel in underground trackway structure inverts shall be made electrically continuous. Minimum requirements for the reinforcing steel from the top of rail down shall include the following:

1 Welding of longitudinal lap splices in the top layer of first-pour reinforcing steel;

2. Welding of all longitudinal members to a transverse (collector) member at intervals not exceeding 500 feet and at electrical (physical) breaks in the longitudinal reinforcing steel such as at expansion joints; and

3. Test facilities shall be installed at each end of station structures and at every collector bar. Facilities shall consist of insulated copper wires, conduits and enclosures terminated at an accessible location.

B. Where fiber reinforced concrete is used in underground trackway structure inverts, provide a continuous bare steel cable in the concrete for monitoring track-to-earth resistance values and stray dc current levels. Minimum requirements for the grounding electrodes shall include the following:

1. Electrodes shall be isolated from any grounding system and shall not directly or indirectly contact the dc negative or positive portions of the traction power system; and

2. Wiring connections to the cable(s) shall be coordinated with the automated track-to-earth resistance facilities required by section 17.3.1.1.C.

C. Precast segmented concrete ring tunnel construction shall meet the requirements in section 17.2.7.6 and the following, or shall be reviewed on an individual basis to determine alternative criteria when they can not be practically modified to meet the provisions specified below:

1. Embedded steel reinforcing members do not require special provisions for establishing electrical continuity but may be welded if desired;

2. Connecting hardware between adjacent rings and ring segments shall not contact the segment reinforcement. Design segment so connecting hardware is inside the segment gasket;

3. Any metallic components, which will be exposed to the soils/groundwaters, shall be coated with a fluidized-bed epoxy resin system or coal-tar two-part epoxy polyamide system; and

4. Evaluating soil conditions and environmental corrosivity to determine the need for barrier coating application. If soils are deemed unacceptable aggressive, select protective coatings in accordance with section 17.2.6.1.

D. Steel liner tunnel construction must be reviewed to determine the need for special measures, such as increased liner thickness, external coating system and/or cathodic protection. Evaluation of increased corrosion control measures shall be based upon the corrosivity of the local soils. Such soils shall be evaluated and steel liner components and corrosion control measures designed to ensure system design life is maintained.

E. Corrosion control methods selected could include considerations for internal and external coatings, segment bonding, test electrodes, and cathodic protection test ports. If cathodic protection is deemed necessary, ensure the structure cross section includes space for cathodic protection rectifier, distribution conduit and power supply.

17.3.2.2 Aerial Trackway Structures

A. Column and Bearing Assemblies, Direct Fixation

This section applies to aerial structures and bridges that use a column and bearing assembly that can be electrically insulated from deck or girder reinforcing steel and will have insulated trackwork construction.

1 Provide a wire mesh current collector mat or provide electrical continuity of top layer reinforcing steel in the deck/girder by welding all longitudinal lap splices.

2. If the top layer of reinforcing steel is made electrically continuous, interconnect all top layer longitudinal reinforcing steel electrically by welding to transverse collector bars installed at breaks in longitudinal reinforcing steel, such as at expansion joints, hinges, and at abutments. Connect collector bars installed on each side of a break with a minimum of two cables.

3. If the top layer of reinforcing steel is made electrically continuous, provide additional transverse collector bars at intermediate locations to maintain a maximum spacing of 500 feet between collector bars.

4. Electrically connect continuous reinforcement to similar reinforcements in contiguous approach slabs and concrete track bed structures.

5. Provide a ground electrode system at each end of the structure and at intermediate locations to maintain a maximum spacing between ground electrode systems of 1,500 feet. The number, location, and earth resistance of the ground electrode system must be determined on an individual structure basis.

6. Provide test facilities at each end of the structure and at intermediate locations to maintain a maximum spacing of 1,500 feet between test points. The facilities will house test wires from the collector bars, rails and ground electrode system, if present.

7. Provide electrical isolation of reinforcing steel in deck/girders from columns, abutments, and other grounded elements. Isolation can be established through the use of insulating elastomeric bearing pads, dielectric sleeves, and washers for anchor bolts and dielectric coatings on selected components. Avoid creation of ground pathways through drain leaders (if present).

B. Column and Bearing Assemblies, Tie and Ballast

This section covers the same type of aerial structures covered in section 17.3.2.2 A, but with tie and ballast track construction. Welding of reinforcing steel in the deck is not required for this configuration. The minimum requirements shall include the following:

1. Provide a waterproofing, electrically insulating membrane with protection board over the entire surface of the deck that will be in contact with the ballast. The membrane system shall have a minimum volume resistivity of 1×10^{10} ohm-centimeters and shall withstand the mechanical stresses imposed by the ballast material and train operation.

2. Provide electrical isolation of reinforcing steel in deck/girders from columns, abutments, and other grounded elements. Isolation can be established through the use of insulating elastomeric bearing pads, dielectric sleeves, and washers for anchor bolts and dielectric coatings on selected components.

C. Bents and Girders, Direct Fixation

1. This section applies to aerial structures that use bent type supports with reinforcing steel extending into the deck/girders. Girders can be pre- or post- tensioned. This type of construction precludes the electrical isolation of deck/girder steel from bent/column steel. Ground electrode systems are not required for these types of structures.

2. Provide electrical continuity of top layer reinforcing steel in the deck/girder by welding all longitudinal lap splices.

3. Electrically interconnect all top layer longitudinal reinforcing steel by welding to transverse collector bars installed at bents and on each side of breaks in longitudinal reinforcing steel, such as at expansion joints, hinges and at abutments (deck side only). Connect collector bars installed on each side of a break with a minimum of two cables. Provide slack for structure movement at joints.

   a. Provide electrical continuity of all column/bent steel by welding appropriate reinforcing to at least two vertical column bars. Make these connections to each of the two vertical bars at the top and bottom of the column/bent.

   b. Electrically interconnect column/bent steel to deck/girder steel by welding at least two vertical column bars to collector bars installed at bents.

   c. Electrically interconnect column/bent steel to footing steel when column/bent steel penetrates the footing.

Weld at least two vertical column/bent bars to footing reinforcing steel.

d. Electrically interconnect pre- or post-tensioned cables to continuous longitudinal reinforcing steel by welding a cable between each anchor plate and the longitudinal reinforcing steel.

e. Provide test facilities at each abutment and at 500-foot spacing.

D. Bents and Girders, Tie and Ballast

This section covers the same type of aerial structures covered in section 17.3.2.2 C, but with tie and ballast track construction.

1. Provide the same features as described in section 17.3.2.2 C, 1 through 5.

2. Provide a waterproofing, electrically insulating membrane over the entire surface of the deck that will be in contact with the ballast. The membrane system shall have a minimum volume resistivity of 1×10^{10} ohm-centimeters to provide a minimum circuit resistance of 1,000 meg-ohms. Such electrical resistance characteristics shall be maintained across the entire membrane regardless of the joining method used for seams.

E. Concrete Deck/Exposed Steel, Direct Fixation

This section applies to bridge structures that use a reinforced concrete deck with exposed steel superstructure and will have insulated trackwork construction. This type of construction precludes the electrical isolation of deck reinforcing steel from superstructure steel.

1. Provide electrical continuity of top layer reinforcing steel in the deck/girder by welding all longitudinal lap splices.

2. Electrically interconnect top layer longitudinal reinforcing steel by welding to transverse collector bars installed at breaks in longitudinal reinforcing steel, such as at expansion joints, hinges, and abutments. Connect collector bars installed on each side of a break with a minimum of two cables.

3. Provide additional transverse collector bars at intermediate locations to maintain a maximum spacing of 500 feet between collector bars.

4. If the total structure length exceeds 250 feet, provide a ground electrode system at each end of the structure and at intermediate locations to maintain a maximum spacing between ground electrode systems of 1,500 feet. The number, location, and earth resistance of the ground electrode system must be determined on an individual structure basis.

5. Provide test facilities at each end of the structure and at intermediate locations to maintain a maximum spacing of 500 feet between test points. The facilities will house test wires from the collector bars and ground electrode system, if present.

6. Provide electrical isolation of reinforcing steel in the deck and superstructure steel from columns, abutments, and other grounded elements. Isolation can be established through the use of insulating elastomeric bearing pads, dielectric sleeves, and washers for anchor bolts and dielectric coatings on selected components.

7. If electrical isolation of reinforcing steel in the deck and superstructure steel from columns, abutments and other grounded elements cannot be obtained, then electrical continuity of metallic components within these latter elements must be established by appropriate welding and bonding procedures.

F. Concrete Deck/Exposed Steel, Tie and Ballast

This section covers the same type of aerial structures as covered in section 17.3.2.2 E, but with tie and ballast track construction. Welding of reinforcing steel in the deck is not required for this configuration.

1. Provide a waterproofing, electrically insulating membrane with protection board over the entire surface of the deck that will be in contact with the ballast. The membrane system shall have a minimum volume resistivity of 1×10^{10} ohm-centimeters and be installed in sufficient thickness to provide an isolation resistance of 1,000 meg-ohms or greater.

2. Provide electrical isolation of reinforcing steel in the deck and superstructure steel from columns, abutments, and other grounded elements. Isolation can be established through the use of insulating elastomeric bearing pads, dielectric sleeves, and washers for anchor bolts, and dielectric coatings on selected components.

3. If electrical isolation of reinforcing steel in the deck and superstructure steel from columns, abutments, and other grounded elements cannot be obtained, then electrical continuity of metallic components within these latter elements must be established by appropriate welding and bonding procedures.

17.3.2.3 Overhead Contact System (OCS) Pole Foundation Grounding

A. All metallic components, inclusive of the pole baseplate, that will be partially embedded or come in contact with concrete surfaces shall be hot-dip galvanized and have a barrier coating. The barrier coating shall extend a minimum of 6 inches into the concrete and a minimum of 1/2 inch above the surface of the concrete.

B. At-Grade OCS Support Poles, provide grounding as indicated in section17.3.1.2.C.

C. OCS poles located on aerial structures shall meet the following criteria, depending on the type of aerial structure.

1. Where the aerial structure does not include welded deck reinforcing steel, electrically interconnect the OCS support poles to a ground electrode system.

a. Provide a copper cable from each OCS support pole to the grounding electrode system. The copper cable shall be sized based upon anticipated fault current and fault clearing time. Thermite weld or braze the cable to the OCS support pole and to the nearest grounding electrode system along the aerial structure deck.

b. The cabling shall be routed in conduit and terminated in junction boxes or test cabinets that also house wires from the deck reinforcing steel and the ground electrode system.

c. Cabling shall be designed to allow for connection of interconnected OCS poles along the aerial structure to all ground electrode systems installed with a particular aerial structure.

2. Where the aerial structure has welded deck reinforcing steel, electrically connect the OCS support poles to the welded deck reinforcing steel.

a. Provide a copper cable from each OCS support pole to the deck reinforcing steel. The copper cable shall be

sized based upon anticipated fault current and fault clearing time.

b. Thermite weld or braze the cable to the OCS support pole and to the nearest electrically continuous reinforcing bar in the aerial structure deck.

17.3.2.4 Utility Structures

A. All piping and conduit shall be non-metallic, unless metallic facilities are required for specific engineering purposes. There are no special provisions required if nonmetallic materials are used.

B Metallic Facilities (Systemwide)

1. Pressure or non-pressure piping exposed within tunnels, pipes, chases, or crawl spaces or embedded in concrete inverts shall not require special provisions. Piping that contains a hazardous material and placed in direct contact with soil or concrete shall be provided with an external bonded coating, electric isolation, and cathodic protection.

2. Internal piping that penetrates tunnel, foundation, or station walls shall be electrically insulated from the external piping to which it connects on the inside of the tunnel or station.

3. Pipe penetrations through exterior walls of underground structures shall use watertight wall sleeves that electrically insulate the pipe from the structure reinforcing.

4. All buried pressurized piping external to tunnels, crawl spaces, and station structures shall meet the criteria specified in section 17.3.3.

17.3.3 Facilities Owned by Others

17.3.3.1 Replacement/Relocated Facilities

A. Corrosion control requirements for buried utilities installed by the owner/operator as part of transit construction shall be the responsibility of the individual utility owner/operator. Minimum stray current corrosion control criteria, when guidance is requested by the utility owner/operator, shall be in accordance with section 17.3.3.2.

B. Relocated or replaced utilities, installed by transit contractors as part of contractual agreement between the transit agency and the utility, shall be installed in accordance with the utility

owner specifications and shall include the following minimum provisions. These provisions are applicable to ferrous and reinforced concrete cylinder piping. Other materials and structures will require individual review.

1. Electrical continuity through the installation of insulated copper wires across all mechanical joints for which electrical continuity cannot be assured. (See Section 17.2.6.4).

2. Electrical access to the utility structure via test facilities installed in accordance with section 17.2.7.1.

   a. The need for additional measures, such as electrical isolation, application of a protective coating system, installation of cathodic protection, or any combination of the preceding, shall be based on the characteristics of the specific structure and to not adversely effect the existing performance within the environment.

   b. Test stations shall be installed on either side of utility crossings of at-grade tracks and at nominal spacing of 500 feet, on utility rearrangements that are parallel to at-grade track.

17.3.3.2 Existing Utility Structures

The need for stray current monitoring facilities shall be determined by the utility operators. Test facilities may be installed at select locations for the purpose of evaluating stray earth current effects during start-up and revenue operations.

17.3.3.3 Existing Bridge Structures

Stray current corrosion control for existing bridge structures shall be addressed by limiting earth current levels at the source (running rails). Meeting the criteria established in sections 17.3.1.1, 17.3.1.2, 17.3.1.3, and 17.3.2.2 will provide the primary stray current control for these facilities.

17.4 ATMOSPHERIC CORROSION CONTROL

A. Coatings shall have established performance records for the intended service and be compatible with the base metal to which they are applied.

B. Coatings shall be able to demonstrate satisfactory gloss retention, color retention, and resistance to chalking over their minimum life expectancies.

C. Coatings shall have minimum life expectancies, defined as the time prior to major maintenance or reapplication, of 15 to 20 years.

17.4.1 Metallic Sacrificial Coatings

All carbon and alloy steel assemblies, fixtures and conduits for use in tunnels, stations, crawlspaces, vaults, or above grade shall be hot dip galvanized. Where appropriate for aesthetic reasons, such items shall also receive an organic overcoat.

17.4.2 Organic Coatings

A. Organic coating systems shall consist of a wash primer (for galvanized and aluminum substrates only), a primer, intermediate coat(s), and a finish coat. Acceptable organic coatings, for exposure to the atmosphere, shall be as follows:

1. Aliphatic polyurethanes
2. Vinyl copolymers
3. Fusion-bonded epoxy polyesters, polyethylenes and nylons
4. Acrylics, where not exposed to direct sunlight
5. Alkyds, where not exposed to direct sunlight
6. Epoxy as a primer where exposed to the atmosphere or as the complete system where sheltered from sunlight

17.4.3 Conversion Coatings

Conversion coatings, such as phosphate and chromate coatings, shall be used as pretreatments only for further application of organic coatings.

17.4.4 Ceramic-Metallic Coatings (Cermets)

This hybrid-type coating system is acceptable for use on metal panels and fastening hardware.

17.4.5 Sealants

Seal all crevices with a polysulfide, polyurethane or silicone sealant.

17.4.6 Barrier Coating System

A. One of the following barrier coating systems shall be used where corrosion protection is needed but appearance is not a primary concern. Apply all coatings according to manufacturer's specifications.

1. Near white blast surface according to SSPC-SP 10. Follow with a three-coat epoxy system; or

2. Near white blast surface according to SSPC-SP 10. Follow with a three-coat epoxy zinc, high build epoxy system.

B. Use one of the following barrier coating systems where corrosion protection and good appearance are needed. Apply all coating according to manufacturer's specifications.

1. Near white blast surface according to SSPC-SP 10. Follow with a three-coat inorganic zinc, high build epoxy, polyester urethane system; or

2. Near white blast surface according to SSPC-SP 10. Follow with a three-coat vinyl system.

TABLE 17-1
ACCEPTABLE CEMENT-TYPE BASED ON SULFATE CONCENTRATIONS OF SOILS AND GROUNDWATERS

Acceptable Cement Type	Percent Water Soluble Sulfate (as SO_4) in Soil Samples (%) in Groundwater (ppm)	Ppm Sulfate (as SO_4)
Type II	0.10 to 0.20	150 to 1,000

END CHAPTER 17

18. FIRE/LIFE SAFETY

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18. FIRE/LIFE SAFETY

18.1 INTRODUCTION

18.1.1 Purpose

This chapter establishes the design criteria for the Sound Transit Link System Fire/Life Safety. The purpose of this document is outlined as follows:

A. The purpose of this chapter is to provide sufficient definition and description of the fire/life safety characteristics to allow the design engineers to select appropriate features for systems, equipment and facilities, in conjunction with local codes and ordinances. It is intended to assure that the Sound Transit Link System achieves the optimal level of file/life safety.

B. To define the fire/life safety requirements, which shall be included as part of the technical provisions in contract documents.

18.1.2 Passenger Safety Objective

A. Passenger safety shall be equal to or exceed that of any light rail transit system now operating in the United States. This shall be accomplished by incorporating design features and the development of procedures for the safe and efficient handling of normal, abnormal, and emergency conditions.

B. The design of the system shall include provisions to detect and alarm unusual conditions, and enable the timely response and action by emergency response forces. As part of this integrated safety approach, design provisions shall enable safe and timely evacuation of patrons and personnel from structures, disabled vehicles, and facilities. The provisions shall also include necessary safeguards to protect patrons, system personnel, and emergency response forces during evacuation and shall minimize exposure to hazards.

18.1.3 Scope

This chapter outlines the fire/life safety criteria in the following areas:

A. Station and site

B. Guideway

C. Signaling

D. Communications

E. Electrical Power

F. Yard and Shop

G. Operations Control Center

H. Training

18.1.4 Applicable Standards, Codes, And Guidelines

A. System Safety and Fire/Life Safety design provisions shall be in accordance with the following standards and guidelines, to the extent used herein. The Reference to a code or standard is the latest edition in effect at the time of use unless otherwise specified.

1. Institute of Electrical and Electronics Engineers (IEEE) 383

2. National Fire Protection Association (NFPA) Standard Nos. 1, 2, 10, 13, 14, , 70, 72, 90A, 101, and 130, as adopted by the Authority Having Jurisdiction.

3. Underwriters Laboratory (UL) Standards 44 and 83

4. International Building Code (IBC), as adopted by the State of Washington and amended by the local jurisdiction.

5. International Fire Code (IFC), as adopted by the State of Washington and amended by the local jurisdiction.

6. Washington Administrative code (WAC 296-155) Standards for Construction Work

7. Seattle Building Code (SBC)

18.2 STATION AND SITE

A. Stations shall be designed to facilitate the movement of patrons in an efficient, safe and secure manner.

B. Passenger Stations are defined as those facilities and their appurtenances used to load and unload passengers, and are located on exclusive, semi-exclusive, or open right-of-way, often with passenger access restricted by fences or other barriers.

1. ***Underground Station:*** Any station with the platform below grade.

2. ***Aerial Station:*** Any station where the platform is located on an elevated guideway.

3. ***Enclosed Station:*** Any station, or portion thereof, that is not open to the atmosphere, and where smoke and heat is not allowed to disperse directly to the atmosphere.

4. ***Open Station:*** Any station, or portion thereof, that is open to the atmosphere, and where smoke and heat is allowed to disperse directly to the atmosphere.

C. This chapter is applicable to elevated, at-grade and underground passenger stations with exception to code requirements noted.

18.2.1 Occupancy

The primary function of a passenger station is to provide a place of waiting for a train or as a means of exit upon detraining. The station shall be classified as a Group A, Division 3 occupancy in accordance with the 2003 International Building Code (IBC) and 2003 International Fire Code (IFC), unless amended by the local jurisdiction.

A. Minimum occupancy load shall be based on IBC Table 1004.1.2, which does not include platform edge, benches, fire cabinets, etc.

B. Maximum occupancy loads shall be based on NFPA 130, but not to exceed an occupancy based on 5 square feet per person according to Chapter 10 of the IBC, (applicable criteria for Group A occupancy classification). Methods for calculating occupancy/required exit widths (IBC or NFPA 130) shall not be mixed; i.e.: occupant load in accordance with the IBC shall be the occupant load based on the square footage indicated in Table 1004.1.2, not the projected occupant load based on the NFPA 130 projected patronage.

18.2.2 Construction Material

A. Underground stations shall not be less than Type I construction as defined in IBC Chapter 6.

B. The minimum type of construction for at-grade and elevated passenger stations shall be IBC Chapter 6 Type I or Type II or combinations of Types I and II approved non-combustible construction.

18.2.3 Station Occupancy Separations

A. Public areas shall be separated from non-public areas by a 2-hour fire separation.

B. In underground stations, public areas shall be separated from non-transit occupancies, traction power substation, and vaults by a 3-hour fire separation.

C. Openings in a 3-hour fire separation shall be protected by a labeled 3-hour door, and in a 2-hour separation by a, 1-1/2 hour door, in accordance with IBC Chapter 3. Doors shall be self-closing and latching where emergency exit doors are provided in public areas, provide panic and fire exit hardware in accordance with IBC 1008.1.9.

D. Doors in a non-environmentally controlled application shall be suitable for ambient condition.

18.2.4 Station Mechanical Requirements

A. Ancillary area ventilation systems shall be arranged so that air is not exhausted into station public occupancy areas in any ventilation mode. Installation of such systems shall be in accordance with NFPA 90A. All required exit enclosures shall be pressurized, in accordance with IBC 1019.1.8. Exception: Open public areas in at-grade or aerial stations.

B. Valve-regulated lead-acid battery systems and rooms housing valve-regulated lead-acid batteries shall be in accordance with IFC Section 609.6. Valve regulated lead-acid battery systems may be housed in the same room as electrical switchgear provided that continuous ventilation is furnished. No airflow shall be annunciated at Operations Control Center (OCC).

1. The no-airflow signal shall activate an alarm at the OCC.

18.2.5 Emergency Ventilation

A. In underground stations, ventilation requirements in accordance with NFPA 130, Chapter 7 shall be provided for the control of heat and smoke in an emergency.

B. In accordance with NFPA 130, ventilation shafts at grade shall be located as follows:

1. Grates (see Chapter 20, HVAC, section 20.7.4, Shaft Design).

2. Shafts and ventilation structures used to exhaust smoke and particles of combustion shall be designed in accordance with Chapter 20, HVAC, section 20.7.4, Shaft Design.

3. Individual emergency ventilation fan motors shall be designed in accordance with Chapter 20, HVAC, section 20.5.5.C, Tunnel ECS, Equipment and Accessories.

C. Emergency fans and dampers shall be designed in accordance with Chapter 20, HVAC, section 20.5.5, Tunnel ECS.

D. Ventilation Controls (See Chapter 20, HVAC, section 20.5.5.C 3 and 4, Tunnel ECS, Equipment and Accessories, Operation and Controls and Instrumentation and Controls.)

1. Fans shall be controlled from the following locations, in descending order of hierarchy:

a. Motor Control Center (MCC)

b. Emergency Management Panel (EMP)

c. Operations Control Center (OCC)

2. Local/MCC control shall be protected from the fans by a two-hour separation, with a protected means of access to the MCC (NFPA 130, paragraph 7.3.4).

3. Air flow and air flow direction shall be positively identified to the OCC, EMP, and MCC when fans are in operation.

4. Trouble alarms shall be annunciated at the MCC, EMP, and OCC.

18.2.6 Station Electrical Requirements

A. Electrical equipment, wiring materials, and installation within passenger stations shall conform to the requirements of the National Electrical Code (NFPA 70). In addition to the requirements of NFPA 130, paragraphs 5.4.2 through 5.4.5.

B. Uninterruptible Power Supply (UPS) in accordance with NFPA 70 Article 700.12 shall be provided for critical Fire/Life systems to include but not be limited to the following (also see Chapter 23, Electrical Systems, section 23.4.2, Power Supply Reliability Requirements):

1. Fire detection, alarm and suppression systems

2. Security control and indicator systems

3. Emergency lighting, to include top and bottom lighting at escalator landings

4. Passenger assistance intercoms

5. Indicator for elevators and escalators

6. Emergency signage to include any automated emergency messages

7. Closed Circuit Television (CCTV)

8. Public Address

9. Radio

10. Emergency Telephone

11. Chapter 23, Electrical Systems, section 23.4.2, Power Supply Reliability Requirements

C. Wire and Cable (See NFPA 130, paragraph 5.4)

D. Conductors for emergency lighting, communications, and other systems required during emergency operations shall be protected from fires and from physical damage by transit vehicles, and from normal transit system operations and maintenance activities (NFPA 130, paragraph 7.7.7).

E. Overcurrent elements, designed to protect emergency lighting and communications equipment and located in spaces other than the main distribution system equipment rooms, shall not depend upon thermal properties for operation.

F. Grounding: (See Chapter 23, Electrical Systems, section 23.5, Systemwide Grounding.)

G. Dual feeders shall be provided for emergency ventilation fans in accordance with NFPA 130, paragraph 7.7.1. Feeders shall be in separate tunnels, conduits, or raceways when possible and protected against damage from fire, and operations and maintenance activities.

H. The secondary source of power for elevator emergency operation shall be in accordance with IBC 3016.6 (See DCM 23.4.1.B)

18.2.7 Means of Egress

A. For at-grade and elevated passenger stations, a minimum of two exits from the platform shall be provided. No point on any station platform

or concourse shall be more than 250 feet from an exit for fully sprinklered stations and 200 feet for non-sprinklered station.

B. For underground stations, a minimum of two exits from the platform shall be provided. No point on any station platform or concourse shall be more than 150 feet from an exit or place of safety.

C. Passenger stations shall be provided with a sufficient exit capacity to permit evacuation of the station platform in four minutes or less, and evacuation of the station public area to a safe area of refuge within six minutes, in accordance with NFPA 130, paragraphs 5.5.3.1 and 5.5.3.2, Annex C. One escalator shall be considered out of service.

   1. Modifications of the evacuation time may be permitted based on an engineering analysis by evaluating material heat release rates, station geometry, and emergency ventilation systems, subject to approval by the Authority Having Jurisdiction (NFPA 130, paragraph 5.5.3.1.2).

   2. For at-grade and elevated structures where the station platform is open to the elements and where the concourse is below or protected from the platform by distance or materials as determined by an appropriate engineering analysis, that concourse shall be permitted to be defined as a “point of safety” (NFPA 130, paragraph 5.5.3.2.1).

   3. For Underground or enclosed stations equipped with an emergency ventilation system designed in accordance with NFPA 130 chapter 7, where the emergency ventilation system provides protection for the concourse from exposure to the effects of a train fire at the platform as confirmed by an engineering analysis, that concourse is permitted to be defined as a “point of safety” (NFPA 130, paragraph 5.5.3.2.2).

   4. Modification of the evacuation time shall be permitted based on an engineering analysis by evaluating material heat release rates, station geometry and emergency ventilation systems (NFPA 130, paragraph 5.5.3.2.3).

   5. The minimum required exit width shall not be less than required by IBC 1005.2.

   6. The areas of Safe Refuge shall comply with IBC 1007.6 where applicable.

D. The exit width shall not be reduced or otherwise diminished to less than the largest minimum width required to that point along the path of exit travel (IBC, section 1005.1).

E. If remote stopping of escalators, only platform bound escalators shall be stopped in a situation requiring station evacuation. Prior to the stop of an escalator (based on a preset time), a message alerting patrons may be announced over the PA. Escalators designed to stop gradually are preferred to an abrupt stop.

F. Stairs and Escalators:

1. Stairs and escalators regularly used by passengers need not be enclosed to be used in the NFPA 130 exit calculations, unless specifically required by the local jurisdiction.

2. Stairs used for egress shall comply with IBC Chapters 10 and 11. Emergency exit stairs in underground stations shall be a minimum of 66” wide.

3. Escalators used for the NFPA calculation shall not constitute more than half of the units of exit at any one level (NFPA130, paragraph 5.5.3.3.2.5).

4. The escalator having the most adverse effect upon egress capacity shall be discounted (NFPA 130, paragraph 5.5.3.3.2.6).

5. If emergency stairs are required to meet exiting capacity, these shall:

a. Conform to IBC Section 1009.

b. Be continuous to grade.

c. Be located off the end of platform, and if two are required, they shall be at opposite ends of the platform.

d. Be rated for 2 hours, with 1-1/2 hour, self-closing and latching doors.

e. Access to grade shall be through standard code-conforming openings in a facility or structure with panic hardware.

f. The travel distance to an exit shall not exceed the requirements of IBC 1015.

G. Exits shall be provided from non-public areas of stations in accordance with the IBC. Exiting into the public area from a separated, non-public area shall be considered as exiting into a refuge area in accordance with IBC 10021.4.

H. The required exit capacity shall be determined by the occupancy as determined by sections 18.2.1 A and B.

1. Exit capacity for the NFPA calculation shall be calculated based upon the NFPA 130, paragraph 5.5.2 unless superseded by the local jurisdiction.

2. The exit capacity for the IBC calculation shall be computed at the rate of one occupant per unit of area as prescribed in the IBC, Table 1004.1.2, unless superseded by local jurisdiction.

   a. There shall be sufficient egress capacity to evacuate the platform in 4 minutes or less, as defined by NFPA 130, paragraph 5.5.2.8, but in no case shall the required egress width be less than prescribed by IBC Section 1005, unless amended by the local jurisdiction.

      1) The minimum number of exits based on occupancy level shall be as follows: 1-500 = 2, 501 - 1000 = 3, over 1000 = 4 (IBC Table 1018.1)

      2) Every required stairway serving floor levels more than 30 feet below stairway level of discharge, except for the main circulation elements, shall comply with the requirements for a smokeproof enclosure as provided in IBC section 1019.1.8, unless amended by the local jurisdiction.

18.2.8 Station Emergency Access

A. Designated fire lanes shall be provided around all passenger stations for emergency response and fire department equipment access. Markings and signage will be per local AHJ requirements.

B. Stations and ancillary rooms shall be accessible to emergency response personnel at all times by use of key-lock box systems and other features.

C. Use of access-control technology is permitted.

18.2.9 Emergency Lighting and Signing

A. Aerial and Underground passenger stations shall have lighting not less than 1 foot-candle at the walking surface along evacuation routes.

B Emergency lighting shall be designed, installed, and maintained in accordance with IBC/IFC Chapter 10.

C. Emergency exits signs shall be provided in accordance with, IBC/IFC Chapter 10, and NFPA 101, except as noted herein. Exit signs shall

be illuminated internally or externally on the face by 5 foot-candles. Self-luminous signs may be used in non-public areas.

D. Emergency lighting shall be designed to highlight the top and bottom of stairs and escalators in addition to the required emergency illumination.

E. Power for the emergency lighting and exit signs shall be from the UPS.

F. In compliance with IBC Chapter 11, underground and elevated stations shall provide both visual and audible announcements when a situation requires emergency action or station evacuation.

G. Means of egress identification shall be provided in accordance with IBC/IFC Chapter 10.

18.2.10 Fire Protection-Stations

Fire protection features shall conform to applicable national, state, and local municipal codes.

A. Protective Signaling Systems

1. Elevated and underground stations shall have an automatic fire detection, alarm, and control system, conforming to NFPA 72, as required.

2. All devices, to include smoke detectors, water flow indicators, fire alarms, suppression systems and so on, when activated, shall annunciate at the OCC and the emergency management panel. The signal location and type of alarm shall be identified.

3. Alarm signals shall be automatically “locked in” until operated devices are returned to normal condition. Fire alarm panel shall be reset only by the Authority Having Jurisdiction.

4. Smoke detectors shall be installed in all rooms that do not have automatic fire sprinklers or as required by the AHJ. Traction power substations, high-voltage electrical rooms, communications rooms, and signal rooms may have dry pre-action automatic fire sprinkler systems that are activated by cross-zoned smoke detectors.

a. Activation of a smoke detector or water flow indicator shall cause all ventilation in the incident zone to be shutdown and induce pressurization to prevent smoke from contaminating the non-incident platform, the unaffected bore, corridors, elevators, and stairs.

b. Activation of a smoke detector or of a water flow indicator in the fire sprinkler zone serving an elevator concourse or lobby, elevator shaft, or elevator equipment room shall cause the elevator to remain or return to the level accepted by the AHJ automatically. Escalators moving in the direction of egress may remain in operation when the fire alarm is activated.

5. Detailed data from the automatic fire detection, alarm, and control systems shall be provided locally in such a manner as to allow emergency response personnel to formulate proper responses. Detailed requirements for these subsystems are contained in the following paragraphs.

B. Fire Suppression Systems

1. Train signaling and communication rooms, if contained within passenger stations, shall be protected by a double interlocked pre-action sprinkler system complying with NFPA 13 and NFPA 72.

   a. The design shall permit activation automatically and manually from outside the room.

   b. Automatic activation shall be through a cross-zoned detection system.

2. Automatic sprinkler protection designed and installed throughout elevated and underground stations, including all public areas, ancillary spaces, and access stairways except as noted elsewhere in accordance with IBC Chapter 9, NFPA 13, as required for fully sprinklered buildings, Seattle Fire Code Section 903 as amended by the local jurisdictions, and approved by the AHJ.

   a. Toilet rooms

   b. Store rooms

   c. Trash rooms

   d. Telephone rooms

   e. Escalator trusses for entrance escalators at underground stations only

   f. Non-designated rooms

   g. Janitor rooms

h. Exceptions will be limited to those permitted by NFPA 13 for fully sprinklered buildings

3. Water flow and trouble alarms shall be annunciated at OCC and the station emergency management panel.

C. Water Supply and Fire Hydrants

Water flow and fire hydrant requirements for all areas of passenger stations shall be in accordance with IBC, IFC Section 508.3 and IFC Appendices B and C, unless amended by the local jurisdiction. See section 18.8.2, Yards, for distribution requirements.

1. Hydrants shall be marked in a manner in accordance with Local Public Utilities or according to the local jurisdiction.

D. Standpipes

See Chapter 24, Plumbing and Fire Protection, section 24.7.3, Standpipe Systems, for standpipe requirements.

E. Underground Standpipes

See Chapter 24, Plumbing and Fire Protection, and section 24.7.3, Standpipe Systems, for standpipe requirements.

F. Portable Fire Extinguishers

1. Multipurpose fire extinguishers shall be located in passenger station ancillary spaces, in accordance with IBC Section 906 and IFC Standard 10-1, and NFPA 10.

2. In electrical rooms, 10:BC carbon dioxide extinguishers shall be provided.

3. At other station locations, 4A40BC extinguishers shall be provided.

G. Emergency Management Panel (EMP)

1. Stations equipped with elevators, escalators, and/or emergency ventilation systems shall be provided with an EMP in accordance with section 18.6.6.

2. The EMP shall be located in the public area in the immediate vicinity of the main (primary) entrance, or as determined by the AHJ.

3. In underground stations the EMP (Annunciator Panel) shall be in accordance with NFPA 72 and IFC Section 509 unless amended by the local jurisdiction.

H. Fire Department Connections

Fire department connections for fire department use in supplying the standpipe system shall be located in accordance with IFC Section 912 unless amended by the local jurisdiction.

18.2.11 Stations and Patron Access

A. Stations shall be designed to facilitate the movement of patrons in an efficient, safe, and secure manner.

B. Passenger stations are defined as those facilities and their apputenances used to load and unload passengers, and are located on exclusive or semi-exclusive right-of-way, with passenger access restricted by fences or other barriers.

C. Right-hand flow patterns shall be maintained, where possible.

D. All walking surfaces shall have slip-resistant surfaces under both dry and wet conditions.

E. Walking surfaces shall be adequately sloped to prevent accumulation of moisture.

F. Access to the facilities shall meet ADA requirements; for example:

(See Sound Transit ADA Guidelines)

1. Curb cuts shall be provided as necessary.

2. Bus loading and unloading zones shall not require crossing traffic lanes.

18.3 GUIDEWAY

18.3.1 Hazardous and Flammable Liquids and Gases

A. Flammable or hazardous liquid or gas lines crossing the right-of-way shall be installed and protected in accordance with the IBC or as required by the local jurisdictions.

B. Cut-offs shall be provided on each side of the right-of-way.

18.3.2 Construction

A. Structures associated with at-grade and elevated guideway shall be of noncombustible material, and not less than Type I or Type II construction, IBC Chapter 6. Structures and bridges shall be designed in accordance with Chapter 8, Structural and Chapter 8A, Seismic Design.

B. Substations located beneath the guideway shall have a non-combustible roof.

C. Fire separations within station ancillary areas shall be provided to separate individual occupancies. For additional requirements see NFPA 130, paragraphs 6.2.1.7 and 6.2.1.7.1.

1. Ancillary areas shall be separated from guideway areas within underwater line sections by a minimum of 3-hour fire-resistive construction (See NFPA 130, paragraph 6.2.1.7.1).

2. Ancillary areas shall be separated from the trainway areas in underground line sections by a minimum of 2-hour fire-resistive construction (NFPA 130, paragraph 6.2.1.7.1).

18.3.3 Means of Access

A. Aerial Guideways

1. Access by emergency-response personnel to the aerial guideway will be through passenger stations, public streets by use of ladder or other equipment, by emergency stairs and elevators as applicable, or as required by the local jurisdiction.

2. Adjacent roadways or special access roads at maximum intervals of 2,500 feet shall be provided for access to the elevated guideway (See NFPA 130, paragraph 6.4.5), or as required by local jurisdiction.

3. Fire department access roads shall be provided to the elevated guideway in accordance with IFC Section 503.

B. At-Grade Guideways

1. Access gates shall be operable with a key box entry system complying with IFC 506 for use by emergency response personnel and shall be provided in security fences as determined by Sound Transit.

2. Where a roadway is fenced, at-grade roadway access gates shall have a minimum unobstructed opening of 20 feet.

3. Personnel gates shall be at least 48 inches wide. Gates shall be located as close as practicable to portals for ease of access to tunnels. (See 18.3.3.A 3)

4. The maintenance access shall be suitable for use by emergency vehicles, if more than 150 feet from a public roadway.

5. Graphics shall be provided adjacent to each gate identifying the track section, geographic location, and traction power feeder zone. Warning signs, identifying the appropriate hazards, shall be posted at access points to the guideway, at fences and barriers.

6. Access by emergency-response personnel to at-grade stations will be from any accessible point along the guideway.

C. Underground Guideways

1. Access by emergency response personnel to underground guideway shall be through passengers stations, vent shaft, emergency exit, portal, rescue train or hi-rail vehicle. (NFPA 130, paragraph 6.2.6)

D. Access by emergency response personnel to U or cut sections of the guideway shall be from the adjacent at-grade access points according to section 18.3.3 B, or when the length exceeds 2,500 feet by access ladders.

18.3.4 Means of Egress

A. Aerial Guideways

1. A 44-inch minimum crosswalk shall be provided through crossover if required to move from the safety walk to the end of platform or to an egress point.

2. Means of egress shall be provided for emergency evacuation of a train at any point along elevated guideway. Maximum travel distance to a point of safe egress shall be in accordance with NFPA 130, paragraphs 6.4.5.2 or as approved by the AHJ.

3. System egress points shall be illuminated. This may be ambient lighting provided that analysis shows it to be reliable and adequate (See NFPA 130 paragraph 6.2.4.7.5 as a possible standard of what can be considered adequate).

4. Walking surfaces shall have a uniform, slip-resistant design (NFPA 130 6.2.6.4).

5. Raised walkways, ramps and stairs shall be provided with a handrail that shall not obstruct egress from the train (NFPA 130, paragraph 6.2.6.6). Other requirements of IBC 1009.11 shall apply.

6. The minimum unobstructed width of egress facilities located within or directly adjacent to the trainway shall be 24 inches measured at the walking surface (NFPA 130, paragraph 6.2.6.11).

7. If a center walkway is constructed, a minimum clear width of 2 feet 6 inches shall be provided. Guideway appurtenances (catenary poles, light standards, passenger assistance intercoms, corrosion control units, etc) shall not encroach on the safety walk clear width.

B. Tunnels

1. In single bore tunnels or where crosspassages are not provided, emergency exit stairways to the surface shall be spaced so that the maximum travel distance to the exit shall not be more than 1250 feet, unless otherwise required by the “Authority Having Jurisdiction”.

   a. The stairway shall be designed in accordance with IBC Section 1009.

   b. The stairway shall be enclosed and shall lead directly to the outdoors or to a safe refuge area.

   c. Stations and portals can be considered exits to the surface.

2. Where trainways in tunnels are divided by a minimum of 2-hour rated fire walls or where trainways are in twin bores. Such an arrangement shall be deemed to afford adequate protection for the passengers via cross-passageways between trainways and, therefore shall be permitted to be utilized in lieu of Emergency exit stairways to the surface.

   a. Cross-passages shall not be farther than 800 feet apart.

   b. Openings in cross-passages shall be protected with 1-1/2 hour fire door assemblies.

   c. A non-contaminated environment shall be provided in that portion of the trainway that is not involved in an emergency and that is being used for evacuation.

d. A ventilation system shall be designed to control smoke and to prevent the cross-passage from being contaminated.

e. An approved evacuation method shall be provided.

f. Cross-passages shall be of 2-hour construction.

3. The minimum unobstructed width for walkways directly adjacent to the trainway shall be 24 inches measured at the walking surface, and 30 inches measured at a height of 56 inches above the walkway and 12 inches measured at a height of 80 inches above the walking surface.

4. Handrails shall be installed at 3 feet 6 inches on the tunnel wall above the safety walk.

C. Crosswalks

1. Crosswalks shall be provided at track level to ensure walkway continuity (NFPA 130, paragraph 6.2.6.7)

2. Crosswalks shall have a uniform walking surface at the top of the rail. (NFPA 130, paragraph 6.2.6.8)

3. Walkway continuity shall be maintained at special trackwork sections (e.g. cross-overs, pocket tracks) (NFPA 130, paragraph 6.2.6.9)

18.3.5 Fire Protection

A. The wayside traction power substations and rooms and structures housing train signaling, communication equipment, or incoming electrical service equipment shall be provided with either an automatic fire detection system, or an automatic fire suppression system as specified by IBC/IFC Chapter 9 and NFPA 13.

B. The status of all detection and suppression systems shall be monitored and displayed at the OCC.

C. Fire extinguishers:

1. Fire extinguishers in accordance with NFPA 10 shall be provided in ancillary rooms located along the guideway, (See Chapter 24, Plumbing and Fire Protection Systems).

2. 4A40BC fire extinguishers shall be installed in tunnel cross-passage recess niches.

D. Standpipes:

1. In tunnel, U or cut sections and elevated trainway sections when the length of the trainway exceeds 400 feet, a Class I standpipe system shall be provided in accordance with NFPA 14 unless amended by the local jurisdiction. (Also see DCM 24.7.3 A)

2. Dry standpipes may be permitted with the approval of the AHJ.

3. Standpipe systems shall be connected to an approved water supply capable of delivering the required file flow in accordance with IFC Appendix B for a minimum of two hours.

4. Water supplies (See Chapter 24, Plumbing and Fire Protection Systems, section 24.7.3, Standpipe Systems.

18.3.6 Flammable and Combustible Liquids Intrusion

See NFPA 130, paragraph 6.2.8

18.3.7 Combustible Components

See NFPA 130, paragraph 6.2.9

18.3.8 Elevated Structures

See NFPA 130, paragraph 6.4

18.4 LIGHT RAIL VEHICLE (LRV)

This section defines the requirements of Fire/Life Safety for the Light Rail Vehicle.

18.4.1 General

A. The vehicle design shall comply with NFPA 130 Chapter 8, except as amended by the local jurisdiction (also see Chapter 8, Structural, section 12, Support of Excavation Structures).

B. The design shall locate equipment outside of the passenger compartment, whenever practicable and isolate potential ignition sources from combustible materials.

C. The LRV end caps, roof and floor shall be designed to prevent propagation of a fire to the vehicle interior.

D. Firestops shall be provided at floor and roof penetrations. In the design of the roof, consideration shall be given to prevention of arc

penetration and susceptibility to ignition of materials in the roof or equipment mounted on it.

E. Exception: Materials used in small parts, such as knobs, rollers, fasteners, adhesives, clips, grommets, small electrical parts, and other small miscellaneous parts, which can be shown to not contribute to a fire propagation and smoke release will be allowed.

18.4.2 Combustible Content

A. The design of the LRV shall place major emphasis upon:

1. Minimizing the total combustible content of the vehicle.

2. Minimizing the heat release rate.

B. Each combustible material shall be specifically identified by supplier's name and type, use in the vehicle, total weight, and heating value in Btu/lb.

C. The total BTU content shall be per Chapter 12, Light Rail Vehicle, section 12.7.7 C, Flammability and Smoke Emission.

D. The total combustible content shall be in accordance with Chapter 12, Light Rail Vehicle, section 12.7.7 A, Flammability and Smoke Emission (see NFPA 130 Table 8.4).

18.4.3 Flammability, Smoke Emission, and Toxicity of Light Rail Vehicle Materials

A. Materials used in the LRV shall be tested by a nationally certified testing facility, (See Chapter 12, Light Rail Vehicle, section 12.7.7, Flammability and Smoke Emission).

B. Previously performed and certified tests for the same vehicle to be used by Sound Transit may be submitted for review and possible approval.

C. Materials and products generally that are recognized to have products of combustion that are highly toxic shall not be used.

D. The LRV floor shall be subjected to a fire exposure test in accordance with NFPA 130, paragraphs 8.6.2.1 and 8.6.2.2 and ASTM E119 for a minimum duration of 30 minutes. Design of floor systems shall take into account the potential fire hazard associated with under-floor operating components, items carried onto a vehicle by riders, and the use and right-of-way characteristics that affect evacuation time of the vehicle (See also NFPA 130, paragraph 8.2.3.1 as applicable).

E. Provision shall be made for a fire/heat load test and/or analysis on roof mounted equipment to ensure structural integrity of the roof. The roof structural assembly shall meet a 15-minute minimum endurance rating as tested in accordance with ASTM E119.

F. Portions of the vehicle body separating major ignition, energy, or fuel-loading sources from the passenger compartment including equipment-carrying portions of vehicle roofs shall have sufficient resistance to fire penetration to the interior of the vehicle by an external fire for a period consistent with the safe evacuation of a full load of passengers from the vehicle in the worst-case situation.

18.4.4 Fire Extinguishers

Approved multipurpose portable fire extinguishers shall be provided in each LRV in each LRV cab and in the passenger compartment.

18.4.5 Electrical Requirements

A. Conductors shall be protected in one or more of the following ways: in flexible metallic conduit or raceways; in nonmetallic raceway ducts or flexible tubing, suitable for vehicle wiring; or in cable boxes.

B. Wires connected to different sources of energy shall not be cabled together or run in the same conduit, raceway, tubing, junction box, or cable unless all such wires are insulated for the highest rated voltage in such locations. Low and high voltage wiring (as indicated herein) shall not be cabled or run together. Wires for lighting auxiliary circuits and for control, signal, and other low-voltage (less than 100 Vac and 150 Vdc) functions shall meet the requirements of ICEAS-19/NEMA WC3 paragraph 6.19.6, or UL Standard 44 for thermosetting insulation and UL Standard 83 for thermoplastic insulation.

C. Power cable shall meet the requirements of IEEE Standard 383, with the additional requirement that circuit integrity continue for 5 minutes after the start of the test.

D. Motor leads shall have an insulation suitable for the intended operating environment and shall be supported and protected so as to offer the least possible chance of mechanical damage.

E. Electrical circuits and associated cabling shall be designed with gap and creepage distance between voltage potentials and car body ground, in accordance with the environmental conditions to which the circuits and cabling will be subjected. The creepage distance shall be consistent with the requirements of NFPA 130, paragraph 8.5.2.3.

F. A main automatic line circuit breaker or a line switch and overload relay shall be provided for the protection of power circuits.

G. Nonconductive protection shall be provided between any part of the current collector assembly that is a line voltage and any other portion that is at ground potential.

H. Emergency lighting and other designated emergency electrical equipment shall be capable of functioning for a minimum of 1 hour, following loss of external power. Emergency lighting shall be provided throughout each passenger vehicle. The minimum illumination level, measured at the floor, shall be 1 foot-candle.

I. The design of battery installation and circuitry shall include the following:

1. Minimal use of organic materials, particularly those having hygroscopic properties.

2. Protection against overcharging.

3. Isolation of battery compartment from car interior.

4. Battery cases that are located away from other vehicle sources of high temperatures, such as resistor banks and compressors.

5. Monitoring over temperature conditions.

6. Ease of inspection and servicing.

18.4.6 Doors and Emergency Exiting

The safety features for the LRV are detailed in Chapter 28, System Safety. Some of the key features are summarized herein.

A. Side doors shall be designed to be opened by patrons under emergency conditions, including the loss of electrical power.

B. At least one door on each side will be capable of being opened by emergency response personnel from outside the vehicle, both manually and electrically.

C. A means shall be provided to permit emergency egress from the vehicle to the guideway (e.g., steps, ramps, etc.). Exception: Not applicable to low-floor vehicles.

18.5 SIGNALING

The signaling blocks shall coincide with the location of emergency ventilation shafts. Further requirements for signaling are covered in Chapter 28, System Safety and in Chapter 14, Signal System.

18.6 COMMUNICATIONS

A. This section defines the Fire/Life safety requirements for communications systems.

B. Dependable, flexible and redundant communication networks shall be provided for continuous contact with required personnel and patrons as follows:

18.6.1 General

A. To support Fire/Life safety requirements, the communications systems must operate in both normal and emergency modes; these must be developed to provide emergency voice communication capability, and to provide data to operating and emergency response personnel during an emergency.

B. Table 18-1 indicates the points between which emergency voice communications capability shall be provided. The additional requirements that must be met by these subsystems in order to fulfill Fire/Life safety functions are contained in the following paragraphs.

18.6.2 Transit Radio Subsystems

A. The transit radio subsystem shall provide at least one dedicated two-way voice communications frequency for fire, police and the EMS group for use in emergency situations. The emergency channel shall have the capability of communicating with transit system personnel on trains, in motor vehicles, and at all locations within the system.

B. Two-way radio voice communication capability for non-transit system emergency response personnel shall be provided by their own equipment; communications shall be provided in tunnels by integrating a non-transit channel with antenna.

C. Provide essentially 100 percent coverage in critical areas of underground stations including, but not limited to, platforms, mezzanines, fire command centers, stair shafts and cross-passages. In no case shall any of these areas be less than 95 percent covered. In less critical inhabitable areas, as determined by the Authority Having Jurisdiction, the coverage shall not be less than 90 percent. For more complete explanation of coverage requirements see Chapter 15, Communications and Central Control, section 15.5.5, B, Radio System.

Table 18-1, Emergency Voice Communications Matrix

To	Patrons on Trains	Patrons in stations	Vehicle Operator	Operations Control Center	On-duty Transit Personnel	Emergency Response Organizations
Patrons on Trains			X			
Patrons in Stations				X		
Vehicle Operator	X			X		
Operations Control Center		X	X		X	X
On-duty Transit Personnel		X		X	X	
Emergency response Personnel		X		X	X	X
Patrons in Elevators				X		

X = Where emergency communication is provided

18.6.3 Emergency Telephone System

See Chapter 15, Communications and Central Control, section 15.5.8, Emergency Telephone System.

A. Emergency Phone System shall be the back-up communications for the Fire Department and other emergency personnel reporting to the scene of an emergency as dictated by Link Emergency Procedures. It shall also serve as an emergency notification system for Link staff.

18.6.4 Passenger Emergency Telephone (PET)

See Chapter 15, Communications and Central Control, section 15.5.9, Passenger Emergency Telephone.

A. PETs shall serve the function of an emergency notification system for passengers in the event of an emergency.

18.6.5 Public Address Subsystem

A. Passenger stations and major maintenance facilities shall have Public Address (PA) Subsystems to allow communications under normal, abnormal and emergency conditions with patrons or employees, as appropriate.

B. The PA shall be zoned by building. Small separated buildings may be included in the zone of a nearby principal building.

C. The public address subsystem shall conform to the requirements of NFPA 72.

D. The OCC shall have the capability of using the public address subsystem to make announcements. Override access to the passenger station or maintenance facilities PA subsystems shall be provided at emergency management panels associated with the specific facility.

Note: For Voice/Alarm Signaling Service see NFPA 72 paragraph 3-8.4.1.3.5.

18.6.6 Emergency Management Panel

A. An Emergency Management Panel (EMP) shall be provided at passenger stations, which have ventilation systems, elevators, and/or escalators.

B. EMPs shall be located as required by the AHJ.

C. The EMP shall incorporate the following provisions:

1. Pre-emption capability for the public address subsystem

2. Distinctive signage and/or lighting for identification

D. The EMP shall serve as the local premises Fire Control Center complying with the intent of NFPA 72 for annunciator panels and IFC, Section 509 unless amended by the local jurisdiction. The EMP shall have the following provisions on a site-specific basis:

1. The emergency voice/alarm communications system unit.

2. Fire-detection and alarm system annunciator system.

3. Annunciator visually indicating the location of the elevators and whether they are operational.

4. Status and control of the emergency ventilation system, including indicators where the fans are being controlled from: OCC, EMP, or MCC, including station and adjacent tunnels that are integrated into the station emergency ventilation scheme.

5. Controls for unlocking **all** stairway doors simultaneously.

6. Sprinkler valve and water-flow detector status indicators.

7. Emergency and standby power (UPS) status indicators.

8. Telephone for fire department use with controlled access to the public telephone system.

9. Schematic building plans indicating the typical floor plan and detailed building core, means of egress, fire protection systems, fire-fighting equipment and fire department access.

10. Work table.

11. Public address system with back-up amplifier capability.

12. Graphics showing the station layouts and zone(s) in alarm and type of alarm.

13. Keys tagged for locked areas.

14. Security system status indicators (see IFC 509).

18.6.7 Fire/Security Subsystem

The fire/security subsystem shall perform the following functions, in accordance with NFPA and UL:

A. Automatic fire detection, alarm, and supervision in accordance with NFPA 72 and UL 864 and 1910.

B. Automatic fire suppression equipment actuation and supervision in accordance with NFPA 13, 14, 15, and 24.

C. Emergency voice communications subsystems status supervision, and control in accordance with NFPA 72.

D. Control and supervision of the status of various mechanical and electrical systems and equipment, as necessary for proper response to emergencies.

E. Intrusion detection, alarm, and supervision, as required by the security design criteria in accordance with UL 1610 and 1638.

F. Control and supervision of the fire/security subsystem shall be at the OCC in accordance with NFPA 72, Chapter 5 and UL 827.

G. UL 827 Compliant Central Station.

H. CCTV - See Chapter 15, Communications and Central Control, section 15.5.6, Closed Circuit Television System.

18.7 ELECTRICAL POWER

This section defines the Fire/Life safety requirements for consideration in the design of electrical power, traction power, and traction power substations.

18.7.1 Electrical Requirements

See Chapter 13, Traction Electrification, Chapter 21, Lighting and Chapter 23, Electrical Systems.

18.7.2 Overhead Catenary Systems

See Chapter 13, Traction Electrification, section 13.6, Overhead Contact System.

18.7.3 Electrical Substations

See Chapter 13, Traction Electrification, section 13.3, Traction Power Substations.

18.7.4 Communications

See Chapter 15, Communications and Central Control.

18.7.5 Blue Light Stations/Emergency Trip Stations (ETS)

See Chapter 13, Traction Electrification.

A. A Blue Light Station is defined as a location within the right-of-way, with the following features:

   1. Identified by a blue light

   2. The ETS shall remove power throughout the designated OCS section on the affected track. Only required at traction power substations.

   3. Emergency telephone with automatic location identification.

   4. Local mechanical lockout capability at traction power substations.

   5. Annunciates at OCC.

   6. The EMP will also have emergency trip and lockout capabilities.

B. ETSs shall be located at the entrance to traction power substations and at the entrances to vehicle maintenance and service buildings. The following locations shall have emergency telephones to facilitate removal of power by the OCC: each end and at each side of the

platform of underground and elevated stations, at cross-passages, emergency access points and other locations as deemed necessary by the AHJ.

C. Activation of the local mechanical lockout shall preclude restoration of all OCS power in the power zone controlled by the emergency trip station until the local mechanical lockout is released.

18.8 MAINTENANCE FACILITY AND YARD

A. This section defines the Fire/Life safety requirements for the design of yard and shops.

B. Applicable IBC, IFC, NFPA 130, local building safety codes, and WISHA shall be incorporated into the design of maintenance facilities.

18.8.1 Maintenance Facilities

A. Maintenance facilities shall be classified as follows, in accordance with NFPA 130, and/or the IBC. Occupancies shall be separated and protected accordingly.

1. Repair Shop – Group S-1, Division 3
2. Maintenance-of-way - Group F-2, Division 2
3. Operations – Group B
   a. Control Center (if incorporated into the facility)
4. Blowdown Facility – Group F-2, Division 2
5. Car Wash Facility – Group F-2, Division 2
6. Electrical Substation – Group S-1, Division 1
7. Paint Shop – Group H-2, Division 2
8. Body Ship – Group H-4, Division 4
9. Storage Buildings – Group S-2, Division 2
10. Offices – Group B
11. Flammable Storage – Group S-1, Division 1
12. Welding Shop – Group H-4, Division 4

13. Classrooms - A-3

B. The applicable sections of IBC, IFC, NFPA 130, local building safety codes, and WISHA shall be incorporated into the design of maintenance facilities.

C. Fire Protection

1. An automatic fire detection, alarm, and control system, conforming to the requirements of NFPA 72, shall be installed at the maintenance facilities site. Water flow alarm and control valve supervision shall be provided for automatic sprinkler systems. A fire alarm annunciator panel shall be provided near the point of primary access to each principal building or building group. (See also: Chapter 15, Communications and Central Control)

2. Approved, automatic sprinkler systems shall be installed in all areas of maintenance facility structures except electrical distribution rooms, signaling rooms, and traction power substations. The sprinkler systems shall be hydraulically designed and installed in accordance with NFPA 13, IBC, Standard 9-1, and local municipal codes. (See also: Chapter 24, Plumbing and Fire Protection)

3. Electronic equipment rooms containing essential communications and signaling equipment shall be provided with an approved, clean agent, fire suppression system.

4. Portable fire extinguishers shall be installed at each passenger assistance intercom and throughout all maintenance facilities and traction power substations, in accordance with IFC Standard 10-1 and IBC.

D. Roof deck coverings of maintenance facilities shall be in accordance with IBC chapter 15 and shall be UL listed. Roof deck coverings shall be listed Class A or Class B in accordance with IFC 1505 and NFPA 256.

18.8.2 Yards

A. Water Supply and Distribution

1. An adequate and reliable water supply shall be available for fire protection, including a sufficient number of properly located hydrants, in accordance with IFC Section 508, as amended by the local jurisdiction and local municipal codes.

2. The hydrant system shall be looped, with an isolation valve. These provisions shall comply with IBC, IFC, and local municipal

codes. Fire pumps, if required, shall be installed in accordance with IBC and IFC.

3. Fire flow of 2,000 gpm at 20 psi shall be provided within 500 feet of the most remote portion of the structure, in accordance with local municipal codes (See IFC Appendix B).

4. Locations of hydrants shall be 300 feet on center and within 150 feet of the structure, and no closer than 10 feet from combustible construction or building openings or as otherwise required by AHJ (See IFC Appendix B).

5. The required number of hydrants is determined by dividing the required fire flow for structure by 2000 and rounding up to the next whole number, or as otherwise determined by AHJ (See IFC Appendix B).

6. Hydrants shall not be closer than 4 feet to any fixed object, unless protected by guard posts, or as otherwise required by AHJ.

B. Emergency Access

1. Emergency access shall be provided to facilities within the yards and shops area through public streets or transit access roads.

2. The yard and shop shall be protected with security fencing.

3. Access gates located in security fencing in the yard shall have openings a minimum of 25 feet unobstructed width.

4. Full access within the yard shall be achieved through a perimeter road and cross lanes. Access shall be provided and maintained in accordance with locally adopted street, road, and access standards.

5. Minimum vertical clearance shall be 15 feet in height.

6. Yard tracks shall allow a minimum clearance of 3 feet between the sides of adjacent transit vehicles. In storage areas, a minimum unobstructed access of 7 feet shall be provided on one side of the vehicle.

7. Turning radii of access roads shall be large enough to permit emergency access. The minimum inside curb radius shall be 25 feet. The minimum outside curb radius shall be 50 feet. The Fire Marshall of the Authority Having Jurisdiction shall approve the turning radius.

8. Access roads shall be provided with approved provisions for turning around fire and emergency apparatus, in accordance with local municipal code requirements.

C. OCC power emergency trip stations shall be located throughout the yard and train storage areas,

D. Mechanical Systems

1. The Authority Having Jurisdiction will determine whether pit areas and associated access areas below floor level must be designed on the basis that flammable liquids and vapor will be present. Mechanical ventilation shall be provided if required.

   a. Pits shall be non-combustible and equipment shall be made of non-combustible construction (see NFPA 130, paragraph 9.3.6.1.1).

   b. Walls, floors and piers shall be constructed of masonry or concrete (see NFPA 130, paragraph 9.3.6.1.2).

   c. Pits shall have two means of egress.

   d. Steps shall be non-combustible and constructed with no free space underneath (see NFPA 130, paragraph 9.3.6.1.3).

2. Mechanical ventilation systems shall be installed in accordance with NFPA 90A. Blower and exhaust systems for vapor removal shall be installed in accordance with NFPA 91. Electrical power and airflow interlocks shall be provided in accordance with IBC, Chapter 12.

3. In buildings supplied with sprinkler systems, permanent draft stops shall be installed in structures having a height of over 25 feet to top of roof trusses, as required by IBC and IFC. Draft stops shall be constructed of rigidly supported, noncombustible material.

4. Battery charging areas shall be ventilated to the outside. See section 18.2.4 for additional requirements.

5. Locations in which painting or cleaning is accomplished, and locations where flammable or combustible materials are stored or used, shall meet the requirements of IFC and IBC.

6. All overhead cranes installed in maintenance facilities shall comply with the standard for cranes and monorails, as required by NFPA 70.

18.9 OPERATIONS CONTROL CENTER (OCC)

A. This section defines the Fire/Life safety requirements for the design of the OCC.

B. The OCC shall be the central point for coordinating all train operations, station operations, and for communicating directly with train operators, maintenance, supervisory, emergency personnel, and patrons (as required).

The following capabilities shall be incorporated into the design of the OCC.

18.9.1 Operations Control Center Facility

A. The OCC shall be a controlled space for housing electronic equipment, personnel, and supporting facilities to be used for operation and supervision of the transit system through signaling, communications, and fire and security management.

B. The facility shall be equipped and used for data processing, status reporting, and transit system supervision. The facility shall permit 24-hour operation. The OCC facility shall comply with NFPA 72 Chapters 5 and 6, IFC 903.4, and UL 827, unless amended by the local jurisdiction.

C. The OCC shall be arranged and equipped to function as the central supervising station for the entire system, in accordance with NFPA 72.

D. During normal operations, the OCC shall provide primary control of transit operations. During emergencies, emergency response personnel shall be responsible for control, supervision, and coordination of emergency activities. The OCC shall retain responsibility for operation of unaffected parts of the system and coordinate transit system response in the emergency area.

E. The Operations Control Center shall be equipped to:

1. Receive, log/printout, and annunciate fire, security, and supervisory alarms.

2. Receive, record, and log Passenger Emergency Telephone messages, including designation of the origin of the call.

3. Communicate with passenger vehicle operators and other on-duty transit personnel.

4. Use the public address subsystem, as needed.

5. Prepare passenger stations for evacuation, if necessary.

6. Selectively remove and restore traction power.

7. Have direct line telephone communication with the dispatch facilities of appropriate fire and emergency response jurisdictions.

8. Monitor appropriate fire and emergency response organization radio channels.

9. Monitor and control signals, track switches, emergency ventilation fans, and pumps.

10. Monitor and control elevators, and escalators (if used).

11. Monitor seismic events.

F. The Operations Control Center shall provide the Fire Department with the capability of coordinating emergency operations. This shall include access to the following (see IFC 509 and NFPA 72, Chapter 5):

1. The emergency voice/alarm communications system unit.

2. Fire detection and alarm system annunciator system.

3. Annunciator visually indicating the location of the elevators and whether they are operational, including escalator stop capability.

4. Status and control of the emergency ventilation system, including indicators of where the fans are being controlled from; OCC, EMP, or MCC.

5. Sprinkler valve and water-flow detector status indicators.

6. Emergency and standby power (UPS) status indicators.

7. Passenger emergency telephone subsystem.

8. Public address system.

9. Graphics showing the station layouts and zone(s) in alarm and type of alarm.

10. Security system status indicators.

11. Direct line to appropriate telephone subsystem.

12. Monitor of selected fire department radio channels.

18.9.2 Construction

A. The OCC facilities shall comply with IBC Chapter 6, Type I or Type II construction requirements. All structural assemblies and building appurtenances in the OCC shall be of noncombustible material.

B. The OCC shall provide and maintain occupancy separations as required by IBC and as follows:

1. The OCC, including ancillary rooms, shall be separated from uncontrolled public access areas and any other occupancy by minimum 2-hour fire rated construction, with the openings protected by labeled 1-1/2 hour fire rated door assemblies.

2. The OCC data processing and control areas shall be separated from all ancillary rooms by minimum 1-hour fire rated separations, with the openings protected by labeled 1-hour fire rated door assemblies.

3. Ancillary areas within the OCC shall comply with the separation and protection requirements. Cabling from the OCC to system operating areas, and to all other services essential to the operation of the OCC, shall be routed separately from other building services.

4. Fire rated door assemblies protecting openings in fire rated separations shall be automatic or self-closing and shall be installed in accordance with NFPA 130.

18.9.3 Interior Finishes

Interior finishes shall meet IBC and IFC requirements, Class I or II. Interior finished shall be Class I for all exits and exit access routes, and for the OCC area. In all other areas, interior finishes shall be Class II.

18.9.4 Access and Egress

A. Access to the OCC building shall meet the requirements of IBC.

B. Egress routes serving the OCC and other occupancies shall be 2-hour fire-rated enclosures, with self-closing and latching, 1-1/2 hour rated doors.

18.9.5 Emergency Lighting

Emergency lighting shall be provided for all egress routes from and throughout the entire OCC area in accordance with IBC.

18.9.6 Fire Protection

A. Water supplies and hydrants for the OCC shall conform to IBC, IFC Chapter 9, and local municipal codes. See section 18.8.2, Yards, for distribution requirements. In addition to the IBC requirements for sprinklers and standpipes found in IBC Sections 904 and 905, the requirements of IBC Standards 9-1 and 9-2 shall also apply.

B. Standpipes, as required by NFPA 130 and IBC shall be installed in the OCC.

C. Automatic sprinkler protection shall be provided throughout the OCC. Automatic sprinkler systems shall be hydraulically calculated, designed, and installed in accordance with NFPA 130 and IBC Section 903.

D. Specialized fire suppression systems, installed in accordance with the requirements of section 18.2.10 shall be provided for areas in the OCC building containing critical communications and train signaling equipment, and for tape storage rooms. Consoles shall be protected, as shall under-floor space.

E. Portable fire extinguishers, conforming to IFC Standard 10-1, shall be installed throughout the OCC building.

18.9.7 Protective Signaling System

A. An automatic fire detection, alarm, and control system, complying with the requirements of NFPA 72 shall be provided throughout the OCC building.

B. Smoke detectors shall be installed throughout all areas of the OCC that are protected by specialized fire suppression systems, (normally unoccupied areas such as electrical rooms).

C. Automatic sprinkler systems shall be provided with water flow alarm and control valve supervision for annunciation at the OCC.

D. Fire alarms, trouble alarms, and supervisory signals shall be transmitted by zone, for annunciation at the OCC, in accordance with NFPA 72.

E. If located within a building having other occupancies, the OCC shall have at least one summary alarm for fire or evacuation notification, initiated from any part of the building.

F. A Fire Control Panel shall be located at the primary entrance. Apply all panel coatings according to manufacturer's specifications.

18.9.8 Mechanical Systems

A. The OCC HVAC systems shall be physically and operationally separated from HVAC systems serving any other occupancy. Redundant fan and/or air conditioning units shall be provided, sized, and arranged so that either unit is capable of serving the OCC facilities.

B. Emergency smoke removal capability shall be provided for the OCC. The smoke removal system shall be designed to utilize 100 percent outside air make-up. The smoke removal system shall have the capability of providing a minimum of six air changes per hour.

C. Battery storage or similar ancillary rooms, in which hydrogen gas or other hazardous gases may be released, shall be ventilated in accordance with IFC Article 64 and section 18.2.4.

D. Other mechanical systems shall be in accordance with IBC.

18.9.9 Electrical Requirements

A. Electrical equipment and wiring materials and installation shall conform to the requirements of NFPA 70, NEC 72 and 75, and IBC.

B. A separate on-site emergency power system shall be provided for the OCC so that the loss of utility electrical power shall not impair any of the OCC function.

18.9.10 Communication Transmission Medium

A. Transmission of fire and security alarms and supervisory signals from transit facilities to the appropriate central supervising station may be accomplished using direct-line cables or a cable transmission subsystem. It is permissible for operational signals to share transmission media with fire and security signals.

B. Whatever means is used for transmission of fire and security signals, the following requirements shall be met:

1. The transmission media shall conform to the requirements of NFPA 72.

2. Common use of transmission media shall not impair the fire alarm function.

18.10 OPERATIONS

A. It is essential that careful planning for safety during operations must be accomplished to ensure the safety and security of passengers and employees, and efficient and reliable service.

B. This section defines the Fire/Life safety requirements during operations planning.

18.10.1 Operational and Maintenance Procedures

A. Operational procedures, including an inspection and maintenance program shall be established to ensure that all Fire/Life safety related equipment is in proper condition, and that personnel are familiar with the use and care of Fire/Life safety related equipment and emergency preparedness procedures.

B. Sound Transit, with the assistance of the emergency response organizations, shall have primary responsibility for accomplishing the above objectives.

C. A program of testing and inspection of Fire/Life safety related equipment shall be developed including a specific program for verifying that necessary maintenance and/or repair is performed.

D. The testing and inspection program shall be in accordance with applicable sections of NFPA standards, WSBC, and manufacturer recommended practices.

E. The safety, security, and Fire/Life safety equipment maintenance program shall be subject to verification. The maintenance program shall include, but not be limited to:

1. Manual or portable fire suppression equipment.
2. Fire alarms and detection systems.
3. Automatic fire suppression systems.
4. Auxiliary fire service equipment.
5. Emergency communication systems.
6. Emergency lighting.
7. Testing and inspection procedures for safety, security, and Fire/Life safety related equipment.
8. Intrusion detection equipment.

9. Elevators and escalators.

10. UPS.

11. Power removal and restoration equipment (e.g., ETS, controls at OCC).

12. Communications system equipment, facilities, and procedures.

13. System facilities indoctrination.

14. Electrification system familiarization.

15. Identification of personnel authorized to make decisions in emergencies.

F. Training, Exercises, Drills and Critiques

1. Sound Transit, in conjunction with the appropriate local emergency response organizations, shall develop and implement a training program for system operations personnel.

2. All personnel shall be familiar with all aspects of the EPP and shall be trained to coordinate their functions efficiently during an emergency.

3. Simulations, drills, and critiques will be conducted.

4. Written records shall be maintained.

5. Emergency training shall be as described in NFPA 130 and as identified by local jurisdictions.

6. This training program shall address all functions to be performed during emergencies on the transit system, and shall include annual scenario based training sessions.

7. Provisions shall be made for make up and refresher training.

8. The training program shall include, but not be limited to, the following:

   a. Pocket sized Field Operations Procedures

   b. Guides, DVD's and outline material similar to KCEMS

18.10.2 Emergency Procedures

A. Safe and efficient operation of the transit system shall require the anticipation of, and planning for, system emergencies. Sound Transit, in conjunction with the appropriate local emergency response organizations, shall establish an emergency preparedness plan and the necessary procedures for the control and coordination of all anticipated emergency response activities.

B. Development of the Emergency Preparedness Plan (EPP) and supporting procedures shall include, but not be limited to, consideration of the emergency scenarios described in NFPA 130 and IFC Chapter 4. It shall be an “All Risk” plan.

C. The EPP will include the information required by NFPA 130 Chapter 10. The EPP shall address three levels of action, based on the degree of severity of the emergency. The degrees of severity are as follows:

   1. Major regional disasters that may affect other areas besides the transit system.

   2. Major transit system incidents that may affect system-wide operations.

   3. Minor transit incidents, such as small fires, medical emergencies, and other similar emergencies that may not affect system-wide operations, but may affect individual train operations.

D. All local emergency response organizations shall be notified immediately if a possible emergency exists. These agencies are identified, but are not limited to those in NFPA 130 Section 10.5. As part of the emergency preparedness plan, Sound Transit shall maintain an up-to-date listing of the local emergency response organizations’ liaison personnel. The list shall be reviewed and tested quarterly to determine accuracy and completeness.

E. The OCC staff members shall be trained annually and shall be qualified in the use of the equipment and systems provided and in the implementation of operational procedures and the emergency preparedness plan.

   1. A procedure shall be developed that addresses the use of the direct-line communication capability with emergency response organizations during transit system emergencies.

   2. A procedure shall be developed to perform OCC from an alternate site to be used when, for any reason, the OCC is out of service.

3. Maintenance of essential OCC functions during a fire or other emergency involving an adjoining or adjacent structure shall be ensured by development of an appropriate procedure.

4. Effective utilization of fire detection, protection, and suppression equipment shall be addressed in a procedure in order to minimize detection and extinguishment time for any fire in the OCC facility.

F. Sound Transit and emergency response organizations' personnel shall be familiar with all aspects of the EPP and shall be trained to coordinate their functions efficiently during an emergency. Simulations, drills, and critiques will be conducted. Written records shall be maintained. Emergency training shall be as described in NFPA 130 and as identified by local jurisdictions.

G. Traction Power Removal and Restoration

1. A procedure for removal and restoration of traction power shall be included in the EPP. The OCC shall be contacted whenever it is necessary to trip an emergency traction power disconnect device. The information to be given to the OCC shall be established in the Emergency Procedures Plan and include the information required by NFPA 130.

2. Control of OCS power shall revert to the OCC when the shutdown of OCS power is no longer required by the involved emergency response organization(s).

H. Training

1. Sound Transit, with the support of the appropriate local emergency response organizations, shall establish training programs and coordinate the Fire/Life safety interfaces necessary to educate and/or familiarize transit system employees and emergency response personnel with transit system equipment, its operations, and the Emergency Preparedness Plan and Procedures.

2. Sound Transit and the appropriate local emergency response organizations shall jointly develop and implement a comprehensive joint training and indoctrination program for emergency response personnel. This program shall include but not be limited to:

a. Communication procedures and facilities

b. System facilities indoctrination

c. Passenger vehicle indoctrination

d. Electrification system

e. Means of emergency access and egress

f. Functions and controls for tunnel ventilation systems

g. System fire detection, alarm, and control systems

h. Familiarization with yard and maintenance facilities

i. Arrangements for fire equipment inspection and testing

j. Emergency medical aid procedures and policies

k. Identification of personnel authorized to make decisions in emergencies

l. Emergency preparedness plans and procedures

m. Training of Transit Employees

n. Moving trains off of victims

o. Critical incident stress debriefing protocols for FD/PD/Transit/M-1 and private ambulance attendants

p. Interaction with Medical Examiner

q. Coordinating cessation of train service to allow rescue and response

END CHAPTER 18

19. OPERATIONS AND MAINTENANCE FACILITY

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19. OPERATIONS AND MAINTENANCE FACILITY

19.1 INTRODUCTION

This chapter presents general criteria for the yard area and maintenance facilities to accommodate a fleet of light rail vehicles (LRV) for the Link LRT. Utilizing the yard and building, the design team shall analyze the traffic flow of the LRVs, the flow of material and the accessibility of operation and maintenance personnel to the facility and the LRVs. The analysis shall include a detailed review of the activities and functions that will be performed at each location in the yard and/or facility. During the design process, the spatial and functional adjacency relationship requirements will be developed to ensure that the facility arrangement will provide expedient and proper traffic and workflow, and space allocations. The facility shall maximize personnel comfort and safety, be compliant with the American with Disabilities Act (ADA), and meet all applicable local, state and federal codes. The interior arrangement of the buildings shall reflect the same considerations to ensure that the fleet will be properly maintained. The configuration of the buildings and the yard layout shall reflect accommodations for the ultimate fleet.

19.1.1 Design Codes and Standards

A. Design requirements for the shop and yard shall comply with all federal, state, and local laws, regulations, rules, requirements, and the preservation of natural resources as well as all laws, ordinances, rules, regulations and lawful orders of any public entity bearing on the performance of the work. Listed below are some of the principal applicable codes:

1. International Building Code (IBC)
2. International Mechanical Code (IMC)
3. National Electrical Code (NEC)
4. National Electrical Safety Code (NESC)
5. Uniform Plumbing Code(UPC)
6. National Fire Protection Association (NFPA)
7. American National Standard Code for Elevators (A17.1)
8. American National Standard Institute (ICC/ANSI A117.1)

9. Americans with Disabilities Act (ADA), including U.S. Department of Transportation, Final Rule - Transportation for Individuals with Disabilities

10. Washington Administrative Code 51-40 (WAC)

11. Washington State Energy Code (WSEC)

12. Washington Building Code (WBC)

13. Transit Security Design Considerations Final Report Nov. 2004(FTA-TRI-MA-26-7085-05)

14. American Society of Heating, Refrigerating and Air Conditioning Engineers (ASHRAE)

15. Sheet Metal and Air Conditioning National Association (SMACNA)

19.1.2 Design Goals

The goal for the design of the new Operations Facility is to provide a facility that will be self-sufficient for all normal Operations & Maintenance (O&M) functions.

19.1.3 Exterior Materials

A. The exterior materials to be used on the facility shall be selected based on durability and appearance. Sound Transit requires a facility that will provide 30 to 50 years of low maintenance, but also provide a pleasing appearance to fit in to the existing area. Materials such as brick, concrete block, pre-cast concrete, and metal siding shall be used.

B. Glazing shall be thermopane insulating glass. Where exposed to direct sun, energy efficient glass shall be used. Exterior wall and roof areas shall be insulated to meet current energy codes. Roof materials shall be selected based on long-term durability and appearance.

C. Flashings shall be either stainless steel or galvanized. Door and window frames shall be painted metal or aluminum.

19.1.4 Interior Materials

A. The emphasis on material selection for the interior of the facility shall be on durability and low maintenance.

B. Finishes shall be as follows:

1. Sealed concrete floors in shop areas;

2. Wall areas in shops shall have a minimum 8 feet' high concrete or concrete block wainscoting;

3. Office areas shall be metal stud and 5/8 inch gypsum-board construction. Floor and ceiling materials appropriate for intended use. Sound insulation shall be provided between adjacent office spaces; and

4. Toilet/shower areas shall have ceramic tile floor and wall finishes.

19.1.5 Structural

A. The following structural criteria shall be followed:

1. The building shall be designed in accordance with the building code adopted by the city in which the building will be located.

2. Roof load 25 psf (additional at snow loading conditions).

3. Soil bearing pressure shall be determined from the geotechnical report.

B. The building structure shall be of concrete or steel fire resistant construction. Use of wood should be avoided.

C. For further detailed structural criteria, refer to Chapter 8, Structural.

19.1.6 Lighting

A. General light levels shall be as follow:

1. Shop Areas 50 fc

2. Pit Area 100 fc

3. Storage Areas 25 fc

4. Office Areas 75 fc

B. Lighting for specific task areas shall be located and designed to meet task requirements.

C. Shop areas shall utilize metal halide fixtures.

D. Office areas shall have T-8 fluorescent light fixtures with electronic energy-saving ballasts.

E. Energy-saving lighting systems and fixtures shall be used where possible.

F. Natural light from skylights, windows, and clerestory windows shall be maximized to reduce dependence on light fixtures during daylight hours.

G. Pits shall have fluorescent lights along both sides aimed upward for undercar lighting with a lens on the bottom for floor lighting.

19.1.7 Corrosion Control and Safety Grounding

A. The maintenance facility shall have equipotential grounding systems for all conductive surfaces exposed to human contact. These shall be accomplished through use of a building perimeter ground. The perimeter ground shall be bonded to intermittent ground rods and bonded to the metal structure of the building and reinforcement bars of the concrete. The reinforcing steel of the main shop floor shall be bonded into a grid pattern and all shop conductive surfaces shall be bonded to the grid. The shop trackwork shall be continuous and bonded to the grid. The shop grid and perimeter ground shall be bonded to the shop substation ground mat. Insulated rail joints shall be located in the ends of the concrete aprons, which will define the extent of the shop grounding system and dc electrical system.

B. Dc stray currents are prevalent in the yard and shop area. Accordingly, ferrous pipe shall be coated with an electrical insulating material and tested prior to burial. Some underground services (such as natural gas) may be better served by use of plastic pipe where the code allows. Joints in piping will require bonding in some locations and insulated joints in others. Refer to Chapter 17, Corrosion Control.

19.1.8 Acoustics

In planning the new facility, noise- and vibration-generating equipment such as air compressors and pumps shall be located away from office areas and/or acoustically isolated. HVAC mechanical units shall be located and specified so that noise and vibration transmission is minimized. In addition, walls, ceilings, and floors in these spaces shall be insulated to further reduce noise transmission to other parts of the facility.

19.1.9 Maintenance

In planning the new facility, Sound Transit's proposed maintenance procedures shall be reviewed and staff operations personnel shall be consulted to ensure that the new facility provides an efficient work environment. Janitorial closets and other maintenance rooms shall be located on each floor and in locations convenient for users. Floor drains, hose bibs, etc. shall be located for convenience of use.

19.1.10 Mechanical Systems

A. Shop areas shall be heated with a gas-fired, radiant heat system. The heating system shall be designed in zones. Maintenance pits shall have a section of wall-mounted hot water radiant heat. Pit areas shall have exhaust air ducts at side walls. Shop compressed air shall be available in all pits at convenient intervals to operate tools.

B. Office, administration, support, and Central Control areas shall have forced air heating, ventilating, and air conditioning systems. The Central Control Facility shall have its own HVAC system. The HVAC system shall be designed in zones appropriate for use and exposure to heating and cooling demands needed to support a 24-hour operational control center. The signals equipment room and shop substation electrical room shall be air conditioned.

19.1.11 Access for the Mobility Impaired

The facility shall be designed to meet applicable federal, state, and local codes for accommodating access for the mobility impaired in effect at the time of facility design.

19.2 FUNCTIONAL REQUIREMENTS

A. Link LRT Operations Facility shall house the following functions:

1. Light Rail Vehicle (LRV) storage
2. Non –Revenue Vehicle support
3. Train make-up and yard dispatch
4. LRV adds and drops
5. Train operator report area
6. Operator and maintenance training
7. Inspection offices and report area
8. LRV service and inspection
9. LRV interior and exterior cleaning;
10. LRV air-conditioning, current collector and resistor unit repair
11. Component repair and rebuild

12. Signal system service and inspection
13. Fare collection (FC) equipment storage and inspection
14. Traction electrification system (TES) service and inspection
15. TES overhead service and inspection
16. Link LRT track maintenance
17. Station cleaning
18. Facilities maintenance
19. LRV re-railing
20. Rail-bound equipment storage
21. Link LRT parts storage
22. Rail transportation administration
23. Rail maintenance administration
24. Rail operations planning
25. Rail maintenance engineering
26. Central Control Facility
27. Link LRT training
28. LRV body shop
29. LRV paint shop
30. Machine & sheet metal shops
31. Wheel truing
32. Wheel assembly pressing
33. Axle component pressing
34. LRV truck maintenance, repair, and overhaul
35. Electronic component repair
36. Signal relay inspection & calibration

37. Fare collection equipment component repair

38. Communications equipment component repair

39. Covered and open storage of Link LRT maintenance-of-way (MOW) materials

40. Security

41. Fire Alarm System

42. Operator wait area

43. Staff lunch and locker rooms

19.3 SITE SELECTION

19.3.1 Site Selection Criteria

A. Site Size: The Yard and Shops site shall be of sufficient size to permit the construction of the facilities necessary to support the initial and ultimate revenue service, fleet sizes, and maintenance functions for each of the specific Sound Transit lines.

B. Site Location: The selected sites shall be located to provide convenient access to the main line with a minimum of deadhead mileage. The site selection process shall include consideration of land acquisition, adaptability, configuration, clearing, and construction costs. Preference shall be given to sites with potential railroad connections.

C. Environmental Impact: The selected sites shall comply with all environmental requirements minimizing the negative impact on adjoining land. Considerations shall include air and noise pollution, traffic, aesthetics, social, economic, and safety, among others.

D. Site Configuration: Configuration of the Yards and Shops shall permit a functionally efficient layout to provide vehicle storage and work flow that minimizes train and personnel movement requirements. Site shape shall accommodate geometry to permit a full trackwork loop bypassing, but allowing access to the storage yard and shop. The site shall be level to store and maintain LRVs without the danger of a car rolling down any grades on the site or toward the main line. The site shall accommodate positioning of the shop and yard trackwork in such a manner to preclude entrapment of cars or trains from access to the storage yard, shop, or mainline. The site shall accommodate layouts that allow the ability to turn LRVs end-for-end. Layout shall allow for at least two entrance and exit points into the yard from and to the mainline. The site will accommodate fire department access to buildings and around stored

vehicles as dictated by the International Fire Code Chapter 5, Section 503.

19.4 SITE PLANNING

19.4.1 Facilities

The operations facility layout shall include:

A. Yard

1. LRV storage area
2. LRV run around loop
3. LRV cleaning area
4. Gate protected parking, service and access roads
5. Outside storage area for MOW, traction power and signal equipment
6. Standpipe system
7. Yard lighting
8. Security/CCTV coverage
9. Refuse collection locations
10. Landscaping

B. LRV main shop

1. LRV exterior wash facility
2. Maintenance vehicle storage building
3. Electrical supplies

C. For track, traction power, OCS, and signals criteria, see separate chapters.

19.5 YARD

19.5.1 LRV Storage Area

A. Sufficient storage tracks shall be provided to accommodate the ultimate fleet size to be stored and maintained. The storage yard shall be arranged to provide space for all LRVs to be stored on level tangent

track in two -four car trains. Area around train storage should be level to facilitate safety of workers moving around trains.

B. Alternate tracks in the LRV storage yard shall be provided with paved access aisles between the tracks. Accordingly, track centers shall be 14'0" where no aisle is required and 19'0" as a minimum where a paved access aisle is required. OCS and lighting poles shall be located between tracks with 14'0" track centers.

C. The layout of the storage yard shall enable movement of LRVs to and from the shop, other yard facilities, and the mainline with the smallest possible number of reverse movements and crossovers, consistent with site space limitations. This shall be accomplished by avoiding the use of stub-end tracks and by proper relationship of yard track orientation to the mainline.

19.5.2 LRV Run Around Loop

A run-around track shall be provided. This track shall provide unimpeded circulation around the yard, enable LRVs to enter the storage tracks from either end, enable LRVs to enter either end of the shop, allow an alternate exit/entrance from and to the main line, and allow LRVs to reach or bypass cleaning, inspection, and blowdown areas (if provided).

19.5.3 Cleaning Area

One track in the maintenance facility shall be dedicated to cleaning the interior of the LRVs. This track will be used to perform daily and scheduled extraordinary interior cleaning of the LRVs. The track shall be equipped with door level access platforms on both side of the car, the full length. Features such as mop sinks and laundry tubs and a fixed vacuum system with hoses at each door opening shall be provided to expedite the interior cleaning process. Storage cabinets shall be provided for cleaning materials. Portable trash containers and a centrally located trash compactor for large trash article and newspapers shall be provided.

19.5.4 Parking and Service Roads

A. Parking and provisions for future parking shall be provided for visitors and employees to a level adequate to accommodate the parking needs of the two largest shift changes or as local jurisdictions require. Access for truck delivery, including trucks with semi-trailers, shall be provided.

B. Service roads shall be provided around the shop, between selected LRV tracks, and to outside storage areas within the yard. Refer to Chapter 18, Fire/Life Safety, for design requirements of service roads.

19.5.5 Outside Storage Areas

Outside storage space shall be provided for the storage of the following types of equipment and structures: OCS poles and large OCS hardware, large signal equipment, lighting poles, rail, ties, special trackwork (such as switches, switch stands, frogs, etc.), other track materials (such as tie plates, spikes, joint bars, insulated joints, etc.), ballast, and reels of wire. Locations of these types of storage areas are not generally critical and can be accommodated as the track layout is refined. Storage areas shall meet local criteria for land use.

19.5.6 Fire Protection System

Fire protection utilities such as hydrants, sprinklers in the building, and extinguishers shall be provided in accordance with local building and fire code requirements in effect at the time of construction of the facility. The hydrants shall be located so as not to block the movement of LRVs when fire hoses are being used. Refer to Chapter 18, Fire/Life Safety, for water supply and distribution requirements. Fire alarm panels and systems shall be designed to conform to NFPA 72 and NFPA 13. Fire alarm system shall alarm at a qualified Central Supervising Station.

19.5.7 Yard Lighting

The yard shall be illuminated to provide a safe working environment for ultimate 24-hour operation of the facility. The lights shall be high-pressure sodium type, shall be automatically controlled by a photoelectric cell, and mounted on high masts. Yard lighting shall be provided to a level of 2 foot-candles average. Lighting shall be shielded so as not to spill on to neighboring properties. Some illuminated signage will be required for yard entrance, building entrance and track numbers at building doorways, etc. All lamp clusters on high mast poles shall be lowerable to ground level with an electrically-operated lowering mechanism.

19.5.8 Security

Operations facility security shall be achieved by fencing the periphery of the yard and by lighting. The fences shall be in accordance with zoning and permitting limits between 6 and 10 feet in height and as a minimum shall be of the chain-link type. Gates shall be provided at all yard track and road accesses and shall provide for minimum interference to LRV movement. Sliding (rolling) gates shall be used. Security lighting shall be placed as necessary to supplement the normal area outside work lighting. A security system compatible and integrated with the Sound Transit Operations Control Center System shall be installed.

19.5.9 Refuse/Recycling Collection

A. Refuse/recycling collection bins, dumpsters, etc. shall be provided at several locations convenient to work areas as well as to collection vehicles. Space allocation limitations associated with the shop and yard site may require the transfer of waste and recycled materials from local collection points to a central location.

B. Certain containers shall be designated for recycling purposes, such as those used for metal waste, and for office waste paper, cardboard, glass, etc.

19.5.10 Landscaping

Landscaping shall be minimal, but meet local land use requirements. The amount and type shall be consistent with the local development requirements for the site. Low maintenance ground cover material (gravel, barkdust, etc.) shall be provided on areas of the site not used for structures, track, or access roads and walkways. Landscaping around the facility shall not block train operator line of sight for any track area.

19.6 LRV MAIN SHOP

19.6.1 LRV Shop Functional Requirements

A. The following general LRV maintenance functional requirements have been established for the shop, and shall dictate the types of service and repair facilities to be provided:

1. Service, remove and replace car pantograph assemblies, and brake resistors
2. Service, remove and replace car heating, ventilation and air-conditioning units
3. Exchange of trucks
4. Exchange of defective components with new or rebuilt parts
5. LRV modifications
6. Repair of miscellaneous system equipment and components
7. Running repair
8. Periodic maintenance
9. Air-conditioning unit secondary maintenance and overhaul

10. Safety inspections
11. Interior and exterior cleaning
12. Sand box filling
13. Loading/off-loading equipment to/from rail bound equipment
14. Truck rebuild
15. Wheel truing
16. Body repairs
17. Painting of LRVs and components
18. Component rebuild
19. Sheet Metal Work
20. Machine Work
21. Wheel and Component replacement on axles
22. Tire replacement on wheels

B. Drainage Systems

1. All drainage systems shall be designed to reduce fire and explosion hazards by the use of non-combustible piping.
2. Where piping is not enclosed, as direct a routing as possible to a safe outside location shall be provided.
3. Oil separators, grease traps, and sand traps shall be installed on all floor drainage systems that serve maintenance and vehicle storage areas.
4. Separators and grease traps shall be approved design and of sufficient capacity to meet the level of waste discharged from the areas.
5. The separator storage capacity shall be of sufficient size to retain all the sludge between cleanings.
6. The surface of the grade floor of storage or maintenance areas shall be on non-combustible material.

7. Roof deck coverings shall be listed Class A or Class B in accordance with NFPA 256.

19.6.2 LRV Shop Layout

A. The shop layout shall follow certain design guidelines as closely as funds and site configuration permit. These guidelines relate to activities and functions that are provided either in the yard or the facility and as a minimum take into consideration the following: the relative location of spaces to each other; areas of the spaces for the type of activity or function; utility requirements; special industrial equipment such as jacks and cranes; floor, pit and platform arrangement, etc.

1. Proximity to mainline and storage yard shall minimize switching movements and accelerate emergency repairs.

2. Run-through tracks in the shop area to provide for efficient flow of LRVs and shall allow entry and exit from either end of the building.

3. A maximum of two linear car positions in the shop to preclude entrapment of an LRV between others when maintenance and repairs are being performed. Up to two through tracks may be required to accommodate four-car trains.

4. Grouping related maintenance and servicing activities to simplify supervision and workflow, and to help minimize the floor space needed for circulation to and from the various interrelated spaces.

5. Proximity of support activities and proper industrial engineering shall be incorporated to maximize circulation efficiency. The building shall be accessible to the handicapped in compliance with the Americans with Disabilities Act, including U.S. Department of Transportation, Final Rule -Transportation for Individuals with Disabilities.

6. Fixed and portable jacks shall be provided for lifting entire LRVs or married pairs, but not train consists.

7. A bridge crane shall be provided with adequate capacity to lift the heaviest LRV component, and assembled motor truck. The bridge crane shall be so located as to allow a highway flatbed tractor/trailer to position itself under the crane and allow motor trucks and trailer trucks to be loaded for shipment. A monorail crane shall be provided at each car position equipped with rooftop access platforms. The crane shall have adequate capacity to remove/replace the heaviest roof-mounted LRV equipment.

8. Turntables and transfer tracks shall be provided for exchange and movement of trucks.

9. The daily/routine maintenance pits shall be a single-level design or bi-level design depending on car equipment configuration and agency needs.

10. Services in the pit areas shall include; compressed air outlets at each support column, a 120V ac duplex receptacle at each column, welder receptacles, an emergency OCS shutdown, floor drains for pit wash down, oil drain for disposing of used gearbox oil, conduits to connect all pits for future addition of other services, radiant heating, exhaust ventilation, provisions for addition of grating at TOR level, approved railings or chains, stairway access, and provisions for vertical movement of tools and components between the shop floor level and the pit level, as well as platform level. In addition to providing service at this level, the material lift shall also service the pit and maintenance floor.

11. Eyewash provisions shall be provided in each maintenance pit.

12. Interlocks shall be provided to assure exclusive operation of the bridge crane *or* the OCS, but not both for each car position. Operation of the crane shall be allowed in a zone over the unit repair area.

13. Platforms with gates shall be provided so that rooftop equipment can be serviced by maintenance personnel without requiring tie off and harness. An interlock on the gate system shall prevent cars from pulling out of the maintenance bay without the gates being secured open. Services on the platforms shall include: compressed air outlets, 120V ac receptacles, welder receptacles, approved railings and gates, under-platform lighting and heating, and an emergency OCS shutdown.

14. An auxiliary power supply (APS) cord, plug and switch to safely provide LRV auxiliary power to LRVs when the shop OCS is not energized. APS provisions shall be provided at each rooftop access platform. APS shall be interlocked with the OCS to assure mutually exclusive operation.

15. Emergency shutdown pushbuttons shall be located throughout the shop at convenient, well traveled locations.

B. The suggested work areas are listed below:

1. Yard Operations and Operations Control Center

2. Fare Inspector Office and Report Area

3. Communications Equipment

4. Training Rooms
5. Janitor
6. Women's Locker Rooms with showers
7. Men's Locker Rooms with showers
8. Men's Room(s)
9. Women's Room(s)
10. Electrical Rooms
11. Boiler & Mechanical Rooms
12. Lunch Room/Ready Room
13. Conference Rooms
14. Administration
15. Office Storage Rooms
16. Component Repair/Rebuild Areas
17. Shop Substation
18. Telephone Equipment Room
19. Signal Equipment Room
20. Compressor Room
21. Maintenance-of-Way Storage and Repair areas
22. Foreman's Office
23. Inspection Pits
24. Rooftop Level Maintenance Platforms
25. Maintenance Areas & Offices
26. Shipping/Receiving
27. Spare Parts Storage (first and second floors)
28. Fare Collection Equipment Repair

29. Employee Exercise Room

30. Stairs/Halls/Lobby/Elevators

31. Blowdown Shop

32. Body Shop

33. Paint Shop

34. Wheel/Axle Shop

35. Wheel Truing Bay

36. Cleaning/Wash Bay

19.6.3 Shop Functional Areas

A. The Battery area shall be provided for battery storage and charging for several sets of LRV batteries.

B. A small tool and parts storage room shall be provided for issuance of small specialized hand tools and frequently used consumable parts. This room shall be located in proximity to the inspection and maintenance area.

C. A bridge crane with adequate capacity to lift motor trucks shall be provided. The crane shall be located to also accommodate removal and replacement (R&R) of major roof-mounted equipment. This shall be interlocked for safety with the OCS.

D. An area for secondary repair of LRV heating, ventilating and air conditioning equipment shall be provided.

E. A parts cleaning area with suitable special ventilation and electrical service shall be provided.

F. Part of the storage area shall be designated for storage of pre-dried sand, purchased in plastic-lined bags.

G. A fire sprinkler system shall be provided throughout the building in compliance with jurisdictional requirements. The system shall be of the dry type in areas prone to freezing and a wet system elsewhere. Chemical fire protection for areas such as electrical rooms, communications rooms, flammable storage, etc., may be necessary depending on local jurisdictional requirements. The system shall be mounted tight to the structure to avoid clearance problems with forklifts.

19.6.4 Support Areas for Shops

A. The following support facilities shall be provided:

1. Separate locker rooms, showers, and restroom facilities for men and women.

2. Employee lunch room, conference room, and operator and maintenance training areas.

3. Foreman's office, storeroom facilities, general work areas and receiving and shipping areas. Receiving and shipping areas shall be designed with docks for loading and unloading materials for the maintenance shops.

4. Spare parts storage, in conjunction with the store's office and loading dock.

5. An interior inventory storage area for wheels, trucks and other large parts.

19.6.5 Central Maintenance, Operations, and Administrative Areas

A. Space shall be provided for the management of the maintenance shops and operations facilities. Space must be provided for the Maintenance and Transportation Managers, unit supervisors, general clerical, and store room supervisors. For functional reasons, the LRV Maintenance Manager, Supervisors, and Foremen shall be located in a second floor office adjacent to the LRV work areas, on top of the LRV.

B. A covered area shall be dedicated for car cleaning operations. In addition to housing cleaning carts, this area shall be provided with a mop sink. It shall have an eyewash, charging plugs for the cleaning carts, and be heated to prevent freezing of water service.

19.6.6 Steam Cleaning of Components

A. Provisions shall be made for steam cleaning and hot water washing of components and assemblies up to truck size. Special equipment shall be required to separate particulate and oil from drainage water prior to discharge to the sanitary sewer system. Special ventilation shall be provided at the steam cleaning area.

19.6.7 Other Requirements

A. Where liquid fuels (gasoline and diesel) and liquefied petroleum gas (LP-gas) are provided, they shall be stored in accordance with IBC.

B. Provisions shall be made for the collection and removal of all flammable, combustible, and/or toxic liquids and greases to an area approved for disposal.

19.6.8 Construction

The minimum type of construction of the maintenance facilities shall be as prescribed in Chapter 18, Fire/Life Safety, section 18.8, Maintenance Facility and Yard.

19.7 EXTERIOR LRV WASH FACILITY

A. An automatic exterior LRV wash facility shall be provided. The washer shall operate automatically on the advance of the car or cars to be washed. The wash facility shall accommodate single LRVs or trains up to four cars in length. Provisions shall be made for the delivery and storage of cleaning agents at or near the washer. Facilities shall be provided to recycle rinse water, and freeze protection provisions shall be included. An auxiliary equipment room shall be provided for pumps, tanks, and pneumatic or hydraulic equipment.

B. The run-through automatic wash facility shall provide only exterior wash of the sides and ends of the LRV. Washing of the roof shall be performed manually at a platform that allows roof access in an area where there is no overhead wire, or where safety precautionary measures are taken to ensure that the contact wire is de-energized.

19.8 MOW BUILDING, PARKING AND STORAGE AREA

A Maintenance of Way (MOW) building shall provide offices and welfare facilities for the right-of-way maintenance personnel. In addition, there shall be a small workshop, and an enclosed storage area that will provide secure storage for high value materials such as copper wire and cables. The storage facility and the workshop shall have overhead doors for pickup truck access. Oversized parking places shall be provided adjacent to the MOW building for the non-revenue vehicles such as tower trucks, platform trucks, dump trucks, etc. A large gravel area shall be provided near the MOW building for storage of bulk materials such as rail, turn-outs, ballast, and ties.

19.9 FUELING FACILITIES

Where provisions are made for facilities to refuel the MOW and supervisors vehicles, emergency switches and other safety and environmental provisions shall be provided in accordance with the International Building Code, Plumbing Code, National Electric Code, and the NFPA. Some of these vehicles may use alternative fuels such as compressed natural gas and the station shall meet all safety and NFPA provisions.

19.10 ELECTRICAL SERVICES

A. A separate substation shall be provided for the shop with shop tracks electrically isolated from the yard tracks. Overhead wire in the yard and in the individual shop shall be sectionalized to allow the shutdown of power to individual car positions in the shop and tracks in the yard without affecting the remainder of the shop or yard. Individual lockable disconnects shall be provided for each section isolation switch to remove traction power when required for maintenance. The shop substation shall be solidly grounded to the building ground network for safety purposes.

B. A separate yard substation shall be provided, with yard trackage electrically isolated from mainline trackage. See Chapter 13, Traction Electrification.

C. 120Vac single phase, and 208V 3-phase service shall be provided to operate small HVAC, machinery, office equipment, and communication equipment all up to 1/2 hp. Incandescent and lighting shall be 120Vac for normal lighting and 125Vdc for emergency egress lights. Fluorescent lighting may be 277Vac or 120Vac for normal lighting.

   1. Shop area (HID) lighting shall be supplied at 277V ac.

   2. All motors and machinery 3/4 hp and over shall be supplied at 480V, 3-phase.

19.11 BATTERIES

A. Areas where vehicle batteries are charged shall be ventilated to the outside to ensure that the maximum hydrogen-air mixture generated during charging is held below the lower explosive limits.

B Where mechanical ventilation systems are required, they shall be installed in accordance with NFPA 91.

19.12 PAINTING AND PAINT REMOVAL

A. Painting and paint removal shall be per NFPA 130, paragraph 9.5.3.

19.13 WELDING

A. Welding will only occur in the building area specifically designed for this purpose and will conform to the requirements in NFPA 130, paragraph 9.5.5 and IFC, Chapter 26.

END CHAPTER 19

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20. HEATING, VENTILATION, AND AIR CONDITIONING

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20. HEATING, VENTILATION, AND AIR CONDITIONING

20.1 INTRODUCTION

20.1.1 Purpose

This chapter describes the functional and design requirements for the environmental control systems (ECS) to provide heating, ventilation, and air-conditioning (HVAC) for Link light rail transit (Link) facilities. It is intended to promote uniformity of design and to standardize the type and location of ECS equipment.

20.1.2 Scope

A. These criteria cover the ECS functional requirements, operation, and control for the following facilities of the Link system:

1. Maintenance Shops
2. Operation Control Center (OCC)
3. Traction power substations (TPSS) in facilities structures
4. Ancillary spaces
5. At-grade and aerial stations
6. Tunnel stations
7. Tunnel line sections

B. The ECS requirements for the transit vehicle are prescribed in Chapter 12, Light Rail Vehicle.

20.1.3 Codes and Standards

The ECS design shall comply with applicable local, state, and national codes. The designer's attention is directed to the requirements of the National Fire Protection Association (NFPA) Standard 130, Fixed Guideway Transit Systems, as amended by the local jurisdiction, the Washington State Energy Code, the Washington State Ventilation and Air Quality Code (WAC 15-13), and the International Mechanical Code (IMC) as amended by the Washington State Building Code Council (WSBCC) (WAC 51-42). Designers shall consult the applicable codes and publications and provide ECS in accordance with the most stringent of the

codes and/or industry practices. Designers shall obtain, maintain, and use at least one set of applicable local and state building, energy, and mechanical codes, including local ordinances, amendments, rulings, and the like, NFPA 90A, NFPA 91, NFPA 130, and other applicable codes and standards referenced herein.

20.1.4 System Interface

The ECS design shall interface with the design parameters set forth in these criteria for other systems as appropriate.

20.2 ENVIRONMENTAL CONTROL SYSTEM

To enable the ECS to control temperature, air velocity, rate of air pressure change, dust, odors, and the direction of spread of smoke during fire emergencies the following shall be provided as prescribed below:

A. HVAC systems shall be provided for offices, employee areas, shops, and maintenance rooms.

B. HVAC systems shall be provided for offices, employee areas, operations control center, computer, and miscellaneous electronics equipment rooms.

C. Ventilation systems shall be provided for TPSS rooms. Heating shall be provided as required.

D. Heating and ventilation systems shall be provided for the ancillary rooms in miscellaneous wayside structures.

E. For at-grade and aerial stations the HVAC systems shall be provided for the ancillary rooms and concession areas, if any. ECS will not be provided for patron areas unless the ECS is part of a joint development project or is specifically direct by Sound Transit.

F. In tunnel stations heating and ventilation systems shall be provided for ancillary rooms and concession areas, if any. Stairway pressurization shall be provided in accordance with IBC requirements. Smoke exhaust shall be provided in accordance with IBC, sections 405 and 909 requirements, where required.

G. Ventilation shafts that terminate at or above grade at each end of a station or between two stations shall be provided. The ventilation shafts shall be equipped with emergency fans, sound attenuation, and damper systems as needed for forced ventilation during congested or emergency operations.

20.3 FUNCTIONAL REQUIREMENTS

20.3.1 HVAC Systems

A. HVAC systems for occupied areas shall maintain an acceptable environment for patrons and operating and maintenance personnel.

B. HVAC systems for equipment fans shall be designed to prolong the life of equipment through control of temperature and pressure.

20.3.2 Tunnel Station and Trackways

A. Operations are considered "normal" when trains are moving through the system according to schedule and passengers are traveling smoothly through stations to and from transit vehicles and trains are traveling in the normal direction and assigned to a specific track.

B. Congested operations result from delays or operational problems, which prevent the free flow of trains through the system. Trains may wait in stations or stop in tunnels. Delays usually range from 30 seconds or longer, although longer delays may be experienced. Passenger evacuation or exposure to hazardous conditions does not occur during congested operations. The emergency fan system may be operated to relieve stale air conditions.

C. Emergency operations generally result from a malfunction of the transit vehicle. The most serious emergency is a stopped train on fire in a tunnel, disrupting traffic and requiring passenger evacuation. The emergency ventilation system shall be designed to maintain a single evacuation path from the train that is clear of smoke and hot gases.

D. Tunnel station public area and tunnel ventilation shall be provided by the emergency fan system. Computer assisted simulations shall be employed to determine appropriate emergency fan system operations.

E. During an emergency in a tunnel line section or station, emergency exit corridors and stairways shall be pressurized.

20.4 DESIGN PARAMETERS

20.4.1 Outside Conditions

A. The outside conditions prescribed herein are for determining the required capacities of HVAC systems. The system equipment shall be suitable for continuous operation (at degraded capacity) during extreme weather conditions. The ventilation, heating, cooling, and

refrigeration equipment shall continue to operate if the outside temperature reaches 92°F or drops to 19°F.

B. Summer Peak Design Conditions (ASHRAE 1997):

1. Maintenance shops and yards:

   78°F dry bulb (DB) and 62°F wet bulb (WB) temperatures (2.0 percent occurrence)

2. Ancillary spaces:

   78°F DB and 62°F WB (2.0 percent occurrence)

3. Train control center:

   82°F DB and 66°F WB (0.5 percent occurrence)

4. Enclosed concession areas:

   78°F DB and 62°F WB (2.0 percent occurrence)

5. Tunnel station air-conditioned spaces:

   78°F DB and 62°F WB (2.0 percent occurrence)

6. Tunnel station trackways and tunnels:

   78°F DB and 62°F WB (2.0 percent occurrence)

C. Winter Minimum Design Condition (ASHRAE 1997):

1. 24°F DB (0.6 percent occurrence)

20.4.2 Inside Conditions for Normal and Congested Operations

A. The number of air changes per hour (total air volume circulated) shall be based on the requirements of applicable codes, heating and cooling loads, or odor control (whichever is greater) but shall not be less than four air changes per hour. Ventilation systems shall be designed to provide cross ventilation. The outside requirement shall be a minimum of 15 cubic feet per minute (cfm) per person for all occupied spaces being heated, ventilated, or air-conditioned.

B. Tables 20-1 through 20-3 detail indoor design conditions for yards and shops, the train control center, and ancillary rooms. Ancillary rooms with electronic equipment may impose more stringent heat removal requirements. Designers shall analyze each room individually, and shall provide an ECS that will provide a room climate suitable for efficient equipment operation.

Table 20-1
INDOOR DESIGN CONDITIONS FOR MAINTENANCE FACILITY

SPACE	WINTER[1]	SUMMER[2]	
	(°F DB)	(°F DB)	(% RH)[3]
General Offices	68	78	50
Shops	68	--	--
Lunch Rooms	68	78	50
Locker Rooms	68	78	50
Staff Room	68	78	50
Conference Room	68	78	50
Training Room	68	78	50
Crew Room	68	78	50
Toilets	68	--	--
Showers	68	--	--
Storage Areas	55	--	--
Custodial Room	68	--	--
Electrical Equipment Room	55	104	--
Mechanical Equipment Room	55	104	--
Battery Room	55	--	50
Computer Room	68	78	50
Uninterruptible Power Supply (UPS) Room	55	104	--
Standby Power Generator Room	55	104	--
Electronic Equipment Room	55	as required	50
Yard Control Room	68	78	50
Elevator Machine Room	55	104	--

Notes to Tables 20-1 through 20-3

1. Winter temperatures are based on the following parameters:
   a) Rooms requiring the temperature to be maintained well above freezing to avoid maintenance problems: 55°F.
   b) Rooms requiring no heating: No value provided. These rooms may be ventilated by transfer air.
2. Summer temperatures are based on the following parameters:
   a) Rooms occupied by personnel dressed in office attire: 75°F.
   b) Rooms with solid state electronic equipment: 75°F (to avoid maintenance problems).
   c) Rooms that may be cooled by ventilation only: 104°F (ambient +10°F).
   d) Rooms requiring no cooling: No value provided. These rooms may be ventilated by transfer air.

   Where:
   °F: Degrees Fahrenheit
   °F DB: Degrees Fahrenheit dry bulb
   % RH: Percentage relative humidity
3. Relative humidity given for design purposes only. Humidifiers are not required, except as noted.

Table 20-2*

INDOOR DESIGN CONDITIONS FOR OPERATIONS CONTROL CENTER

SPACE	WINTER[1]	SUMMER[2]	
	(°F DB)	(°F DB)	(% RH)
General Offices	68	78	50
Reception Area	68	78	50
Staff Rooms	68	78	50
Conference Room	68	78	50
Training Room	68	78	50
Crew Room	68	78	50
Main Control Room	68	78	50
Tape Storage Room	68	78	50
Computer Room	68	78	50
Electronics Shops	68	78	50
Storage Areas	55	--	--
Locker Rooms	68	78	50
Showers	68	--	--
Toilets	68	--	--
Custodial Rooms	68	--	--
Electrical Equipment Room	55	104	--
Mechanical Equipment Room	55	104	--
Electronic Equipment Room	68	as required	50
UPS Room	68	104	50
Standby Power Generator Room	55	104	--
Closed Circuit Television Room	68	78	50
Security Control Room	68	78	50
Battery Room	55	--	50

* Notes listed under Table 20-1 are also applicable to this table.

Table 20-3*

INDOOR DESIGN CONDITIONS FOR ANCILLARY ROOMS

SPACE	WINTER[1]	SUMMER[2]	
	(°F DB)	(°F DB)	(% RH)
Electronic Equipment Rooms	68	as required	50
Traction Power Substations	--	104	--
Electrical Equipment Rooms	55	104	--
Mechanical Equipment Rooms	55	104	--
Elevator Machine Rooms	55	104	--
Telephone Equipment Rooms	55	--	--
Battery Rooms	68	--	50
Toilets	68	--	--
Custodial Rooms	68	--	--
Trash Rooms	55	--	--
Storage Rooms	55	--	--
Water Meter Vaults	55	--	--
Valve Rooms	55	--	--
Pump Rooms	55	--	--
Sewage Ejector Rooms	55	--	--
Computer Room	68	78	50
UPS Room	55	104	50
Standby Power Gen. Room	55	--	--
Station ECS Control Room	55	--	50
Multipurpose Room	55	--	50

* Notes listed under Table 20-1 are also applicable to this table.

C. Indoor Design Conditions - Other Facilities.

1. At-Grade and Aerial Stations Platform Areas. Ambient conditions.

2. At-Grade and Aerial Station Concession Areas. Summer dry bulb temperature: 75°F, relative humidity: 30 percent; winter: 70°F.

D. Tunnel Station Platform and Mezzanine Areas

1. Dry bulb temperature

   a. ***Summer:*** 10°F above ambient

   b. ***Winter:*** Heating will not be provided

2. ***Humidity:*** No control

3. Horizontal and sloping air velocity

   (Platform, mezzanine, entranceways, escalators, stairways)

   Average - Not greater than 600 feet per minute (fpm)

   Maximum - Not greater than 1,000 fpm

4. The criterion for rapid pressure changes, applicable when the total change in pressure is greater than 0.10 pound per square inch (psi) (2.8 inches per water gauge) (in. w.g.), is that no person (either patron or employee) shall be subjected to a rate of pressure greater than 0.06 psi per second (1.7-in. w.g. per second).

E. Tunnel Station Enclosed Concession Areas

1. ***Summer:*** 78°F dry bulb temperature, 30 percent relative humidity

2. ***Winter:*** 68°F

F. Tunnels

1. ***Dry bulb temperature (maximum):*** Ambient plus 10°F.

2. ***Dry bulb temperature (minimum):*** Heating will not be provided. Temperatures below freezing could occur in locations near portals and extend 1,500 feet into the tunnel.

3. ***Humidity:*** Humidity control is not required.

4. ***Air Velocity:*** Unoccupied tunnels: No control.

5. The criterion for rapid pressure changes, applicable when the total change in pressure is greater than 0.10 psi (2.8-in. w.g.), is that no person (either patron or employee) shall be subjected to a rate of pressure change greater than 0.06 psi per second (1.7-in. w.g. per second).

G. Normal Operations Train Frequency – see Chapter 2, Operations.

20.4.3 Design Conditions for Emergency Operations

A. The design fire scenarios are as follows: a stopped train on fire in a tunnel, or a stopped train on fire in a tunnel station. The size of the emergency ventilation system, the number of fans activated in an emergency situation, the type of ventilation equipment provided, and the built-in system reliability shall be designed to meet these scenarios. During a design case tunnel fire that involves a single- or multiple-car train, the following design parameters shall apply:

1. ***Vehicle Fire Heat Load:*** In accordance with NFPA 130 and as approved by the Fire/Life Safety Committee. Refer to Chapter 12, Light Rail Vehicle, section 12.7.7 C, Flammability and Smoke Emission.

2. ***Train Fire Heat Release Rate:*** In accordance with NFPA 130 and as approved by the Fire/Life Safety Committee. Refer to Chapter 12, Light Rail Vehicle, section 12.7.7 C, Flammability and Smoke Emission.

3. ***Station:*** The maximum air temperature in the evacuation route shall be 140°F or less, ignoring radiant heating.

4. ***Tunnels:*** Tunnel design conditions are for the evacuation route only. For tunnel fires, sufficient mechanical ventilation shall be provided to move smoke in one direction or the other as required to maintain tolerable conditions in a single evacuation route from one side of the fire. The maximum temperature in the evacuation route shall be 140°F or less, ignoring radiant heating.

5. The minimum air velocity in the evacuation path shall not be less than that required to control the spread of smoke and hot gases from the fire into the evacuation path. The maximum air velocity in the evacuation path shall be 2,200 fpm.

6. The Carbon monoxide (CO) generated during smoke conditions shall not exceed 800 PPM (parts per million) based on a 30-minute evacuation period. CO concentrations shall decrease as the evacuation period increases.

7. Smoke obscuration levels that are continuously maintained below the point at which a sign illuminated at 7.5 foot-candles is discernible at 30 ft (9.1m). Doors and walls are discernible at 33 ft (10m).

8. Engineering analysis shall include a validated subway analytical simulation program such as would result from the application of computational fluid dynamics (CFD) techniques. The results of the analysis can be measured during commissioning to confirm the mechanical ventilation system as-built meets the requirements determined by the analysis.

9. Engineering analysis shall address (1) heat release rate of vehicle, (2) fire growth rate, (3) station and trainway geometries, (4) fan system and devices, and (5) a program of predetermined emergency response procedures.

10. The emergency ventilation system shall maintain the required flow rates for a minimum of 1 hour.

11. The emergency ventilation system shall be capable of reaching full operation within 180 seconds.

12. The emergency ventilation system shall be designed for the maximum number of trains between ventilation shafts during an emergency.

20.4.4 Design Velocities for Air Distribution Systems

A. Design velocities shall be selected to provide the required system performance and to minimize pressure loss and energy consumption, air-borne noise generation, draft, and the intake of dust particles. The design velocities in air distribution systems are described below:

1. Sheet metal supply and return-air duct sizes shall be determined in accordance with the requirements prescribed for low-velocity air-distribution systems in the duct design chapter of the Fundamentals of the American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE), latest edition.

2. Emergency ventilation shafts (EVS) shall have a nominal air velocity of 1,800 fpm or less and a maximum air velocity of 2,200 fpm. Other concrete ducts, plenums and shafts shall have a nominal air velocity of 1,500 fpm or less and a maximum air velocity of 1,800 fpm.

3. Supply registers shall be selected for throw and noise criteria. (Noise criteria is stated in section 20.4.6. Throw must be consistent with room architecture).

4. Variable Air Volume (VAV) terminals shall be selected for required air flow, pressure, and noise criteria.

5. Diffusers shall be selected for throw and noise criteria.

6. Exhaust and return grilles shall have a capacity based on maximum velocity of 500 fpm over the gross area.

7. Transfer grilles shall have a maximum velocity of 250 fpm over the gross area.

8. Transfer louvers shall have a maximum velocity of 250 fpm over gross area.

9. Tunnel ventilation fan dampers shall have a maximum air velocity of 2,000 fpm over the gross area.

10. Fan sound attenuators have a maximum air velocity of 2,000 fpm over the gross area.

11. Bypass dampers shall have a maximum velocity of approximately 1,000 fpm over the gross area.

20.4.5 Noise Criteria

A. A proper acoustical environment is as important to human comfort as any of the other environmental factors controlled by ECS. Improper design of ECS equipment can create an unacceptable acoustic environment. The primary objective of ECS acoustical design is to achieve acceptable sound levels for all activities and people involved; this does not necessarily mean the lowest possible sound levels, however. Because of the wide range of activities, appropriate indoor acoustical design levels will vary considerably from room to room and acceptable outdoor levels will depend on local ambient sound conditions. Proper sound levels at various listener locations shall be achieved by controlling the sound generation of the various sources and the sound transmission from the sources to the listeners.

B. The maximum permissible sound levels of ECS shall be as prescribed in Chapter 3, Environmental. Sound control for environmental control systems shall be designed in accordance with the procedure outlined in the noise and vibration chapter of these criteria and the Sound and Vibration Control chapter of the Handbook of Systems and Applications (ASHRAE), latest edition, and shall comply with local municipal codes and ordinances.

20.5 SYSTEMS AND EQUIPMENT

20.5.1 HVAC Systems for Maintenance Shops

A. The concepts described in these criteria are applicable to HVAC systems, equipment, operation, and controls in the indicated areas of major repair shops, service and inspection shops, and yards.

B. General Office Areas and Shops. The HVAC system shall consist of unitary or split-package air-conditioners with an air-distribution system, controls, drives and accessories. The condensing units for split-package systems shall be roof- or ground-mounted, and air-handling units (AHUs) shall be located in the mechanical equipment room or within the space required. Unitary packages shall be roof mounted. A gas-fired furnace shall be included in each air-handler for heating supply air. All gas heating equipment shall be equipped with IRI rated combustion controls. All air-conditioning systems in excess of 2000 cfm shall be designed so that they can modulate from the minimum outside air required for ventilation to 100 percent outside air. A ducted return air system shall be provided with registers located in each conditioned office space. The operation of the HVAC system shall be thermostatically controlled.

C. If a source of chilled water is conveniently available at a maintenance facility, then the cost-effectiveness of cooling with purchased chilled water shall be analyzed. The HVAC system with purchased chilled water shall include chilled water circulating pumps, air-handling units with relief systems, return-air fans, etc. The air distribution ductwork and controls for the general office area HVAC systems shall be separated from the air distribution ductwork and from the controls for the shop HVAC systems. The designer may propose a variable air volume (VAV) system for general office spaces as an alternate design. This alternative design must include a system description and a cost comparison with the constant volume system.

D. The cooling load shall be based on a summation of the following heat gains:

1. Occupancy

2. A lighting load of 3 watts per square foot (W/ft^2) (or actual lighting load when available) and power requirements of 1 W/ft^2 of space (or actual load when available)

3. Ventilation and make-up air

4. Solar and transmission gains (where applicable)

5. Equipment heat rejection based on usage factor

a. The heating load shall be based on a summation of the transmission heat loss and ventilation air heat load, and equipment heat loads as applicable.

b. Air-handling units for split-packages shall include the following components:

1) Mixing Plenum

2) Outside and Return Air Dampers of the Opposed-Blade Type. Damper operations shall be electrically controlled.

3) Air Filter Section

4) Direct Expansion (DX) Coils Section. DX coils shall have a maximum face velocity of 550 fpm. The number of fins per inch shall not be greater than eight.

5) Centrifugal Fans With Non-Overloading Motors. Each fan shall be complete with electric motor, vibration isolators for mounting the fan, and motor base and belt guard. Electric motors for each fan unit shall be selected so that the fan power requirement at any point on the fan power-capacity curve does not exceed the horsepower rating of the motors. For belt-drive fans, an adjustable sheave V-belt drive shall be provided.

6) Controls for units shall consist of the following:

a) Across-the-line, circuit-breaker-type magnetic motor starters

b) Local manual on/off/automatic fan switches

c) Remote control terminals from the space thermostat

d) Terminals for remote monitoring and control

7) The refrigeration system shall include air-cooled condensing units. Each unit shall consist of the following: semi-hermetic reciprocating type compressors, condensing coils with integral subcooling; supporting casing with standard direct-drive, propeller-type fans; motors; and head pressure control. Units shall be factory packaged. With ambient air at 82°F dry bulb entering the condenser with 15°F subcooling, the saturated suction temperature shall be 40°F at a condensing temperature of 120°F.

6. Sufficient access around A/C and air-handling units shall be provided for the maintenance of fans, coils, and air filters and to facilitate coil and filter removal and reinstallation as recommended by the equipment manufacturers.

E. Heating shall be provided as recommended by the spray paint equipment supplier. To maintain negative pressure in paint spray booths, the ventilation system for the paint spray area shall be sized so that the supply air volume is five percent less than the air volume exhausted by the paint spray booth exhaust. The number of air changes per hour (the ventilation rate) shall be as recommended by the spray paint equipment supplier, but the number of changes shall not be less than the rate required by the applicable codes. The filtration of supply and exhaust air shall be provided as recommended by the spray paint equipment supplier and as required by the applicable codes. Exhaust air filters shall be capable of removing paint and dust. Exhaust fan motors and temperature control equipment shall be of explosion-proof construction. Spray finishing operations shall be in accordance with IBC/IFC Chapter 15. A Seattle Fire Department permit is required for conducting spray finishing.

F. In mechanical equipment rooms the ventilation and heating shall be as that described in section 20.5.3 for the ancillary rooms.

G. The locker rooms shall receive heat and conditioned air from the general office HVAC unit described in General Office Areas, Open Shops, and Enclosed Shops section above. If HVAC cannot be provided from the general office area, a packaged HVAC unit shall be provided.

H. Toilets

1. When adjacent to locker rooms, toilet rooms shall be heated with secondary air transferred from adjacent locker rooms.

2. In the general office area, toilet rooms shall receive heat and air-conditioned air from the general office unit described in the general office areas, open shops, and enclosed shops section above. Toilet room exhaust fans shall operate continuously when offices are occupied.

3. Other toilet rooms located within a general shop area shall be heated and ventilated. Toilet room exhaust fans shall be controlled by the light switch with a time delay on light off.

I. In electric equipment rooms the ventilation system shall be as that described in section 20.5.3 for the ancillary rooms. Where required to prevent condensation, electrical equipment rooms shall be heated by

means of transferring secondary air from adjacent heated areas. Where additional heating is required, electric heaters controlled by a room thermostat shall be provided.

J. The train operators' lounge and lunch room shall be provided heat and A/C from the general office unit described in the General Office Areas and Shops section above, or it may have its own packaged HVAC unit.

K. In all other areas the HVAC criteria for all other areas shall conform as applicable to the requirements of section 20.5.3.

L. Blow-down is dust removal using either compressed air or water for routine service and inspection access reasons and not be confused with long-term cleaning, which occurs at intervals greater than one service and inspection cycle. The designer shall confirm the adequacy of the below criteria (which assumes a manned facility that may be used for purposes in addition to blow-down rather than a blow-down facility having industrial robots) with the authorities having jurisdiction prior to beginning final design.

1. A supply and exhaust ventilation system shall be furnished to provide safety and comfort to the operating personnel and to remove airborne dust resulting from cleaning of under-carriage equipment of the vehicles.

2. General ventilation at the rate of 10 air changes per hour shall be provided for the total enclosed area. Exhaust or air extraction rate for pit area shall be 4 cubic feet per minute (cfm) per square foot. Make-up or supply air shall be less than the exhaust air.

3. Roof-mounted exhaust fans and packaged or unitary HVAC type make-up air units shall be used to provide the required ventilation. If the blow-down booth is located within the maintenance building, the exhaust fans and a split-package HVAC type make-up air units shall be mounted on the booth roof. Air-cooled condensers for the split-package HVAC units shall be mounted on the building roof. Exhaust air grills shall be located near the booth floor and the pit floor, with a minimum face velocity of 175 feet per minute (fpm). Make-up air shall be introduced at the roof level and near the work platforms.

4. Appropriate air distribution ductwork, air filters, and automatic temperature controls shall be provided. Wet scrubbers shall be provided for the exhaust air system to remove dust particles before exhausting air to the outdoors. The scrubber shall be of the dynamic precipitator type, with an exhauster, water sprayer, and freeze protection. Clean air shall be discharged to the

atmosphere. The water/dust slurry shall be discharged into the sanitary sewer after clarification.

5. In the Operation and Control center the supply and exhaust ventilation system shall be manually controlled. When temperature drops below 68°F, the heating system shall be energized.

6. The make-up air and exhaust systems shall be interlocked to prevent operation of one system by itself. Scrubbers shall be interlocked with exhaust air and water supply systems.

7. The summer-winter-off switch shall be interlocked with compressed air supply and electrical power supply to the under-car cleaning equipment. In the off position, the compressed air and power supply to the cleaning equipment shall be turned off.

8. All doors to the blow-down facility shall be equipped with interlocks so that the make-up air and exhaust systems, and the compressed air and power supply to the cleaning equipment, are shut off automatically when any one door is opened.

20.5.2 Operation Control Center

A. The concepts described in these criteria are applicable to the heating, ventilation, and air-conditioning systems, equipment, operation, and controls in the OCC. Both outside and indoor peak design conditions for summer and winter shall conform to the requirements prescribed in section 20.4.

1. For a free-standing building located outdoors, or for an underground facility where chilled water is not conveniently available, the HVAC system shall consist of two split-package air-conditioning units with two remote air-cooled condensers. Each unit shall be capable of providing 100 percent of the total cooling load. Each system shall be complete with refrigerant piping, controls, drives, and accessories. One of the two systems shall be provided as a standby. The operating and standby units should alternate functions every 1 to 2 weeks. The air distribution ductwork shall be common. Outside air for ventilation shall be provided as required.

2. An underground OCC shall be cooled using purchased chilled water if conveniently available. The HVAC system shall include air-handling units, chilled water circulating pumps, and exhaust and relief fans. As a minimum, rooms such as, the main control room, the communications equipment room, and the computer equipment room shall be provided with a backup air-conditioning

system. The backup air-conditioning system shall consist of a split-package A/C unit with a remote air-cooled condenser. Computer rooms shall include provisions for maintaining the required humidity level.

B. A/C Equipment and Accessories

1. For indoor units each unit shall be completely pre-piped and prewired internally. Compressors shall be a heavy-duty, semi-hermetic type. The fans shall be belt-driven, centrifugal with forward-curved blades and double inlets. Fan motors shall have an adjustable mount and an adjustable sheave to vary the fan speed. The reheating apparatus shall be electric. Air filters shall be provided for pre-filter and final-filter.

2. For outdoor units the condensers shall maintain adequate condensing temperature for an ambient air temperature range of 24°F to 82°F. Air-cooled condensers shall have direct-driven propeller fans.

C. To maintain step control for temperature and humidity conditions, a solid state control system shall be used. The indoor temperature and humidity sensing elements shall be located in the return air stream. Provide at least two stages of cooling and up to three stages of reheat as required to maintain close room temperature tolerances. The humidity controller shall consist of one stage of humidification and one stage of dehumidification. The outside air sensors shall be provided in the fresh air intake duct. System operating mode configurations shall range from full cooling with minimum outside air to maximum free cooling with 100 percent outside air.

D. Air-conditioning equipment serving the OCC shall be wired to the standby power supply as prescribed in the facilities electrical requirements chapter of these criteria.

20.5.3 Ancillary Space HVAC Systems

A. Communication and Signaling (C&S) Rooms

1. The air-conditioning system, when required, shall be designed so that the minimum outside air requirement is satisfied. Approximately 90 percent of the supply air shall be recirculated and 10 percent shall be exhausted by exfiltration to maintain positive pressure within the space. Supply air shall be filtered.

2. The cooling load shall be calculated based on a summation of the following heat gains:

a. Internal equipment load;

b. Lighting load of 3 W/ft^2 (or actual lighting load if available);

c. Outside air load, and

d. Solar and transmission gains (where applicable).

3. Air-handling unit equipment shall be of the DX split-system type, with an air-handling unit in the room adjacent to or within the C&S room. Air-handling units shall include filters, DX cooling coils, a centrifugal fan, and a condensate drain pan. Installation shall include automatic temperature controls and a remote, air-cooled condensing unit. Although not essential, a system with dual compressors (each with 50 percent capacity), is preferred. Air-cooled condensing units for C&S rooms in Tunnel stations shall be located within mechanical equipment rooms or exhaust-air shaft, with discharge air ducted to an exhaust-air shaft. Condensing unit for aerial and at-grade C&S rooms shall be located outdoors. A condensing unit may be part of the air-handling unit, or it may be remote from it. Where chilled water is conveniently available, an air-handling unit with chilled water coils shall be provided.

4. The operation and control of the HVAC system shall be controlled by a room thermostat. The ventilation system will be automatically shut down in the event of fire or smoke detection within the C&S rooms. The system shall have provisions so that high-temperature indicators can transmit a summary fault indication to the OCC.

B. Traction Power Substations

1. A ventilation system is required in all enclosed TPSS to remove heat generated by the electrical equipment, and to limit the operating temperatures within substations to the design operating conditions prescribed in section 20.4.2. Ventilation system shall provide supply filtered, 100 percent outdoor air to TPSS. Exhaust air shall discharge to outdoors.

2. The ventilation capacity shall be based on a summation of the following internal heat gains:

a. Lighting load of 3 w/ft^2 (Use actual lighting load when available);

b. Solar and transmission gains (where applicable), and

c. Heat rejected by the electrical equipment.

3. The system shall consist of two identical supply fans, motorized dampers, filters, an air distribution system, automatic temperature controls, and an alternator to change lead-lag fan sequence. The design of supply and exhaust ducts shall be based on two-fan operation. Ventilation air shall not be taken from a tunnel or exhausted into a tunnel. A positive pressure shall be maintained within the room when the ventilation system is in operation. Fans shall be selected with sound power levels such that with both supply fans in operation the noise level in the substation does not exceed the maximum allowable noise level as prescribed in the noise and vibration Chapter 3, Environmental, of these criteria. Where possible, exhaust air shall be through dampers, rather than a separate exhaust fan system.

4. The operation and control of the fans shall be controlled by adjustable thermostats located within the substation. For example, when the space temperature rises to 86°F, the first (or lead) fan will start. On a continued rise to 104°F, the second (or lag) fan will start. On a fall in temperature to 100°F, the lag fan will stop. On a continued fall in temperature to 80°F, the lead fan will stop. By means of an alternator, the lead fan of one cycle will become the lag fan on the next cycle. This will keep the number of starts and hours of operation approximately equal. Local manual control (a time switch) shall be provided so that the fans can be turned on during human occupancy of the substation. The ventilation system shall be automatically shut down in the event of fire or smoke detection within the TPSS. The system shall have provisions so that high-temperature can transmit a system fault indication to the OCC.

C. The concepts described in section 20.5.2 for HVAC systems for the OCC are applicable to HVAC systems for computer rooms.

D. Auxiliary Electrical Rooms.

1. Ventilation system shall be provided at the air intake to the space and a positive pressure shall be maintained when the system is in operation.

2. The ventilation capacity shall be based on a summation of the following internal heat gains:

   a. Two percent of the installed transformer capacity

   b. Heat rejected by the electrical equipment

   c. Solar and transmission gains (where applicable)

d. A lighting load of 3 w/ft^2 (use actual lighting load when available).

3. The system shall consist of one or more supply fans, distribution ductwork and devices, air filters, motorized damper, automatic temperature controls, and intake and exhaust louvers. Air shall not be drawn from or discharged into tunnels. Use of exhaust fans shall be minimized.

4. Each system shall be controlled by an adjustable thermostat within the ancillary room having the highest continuous heat load served by the supply fan being controlled. For example, the fans shall start when the space temperature rises to 86°F or above and stop when the temperature falls to 80°F or below. Local manual control via a time switch shall be provided for operation of the ventilation system during human occupancy of the room. The ventilation system shall be automatically shut down in the event of fire or smoke detection within the room. A positive pressure within the room shall be maintained when the system is in operation.

E. Valve-regulated lead-acid battery systems having a liquid capacity of more than 50 gallons used for facility standby power, emergency power or uninterrupted power supplies shall be in accordance with Section 608 of the International Building Code as adopted by the State of Washington and amended by the local jurisdiction. Vented (flooded) lead-acid batteries shall be in accordance with IFC Section 609.

F. Miscellaneous Ancillary Rooms.

1. Ventilation shall be provided for each ancillary room shown on the project definition drawings. Air shall be discharged to outdoors. Ventilation air shall be provided as required and shall be taken from adjacent areas or outside as applicable. When taken from outdoors, air shall be filtered. Each ventilation system shall be shut down automatically in the event of the detection of fire or smoke within the area served.

2. For the operation and control of the toilet rooms, an exhaust fan shall be provided that operates only when associated lighting is energized, with a time-delay on the light "off" switch. The ventilation system shall operate continuously in the following rooms: trash, sewage ejector, sump-pump, and battery rooms. Ventilation system shall be actuated by the light switch with time-delay off in custodial and storage room. In elevator machine rooms and the electrical equipment rooms, the ventilation system shall be controlled by a room thermostat and by manual override.

Ventilation system shall be automatically shut down in the event of fire or smoke detection within the room.

20.5.4 Concession Area HVAC Systems

A. At-Grade and Aerial Stations

1. The HVAC system for concession spaces provided at aerial and at-grade stations shall consist of a split-packaged or a self-contained, pre-packaged heat pump/air-conditioner complete with an air distribution system, controls, drives, and accessories.

2. The HVAC equipment and operating controls shall conform to the requirements prescribed in section 20.5.1

3. The operation of the HVAC system shall be controlled by a space thermostat and by a manual override.

4. Metering devices shall be provided for domestic water and electricity consumption for each concession space as approximate to monitor individual tenant consumption.

B. Tunnel Stations.

1. The HVAC system shall be used for concession spaces at tunnel stations shall consist of a split packaged air cooler system(s) complete with air distribution ductwork, controls and accessories. Fresh air/exhaust air connections to the station air distribution system shall be provided.

2. Air-handling and fan-coil units shall conform to the requirements prescribed in section 20.5.1 for identical HVAC equipment.

3. The operation and control of the HVAC system shall be controlled by a space thermostat and by manual override. The ventilation system shall be automatically shut down in the event of fire or smoke detection within the room.

4. Metering devices for chilled water, domestic water, and electric power consumption shall be provided for each concession space as appropriate to monitor individual tenant consumption.

20.5.5 Tunnel ECS

A. The concepts described in these criteria are applicable for tunnel stations and tunnels.

1. The emergency fan system shall be designed to achieve the objectives established for emergency situations (see section

20.4.3). In these situations, the function of the emergency fan system is to maintain a relatively safe path of egress through a tunnel section in case it becomes necessary to evacuate persons from the Link system. The emergency fan system shall assist emergency personnel in gaining access to the source of the emergency by controlling the flow of smoke in the tunnel. The fan system shall be used to remove smoke from the platform and mezzanine areas at the station. The fan system may be used for comfort conditioning on hot days and during congested operations.

2. For achieving the above objectives, the basic concept of operation and control of the emergency fan system is to provide a source of fresh air into the evacuation path and to keep smoke and heat away from the path.

3. The ventilation system shall be capable of moving air in either direction in the tunnel at the required air velocity to mitigate backlayering of the smoke from a design-condition fire (see section 20.4.3).

4. Fan dampers and bypass dampers must be interlocked such that the former open and the latter close when their respective fan are started. The "power-off" mode for damper positions shall be "open" for fan dampers and "closed" for bypass dampers.

B. For a typical two-track tunnel station, a total of four fans shall be provided, two at each end of the station. Emergency Ventilation Shafts (EVS) shall be provided at each end of the station. Additional emergency fans may be located at mid-tunnel vent shaft cross-overs or other selected locations

1. Fans may be housed in fan rooms or shafts and arranged horizontally or vertically. Forward airflow shall be in the exhaust mode, so that the air flow is to the outdoors from the tunnel. Fan damper shall be located between fan and EVS. Bypass damper shall be located so that piston-effect air flow is routed to EVS and not through fan. Track dampers shall be located so that air flow caused by emergency fan operations can be diverted to or from either tunnel bore.

2. Fan motor starters and related operating control devices shall be isolated from the ventilation airflow by a separation in accordance with NFPA 130.

C. All system components located in the airstream shall be capable of operating in accordance with NFPA 130, paragraph 7.3.

1. Emergency fans shall be of the axial-flow type with an internally mounted, direct-drive motor. Individual emergency ventilation fan motors shall be designed to achieve their full operating speed in no more than 30 seconds from stopped position when started across the line and in no more than 60 seconds for variable speed motors. (See NFPA 130, paragraph 7.3.1.1.) Fans shall be reversible within a 60-second time interval so as to either supply or exhaust air to or from the trackway. Fans shall have manually adjustable-pitch blades to permit a change in pressure versus air flow capacity for either system balancing or for future system modification. The minimum acceptable reverse (supply) air flow capacity shall be 90 percent of the forward (exhaust) air flow capacity. Fans shall have a total fan efficiency of not less than 60 percent in the forward (exhaust) flow mode.

    a. When required to meet the noise criteria of Chapter 3, Environmental, a fan shall be provided with modular, rectangular sound attenuators on either or both inlet and discharge sides. The exact length of sound attenuators shall be based on the dynamic insertion loss (DIL) levels to be provided to the designer. Primary method of sound attenuation shall be by sound lining of the EVS.

    b. Track, fan, and bypass dampers shall be the heavy duty, industrial, parallel-blade type. Dampers and their associated structural supporting members shall be capable of withstanding a maximum differential static pressure across the dampers of 16 inches water gauge, and minimum differential static pressure of 6 inches of water gauge for 2,000,000 reversals. Each damper will indicate the fully open position and the fully closed position. Installed dampers shall withstand maximum static pressure caused by fan operation against a closed damper.

    c. Emergency ventilation fans, their motors, and all related components exposed to the exhaust airflow shall be designed to operate in an ambient atmosphere of 482°F for a minimum of 1 hour. (See NFPA 230 7.3.2.)

    d. Fans shall be rated in accordance with ANSI/AMCA 210, AMCA 300-96, ASHRAE Handbook Fundamentals, and ASHRAE 149. (See NFPA 230 7.3.3.)

    e. Thermal overload protective devices on motor control devices used for emergency ventilation shall not be permitted. (See NFPA 130, paragraph 7.3.4.1.)

2. Air distribution ductwork shall conform to the requirements prescribed in section 20.6, except that ductwork on both sides of fan shall be designed and installed to withstand static pressure developed by the fan when operating against closed dampers, and shall not be less than 10-in. w.g. positive pressure or more than 10-in. w.g. negative pressure. Ducts that pass through fire-rated walls shall meet the requirement of NFPA 221. Reference NFPA 91 2-1.10 – 2-1.12.

3. During normal operations, the emergency fans will not be operated and their associated fan dampers will be closed. When platform temperatures rise above a preset temperature, the emergency fan system will be operated in a pre-programmed scenario that is actuated through the SCADA System. Depending on the temperature at station platform level, the bypass dampers will be either opened or closed. Usually the bypass dampers will be open. When platform temperatures fall below 60°F, the bypass dampers shall be closed to allow train heat to warm the system.

4. The control system shall have capability of controlling all operating modes of emergency fan system, both remotely from OCC and locally from the Emergency Management Panel (EMP) located at the Fare Command Center (FCC).

   a. Local control panel at station and ventilation shafts shall control fans and dampers located on the premise. Fan and damper positions in all operating modes shall be annunciated to the OCC and at the local control panel.

   b. The primary control of the emergency fan system is from the OCC through the SCADA System. Ventilation scenarios for each emergency condition shall be developed and coordinated with Sound Transit and local AHJ, so that pre-programmed scenarios can be developed.

   c. Local fan motor starters and related operating control devices shall be located away from the direct airstream of the fans.

D. Duct design and solution shall be coordinated with architects, lighting designers, electrical designers, mechanical designers, public address system, structural designers, and other designers.

20.6 AIR-DISTRIBUTION SYSTEM DESIGN

20.6.1 General

A. All air-distribution duct systems shall be designed based on recommendations and in accordance with information contained in the

latest edition of the ASHRAE Handbook of Fundamentals and NFPA 90A. Supply duct sizes shall be selected for an equal pressure drop or static regain method as appropriate. Maximum velocities shall not exceed those described in section 20.5.4. Air distribution ductwork for ancillary area ventilation systems shall be so arranged that air is not exhausted into or obtained from station public occupancy areas. Air shall not be obtained from or exhausted to tunnel without prior approval of Sound Transit.

B. Ducts shall be constructed of galvanized steel, to a Pressure Class of not less than 4-in. w.g., Seal Class A, and in accordance with HVAC Duct Construction Standards by the Sheet Metal and Air-Conditioning Contractors National Association, Inc. (SMACNA). Ductwork having a pressure class greater than 10-in. w.g., shall be fabricated in accordance with SMACNA Rectangular Industrial Duct Construction Standards or SMACNA Round Industrial Duct Construction Standards. SMACNA symbols for ventilation and air conditioning shall be used on drawings. Duct material and construction shall conform to NFPA 91, 2-2.

20.6.2 Pressure Losses

Pressure loss calculations shall be performed in accordance with the ASHRAE Handbook of Fundamentals. The static pressure differential across any supply or return air terminal shall not exceed 0.25 inch water gauge when the system is operating at full capacity. The static pressure drop across the grill/register shall not exceed 0.60 inch water gauge when the system is operating at full capacity.

20.6.3 Supply Air Registers and Diffusers

All supply air registers and diffusers shall be selected to provide the required throw and spread within the noise criteria. All registers shall be provided with adjustable and double-deflection louvers and spin taps or opposed-blade adjustment volume dampers. Volume dampers shall be key-operable through the face of the register. All ceiling diffusers shall be the square, rectangular, circular, or linear type with adjustable throw, opposed-blade adjustable volume dampers, and adjustable air extractors.

20.6.4 Variable Air Volume Terminals

When provided, variable air volume (VAV) terminals shall be pressure-independent and shall reset air volume as determined by the space thermostat regardless of any changes in system air pressure. Terminals shall be system powered and shall require no more than 1-inch water gauge static pressure regardless of air quantity. The casing shall be of double shell construction meeting SMACNA standards with sandwiched "foamed in place" insulation. Terminals shall be complete with factory

furnished system powered actuators, controls, and thermostats. Outside air requirements shall be maintained throughout the range of VAV operation.

20.6.5 Exhaust and Return Air Grilles

Either exhaust or return air grilles shall be equipped with fixed, non-see-through blades or louvers, or the duct behind the grille shall be painted matte black. All grilles shall be equipped with opposed-blade, adjustable-volume dampers key-operated through the face.

20.6.6 Volume Dampers

Adjustable, opposed-blade volume dampers shall be provided for all branch ducts serving multiple outlets. All dampers shall be equipped with locking quadrants with blades sufficiently stiffened at the edges to effectively close off the duct. Under all conditions of operation, they shall be free from vibration.

20.6.7 Splitter Dampers

Splitter dampers may be used in multiple duct fittings for initial balancing in place of individual opposed-blade volume dampers in each branch of the multiple duct fitting. These splitters shall be adjustable through locking quadrants and shall be single-bladed. The blades shall have edges sufficiently stiffened to avoid vibration under all conditions of operation.

20.6.8 Fire Dampers and Fire/Smoke Dampers

Fire dampers shall be provided in ducts which pass through fire-rated floors, walls, and barriers. Fire/smoke dampers (FSD) (Leakage Rated Dampers) shall be provided where required for smoke control. FSD shall have electric actuator for smoke control and may be used in stead of a motorized damper. All fire dampers shall be Underwriters Laboratories, Inc. (UL) listed. Dampers shall be tested in accordance with UL 555 for fire dampers, and UL 555S for fire smoke dampers. Fire dampers, including their sleeves, smoke dampers, and ceiling dampers shall be installed in accordance with the conditions of their listings and the manufacturer's installation instructions.

20.6.9 Backdraft and Relief Dampers

Backdraft or motorized shutoff dampers shall be used on exhaust fans where more than a single fan discharges into a common exhaust. Weighted relief dampers shall be used in exhaust ducts and openings where a positive pressure is required to be maintained by a forced air supply and relief exhaust. All backdraft and relief dampers shall be the multi-bladed gravity type with neoprene cushioning on blade edges.

20.6.10 Air Extractors

Air extractors or 45-degree entry shall be used in branch duct connections. Air extractors are used for registers and diffusers where there is inadequate space for installing multi-bladed volume dampers. All air extractors shall be the movable blade, pivoted type.

20.6.11 Turning Vanes

All elbows shall have a full centerline radius at least 1.5 times the width of the duct. Where full-radius curves are not feasible, elbows shall be provided with turning vanes. All turning vanes shall be the double radius type.

20.6.12 Access Doors

Access doors shall be included in ducts and plenums to provide access to fans, dampers, duct-smoke detectors, fire dampers, turning vanes, coils, filters, other devised, and where required by code. Door edges shall rest against neoprene gaskets to form an airtight enclosure. Access doors in plenums shall be hinged and furnished with latches operable from both inside and outside. Duct access doors shall be hinged or fastened by toggle tabs or wing nuts. Access doors in insulated ducts and plenums shall be insulated using sheet metal-insulation-sheet metal construction. Access door site shall be appropriate for the task. Where ducts are stacked and access is needed to the upper ducts, special consideration shall be given to the access method. Access doors shall be designed for their intended purpose and shall be in accordance with NFPA 91 2-3.

20.6.13 Flexible Duct Connectors

Flexible duct connectors shall be used on all fan and air-handling units to connect units to ductwork. The length of each joint shall be selected to adequately accommodate both horizontal and vertical deflections of the fan units. The flexible material shall not be less than 4 inches, however.

20.6.14 Insulation

A. The insulation on indoor ductwork shall be composite insulation with a metal jacket or an aluminum facing. The adhesive used to adhere a jacket or facing to the insulation shall meet fire and smoke hazard ratings as tested by the American Society for Testing Materials ASTM E84 procedure, the NFPA 255 procedure, and the Underwriters Laboratories, Inc. (UL) 723 procedure. In addition to meeting these ratings, the adhesive shall not exceed a flame spread of 25, a fuel contribution of 50, and a smoke development of 50. Accessories such as adhesives, mastics, cements, tapes, and cloths for fittings shall be similar component ratings.

B. Insulation shall be provided for the following:

1. Heating and A/C supply and return ducts, except inside air conditioned space.

2. Ducts subject to condensation (including these inside conditioned space).

20.6.15 Supports

Supports for Pressure Class 10-in. w.g., and less duct shall conform to SMACNA standards as appropriate for the pressure class and seismic zone. Hangers and supports shall be designed to carry weight of duct and shall be in accordance with NFPA 91 2-5.

20.7 VENTILATION SHAFTS AND AIR TERMINALS AT GRADE

The maximum air velocity through a grating or louver shall be computed using the gross free face area of the grating or louver, exclusive of any supports. In accordance with current local codes and national standards, no intake or exhaust shall terminate in a street or roadway. Shaft location shall be reviewed by Safety and Security personnel to prevent possibilities of public endangerment and/or acts of terrorism. All ventilation shafts and terminals at or above grade shall be sized, designed, and spaced in accordance with the following:

20.7.1 Normal Operations

For discharges in a sidewalk, the peak outflow air velocity shall not exceed 500 fpm. For discharges 8 feet or more above sidewalk level or away from public areas, the peak discharge velocity shall be limited by the noise criteria but shall not provide a pressure loss greater than 0.50 inch water gauge. For outside air intakes 8 feet or more above grade or away from public areas, the peak intake air velocity shall not exceed 1,200 fpm. For outside air intakes less than 8 feet above grade, the peak intake air velocity shall not exceed 1,000 fpm.

20.7.2 Emergency Operations

For discharges in a sidewalk, the peak outflow air velocity shall not exceed 1,000 fpm. For discharges 8 feet or more above sidewalk level or away from public areas, the peak discharge velocity shall be limited by the noise criteria. Pressure losses shall not exceed 0.75 inch water gauge, however.

20.7.3 Shafts and Terminal Locations

Ventilation intake and discharge terminals at street level shall be located to avoid pedestrian and vehicle crossings and to minimize the danger of

flooding from the sidewalk or street. When located in sidewalks, they shall not occupy more than 40 percent of the sidewalk width. Where possible, they shall be located in median strips or in off-street locations, and shall be suitably screened with planters or other decorative treatments. Under no circumstance shall ventilation shaft openings be located in roadways, driveways, near motor vehicle stops, or anywhere fuel, fuel fumes, or high concentrations of exhaust fumes can be drawn into the ventilation shafts. At-grade surfaces shall be sloped away from the gratings of shafts to minimize the flow of water into the shafts.

20.7.4 Shaft Design

A. Shafts shall be designed so that sudden transitions in the shaft cross section are avoided and the minimum number of bends and elbows are used. Turning vanes may be used to reduce pressure losses, and the streamlining of obstructions in fan shaft passages shall be undertaken where required. Air passages shall be constructed of smooth concrete or sheet metal ductwork. Exhaust airshafts may be combined into a common shaft and outside air intake shafts may be combined into a common shaft. Under no circumstances shall exhaust and intake shafts be combined into a common shaft. Air may be exhausted through a fire/smoke damper into the EVS. Ventilation supply air shall not be from the EVS.

B. Ventilation air intake and discharge facilities shall be designed so that an adequate distance is provided between intake and exhaust to prevent recirculation. The following formula shall be used to calculate the minimum horizontal distance between adjacent ventilation shaft openings to the surface at the same elevation.

$$d = b \times (L_1 + L_2)$$

Where:

d =	Minimum distance in feet between edges of the adjacent openings.
L_1 and L_2 =	Lengths in feet of the adjacent parallel sides of the openings.
b = 0.25	If one shaft is a tunnel ventilation shaft and the other is a station exhaust shaft.
b = 0.50	If one shaft is a station fresh air intake shaft and the other is a station exhaust shaft.
b = 0.25	If one shaft is a tunnel ventilation shaft and the other is a station fresh air intake shaft.

C. Ventilation shaft terminals at grade level shall be separated by a minimum horizontal distance of 40 feet from the closest station entrance or the closest surface emergency stair doorway. Where this

is not practical, the horizontal distance may be reduced to 15 feet if the closest ventilation shaft terminal is raised a minimum of 8 feet above the top of the station entrance door or emergency stair doorway.

D. EVS shall not terminate closer than 10 feet from occupied structure.

20.8 PIPING

20.8.1 General

All piping systems shall be designed to meet the requirements of American National Standards Institute (ANSI) B.31 (all applicable sections). All pipe fittings, flanges, valves, and accessories shall comply with ANSI B16.10 (all applicable sections for dimensional requirements). All piping systems shall be designed and arranged for neat appearance. They shall be properly sloped for drainage and venting, and properly supported, guided, and anchored to provide complete flexibility and to maintain the integrity of all systems without any damage or leaks under all operating conditions. All valves and accessories shall be installed in a systematic manner in places accessible for operation without the use of chains or additional operating platforms. Sleeves and escutcheons shall be provided wherever pipes pass through walls. Provide fire-rated assemblies for pipe passing through fire-rated walls and floor/ceiling assemblies.

20.8.2 Pipe Unions or Flanges

To facilitate easy removal for servicing, unions or flanges shall be provided on both the inlets and the outlets of all apparatus, isolation valves, control valves, and accessories. Wherever two pipes made of dissimilar metals are connected, a dielectric union shall be used to isolate the two pipes from each other. Dielectric unions and flanges may also be required for cathodic protection.

20.8.3 Valves

Isolation valves shall be provided on both sides of such apparatus as chillers, cooling towers, pumps, heating coils, control valves, multiple installations, and piping branches. The installation of all valves shall be designed to give a neat appearance and provide easy grouping with all parts accessible for operation and maintenance. Valve stems shall be horizontal wherever possible.

20.8.4 Piping Accessories

To ensure the trouble-free operation of all piping systems, all required piping accessories shall be provided. These accessories shall include

strainers, vent cocks, dirt-and-drip legs with drain-and-flush connections, expansion tanks, liquid flow indicators, balancing cocks, relief valves, pressure and temperature gauges, etc. All piping accessories requiring maintenance or replacement of parts shall be installed in accessible places. All dials of gauges and indicators shall be of sufficient size and arranged to be easily seen and read.

20.8.5 Pipe Expansion Joints

The use of pipe expansion joints shall be avoided wherever possible. Pipe systems shall be arranged to have sufficient offsets and expansion loops to accommodate thermal expansion and vibration. Pipe expansion joints may be used only where pipe expansion loops are impractical. All such expansion joints shall be of stainless steel or monel metal. They shall be the double-compensating type with an anchor in the middle. These shall be guided on both sides in strict accordance with the manufacturer's recommendation. All expansion joints shall be flanged to facilitate easy and quick replacement.

20.8.6 Flexible Pipe Connectors

The use of flexible pipe connectors to connect piping to heating and cooling apparatus shall be restricted to cases where providing piping offsets for flexibility is impractical. Where flexible pipe connectors are used, such as on resiliently mounted air-handling units and pumps, these flexible pipe connectors shall be of stainless steel or monel construction with flanged ends for quick and easy dismantling from the pipe systems. They shall be of sufficient length to provide an overall stiffness less than the resilient mounts used for supporting the apparatus.

20.8.7 Pipe Supports, Hangers, Guides and Anchors

Pipe supports, hangers, guides and anchors shall be designed to assure proper alignment of all pipes for operating conditions. The forces caused by seismic events, the motion of the fluid, the weight of the fluid, piping, valves and insulation and thermal expansion/contraction shall be considered as appropriate. All hangers and supports shall be so arranged as to prevent the transmission of vibration from the piping to the structure. Anchors and guides shall be designed to allow pipes to expand and contract without a build-up of excessive stress. Pipe rollers shall be used with all hangers where pipe movement due to expansion or contraction exceeds 0.5 inch. Spring hangers of constant or variable load types, as the case requires, shall be used when piping is connected to vibrating equipment and where supporting vertical pipes. Seismic calculations for piping supports shall be sealed by a structural engineer registered in the State of Washington.

20.8.8 Insulation

Composite insulation with a metal jacket or Kraft facing shall be used on indoor piping as appropriate. The adhesive used to adhere the jacket or facing to the insulation shall meet the fire and smoke hazard ratings as tested by procedures ASTM E84, NFPA 255, and UL 723. In addition, this adhesive shall not exceed a flame spread of 25, a fuel contribution of 50, and a smoke development of 50. Accessories such as adhesives, mastics, cements, tapes, and cloths for fittings shall have similar component ratings. Insulation for chilled water supply and return piping, and cooling tower condenser return (to water chiller) piping shall be two-piece, heavy density, sectional insulation jacketed with an embossed vapor barrier laminate. Insulation for refrigeration suction piping shall be a 2-inch thick (minimum) slip-on-type premolded cellular glass.

20.8.9 Freeze Protection

The designers shall analyze each piping installation at unheated spaces for the potential of water lines freezing during winter months. Where required, electric-resistance tape shall be provided in addition to insulation. Provisions shall also be made to allow for the drainage of piping that will be subject to freezing temperatures.

20.8.10 Pumps

As conditions dictate, pumps shall be either single- or double-suction. Pumps shall be arranged so that they can be serviced without any removal of the piping system. This shall include any disconnection of piping from the pumps. Pumps shall have the following characteristics.

Maximum Pump Speed:	1,800 RPM.
Operating Efficiency at design flow rate:	Within 5 percent of maximum efficiency.
Pump Type:	Non-overloading.

20.9 EQUIPMENT FOUNDATIONS

All floor-mounted equipment shall be placed on reinforced concrete housekeeping pads at least 4 inches high. Pads shall be tied to the floor by floor-reinforcing bar grid, dowels, or anchor bolts.

20.10 EQUIPMENT ACCESS

Provision shall be made for the installation and removal of each completely factory-built item of equipment. All ventilation shafts extending up to grade,

openings into shafts, hatches, hatchways, removable gratings, access plates, and doors intended for use in the installation and removal of mechanical equipment shall be sized, with adequate clearances, so that it can be moved between grade and its location without the need for special disassembly. The installation and removal of equipment from underground mechanical equipment rooms preferably shall be accommodated by providing hatches in slabs and/or providing removable gratings at grade. Where this is not feasible or economical, the installation and removal of equipment may be accommodated by providing openings above or adjacent to the trackway.

20.11 EQUIPMENT HANDLING

Provision shall be made in the form of monorails, lifting hooks, and removable panels for the installation and removal of equipment. Structural openings shall be sized so that each complete factory-built item of equipment can be installed or removed without disassembly or special construction/demolition. Design shall include illustrated study showing how equipment can be installed originally and removed and replaced through station or structure doorways and openings.

20.12 VIBRATION ISOLATION

All equipment, which produces vibrations, shall be isolated from the structure by spring or rubber-in-shear vibration isolators. All piping and ducts attached to rotating and oscillating equipment shall be isolated from such equipment by flexible connections. Inertia blocks shall be provided as required. Vibration control for environmental control systems shall be designed in accordance with the sound and vibration control chapter of the Handbook of Systems and Applications (ASHRAE, latest edition).

20.13 AIR FILTRATION

Supply air units shall be provided with replaceable media filter sections arranged in banks as appropriate. Air filter material shall be rated UL Class I.

20.14 DRAINAGE SYSTEM

All drainage from HVAC systems shall be removed through waste drains only. No mechanical equipment drain shall be connected directly into any drain system. Indirect drain connectors with an air gap shall be used. Oil separators shall be installed where required by code.

20.15 ROUGHING-IN

In buildings and stations that are to be constructed in stages under separate contracts, sleeves and block-outs shall be provided in the early state structures to accommodate fan, piping, and ductwork installation by later-stage contractors. The locations and sizes of the sleeves and block-outs shall be accurately dimensioned to facilitate the subsequent piping and ductwork installation under later-stage contracts and shall be coordinated with other items such as raceways, sprinklers, lighting fixtures, etc. Pipe sleeves in exterior walls shall be sized to provide sufficient space for watertight sealing around carrier pipes.

END CHAPTER 20

21. LIGHTING

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21. LIGHTING

21.1 INTRODUCTION

A. The lighting criteria contained herein are intended to provide the functional and aesthetic guidelines necessary to design lighting for site areas, passenger stations, tunnels, trackway sections, transit-related parking facilities, and yards and shops. Conformance with these criteria is necessary to ensure adequate lighting levels for the system facilities, and provide intended quality, convenience, safety, and efficiency for the Link system.

B. Trackway illumination shall be provided only if specifically directed.

C. Lighting of streets and highways shall conform to the criteria and standards of the appropriate agency.

21.1.1 Design Objectives

A. General objectives for transit facility lighting are as follow:

1. Promote safety by identifying and properly illuminating areas and elements of potential hazard. Of special concern are potential tripping hazards such as at vertical circulation elements and at platform edges where crowding and rapid transfer to and from trains can be anticipated.

2. Provide an environment that is secure, discourages crime, and enables surveillance of facilities by crime prevention authorities.

3. Enhance the system's visual and functional clarity by differentiating between site circulation networks such as drop-off zones and parking areas, station entrances, escalators, fare vending areas, platforms, tunnels, maintenance shops and storage yards. Adequate lighting is particularly important to facilitate system use by partially sighted individuals.

4. Reinforce the presentation of signs and self-illuminating message displays.

B. The following requirements apply to all facilities:

1. The lighting system shall provide the intended quality and quantity of light for individual areas and be free from glare. Avoid using luminaries that emit light above the horizontal plane. Minimize direct light onto nearby windows and illumination onto adjacent properties.

2. The lighting system shall be energy-efficient using high-efficiency light sources and auxiliary equipment. Luminaires shall have integral ballasts and fuses unless special considerations dictate otherwise.

3. Lighting equipment shall be vandal resistant in spaces accessible to patrons or to the public.

4. The lighting system shall be designed to minimize capital and maintenance costs. Luminaire locations shall permit ready accessibility for relamping and periodic cleaning. Luminaires shall not be placed over escalators or stairwells without consideration for maintenance access.

5. Lighting shall be designed to satisfy security requirements and to provide a pleasant environment.

6. Lighting system shall be designed so that the failure of any single luminaire does not leave an area in total darkness.

21.1.2 Codes and Standards

A. Illuminating Engineering Society of North America (IESNA) Lighting Handbook

B. *Lighting for Parking Facilities* (IESNA RP-20-98)

C. *Guideline for Security Lighting for People, Property, and Public Spaces* (IESNA G-1-03)

D. *Roadway Lighting (IESNA RP-8-00)*

E. Americans with Disabilities Act

F. Underwriters' Laboratories, Inc.

G. Standard for Fixed Guideway Transit Systems (NFPA 130)

H. International Building Code

I. National Electrical Code (NFPA 70)

J. Washington Utilities and Transportation Commission (WUTC)

K. Washington State Energy Code

21.1.3 Standard Equipment

A. Consistency of appearance and lighting levels throughout Sound Transit facilities can best be achieved with a high degree of standardization of lighting system components. To that end, all luminaires and lamp types shall be standardized system-wide to provide design and perceptual unity and simplify maintenance requirements. A systemwide approach to lighting design will allow for cost-effective procurement of lamps, luminaires, and auxiliary equipment as well as standardized installation, repair, maintenance, and replacement.

B. Standard Lamp Schedule. The following lamp types have been identified as standard for all Link facilities. Use of other lamp types will be permitted only with written permission of Sound Transit.

Rating (Watts)	Lamp Description	Length (Inches)	Initial (Lumens)	Rated Life (hours)	Color Temp (^{0}Kelvin)	CRI
18	F18DTT	6	1,200	10,000	3500	82
32	F32TRT	5-3/4	2,200	12,000	3500	82
32	F32T8/835	48	2,950	24,000	3500	86
35	MH35PAR30/FL	4-7/8	2,400	10,000	3000	81
38	F40TT	22-1/2	3,150	20,000	3500	82
54	F54T5/835/HO	46	5,000	20,000	3500	85
70	MH70/ED17	5-7/16	6,200	15,000	3000	80
70	MH70/T6	4-1/2	6,200	15,000	3000	83
100	MH100/ED17	5-7/16	9,200	12,500	3000	83
100	MH100/PAR38 FL	5-7/16	6,500	12,500	3000	83
100	HPS100/ED17	5-7/16	9,500	24,000	2000	81
175	MH175/ED17	5-7/16	17,500	15,000	4000	75
250	MH250/ED28	8 1/4	23,000	15,000	4000	65
400	MH400/ED37	11-1/2	44,000	20,000	4000	65

21.1.4 Lamps

A. Lamps used for illumination of passenger stations and ancillary areas including parking lots and pedestrian walkways in the vicinity of transit stations shall be fluorescent or high-intensity discharge type and have a minimum color rendering index of 65. Metal halide lamps and auxiliaries shall be pulsed-start. In areas not generally accessible to transit patrons such as maintenance yards and tunnels, lamps with a lower color rendering index such as high pressure sodium may be employed, but visibility needs should be carefully evaluated.

B. Innovative lighting systems incorporating new technology light sources such as sulfur lamps should be evaluated on a life cycle cost

basis to determine advisability of application for Sound Transit facilities.

21.1.5 Illuminance Levels

A. Illuminance levels shall define and differentiate between task areas, decision and transition points, and areas of potential hazard. In addition to quantity of light, it is essential that illumination be designed to provide uniform distribution. Luminaires shall be selected, located, and/or aimed to accomplish their primary purpose while producing a minimum of objectionable glare and/or interference with task accuracy, vehicular traffic, and neighboring areas.

B. Illuminance and luminance levels shall meet the recommendations of the Illuminating Engineering Society of North America except as specifically noted below: Unless otherwise indicated, use a maximum uniformity ratio of 3:1.

1. Interior Locations

	Illuminance/Average Horizontal Footcandles
Station Platforms	20
Concessions	20
Staff Rooms	50
Stairs, Elevators, Escalators	15
Mechanical, Electrical, Communications Rooms	15
Storage/Custodial Rooms, Toilets	15
Elevator Machine Rooms	20

2. Exterior Locations

	Illuminance/Average Horizontal Footcandles
Station Platforms, Covered	5
Station Platforms, Uncovered	5
Fare Vending Area	10
Parking Lots & Accessways	IESNA RP-20 * Enhanced Security
Load/Unload, Passenger Drop-off, Bicycle Stands	5
Pedestrian Walkways (adjacent to roadways)	5

Outdoor Plazas	5
Bus-Loading Zones	5
Outdoor Entrances to Escalators & Stairways	10
Bus Roadways	5

* Where security is a special concern or local law enforcement agencies feel that greater lighting levels are required, lighting design shall also comply with IESNA G-1-03.

3. At-Grade Trackway in mixed traffic areas

a. Commercial districts

Average Luminance	0.8 candela per square meter
Average Illuminance	12 lux (1.1 footcandle)
Average to Minimum Ratio	3:1
Maximum to Minimum Ratio	5:1
Veiling Luminance Ratio	0.4:1

b. Intermediate districts
(Mixed Commercial and Residential)

Average Luminance	0.6 candela per square meter
Average Illuminance	9 lux (0.8 footcandle)
Average to Minimum Ratio	3.5:1
Maximum to Minimum Ratio	6:1
Veiling Luminance Ratio	0.4:1

C. Vehicular Crossings:

1. Average luminance at grade crossings shall be greater or equal to 1.5 times average luminance of roadway and ratio of average to minimum at intersection shall be less than or equal to 2.5. Roadway lighting is recommended in accordance with IESNA RP-8-00 and shall have a minimum luminance of 0.8 candela per square meter or an illuminance of 8 lux (0.7 footcandle) for an area extending 30m (100 feet) on both sides of the tracks.

2. At-grade Crossings shall have an average maintained vertical illuminance of at least 1.0 footcandle at a distance 5 feet from the centerline of the tracks. The illuminated plane shall encompass the full width of the crossing plus 5 feet on each side of the roadway and be 15 feet in height.

D. Pedestrian Crossing:

1. Lighting shall provide 1.5 times trackway illumination for 100 feet before and after crossing, or a minimum of 1.2 footcandles or 1.7 footcandles depending on location.

21.1.6 Station Site and Plaza Lighting

Station site lighting includes internal site circulation and access to the station. The placement of luminaires shall not obstruct the movement of vehicles. Luminaire placement shall be coordinated with the landscape and site plan to protect light standards that are located adjacent to roadways, and to ensure that plantings will not obscure the lighting distribution pattern. Lighting of outdoor plazas, station sites, pedestrian walkways, and similar areas shall be accomplished by utilizing luminaires on low poles. Illuminated bollards and other low-mounted luminaires shall not be used. Security lighting (minimum lighting level after station shutdown) shall be provided using the same pole-mounted luminaires fed from a separate security lighting circuit with photocontrol only. In Ticket Vending Machine (TVM) areas, lighting design shall ensure that glare from luminaires does not obscure visibility of touch-screen displays.

21.1.7 Vehicular Access Lighting

Vehicular access lighting shall provide a natural lead-in to the bus areas and passenger drop-off zones. The illuminance on all access and egress roads shall be graduated up or down to the illuminance level of the adjacent street or highway.

21.1.8 Pedestrian Access Lighting

Pedestrian access lighting shall define pedestrian walkways, crosswalks, ramps, stairs and bridges. Lighting shall sufficiently define the decision and transition points and areas of potential hazard.

21.1.9 Station Platform and Public Area Lighting

A. Platform area lighting shall be in waiting and loading areas. The lighting elements shall extend the entire length of the platform and shall demarcate the platform and emphasize the platform edge, vertical vehicle surfaces, and landings associated with elevators and stairs. Care shall be taken to avoid blinding Link operators or other vehicle drivers with excessive or misdirected lighting.

B. Luminaires and lamps to accentuate specific architectural features or artistic works shall be selected by the designer from the standard luminaire/lamp palette or may be custom for the application if approved by Sound Transit.

21.1.10 Tunnel Lighting

A. The average maintained illuminance level for tunnel walkway and trackway shall be 1 footcandle, with a minimum of 0.25 footcandle. Tunnel lighting fixtures shall be fluorescent or high intensity discharge type and located where they do not infringe on vehicle clearances. Luminaires shall be suitable for a wet, corrosive environment and chosen to provide a glare-free illumination for either direction of travel on the illuminated trackway. Lighting fixtures in the tunnel shall be fed from an emergency circuit.

B. Areas containing track switches and other equipment requiring maintenance shall be lighted to a higher level than the running tunnel. Luminaires shall be mounted clear of the vehicle envelope on both sides of the tunnel wall and provide an average illuminance level of 2.0 footcandles through the area of the switch.

C. Alternate tunnel luminaires shall be fed from separate circuits in separate lighting panelboards in adjacent stations. Each tunnel luminaire shall be provided with a disconnecting switch adjacent the luminaire such that all power to the luminaire can be disconnected for luminaire maintenance.

D. Each tunnel cross-passage shall have at least two fixtures connected to different tunnel lighting circuits with a luminance level required in section 21.1.10 A.

21.1.11 At-Grade Trackway Lighting

A. Trackway illumination is required:

1. At all at-grade roadway crossing locations, (see section 21.1.5).

2. Where safe vehicle stopping distance (emergency braking condition) exceeds nighttime visibility for operating speed using appropriate vehicle lighting (low beam, high beam or cyclops lamp operation). Note that appropriate vehicle lighting is determined by trackway environment, a function of adjacent roadway, direction of vehicle travel on adjacent roadway, etc. (Intrusion mitigation measures may be substituted for supplemental illumination in areas of exclusive right-of-way as determined by Sound Transit.)

3. At designated at-grade pedestrian crossing locations (e.g., Z-crossing configuration).

21.1.12 Aerial Trackway Lighting

A. Lighting of aerial trackway and walkways shall be provided only at egress points from the guideway.

21.2 CONTROL OF LIGHTING SYSTEMS

A. Lighting control shall be designed to use energy efficiently. Automatic and manual control arrangements shall ensure efficient utilization of energy and maintenance procedures. All exterior site areas shall be artificially illuminated when ambient illuminance drops below 10 footcandles. During night-time, non-revenue hours, provide security lighting as required to deter crime and vandalism. (Non-revenue hours shall be considered as the period from 30 minutes after service stops to 30 minutes before service starts). Provision shall be made for photocontrol with time control provided through the Central Control System and manual override. Ancillary areas shall be individually switched.

B. For energy conservation, the use of daylighting is encouraged. Where daylight is used to supplement electric lighting, evaluate lighting zones, which can be effectively illuminated using daylight and design the lighting control system using appropriate photoelectric controls.

21.3 EMERGENCY LIGHTING

A. Emergency lighting in enclosed and underground transit facilities shall consist of appropriately located luminaires which will provide adequate lighting for the orderly egress of patrons and employees during power failure. The lighting and wiring system shall meet applicable requirements of NFPA 130, International Building Code, and the National Electrical Code. The luminaires and all exit, egress, and essential directional signage, shall be powered by an emergency power source as described below.

B. Emergency lighting for stairs shall be designed to emphasize the top and bottom steps or landings.

21.3.1 Emergency Power and Lighting Requirements

A. Emergency lighting shall be provided at the following locations:

1. Enclosed (Indoor or Underground) Public Facilities. Emergency illumination shall meet the requirements of the International Building Code.
2. Train tunnels shall have emergency lighting sufficient for safe evacuation of patrons in conformance with NFPA 130. Emergency illumination shall be independent of the electric utility supplies.

3. Tunnel emergency exits for egress to points of safety shall be illuminated. The lighting system shall provide for immediate recognition of these points to assist in the safe evacuation of passengers.

4. Exit Signs in Enclosed Public Facilities: All exit signs shall be connected to an emergency circuit or be self-illuminating with integral battery pack/charger. Exit signs shall be light-emitting diode type unless otherwise approved.

5. Electrical and Systems Equipment Rooms: Provide minimum 1.0 footcandle emergency illumination at floor level.

B. Emergency power supply shall consist of the following:

1. In transit tunnel and underground passenger stations, power shall be supplied from two separate utility sources for 'essential' and 'critical' loads. The electrical system shall automatically switch from one utility source to the backup source in case of outage. If a second utility source of sufficient reliability is not available, the second source may consist of a standby emergency generating system.

2. Emergency lighting in tunnels and underground stations is considered a 'critical' load and shall be supplied through an uninterruptible power supply (UPS) system.

3. For elevated stations, provide emergency lighting from a UPS system.

4. Emergency lighting is not necessary for at-grade stations if ambient street lighting is sufficient to provide the minimum required levels

5. In special cases, where the cost of running an emergency circuit is not justified, backup power shall be provided by an integral or separate battery-backup power supply powered by a wet-cell nickel-cadmium battery.

C. Refer to Chapter 23, Electrical Systems, for detailed information on 'essential' and 'critical' loads and electrical system requirements.

21.4 YARD AND SHOPS LIGHTING

For other lighting requirements of yard and shops, refer to Chapter 19, Operations and Maintenance Facility.

21.5 ELECTRICAL WIRING

For requirements for electrical wiring, refer to Chapter 23, Electrical Systems.

END CHAPTER 21

22. FIRE ALARM SYSTEMS

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22. FIRE ALARM SYSTEMS

22.1 INTRODUCTION

This chapter prescribes the objectives for implementing the basic systemwide fire alarm systems, intrusion alarm systems, and controlled-access systems philosophies and methodologies of Sound Transit Link light rail (Link).

22.1.1 Applicable Codes, Standards, and Guidelines

A. Designers shall obtain, maintain, and use at least one set of applicable reference documents.

B. System design provisions shall be in accordance with the codes, standards, and guidelines listed below, including references therein and amendments by the Authority Having Jurisdiction (AHJ). Design shall be in accordance with the edition or revision in effect at time of design contract award. Identification of edition in this Criteria Chapter is for convenience only and does not supersede the edition in effect at time of design contract award, unless specifically noted otherwise herein.

1. National Fire Protection Association (NFPA)

   a. NFPA 72, National Fire Code

   b. NFPA 130, Standard for Fixed Guideway Transit Systems

2. Sound Transit Link light rail

   a. Chapter 18, Fire/Life Safety

   b. Chapter 23, Electrical Systems

3. State of Washington

   a. Washington State Building Code, Chapter 51-40 of Washington Administrative Code (WAC 51-40)

   b. International Building Code (IBC)

   c. International Fire Code (IFC), Standard and amendments - WAC 51-44 and WAC 51-45

d. International Mechanical Code (IMC), Standard and amendments - WAC 51-44

e. International Plumbing Code (IPC), Standard and amendments – WAC 51-46 and WAC 51-47

f. National Elevator Code, Standard and amendments – WAC 296-81, WAC 296-86, and WAC 296-95

g. Amendments, ordinances, and regulations by AHJ to above codes.

4. Underwriters Laboratories Inc. (UL)

a. UL 827, Central-station Alarm Services

C. When conflicts arise between applicable standards, codes, and guidelines; designers shall apply to the Chair of the Sound Transit Link Fire/Life Safety Committee for resolution.

22.2 FIRE ALARM SYSTEMS

22.2.1 General

Fire alarm systems shall be provided to protect life and property at each aerial passenger station, underground passenger station, and traction power substation. Fire alarm systems shall include initiating devices, fire-alarm-control panel (FACP), and related circuitry, and shall be connected to a Central Station fire alarm system located in the Operations Central Control (OCC). Underground passenger stations shall provide the FACP functionality into an emergency management panel (EMP) located at the Fire Command Center (FCC).

22.2.2 Design and Installation

The design, design calculations, drawings, and specifications shall be prepared and sealed by a professional fire-protection engineer licensed by the State of Washington. Installation shall be by installers certified to install fire alarm systems by the State of Washington and the AHJ.

22.2.3 Local System

A. The fire alarm system at an individual facility shall be monitored by a proprietary fire-alarm system that complies with UL 827. NFPA 72 and the other applicable codes, guidelines, and standards referenced in UL 827 shall be applied to the design of all fire alarm systems. Fire alarm systems shall comply with Chapter 11, *Accessibility*, of the

WSBC as amended by the local jurisdictions and with Americans with Disabilities (ADA) requirements.

B. Underground passenger stations including ancillary spaces and rooms shall be protected by protective signaling systems (fire alarm systems) in accordance with NFPA 130. Other buildings and equipment shall be protected by fire alarm systems in accordance with IBC and IFC. See Chapter 18, Fire/life Safety, for occupancy classifications of buildings, rooms, and structures.

C. Fire alarm systems are considered a fire and life safety system and are a critical load as defined in Chapter 23, Electrical Systems.

D. Fire alarm systems shall have presignal feature as described in NFPA 72 with initial fire alarm sounding at the OCC. Each fire alarm system shall include alarm verifications features. Provide signal silencing at the local fire control panel for alarm, trouble, and supervisory signals in accordance with NFPA 72.

22.2.4 Fire Alarm Control Panel and Emergency Management Panel

A. Fire alarm control panel (FACP) shall provide visual status of each alarm initiating-, supervisory-, and trouble- device. The display shall have the location of each alarm initiating-, supervisory and trouble device. FACP shall include supervisory, and trouble signals; connection to SCADA and the EMP for execution of the emergency scenarios approved by the AHJ; emergency voice communication with the OCC; and alarm reset controls and alarm disable control.

B. Emergency Management Panel (EMP) shall provide a graphical and text based emergency services interface to monitor and control safety critical devices during an emergency and in the event that the OCC is unable to provide these functions or as demanded by the circumstances of the emergency. EMP shall be able to at least monitor and control the following devices and systems:

1. All Electrical Systems; Traction, Station, UPS

2. Tunnel Emergency Ventilation

3. Fire Alarm Detection and Suppression

4. Security Systems

To assist Emergency Services in controlling the situation, a full compliment of communication systems, maps, and keys shall be supplied. A more thorough description of the EMP is located in Chapter 15, Communications and Central Control, section 15.5.11, Emergency Management Panel.

22.2.5 Initiating Devices, Notification Appliances, and Signaling Lines

A. Circuits for initiating devices, notification appliances, and signaling lines, as required by code, shall be in conformance with NFPA 72 Class A. Initiating devices shall be in conformance with NFPA 72 Class A, Style 6. Notification appliance circuits shall conform to NFPA 72, section 6.9.

1. In Passenger Stations and related ancillary rooms provide smoke detectors as the automatic fire-detection-initiating device as required by code. See NFPA 130, paragraph 5.7, 2003 edition.

2. Cross-zoned heat and smoke detectors shall be provided in Traction Power Substations. They shall be connected to the central supervising station. Signals received from the detectors shall be readily identifiable as to origin of the signals. See NFPA 72.

3. The Operations and Maintenance Facility shall be designed in accordance with IBC, IFC, and NFPA 130, paragraph 9.4.2, 2003 edition.

4. Cross-zoned heat and smoke detectors shall be provided at Incoming Electric Service Rooms. They shall be connected to the central supervising station. Signals received from the detectors shall be readily identifiable as to origin of the signals. See NFPA 72.

5. The Elevator Lobby, Landing, Hoistway, and Machine Room shall be designed in accordance with ASME A17.1, IBC, and WSBC.

6. Heat detectors shall provide combination fixed temperature and rate-of-rise and heat detection.

7. When actuated, duct-mounted smoke detectors and concealed fire detectors shall activate a strobe light. Provide a separate strobe light for each detector. Locate the strobe light where it is readily seen. Provide a permanent placard proximate to the strobe light that identifies the location of the detector. Duct detectors shall report to OCC as a supervisory signal per NFPA 72.

22.2.6 Operational Control Center (OCC)

All alarm initiating-, supervisory-, and trouble- devices on the ST Link System shall report to a stand-alone listed central station located in the Central Control Facility. The central station shall comply with NFPA 72 and UL 827.

END CHAPTER 22

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23. ELECTRICAL SYSTEMS

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23. ELECTRICAL SYSTEMS

23.1 INTRODUCTION

A. This chapter establishes the design criteria for various electrical facilities including passenger stations, park-and-ride facilities, traction power substation buildings, systems buildings, and signal, communications, and power ductbanks. These criteria include requirements for the function and design of electrical and related systems. Refer to Chapter 13, Traction Electrification, for electrical requirements specific to the dc traction power supply and distribution system. Refer to Chapter 21, Lighting, for requirements specific to normal and emergency lighting systems. The electrical and mechanical equipment requiring power include the following:

1. Lighting
2. Heating, Ventilation and Air Conditioning (HVAC) Equipment
3. Vertical Transportation Equipment (Elevators and Escalators)
4. Pumping and Other Miscellaneous Mechanical Equipment
5. Fare Collection Equipment
6. Communications and Video Surveillance
7. Emergency Lighting and Power Systems
8. Transit Signal Equipment

B. Codes and Standards

1. Ac electrical system design shall conform to the latest edition of the following standards, codes, and regulations where applicable:

   a. National Electrical Code (NEC) (NFPA 70)

   b. National Electrical Safety Code (NESC) (ANSI/IEEE C2)

   c. Electrical Safety Standards, Administration, and Installation (WAC 296-46)

   d. Electrical Codes or amendments of the local authority having jurisdiction

   e. International Building Code

f. Standard for Fixed Guideway Transit Systems (NFPA 130)

g. Guide for Safety in Ac Substation Grounding (IEEE 80)

C. Products

Where appropriate, equipment shall be listed and labeled by a nationally recognized electrical safety testing organization. If product listing is not available, equipment shall be factory or field-inspected to ensure compliance with appropriate industry standards and certified for the intended use as required by the Authority Having Jurisdiction.

23.2 ELECTRICAL REQUIREMENTS

A. These criteria apply to ac power systems in the following facilities:

1. Passenger Stations and Adjacent Areas
2. Traction Power Substation Buildings (Ac Systems Only)
3. Signal and Communications Buildings
4. Transitways and connecting structures
5. Operations and Maintenance Facilities
6. Other Light Rail Transit-Related Facilities

23.2.1 System Voltages

A. Facilities shall have either 120/240V, single-phase or 208V/120V, three-phase ac power service. If required, due to the nature and amount of load, a 480V/277V, three-phase service may be required.

B. Utilization Voltages

1. Lighting

Fluorescent	120 Vac 1 Phase 277 Vac 1 Phase, if available
Incandescent	120 Vac 1 Phase
High Intensity Discharge	120 Vac 1 Phase 240 Vac 1 Phase for area lights 277 Vac 1 Phase, if available

2. Mechanical Equipment and Motors

Motors, 1HP and above	240 Vac 1 Phase 480 Vac 3 Phase, if available 208 Vac 3 Phase, if available
Motors, less than 1HP	120 Vac 1 Phase
Controls for Mechanical Equipment	120 Vac 1 phase
Controls for Electrical Switchgear	120 Vdc
Fare Collection Equipment	120 V 1 Phase
Communications and Video Equipment	120 V 1 Phase
Other loads	Use applicable voltage

C. Where single-phase power is taken from a 3-phase source, the loads shall be balanced among the three distribution phases.

23.2.2 System Capacity

A. The power distribution panel shall be of sufficient capacity to power all loads with 20 percent reserve.

B. Demand Factors

1. In calculating system capacity, the following demand factors shall apply:

Element	**Demand Factor**
Lighting (normal)	1.0
Lighting (emergency)	1.0
Heating	1.0
Ventilation	1.0
Air Conditioning	1.0
Fare Collection Equipment	0.5
Communications and Cable TV	1.0

2. For other systems the demand factor varies with duty cycle and code requirements.

3. Maximum load for convenience receptacles on a circuit shall be 8 percent of circuit capacity based on a demand load of 180 VA per receptacle. Lighting shall be considered a continuous load.

C. Transformer Sizing

Transformer size selection shall be based upon the connected load and demand factors listed above with the transformer independently powering the entire station electrical load. The transformer shall provide rated VA plus a 20 percent allowance for load growth and EE-rated for energy efficiency. Where transformers supply emergency ventilation fans, additional capacity may be provided considering the overload rating of the transformer and addition of transformer cooling fans.

23.2.3 Power Distribution Method

A. The distribution system shall be designed so that failure of any one feeder or branch overcurrent device, conductor, or raceway will not result in total disruption of electrical services required for safe operation of the facility. For aerial and at-grade stations, operation of the facility may be limited or curtailed depending upon the extent of disruption.

23.2.4 Equipment

A. General

Equipment requirements shall be based upon electrical load studies.

B. Low Voltage Branch Circuit and Distribution Panelboards

The low voltage panelboards shall be composed of a main circuit breaker and distribution or branch circuit breakers for each feeder or branch circuit. Main circuit breaker may be omitted when feeder overcurrent protective device is in the same room as the panelboard.

C. Instrumentation and Metering

Electrical utility metering shall conform to the requirements of the serving electrical utility.

D. Overload and Fault Coordination – Underground and Enclosed Stations

Phase overcurrent and ground fault devices shall be coordinated such that ground faults, short circuits, or overloads will trip only the immediate upstream protective device from the point where the fault or overload occurs. Main circuit breakers for panelboard shall be coordinated so that the main circuit breaker is selectively coordinated with the feeder circuit breaker.

23.2.5 Wiring

A. Conductors shall be installed in raceways. Raceways shall include a bare or insulated equipment grounding conductor sized in accordance with the NEC.

B. Raceways, ducts, boxes, cabinets, and equipment enclosures located in tunnels shall be capable of withstanding temperatures to 500° C and shall not support combustion.

C. Insulation shall conform to Article 310 of NFPA 70 types XHHW and RHW insulation. Type THHN/THWN is not acceptable.

D. Conductors for emergency lighting, communications, and other systems required during emergency operations shall be protected from physical damage from transit vehicles or other normal transit system operations and from fires.

23.3 TRACTION POWER SUBSTATIONS

For requirements for Traction Power Substation equipment, refer to Chapter 13, Traction Electrification Systems.

23.4 EMERGENCY POWER SYSTEMS

Emergency power systems shall be designed to provide power to selected systems in the event of outage of normal power.

23.4.1 Classification of Loads

Electrical loads shall be classified as follows:

A. ***Nonessential:*** Includes all loads not classified essential or critical. Normal loads include:

1. Normal lighting
2. Escalators
3. Station security grilles
4. Hydraulic Elevators
5. Other elevators serving aerial stations

B. ***Essential:*** Loads that are determined to affect life safety or critically affect station operations and therefore require an emergency power

source but can tolerate brief interruptions less than 10 seconds in duration. Essential loads shall include the following:

1. Tunnel ventilation fans and dampers
2. Sump pumps
3. Station ventilation and pressurization fans and dampers
4. Stair pressurization fans
5. Track isolation dampers
6. Tunnel station loads including elevators
7. OCC and CCC ventilation fans and dampers
8. Mechanical controls

C. ***Critical:*** Loads that cannot tolerate any interruption longer than 1/4 cycle or that warrant extra backup. Critical loads shall include the following:

1. Emergency lighting
2. Fire and life safety systems
3. Communications systems
4. Blue-light stations
5. Switchgear controls
6. Control power for critical or essential systems
7. Operations Control Center
8. Communications Control Center

23.4.2 Power Supply Reliability Requirements

A. Requirements for electrical system reliability vary, depending on the transit system configuration. An elevated or at-grade rail system, which has mostly non-essential loads, requires a lesser degree of reliability. An underground system, which has many essential and critical loads, has the greatest need for system reliability.

1. Nonessential Loads

   Electrical service to nonessential loads shall be provided from one source. There will be no provision to transfer to an alternate power source.

2. Essential Loads

   Electrical service to essential loads shall be from a normal source, with provisions to transfer automatically to an alternate emergency source.

3. Critical Loads

   Electrical power for critical loads shall be from an UPS with minimum battery backup time of 90 minutes. The UPS shall be fed from a secondary or emergency source if available. Fire detection and other critical systems that require low-voltage dc for normal operation may utilize internal battery dc power supplies.

23.4.3 Emergency Power Source Selection

Emergency power sources shall be selected on the basis of reliability and lowest life-cycle cost. Possible sources include integral batteries in lighting fixtures, a central battery system, standby engine-generator system, or redundant utility service. Redundant utility services are acceptable only if it can be demonstrated that the sources are substantially independent.

23.4.4 Emergency Lighting

Battery-powered emergency light units shall be employed only where other options are not feasible. Batteries for such units shall be nickel-cadmium type cell battery unit. The units and shall include an integral charger suitable to maintain the charge level of the battery without overcharging, and of recharging the battery within 12 hours after restoration of power.

23.5 SYSTEMWIDE GROUNDING

23.5.1 General Requirements

Project elements, including platform structures, traction power substations, fences, guardrails and other metallic objects with substantial exposure to overhead contact system and personal contact within the right-of-way, shall be grounded as described in this section.

23.5.2 Stations

Grounding for passenger stations shall consist of a ground system under each facility comprised of a buried, exothermically- welded grid-and-rod system. All metal components of transit facilities and within 15 feet of centerline of track including shelters, fences, poles, guardrails, handrails, and bollards that are susceptible to contact by patrons and/or operating and maintenance personnel and likely to be come energized by a fallen overhead contact wire, shall be electrically bonded to the ground grid. Ground electrical raceways, fittings, and equipment as required by the National Electrical Code.

23.5.3 Fences

Conductive fencing within 15 feet of the centerline of the track shall be grounded. Where the fence is interrupted by gates, the fence shall be grounded at each side of the gate and a flexible ground strap used to bond the gate to the fence. Fences shall also be grounded at or near the location of a supply line or lines crossing them, and additionally, at distances not exceeding 150 feet on either side.

23.5.4 Other Metallic Objects within ROW

A. Other substantial or prominent metallic objects within 15 feet of the centerline of track, including guardrails on bridges, or aerial guideway shall be grounded.

B. Grounding connections shall not be made on mechanical and utility pipes (including water) on the service side of dielectric couplings.

23.6 CONDUIT AND DUCTBANKS

23.6.1 Scope

This section applies to raceways and ductbanks for traction power, signals, communications, low voltage, and medium voltage (15 kV or 26 kV) ac including stations, systems buildings, and park and ride facilities.

23.6.2 General

A. Wire and cable shall be protected by raceway, except for low voltage signal or communication wiring or medium-voltage metal-clad cable where protected from physical damage.

B. Raceways shall be galvanized rigid steel conduit, electrical metallic tubing, epoxy fiberglass conduit or PVC conduit as specified in the following paragraphs. Supplemental corrosion protective coatings for

metal conduit shall be either hard-finish coal-tar epoxy or factory-applied PVC.

1. Raceways below grade shall be one of the following:

   a. Galvanized rigid steel conduit provided with continuous, supplemental corrosion protection for the entire embedded or buried portion plus a minimum of 12 inches on each end.

   b. Epoxy fiberglass conduit or Schedule 40 PVC conduit where buried at least 12 inches below the surface of concrete slabs or if conduits are provided with at least 2 inches of reinforced concrete encasement on all sides.

   c. All stubs above grade shall be encased in concrete. For stubs above grade in locations where protected from physical damage, use galvanized rigid steel conduit, epoxy fiberglass conduit, or schedule 80 PVC. Where exposed to physical damage, use galvanized rigid steel conduit

   d. Schedule 20 (TYPE EB) PVC conduit is permitted only in reinforced concrete ductbanks. Type EB conduit shall be used only in straight sections or where bends can be made cold (see below).

2. Raceways above grade shall be one of the following:

   a. Galvanized rigid steel conduit. Provide with supplemental corrosion protection where in contact with concrete surface or non-ferrous metals.

   b. Electrical metallic tubing is permitted in interior, dry locations where concealed behind building finishes and at least 12 inches above floor level. It also may be surface-mounted in areas not accessible to the public except within 48 inches of the floor in mechanical equipment rooms or other areas subject to movement of large equipment. Provide with supplemental corrosion protection where in contact with concrete surfaces or non-ferrous metals.

   c. Epoxy fiberglass conduit is permitted in concealed areas not used for air handling and where protected from damage.

C. Raceway Bends: Bends in raceways shall be factory-made or field-made in accordance with the following requirements:

1. No more than 270 degrees of bend are permitted between pull-points.

2. Bends shall have a radius (measured to the inside curvature of the raceway) no less than the following requirements.

Nominal Conduit Size (inches)	Conduit Bend Radius (inches)
2	24
2-1/2	27
3	30
3-1/2	33
4	36
5	42
6	48

3. Field bends shall be made using bending equipment and procedures acceptable to the conduit manufacturer.

4. Bending restriction for different conduit types:

   a. Bends in Schedule 40 PVC conduit shall have a bend radius not less than 6 feet if conduit segment length (between pull-points) is greater than 200 feet.

   b. Type EB conduit in ductbanks may be cold-bent if the bend radius is no less than 100 feet. Heat-bending of Type EB conduit is not permitted.

D. A minimum 20 percent spare raceway capacity shall be provided, except where determined that spare capacity is not necessary and that undue expense would be incurred.

23.6.3 System Ductbanks

A. Ductbanks are constructed of raceways, concrete encased, and reinforced with steel. The exact dimensions vary with the number and size of raceways, but in most cases consist of a central core of raceways assembled with manufacturer's standard spacers to allow a minimum of at least 1-1/2 inches of space between raceways for signal/communications ductbanks and three inches for power. The outside envelope consists of a minimum of three inches of concrete on all four sides. The ductbanks are set on a prepared and compacted bed of 3/4-inch minus gravel or sand, usually 3 or more inches in depth. The ductbanks are structurally designed to withstand the load intended. A maximum of sixteen raceways will be permitted in any one ductbank where terminated in a single handhole or manhole.

B. Except in special cases, system ductbanks will be located longitudinally along the length of the track and between the tracks. Where special conditions exist, ductbanks may be located along the outside of the tracks, or in any adjacent area as required by the special circumstances.

C. Lateral crossings underneath the tracks are permitted, but should be minimized. Where necessary, the ductbank may be located directly under the tracks longitudinally, but in no case may a manhole or handhole be located between the rails.

D. Where obstacles such as pole bases are encountered, the ductbank will be gradually offset around the structure, and at all times retain the minimum dimensions of the envelope and structural integrity.

E. System ductbanks shall be located to avoid interference by existing utilities, provide 3 or more feet of cover, and at the same time not require excessive manhole or handhole depths.

F. Manholes and handholes shall be of the pre-cast type, complete with cable supports, and pulling irons. Where manholes or handholes are installed, a ground rod shall be driven, and all metallic parts grounded. Where installed in streets, they shall be equipped with a traffic-rated cast iron cover and grade ring, which can be adjusted for final grade. In other locations, covers may be welded steel.

23.6.4 Medium Voltage Conduits and Ductbanks

A. If medium voltage (greater than 600V) 60 Hz ac feeders are used, they shall be run in galvanized steel conduits or concrete-encased, nonmetallic ducts, and the conductors separated from other systems.

B. If required, because of electromagnetic interference (EMI), medium voltage ac conductors shall be run in galvanized rigid steel conduit, or other means taken to mitigate the effects of the EMI.

C. Medium voltage conduits shall have a bending radius no smaller than 36 inches.

D. Concrete used for medium-voltage ductbank encasement shall be dyed substantially red in color. Provide marking tape appropriate for high voltage electrical circuits and install tape 12 inches above the top of the ductbank or conduit run.

23.6.5 Station Platforms

Junction and pull boxes shall consist of concrete handholes set in the rough concrete slab. All conduit penetrations into the concrete handhole shall be horizontal or vertical and provided with insulated bonding bushings and bonding jumpers. The metallic fittings and supports within the box shall be bonded to the raceway system with #6 AWG minimum bare, stranded copper jumper cable. Metallic lids shall be bonded to interior grounding conductors or to a separate grounding rod within the handhole.

23.6.6 Park-and-Ride Lighting and Street Lighting Circuits

For park-and-ride lot lighting and street lighting, raceways shall be PVC-coated rigid steel conduit, schedule 40 PVC, or epoxy fiberglass, and direct-buried 36 inches below grade. PVC/GRS or epoxy fiberglass shall be used where raceways are installed above 36 inches below grade and for all bends. PVC-coated rigid steel conduit shall be used for exposed transitions from below- to above-ground.

23.7 LIGHTING

For requirements for Lighting, refer to Chapter 21, Lighting.

END CHAPTER 23

24. PLUMBING AND FIRE PROTECTION SYSTEMS

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24. PLUMBING AND FIRE PROTECTION SYSTEMS

24.1 INTRODUCTION

A. These criteria describe the functional and design requirements for the facilities plumbing, drainage, and fire protection systems. They are intended to promote uniformity of design and to standardize the type of plumbing and drainage equipment and its location throughout the system.

24.2 SCOPE

A. These criteria cover the facilities plumbing, drainage, and fire protection systems for aerial, at-grade, and tunnel stations; tunnels, yards and maintenance shops; train control center(s); and miscellaneous wayside ancillary spaces. In addition, they prescribe the requirements for sewage systems for human waste and other waste-fluids to the public sewers.

B. The design of site drainage for buildings, parking lots, park-ride facilities, and for aerial and at-grade portions of the system shall be in accordance with the requirements described in Chapter 6, Civil Work, and Chapter 7, Utilities. Fire and intrusion alarm system requirements are described in the fire and intrusion alarm systems chapter of these criteria.

24.3 SYSTEM INTERFACES

The design of the plumbing, drainage, and fire protection systems shall interface with all appropriate design criteria for all systems.

24.4 CODES AND STANDARDS

A. The plumbing systems shall comply with the International Building Code as adopted by the State of Washington and amended by the local jurisdictions. The drainage systems design shall comply with all applicable local codes of the city and county to which they pertain and with the State of Washington codes. In addition, the fire protection systems design shall comply with the International Fire Code, Chapter 9 as adopted by the State of Washington and amended by the local jurisdiction. Automatic sprinkler systems shall comply with IBC/IFC Section 903 including local amendments.

B. The designer's attention is further directed to the requirements of Fixed Guideway Transit Systems (National Fire Protection Association [NFPA] NFPA 130: hereafter cited as NFPA 130) and the International Plumbing Code as adopted by the State of Washington and amended by the local jurisdictions. Designers shall consult all appropriate codes and publications

and provide plumbing drainage and fire protection systems in accordance with the most stringent of the applicable codes and industry practices.

24.5 PLUMBING AND DRAINAGE

24.5.1 Functional Requirements

A. All plumbing and drainage systems shall be designed for the following functional requirements:

1. Water Distribution

   Convey water from public utility distribution and/or storage points to stations, buildings, and other consumption and service points.

2. Waste Return

   Collect and convey storm drainage to the public storm sewer system and sanitary sewage to the public sanitary sewer system from stations, buildings, and subsurface line sections.

24.5.2 Water Service

A. Potable Cold Water Systems

1. The domestic water service connection to each facility shall be sized for the total peak demand. The domestic water service connection to each underground station shall be a minimum of 2 inches in diameter. Each service shall have a main shutoff valve and backflow preventer immediately inside the structure wall of station or building. Remote meter reading facilities shall be provided for all facilities.

2. Stations, ventilation shafts, maintenance shops, train control center, and other buildings having plumbing fixtures shall be served with water mains sized for the total plumbing fixture demand, plus 10 percent for future expansion. Minimum fixture service requirements in accordance with the Uniform Plumbing Code and local amendments calculated from the following fixture unit values:

Water Closet, flush valve	For the first flush valve: 40 fixture units For the second flush valve: 30 fixture units For the third flush valve: 20 fixture units For the fourth flush valve: 15 fixture units For the fifth, sixth, etc. valve: 10 fixture units
Urinal, flush valve	5 fixture units
Lavatory	2 fixture units
Service Sink	3 fixture units
Drinking fountain	2 fixture unit
Shower	4 fixture units
Hose bibb	3 fixture units + continuous demand outlet of 5 gallons per minute (gpm)
Sink (wash-up, each set of faucets)	2 fixture units
Sink (wash-up, circular spray)	4 fixture units

3. The service requirements of such outlets as cooling tower make-up water, which are likely to impose additional demand, shall be estimated separately and added to the above fixture service requirements to determine the required total service connection capacity.

4. Water service connection at each facility for fire protection systems shall be separate from that for domestic water systems. Refer to the fire protection systems section of this chapter for further information.

5. The domestic water service shall be provided with a pressure-reducing valve when city pressure at the lowest point of use inside the structure is higher than 60 pounds per square inch (psi). The pressure-reducing valve shall be generally located on the discharge side of the main shutoff valve immediately inside the building wall except for deep underground stations, where a

pressure-reducing valve shall be located at the lowest level of distribution. Sizing of the domestic water distribution lines shall be based on maintaining uniform pressure at all plumbing fixtures located at the same level, to minimize shock and water hammer, and to maintain a minimum of 15 psi pressure at each flush valve. All pipe lines shall be run in a systematic manner, parallel and at right angles with walls, and properly pitched for drainage. Water hammer arresters shall be provided for long pipe runs, and branches with flush valves. In addition to the main shutoff valve, isolation valves shall be provided in branch lines and for each floor level to facilitate maintenance in individual areas without losing service for the entire facility. Pressure-reducing valves and backflow preventers shall be provided where automatic makeup for heating, ventilating, and air-conditioning (HVAC) equipment is connected to the potable water system.

B. Hot Water Systems

Hot water systems for facilities having lavatories, showers, and service sinks shall include water heaters, circulating hot water pumps where required, hot water distribution piping, and pipe accessories. All hot water pipes serving more than a single fixture shall be sized for the simultaneous fixture demand with a minimum pipe size of 3/4 inch. All pipes shall be arranged in a systematic manner, and provisions made for thermal expansion and drainage. All hot-water pipes shall be insulated. Isolation valves shall be provided for all branches to facilitate maintenance.

24.5.3 Plumbing Fixtures

A. General

Location and type of plumbing fixtures shall be fully coordinated with the architectural requirements and in accordance with the IBC.

B. Fixtures

Water closets shall be wall-hung, of the siphon-jet, elongated-bowl type, and provided with a flush valve. Urinals shall be wall-hung, of the siphon-jet type, and provided with a flush valve. Lavatories shall be wall-hung. All wall-hung fixtures shall be supported by standard chair supports. Service sinks shall be of stainless steel or monolithic precast terrazzo equipped with a stainless steel rim guard. Water-coolers shall be wall mounted, and shall have a bubbler of vandal-proof design. The service sink in the battery room shall be acid-resistant and equipped with a wall hanger, rim-guard, and standard trap. Showers shall have private compartments complete with partitions, receptors, curtain rails and curtains. The wash fountain shall be of precast terrazzo, circular or semi-circular and foot-

operated with supplies from below, and shall have a vent-off drain, powdered soap dispenser, with chrome finish hardware.

C. Fixtures for Persons With Disabilities

In stations and other facilities having more than one toilet (for each sex), plumbing fixtures in one toilet for each sex shall be installed to accommodate persons with disabilities in wheelchairs where required. In stations and other facilities having only one toilet, plumbing fixtures shall be installed to accommodate persons with disabilities in wheelchairs in accordance with ANSI codes and the applicable provisions of the International Building Code and City of Seattle amendments.

D. Hose Bibbs and Box Hydrants

Hose bibbs shall be provided in toilet and trash rooms; battery rooms; in the vicinity of the elevator and escalator pits; in aerial; at-grade; and tunnel station platforms; at station entrances; and in the concourse areas of stations and other areas where periodic cleaning is required. For station platform areas, a 3/4-inch hose bibb as close as practicable to the centered of each platform, and additional hose bibbs as required, shall be provided so that any point of the platform (excluding the trackway) is not more than 75 feet from a hose bibb. All hose bibbs inside buildings and tunnel stations with side platforms shall be installed in walls in stainless steel boxes with flanges flush with the wall. All exterior hose bibbs shall be installed in exterior walls in brass boxes with flanges flush with the wall. Hose bibbs for aerial, at-grade, and tunnel stations with center platforms shall be brass box hydrant type and shall be installed in platforms with flanges flush with finished floor. All exterior hose bibbs and box hydrants in unheated areas shall be a non-freeze type. Hose bibbs in battery rooms shall have an acid-resistant finish.

E. Water Supply

All water supplies to fixtures in public areas shall have key-operated service valves. Each connection shall be designed for the pressure as recommended by the fixture manufacturer but not less than 15 psi for flush valves and not less than 8 psi for other fixtures. Water supply to lavatories and flush-valve fixtures shall have water-shock absorbing provisions. Vacuum breakers shall be provided on all outlets with hose bibb connections and submerged inlets.

F. Plumbing Fixture Connections

All services and piping connections for plumbing fixtures shall be selected in accordance with Table 24-1.

TABLE 24-1
SERVICES AND PIPING CONNECTIONS FOR PLUMBING FIXTURES

(All dimensions are in inches)

Fixture	*Fixture Symbol Remarks*	*Soil or Waste*	*or*	*Trap Size*	*Vent Pipe*	*HW Pipe*	*CW Pipe*
Water Closet	P-1 Wall Mounted	4		Integral	2	no	1
Urinal	P-2 Wall Mounted	2		1-1/2	1-1/2	no	3/4
Lavatory	P-3 Wall Mounted	1-1/2		1-1/4 x 1-1/2	1-1/2	1/2	1/2
Mop Service Basin	P-4 Wall Mounted	3		3	1-1/2	1/2	1/2
Drinking Fountain	P-5 Wall Mounted	1-1/2		1-1/4 x 1-1/2	1-1/2	no	1/2
Hose Bibb	HB Flush with walls	no		no	no	no	3/4
Floor Drain	FD Flush with floors	3 minimum		3	1-1/2	no	*
Eye Wash/Body Shower	P-6	3		no	no	no	1-1/4

*Primed traps shall be provided as required by local codes.

24.5.4 Domestic Water Heaters

A. General

1. Domestic water heaters of 30 gallons or less capacity shall be electric and shall not have water softeners. Above 30 gallons, all water heaters shall be a natural gas fired type, unless natural gas is not conveniently available in which case the water heaters may be electric regardless of capacity. Water heaters shall be properly sized for the plumbing fixture demand and shall be Underwriters Laboratories, Inc. (UL) listed and bear the American Society of Mechanical Engineers (ASME) stamp of approval. The requirements for water softeners and their type shall be determined by the source water quality. Water heaters shall be seismically secured in place.

2. Where judged to be necessary, a hot water return pump shall be provided for circulation. The operation of the hot water return

pump shall be controlled with an aquastat located in the hot water return piping, immediately before the heater.

B. Gas Fired Water Heaters

All gas fired water heater shall be of storage type, with approximately 100° F recovery capacity sized for the demand of plumbing fixtures to be served by each heater. Heaters shall be provided with electronic ignition. Heaters shall be glass-lined and equipped with temperature and safety controls, and thermal insulation. Where natural gas is not conveniently available, electric water heater as described in the following paragraph shall be provided.

C. Electric Water Heaters

Electric water heaters with a capacity of 10 gallons or less shall be the instantaneous type. All electric water heaters with a capacity above 10 gallons shall be the storage type, with approximately 100°F recovery capacity sized for plumbing fixture demand served by the heater. Heaters shall be glass-lined and equipped with fast acting dual element immersion heating, temperature and safety controls, and thermal insulation. Units with heating elements of 2,900 watts or less shall be suitable for a 120 volt/1-phase power supply. Units with heating elements of 5,500 watts or less shall be suitable for a 208 volt/1-phase power supply. Units with heating elements above 5,500 watts shall be suitable for a 480 volt/3-phase power supply.

24.5.5 Eyewash Facilities

A. In passenger stations and other buildings with water service, each battery room shall have one wall-mounted emergency eye-and-face-wash fixture, with bowl, connected to the cold-water piping system and with a direct drain to the sanitary sewer system. Where the battery room is located in a facility without water service, the capability for eye protection shall be provided by a portable eyewash apparatus.

24.5.6 Drains

All floor, area, and roof drains shall be of bottom outlet type wherever possible. Where space is not adequate to use bottom outlet drains, drains with side outlet may be substituted. All drains used in membrane waterproof floors and roofs shall be provided with flashing collars securely clamped to the waterproof membranes or flashing. Floor drains in public areas shall be bronze or stainless steel finish. Finish is to be determined by floor material, which must be coordinated with the architectural requirements. Floor drains in public spaces shall be installed with vandalproof screws. Drains for fire protection piping shall comply with NFPA 13.

A. Floor Drains

1. Floor drains shall be provided at building and station entrances, underneath walk-off mats near entrances, in emergency exit stairwells, trash rooms, and custodial rooms, and in all unassigned rooms in aerial, at-grade, and tunnel stations and subsurface line sections. Drainage provision at station main entrances, building entrances, as well as approach areas of elevators and escalators at-grade level, shall be a trench-drain type. Escalator and elevator pits shall have small sumps for pumping out accumulated water by means of a portable pump. Toilet rooms containing two or more water closets or a combination of one water closet and one urinal shall be equipped with a floor drain.

2. Drains shall be provided in all unassigned rooms and in underground spaces having automatic sprinklers. Provide primed traps as required by local codes. Floor drains in battery rooms shall be acid resistant. Floor drains in spaces beneath station platforms, ventilation shafts, ventilation grating areas, and other areas subject to clogging shall have bronze dome strainers.

3. Floor drains shall be provided immediately beneath all hose bibbs located inside buildings and tunnel stations. Station platforms which have a slope toward the trackway of at least one percent do not require floor drains beneath the hose bibbs. Platforms with a lesser slope shall be provided with a floor drain immediately beneath each hose bibb.

B. Area Drains

Area drains shall be provided at station and building entrance areas and emergency exits, exterior elevators, and escalators.

C. Roof Drains

1. Roof drainage systems shall be designed to handle the rainfall intensity for 100-year frequency.

2. Roof drains shall be of cast iron, copper, lead, or other approved corrosion-resistant material. Roof drains passing through the roof into the interior of a building shall be made watertight at the roof line by the use of a suitable flashing material.

3. Roof drains shall be equipped with strainers extending not less than 4 inches above the roof surface. Drains shall have a minimum inlet area 1-1/2 times the area of the pipe to which they are connected.

4. Roof deck drain strainers for use on parking decks and similar occupied areas may be of an approved flat-surface type which is level with the deck. Such drains shall have an inlet area not less than 2 times the area of the pipe to which they are connected. The strainers shall be suitable for the anticipated maximum traffic load.

D. Trackway Drains

Trackway drains inside tunnel stations and subsurface line sections shall consist of concrete drainage slots, concrete catch basins, and concrete manholes with cast-iron gratings. No traps or vents shall be provided for the track drainage system.

24.5.7 Traps

A. All traps shall be of plain pattern having a seal of not less than 2-1/2 inches and not greater than 4 inches. All traps shall be of the same material as that for the piping system to which they are connected. All exposed traps in toilet rooms shall have chrome finish. Trap primers shall be provided where floor drains are not used frequently and as required by local codes.

B. All floor drains connected to the sanitary sewer system shall be provided with a trap.

24.5.8 Clean-Outs

Clean outs shall be provided on all soil, waste, and drain lines for each pair of 45-degree bends and for each 90-degree bend, and for each 50 feet of straight run, except track drainage for which maintenance of the drain pipes will be through the catch basins. All clean-outs brought to finished floors shall terminate with removable clean-out brass covers at paved tile floors, or stainless steel cover on concrete floors, flushed with the floor. Clean-outs shall be of the same size as the size of pipes served for pipe 4 inches and smaller; 4 inches for pipe sized 4 inches to 6 inches, and 6 inches for pipe sized larger than 6 inches. No floor clean-outs in public areas shall be provided. Floor clean-outs from public areas shall be extended to non-public areas.

24.5.9 Soil and Waste Systems

The soil and waste system for facilities shall include soil and waste piping from all plumbing fixtures and floor drains, sewage ejector stations, and ejector discharge piping for tunnel stations. All soil and waste pipes shall be sized for fixture demand, and as required by applicable plumbing codes and ordinances.

24.5.10 Vent Systems

Complete vent systems shall be provided for all soil and waste systems and sized in compliance with applicable plumbing codes and ordinances. All horizontal vent pipes shall be kept as short as possible, pitched at ¼ inch per foot toward soil and waste pipes, than rise to the outside in the most direct way. Each vent riser shall be properly flashed at roof penetration. Vent risers for underground facilities, terminating in planting areas at street level shall be provided with vandal-proof and rodent-proof caps.

24.5.11 Sewage Ejection Systems

A. General

Due consideration shall be given to performance, noise, durability, standardization, and handling characteristics when selecting equipment for the sewage ejection systems. All equipment selected for the sewage ejection systems shall be manufacturer's standard products or "suitable for competitive pricing." For corrosion control requirements refer to the corrosion control/grounding chapter of these criteria.

B. Ejector Stations

Tunnel stations and other subsurface facilities having toilets shall be provided with sewage ejector stations. Sewage ejector stations shall be of electric duplex vertical centrifugal wet pit sump pumps (see section 24.6.8).

24.5.12 Grease, Oil, and Sand Interceptors

A. Grease, oil, and sand interceptors shall be provided as required by environmental standards for effluent to public waters. Interceptors shall conform to all local codes that govern the installation.

B. Floor drainage systems serving maintenance shops and vehicle storage areas shall be provided with oil and grease separators, and sand traps for extraction of oil, grease, sand, and other substances that are harmful or hazardous to the structure or to public drainage systems. Separators and traps shall have sufficient capacity to retain all sludge between cleanings.

24.5.13 Sanitary Facilities

All drains from mop sinks, lavatories, water closets, and other miscellaneous drains/sanitary waste shall be run by gravity where feasible to existing public sanitary sewers. If a gravity run cannot be accomplished, drains/sanitary waste lines shall be run to sewage

ejector pits equipped with a sump equipped with non-clog duplex vertical centrifugal wet pit sump pumps. The discharge shall then be pumped to the nearest public sanitary sewer line(s). For corrosion control requirements refer to the corrosion control/grounding chapter of these criteria.

24.6 SUBSURFACE DRAINAGE

24.6.1 General

A. The criteria of this chapter pertain to the design of tunnel drainage facilities. The following shall apply:

1. Invert elevations and the location of drainage facilities at the interface between contract units shall be coordinated with related designers.

2. To the best extent possible, drainage shall be by gravity flow. Where collection points are below the elevation of gravity outfalls, pumping stations shall be provided.

3. To the best extent possible, surface drainage (except from platforms and seepage water in tunnel stations and tunnels) from entrances, ventilation shafts, and similar openings, shall not be conveyed to the trackway drainage systems. This drainage shall be intercepted before it enters into the track drainage system and diverted to the public sewer system in accordance with the requirements of the drainage chapter of these criteria.

24.6.2 Location of Drains

A. Drainage pumps shall be provided at low points that cannot be drained by gravity.

B. In subsurface line sections, invert drainage slots shall carry drainage to pumping stations at the low point. Drainage slot inlets or sumps shall be provided at a maximum interval of 300 feet so that the drainage inlet spacing also satisfies the spacing requirements for clean-outs or manholes.

C. In stations, drainage slot inlets or sumps shall be provided at a maximum interval of 100 feet along each trackway.

D. Gravity drainage from the low point in the space under platforms shall be provided and shall be connected to the storm or track drainage system. Where a wall divides the space under the platform, sleeves shall be provided through the wall, at the top of the base slab, to permit inter-space flow to the low point.

E. Where gravity drainage from the low point in the spaces under platforms to the storm or track drainage system is not possible, the drainage shall be collected in a sump. These sumps shall be equipped with automatic duplex sump pumps and check valves to discharge the collected drainage into the storm or track drainage system. A backwater valve shall be provided in the pump discharge line immediately at the connection to storm or track drainage system.

F. Where the provision for gravity drainage to the sanitary drainage system with oil interceptor is impractical, a drainage sump 24 inches square by 18 inches deep, without outlet, shall be provided in each escalator pit, elevator pit, and elevator machine room. Provisions shall be made for inspection and periodic emptying by means of a portable pump.

24.6.3 Drainage Fittings

A. The following fittings shall be provided:

1. A manhole frame and cover shall be provided at each access to the main track drain.

2. A drain inlet, made of cast iron grating, shall be provided at each drainage inlet, with a connection to the main track drain.

3. A scupper drain shall be provided at the drain inlet from fan shafts and vent shafts.

4. Clean-outs with cover shall be provided where access to the drainage piping is required for clean-out purposes, and at prescribed intervals.

24.6.4 Drainage Piping

A. Piping for drainage systems shall be provided as follows:

Drainage piping for both the open-track and subsurfaces sections shall be designed in accordance with the requirements as prescribed in Table 24-2.

Table 24-2
DRAINAGE PIPE SIZES

Diameter (inches)	Material	Use
4	Extra-heavy-weight cast iron	Drain connections in structural walls and floor
6	Extra-heavy-weight cast iron	Drain connections in structural walls and floor
6	Extra-heavy-weight cast iron	Branch connections in structures and underground
8	Polyvinyl chloride (PVC) sewer pipe schedule 80	Station track drain and subsurface line track drainage
10	PVC sewer pipe schedule 80	Station track drain and subsurface line drainage

24.6.5 Drainage Volumes

A. The volumes of water to be handled by each system shall be calculated as follows:

1. Drainage of Open Areas into the Subsurface Drainage System. Drainage volumes from decks, entrances, ventilation shafts, and similar openings flowing into the subsurfaces drainage system shall be calculated by means of the following formula.

   Q = CIA
   Where:
   Q= Runoff volume, in cubic feet per second
   A= Drainage area, in acres
   C= Coefficient of runoff
   I= Rainfall intensity in inches per hour

2. For additional requirements, see the drainage section of Chapter 6, Civil Work.

B. Drainage volumes in subsurface structures in earth, designed to collect groundwater, shall be based on the following formula:

   q = (a/14)+(L/500)

   Where:

   q = Volume, in gallons per minute

a = Horizontal projected area, in square feet, of all surface openings, such as station entrances, and fan shafts

L = Linear feet of subsurface structure in the drainage system

C. Drainage volumes in subsurface in rock, designed to collect groundwater in order to relieve hydrostatic pressure, shall be based on the following formula:

$$q = (a/14)+(L/50)$$

Where q, a, and L are as defined in the previous section.

D. Under-track drainage system in subsurface sections shall be designed to carry drainage resulting from fire-fighting efforts to trackway drainage pumping stations. In a design case scenario of fire emergency in a tunnel, it is estimated that fire department personnel will normally use two fire hoses to fight the fire. Therefore, the main drain line and branch drain lines shall be designed to carry 500 GPM.

24.6.6 Flow Formula

A. Flow and velocity of drainage piping shall be calculated using Manning's formula, expressed as follows:

$$V = (1.486/n)\ (R)^{2/3}\ (S)^{1/2}$$

$$Q = AV$$

Where:

Q = Volume, in cubic feet per second

A = Cross sectional area of the pipe in square feet

V = Velocity of flow in pipe in feet per second

n = Roughness coefficient of the pipe

R = Hydraulic radius, which is the area of flow divided by wetted perimeter (R=A/p)

S = Slope of the hydraulic gradient

p = Wetted perimeter

In the use of this formula, the following factors for "n" shall be used:

n = 0.012 for concrete pipe

n = 0.013 for cast iron pipe

n = 0.011 for polyvinyl chloride pipe

24.6.7 Grades

A. Drainage piping shall have the minimum grades indicated in Table 24-3:

TABLE 24-3
DRAINAGE PIPING - MINIMUM GRADES

Pipe Diameter (Inches)	Minimum Grade
4	2.0 percent or 0.25 inch per foot
6	1.0 percent or 0.125 inch per foot
8	0.70 percent or 0.085 inch per foot
10	0.30 percent or 0.036 inch per foot

B. For the design of main drains, the designer shall consider the economics of increasing the size of the drain line to permit as close a correlation as possible between the drain profile and the top of the rail profile.

C. Main drain lines shall be designed in such a manner that the grades produce a minimum velocity of 2.5 feet per second with the pipe flowing 50 percent full.

24.6.8 Pumping Stations

A. Each track drainage or sewage sump pump station shall consist of a concrete wet well with two non-clog vertical centrifugal wet pit pumps, or a wet well with two submersible pumps. In addition, a seepage water (interceptor) pump at each track drainage pumping station shall be provided. Water level controls shall be provided with remote indication of high water condition, electric pump “on-off-automatic” switch, lead lag control, electric alternators, level rise indicator, and connections to street mains.

1. Sump pumps shall be fully sealed to exclude moisture, abrasive materials, corrosive gases, and all other matter that may contribute to wear. Pumps shall be the non-clog sewage, vertical centrifugal or submersible, wet basin type. Impellers shall be grinding type, with clearance adequate to pass 3-inch solids.

2. Each group shall have a capacity equal to 100 percent of the calculated drainage volume including infiltration and seepage. The minimum capacity of each track drainage pump in pumping station at the low point shall be 500 GPM; the minimum capacity

of each seepage water or interceptor pumps at the low point in the track drainage system shall be 150 GPM.

3. The minimum capacity of each sewage sump pump shall be 30 GPM with 4 inches minimum sewage discharge line.

4. The pump head (total dynamic head) shall suit the static and friction heads of each installation; the friction head shall be calculated with two pumps operating. In determining the pump head, an investigation of existing sewers shall be made. If the existing sewer is liable to be overcharged, the pump discharge shall be increased to exceed the overcharge head.

5. Motors shall be non-overloading at any point of pump curve. Motors for trackway drainage pumps shall be of explosion-proof construction.

   a. Motors 1/2 HP and smaller shall be suitable for 120 volts, single-phase power supply. Motors larger than ½ HP shall be suitable for 480 volts three-phase power supply.

6. Level controls shall be mechanical or electrical type. A local high-water alarm and provisions for remote indication of high-water condition shall be provided. Provisions for manual testing of such level controls shall be located adjacent to pump controllers.

7. Pump connections to discharge header shall be made with Y-connections or lateral. A check valve and gate valve shall be provided in each pump discharge line. In order to prevent freezing, provisions shall be made by means of automatic bail drip or motorized valve to drain the standing water from the discharge line back into the sump after the pumps are de-energized.

24.7 FIRE PROTECTION SYSTEMS

24.7.1 Types of Fire Protection Systems

A. The following types of fire protection systems shall be provided:

1. Automatic sprinkler systems (wet and dry);

2. Standpipe systems (wet and dry) with fire hose valve cabinets where indicated;

3. Portable fire extinguishers; and

4. Approved clean agent fire suppression system.

24.7.2 Automatic Sprinkler Systems

A. General

1. Sprinkler systems shall include the following:

a. Main water supply, back-flow preventer, fire department inlet connections, all piping from inlet connections and water supply mains to sprinkler heads, drain lines, provisions for connection to remote alarm devices, pipe fittings, valves, hangers, inserts, sleeves, escutcheons, necessary tools, and appurtenances.

b. Inlet connections shall comply with the requirements of the local jurisdictions.

c. Automatic sprinklers shall be in accordance with NFPA 13 and Section 903 of the International Fire Code as amended by the local jurisdictions. Where piping is subject to freezing temperatures, a dry pipe sprinkler system of the pre-action type with deluge valve activated through smoke/heat detectors shall be provided. Sprinkler systems shall be provided in the unassigned spaces at stations, maintenance shops, train control center, and other locations as described herein. The sprinkler system may be combined with the standpipe system.

d. Automatic sprinkler systems shall comply with Installation of Sprinkler Systems (NFPA 13), NFPA 130, International Fire Code as adopted by the State of Washington and amended by the local jurisdiction.

e. Sprinkler Density and Area Coverage for office areas, locker rooms, lounges, concession stands, restaurant service areas, storage areas, workshops, trash rooms and mechanical rooms shall be in compliance with NFPA 13.

f. Depending on local requirements, electrical rooms containing high voltage equipment may require other means of fire protection, rather than sprinklers.

g. Manually operated suppression systems may be installed if approved by the AHJ.

B. Aerial and At-Grade Stations

Automatic sprinklers shall be provided in all non-public areas as well as in concession stands and restaurant service areas where such facilities are located within passenger stations. Automatic sprinklers shall be in accordance with NFPA 13 and Section 903 of the International Fire Code as amended by the local jurisdictions.

Communications and Electrical rooms shall be provided with a double interlocked sprinkler system. For public areas consult local jurisdiction for special requirements.

C. Tunnel Stations and Subsurface Unassigned Spaces

Automatic sprinkler systems shall be provided in all public and non-public areas, in all escalator steel truss areas and escalator pits, and elevator shafts. Automatic sprinklers shall be in accordance with NFPA 13 and Section 903 of the International Fire Code as amended by the local jurisdictions. Electronic equipment rooms such as radio repair, telephones, and computer rooms have double interlocked pre-action sprinkler systems.

D. Maintenance Facilities

1. Automatic sprinkler systems shall be provided in all areas of maintenance buildings. The sprinkler systems shall be for light, ordinary, or extra hazard classification as appropriate, and shall be hydraulically designed in accordance with all applicable codes. Sprinkler systems in areas that are unheated or subject to freezing shall be dry type systems. Sprinkler heads in paint spray booths shall have listed protective plastic caps. Sprinkler heads subject to damage shall have protective cages.

2. Electronics equipment rooms such as radio repair, telephones, and computers shall have double interlocked pre-action sprinkler systems.

E. Operational Control Center (OCC)

An automatic wet pipe sprinkler system shall be provided throughout the train control center in accordance with NFPA 13. Sprinkler heads subject to damage may have protective caps if acceptable to the AHJ. Appurtenances to sprinkler systems shall be listed for their intended use. If the OCC is in a building having occupancy not directly related to transit system operations, the automatic sprinkler system shall be supplied from an independent connection to the municipal water supply. The OCC computer room, data archive room, and other electronics equipment rooms as indicated on project definition drawings shall have double interlocked pre-action sprinkler systems.

24.7.3 Standpipe Systems

A. General

1. Standpipe systems shall conform to the requirements of Installation of Standpipe and Hose Systems, NFPA 14 and as delineated and specified by class type in the International Fire

Code as amended by the local jurisdiction. Standpipe systems shall include fire department inlet connections, main water supply, piping from inlet connections to mains, hose valves, fire hose cabinets, drain lines, pipe fittings, control valves, hangers, sleeves, tools and appurtenances as required for a complete and working system. Standpipe systems shall be provided at tunnel stations, tunnels, maintenance facilities, OCC, and other locations described below. See IBC/IFC Section 905 including local amendments.

2. Standpipe hose connections shall be accessible and located so that all portions of the building are within spacing requirement for class of service.

3. Standpipes shall be located in every required stairway. A hose connection shall be provided for each floor level above and below grade. Hose connections shall be located at intermediate floor level landings between floors, unless otherwise approved by the fire code official.

4. Fire hose cabinets shall be identified in an approved manner by a permanently attached sign with letters not less than 2 inches high in a color that contracts with the background color, indicating the equipment contained therein per IBC/IFC Section 905.7.1.

B. Aerial Stations

All areas of passenger stations shall be within 300 feet of a fire hydrant connected to a public water supply. Fire hydrants and water supply mains shall be in accordance with applicable codes. At-grade stations shall not be provided with a standpipe system.

1. The system shall have hose outlet connections at 200-foot intervals.

2. Each hose connection shall consist of a 2.5-inch angle valve equipped with a 2.5-inch cap.

3. The system shall be sized to supply 500 GPM at the hydraulically most remote outlet.

4. Provision for draining the complete system shall be provided.

5. Fire department connections located at-grade shall be within 100 feet of vehicular access and within 100 feet of a street hydrant.

6. The zones supplied by each connection shall be clearly identified by identification plates attached to the fire department

connections. Identifying numbers shall also be provided at each hose valve in tunnels in accordance with the requirements of NFPA 130.

7. At-grade stations shall not be provided with a standpipe system.

C. Tunnel Stations

1. A Class I NFPA wet standpipe system shall be provided throughout the station entranceways and platforms. Station shafts for new deep underground stations shall also have Class I standpipe systems. The Class I standpipe system shall be designed and installed in accordance with IBC Section 905, NFPA 14 and NFPA 130 Sections 5.7.4.1 and 6.2.7.2; and include 2.5 inch hose outlet valves spaced such that all areas shall be within 150 feet of a 2.5 inch hose valve outlet, including in and around any transit vehicles, which may be stopped at the station. For stair shafts at new deep underground stations, a 2.5 inch hose valve outlet shall be provided both inside and outside stair at every level where there is an equipment floor and in the vestibules at the back entrances to the tunnels.

2. The station standpipe shall be fed from fire protection valve pits (FPVP), located at-grade, at each end of the station. Each FPVP shall be:

   a. Fed from separate water mains which are at least 8 inches in diameter

   b. Connected to the tunnel standpipes

   c. Provided with 4-way valve connections

   d. Provided with graphics describing the operation

   e. Opened by a hydrant wrench

   f. Designed for natural ventilation

   g. Valves shall have tamper switches monitored by station fire alarm system and OCC

3. The standpipe system shall be cross-connected in stations, so that the station standpipe can be fed from either FPVP. Cross-connect valves used to isolate system, shall be maintained in open position. Valves shall have tamper switches supervised by station fire alarm system and OCC.

D. Maintenance Facilities

In addition to the automatic sprinkler system described above, a Class I wet standpipe system shall be provided in all areas of major repair, service and inspection shops, with the spacings and locations of the hose connections as indicated above.

E. Operations Control Center

In addition to the automatic sprinkler system, a Class I wet standpipe system shall be provided in all areas with spacings and locations of the hose connections as indicated above. A separate fire department connection, clearly marked with its intended use, shall be provided within 100 feet of a street hydrant and within 100 feet of vehicular access.

F. Guideways

1. At-grade guideways may not be provided with standpipes if an adequate water supply is available from existing or newly installed hydrants. If installed, they shall meet the requirements of section 24.7.3. B, 2 through 8.

2. Tunnel Segments

   a. A standpipe system (looped configuration) shall be provided at portals and in each guideway tunnel.

   b. The location shall be on the tunnel wall along the safety walk.

   c. The system shall have hose outlet connections at 200-foot intervals.

   d. Each hose connection shall consist of a 2.5-inch angle valve equipped with a 2.5-inch cap.

   e. The system shall be sized to supply 500 GPM at the hydraulically most remote outlet.

   f. Provision for draining the complete system shall be provided.

   g. Fire department connections located at-grade shall be within 100 feet on a street hydrant.

   h. The zones supplied by each connection shall be clearly identified by identification plates attached to the fire department connections. Identifying numbers shall also be

provided at each hose valve in tunnels in accordance with the requirements on NFPA 13.

i. If a dry standpipe is used, the fill time for dry pipe systems shall not exceed 10 minutes.

j. Sectionalizing valves shall be provided to isolate the standpipe system subject to damage due to vehicle derailments.

k. An FPVP may be co-located with ventilation shafts/emergency stairs to grade which may be constructed between stations to comply with NFPA 130 ventilation and/or exiting requirements.

l. Water flow shall be annunciated at the EMP/FACP and at the OCC.

m. During construction, a temporary or permanent standpipe system shall comply with NFPA 130, 6.2.72, NFPA 241 and section 6.2.7.3 and shall be installed and maintained when the tunnel segment exceeds 300 feet from the tunnel face. If a temporary standpipe system is installed, if shall not be removed until the permanent standpipe system is accepted.

3. Elevated Guideway

a. A dry standpipe systems (looped configuration) shall be provided on all elevated guideways when the length of the elevated portions exceeds 400 feet.

b. The location shall be along the safety walk.

c. The system shall have hose outlet connections at 200-foot intervals.

d. Each hose connection shall consist of a 2.5-inch angle valve equipped with a 2.5-inch cap.

e. The system shall be sized to supply 500 GPM at he hydraulically most remote outlet.

f. Provision for draining the complete system shall be provided.

g. Fire department connections located at-grade shall be within 100 feet of vehicular access and within 100 feet of a street hydrant.

h. The zones supplied by each connection shall be clearly identified by identification plates attached to the fire department connections. Identifying numbers shall also be

provided at each hose valve in tunnels in accordance with the requirements of NFPA 13.

i. Sectionalizing valves shall be provided to isolate the standpipe system subject to damage due to vehicle derailments.

j. Water flow shall be annunciated at the FACP and OCC.

4. An FPVP shall be co-located with ventilation shafts/emergency stairs to grade which may be constructed between stations to comply with NFPA 130 ventilation and/or exiting requirements.

5. Water flow shall be annunciated at the FCP and OCC.

6. During construction, a temporary or permanent standpipe system shall comply with NFPA 130, section 6.2.7.3 and shall be installed and maintained no further than 200 feet from the tunnel face. If a temporary standpipe system is installed, it shall not be removed until the permanent standpipe system has been accepted.

7. Construction standpipes shall comply with NFPA 241 (Underground construction).

G. Acceptable water supplies shall include the following:

1. Municipal or privately owned waterworks systems that have adequate pressure and flow rate and a level of integrity acceptable to the AHJ.

2. Automatic or manually controlled fire pumps that are connected to an approved water source.

3. Pressure-type or gravity-type storage tanks that are installed in accordance with NFPA 22, or as required by the local jurisdiction.

24.7.4 Fire Hose Valve Cabinets

A. Fire hose valve cabinets equipped as required, shall be provided to achieve coverage of all the areas specified below. This coverage shall be in accordance with Installation of Standpipe and Hose Systems, NFPA 14. Each cabinet shall be equipped with a 2.5-inch valve and fire extinguisher where required.

B. Fire hose valve cabinets shall be located in the following areas:

1. In Tunnel stations fire hose cabinets shall be provided at the mezzanine, platform, and concessions.

2. In Maintenance facilities fire hose cabinets shall be provided for all areas.

3. In the Operations control center fire hose cabinets shall be provided for all areas.

24.7.5 Fire Hydrants

A. Lines and Stations

A fire hydrant of the type approved by the local authority having jurisdiction shall comply with the International Fire Code, Chapter 9 and shall be provided at each of the following locations:

1. Within 300 feet of each location where the light rail guideway crosses over a traveled way or access road;

2. Within 100 feet of each fire department connection to a standpipe system;

3. Within 150 feet of each tunnel station entrance or access point; and

4. The above 150-foot limits are maximums; it is desirable that a fire hydrant be located as close as possible.

B. Operations Control Center (OCC)

Fire hydrants shall be provided along the access road to the OCC at a maximum spacing of 300 feet, if the operations control center is an at-grade free-standing building.

C. Maintenance Shops and Yards

1. Fire hydrants shall be provided at a maximum spacing of 300 feet along the access roads to the yard and shop facilities in accordance with NFPA 24 and IFC 508 or as required by the local jurisdiction.

2. In the yards, fire hydrants shall be spaced not farther than 300 feet apart and not closer than 50 feet to any building in accordance with Installation of Private Fire Service Mains and their Appurtenances (NFPA 24). The piping shall be installed with a post indicator valve to form a loop with the feed connection to the municipal water supply. Where post indicator valves cannot be used, underground gate valves may be used, provided their locations and direction of turning to open are plainly marked. Operating tools for underground valves shall be provided.

D. Fire Hydrant Reflectors

As described in Chapter 11, Traffic Control, blue fire hydrant reflectors (reflective pavement markers) shall be installed at the centerline of the roadway opposite to each fire hydrant.

24.7.6 Water Supply

A. General

1. A water supply system separate from a domestic water supply system shall be provided for all automatic sprinkler and standpipe systems.

2. The adequacy of water supply shall be determined by flow tests or other suitable means. Where flow tests are made, the flow rate in gallons per minute together with the static and residual pressures shall be indicated on the plans. Adequacy of water supply may be determined from the records of the owner of the water supply system.

3. Street mains from the local municipality supplying water service for fire protection, shall be sized to carry the fire protection water design flow, but in no case shall they have a diameter of less than 8 inches. Where both sprinkler and standpipe systems are served, the building fire main shall not be less than 6 inches in diameter. Where only standpipe systems are served, the building fire main shall not be less than 4 inches in diameter.

4. No pressure-regulating valves shall be used in fire protection water supply mains. Where such devices are judged to be necessary, the designer shall obtain special permission from the local authority having jurisdiction. Unless otherwise required by the owner of the water supply system, meters shall not be installed in fire protection water supply mains to light rail facilities.

5. Where connections are made to a public water system, it shall be necessary to guard against possible contamination of the public water supply. The requirements of the local jurisdiction shall be met. As a minimum, however, a back-flow preventer with detector check shall be provided on fire protection water mains on the discharge (or load) side of the main shutoff valve or immediately inside the building wall.

B. Fire Pump

1. As a single source of water supply, an automatically controlled fire pump in accordance with NFPA 20, taking water from a water

main of adequate capacity may under certain conditions be acceptable to the local authority having jurisdiction.

2. Where a pump is the only means of supplying water, the pump shall be centrifugal and shall be provided with the supervisory service from an approved proprietary system or equivalent. This supervisory system shall provide the means for a positive indication that the pump has operated normally. This arrangement shall be in addition to the supervision of power supply and any other features required by the local authority having jurisdiction. Pumping shall provide adequate flow and pressure in accordance with the AHJ.

3. The fire pump shall be connected to a continuous power source or an emergency power generation source, and shall have its own auto-transfer switch. Overload relays to protect the pump motor shall not be provided.

4. As required by the local authority having jurisdiction, provisions shall be made to test the fire pump on a periodic basis. If hose outlets are provided for this purpose, they shall be located outdoors and their intended use clearly marked. The location and type of testing facility shall be coordinated with the architect.

24.7.7 Fire Department Connections

A. Fire department inlet connections for automatic sprinkler and standpipe systems shall be located at the primary entrance to underground and elevated stations within 25 feet of vehicular access for hydrant spacing and locations shall be determined in accordance with local municipal code, and IFC section 612, or as approved by the Fire Code Officials.

B. A four-way manifold fire department connection (FDC), subject to the approval of the AHJ, at each stairway and vent shaft through which the local fire department can pump water into the sprinkler, standpipe, or other system furnishing water for the fire protection system. The vent shaft shall apply to new deep underground stations. There shall be no shutoff valve between the fire department connection and the system feed mains.

C. In each fire department connection line, an approved check valve shall be installed. The valve shall be located as close as practical to the point where it joins the system.

D. The sprinkler pipe and standpipe systems between the check valve and the fire department connection shall be equipped with an

approved automatic drip arranged to discharge to a proper place. In tunnel line sections, the discharge shall be extended to track level.

E. The fire hose threads shall comply with the local fire departments' hose threads.

F. Fire department connections shall be provided at the access-road side of buildings and shall be located and arranged so that the hose lines can be readily and conveniently attached to the inlets without interference with any nearby objects, including buildings, fences, posts, other fire department connections, or street traffic.

G. Fire department connections shall be designated by a sign having raised letters at least 1 inch in size and cast on a plate or fitting reading "AUTO-SPKLR," OPEN SPKLR," OR "STANDPIPE," whichever is appropriate. The sign shall indicate the inlet pump pressure. The sign shall also have a chrome finish. The location of fire department connections shall be as indicated on project definition drawings.

24.7.8 Portable Fire Extinguishers

A. Portable fire extinguishers with a minimum rating of 40A, 60BC. ABC multi-purpose dry chemical, and UL approved shall be provided in accordance with Portable Fire Extinguishers, NFPA 10 and as modified by these criteria. If restaurant or concession kitchens are included in the station design they shall be provided with a Class K portable fire extinguisher within 3 feet of the cookers.

B. Fire extinguishers shall be mounted in cabinets in finished spaces. Extinguishers shall be surface mounted in unfinished spaces. Recessed cabinets in public areas of the station platform and concourse shall be provided for the installation of fire extinguishers. The locations of such recesses shall be as indicated on project definition drawings.

C. Portable fire extinguishers shall be in accordance with NFPA 10. The minimum travel distance to the nearest extinguisher shall not exceed the distance prescribed in NFPA 10 Table 3-2.1. They, shall be located in the following areas:

1. Underground Guideways - at cross passages

2. Aerial Stations

3. Ancillary spaces

4. In Underground Stations fire extinguishers shall be located on station platforms and at other locations as required by hazard type

and space utilization: The maximum travel distance to the nearest extinguisher shall not exceed 75 feet in public areas.

5. Fire Extinguishers shall be installed in all Train Control Centers.

6. Throughout the maintenance facilities and at each emergency phone in the facility.

D. Portable fire extinguishers, carbon dioxide type, shall be provided in power substations, signaling rooms and communication rooms in addition to ABC extinguishers. Maximum travel distance to the nearest group of extinguishers shall be 50 feet.

24.8 VALVES

24.8.1 General

Isolation valves shall be provided on both sides of warm water heater, on each pressure main at building and at stations, on each branch of distribution mains, at each plumbing fixture (except where several units are installed in a battery, for which one isolation valve shall be adequate), on both sides of in-line accessories, and on equipment that requires removal or isolation from pressure for maintenance. All valves for water and compressed air shall be made of bronze, with screwed ends for up to 2-inch sizes, and IBBM (iron body, bronze mounted) with flanged ends for 2-1/2 inches and larger sizes. Valves shall be tagged and charted. Alarm check valves shall be installed on all fire service lines.

24.8.2 Valve Monitoring Requirements

A. All control valves in water supply piping to the automatic sprinkler and standpipe systems shall be continuously monitored with the use of tamper-proof switches which are Underwriters Laboratories, Inc. (UL) listed and Factory Mutual (FM) approved. The closure of control valve(s) or the removal of switches shall be annunciated to the train control center, as shown in the applicable standard, directive, and project definition drawings. For additional information regarding monitoring see Chapter 15, Communications and Central Control and Chapter 22, Fire Alarm Systems.

B. Liquid flow indicators (flow switches) shall be provided in building fire main or branch piping feeding sprinkler loops. The operation of fire pumps and the activation of pre-action deluge valves shall be monitored. Except for the maintenance facilities, the detection of water flow to a sprinkler system and the activation of deluge valves for a pre-action dry pipe system shall be annunciated to the train control center as shown in the applicable standard, directive, and project definition drawings. All sprinkler systems shall be monitored by an

approved proprietarily central supervising station in accordance with NFPA 72, Chapter 8.

C. Valves will be annunciated at the FACP, EMPs, at the FCC and OCC.

24.8.3 Motorized Valves

A. Motorized valves used for fire protection piping shall be listed for their intended use.

B. Motorized valves including the associated switches, water flow indicators on their attached piping shall be annunciated at the FACP and the EMPs located in the FCC and at OCC

24.9 PIPING

24.9.1 General

A. All pressure piping systems shall be designed to meet the requirements of the Code of Pressure Piping, American National Standards Institute (ANSI) A21, B31, and B125, in all applicable sections. All pipe fittings, flanges, valves, and accessories shall comply with the requirements of ANSI B16, in all applicable sections, for dimensional requirements. All piping systems shall be designed and arranged for neat appearance, properly sloped for drainage and venting, properly supported, guided, and anchored to provide complete flexibility, and maintaining the integrity of all systems without any damage or leaks during extremes of operating conditions.

B. Piping shall be accessible and shall not be embedded in concrete structures unless embedment is unavoidable because of architectural or structural requirements. Embedded piping shall be provided with adequate clean-outs or access points. Piping in public areas of stations shall not be exposed. All valves and accessories shall preferably be arranged in a manner so as to be accessible for operation without the use of chains or additional operating platforms. Where this is not possible, and valves are above 6 feet, they shall be chain-operated. Sleeves and escutcheons shall be provided wherever pipes pass through structures.

C. Battery room drainage piping shall be of chemically resistant material and the waste shall be neutralized prior to connection to the sanitary drainage.

D. The requirements for exterior piping beyond 5 feet of the building line are described in the utilities chapter of these criteria.

E. Corrosion control measure shall be provided in accordance with the requirements prescribed in the corrosion control/grounding chapter of these criteria.

F. Fire protection system piping must be acceptance tested (inspected) by the State of Washington or AHJ certified personnel prior to burying or covering.

24.9.2 Piping Accessories

A. All required piping accessories shall be of sufficient size and provided to assure trouble-free balancing, control, access, and operation of all piping systems.

B. These accessories shall include, but not be limited to, strainers, vent cocks, dirt and drip legs with drain and flush connection, liquid flow indicators, vacuum breakers, backwater valves, backflow preventers, pressure reducing valves, shock absorbers and water-hammer arresters, drain and drip legs for gas and compressed air systems, moisture traps for compressed air systems, balancing cocks, relief valves, isolation valves, and pressure and temperature gauges. All piping accessories requiring maintenance or replacement shall be located in accessible places.

C. All dials of gauges and indicators shall be of English or English/International System of Units (SI) units of measurement and shall be of sufficient size and arranged to be easily seen and read from operating floor levels.

D. Piping expansion joints shall be selected to provide for not less than 150 percent of the calculated traverse movements. All valves shall be tagged and charted.

24.9.3 Pipe and Fittings

A. All station track drainage and subsurface line track drainage pipes and all waste and soil pipes shall be service-weight cast-iron pipe with no hub fittings. Soil pipe from fixtures shall have a slope of 0.25 inch per foot (2 percent slope) in the direction of flow, except that soil pipe running the length of the station shall have a slope of 0.125 inch per foot (1 percent slope) in the direction of flow. Pipes three inches in diameter or less shall be installed at a slope of 0.25 inch per foot (2 percent slope).

B. Vent pipes shall be galvanized steel threaded pipe, service-weight cast iron pipe with bell and spigot fittings or hubless, properly pitched, and shall exit the structure.

C. Cold-water piping embedded in structures shall be hard-drawn copper tubing type “K”, all other hot-and cold-water piping shall be hard-drawn copper tubing type “L” with wrought brass or copper fittings. Copper tubing type “K” and “L” shall be as per American Society for Testing Materials (ASTM) B88.

D. Force mains shall be of ductile iron pipe with joints of a type approved by the local authority having jurisdiction.

E. Water service piping shall be ductile iron with dual mechanical-joint type for pipe 2 inches and above, and type “K” copper with wrought fittings for pipe sizes less than 2 inches.

F. Hose bibbs shall be provided with integral vacuum breaker. Hose bibbs in public areas shall be installed in recessed boxes, operated with keys. Hose bibbs in areas subject to freezing temperatures shall be non-freeze type. The location of hose bibbs shall be coordinated with the architectural requirements.

G. The minimum diameter of waste pipe installed underground or embedded in structural slabs shall be 4 inches.

H. Dielectric couplings shall be provided for the connection of pipes of dissimilar metals and in all metallic piping entering a facility.

24.10 INSULATION AND FREEZE PROTECTION

24.10.1 Insulation

The following piping shall be insulated:

A. Hot water piping;

B. Portions of all water piping subject to freezing temperatures, and

C. Portions of drainage and cold water piping subject to sweating.

24.10.2 Freeze Protection

Designers shall analyze the piping installation at each station and other unheated spaces for possible freezing of fire and domestic water lines during winter months. In these cases, it is recommended that a dry pipe system be installed. Drains provided at low points in water lines installed in spaces under station platforms shall be extended to trackway areas so that they are easily accessible. Each drain shall have a valved connection.

24.11 EQUIPMENT HANDLING

Provision shall be made in the form of monorail, guide rail, lifting hooks and removable panels for the installation and removal of pumping equipment. Structural openings shall be sized so that each complete factory-built item of equipment can be installed without disassembly or special construction.

24.12 VIBRATION ISOLATION

All equipment that produces vibrations shall be isolated from the structure by vibration isolators. All piping attached to rotating equipment shall be isolated from such equipment by flexible connections. Inertia blocks shall be provided as required.

24.13 ROUGHING-IN

In stations and buildings which are to be constructed in stages under separate contracts, sleeves and block-outs shall be provided in the early stage contracts to accommodate plumbing and fire protection equipment, plumbing fixtures and piping installations by later-stage contractors. The locations and sizes of the sleeves and block-outs shall be accurately dimensioned for the structural contracts to facilitate the subsequent plumbing fixtures and piping installation under later-stage contracts. Sleeves shall be 2 inches larger than proposed pipe diameter.

END CHAPTER 24

25. ELEVATORS AND ESCALATORS

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25. ELEVATORS AND ESCALATORS

25.1 INTRODUCTION

A. These criteria describe the functional and design requirements for passenger elevators, freight elevators, and escalators that will be furnished and installed under systemwide contracts.

B. These criteria are intended to familiarize the designer with the type of elevators and escalators to be provided, and to emphasize the importance of the coordinating efforts required to facilitate their installation during the execution of facilities contracts.

25.2 SCOPE

These criteria cover the elevators and escalators for aerial and subway stations, the operations control center, shops, and other similar facilities throughout the system. The criteria also cover freight elevators in the maintenance facility and shops. The design of elevators and escalators shall interface with design criteria for all related systems. Support functions shall be included in the procurement specification. These include quality assurance, manuals, maintenance program, reliability, availability, maintainability, and safety. Reference should be made to Chapter 9, Stations, for additional criteria.

25.3 CODES AND STANDARDS

A. The design of elevators and escalators shall comply with all local codes of the city and county to which they pertain, as well as with State of Washington codes and with the Americans with Disabilities Act (ADA). In addition, the design shall comply, unless otherwise prescribed, with industry standards and recommended practices.

B. The designer shall comply with the requirements of the National Fire Protection Association (NFPA) Standard 130 (latest edition), "Standard For Fixed Guideway Transit Systems" as amended by the local jurisdiction; and the latest edition and supplements of the American Society of Mechanical Engineers, (ASME) A17.1 Safety Code for Elevators and Escalators.

C. The designer shall consult the applicable codes and publications and provide the design for the interface facilities for elevators and escalators in accordance with the most stringent of codes and industry practices.

25.4 SYSTEM INTERFACE

The location of elevators and escalators shall be shown on the preliminary design drawings. The facilities design shall provide the interface required for installation and trouble-free operation of elevators, escalators and associated equipment.

25.5 VERTICAL CIRCULATION ELEMENTS

All vertical circulation elements shall take into account the requirements imposed by considerations of fire safety, patronage, material flow and personnel traffic. The requirements for stairs, walkways, and ramps are described in the architecture functional requirements of stations, shops and other facilities chapters of these criteria.

25.6 ELEVATORS

25.6.1 General

A. All passenger and freight elevators shall be fully automatic. The rated capacity of each passenger elevator shall be a minimum of 3500 pounds based on patronage. In stations where the rise between public levels exceeds 50 feet, passenger elevators shall be high speed traction type with rated capacity of 4500 pounds minimum. The rated capacity of each freight elevator shall be 8000 pounds minimum. The elevators shall be designed, as applicable, for the movement of passengers, Link personnel, equipment, and vehicle parts. They shall be sized to accommodate wheelchairs, and stretchers for emergencies. The minimum speed of passenger elevators shall be 125 feet per minute (fpm). The minimum speed of freight elevators shall be 100 fpm.

B. Elevators shall be provided between each platform and street level, or between each platform and the mezzanine and between the mezzanine and the street level. Elevators shall also serve any non-public levels required for equipment rooms and Fire Department access. Elevators at street level shall be located near a passenger vehicle loading zone. In stations with parking facilities, passenger elevators shall be located near the parking for persons with disabilities.

C. Overall cab dimensions shall be suitable for above requirements. Controls shall be of type and location to satisfy the ADA standards for persons with disabilities.

25.6.2 Transit Specific Requirements

A. Passenger elevators shall provide vertical transportation between station levels for passengers, including individuals who have disabilities and senior citizens, passengers with bicycles, and for the movement of maintenance equipment. Because passenger elevators will be used for transporting maintenance equipment, they shall be designed for anticipated loads and for durability.

B. The elevator approaches, interior cab layouts, controls, and graphics shall be identical for all passenger elevators throughout this system to the maximum extent practical. People with disabilities and senior citizens in addition to other passengers who use elevators should not have difficulty in orienting themselves in the system. Elevators shall be operable by patrons during revenue service hours, by using the cab controls or the call buttons at each landing. The Operational Control Center shall also be capable of operating all elevators. Elevators shall have the ability to cycle on their own, especially during colder months to ensure their operation.

C. Elevator cabs and hoistways shall be constructed of glass to the maximum extent that is consistent with building code requirements to enhance both actual and perceived security of the elevator and passengers.

D. The system life cycle should be taken into consideration in the selection of the equipment design, finishes, and installation to achieve improved reliability and reduced maintenance cost.

E. An analysis of operation failure data and maintenance requirements of elevators shall be performed to establish their adequacy for transit usage.

25.6.3 Cars and Entrances

A. For passenger elevators, a one-piece, chemical and stain resistant flooring with integral base shall be provided on the car platform floor. The floor shall be stainless steel, sloped to the center. The platform for freight elevators shall be designed for Class A loading and provided with top floor fabricated from checkered steel plate. The underside of platform shall be fireproofed.

B. The elevator cab shall be of a design developed especially for the Link light rail (Link) system needs and architectural requirements. The cab of a passenger elevator shall be sized to accommodate a stretcher or one occupied wheelchair or the largest unit of maintenance equipment that must be moved between the levels served. The cabs of elevators serving deep underground stations

shall be sized to accommodate two 30-inch by 72-inch stretchers without turning, plus attendants. The cab of a freight elevator shall be sized to accommodate the largest vehicle part to be moved between the levels to be served. All metal cladding, floors, railings and trim shall be stainless steel. Wall finishes shall be glass and/or stainless steel panels with a repairable non-directional finish.

C. Fluorescent light fixtures shall be furnished in the car above the ceiling and shall be recessed. The light shall be controlled by a key-operated switch in the car operating panel.

D. An emergency power unit employing a 12 volt sealed rechargeable battery and totally static circuits shall be provided which shall illuminate the elevator car and provide current to alarm bell in event of normal power failure.

E. The car entrance for passenger elevators shall be provided with horizontal sliding doors, hung on sheave hangers with tires running on a track and guided at the bottom by nonmetallic shoes sliding in threshold grove. The car entrance for freight elevators shall be provided with either horizontal or vertical up-side type doors that maximize the opening. Hoistway doors shall be installed at each landing. Car and hoistway doors shall be operated simultaneously. Door movements shall be electrically controlled and cushioned at both limits of travel, and the door operating mechanism shall be arranged for manual operation in event of power failure. Doors should be equipped with vision panels to maximum practical extent. At deep tunnel stations, vision panels shall include a reflective interlayer that limits shaft visibility during the ride. Doors should have photo sensors (rather than retractable edges) to detect obstructions when closing. This type of system requires no contact before adjusting, as does the retractable edge type. Doors shall automatically open as the car arrives at landing and shall automatically close after an adjustable interval or when the car is dispatched to another landing.

25.6.4 Signal Equipment

A. An emergency alarm bell shall be provided in conformance to the requirements of ASME A17.1 and shall be connected to a plainly marked pushbutton in the car operating panel.

B. A "Door Open" bell shall be provided on the car. It shall be connected to the direction buttons in the car and landing pushbutton stations. The bell shall ring when any button is pressed if any door is open.

C. Each landing station shall contain "In Use" signal lights to indicate that the car is in motion and that it cannot be called until it has completed the registered call, at which time the signal light will be extinguished

and the car will be available to answer the next call registered. Car and landing shall be equipped with illuminated pushbuttons.

25.6.5 Communication Equipment

Pushbutton-activated passenger emergency telephone (PET) shall be provided in each elevator cab for use by the public and employees. The phone equipment shall be fully recessed in cab panels and located to provide communication capability between the Operations Control Center (OCC) and the elevator cab. The PET system shall become active with momentary pressure on the pushbutton. An emergency telephone (ETEL) for use by emergency response personnel shall also be provided in a cabinet accessed by a keyed door in the car wall. For specific guidance, refer to the Communications and Control Center, Chapter 15 of these criteria.

25.6.6 Failure Protection

The electrical control circuit shall be designed so that if a malfunction should occur due to motor starter failure, low oil volume or loss of pressure in the system, or the car failing to reach a landing in the up direction within a pre-determined time, the elevator car will automatically descend to the lowest terminal landing. The doors will automatically open when the car reaches that landing to allow passengers to depart. The doors will then automatically close and control buttons, except the "door open" button in the car station, shall be made inoperative. A car top inspection station with an "Emergency Stop" switch and with constant pressure "up-down" direction buttons shall make the normal operating devices inoperative and give the inspector complete control of the elevator.

25.6.7 Standby Power

A. In stations where standby power is required by IBC, section 3003.1, to operate elevators, power shall be provided to allow elevators to run at full speed and capacity and to operate car lighting and exhaust fan, emergency call button, intercom amplifier, hoist machine cooling fan, and machine room ventilation.

B. Standby power shall be provided to all elevator cars to operate the car alarm bell and the emergency light fixture.

25.6.8 Operation

A. Operation shall be "selective-collective" automatic pushbutton without attendant.

1. The elevator shall be controlled automatically by means of pushbuttons in the car numbered to correspond to the public

levels served, for registering car stops and by "Call" pushbuttons at landings. Each hoistway landing door shall have an ‘up’ and/or ‘down’ call button as appropriate. These push buttons are active continuously during revenue service hours and on demand by contacting the OCC during non- service hours.

2. An adjustable time delay, non-interference feature shall be incorporated in the control circuit to allow ample time for opening the car and hoistway doors before the car can be dispatched to another landing.

3. An emergency stop switch shall be provided in the car pushbutton station which when in the off position, will render the elevator inoperative, and which will enable the passenger to stop the car at any point during its travel.

4. Each passenger elevator car shall have a control panel in a locked cabinet in the car wall, with a key switch for operator control, and a key switch for fire department use. A duplicate set of controls shall be provided in the Fire Command Center and Central Control Facility.

B. Electric limit switches shall be placed in the hatchway near the terminal landings and be designed to cut off electric current, stop the car, and sound an alarm should it run beyond either terminal landing.

C. The elevator shall be provided with a self-leveling feature that will automatically bring the car to the floor landings. Car doors shall not open until the car is level with the landing. Within its zone the self-leveling shall be entirely automatic and independent of the operation device and shall correct for overtravel or undertravel. The car shall be maintained approximately level with the landing irrespective of the load.

D. Each hoistway entrance shall be equipped with an interlock. The interlock shall be designed to prevent operation of the car away from the landing until the doors are locked in the closed position and shall prevent opening the door from any landing on the corridor side unless the car is at rest at that landing. Unlocking devices shall be provided to permit authorized persons to gain access to the hoistway.

25.6.9 Cab Ventilation

Cab ventilation shall be supplied by a single-speed exhaust blower located above the plenum and mounted to the car top. The ceiling grille shall match finished ceiling surface.

25.6.10 Noise Levels

Elevators and associated equipment shall not produce steady-state and transient noise levels in excess of the noise levels prescribed for elevators in Chapter 3, Environmental.

25.6.11 Machine Rooms, System Elements, and Elevator Pits

A. Hydraulic elevator machine rooms shall be located as near as possible to hoistways, but clear of public walking and landing areas. Hydraulic lines shall be straight runs between the elevator and machine room. Traction elevator machine rooms shall be located above the hoistway, unless physical constraints or zoning height limits dictate alternate solutions. Adequate space shall be provided in machine rooms for installation and maintenance procedures as recommended by the manufacturer, including convenience outlets, lighting, and ventilation.

B. System elements shall include guide rails, speed governors, safety brakes, hydraulic lifts, pipes and pumps, cabs, and landing doors, all as appropriate to the particular design selected.

C. Elevator pits shall be lined with a non-porous material to contain fluid leaks and shall have a sump pump if gravity drains are not feasible.

25.6.12 Reliability and Maintainability

A. Elevator reliability is a major priority during the design of the Link facilities. Elevators shall be installed to make the system or facility fully accessible to the elderly and handicapped patrons requiring special access provisions, as well as other patrons or employees during the course of their duties.

   Elevator reliability requirements shall be established considering that only single elevator installations shall be provided in many of the system facilities and stations.

B. Elevator effectiveness will be obtained more economically through the application of maintainability design features (reduction in equipment repair time) than through reliability improvements (increases in the equipment mean time between failures).

C. Elevator availability shall be enhanced by a well planned and implemented maintenance program, which also results in a reduction of Mean Restoration Time (MRT).

D. Considerations in maintenance predictions shall include five different maintenance functions. The first two consist of scheduled services and the last two of unscheduled services.

1. Examination hours
2. Repair hours
3. Lead time required for supply of replacement parts
4. Call backs, regular time
5. Call backs, overtime

E. Examination hours shall be used to lubricate, adjust, and clean the equipment and its components during nonrevenue service.

F. Repair hours shall consist of time spent in replacing worn or damaged parts.

G. Emergency and call-back service on a 24 hour-a-day basis shall be provided and shall consist of time spent returning the equipment to service following service interruptions caused by activation of safety circuits or overload protection.

25.6.13 Fire Protection for Elevators

The elevators shall meet state and local requirements for automatic sprinkler systems in elevator machine rooms, hoistways and pits.

25.7 ESCALATORS

25.7.1 General

Escalators shall be of a type designed for use in public transportation terminals suitable for indoor or outdoor installations, as applicable. The escalator design shall be of such finishes, materials, and components as to deter and resist vandalism. The escalators shall conform to the following:

A. The width of each escalator shall be a nominal 48 inches, measured at a point between the balustrade, 27 inches above the nose line of the step treads.

B. Escalators' speed shall be 100 FPM, and shall be fully reversible; as well as capable of operating under full load as defined by ASME Code A17.1 in either an up or down direction.

C. Escalator maintenance access shall be from above except where the station design allows for direct access from a room below the escalator landing.

25.7.2 Transit Specific Requirements

A. Escalators in transit use operate under conditions substantially more severe than in commercial establishments, handling thousands of patrons on a daily basis, and generally in large groups. Therefore, great care must be exercised to ensure that all elements are rugged enough to meet the usage demands, with a minimum of maintenance.

B. The system life cycle shall be considered in the selection of the equipment design, finishes, and installation for reduced maintenance cost.

25.7.3 Escalator Classification

A. Escalators to be furnished shall have three classifications: A, B, and C, which are applied to the wellway structure design.

B. The classes of escalators are based on the following ranges of rise:

Class A: 0-20 feet
Class B: 20-35 feet
Class C: Over 35 feet

C. All escalators shall have at both upper and lower landings three level treads exposed to form a horizontal platform at fade-out. In addition, all escalators shall have the drive machine and controller located within the escalator truss.

25.7.4 Overall Design Requirements

A. All escalators shall consist of a truss assembly, step-drive units, steps and step chains, driving machine and controller, safety devices, comb and deck plates, handrails and deck trim, newels and balustrades, balustrade lights, and other accessories and appurtenances. The sides and underside of the truss, exterior of the escalator, and machinery spaces shall be enclosed in stainless steel, where exposed to public areas.

B. Escalator safety devices shall, as required by code, include a safety brake activated if the step chains break or the step-chain tension drops below a predetermined level; a power supply cutoff to stop the escalator if it overspeeds by some fixed percentage provision for automatic stopping if the direction of travel is accidentally reversed; provision for automatic stopping if the treads are separated from the comb plate or the interior skirt panels by a predetermined amount; emergency stop buttons at upper and lower landings; and a status monitoring control panel also located in the Operational Control Center.

25.7.5 Drip Pans

Oil-tight drip pans shall be provided in the truss for the entire length of the truss and machinery space. The machinery space and truss pans shall be of sufficient strength to support the weight of two service personnel. The drip pans shall be designed to provide access to the wellway surface under the drip pan.

25.7.6 Step Assembly

A. The step frame and unit step shall be braced to carry the step treads and the maximum rated load per step under eccentric loading conditions without distortion. In addition, step assemblies and unit steps shall be designed for easy replacement.

B. Step treads shall be designed to mesh with the comb plates.

C. Step risers shall form an interlocking unit with the step tread of the adjacent step to minimize seizure of articles between the riser of one step and the tread of the following step.

D. Safety risers shall form an interlocking unit with the step tread of the adjacent step to minimize seizure of articles between the riser of one step and the tread of the following step.

E. Safety demarcation lines or strips shall be provided in step treads to assist demarcation between treads when they are level at top and bottom landings.

25.7.7 Comb Plate Assembly

A. Comb plate assemblies shall have an anti-slip surface. The comb shall have closely spaced teeth arranged so that the step tread cleats pass between the teeth with minimum clearance.

B. Comb teeth shall be made in sections so that any damaged or worn sections can be readily replaced without disturbing the main comb plates. The comb teeth shall have a continuation of the comb plate non-slip surface.

C. Step demarcation lights shall be provided at both the lower and upper ends of each escalator immediately outbound of the comb plate.

25.7.8 Landings

The landing plates shall have an anti-slip surface at the upper and lower landings to cover the entire areas within the outline of the truss. Removable sections of the landing plate shall be provided at the upper and lower ends for maintenance access.

25.7.9 Handrails

A. A handrail drive shall be provided with a self-adjusting handrail tension device to take up the stretch. The handrail drive mechanism shall provide motion to the handrails to obtain the same rate of speed and direction of travel as the escalator steps.

B. The handrail shall run on guides to allow easy movement of the handrail. The guides shall be shaped to prevent the handrail from being thrown off the guides.

C. The handrail shall be constructed to form a smooth, endless loop. It shall have white inserts molded into it as non-separating integral part. At least one insert shall be visible at all times as the handrail turns around the newel extensions.

25.7.10 Brakes and Sequence of Operation

A. All brakes shall be failsafe and applied and released in accordance with ASME Standard A17.1. Deceleration and stopping shall be smooth and without shock. The brakes shall be adjustable for stopping at various speeds.

B. Each escalator shall have an electrically released, mechanically applied emergency brake capable of stopping the up or down traveling escalator with any load up to rated load upon activation of any normal stop control, "EMERGENCY STOP" button, or safety device, or upon loss of power.

C. The activation of any safety device or "EMERGENCY STOP" button, or the loss of electric power, shall operate the emergency brake. The emergency brake shall be electrically interlocked with the motor circuits. If the escalator is stopped for any reason, a key switch shall be capable of starting the escalator after the safety device has been reset.

25.7.11 Operating Devices

Each escalator shall have operating switches with the respective controls on a control panel located at upper and lower landings in the level portion of the balustrade deck cover outside the handrails.

25.7.12 Emergency Stop Button

The emergency stop button shall be a red, momentary-contact, manually operated pushbutton. The pushbutton shall be protected against accidental operation with a transparent cover that can be easily lifted. The button shall be located opposite the control panel adjacent to the handrail return at the upper and lower landings. The cover for the button

shall be marked "EMERGENCY STOP". The cover shall be provided with a switch to initiate an audible alarm when the cover is lifted. When pressed, the 'EMERGENCY STOP" button shall stop the escalator. The alarm shall stop automatically when the cover is released and returned to the closed position.

25.7.13 Safety Devices

The safety devices specified in the latest edition of ASME A17.1 and supplements shall be provided, including the following:

A. ***Speed Governor:*** A speed governor shall be provided to cause the interruption of power to the driving machine if the speed of the steps exceeds more than 40 percent above the rated speed.

B. ***Broken Step-Chain or Step-Link Device:*** A broken step-chain or step-link device shall be provided, to cause the interruption of power to the drive machine if a step-chain or step-link breaks.

C. ***Broken Drive-Chain Device:*** When the driving machine is connected to the main drive shaft by a chain, a device shall be provided to cause the application of the brake on the main drive shaft if the drive chain breaks.

D. ***Skirt Obstruction Device:*** A device shall be provided to open the power circuit to the escalator driving machine motor and brake should an object become wedged between the step and the skirt panel as the step approaches either the upper or lower landing.

E. ***Reversal Stop Device:*** A device shall be provided to open the power circuit to the driving machine motor and operate the brake in case of accidental direction reversal while the escalator is operating in the ascending direction.

F. ***Slide Prevention Device:*** Surface projections shall be provided on the surface of the outer decks between escalators or adjacent walls to discourage patrons from sliding down the channels.

25.7.14 Noise Levels

Escalators and associated equipment shall not produce noise levels in either free-running or under full load conditions in excess of the noise levels prescribed for escalators in Chapter 3, Environmental.

25.7.15 Reliability and Maintenance

A. Reliability is a key element in escalator operation because of its impact on passenger flow.

Projected usage for the escalators is 140 hours per week, which is substantially higher than usage factors for commercial installations. This could result in decreased reliability unless specific reliability requirements are established. Therefore, state-of-the-art MTBF and MTTR shall be investigated to establish a realistic reliability goal to be included as part of the procurement documents.

B. Considerations in maintenance predictions shall include four different maintenance functions as listed below. The first two consist of scheduled services and the last two of unscheduled services.

1. Examination hours
2. Repair hours
3. Lead time for supply of replacement parts
4. Call back, regular time
5. Call back, overtime

C. Examination hours shall be used to lubricate, adjust, and clean the equipment and its components during nonrevenue service.

D. Repair hours shall consist of time spend in replacing worn or damaged parts. Components such as handrails, drive chains, and step chains shall be replaced periodically or when they wear out.

E. Emergency and call-back service on a 24 hour-a-day basis shall be provided and shall consist of time spent returning the equipment to service following service interruptions caused by activation of safety circuits or overload protection.

25.8 ROUGHING-IN

In buildings and stations which are to be constructed in stages under separate contracts, block-outs for equipment, and sleeves for hydraulic, fire protection and drainage piping, and conduit shall be provided in the early stage structures to accommodate equipment and piping installations by later stage contractors. The locations and sizes of the sleeves and block-outs shall be accurately dimensioned under structural contracts to facilitate the subsequent equipment, piping and conduit installation under later-stage contracts.

END CHAPTER 25

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26. SYSTEMS ASSURANCE

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26. SYSTEMS ASSURANCE

26.1 INTRODUCTION

This chapter establishes the design criteria for the Sound Transit Link light rail Transit System maintainability, reliability, quality assurance, and human engineering. The purpose of this document is outlined as follows:

A. To provide sufficient definition and description of systems assurance characteristics to allow design engineers to select appropriate features and facilities. This document is designed to outline those standards and guidelines that, if followed, will ensure that the Sound Transit Link System achieves the optimal level of system dependability.

B. To define the system assurance requirements that shall be included as part of the technical provisions in contract specification documents.

26.2 RELIABILITY

The reliability achieved by the Sound Transit Link System is directly dependent on the reliability requirements imposed on the system contractors, the emphasis placed on reliability management, and execution of those requirements. It is intended that the reliability performance criteria established in this chapter will ensure procurement of reliable equipment capable of meeting the system operational requirements.

26.2.1 Reliability Program

Sound Transit shall establish and maintain an effective reliability program. The program shall be planned, integrated, and developed in conjunction with other design, development, and production functions to permit the achievement of the project goals and objectives. A Reliability Plan is required to ensure that the management and technical skills necessary to achieve Sound Transit Link reliability objectives are applied in a coherent and organized manner.

A. Reliability Plan includes:

1. A detailed listing and description of each task
2. The timing of each task and related milestones
3. The organizational element responsible for each task
4. Identification of reliability problems requiring resolution

5. Procedures for recording reliability problem resolution

B. Reliability Plan - Contractors

Manufacturers of the following system equipment shall be required to establish, submit for approval, and maintain a Reliability Plan:

1. Light Rail Vehicles
2. Train Signaling
3. Communications and Controls
4. Fare Collection Equipment
5. Environmental Control Systems
6. Traction Electrification
7. Elevators
8. Escalators

26.2.2 Quantitative Design Requirements

A. An essential prerequisite to the achievement and control of reliability in hardware systems and equipment is the quantitative definition of these parameters as design requirements. Contractor compliance with quantitative requirements is necessary to ensure procurement of reliable equipment capable of meeting the performance criteria and operational objectives of the rapid transit system. Excessive maintenance costs and operating delays could be experienced by the Sound Transit Link System if adequate reliability controls are not imposed on system contractors and rigorously enforced. The reliability requirements shall ensure that all contractors:

1. Design the system optimally
2. Use reliable hardware in critical areas
3. Effectively integrate systems and subsystems
4. Minimize the life cycle cost of the product

B. Reliability Requirements for System Equipment

During the Final Design Engineering phase of project development, quantitative reliability requirements for system equipment shall be established. These numerical requirements shall be included in the

appropriate equipment procurement documents. All contractors shall be required to demonstrate the satisfactory achievement of the requirements.

C. Reliability Requirements Report

During Final Engineering, a study to determine the numerical values for the reliability of system components shall be conducted. The requirements shall be published in a report which includes, at a minimum:

1. Reliability allocations for all major system equipment and critical equipment components

2. Model definitions and equations

3. Goals for availability, dependability, and reliability consistent with the Sound Transit Link System Operating Criteria

4. Basis for the goals and numerical requirements

5. The requirements shall be defined in terms of Mean Time Between Failures (MTBF), Mean Time Between Service Failures (MTBSF), Mean Cycles Between Failures (MCBF), Mean Time To Repair (MTTR), and failure rates (λ)

D. Failure Modes, Effects, and Criticality Analyses (FMECA)

Contractors for the following systems shall be required to prepare and submit for approval a FMECA to identify all critical single point failure modes. The FMECA shall be conducted to the lowest replaceable module:

1. Light Rail Vehicles

2. Train Signaling

3. Communications and Controls

4. Traction Electrification

5. Fare Collection Equipment

6. Environmental Control

E. Reliability Analyses

Contractors for the Vehicle, Signaling, Communications and Control, Environmental Control and Fare Collection systems shall be required

to prepare and submit for approval a Reliability Analysis which shall include, as a minimum:

1. System definitions and related assumptions
2. Functional flow and reliability block diagrams
3. Description of data base and any adjustment factors
4. System and subsystem failure assumptions and predicted MTBF, MTBSF, MCBF, etc., as appropriate
5. Comparison of reliability predictions with allocations in the Reliability Requirements Report
6. Impact of operating or design changes on predicted values
7. Definitions of all interfaces, such that every part is identified as being part of a particular subsystem

F. Reliability Demonstration Testing

Contract documents shall require the achievement and demonstration of reliability requirements both by analysis and demonstration testing. The contractors for Vehicle, Signaling, Communications and Control, Traction Electrification, Environmental Control and Fare Collection systems shall be required to develop and gain approval of Reliability Demonstration Test Plans. The Reliability Test Plan shall include:

1. Criteria to be used for evaluating the equipment under test
2. The failure reporting procedures to be used by the contractor
3. The mathematical verification that the test shall demonstrate the required MTBF, MTBSF, MCBF, MTTR and failure rates specified in contract documents

26.2.3 Warranties

A. The reliable operations of subsystems are critical if the Sound Transit Link System is to meet its operational objectives. Reliability problems with propulsion systems components in the vehicles and with fare collection equipment can be particularly troublesome and result in a deterioration of system availability.

B. Contractors shall be legally bound to ensure that contract reliability requirements are achieved.

C. Failure Rate Warranties

In addition to the time warranties included for specified time periods after acceptance or delivery, additional warranty requirements relating to the maximum failure rates on particular components may be imposed on the following contractors:

1. Light Rail Vehicles
2. Fare Collection Equipment
3. Train Signaling
4. Communications and Controls
5. Traction Electrification
6. Environmental Control

26.2.4 Reliability Data

A. Project management shall enforce the reliability requirements incorporated into contract documents. The contractor shall be required to demonstrate the achievement or prove the failure of those requirements and track system reliability during testing and revenue service.

B. Reliability Data Collection and Reporting System

The operating authority shall develop a computerized reliability data collection and reporting system capable of tracking compliance with contractual reliability requirements. The data collection formats shall meet the needs of both contractors and the operating authority. Contractors shall be required to use the format designed for reporting failures. The data system shall be integrated to the extent possible with other system assurance data collection and reporting efforts, such as maintenance and warranty enforcement.

26.2.5 System Design Life and Environment

The components and materials selected for the Sound Transit Link System shall be of a quality and design to perform over the life of the system in the U.S. Northwest environment.

A. System Life

The system elements described below shall be suitable for a lifetime of use in the U.S. Northwest environment, with normal maintenance and overhaul for the following number of years:

Vehicle Body	30 years
Signaling	25 years
Fare Collection	25 years
Tunnels	100 years
Trackwork	30 years

B. System Environment

The system elements shall be capable of being operated, stored, and maintained at specified performance levels without impairment resulting from the impact of the following environmental parameters throughout the indicated range of values:

Air Temperature	Extreme Minimum -10 ^{o}F Extreme Maximum 110 ^{o}F Average Minimum 44.1^{o}F Average Maximum 59.3 ^{o}F
Relative Humidity 24-hour range	15% to 60%
Extreme Rainfall in 24 hours	Maximum recorded 3.4”
Average Rainfall in 24 hours	0.5”

Wind Speed	Average 25mph Maximum 50mph
Air Pollution	
Dust Particles: Size Concentration	 Microns(Maximum)(Average) 36 Daily Max. 12.1 Annual
Acid Precipitation	Average Ph of Puget Sound Region
Gases and Fumes:	
Types	Maximum Concentrations
Carbon monoxide (CO)	ppm 97% of EPA Max.
Sulfur Oxide (SO,)	ppm 30% of EPA Max.
Ozone (O2)	ppm 85% of EPA Max.
Carbon /Dioxide (CO_2)	ppm 90% of EPA Max.

26.3 MAINTAINABILITY

A. In the process of optimizing the design of the transit system, maintainability is a major factor which affects the overall system life cycle cost. Lack of emphasis on maintainability design can result in extensive maintenance costs in future years. The degree of maintainability achieved by the Sound Transit Link System is directly dependent on requirements imposed on system contractors and the level of management emphasis on maintainability during the design phase of the system.

B. The primary objectives of the maintainability criteria are to enhance the transit system's availability, and minimize maintenance, labor, and material costs,

vehicle downtime, and the need for specialized or highly skilled maintenance repair persons.

26.3.1 Maintainability Program

Project management shall establish and maintain an effective maintainability program. It shall be planned, integrated, and developed in conjunction with other design, development, and production functions to permit the achievement of the project goals and objectives.

A. Maintainability Plan

The Maintainability Plan shall include:

1. A detailed listing and description of each task
2. The timing of each task and related milestones
3. The organizational element responsible for each task
4. Identification of maintainability problems requiring resolution
5. Procedures for recording maintainability problem resolution

The Plan shall be modeled after MIL-HDBK-470, Maintainability Program Requirements for System and Equipment.

B. Maintainability Plan - Contractors

Manufacturers of the following system equipment shall be required to establish, submit for approval, and maintain a Maintainability Plan:

1. Light Rail Vehicles
2. Train Signaling
3. Communications and Controls
4. Fare Collection Equipment
5. Traction Electrification
6. Elevators
7. Escalators
8. Environmental Control System

26.3.2 Quantitative and Qualitative Design Requirements

Quantitative and qualitative maintainability requirements shall be established. These requirements shall be incorporated into the appropriate contract documents. Maintainability analyses shall be used during the design, production, and testing of the equipment to evaluate the degree of achievement of maintainability design requirements.

A. Maintenance Concepts

A detailed Maintenance Concept shall be developed and submitted for approval by the contractors. The maintenance concept shall include a description of how the contractor intends to achieve the maintenance requirements identified the contract documents. The maintenance concept shall cover the following, as a minimum:

1. Maintenance Levels
    - a. System repairs done on operating authority property
    - b. Module and component repairs done on operating authority property
    - c. Module and component repairs done at contractor's facilities
2. Maintenance Tasks
    - a. Scheduled Maintenance
        - 1) Preventive Maintenance
        - 2) Service Maintenance
    - b. Corrective Maintenance
3. Shop Facilities
    - a. Central shop maintenance activities
    - b. Satellite shop maintenance activities
    - c. Component Repair Facilities
4. Shop Equipment and Tools
    - a. Furnished by Vehicle/Signaling/Communications and Control/Fare Collection/Environmental Control Contractor

b. Furnished by Shop Equipment Contractor

5. Spare Part Requirements

a. Expected Part Life

b. Consumables and Repairables

6. Skill Levels and Mechanics Requirements

B. Maintenance Analysis

A Maintenance Analysis shall be developed and submitted by the Vehicle, Signaling, Communications and Control, Traction Electrification, Environmental Control and Fare Collection contractors. The Maintenance Analysis shall describe all the maintenance tasks operating authority personnel may be required to perform on the system. The analysis shall include for each maintenance task, as a minimum:

1. Frequency of task

2. Time to perform

3. Test equipment, tools, and facilities required

4. Crew size and skill level

5. Manuals and instructions needed

26.3.3 Maintainability Data

Project management shall enforce the maintainability requirements incorporated into contract documents. The operating authority shall demonstrate achievement of maintainability requirements and track maintenance costs during testing and revenue service.

A. Maintenance Data Collection and Reporting System

The operating authority shall develop a computerized Maintenance Data Collection and Reporting System capable of collecting and reporting maintenance statistics. The data collection formats will meet the needs of both contractors and the Sound Transit Link Maintenance Department. The data system shall be integrated to the extent possible with other system assurance data collection and reporting efforts, such as reliability and warranty enforcement.

26.3.4 Manuals

Maintenance department employees shall have detailed instructions that cover the servicing and repair of all Sound Transit Link system components.

A. Maintenance Manuals

All suppliers and contractors shall be required to submit for approval maintenance manuals which contain all the information needed to service, maintain, repair, inspect, adjust, troubleshoot, replace, and overhaul each component or subsystem. Requirements for the maintenance manuals shall include, but not be limited to:

1. Running Maintenance and Servicing Manuals
2. Heavy Repair Maintenance Manuals
3. Parts Catalogs
4. Test Equipment Maintenance Manuals

B. Manual Format and Size

The manuals shall be designed for continuous, long-term service in a maintenance shop environment. All manuals shall be in both pocket size (3-1/2 inches by 8 inches by less than 1 inch thick) and standard size (8-1/2 inches wide by 11 inches high). All manuals shall be prepared in accordance with normal commercial standards, using MIL-M-38784 and MIL-STD-24784 as guides for format and technical content, respectively.

26.3.5 Training

Maintenance personnel shall undergo a comprehensive training program for maintaining all system elements. The training shall be sufficient for and compatible with system start up requirements. The training shall provide a level of education and ability to ensure the competent maintenance of the transit system and associated equipment.

A. Training of Maintenance Personnel

Contractors shall be required to provide a comprehensive training program for maintenance personnel. Contractors shall provide course materials, instructors, training aids, equipment, and all literature required. The contractor shall train all maintenance personnel to a level of competence such that work performed by these personnel will not void any of the warranties or guarantees in effect.

26.3.6 Human Factors Considerations

To efficiently service and repair system equipment, maintenance personnel must be able to accomplish maintenance tasks in minimum time with minimal effort.

A. General Maintainability

Contractors shall incorporate qualitative features into all equipment whenever feasible. MIL-STD-1472F shall be used as a guide, along with the design features in the "Maintainability Checklist" provided in paragraph 15.3.6 of UMTA Report No. IT-06-0027-A "Guideline Specification for Urban Rail Cars".

26.4 QUALITY ASSURANCE

A. The quality of the equipment procured and installed, and the facilities constructed for the Sound Transit Link Project is highly dependent on the quality assurance programs imposed on contractors/suppliers and the emphasis placed on enforcing those quality requirements by management.

B. Inadequate definition and control of the contractors'/suppliers' quality programs will increase the chances that the Sound Transit Link System will end up with unreliable components, requiring excessive system downtime and maintenance costs.

26.4.1 Quality Assurance Program

Project management shall establish and maintain an effective quality assurance program. An effective and economical quality program, planned and developed in consonance with reliability, maintainability, and configuration management programs will permit the realization of Sound Transit Link Project goals and objectives.

A. Quality Assurance Program Plan

A Quality Assurance Program Plan shall be developed and identify the organizational elements and the key personnel responsible for managing the overall quality assurance program. The plan shall also clearly define the related responsibilities for accomplishment of specific quality assurance tasks.

The Quality Assurance Program Plan shall include:

1. A detailed listing and description of each task

2. The timing of each task and related milestones

3. The organizational element responsible for each task

4. Identification of quality assurance problems requiring resolution

5. Procedures for recording of quality assurance problem resolution

B. The Quality Assurance Program Plan shall be consistent with MIL-Q9858A, Quality Program Requirements and the Federal Transit Administration Guidelines, FTA-IT-90-5001-02.1. A Quality Assurance Manual shall be developed to provide the detailed procedures necessary for the establishment and implementation of the control features required.

C. Quality Assurance Plan - Contractors

Manufacturers of the following project elements shall be required to establish and maintain a Quality Assurance Plan:

1. O&M Facilities

2. Light Rail Vehicle

3. Train Signaling

4. Fare Collection Equipment

5. Communications and Controls

6. Escalators

7. Elevators

8. Uninterruptible Power Supply

9. Trackwork

10. Traction Electrification

11. Environmental Control System

26.4.2 Warranties

Equipment and facilities shall be designed to minimize life cycle cost and ensure that the costs of defective or improper building or manufacture are imposed on the contractor.

A. Warranty Requirements

Warranty provisions shall be included in all contracts, both civil and system, to assure that the costs of replacing and repairing defective

materials and components are clearly the responsibility of the contractor. In addition to general warranties which cover a time period from acceptance or delivery of a facility or piece of equipment, additional time warranties shall be included in the light rail vehicle contract:

1. Carbody
2. Truck structural elements
3. Traction motors, except brushes

26.4.3 Quality Program Content

An effective quality assurance program is required of each contractor to ensure adequate quality of all system elements and components throughout design, development, manufacture or construction, assembly, inspection, test, delivery, and installation.

A. Receiving Inspection

Contractors shall provide for the inspection of all incoming material; Statistical sampling as defined herein is acceptable. All bills of laden, material certifications, and test reports used as the basis for acceptance by the contractors shall be maintained as Quality Records.

B. Statistical Sampling Plans

Statistical sampling used in inspection shall be fully documented and based on generally recognized and accepted statistical quality assurance practices, such as those defined in MIL-STD1916 or ASQ Z1.9.

C. Changes to Drawings and Specifications

Contractors shall ensure that all inspection and acceptance tests are based on the latest revision or change to drawings and specifications. An acceptable control system shall be established and maintained by each contractor. The contractor's responsibility for control of changes to drawings and documentation shall extend to suppliers for the contract.

D. Identification of Inspection Status

Contractors shall maintain a system for identifying the progressive inspection status of components or materials as to their acceptance, rejection, or non-inspection.

E. Shipping Inspection

Each contractor's Quality Assurance Program shall provide for the proper inspection of products to ensure completion of manufacturing and conformance.

F. Quality Assurance Organization

The organization of each contractor's Quality Assurance Program shall be well defined. Quality assurance personnel shall have sufficient, well-defined responsibilities and organizational freedom which encourage the identification and evaluation of quality problems. Contractor's selected to build Sound Transit Link equipment and/or facilities shall have a Quality Assurance Program that can initiate, recommend and provide solutions, verify the implementation of the solutions, and control further processing, manufacture, delivery, and installation until proper disposition and compliance with contract requirements has been obtained.

G. Qualification of Personnel

Contractor personnel, consultants, and subcontractors performing inspections, tests, or special processes shall be qualified for such work based on prior experience and training. Records of personnel qualifications shall be maintained and available for Sound Transit Link project management review.

H. In-Process Inspection

The contractor's Quality Assurance Program shall ensure that all machining, wiring, batching, shaping, and all basic production operations of any type, together with all processing and fabricating of any type, shall be accomplished under controlled conditions. Controlled conditions shall include documented work instruction, inspection and test requirements, adequate production equipment, and any special working environment.

I. Handling, Storage and Delivery

The contractor's Quality Assurance Program shall provide for adequate work and inspection instructions for handling, storing, preserving, packing, marking, and shipping to protect the quality of products and to prevent damage, loss, deterioration, degradation, or substitution thereof.

J. Corrective Action

Contractors shall establish, maintain, and document procedures to ensure that conditions adverse to quality, such as failures, malfunctions, deficiencies, deviations, and defects in material and equipment, are promptly identified and corrected.

K. Nonconforming Material

Contractors shall establish and maintain an effective and positive system for controlling nonconforming material including procedures for identification, segregation, and disposition. A Material Review Board consisting of appropriate Sound Transit Link project management, contractor, Quality Assurance, and design personnel shall be established to disposition nonconforming material for repair or to use-as-is.

L. Quality Audits and Surveillances

A formal comprehensive system of planned and periodic audits and impromptu surveillance shall be carried out by the Sound Transit Link quality management to verify designer and contractor compliance with all aspects of the Quality Assurance Program. The audits shall be performed at predetermined periods and by qualified quality assurance managers, quality assurance specialists and quality assurance consultants. The quality surveillances shall be performed based on current design and construction activities, as well as, known and suspected problem areas. Audit and surveillances results shall be documented and reviewed by responsible contractor and project management personnel.

26.5 HUMAN ENGINEERING

A. Sound Transit Link operating systems equipment and facilities shall be designed to provide work environments which foster effective procedures, work patterns, and personnel safety and health, and which minimize discomfort, distraction and any other factors which degrade human performance or increase error. Design shall also be directed toward minimizing personnel and training requirements within the limits of time, cost, and performance tradeoffs.

B. Special emphasis shall be placed on solving the problems of the elderly, disabled, and non-English speaking Sound Transit Link riders.

26.5.1 Human Factors Program

Project management shall establish and maintain a human factors program which will permit the attainment of project goals and objectives.

A. Human Factors Program Plan

A Human Factors Program Plan shall be developed and describe the method for assuring analysis of critical human factors including:

1. Equipment design
2. Passenger acceptance
3. Maintainability
4. Operator controls
5. Operational safety

The Program Plan shall reference MIL-STD-1472C, Human Engineering Design Criteria.

B. Human Factors Program Plan - Contractors

The passenger vehicle contractor shall be required to establish, submit for approval, and maintain a Human Factors Program Plan. The plan shall describe the major tasks the contractor will perform during the program, along with a schedule for each.

C. Human Factors Report

A report shall be submitted for approval by the vehicle contractor prior to the Preliminary Design Review (PDR) summarizing the human engineering effort for the entire program. The report shall include the following:

1. Reasons a particular alternative was chosen or recommended;
2. A description of the major assumptions and limitations, including data ensuring that operator performance and passenger acceptance have been considered;
3. The results of any approved mock-up or simulation program to determine the requirements for layout and design; and

4. The results to date of any analysis performed to determine the requirements for development of specialized training and training equipment.

D. Barrier Free Design

Designers shall make specific provisions for the reduction and possible elimination of operating barriers in all Sound Transit Link elements (passenger stations, vehicles, platforms, fare barriers, operating and maintenance facilities) which impede the mobility of elderly and disabled handicapped patrons and system employees. References and specific requirements pertaining to accessibility by the elderly and handicapped are contained in Elderly & Handicapped/Americans with Disabilities Act Design Criteria & Standards.

26.5.2 Elderly and Handicapped Accessibility

Contractor shall ensure compliance with the regulations pertaining to barrier free design as contained in the International Building Code, Seattle Municipal Code, and/or City of SeaTac Municipal Code.

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27 ST*art*, SOUND TRANSIT ART PROGRAM

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27. ST*ART*, SOUND TRANSIT ART PROGRAM

27.1 INTRODUCTION

It has long been recognized that the sensitive use of art and design in transit systems gives vibrancy to public spaces and presents an image of the local culture and architectural heritage. But more recently, the power of art as a tool in establishing relationships with the community has been recognized. The artistic processes and review procedures of public art give citizens an avenue for participation in the project process. By becoming invested in a project, the community works toward implementing rather than opposing it. Through this process, the community also develops a sense of ownership and pride that can carry over beyond design and construction, and make them partners in maintaining the facility. Just as Sound Transit is building a regional transit system to link the communities of this region, it has structured a public art program that enhances these linkages.

27.2 COLLABORATION

Collaboration is the primary method Sound Transit will use when working on the system. Sound Transit defines collaboration as the willingness of different types of people to share their perspectives to identify and solve engineering, design, and art challenges. This process involves free interaction among engineers, artists and design professionals, administrators, and the public. In a successful collaboration, all participants remain open to each other, listen carefully, and challenge with sensitivity.

27.3 FEDERAL POLICY

Federal Transit Administration policy Circular 9400.1A encourages including art in mass transit projects:

"The visual quality of the nation's mass transit systems has a profound impact on transit patrons and the community at large. Mass transit systems should be positive symbols for cities, attracting local riders, tourists, and the attention of decision-makers for national and international events. Good design and art can improve the appearance and safety of a facility, give vibrancy to its public spaces, and make patrons feel welcome. Good design and art will also contribute to the goal that transit facilities help to create livable communities."

27.4 ADOPTED POLICY

A. On September 11, 1997, in Motion No. 40, the Board of the Central Puget Sound Regional Transit Authority made a commitment to the integration of public art in the Sound Transit system. The Motion states:

1. Implementation of the Sound Transit system will include works of art that contribute to a positive experience for system users and affected communities.

2. Artists will participate in the design of transit facilities and public spaces to maximize the opportunities for integrating art into construction.

3. Affected communities will be involved in decisions regarding where and what type of art is appropriate in their communities, and in the selection of artists to execute the artwork.

B. In order to carry out the policy adopted by the Board and to initiate the Sound Transit art program – ST*art*, (Resolution No. 98-1) was established. (See Appendix A for complete text).

27.5 GOALS FOR ST*ART*

A. Collaborate with staff, engineers, architects, designers, other artists and communities:

1. Form and maintain good partnerships

2. Share ideas, review process frequently, maintain flexibility and openness

3. Continue meaningful and specific community involvement through design and construction

4. Be a good neighbor by considering and addressing project impacts

B. Innovate, raise questions, help solve problems:

1. Provoke thought, surprise, wonder and memory

2. Challenge assumptions, seek fresh opportunities

C. Enhance uniqueness of the region and its communities:

1. Respond to what exists, both natural and human

2. Honor communities

D. Treat travel as a rich experience:

1. Highlight transitions, movement, rhythm, views, time
2. Express the value of public transportation through design
3. Support regional connections

E. Humanize experience of transit for all:

1. Serve riders as well as community at large
2. Consider all senses, expand the notion of accessibility (ADA)

F. Make "sense" of the system:

1. Support wayfinding through images, landmarks, etc.
2. Integrate function, aesthetics, meaning and metaphor
3. Reveal function, structure and connections

G. Inspire stewardship of site and system:

1. Support ownership and pride
2. Incorporate maintenance into design

27.6 APPROACH FOR ST*ART*

27.6.1 Integrated Art

Integrated art is a primary focus of the ST*art* Program which defines it from three perspectives. Artworks may embrace any combination of these perspectives: Integrated art intellectually and emotionally supports the artistic vision.

A. Conceptual of a site.

B. Functional: Integrated art fuses utility with the artistic vision of a site.

C. Material: Materials support the artistic concept while recognizing the vital role of durability and maintenance.

27.6.2 Collaboration

Collaboration is the primary method artists will use when working on the system. The ST*art* Program defines collaboration as the willingness of

different types of people to share their perspectives to identify and solve art and design challenges. This process involves free interaction among artists and design professionals, administrators and the public. In a successful collaboration, all participants remain open to each other, listen carefully, and challenge with sensitivity.

27.7 OPPORTUNITIES FOR ART

Transit agencies in this country have 20 years' experience in developing and refining art programs. Research into this experience reveals a wide range of ways in which art has contributed to enhancing the everyday act of commuting. Discrete artworks that celebrate the history, culture, and people of the region are important and will be included in Sound Transit. However, the integration of art and architecture is essential because concerns regarding safety, operations, maintenance, vandalism, and pedestrian flow often preclude many of the opportunities for discrete art objects. In addition, many functional aspects of a transit system can be transformed and enlivened by the application of art and artistic ideas.

The ST*art* Program looks at the following categories and examples as a way to begin examining the variety of different opportunities that might exist.

27.7.1 Systemwide Artwork

A. Concepts - which are carried throughout the system. An idea, a narrative, a thread which runs throughout the system or through specific parts of a system, tying the system or artwork together conceptually from one place to another, one mode to another, etc.

B. Components - which are repeated and/or treated in a related or similar way throughout the system.

27.7.2 Examples of Potential Opportunities

A. Environmental / Land-related / Ecological

1. Stormwater treatment
2. Native plantings
3. Environmental information such as wind and temperature
4. Edges and transitions
5. Trackways between stations, OCS
6. Landscape edges to adjacent properties

7. Sidewalks adjacent to park-and-rides or stations
8. Re-use construction debris or elements which become obsolete during construction
9. Track rails as railings

B. Architectural

1. Shelters created by “light”
2. Total station design by collaboration or artist lead
3. Functional: benches, drinking fountains, railings, fences, fare vending, security systems
4. Brackets or other shelter supports
5. Utility and substation building design or surface treatments

C. Collectibles

1. Fare cards
2. Bus schedules
3. Contractors’ tape

D. Engineering

1. Control boxes as sculpture
2. Highway cloverleaf as gateway
3. Highway bridges

E. Maintenance

1. Maintenance as performance art
2. Focus on the craft of maintenance

F. Wayfinding

1. Landmarks
2. Signage
3. Pathways

4. Accessible path
5. Electronic information boards kiosks

G. Tactile / Multi-sensory

1. Art for weak-sighted
2. Vehicle sounds
3. Fragrant landscaping
4. Textured railings

H. Vehicular

1. Inside and outside
2. Announcements or attention-getting sounds

I. Community Amenity or Events

1. Flea markets on weekends
2. Tours of the “system as destination”
3. Performance spaces
4. Sculpture gardens
5. Community bulletin boards
6. Time capsules

J. Documentation of Process or Program

1. Photography, video, CD-ROM

K. Temporary

1. Construction fence
2. “Prequel” Works: works which occur as an overture to station opening (design-construction)

L. Temporal or Time-activated

1. Video, closed-circuit work

2. Oxidation
3. Photography
4. Seasonal plantings
5. Sun-activated shadow play

27.8 INVOLVEMENT OF ARTISTS

Three level of artists' involvement: System, Project and Commissioned artists. Roles are outlined below.

27.8.1 System Artists

Provide a systemwide perspective for the ST*art* program.

A. Collaborate with Art Program Coordinator to:

1. Establish budgets, scopes of work
2. Develop and share overview of system as a whole, collaborate on inter-modal issues
3. Participate in design sessions with other designers and artists regarding system-wide priorities

B. Design and make art

1. Work to establish overall conceptual threads that inform system
2. Assist in design of systemwide elements
3. Design and implement specific projects as appropriate

C. Maintain ongoing collaborative relationships

1. Serve as resource/sounding board for other artists, artist selection panels, Sound Transit staff
2. Plan and participate in periodic charettes, work sessions, and information-sharing meetings
3. Establish and maintain efficient, creative feedback system
4. Mentor where appropriate, encouraging opportunities for wide range of artists

D. Evaluate work and process throughout design and construction

1. Meet with thinkers from other disciplines (philosophers, planners, etc.)

2. Allow "chaos" to keep our thinking fresh

E. Integrate artwork into overall agency thinking

1. Generate enthusiasm for integrated artwork

F. Advocate for ST*art* program, serve as spokesperson

27.8.2 Project Artists

Responsible for art at stations, facilities, and line segments and other major components of the system.

A. Develop the art and design in close collaboration with local communities, consultant design teams, and Sound Transit staff.

B. Develop a unifying art concept, create a vision for carrying out this concept, and give form to this vision by identifying art opportunities.

C. Recommend opportunities for commissioned artists.

D. Work with the same schedule as the design team consultants. Sound Transit art and design review processes will be combined.

27.8.3 Commissioned Artists

Commissioned artists will work in a more focused way than system or project artists in response to more specific opportunities identified by a Project Artist and Design Team.

27.9 COMMUNITY INVOLVEMENT

A. ***Artist Selection:*** ST*art* works with local arts commissions and community representatives to select artists appropriate for projects within their jurisdiction. As a resource to the selection process, ST*art* has developed a roster of approximately 600 qualified artists. Application to the roster is open to all artists on an ongoing basis.

B. ***Artwork Review:*** Because art is intended to be an integral part of Sound Transit facilities, it is reviewed during the design review process organized for each project. Artwork is included in site plans and public presentation materials. In addition, artists meet regularly with local arts commissions and committees to receive input and advice.

27.10 FUNDING

A. In keeping with local precedents and FTA guidelines, the Sound Transit budget for art will be calculated as 1 percent of capital construction costs, excluding the cost of tunneling. The funds generated for art will be pooled within each subarea. Opportunities for integrating art will be evaluated for the system as a whole before determining where art is most appropriate and how much money should be allocated for art at specific locations within each sub-area.

B. The 1 percent for art policy will allow the art program to begin without committing to specific dollar amounts until cost estimates for specific construction projects are more firmly established. Because it is anticipated that much of the art will be completely integrated into construction, determining the specific costs attributable to the art budget may not be possible. Costs will be reasonably assigned based on the best judgment of those collaborating on the Sound Transit art and design tasks.

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28. SYSTEM SAFETY

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28. SYSTEM SAFETY

28.1 INTRODUCTION

A. The system safety criteria, as presented herein, are a compendium of requirements that are substantially supported by codes and standards. The criteria included in this chapter meet or exceed safety-related codes, standards, and regulations promulgated by local, state, and federal authorities and should be followed to ensure that system safety is considered during the design of facilities, systems, and equipment. Where more than one code or standard may apply, the more restrictive shall govern except as noted herein. This light rail transit system shall be designed in compliance with local municipal codes except where specifically exempted.

B. System safety requirements are also interdependent on systems assurance (e.g., reliability, maintainability, and availability), which is addressed in Chapter 26, Systems Assurance, Chapter 18, Fire/Life Safety, and Chapter 29, Security.

28.1.1 Safety Policy

A. It is management policy that safety be a primary consideration throughout the evolution of the Sound Transit Link System, from Preliminary Engineering through revenue operations. To fulfill the obligation of this policy, all applicable codes and regulations, augmented by modern system safety engineering technology and industry standards, are used to ensure that the System achieves a level of safety that equals or exceeds that of other rail transit systems.

B. The Link System Safety Program Plan shall be the governing document for requirements, methodology and implementation of system safety. All elements of this Design Criteria shall comply with that plan.

C. During the Preliminary Engineering and Final Design phases, safety can be achieved by eliminating, minimizing, or controlling hazards through analysis, review, and design selection. This includes provisions for emergencies such as an emergency communications network, on-site emergency equipment, and access by emergency forces.

D. The Link Safety Certification Plan shall describe the procedures and methods that document attainment to the safety related elements of these Design Criteria.

28.1.2 Purpose

A. This document presents the safety criteria and performance requirements for the Sound Transit Light Rail Transit project. The purpose of this safety document is to provide sufficient definition and description of all facets of the safety approach and concept so design engineers and architects have guidance for the proper selection of equipment and design of facilities. Through these criteria, safety considerations shall be integrated into all aspects of design specification preparation, equipment selection, construction, architectural concepts, procedures, and operations.

B. The design of the system shall include provisions to detect and alarm unusual conditions, and enable the timely response and action by emergency response forces. As part of this integrated safety approach, design provisions shall enable safe and timely evacuation of patrons and personnel from structures, disabled vehicles, and facilities. The provisions shall also include necessary safeguards to protect patrons, system personnel, and emergency response forces during evacuation and shall minimize exposure to hazards.

28.1.3 Program Objective

A. The objectives of the safety program are the elimination or control of Category I and II hazards as defined in MIL-STD 882C and the assurance that no single point failure in a dynamic system nor common cause failures result in an unsafe condition.

B. To achieve these objectives and provide a level of safety that equals or exceeds that of other rail transit systems requires a comprehensive and complete system safety program.

28.1.4 Scope

This document outlines the safety criteria in the following areas:

A. Station and Site

B. Communications

C. Light Rail Vehicle

D. Signaling

E. Power

F. Sound Transit Link Operations

G. Operations, Maintenance, and Training

28.1.5 Definitions

The definitions in the American Public Transit Association (APTA) lexicon apply unless modified herein.

28.1.6 Applicable Codes and Standards

The applicable codes and standards are listed in Chapter 18, Fire/Life Safety. Where a conflict exists between codes, the more restrictive code shall apply unless approved otherwise by the Authority Having Jurisdiction (AHJ).

28.1.7 Construction Safety

During construction, the highest safety standards and practices for major public works projects shall be upheld. Construction personnel, the public, and system employees shall not be exposed to unnecessary safety hazards. The requirements of Section 1926 of WISHA and Chapter 296-155WAC shall be observed and NFPA 241. (Also see FTA-MA-26-5005)

28.2 SAFETY METHODOLOGY

28.2.1 Hazards

A. Identified hazards shall be eliminated or controlled using the following hierarchy of hazard resolution:

1. Design for Minimum Hazard

   Provisions shall be made in all initial designs for the elimination of hazards. If the identified hazards cannot be eliminated, then the hazards shall be controlled through alternative designs.

2. Safety Devices

   Hazards that cannot be eliminated or controlled through design shall be controlled to an acceptable level through the use of fixed, automatic, or other protective safety design features or devices. Provision shall be made for periodic functional checks of safety devices.

3. Warning Devices

   When neither design nor safety devices can effectively eliminate or control an identified hazard, devices shall be used to detect the hazard and to generate an adequate warning signal to provide for

operating personnel/public reaction. Warning signals and their application shall be designed to minimize the probability of incorrect operating personnel/public reaction to the signals.

4. Procedures and Training

   Where it is impossible to eliminate or adequately control a hazard through design or use of safety and warning devices, procedures and training shall be used to control the hazard. Precautionary notation shall be standardized, and certain safety-critical tasks shall require certification of personnel.

28.2.2 Criteria Application

A. The following criteria are categorized by major systems with subsystems referenced as lower-tier components.

   1. Areas that present a high degree of hazard probability are highlighted in each category. This is not an all-inclusive listing. The Architect/Engineer of Record is responsible for designing a safe system in accordance with all applicable codes and standards, and to detect and/or avoid any unsafe condition that may be inherent in a specific design solution.

   2. Special attention to unsafe conditions shall be given in areas where systems or subsystems interface or where there are overlapping areas of design responsibility.

28.3 STATION AND ENTRANCE SITE

28.3.1 Station and Entrance Site Layout

A. A station and entrance site layout shall be provided as follows:

   1. Access points shall be located to preclude traffic congestion, and traffic patterns for vehicles and pedestrians shall be clearly marked.

   2. Vehicle patterns that cross or result in counter-flow shall be minimized.

   3. Patron drop-off zones shall be located to minimize patron exposure to traffic. Patrons shall be able to move directly to the station entrance without crossing traffic lanes.

   4. If public parking is provided, spaces shall be set aside for the handicapped at the closest point to the station entrance to minimize their exposure to traffic and to reduce their travel distance. The number and design of handicapped parking spaces shall comply with

the local municipal codes, the Authority Having Jurisdiction, the IBC, and other municipal codes as applicable.

5. Bus loading and unloading zones shall be located so patrons do not have to cross traffic lanes.

6. Crosswalks shall be clearly defined and well marked. Crosswalks and sidewalks shall be provided with slip-resistant surfaces. Minimum coefficient of friction of 0.50, wet or dry, shall be provided.

7. Curb cuts shall be provided where required by (See 28 CFR, Part 36 4.7 (ADA)).

8. They shall be designed to the applicable municipal codes.

9. Maximum visibility shall be provided.

28.3.2 Station Features

A. Signing

Distinct, legible, and correctly located signing shall be provided as follows:

1. Clear and well illuminated signing and graphics shall be provided in stations. The signing and graphics shall be located in a manner that enhances the safety and convenience of patrons.

2. Right-hand traffic shall be encouraged through signing.

B. Architectural Psychology

As a minimum, any design features or vistas that may distract patrons' attention at the top or foot of stairs and escalators shall be avoided.

C. Platform

1. A platform safety strip shall have a width of 24 inches, be slip resistant and yellow in color, be of different color and texture than the main platform area, and be in conformance with 28 CFR Part 36 10.3.1 (8) (ADA).

2. The horizontal and vertical misalignment between the vehicle doors and the platform edge shall be minimized to reduce the tripping hazard and the possibility for an object or limb to be caught between the vehicle and platform.

3. The platform design shall be coordinated with the track layout and the vehicle static and dynamic outlines to provide an acceptable

interface between the platform and vehicle. This interface shall minimize horizontal and vertical gaps at the vehicle door threshold. The dimensions shall be a maximum 3 inches for horizontal gap between platform and vehicle static outline, and vertical shall be within 5/8 inch of the station platform. See 28 CFR, Part 36 10.3 (9) & 49 CFR, Part 38 38.53 (d).

4. Pedestrians shall not be exposed to bumping hazards on the platforms or public ways.

5. Circulation Path Clearances (See 28 CFR 4.4.1.)

   a. Sufficient clear space shall be provided around overhead and side projections and corners to reduce the potential for bumping and walking into protuberances. Objects shall be recessed if practicable.

   b. Within the stations, at least one accessible path from the entrance to the platform shall be provided.

D. Station Walking Surfaces

To reduce the potential of slipping, tripping, and falling, all walking surfaces including the public areas and the ancillary spaces shall be constructed of materials selected for their slip-resistant qualities in both wet and dry states.

E. Walkway Screening

When passarelles or pedestrian walkways are provided over the trackway and/or public areas, the walkways shall be screened.

F. Top of Parapet

The architectural treatment of stairs, escalators, and visual openings may include the use of parapets. The top of the parapet shall be sloped away from the vertical circulation elements and visual openings to prevent objects being placed upon them.

G. Railings/Guardrails

Railings and guardrails shall meet the applicable municipal codes regarding heights and loadings. The design shall not permit dropped objects to roll underneath and fall to the lower level(s). Additionally, the following shall be provided:

1. Railings and guardrails shall comply with the requirements of IBC 1009.11 and 12, NFPA 130, and the applicable local codes.

2. Glazed railings shall not be installed.

28.3.3 Elevators/Escalators

(See also: Chapter 25, Elevators and Escalators)

The following elevator/escalator design considerations shall be provided:

A. Elevators

1. Applicable Municipal Code requires elevators in stations to accommodate the elderly and the handicapped in accordance with ADA. The elevators shall also be sized to meet the requirements of emergency rescue teams.

2. Elevators shall meet the safety requirements in ANSI A17.1.2.7 and the handicapped requirements in 28 CFR, Part 36 4.10 (ADA).

3. Two-way communication capability from within the elevator cab shall be provided between the patron and the Sound Transit Link Operations. (See 9.6.4; 28 CFR, Part 36 4.10.14 (ADA)).

4. Elevators shall have both a passenger emergency telephone (see Chapter 15, section 15.5.9, Passenger Emergency Telephone) and an emergency telephone in a locked cabinet for emergency response personnel use.

5. Elevators shall be sized to accommodate a horizontally positioned stretcher of the type carried by emergency vehicles. (See ASTM 17.1–2.27 and 28 CFR 4.10).

6. Remote elevator indicators and controls shall be provided at Sound Transit Link Operations for emergency operation.

7. Provisions shall be incorporated in the design to lower the elevator to a pre-designated level in an emergency power loss. (See ASTM A17.1 – 3.26.10).

8. Keys for access to and for the operation of elevator elements shall be tagged, labeled, and retained in a key box. The elevator key box shall contain fire emergency service keys (Phase I and Phase II, one key for each switch). ASTM A17.1 – 27.8 and SFC 506.1 unless amended by the local jurisdiction.

9. Deep Tunnel Stations requirements see Chapter 25, Elevators and Escalators, section 25.6.1, General, section 25.6.3 B, Car Enclosures, and section 25.6.3 E, Doors.

B. Escalators

The following shall be provided to minimize patron confusion and improve circulation:

1. Escalators shall meet the safety requirements in ANSI A17.1.

2. Signing and graphics shall be provided to enable patrons to determine the direction of escalator motion prior to their arrival at, and well clear of, the landing plate.

3. Adequate queuing space shall be provided at both the top and bottom of escalators. See NFPA 130 8.8.1.2 (1) & 49 CFR, Part 38 38.87.

4. Provisions shall be made for safe closure during maintenance and for a minimum of pedestrian flow impairment.

5. Indicators of the location and status by station shall be provided at OCC. See NFPA 130 8.8.1.2 (2).

6. Emergency stop buttons shall be located on the top of the balustrade at the top and bottom landings. The configuration shall prevent inadvertent actuation. See ASTM A17.1 6.1.6.3.1.

7. Escalators designed to stop gradually are preferred to an abrupt stop when the emergency stop control is activated. See ASTM A17.1 6.1.6.3.2.

8. Escalators shall be provided with a remote stopping capability if approved by the AHJ.

28.3.4 Stairs

A. Stair tread-riser relationship shall be one that easily accommodates travel in both directions, is usable under all types of weather, and minimizes the hazard of tripping or falling. Additionally, the following shall be provided:

1. The tread-riser relationship shall meet the requirements of IBC Chapter 9, 10, and 11.

2. The stairs shall be of a slip-resistant material with an eased nosing that is distinct and meets the requirements of 28 CFR, Part 36 4.9.3, (ADA).

3. When gutters/runnels are provided, they shall be protected by the handrails.

4. Handrails shall be continuous and meet the requirements of 28 CFR, Part 36 4.26 & 49 CFR, Part 38 38.83(13) (ADA) and IBC Section 1009.11 as amended by the local jurisdiction.

5. Non-public stairs shall comply with IBC Chapter 10 and 11. (See Chapter 18, Fire/Life Safety, section 18.7.5, Blue Light Stations/Emergency Trip Stations)

28.3.5 Fare Collection

(See also: Chapter 16, Fare Collection)

A. Place equipment in locations that do not impede exiting of patrons.

B. Provisions shall be incorporated to permit access by the handicapped using wheelchairs.

28.3.6 Vehicle Approach System

A visual method shall be provided to alert patrons of the impending arrival of a train. This requirement may be satisfied by ensuring provision of a horn and headlights on the passenger vehicles. (28 CFR, Part 36 4.28.3 (ADA).

28.3.7 Other Design Features for Station and Site

A. Maps shall be provided showing locations of shutoff controls for water, electricity, and fuel lines. These maps shall be located in the Emergency Management Panel (EMP).

B. Guard and restraining rails and similar items where trains pose a clear danger to patrons, personnel, or equipment.

C. Adequate lighting of stairs and escalators shall be provided to promote patron safety.

28.4 COMMUNICATIONS

28.4.1 Closed Circuit Television (CCTV)

Electronic surveillance shall be provided to view selected station areas and can be recorded or monitored. (See Chapter 15, Communications and Central Control, Section 15.5.6, Closed Circuit Television System).

28.4.2 Public Address System

A. Public Address (PA) system shall be provided as follows: (See also: Chapter 15, Communications and Central Control, section 15.5.4, Public Address and Variable Message Sign).

1. The PA system shall provide full station coverage at a level sufficient to be heard over normal train, equipment, and public noise.

2. The PA system installation shall be designed so that the loss of utility power will not cause loss of PA capability.

3. PA system access shall be provided at the Operation Control Center and Emergency Management Panel.

28.4.3 Passenger Emergency Telephone Service

A. Passenger Emergency Telephone (PET) service shall provide direct communications with OCC. PETs shall be provided at each passenger station, along the trainway, and at maintenance/train storage facilities as designated in Chapter 18, Fire/Life Safety, section 18.6.4, Passenger Emergency Telephone. (See also: Chapter 15, Communications and Central Control, section 15.5.9, Passenger Emergency Telephone).

B. Passenger Emergency Telephone shall be readily accessible and operable by elderly and handicapped patrons. Dimensions shall be as required in the Municipal Code and Uniform Building Code of the Authority Having Jurisdiction. See 28 CFR, Part 36 4.31 (ADA) for guidelines regarding clear floor space around PETs, mounting height and protruding objects.

28.4.4 Public Telephones

A. Public telephones shall be provided in elevated and underground stations at all levels.

B. Public telephones shall be accessible to and usable by the functionally disabled, and shall comply with 28 CFR, Part 36 4.31 (ADA)

C. Telephones shall be vandal-resistant.

D. Multiple channel capability shall be provided for emergency transmission in case of transmitter failure.

28.4.5 Radio

Radio communications system shall be capable of providing clear signal throughout the system including tunnels, tunnel stations and ancillary spaces (See also: Chapter 15, Communications and Central Control, section 15.5.5, Radio System).

28.5 LIGHT RAIL VEHICLE (LRV)

(See also: Chapter 12, Light Rail Vehicle)

28.5.1 Doors

Also see 49 CFR, Part 38 38.73 (ADA).

A. Side Door Interlocks

A very serious safety condition would exist if side doors should open on a moving train or if a train should start moving while the doors are still open. Side door interlocks and detection circuits shall be safety-critical and provided as follows:

1. Doors shall be interlocked with propulsion power to prevent side doors from opening until the train is properly berthed and stopped at the platform with braking applied, and prevent train motion until all side doors are closed and locked.

2. The train operator side door controls shall be on the same side of the operator's cab as the doors being operated.

3. Side door edges shall be designed to permit the withdrawal of trapped clothing or articles.

4. A sensing circuit shall be provided to recycle doors when an obstruction is met.

5. The design of the door control signal shall ensure that non-commanded doors will not open. Left and right doors shall not share components whereby a spurious signal could open a door without an authorized command.

6. A positive side door control device shall be provided to prevent side doors from unintentionally sliding open.

7. Exterior side door status lights shall be provided to indicate status.

B. Side Door Warning Signal

Patrons shall be alerted when doors are ready to close. An audible warning shall sound and the vehicle doors shall begin to close. A combination of audible and visual warnings to alert hearing-impaired patrons shall be utilized if practical.

C. Manual Release

Manual release of side doors shall be provided as follows:

1. Interior manual side door controls shall be provided for use by the patrons and shall be adequately signed on operation.

2. Exterior manual side door controls shall be provided on the designated set of side doors for use by operating, maintenance, and/or emergency response personnel.

D. Door Width

Side door openings shall be wide enough to permit use by patrons in wheelchairs. Minimum clear width is 32 inches.

28.5.2 Lighting

A. The illumination inside a car shall be maintained at a level that permits normal visibility.

B. Interior lighting levels 20 or more foot-candles measured 36 inches above the floor.

C. Emergency lighting shall be provided and powered by a battery backup system, 1 foot-candle for 1 hour. After 1 hour of continuous illumination the lighting illumination level shall not be less than 60 percent.

28.5.3 Communications

A. On-board communications shall be provided as follows:

1. Intercom communications shall be provided between the operator and passengers.

2. A public address system shall be provided to permit one-way communication between the train operator and passengers.

3. Communications capability between OCC and the train operator shall be provided.

4. All vehicles shall be numbered uniquely to provide for positive identification.

5. Emergency communication capabilities for the vehicle shall be provided with a battery backup power system.

28.5.4 Windows

The following provisions shall be made to mitigate hazards caused by objects striking and shattering or penetrating windshields, side windows, and cab windows:

A. All windows shall be of the single-glazed, fixed type. All end facing windows and their glazing strips shall meet the impact test requirements of 49 CFR 223 Type 1 for front facing glazing. All side facing windows

and their glazing strips are required to meet the impact test requirements for 49 CFR 223 Type II for side facing glazing.

B. All windows shall be impact and fire resistant material (see NFPA 130, Table 8.4). The windows shall meet the requirements of 49 CFR Part 223, Appendix A, and resist the penetration of flying objects without shattering or spalling.

C. Means shall be provided to remove designated egress windows from both the vehicle interior and exterior.

D. Removable windows shall be identified and clear instructions provided for passengers and emergency response forces.

E. Car interiors shall be visible from other LRVs in the consist and from outside of the vehicle.

F. Anti-climbers shall be provided at each end of a vehicle.

G. Provisions shall be made for electrical, pneumatic or hydraulic isolation of defective vehicle systems.

28.5.5 Interior Design Features

A. Seating and standing arrangement shall enable patrons to move easily and safely within a moving or stopped vehicle. In addition, provisions shall be made for priority seating for the elderly and physically disabled. See 49 CFR, Part 38 38.75 (ADA).

B. Human factors shall be used in the design of the physical features, including the passenger and operator seats and the cab and console layout.

C. Sharp edges and protrusions shall be avoided.

D. Protective cushioning shall be provided on seats as appropriate.

E. Within each car, a location that does not interfere with the other patrons' movements shall be identified for securing a wheelchair.

28.5.6 Power/Propulsion

Normal or abnormal/emergency conditions or operations shall not result in unsafe conditions.

28.5.7 Braking

A. Emergency brake control shall be fail-safe to the extent that no single failure or series of common mode or common cause failures can result in less than 75 percent of emergency braking effort being available.

B. The emergency stop circuit shall ensure an irretrievable stop after an emergency application is initiated and ensure that the train is brought to zero speed before it can proceed in any mode of operation.

C. There shall be redundant methods of automatically/ manually applying emergency braking.

28.5.8 Auxiliary and Electrical

A. Failures or malfunctions shall not result in unsafe operations or conditions.

B. Approved protection shall be provided against short circuits and overloads.

C. High voltage circuits shall be provided with appropriate identifications in accordance with transit industry standards and codes.

D. High voltage power shall be physically separated from communications circuitry and low voltage control circuitry.

28.5.9 Heating, Ventilation, and Air Conditioning

A. Ventilation equipment throughout the train shall be operable from the controlling cab.

B. Heater elements shall incorporate protective devices for the following failures:

1. Failure of the ventilation air flow

2. Failure of the temperature controls

3. Short circuits in supply wiring

28.5.10 Cab Controls/Indicators

A. Malfunctions and failures of safety-critical vehicle systems shall be detected and annunciated in the vehicle. As a minimum, these shall include:

1. Actual train and civil speed indications

2. Power/propulsion failures

3. Door open and close signals and any door malfunctions

4. Braking failures/malfunctions

5. Trip stop violations

B. Other console controls to be provided shall include:

1. The controller shall be equipped with “deadman” or equivalent capability.

2. A key-on, key-off switch shall be provided that is interlocked such that only the controller at the front of the lead vehicle of a multi-vehicle train is operable.

3. An emergency stop button shall be provided that is capable of being activated from any console on a train-lined consist.

4. Capability for automatic uncoupling shall be provided.

5. Audible warning devices shall be provided on the operator’s console that has both, high and low output volumes. Low volumes are intended for tunnel use, and the higher volume (horn) for external use. An output of 95± 2 dba at a distance of 100 feet at the high volume level and 85± 2 dba at the low volume level shall be provided. Both output levels shall be adjustable. If a bell is used, it shall emit a minimum of 80 dba at 50 feet.

28.5.11 Other Design Features

A. The following features shall be included:

1. Patron emergency instructions shall be placed in each vehicle.

2. Emergency equipment to aid in evacuating the vehicle shall be located within the vehicle.

3. Fire extinguishers shall be provided in accordance with Chapter 18, Fire/Life Safety, section 18.4.4, Fire Extinguishers.

4. Exterior lighting shall include vehicle headlights and taillights.

5. Locations of fire extinguishers and door releases shall be clearly marked.

6. Vehicle electrical, electromechanical, hydraulic and mechanical system designs shall use approved redundancy, fail-safe, or fail-operational principles.

7. Anti-climbers shall be provided at each end of a vehicle.

8. Provisions shall be made to electrically and pneumatically isolate a vehicle that has an operational malfunction, such as stuck brakes or inoperable traction devices, from the remainder of the vehicles within that consist.

28.6 POWER

See also: Chapter 13, Traction Electrification and Chapter 23, Electrical Systems.

This section defines the system safety requirements for electrical power, overhead contact system, traction power substations, and emergency trip stations.

28.6.1 General

A Provisions shall be made for both local and remote control (from the OCC) of the maintenance yard and shop traction power substation. Special procedures shall be required for restoration of yard and shop traction power.

B. Line traction power substations will be controlled from OCC.

C. Electrical grounding and lightning protection shall be provided for the traction power substations in accordance with NFPA 70.

D. OCC shall have the capability to turnoff and control essential ac and dc switchgear functions, to include the OCS segments. Alarms and visual indication of status changes, faults, and other abnormal conditions associated with traction power substations shall be annunciated.

28.6.2 Emergency Trip Station

A. An Emergency Trip Station (ETS) shall be provided at TPSS, and at aerial and underground station's EMP or fire control panel locations and identified by a blue light and co-located with an emergency phone. (See Chapter 18, Fire/Life Safety, section 18.7.5, Blue Light Stations/Emergency Trip Stations and Chapter 13, Traction Electrification, section 13.3.13, Emergency Trip Stations).

1. ETS shall be enclosed in a weather-resistant box, and the location shall be identified and easily opened.

28.6.3 Station Emergency Power Requirements

A. During power failures, emergency power shall be available at designated locations of each station and for those functions considered critical.

B. Dual primary feeders shall be provided.

C. As a minimum, emergency power shall be provided for the following functions:

1. Public address
2. Automatic and manual fire suppression systems (elevated and subway only)
3. Fire detection and alarming (elevated and subway only)
4. Security detection and alarming (elevated and subway only)
5. Selected closed circuit television cameras and monitors (elevated and subway only)
6. Radio
7. Emergency egress and exit signage
8. Emergency lighting
9. Emergency telephones
10. Selected elevators for deep tunnel stations

28.6.4 Tunnel Emergency Power Requirements

A. The loss of a single substation or a tunnel feeder shall not interrupt the functioning of safety-critical systems, such as the ventilation system, ETS, telephones, and lighting and elevators in deep stations where they are used for exiting.

B. Tunnel fans and lighting shall be fed from two separate power feeders.

28.6.5 Substations

A. Consideration shall be given to all subsystems comprising the power system to assure acceptable safe levels of safe operation.

B. Switchgear shall have shutoff capability and an interlocked tripping mechanism to protect personnel from accidental contact with live power circuits when the circuit breaker is removed.

C. Circuit interrupting devices which do not have load break capability shall be equipped with interlocks to prevent unsafe operation. Arc chutes shall be provided on load break equipment where necessary to control the power interruption process.

D. High-voltage terminations shall be protected to prevent accidental intrusion from an external source.

E. Power "on" warning lights shall be provided on all main ac/dc circuit breakers.

F. High dielectric strength treatment shall be used as insulation protection on the floor around the perimeter of DC conversion equipment and switchgear and shall extend a minimum of 5 feet. Clearance around this equipment shall prevent personnel from bridging grounded surfaces. If such clearance cannot be provided, grounded surfaces shall be adequately insulated eight feet in the vertical and horizontal direction.

G. Access to substations shall be restricted to properly trained and authorized personnel only. Entrances shall be locked, and intrusion detection shall be provided to detect unauthorized entry.

H Key locks shall be provided on all manual ac/dc breaker control cabinets. Doors to the traction power rectifier and transformer shall be provided with power interlock safety switches.

I Electrical substations shall utilize dry-type transformers.

J. If dry-type transformers cannot be utilized then electrical substations shall conform to the following requirements: (See also: Chapter 14, Signal System).

1. Separation distances between oil-filled transformers and other structures shall be as shown in Table 28-1.

TABLE 28-1:
Oil-Filled Transformer Separation Requirements

	Distance (feet)	
Structure Type	<100 Mva	>100 Mva
Non-system structures of wood construction	100	100
Passenger station and shelter stop public areas	50	75
Transformers and structures of noncombustible construction	25	50

2. When separation distances cannot be maintained, one of the following mitigating measures shall be provided:

   a. A three-sided, two-hour enclosure with noncombustible roof for each transformer of less than 100 Mva capacity within 25 feet of exposed noncombustible walls and for larger capacity transformer within 50 feet of noncombustible walls.

   b. Drainage for oil-filled transformers shall be provided under the transformers by means of a gravel-filled enclosure that includes a trench drain of sufficient capacity to hold 100 percent of the oil contents of the largest transformer. As an alternative, the transformers shall be located on a concrete slab, sloped away from the transformers and adjacent structures toward a collection area. The collection area shall have sufficient capacity to hold 100 percent of the oil contents of the largest transformer.

   c. The use of less flammable transformer fluids may reduce or eliminate exposure protection requirements. Less flammable transformer fluids shall be UL listed and have a flash point of at least 572°F (300°C) and the convective and radiant heat release rates shall be known.

K. High-voltage terminations shall be protected to prevent accidental contact.

L Substation monitoring devices for dc equipment enclosed in metal housings shall detect and annunciate the condition when the dc equipment enclosure is grounded or a positive bus is being faulted to the enclosure.

M Rubber matting of high dielectric strength, or an epoxy coating, shall be provided on the floor around the perimeter of dc conversion equipment and switchgear. This insulation protection shall extend a minimum of 4 feet. Equipment clearances shall be provided such that personnel cannot bridge to grounded surfaces. Otherwise, grounded surfaces shall be insulated.

N. Two means of egress shall be provided from each incoming electrical substation.

O. Traction power substations shall have ac receptacles isolated to prevent accidental grounding of the dc power when using test equipment.

28.6.6 Other Design Features

A. Other design features shall be included as follows:

1. All critical support facilities (e.g., substations, Sound Transit Link Operations power) shall have subsystem status indicators on the status board

2. All electrical power distribution facilities shall be protected from known 100-year flood levels

3. Equipment provided shall protect against battery overcharging

4. Battery rooms shall contain a fixed eye wash unit

28.7 SIGNALING

This chapter defines the requirements of system safety for signaling systems.

28.7.1 General

The signaling system utilized shall be designed to provide safe braking and comply with the provisions of the AAR Signal Manual of Recommended Practices and operating speeds as specified in Chapter 14, Signal System.

28.7.2 Design of Signal Control Apparatus and Logic Circuits

A. Signal control apparatus and circuits shall be designed to meet the following:

1. Vital components shall be of a proven design.

2. Vital components shall be designed so that restrictive (rather than permissive) movements occur when a component fails.

3. Vital control circuits shall be designed such that, if interrupted or de-energized, they shall cause the controlled function to assume its most restrictive condition.

4. Hardware and software errors/malfunctions that may compromise vital data shall produce a non-recoverable error resulting in a system shut down.

5. Vital circuits not within a single apparatus enclosure shall have double-wire, double-break control.

6. Isolation will be provided between all circuits and sources other than those intended for the circuit to prevent a flow of current of more than

50 percent of the release value of any relay or other safety device used in the circuit.

28.7.3 Location, Aspects, and Indications of Wayside Signals

A. Care shall be taken to locate wayside signals at predetermined distances and sufficiently visible to preclude confusion with signals governing the operation of motor vehicles.

B. Signaling shall accommodate reverse running operations.

C. Speed limit signs should be clearly visible from the train operator's cab at all times and shall be posted in advance of speed change zones and at intermediate points (if the speed zone exceeds 1,000 feet in length). Train run-through of stations shall be at a reduced speed designated by rule. Where sight lines do not permit easy identification of a station location, warning signs shall be posted on the guideway.

28.7.4 Requirements of Wayside Signal and Cab-Signal Control Circuits

A. Wayside signal control circuits shall be designed and installed so that each interlocking signal governing vehicle movements into a block will display its most restrictive aspect or as a signal indication that shall display its most restrictive speed indication, should any of the following conditions exist within the block:

1. Occupancy by a rail vehicle or train

2. Presence of detectable right-of-way hazards

3. Improper switch point closure

4. Fouling point derail not in position, if utilized

5. Track relay or signal control circuit de-energized

28.7.5 Signal Block Design

The fixed block system shall be designed and installed with sufficient separation so that a signal/cab-signal displaying the most restrictive aspect or speed indication is accomplished by means of a brake application (other than emergency application). The braking shall be initiated at such signal, either by stopping at the signal or block where required, or by a reduction in speed as prescribed by the next signal or block.

28.7.6 Electromagnetic Compatibility

The signal system shall be designed and installed to tolerate reasonable electromagnetic interference and will have adequate protection against false

energization, miscodes, and/or improper codes caused by the vehicle propulsion apparatus or other spurious electromagnetic radiation sources.

28.8 SOUND TRANSIT LINK OPERATIONS

The Link Operations Control Center (OCC) shall be the focal point for maintaining an overview of train operations, train supervision, and station operation, and also for communicating directions and conditions to operators, maintenance, and, supervisory and emergency personnel. To accomplish these functions, the following capabilities shall be incorporated into the design.

28.8.1 Communications

A. Dependable, flexible and redundant communication networks shall be provided to ensure continuous contact with required personnel and patrons.

B. Radio communications system shall be provided as follows:

1. Operations
2. Maintenance
3. Police emergency
4. Fire emergency

C. OCC shall have a capability for two-way communications with vehicle operators.

D. Operating personnel shall be able to initiate communication with Sound transit Link Operations via the emergency telephone system. These communications shall be recorded and retained.

E. OCC shall have the capability for multiple telephone and radio communications reception, call out, and cross-patch.

F. The radio and emergency telephone subsystems shall be independent so as to prevent a single failure from causing the loss of both.

G. Operating personnel shall have the ability to initiate pre-recorded messages to be displayed over the PA/VMS or to generate ad-hoc messages using a PA microphone and/or keyboard.

28.8.2 Displays and Controls

A. Sufficient displays and controls shall be installed to permit OCC to continuously track the status of trains and critical station and tunnel functions.

B. A means to continuously monitor Fire/Life Safety functions shall be provided.

C. Mimic boards and controls for train control and power shall be provided.

D. The control of emergency ventilation fans shall be provided. Where the control resides shall be displayed (OCC, EMP, or MCC).

E. In an emergency incoming and safety related messages shall be audibly received and recorded at the OCC.

28.8.3 Alarms

A. Audible and visual alarms, and supervisory signals shall be provided for the following, as a minimum:

1. Fire Detection and Suppression Systems

2. Power failure

3. Intrusion

4. Pump failure or high/low water alarms

5. Elevator or escalator failure or malfunction

28.8.4 Other Design Features

A. The following design features shall be included in the OCC.

1. Terminology, size of letters and numbers, and colors as applied to controls, indicators, and signage shall be consistent throughout the Sound Transit Link Operations system and interfaces.

2. Human factors shall be considered in the design of overall systems and individual displays, consoles, and components. Grouping of indicators and controls for accurate response and visibility of indicators from the operators' positions are areas requiring special consideration. Consideration shall be given to the Sound Transit Link Operations single operator response in emergency situations.

28.9 WAYS AND STRUCTURES

28.9.1 Shops

A. Design features shall be provided to enhance the continuing safe performance of maintenance activities.

B. Shops shall be provided with dual power feeders and/or one power feeder and an emergency power source. If an emergency power source is provided, it shall have adequate reserve to bring all machinery to a safe, shutdown condition where required.

C. Maintenance and auxiliary vehicles shall have positive train protection capability for detection purposes.

D. The yard design shall provide the capability to perform daily safety and operational checks on all trains prior to trains entering revenue service.

E. Non-combustible, slip-resistant surfaces shall be provided in all maintenance facilities areas.

F. Vehicular traffic within the yard and crossing tracks shall be protected.

G. Storage rooms and rooms containing combustible or hazardous materials or high-energy sources/equipment shall be provided with emergency exits.

H. Overhead ac/dc power systems shall be protected or recessed to prevent inadvertent contact with movable maintenance platforms, ladders, or mobile cranes.

I. Emergency eyewash and body shower systems and drainage shall be provided in the immediate area of the battery service and storage.

J. Battery racks shall be provided for maximum protection against battery damage, and for ease of accessibility.

K. Rotating or other moving machinery shall be enclosed or properly guarded from personnel contact, and located away from pedestrian flow and maintenance activities.

L. High-temperature equipment and piping shall be properly guarded or covered with approved insulation in locations where contact by personnel or combustibles may occur. Routing of high-temperature liquids over maintenance activities, personnel areas, or electrical equipment shall be avoided.

M. The substation supplying the shop ac power shall be isolated from the yard and operate with the negative solidly grounded.

28.9.2 Tunnels

A. The tunnels shall be sized to safely accept the dynamic outline of the vehicles, with appropriate clearances, and accommodate other features such as the safety walks, milepost, and marker signals. In addition:

1. Continuous safety walks conforming to Fire/Life Safety criteria requirements shall be provided throughout the revenue line system. Walkways shall be free of tripping hazards or equipment intrusion into walkway space. Walkways shall be a minimum of 2’-6” wide.

2. Crosspassage doors shall be 1-1/2 hour rated doors capable of withstanding the transient pressures created by the piston effect of trains, reversible in direction.

3. Crosspassages shall provide a standardized location for special equipment, such as emergency trip stations, emergency telephones and fire protection equipment.

4. Studies shall be performed to determine the need to control water infiltration and flooding.

5. Tunnel sections subject to flooding shall be provided with sump pumps designed to handle the infiltrated water resulting from a100-year storm. One hundred percent redundancy shall be provided.

28.9.3 Guideway

A. The guideway shall be protected to prevent vehicular or pedestrian encroachment except at designated points of entrance and egress such as stations, surface transit interchange areas, and parking lots. Patron and other public areas shall be physically separated from operational service areas.

B. Passengers shall enter the guideway area only in an emergency that requires the evacuation of a disabled train. Evacuation shall be undertaken only when other means such as train to train transfers are not possible or desired.

C. There shall be adequate provisions for access and egress by emergency service vehicles and personnel.

D. The design of structures adjacent to the running rails shall be such that the grounding system will limit the potential differences between the passenger vehicles or running rails and any grounded structure or equipment, to protect personnel from dangerous electrical shock. Grounded fixtures in public areas of station platforms shall provide a minimum clearance of 6 feet to the vehicle dynamic envelope.

E. Warning devices shall be installed at locations where pedestrian or vehicular traffic are permitted to cross the guideway.

F. Lane markings, curbs, fencing, and other appropriate means shall be provided to identify the right-of-way and warn the general public of potential danger.

G. Grade crossing protection shall be coordinated with Chapter 11, Traffic Control, Chapter 14, Signal System and Chapter 18, Fire/Life Safety.

H. The roadbed shall be designed to allow for rapid drainage of any water from the tracks and along the roadbed.

28.10 OPERATIONS, MAINTENANCE, AND TRAINING

28.10.1 Manuals and Instructions

Contractors shall be required to provide operating and maintenance manuals and instructions. Safety instructions, warnings, and cautions to alert users to potentially unsafe conditions shall be included. Emergency operating guidelines/instructions shall also be addressed, as appropriate.

28.10.2 Training Programs

A. Systemwide equipment procurement contracts shall require development of training manuals and instructions for operating authority supervisory, maintenance control, and operating personnel. Training programs shall address the following areas, as a minimum:

1. Quick and effective response to abnormal and emergency situations
2. Minimum skill level requirements
3. Identification and use of safety features

END OF CHAPTER 28

29. SECURITY

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29. SECURITY

29.1 INTRODUCTION

29.1.1 Policy Statement

A. The protection of agency assets, personnel, customers, and information is of primary concern to Sound Transit's management and employees. It is the policy of Sound Transit to ensure that security planning relies upon an integrated approach which incorporates crime prevention, physical security, access control, employee training, technology, emergency preparedness, and other measures to achieve a comprehensive Security Plan.

B. This chapter establishes the design criteria for the Sound Transit Link light rail Link System Security. The purpose of this chapter is:

1. To provide sufficient definition and description of security characteristics to allow design engineers to select appropriate features for systems equipment and facilities. This document is designed to outline those standards and guidelines that, if followed, will ensure that the Sound Transit Link System achieves the optimal level of system security.

2. To define the safety and security requirements which shall be included as part of the technical provisions in contract specification documents.

29.1.2 Safety and Security Objectives

A. The safety and security achieved by the Sound Transit Link System is directly dependent on the requirements imposed on the system contractors and the emphasis placed on safety and security management. It is intended that the performance criteria established in this chapter will ensure procurement of equipment capable of meeting the system operational requirements in a safe and secure manner.

B. Safety and Security Program

Sound Transit Link project management shall establish and maintain an effective safety and security program. The program shall be planned, integrated, and developed in conjunction with the reliability and fire/life safety requirements as well as other design, development, and production functions to permit the achievement of the project

goals and objectives. A System Safety Program Plan is required to assure the management and technical skills necessary to achieve Sound Transit Link safety and security objectives are applied in a coherent and organized manner.

C. The security requirements are a subset of the System Safety Program Plan and shall include:

1. A detailed listing and description of each security task
2. The timing of each security task and related milestones
3. The organizational element responsible for each task
4. Identification of security problems requiring resolution
5. Analysis to be performed
6. Security Certification Program
7. Procedures for recording and tracking security problem resolution
8. Testing required to verify compliance with the specified security requirements

D. System Safety & Security Program Plan - Contractors

Manufacturers of the following system equipment shall be required to establish, submit for approval, and maintain a System Safety and Security Program Plan:

1. Vehicle
2. Train Control
3. Communications
4. Traction Electrification

E. References

1. Threat and Vulnerability Assessment
2. Security Plan

29.1.3 Applicable Standards, Codes and Guidelines

A. Security design provisions shall be in accordance with the following standards and guidelines, to the extent used herein. Refer to

Chapter 18, Fire/Life Safety, section 18.1.4, Applicable Standards, Codes and Guidelines, for additional guidelines.

1. "Public Transit System Security and Emergency Preparedness Planning Guide," Final Report, U.S. Department of Transportation, Federal Transit Administration, FTA-MA-26-5019-03-01, DOT-VNTSC-FTA-03-01, January 2003.

2. "Transit Security Design Considerations", Final Report, November 2004. U.S. Department of Transportation, Federal Transit Administration (FTA), FTA-TRI-MA-26-7085-05, DOT-VNTSC-FTA-05-02.

3. Sound Transit regional Transportation Authority/King County Metro Inter-governmental Agreement of Operations.

4. Design of all station areas, platforms, buildings and storage areas shall be prepared in accordance with Transit Security Design Considerations, FTA-TRI-MA-26-7085-05, November 2004, requirements as noted in Appendix C.

29.1.4 Scope

The security criteria, as presented herein, is a compendium of requirements that are substantially supported by codes and standards. The criteria included in this chapter meet or exceed safety and security related codes, standards and regulations promulgated by local, state and federal authorities and should be followed to ensure that System Safety (Chapter 28), Fire/Life Safety (Chapter 18), and security are considered during the design of facilities, systems and equipment. Where more than one code or standard may apply, the more restrictive shall govern except as noted herein.

29.2 STATION SITE

A. Stations shall be designed to facilitate the movement of patrons in an efficient, safe and secure manner.

B. The security program shall ensure that the design of Link system stations include features that enhance both the actual and perceived security of the using public. Of equal importance is the need to protect system employees from crime or harassment, and system property from loss, damage, or vandalism. This chapter contains criteria for achieving these objectives.

29.2.1 Site

A. In general, Link facility designs shall include features that enhance patron security through:

1. Maximum visibility of the entrances and the facility from adjacent areas.

2. Vegetation not hindering fields of vision.

3. Surfaces and equipment accessible to the public, (fare machines, emergency or call for aid telephones).

4. Station floors and walls vandal-resistant.

5. Adequate lighting and accessibility to the site.

6. Clear lines of sight of parking lots, adequate illumination and ease of access for surveillance.

29.2.2 Passenger Stations

A. The design of passenger stations shall be open, with long, unbroken lines of sight, eliminating all dark or obscure areas.

B. Equipment or ancillary rooms shall be separated from the public areas by vandal resistant doors that normally shall be locked, using key combination or magnetically activated dead-bolt locks. Unauthorized entry shall alarm at OCC.

C. In accordance with Board Motion 98-67, public rest rooms will not be provided as a standard feature at passenger stations, but may be provided where existing in combination with adjacent transit facilities, parking garages, or park-and-rides. Employee restrooms, where provided, shall be locked.

D. Station illumination levels shall be selected to maintain a reasonable level of security during non-daylight hours.

E. Underground and elevated stations shall be secured during non-revenue hours by roll-down gates or equivalent measures. Attempts to open gates without proper devices and/or authorization shall alarm at OCC.

F. Unauthorized entry into emergency stairs from grade shall alarm at OCC.

G. Access by emergency vehicles to station structures shall be provided. All portions of the interior of the stations shall be accessible to

emergency personnel, with the use of only those keys or special tools that are essential.

H. Tampering with fare collection equipment shall alarm at OCC.

I. At-grade locations shall be selected for security and ease of surveillance by security forces and users.

29.2.3 Elevators

A. In addition to the provisions of Chapter 18, Fire/Life Safety, the elevators shall include the following features:

1. Elevators shall have glass door panels (except where used for high-speed emergency egress) and two-way voice communications with OCC.

2. Elevators shall be passenger-activated.

3. Elevators shall be monitored by SCADA.

29.3 GUIDEWAY

A. Wherever practical, guideways on shared and semi-exclusive right-of-way shall be protected from encroachment of unauthorized vehicles, people, or objects.

B. Curbs, tactile surfaces, or other techniques shall be used to separate the LRV rights-of-way in streets.

C. Where the trains operate in a highway median and fencing is provided, vehicular encroachment devices shall be provided on the fencing, which alarm audibly and visually at OCC.

D. On highway ramps, bridges and other traffic elements, which cross over the right-of-way, barriers/fencing shall deter vehicular or load intrusion and the dropping of objects onto the guideway. Where appropriate, nonscalable fencing shall be used.

E. Fencing shall meet local building codes with respect to setbacks, and height.

29.4 LIGHT RAIL VEHICLE (LRV)

This section defines the security requirements for LRVs.

29.4.1 General Requirements

A. The interior finish of the transit vehicle, including seats, seat backs, and trim panels, shall be made from vandal-resistant material.

B. Seats, seat backs, and equipment access panels shall be removable only with the use of special tools.

C. Passenger Intercoms shall be provided in each car for communications with the operator.

D. See Chapter 12, Light Rail Vehicle, for additional requirements.

29.5 SIGNALING

A. Wayside equipment shall be protected by the use of tamper-resistant covers for switch machines, equipment boxes, and signaling standards, as well as vandal-resistant trackside electrical connections.

B. Where deemed appropriate, further protection may be provided through intrusion-detection devices.

C. See Chapter 14, Signal System, for additional requirements.

29.6 COMMUNICATIONS

A. Dependable, flexible and redundant communication networks shall be provided for continuous contact with required personnel and patrons.

B. See Chapter 18, Fire/Life Safety, section 18.5, Signaling and Chapter 28, System Safety, section 28.4, Communications, for additional fire/life safety and system safety requirements for the design of communications systems.

C. See Chapter 15, Communications and Central Control, for additional requirements.

29.6.1 Closed Circuit Television (CCTV) Monitoring

A. CCTV monitoring capability shall be provided at all high-risk and security-sensitive areas.

B. The security coverage shall include: platform edge, passenger emergency telephones, fare collection array, entrances and exits to elevators (see Chapter 9, Stations, section 9.6.4, Elevators), and sensitive areas of the maintenance facilities, not directly observable from the yard control tower.

C. Signals from the monitoring cameras shall be returned to the OCC central control for display on video monitors. Cameras may be sequenced throughout the station except for dedicated cameras at the underground station platforms.

D. Cameras shall be capable of operating effectively at emergency light levels.

29.6.2 Intrusion Alarm System

A. An intrusion-detection and alarm system shall be applied throughout the Sound Transit Link System. The intrusion-detection systems shall allow Sound Transit Link to detect unwarranted and forced entry to non-public areas. The instruction-detection methodology shall be selected by Sound Transit Link after review and evaluation of similar light rail transit systems in the United States, current technology, recommendations of security specialists, and Sound transit policy. Intrusion-detection systems shall not inhibit egress to an area of safety. The intrusion alarm system shall be supportive of a central-station burglar-alarm system that complies with UL 827 by complying with the applicable codes and standards referenced in UL 827.

B. The intrusion-detection system shall detect activities related to intrusion and encroachment involving designated doors, gates, windows, and fare-collection equipment. Detection of such activities shall be reported to the central station at the central control facility. In addition, local audible alarms shall be provided for intrusion-detection at emergency exit doors and hatches.

C. The Sound Transit Link evaluation will pay particular attention to applying instruction-detection to the following areas:

1. Ancillary rooms directly connected to a public area.

2. Ancillary rooms connected to a corridor, hall, vestibule, or landing that is directly connected to a public area.

3. Closed-circuit-television observation rooms when housed in rooms that are barrier-separated from control rooms or other areas.

4. Communications rooms and buildings, including telephone-equipment rooms.

5. Control rooms and towers.

6. Data processing rooms.

7. Electrical equipment rooms, whether designated an auxiliary power, battery, electrical, utility power, meter, or other name.

8. Emergency exits.
9. Emergency exit hatches.
10. Operations computer rooms.
11. Passenger station entry rolling grilles, gates, doors, and the like.
12. Signaling rooms and buildings.
13. Sprinkler valve rooms.
14. Traction power substations.
15. Yard control towers.
16. Rooms and areas associated with fare collection and money.

29.7 ELECTRICAL POWER

A. This section defines the security requirements for the design of electrical power, traction power and traction power substations.

B. External equipment shall be enclosed by non-scalable barriers of suitable height, which will also deter hurling of objects into the enclosure.

C. Intrusion-detection shall be installed.

D. Gap-tie station structures, if used, shall receive the same level of protection as the traction power substations.

E. See Chapter 13, Traction Electrification, for additional requirements.

29.8 YARDS AND SHOPS

This section defines the security requirement for yard and shops.

29.8.1 Maintenance Facilities (Yards and Shops)

A. The maintenance facilities shall be enclosed by a nonscalable barrier of sufficient height to deter intruders.

B. A clear zone adjacent to the barrier to avoid obstructing visibility and offering protection or concealment to vandals or intruders shall be provided.

C. Only a single, monitored security gate for controlling access and egress to normal surface traffic should be provided. The access

points shall meet the requirements of primary access of emergency personnel and equipment to include:

1. Entry shall be by means of coded employee identification to activate gate arms, gate fences or other gate barriers.

D. Within the shop, equipment and parts storage shall be secured and issuance controlled through procedures.

E. See Chapter 19, Operations and Maintenance Facility, for additional requirements.

29.9 OPERATIONS CONTROL CENTER (OCC)

A. This section defines the security requirements for the design of the OCC and parking facilities.

B. The OCC shall be the central point for coordinating all train operations, station operations and for communicating directly with train operators, maintenance, supervisory, emergency personnel, and patrons (as required). The following capabilities shall be incorporated into the design of the OCC.

C. See Chapter 15, Communication and Central Control, and Chapter 19, Operations and Maintenance Facility, for additional requirements.

29.9.1 Operations Control Center (OCC)

A. Special provisions shall be made for the protection of critical activities and equipment of the OCC functions.

B. Entry into the control room shall be controlled and limited to those specifically authorized. Entry into any viewing room, if provided, shall also be controlled and restricted to visitors being escorted by authorized employees. Doors providing entry into the control room and into the viewing room shall be appropriately protected with locks. If a window is provided between the viewing room and the control room, it shall be of impact-resistant safety glass or other appropriate material. The window frame shall be designed to resist removal of the glass from the frame.

29.10 PARKING LOTS

A. Parking lots associated with the Sound Transit system shall be designed to maximize the visibility of all parts of the lots from surrounding areas. Lighting shall be used to prevent the creation of dark areas during non-daylight hours. If there is a charge for parking, then provisions shall be made for secure, on-site storage of any money collected, for the protection of personnel, and for

the pick-up and transport of the collected funds.

B. Parking Lot Emergency Telephones shall be identified and installed within 500 feet of any location within the lot. Where determined appropriate and necessary for security, CCTV cameras shall be installed to monitor the parking facilities.

29.11 TRAINING

A. It is essential that careful planning must be accomplished to ensure the safety and security of passengers and employees, and efficient and reliable service.

B. All Link system employees involved in the design shall undergo training and orientation regarding their contribution to security, and to anticipate potential security-related problems that they could be expected to respond to, or assist in. This training/orientation should emphasize their contribution toward security.

C. All personnel providing security on the Sound Transit Link system shall be required, as a minimum, to undergo training on the subjects identified in Chapter 18, Fire/Life Safety.

D. Sound Transit will provide Security Awareness Training to all employees and will ensure that Passenger Security Awareness Signage is posted at all stations and on all LRV's.

29.12 CONTROLLED-ACCESS FUNCTIONAL REQUIREMENTS

29.12.1 General

A. A key-actuated controlled-access system (door locks and the like) shall be applied throughout the Sound Transit Link System to allow Sound Transit Link personnel entry to non-public areas. Controlled-access systems shall not inhibit egress to an area of safety.

B. Door locks and other controlled access methods used during construction and other pre-revenue activities shall be removed and replaced by the permanent controlled access system.

C. Unique keys shall be applied to each of the following:

1. Fare collection equipment
2. Rooms associated with money
3. Restrooms

4. Communications, computer, data processing, and signal rooms
5. Security-related areas
6. Traction power and high voltage electrical rooms (26kV, for example)
7. Central control
8. Yard control towers.

END CHAPTER 29

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APPENDIX A

SOUND TRANSIT BOARD MOTIONS

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SOUND TRANSIT BOARD MOTIONS

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Regional Transit Authority
Motion No. 40

A motion of the Board of the Regional Transit Authority for the Pierce, King and Snohomish Counties region committing to the integration of public art in the implementation of the *Sound Transit* system.

Motion:

It is hereby moved by the Board of the Regional Transit Authority that:

Commitments to public art:

- Implementation of the *Sound Transit* system will include works of art that contribute to a positive experience for system users and affected communities.
- Artists will participate in the design of transit facilities and public spaces to maximize the opportunities for integrating art into construction.
- Affected communities will be involved in decisions regarding where and what type of art is appropriate in their communities, and in the selection of artists to execute the artwork.

Master plan and budget:

Staff is directed to:

- Develop a master plan for art, which will identify opportunities for integration of art in the Sound Transit system and policies and procedures for implementing the art program.
- Identify appropriate alternative art program budgets for Board review and discussion, followed by a resolution for adoption of a budget.
- Establish a Sound Transit art advisory group to provide advice in the development and implementation of the art program.

Interim policy direction:

- Progress in implementing *Sound Transit* projects is to continue while the art master plan and budget are being developed. Any interlocal agreements, requests for consultant proposals or contracts prepared during this time should reflect the policy direction provided in this motion.

Approved by the Board of the Regional Transit Authority for the Pierce, King, and Snohomish Counties region at a meeting thereof on the 11th day of September 1997.

Bob Drewel
Bob Drewel
Board Chair

ATTEST:

Marcia Walker
Marcia Walker
Board Administrator

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SOUND TRANSIT

MOTION NO. M98-58

A motion of the Board of the Central Puget Sound Regional Transit Authority to establish policy for station/facility design issues common to all three Lines of Business with respect to Automated Teller Machines (ATM's), Bicycles, Passenger Amenities, and Signage.

Background:

The three Lines of Business have been developing design elements in common to ensure all of Sound Transit will work as a unified whole and to assist in the development and maintenance of integrated systems. The goal is to establish policy and criteria that will serve all Lines of Business and work with our partnering agencies in the region. We wish to determine the common thread of design elements that applies to all facilities versus standardization throughout. This approach encourages uniformity where it is most advantageous and also allows individuality. This motion identifies policy issues for ATM's, Bicycles, Passenger Amenities and Signage, as they relate to station/facility design. Background information, including other systems experiences, costs, and options for each of these issues was presented to the Board on August 13, 1998. After policy decisions are determined, specific design criteria will be drafted for designing and developing Sound Transit facilities.

Motion:

It is hereby moved by the Board of the Central Puget Sound Regional Transit Authority that the following items are adopted as policy for all three Lines of Business station/facility design:

A. Automated Teller Machines (ATM's)

With respect to ATM's, Sound Transit shall:

- provide as a customer convenience at Sound Transit facilities where market conditions support such a use through contracts with private financial providers
- provide provisions for ATM's in projected growth locations to accommodate future installations
- pursue advantageous and cost effective services for installation, operation and maintenance with private financial providers
- condition contracts with financial providers to enable purchase of transit passes
- locate in a safe environment, which does not impede the general flow of traffic

B. Bicycles

With respect to bicycles at stations/facilities, Sound Transit shall:

- design facilities to provide ample space for maneuvering bicycles in and through stations and onto vehicles

- provide a mix of storage lockers and locking racks, based on projected patronage of facilities
- provide storage areas open to circulation, on direct paths from access points, and to not impede pedestrian and vehicular traffic flows
- designate areas, where possible, for storage expansion to accommodate bicycle ridership increases

C. Passenger Amenities

With respect to passenger amenities at stations/facilities, Sound Transit shall:

- provide comfort for the customer in the manner of weather protection, benches, lighting, etc.
- provide high quality civic architecture with high quality public art
- design appropriately sited facilities that are easily maintained, vandal resistant and constructed of durable materials
- layout facilities to minimize walking distances between modes of transit
- include design elements that extend between Sound Transit and other transit agency modes, which may include weather protection in conjunction with other agencies, signage, lighting, and finishes
- provide amenities, such as benches, water fountains and lighting, to assure safe, comfortable use of facilities
- develop performance criteria for system-wide lighting that will promote energy efficiency and minimize number of lamp types for ease of maintenance

Weather Protection

- provide weather protection at all stations/facilities that generously accommodates average peak period estimated ridership, and consider special event station needs separately
- extend weather protection fully to the vehicle loading zone, whenever possible
- provide protection from wind blown rain/snow and develop gutter systems that assure protection from the elements
- provide protection for exterior fixtures such as fare-vending and signage to aid customer comfort and as preventative maintenance of appurtenances

Heating/Cooling

- provide mechanical ventilation systems, as required by code, in structured parking and tunnel areas
- not provide heating or cooling at exterior stations/facilities as they are not effective nor energy efficient, and are expensive to purchase, install, operate and maintain

D. Signage

With respect to signage, Sound Transit shall:

- develop a system-wide signage program that is clear, concise and consistent as a unified baseline that allows flexibility for each line of business and integrates with other agency signage systems
- locate trailblazing signs on major interstates, highways, and arterials within a ½ mile radius of facilities, and neighborhood streets within ¼ mile radius as well as main pedestrian routes
- consider, on a site by site basis, installation of trailblazing signs from major regional facilities
- work with local agencies to determine appropriate installation locations and responsibility for continued maintenance of trailblazing signs
- make provisions for locating community bulletin boards at facilities
- install community bulletin boards upon the formal request of local jurisdictions where agreements are developed for those communities to provide the appropriate media and maintain the bulletin boards, whether it be for paper notices or electronic media, except in the case of major multi-modal facilities
- locate bulletin boards so as not to interfere with signage, public art or use of the facility and impede traffic flow

Adopted by the Board of the Central Puget Sound Regional Transit Authority at a regular meeting thereof on the 13th day of August, 1998.

Bob Drewel
Board Chair

ATTEST:

Marcia Walker
Board Administrator

SOUND TRANSIT

MOTION NO. M98-58

Station/Facility Design Issues in Common
For
Commuter Rail, Link Light Rail and Regional Express

BACKGROUND AND COMMENTS

Meeting:	Date:	Type of Action:	Staff Contact:	Phone:
Board Meeting	8/13/98	Action	Betty Laurs, Commuter Rail Debora Ashland, Link Light Rail Linda Smith, Regional Express	206-689-7440 206-689-3309 206-689-4922

ACTION:

The adoption of Motion No. M98-58 is being requested of the Board at this time for some of the design issues in common to all three Lines of Business as they relate to station/facility design. Our intent for this meeting is to further discuss the station design policy issues for ATM's, Bicycles, Passenger Amenities and Signage and present staff recommendations. The number of design issues for Sound Transit facilities is fairly extensive and will require several meetings to complete all Board action items. The remainder of the policy issues will be discussed at the Board Meeting on August 27, 1998. All Design Issues in Common will be incorporated into each Line of Business Design Criteria Manual.

BACKGROUND:

In order to proceed with design and engineering, Sound Transit's philosophy needs to be addressed, with respect to design, maintenance and operation of facilities. This will set the standards for which design criteria can be established and create a basis for designers, engineers and architects to begin their work on station design.

The three Lines of Business have been discussing design elements in common to ensure all of Sound Transit will work as a unified whole and to assist in the development and maintenance of integrated systems. The goal is to establish policy and criteria that will serve all Lines of Business and work with our partnering agencies in the region. System-wide standardization can encompass a spectrum of issues from mandating uniformity throughout to allowing individual design everywhere. We wish to determine the common thread of issues that applies to all facilities. This approach encourages uniformity where it is most advantageous and allows individuality by each Line of Business, and by region, community and neighborhood where it is appropriate.

At the July 17, 1998 Executive Committee Meeting, we generally discussed all the design elements listed on the updated attached spreadsheet. The items under consideration at this time are shaded. We have added to the list Security and Facility / Station. We are continuing to develop information and recommendations on each of the policy issues. We will be presenting at the Board meeting each design element in the following format to facilitate the policy discussion:

1. Description of Element
2. Background
   a. Others' experiences
   b. Costs: construction, operating, maintenance
3. Options
4. Staff Recommended Approach
5. Policy Decisions
6. Criteria / Standards / Physical Requirements (to be developed in detail after policy decision)

This written material contains only staff recommendations for ATM's, Bicycles, Passenger Amenities and Signage, as they relate to station/facility design. Background information, including other systems experiences, costs, and options for each of these issues will be presented to the Board on August 13, 1998 for further discussion. The August 27, 1998 Board Meeting will address Concessions, Restrooms, Security and Advertising that pertain to station/facility design. After policy decisions are determined, specific design criteria will be drafted for designing and developing Sound Transit facilities.

STAFF RECOMMENDATIONS FOR AUGUST 13, 1998 BOARD MEETING:

Automated Teller Machines (ATM's)

Accommodations for Automated Teller Machines will be provided at Sound Transit facilities as a customer convenience in multi-modal stations/facilities where the private financial providers determine that market conditions support such a use. Where market conditions do not warrant the installation of an ATM at station opening, provisions will be made for projected growth locations to accommodate a future installation, such as spare capacity for power and installation of conduit.

ATM's within Sound Transit facilities shall be located in a safe environment, which does not impede the general flow of traffic during peak periods.

Sound Transit shall pursue advantageous and cost effective services for installation, operation and maintenance of ATM's with private financial providers.

Sound Transit shall condition contracts with financial providers to enable purchase of transit passes through ATM transactions.

Bicycles

Bicycles will be a common method of transportation to and from Sound Transit facilities. As identified in the Sound Move Plan, we will work with local jurisdictions and communities to determine appropriate bicycle improvements within a ½ mile radius of stations. We intend to come back to the Board with the recommendations on access to facilities after these joint discussions.

This policy decision only deals with bicycle station/facility design issues. Facilities shall be designed to provide ample space for maneuvering bicycles in and through stations and onto vehicles. Bicycles can be accommodated on Light Rail vehicles, Sounder vehicles and Regional Express buses.

Bicycle storage at stations shall be provided. A mix of storage lockers and locking racks will allow frequent and infrequent users of the system to safely store their bicycles. The quantity of lockers and bike racks shall be based on projected patronage of facilities. Both storage lockers and bike racks shall be provided in areas open to circulation, on direct paths from access points, and to not impede pedestrian and vehicular traffic flows. Additional area should be designated, where possible, for expansion to accommodate bicycle ridership increases in the future.

Passenger Amenities

Passenger Amenities include items that provide comfort for the customer. These items include, but are not limited to, weather protection, benches, lighting, heating/cooling, et cetera.

Facilities shall be quality civic architecture with quality public art. Facilities shall be appropriately sited, easily maintained, vandal resistant and constructed of durable materials.

Layout of facilities shall minimize walking distances between modes of transit. Design of facilities shall include elements that extend between Sound Transit and other transit agency modes in consideration of transferring patrons. These elements may include weather protection in conjunction with other agencies, as well as signage, lighting, and finishes.

Sound Transit will provide weather protection at all stations/facilities. The extent of coverage shall generously accommodate average peak period estimated ridership. Special consideration should be given to special event stations. Weather protection shall extend fully to the vehicle loading zone, whenever possible. Designs shall accommodate protection from wind blown rain/snow and gutter systems shall assure protection from elements. Exterior fixtures such as farevending and signage shall also be protected from the weather to aid customer comfort and as preventative maintenance of appurtenances.

Passenger amenities, such as benches and lighting, will be provided to assure safe, comfortable use of Sound Transit facilities. Performance criteria will be developed for system-wide lighting that will promote energy efficiency and minimize number of lamp types for ease of maintenance.

To provide easily maintained and cost effective operations, no heating or cooling will be provided at stations/facilities. Due to the Washington State Energy Code requirements, exterior heating systems that meet code are less than effective, according to Intercity Transit who has installed these systems in their Olympia Transit Center. The allowable low wattage units do not provide much heat and are expensive to purchase, install, operate and maintain. Mechanical ventilation systems will be provided, as required, in structured parking and tunnel areas.

Signage

Sound Transit will develop a system-wide signage program that is clear, concise and consistent. This program will set a unified baseline for Sound Transit, yet allow flexibility of each line of business to expand as needed to accommodate all types of facilities (examples: park and rides, tunnel or aerial light rail stations). The program shall recognize the needs of other agencies and integrate with their signage systems.

The Sound Transit signage system will include:

- trailblazers to stations and facilities (policy direction needed, see below);
- identification signs to mark station entrances or facilities;
- wayfinding or directional information within stations and facilities;
- signage that provides information on how to use services, fares, schedules in the form of informational kiosks, customer information centers, et cetera;
- safety and regulatory signage to promote safe use of facilities;
- the ability to adapt to local signage code regulations; and,
- potential for community bulletin boards where appropriate and if supported by the community (policy direction needed, see below).

The signage system will use the latest 'state of the art,' design principles, incorporating:

- easily readable type faces and images;
- ADA features to meet the needs of the disabled community;
- international pictograms and symbols;
- current technology, including dynamic, multi-lingual, audio and electronic messages wherever appropriate and feasible;
- electronic informational kiosks linked to other regional informational systems to provide our customers with the latest information and services; and,
- designs that can be easily maintained with realistic life cycle costs.

Sound Transit shall work with local agencies to determine appropriate installation locations and responsibility for continued maintenance of trailblazing signs. Trailblazing signs shall be located on major interstates, highways, and arterials within a ½ mile radius, and neighborhood streets within ¼ mile radius as well as main pedestrian routes such as the Burke-Gilman, Green River, and Cedar River trails. Special conditions shall also be considered on a site by site basis to promote ease of wayfinding, such as station directional signage from major facilities (SeaTac Airport, Southcenter, Regional Justice Center, Safeco Stadium, et cetera).

Provisions for community bulletin boards shall be provided at Sound Transit facilities. They shall be located to not interfere with signage, public art or use of the facility and traffic flow.

Installation of bulletin boards, whether they are for paper notices or electronic media, will be provided at the formal request of the local jurisdiction and where agreements are developed with communities to provide the appropriate media and maintain the bulletin boards.

RELEVANT BOARD POLICIES AND PREVIOUS ACTIONS TAKEN:

- Adoption of *Sound Move*, The Ten-Year Regional Transit System Plan (May 31, 1996)
- Resolution No. 98-3 (January 22, 1998), Light Rail Consultant Contract with PSTC
- Resolution No. 98-11 (April 9, 1998)
- Executive Committee Discussion on July 17, 1998 (No action)

KEY FEATURES:

Staff recommendations for Station/Facility Design Issues for ATM's, Bicycles, Passenger Amenities and Signage as they pertain to design issues in common for all Lines of Business: Commuter Rail, Link Light Rail and Regional Express, and in partnership with the other regional providers, and jurisdictions.

ALTERNATIVES:

The following alternatives are available for Board action:

1. Adopt the design policy issues as presented above after discussion of all material.
2. Adopt a portion of the design policy issues as presented above to allow design work to continue and list specific items as needing further review and/or discussion.

CONSEQUENCES OF DELAY:

Agreement on the design criteria is essential to continuing the design phase for all three Lines of Business. We expect to have all the design criteria in place by the end of September 1998.

The Sounder staff is currently working with the cities and their Technical Advisory Committees to choose design teams for all stations between Tacoma and Seattle. The selection process has been completed and contracts are pending. Board award of design contract is expected in August 1998 with the design period extending from September 1998 through January 1999.

Regional Express has awarded contracts for environmental review and preliminary design for several community connections and direct access improvement projects. Environmental analysis is underway and preliminary design will begin in the fall of 1998.

Link Light Rail has awarded design contracts to Puget Sound Transit Consultants (PSTC) for all stations. Conceptual design work will be completed in December 1998 with preliminary engineering finishing by December 1999.

Schedules for all three Lines of Business are based on the implementation plan adopted by Sound Move and allow little deviation. Delay in design criteria development will negatively affect the facility design schedule, which will negatively affect the overall construction schedule for all Lines of Business.

Attachment

ATTACHMENT
MOTION NO. M98-58

Station/Facility Design Issues in Common for Commuter Rail, Link Light Rail and Regional Express

Issues	Policy Issue	Operational Issue	Maintenance Issue	Design Issue	Comments
Overall Facility Design					
ADA Features			●	●	
ATM's	●			●	Yes / No?, Where?, How are they contracted?
Art			●	●	
Bicycles	●	●		●	Access?, Provide storage?
Concessions	●			●	Yes / No?, What?, Where?
Equipment (farevending, etc.)			●	●	
Landscaping			●	●	
Lighting (lamp type and internal optics)		●	●	●	See passenger amenities below.
Newspapers				●	
Parking Facility Design		●		●	
Passenger Amenities	●		●	●	Weather protection, benches, heaters, lighting
Performance Criteria		●	●	●	
Restrooms	●	●	●	●	Yes / No?, Where?, Who maintains?
Systems (comm., emerg. egress, etc.)		●	●		
Telephones				●	
Weather Protection		●	●	●	See passenger amenities above.
Security	●	●	●	●	Extent of security to be provided?
Signage / Wayfinding					
Station Identification				●	
Trailblazing	●			●	How far from stations?
Directional / Informational				●	
Electronic / Audio				●	
Community Bulletin (electronic/video?)	●		●	●	Yes / No?, Who maintains?
Advertising					
Interior of Vehicles	●			●	Yes / No?, Where?, Content?, How contracted?
Exterior of Vehicles	●			●	Yes / No?, Where?, Content?, How contracted?
In Facilities	●			●	Yes / No?, Where?, Content?, How contracted?
Station/Facility Development					
Joint Use Development		●	●	●	Site specifics addressed separately
Transit Oriented Development		●	●	●	Site specifics addressed separately

SOUND TRANSIT

MOTION NO. M98-60

A motion of the Board of the Central Puget Sound Regional Transit Authority to establish policy for Link Light Rail design issues.

Background:

In order to continue with conceptual and preliminary engineering, design criteria need to be established. These design criteria will set the standard for how Sound Transit will proceed with design and construction of the system by creating a basis for the engineers, architects and designers. This motion presents policy issues for Architectural Expression of the stations, Vertical/ Horizontal Circulation, Guideway Architecture and Streetscape issues. After policy decisions are determined, specific design criteria will be drafted for designing and developing Sound Transit facilities.

Motion:

The Board of the Central Puget Sound hereby moves that the Regional Transit Authority adopt the following items as policy for Link Light Rail design criteria:

A. Architectural Expression

With respect to the architectural expression of stations, Sound Transit shall:

- provide a balanced approach to station design, allowing station organization and selected functional elements to be standardized, yet also allowing designs to be responsive to the diversity of their immediate environs
- organize stations to be consistent and clear to the users recognizing the site-specific requirements of individual types of stations, as in at-grade facilities
- standardize system-wide equipment, such as fare-vending machines, elevators and escalators, emergency and security equipment, in order to promote cost effectiveness for initial construction and long term maintenance costs
- standardize the platform edge and safety zone to minimize safety issues
- develop families of parts or materials and performance criteria for other station components, such as lighting, trash receptacles, seating, railings, finish materials and landscaping
- follow the Sound Transit system-wide signage program currently in development, and the Light Rail system shall modify the overall Sound Transit signage program in unique Light Rail situations, such as aerial and tunnel stations
- pursue a thorough and ongoing neighborhood involvement process in order to respond to the neighborhood context, goals and principles, recognizing that those may be broadly and creatively addressed through station programming and design

B. Vertical/Horizontal Circulation

With respect to vertical and horizontal circulation, Sound Transit shall:

- establish performance standards and design criteria for pedestrian circulation elements and associated spaces based on code requirements, ADA requirements, patronage characteristics and established transit planning practices
- provide stairs and ramps as the primary vertical circulation elements where the vertical rise between public circulation levels is 12 feet or less, unless high patron volumes warrant the use of escalators (over 5,000 patrons a day)
- provide a combination of stairs, elevators and escalators in the up direction only where the vertical rise between public levels exceeds 12 feet but does not exceed 25 feet, unless high patron volumes warrant otherwise (over 5,000 patrons a day)
- provide escalators in both directions, in addition to elevators and stairs, when the vertical rise exceeds 25 feet and in heavily patronized stations (over 5,000 patrons a day)
- provide high-speed elevators as the primary means of vertical transportation where the depth of the subway station exceeds 120 feet from entry level to platform level

C. Guideway Architecture

With respect to guideway architecture, Sound Transit shall:

- integrate with the community and neighborhood character
- enhance the street as an amenity and provide human scale (see Streetscape below)
- consider not only existing conditions, but shall recognize adopted community/neighborhood plans for the future
- integrate the public art process into the design and development of all guideway architecture
- address tunnel segments as guideway architecture rather than solely utilitarian components

<u>At-Grade Architecture</u>

- be responsive to the streetscape and consistent with the neighborhood context
- develop cost effective improvements that are equitable throughout all alignments
- select appropriate materials that conform to Sound Transit's developed family of materials, such as landscaping and paving

<u>Aerial Guideway</u>

- develop aerial guideway architecture that is responsive to scale and character of the neighborhood
- develop structurally efficient, cost effective guideways
- be adaptable to a variety of contextual situations while having a distinct "signature"

D. Overhead Contact System (OCS)

With respect to overhead contact system, Sound Transit shall:

- consider urban design and aesthetic considerations of poles and hardware
- develop OCS which are in character and scale with their immediate environs
- pursue the joint use of poles for OCS, street lighting and signing
- integrate the public art process in design and development
- develop cost-effective designs

E. Streetscape

With respect to streetscape, Sound Transit shall:

- design in character with the community and recognize the need to develop stations as part of a larger community environment
- develop in conjunction with local agencies and their adopted neighborhood plans
- improve areas equitably throughout the entire Link system
- limit improvements to those required for operations of the transit system and to the confines of the right of way disturbed by construction of the system
- provide ample pedestrian access from adjacent streets
- provide connections to other adjacent transit facilities, whenever possible
- improve areas beyond the scope of transit related facilities as joint improvements with local jurisdictions, when in the public right of way, and with local developers or communities in private property areas
- work with local public transportation agencies, communities and local governments to include making improvements within one-half mile of each station for safe, easy transit, pedestrian and bicycle access as outlined in Sound Move

Adopted by the Board of the Central Puget Sound Regional Transit Authority at a regular meeting thereof on the 27th of August, 1998.

Paul E. Miller

Paul Miller
Board Chair

ATTEST:

Marcia Walker

Marcia Walker
Board Administrator

SOUND TRANSIT

MOTION NO. M98-60

Design Issues
Link Light Rail Urban Design Components,
Guideway and Station Design

BACKGROUND AND COMMENTS

Meeting:	Date:	Type of Action:	Staff Contact:	Phone:
Board	7/23/98	Discussion	Paul Bay, Director, Link Light Rail	206-689-4761
Executive Committee	8/21/98	Action to recommend Board approval (Meeting Cancelled)		
Board	8/27/98	Action		

ACTION:

The adoption of Motion No. M98-60 is being requested of the Board at this time for design issues specific to the Link Light Rail system. These include Urban Design Components, Guideway and Station Design issues. Light Rail vehicle design criteria will also need to be addressed and will be done separately from this motion. Many additional design issues pertain to all three lines of business: Link Light Rail, Regional Express and Commuter Rail. The items of commonality are being addressed in separate discussions with the Board.

BACKGROUND:

In order to continue with conceptual and preliminary engineering, design criteria need to be established. These design criteria will set the standard for how Sound Transit will proceed with design and construction of the system by creating a basis for the engineers, architects and designers.

STAFF RECOMMENDATIONS FOR AUGUST 21, 1998 EXECUTIVE COMMITTEE

This following material contains staff recommendations for Architectural Expression of the stations, Vertical/ Horizontal Circulation, Guideway Architecture and Streetscape issues. In addition to specific recommendations, herein, we also recognize and are sensitive to the issue of "fairness" of design; that one community is not treated any differently than another based on relative influence or wealth. We have used the term equity in the text of this document to address that awareness. It is our intention that all elements of the Link Light Rail system be consistent and provide a high degree of quality overall.

Architectural Expression

There are three basic approaches to station design. One approach has an individual expression for each station, another applies a unified system-wide design concept, and the third is to provide a balanced approach with some elements of continuity and some of differentiation.

Sound Transit shall provide a balanced approach to station design, allowing station organization and selected functional elements to be standardized, yet also allowing designs to be individualized and responsive to the diversity of their surroundings. The spatial organization of stations shall be as consistent and clear to the users as possible, recognizing the site-specific requirements of individual types of stations, as in at-grade facilities.

System-wide equipment, such as fare-vending machines, elevators and escalators, shall be standardized in order to promote cost effectiveness for initial construction and maintenance costs. Emergency and security equipment should also be considered as standardized system-wide elements. In addition, the platform edge and safety zone shall be consistent throughout all Light Rail stations to minimize safety issues.

Sound Transit shall develop families of parts or materials, including performance criteria, and for other station components such as lighting, trash receptacles, seating, railings, finish materials and landscaping. These families of materials can be used to establish repetitive themes, while allowing flexibility of other elements. The regional image may be exploited in one instance, while another element may be echoed as a community theme for more than one station, such as lighting.

Light Rail signing and graphics will follow the Sound Transit system-wide signage program currently in development. Where additional situations warrant more extensive signing, such as aerial and tunnel stations, the Light Rail signage system shall build on the Sound Transit program by echoing the criteria that will be established.

Vertical/Horizontal Circulation

The Link Light Rail system will include at-grade, subway, and aerial stations--the latter two of which will require stairs, ramps, escalators and elevators to facilitate patron movement. The design of these pedestrian circulation elements and associated spaces will require that a set of performance standards and design criteria be established. These criteria will, in part, be based on code requirements, ADA requirements, patronage characteristics and established transit planning practices.

To facilitate the continuation of work on individual station design concepts, preliminary criteria are required for certain vertical circulation elements in grade separated stations, particularly escalators. In some stations, it will be beneficial to have longer runs of escalators, as well as elevators, in order to connect patrons from further away, thereby expanding the station further into the community. The following criteria are primarily based on vertical height change. However, higher patronage of a station may warrant an increased level of vertical circulation. Stations with patronage exceeding 5,000 to 6,000 people a day, regardless of vertical height change, may require additional stairs or escalators to accommodate moving people more expeditiously. The Seattle Bus Tunnel provides escalators in the up direction only and currently serves between 5,000 and 15,000 patrons a day.

- Where the vertical rise between public circulation levels is 12 feet or less, stairs and ramps should be the primary vertical circulation elements, unless high patron volumes warrant the use of escalators.

- Where the vertical rise between public levels exceeds 12 feet but does not exceed 25 feet, vertical circulation shall be provided with elevators, stairs and escalators in the up direction only, unless high patron volumes warrant otherwise.
- In addition to elevators and stairs, escalators should be provided in both directions when the vertical rise exceeds 25 feet and in heavily patronized stations. Where the depth of the subway station exceeds 120 feet from entry level to platform level, high-speed elevators shall be the primary means of vertical transportation.

Guideway Architecture

Guideway architecture consists of at-grade and aerial alignments. Tunnel segments will be utilitarian and therefore not addressed as guideway architecture. Both aerial and at-grade situations will raise urban design and aesthetic considerations in selected environs. All guideway architecture shall integrate with the community and neighborhood character, enhance the street as an amenity, and provide human scale. Design of these elements shall consider not only existing conditions, but shall recognize adopted community/neighborhood plans for the future. In addition, the Sound Transit public art process will be an essential part of the design and development of all guideway architecture.

At-Grade Architecture

At-grade alignments will require trackway to be integrated into the local surroundings. This trackway shall be responsive to the streetscape, consistent with the neighborhood context, cost effective and equitable throughout all alignments. Selection of appropriate materials, such as landscaping and paving, shall conform to Sound Transit's developed family of materials and coordinate with local jurisdiction requirements.

Aerial Guideway

Aerial guideway and the supporting structure shall be appropriately scaled and adaptable to a variety of contextual situations, particularly pedestrian-oriented urban environments. A basic aerial guideway architectural concept should adapt to the local communities while retaining a regional distinct "signature". The guideway shall be developed to be structurally efficient and cost effective.

Overhead Contact System (OCS)

The Link Light Rail system will utilize an overhead power distribution system for vehicle power. The poles and hardware of this system shall be responsive to urban design and aesthetic considerations. For all locations, cost-effective designs should be developed for the OCS, which are in character and scale with their immediate environs. Where possible, the joint use of poles for OCS, street lighting and signing should be pursued. The Sound Transit public art process will also be an integral part of the design and development of the OCS.

Streetscape

Streetscape design shall be in character with the community, developed in conjunction with local agencies and their adopted neighborhood plans and equitable throughout the entire Link system. Sound Transit recognizes the need to develop stations as part of a larger community environment. However, clear direction needs to be provided to engineers and architects in order

to determine the limits of Link Light Rail station and alignment improvements and surrounding neighborhood or streetscape development.

Design and construction of light rail facilities shall be limited to required improvements to operate the transit system, the confines of the right of way disturbed by construction of the system and to provide ample pedestrian access from adjacent streets. Whenever possible, connections will be made to other adjacent transit facilities. Improvements beyond the scope of providing transit related facilities will be considered as joint improvements with local jurisdictions, when in the public right of way, and with local developers or communities in private property areas.

These items will be coordinated into the overall Design Criteria Manual for Link Light Rail Transit Project that is currently in draft form. The conceptual design of the Link Light Rail is scheduled for completion by the end of 1998 with preliminary engineering to be complete by December 1999.

RELEVANT BOARD POLICIES AND PREVIOUS ACTIONS TAKEN:

- Adoption of *Sound Move*, The Ten-Year Regional Transit System Plan (May 31, 1996)
- Adoption of Fiscal Year 1998 Budget (December 11, 1997)
- Resolution No. 98-3 (January 22, 1998)

KEY FEATURES:

Staff recommendations for the establishment of design criteria to be used in the design of the Link Light Rail system, stations and urban design components.

ALTERNATIVES:

The following alternatives would be available for Board action:

1. Adopt the design policy issues as presented after discussion of all material.
2. Adopt a portion of the design policy issues to allow design work to continue with specific items listed as needing further review and/or discussion.

CONSEQUENCES OF DELAY:

Agreement on the design criteria is essential to continue conceptual design phase on the Link Light Rail System. Delay in conceptual design will adversely affect the facility design schedule, thereby negatively affecting the overall construction schedule. Schedules are aggressive to meet operational dates as adopted by Sound Move and do not allow much flexibility.

Attachment

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SOUND TRANSIT

MOTION NO. M98-64

A motion of the Board of the Central Puget Sound Regional Transit Authority to establish policy for station/facility design issues common to all three Lines of Business with respect to Security.

Background:

The three Lines of Business have been developing design elements in common to ensure all of Sound Transit will work as a unified whole and to assist in the development and maintenance of integrated systems. The goal is to establish policy and criteria that will serve all Lines of Business and work with our partnering agencies in the region. We wish to determine the common thread of design elements that applies to all facilities versus standardization throughout. This approach encourages uniformity where it is most advantageous and also allows individuality. This motion identifies policy issues for Security as they relate to station/facility design. Background information, including other systems experiences, costs, and options for each of these issues was presented to the Board on August 27, 1998. After policy decisions are determined, specific design criteria will be drafted for designing and developing Sound Transit facilities.

Motion:

It is hereby moved by the Board of the Central Puget Sound Regional Transit Authority that the following items are adopted as policy for all three Lines of Business station/facility design:

Security in Stations / Facilities:

With respect to Security, Sound Transit shall:

- Provide and design safe and secure facilities with strong civic presence that is integrated into the community so they may support a vital, active, environment that will enhance the security of the facilities.
- Develop a security program to address facility needs as well as operational plans.
- Form a Security Committee represented by the three Lines of Business and Sound Transit's Risk Manager to research the best security practices and develop recommendations for implementation in coordination with partnering agencies.
- Promote safe and secure facilities by designing facilities to meet Crime Prevention through Environmental Design guidelines established by experienced professionals and operators.
- Design facilities to allow patrons to observe surroundings and paths and allow observation of patron areas and paths by security/safety personnel and neighboring uses.
- Provide lighting and landscaping with the utmost importance on safety and security with all paths to be illuminated to appropriate levels.
- Provide materials that are resistant to vandalism and easily repairable if damaged.

- Provide obvious, legible, clear, and consistent emergency and warning signage.
- Make provisions for closed circuit television monitors and public pay-phones for emergencies at all facilities. The determination of where cameras will be placed, how they will be monitored, and where emergency phones will be located will be determined with the assistance of the Security Committee.

Adopted by the Board of the Central Puget Sound Regional Transit Authority at a regular meeting thereof on the 27th day of August, 1998.

Paul Miller
Board Chair

ATTEST:

Marcia Walker
Board Administrator

SOUND TRANSIT

MOTION NO. M98-64, M98-65 and M98-66

Station/Facility Design Issues in Common For Commuter Rail, Link Light Rail, and Regional Express

BACKGROUND AND COMMENTS

Meeting:	Date:	Type of Action:	Staff Contact:	Phone:
Board of Directors	8/27/98	Action	Betty Laurs, Commuter Rail Deborah Ashland, Link Light Rail Linda Smith, Regional Express	206-689-7440 206-689-3309 206-689-4922

ACTION:

The adoption of Motions No. M98-64, M98-65 and M98-66 is being requested of the Board at this time for some of the design issues in common to all three Lines of Business as they relate to station/facility design. Our intent for this meeting is to further discuss the station design policy issues for advertising, concessions, public restrooms, and security and present staff recommendations. All Design Issues in Common will be incorporated into each Line of Business Design Criteria Manual.

BACKGROUND:

In order to proceed with design and engineering, Sound Transit's philosophy needs to be addressed, with respect to design, maintenance, and operation of facilities. This will set the standards for which design criteria can be established and create a basis for designers, engineers, and architects to begin their work on station design.

The three Lines of Business have been discussing design elements in common to ensure all of Sound Transit will work as a unified whole and to assist in the development and maintenance of integrated systems. The goal is to establish policy and criteria that will serve all Lines of Business and work with our partnering agencies in the region. We wish to determine the common thread of issues that applies to all facilities.

At the July 17, 1998 Executive Committee Meeting, we generally discussed all the design elements listed on the updated attached spreadsheet. The items under consideration at this time are shaded. At the Board meeting we will be presenting each design element in the following format to facilitate the policy discussion:

1. Description of Element
2. Background
   a. Others experiences
   b. Costs: construction, operating, maintenance and revenue
3. Options
4. Staff Recommended Approach
5. Policy Decisions
6. Criteria/Standards/Physical Requirements (to be developed in detail after policy decision)

This written material contains only staff recommendations for advertising, concessions, and security as they relate to station/facility design. Staff will provide specific information and recommendations at the meeting on August 27, 1998 on public restrooms, in addition to background information, including other systems experiences, costs, and options for each of these four issues for further discussion. After policy decisions are determined, specific design criteria will be drafted for designing and developing Sound Transit facilities.

STAFF RECOMMENDATIONS FOR AUGUST 27, 1998 BOARD MEETING:

Advertising in Stations/Facilities

The Board has not precluded advertising on vehicles; however, the Board has not adopted a policy to date on this issue. If the Board makes the decision to include advertising on vehicles and in facilities, an operational policy will need to be developed to deal with the specific contractual arrangement for securing advertising, as well as the content of advertising. At this time, staff recommends that station/facility design parameters allow for advertising to be installed in Sound Transit facilities.

We are recommending that all facility designs identify or designate locations appropriate for advertising. These areas must not conflict with wayfinding, signage, and operations of the station or facility. Designated advertising locations should not be where points of decision are being made by patrons or where confusion may result due to its presence, such as near fare vending equipment. Advertising shall be subservient to the function and architectural expression of the station. The specified location for advertising shall look complete and finished whether advertising is installed at this time or if it is added later.

The placement of advertising should fit within the parameters of the Sound Transit signage program. An interchangeable hardware system shall be developed so that advertising can be easily installed and removed on a regular basis. Standardized formats or packages should be available to work on an individual or multiple basis.

Security in Stations/Facilities

In order to provide comfort for our patrons, Sound Transit shall provide safe and secure facilities. To meet that goal, we will develop a security program to address facility needs, as well as operational plans. Sound Transit is forming a Security Committee represented by the three Lines of Business and Sound Transit's Risk Manager to research the best security practices and develop recommendations for implementation. This effort will be done in coordination with our partner agencies and jurisdictions to build on their experiences and expertise.

To proceed with facility design, staff recommends that we promote safe and secure facilities by designing facilities to meet Crime Prevention through Environmental design guidelines established by professionals with vast experience in this field. Coupling this information with the collective knowledge of local expertise and design professionals, we recommend the following:

- Facilities shall be designed to allow patrons to observe surroundings and paths, as well as observation of patron areas and paths by security/safety personnel and neighboring uses.
- Lighting and landscaping will be designed with utmost importance on safety and security.
- Materials used shall be resistant to vandalism and easily repairable if damaged.

- Emergency and warning signage shall be obvious, legible, clear, and consistent.
- Provisions shall be made for closed circuit television monitors and pay phones that can be used in emergencies. The determination of where cameras will be placed, how they will be monitored, and where phones will be located will be determined with the assistance of the Security Committee.

We know that staffed facilities increase the perception of and safety for our customers. Staffing may be warranted in some locations. This will be determined by each Line of Business in their Operating Plans. There may be the potential to share these services and personnel with other agencies. These factors will be considered in the recommendations to be developed by the Security Committee.

Public Restrooms in Stations/Facilities

Our primary goal is to build an efficient transportation system for the Puget Sound area. The citizens of this region have designated specific dollar amounts to build the best transportation system possible. To do that, difficult choices are required to keep our costs intact and our focus on transportation. The topic of whether or not to provide public restrooms for our patrons is one of those difficult decisions. We must balance the obvious cost concerns, both short and long term, with the potential comfort of customers. There are added issues of security, potential vandalism, and long-term durability of these facilities. In weighing the issues, staff has determined that public restrooms should be provided where they will be most warranted; have the greatest security; where regular, effective maintenance can be provided; and where costs are shared with all agencies using that facility.

Staff is in the process of conducting research and gathering information from local and national operators to develop background information and specific recommendations on public restrooms. This information will be presented to the Board at the meeting on August 27, 1998 to initiate discussion on this important issue. Staff intends to recommend that public restrooms be included in some of the facilities in our region based on the type of facility and criteria to be developed by each Line of Business to reflect their particular operating environment.

Concessions in Stations/Facilities

Concessions are a potential revenue source for Sound Transit and also provide customer conveniences. They can promote a sense of friendliness, comfort, and safety to our users. However, they are one of the largest factors affecting facility design, in that additional space needs to be provided. Concession areas require the utmost flexibility in facilities. They often change; and therefore, require on-going facility management that can be handled within the agency or contracted to a vendor. There are two types of concessions that can be provided at Sound Transit facilities. One is the method of moveable carts that come to the facility on a daily basis and plug into utilities. The other is a built-in arrangement that would require permanent connection of utilities.

The moveable cart method requires less space at the stations than built in concessions. They are usually self-contained and only require electricity, possibly water, space for the cart, and an area for queuing. Cart vendors usually operate for a few hours in the morning and again in the afternoon. Staff provisions are typically not provided.

The built-in concessions require permanent utilities of electricity, water, sewer, and possibly gas. They also require the most area. This space needs to be flexible enough to accommodate a

variety of uses, so as not to limit prospective tenants. Typically, these concessions would be open all day and possibly in the evening and would require staff restrooms at a minimum. Depending on the type of business, public restrooms may also be required to meet health code requirements.

Sound Transit should promote the idea of concessions in facilities where the market supports them. Because of the similarities and ties between providing restrooms and concessions, staff recommends that built-in areas for concessions be provided for at all stations, if the market can sustain them, where restrooms are recommended.. Built-in concessions should also be considered at stations where utilities are already provided for staff restrooms. If these facilities do not support concessions at this time, future growth may warrant concessions at a later date. This should be determined in the design of those facilities and future provisions made. Cart-type concessions shall be encouraged and provided for in multi-modal stations/facilities where space permits. These provisions should include a specific area, electricity, and possibly access to water. Built-in and cart-type concessions should also be considered in street-level locations of aerial light rail stations. This will be dependant upon how and where the station touches the ground and how much area would be available for concessions.

Concessions are not recommended for stations in the public right-of-way for safety reasons. Tunnel stations can provide areas for concessions, but have tremendous cost impacts for providing space, water, and sewer that would not be offset by market-driven lease arrangements. Additional space built at a tunnel station is extremely expensive on a square foot basis. Code issues will also be affected if concession areas are provided, such as fire sprinkler requirements. Concessions can also pull market from the surface street businesses.

Concessions should also be encouraged in joint use development to enable patrons to pick-up the paper or their morning coffee directly adjacent to the station.

A by-product of concessions is increased garbage. In all Sound Transit facilities, and especially where concessions are provided, we will need to work with local waste management companies to determine the best methods for garbage collection, including recycling, where possible. This will depend upon who maintains the facility, the concessionaire agreements, and local disposal services.

Additional background information and costs will be presented at the Board meeting for further review. A separate motion for each item presented herein is attached for review and possible action at the August 27, 1998 Board meeting.

RELEVANT BOARD POLICIES AND PREVIOUS ACTIONS TAKEN:

- Adoption of *Sound Move*, The Ten-Year Regional Transit System Plan (May 31, 1996)
- Resolution No. 98-3 (January 22, 1998), Light Rail Consultant Contract with PSTC
- Resolution No. 98-11 (April 9, 1998)
- Executive Committee Discussion on July 17, 1998 (No action)

KEY FEATURES:

Staff recommendations for Station/Facility Design Issues for advertising, concessions, public restrooms, and security, as they pertain to design issues in common for all Lines of Business: Commuter Rail, Link Light Rail, and Regional Express, and in partnership with the other regional providers and jurisdictions.

ALTERNATIVES:

The following alternatives are available for Board action:

1. Adopt the design policy issues as presented above and as outlined in the attached Motions after discussion of all material.
2. Adopt a portion of the design policy issues as presented above to allow design work to continue and list specific items as needing further review and/or discussion.

CONSEQUENCES OF DELAY:

Agreement on the design criteria is essential to continuing the design phase for all three Lines of Business. We expect to have all the design criteria in place by the end of September, 1998.

The Sounder staff is currently working with the cities and their Technical Advisory Committees to choose design teams for all stations between Tacoma and Seattle. The selection process has been completed and contracts are pending. Board award of design contract is expected in August, 1998 with the design period extending from September, 1998 through January, 1999.

Regional Express has awarded contracts for environmental review and preliminary design for several community connections and direct access improvement projects. Environmental analysis is underway and preliminary design will begin in the fall of 1998.

Link Light Rail has awarded design contracts to Puget Sound Transit Consultants (PSTC) for all stations. Conceptual design work will be completed in December, 1998 with preliminary engineering finishing by December, 1999.

Schedules for all three Lines of Business are based on the implementation plan adopted by *Sound Move* and allow little deviation. Delay in design criteria development will negatively affect the facility design schedule, which will negatively affect the overall construction schedule for all Lines of Business.

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SOUND TRANSIT

MOTION NO. M98-66

A motion of the Board of the Central Puget Sound Regional Transit Authority to establish policy for station/facility design issues common to all three Lines of Business with respect to concessions.

Background:

The three Lines of Business have been developing design elements in common to ensure all of Sound Transit will work as a unified whole and to assist in the development and maintenance of integrated systems. The goal is to establish policy and criteria that will serve all Lines of Business and work with our partnering agencies in the region. We wish to determine the common thread of design elements that applies to all facilities versus standardization throughout. This approach encourages uniformity where it is most advantageous and also allows individuality. This motion identifies policy issues for concessions, as they relate to station/facility design. Background information, including other systems experiences, costs, and options for each of these issues was presented to the Board on August 27, 1998. After policy decisions are determined, specific design criteria will be drafted for designing and developing Sound Transit facilities.

Motion:

It is hereby moved by the Board of the Central Puget Sound Regional Transit Authority that the following items are adopted as policy for all three Lines of Business station/facility design:

Concessions

With respect to concessions, Sound Transit shall:

- Promote concessions in facilities as supported by the consumer market, to increase security, and customer convenience in facilities.
- Provide built-in areas for concessions at facilities where restrooms are recommended, if the market can sustain them.
- Consider built-in concessions at stations where utilities are already provided for other purposes such as restrooms.
- Provide for cart-type concessions by way of electricity, access to water, and square footage in multi-modal facilities where space allows.
- Consider built-in and cart-type concessions in street-level locations of aerial light rail stations, dependant upon how and where the station touches the ground and how much area would be available for concessions.
- Provide for concessions in tunnel stations if capital cost impacts for providing space, water, and sewer can be offset by market-driven lease arrangements.
- Encourage concessions in joint use or transit-oriented development adjacent to the stations.

ALTERNATIVES:

The following alternatives are available for Board action:

1. Adopt the design policy issues as presented above and as outlined in the attached Motions after discussion of all material.
2. Adopt a portion of the design policy issues as presented above to allow design work to continue and list specific items as needing further review and/or discussion.

CONSEQUENCES OF DELAY:

Agreement on the design criteria is essential to continuing the design phase for all three Lines of Business. We expect to have all the design criteria in place by the end of September, 1998.

The Sounder staff is currently working with the cities and their Technical Advisory Committees to choose design teams for all stations between Tacoma and Seattle. The selection process has been completed and contracts are pending. Board award of design contract is expected in August, 1998 with the design period extending from September, 1998 through January, 1999.

Regional Express has awarded contracts for environmental review and preliminary design for several community connections and direct access improvement projects. Environmental analysis is underway and preliminary design will begin in the fall of 1998.

Link Light Rail has awarded design contracts to Puget Sound Transit Consultants (PSTC) for all stations. Conceptual design work will be completed in December, 1998 with preliminary engineering finishing by December, 1999.

Schedules for all three Lines of Business are based on the implementation plan adopted by *Sound Move* and allow little deviation. Delay in design criteria development will negatively affect the facility design schedule, which will negatively affect the overall construction schedule for all Lines of Business.

Adopted by the Board of the Central Puget Sound Regional Transit Authority at a regular meeting thereof on the 27th day of August, 1998.

Paul Miller
Board Chair

ATTEST:

Marcia Walker
Board Administrator

SOUND TRANSIT

MOTION NO. M98-64, M98-65 and M98-66

Station/Facility Design Issues in Common For Commuter Rail, Link Light Rail, and Regional Express

BACKGROUND AND COMMENTS

Meeting:	Date:	Type of Action:	Staff Contact:	Phone:
Board of Directors	8/27/98	Action	Betty Laurs, Commuter Rail Deborah Ashland, Link Light Rail Linda Smith, Regional Express	206-689-7440 206-689-3309 206-689-4922

ACTION:

The adoption of Motions No. M98-64, M98-65 and M98-66 is being requested of the Board at this time for some of the design issues in common to all three Lines of Business as they relate to station/facility design. Our intent for this meeting is to further discuss the station design policy issues for advertising, concessions, public restrooms, and security and present staff recommendations. All Design Issues in Common will be incorporated into each Line of Business Design Criteria Manual.

BACKGROUND:

In order to proceed with design and engineering, Sound Transit's philosophy needs to be addressed, with respect to design, maintenance, and operation of facilities. This will set the standards for which design criteria can be established and create a basis for designers, engineers, and architects to begin their work on station design.

The three Lines of Business have been discussing design elements in common to ensure all of Sound Transit will work as a unified whole and to assist in the development and maintenance of integrated systems. The goal is to establish policy and criteria that will serve all Lines of Business and work with our partnering agencies in the region. We wish to determine the common thread of issues that applies to all facilities.

At the July 17, 1998 Executive Committee Meeting, we generally discussed all the design elements listed on the updated attached spreadsheet. The items under consideration at this time are shaded. At the Board meeting we will be presenting each design element in the following format to facilitate the policy discussion:

1. Description of Element
2. Background
   a. Others experiences
   b. Costs: construction, operating, maintenance and revenue
3. Options
4. Staff Recommended Approach
5. Policy Decisions
6. Criteria/Standards/Physical Requirements (to be developed in detail after policy decision)

This written material contains only staff recommendations for advertising, concessions, and security as they relate to station/facility design. Staff will provide specific information and recommendations at the meeting on August 27, 1998 on public restrooms, in addition to background information, including other systems experiences, costs, and options for each of these four issues for further discussion. After policy decisions are determined, specific design criteria will be drafted for designing and developing Sound Transit facilities.

STAFF RECOMMENDATIONS FOR AUGUST 27, 1998 BOARD MEETING:

Advertising in Stations/Facilities

The Board has not precluded advertising on vehicles; however, the Board has not adopted a policy to date on this issue. If the Board makes the decision to include advertising on vehicles and in facilities, an operational policy will need to be developed to deal with the specific contractual arrangement for securing advertising, as well as the content of advertising. At this time, staff recommends that station/facility design parameters allow for advertising to be installed in Sound Transit facilities.

We are recommending that all facility designs identify or designate locations appropriate for advertising. These areas must not conflict with wayfinding, signage, and operations of the station or facility. Designated advertising locations should not be where points of decision are being made by patrons or where confusion may result due to its presence, such as near fare vending equipment. Advertising shall be subservient to the function and architectural expression of the station. The specified location for advertising shall look complete and finished whether advertising is installed at this time or if it is added later.

The placement of advertising should fit within the parameters of the Sound Transit signage program. An interchangeable hardware system shall be developed so that advertising can be easily installed and removed on a regular basis. Standardized formats or packages should be available to work on an individual or multiple basis.

Security in Stations/Facilities

In order to provide comfort for our patrons, Sound Transit shall provide safe and secure facilities. To meet that goal, we will develop a security program to address facility needs, as well as operational plans. Sound Transit is forming a Security Committee represented by the three Lines of Business and Sound Transit's Risk Manager to research the best security practices and develop recommendations for implementation. This effort will be done in coordination with our partner agencies and jurisdictions to build on their experiences and expertise.

To proceed with facility design, staff recommends that we promote safe and secure facilities by designing facilities to meet Crime Prevention through Environmental design guidelines established by professionals with vast experience in this field. Coupling this information with the collective knowledge of local expertise and design professionals, we recommend the following:

- Facilities shall be designed to allow patrons to observe surroundings and paths, as well as observation of patron areas and paths by security/safety personnel and neighboring uses.
- Lighting and landscaping will be designed with utmost importance on safety and security.
- Materials used shall be resistant to vandalism and easily repairable if damaged.

- Emergency and warning signage shall be obvious, legible, clear, and consistent.
- Provisions shall be made for closed circuit television monitors and pay phones that can be used in emergencies. The determination of where cameras will be placed, how they will be monitored, and where phones will be located will be determined with the assistance of the Security Committee.

We know that staffed facilities increase the perception of and safety for our customers. Staffing may be warranted in some locations. This will be determined by each Line of Business in their Operating Plans. There may be the potential to share these services and personnel with other agencies. These factors will be considered in the recommendations to be developed by the Security Committee.

Public Restrooms in Stations/Facilities

Our primary goal is to build an efficient transportation system for the Puget Sound area. The citizens of this region have designated specific dollar amounts to build the best transportation system possible. To do that, difficult choices are required to keep our costs intact and our focus on transportation. The topic of whether or not to provide public restrooms for our patrons is one of those difficult decisions. We must balance the obvious cost concerns, both short and long term, with the potential comfort of customers. There are added issues of security, potential vandalism, and long-term durability of these facilities. In weighing the issues, staff has determined that public restrooms should be provided where they will be most warranted; have the greatest security; where regular, effective maintenance can be provided; and where costs are shared with all agencies using that facility.

Staff is in the process of conducting research and gathering information from local and national operators to develop background information and specific recommendations on public restrooms. This information will be presented to the Board at the meeting on August 27, 1998 to initiate discussion on this important issue. Staff intends to recommend that public restrooms be included in some of the facilities in our region based on the type of facility and criteria to be developed by each Line of Business to reflect their particular operating environment.

Concessions in Stations/Facilities

Concessions are a potential revenue source for Sound Transit and also provide customer conveniences. They can promote a sense of friendliness, comfort, and safety to our users. However, they are one of the largest factors affecting facility design, in that additional space needs to be provided. Concession areas require the utmost flexibility in facilities. They often change; and therefore, require on-going facility management that can be handled within the agency or contracted to a vendor. There are two types of concessions that can be provided at Sound Transit facilities. One is the method of moveable carts that come to the facility on a daily basis and plug into utilities. The other is a built-in arrangement that would require permanent connection of utilities.

The moveable cart method requires less space at the stations than built in concessions. They are usually self-contained and only require electricity, possibly water, space for the cart, and an area for queuing. Cart vendors usually operate for a few hours in the morning and again in the afternoon. Staff provisions are typically not provided.

The built-in concessions require permanent utilities of electricity, water, sewer, and possibly gas. They also require the most area. This space needs to be flexible enough to accommodate a

SOUND TRANSIT

MOTION NO. M98-67

A motion of the Board of the Central Puget Sound Regional Transit Authority to establish policy for station/facility design issues common to all three Lines of Business with respect to Public Restrooms and Drinking Fountains.

Background:

The three Lines of Business have been developing design elements in common to ensure all of Sound Transit will work as a unified whole and to assist in the development and maintenance of integrated systems. The goal is to establish policy and criteria that will serve all Lines of Business and work with our partnering agencies in the region. We wish to determine the common thread of design elements that applies to all facilities versus standardization throughout. This approach encourages uniformity where it is most advantageous and also allows individuality. This motion identifies policy issues for public restrooms and drinking fountains, as they relate to station/facility design. Background information, including other systems experiences, costs, and options for each of these issues, was presented to the Board on August 27, 1998 and September 10, 1998. After policy decisions are determined, specific design criteria will be drafted for designing and developing Sound Transit facilities.

Motion:

It is hereby moved by the Board of the Central Puget Sound Regional Transit Authority that the following items are adopted as policy for all three Lines of Business station/facility design:

Public Restrooms:

With respect to public restrooms, Sound Transit shall:

A. Provide public restrooms where all or most of the following criteria are met:
   1. Where they have the greatest security, staffing is present, effective maintenance can be provided, and costs are shared with all agencies using that facility.
   2. Where staffing is already provided for activities such as concessions, customer service, service supervision, or security.
   3. Where concessions are in place and concession revenue covers the ongoing operating and maintenance expense for public restrooms.
   4. Where capital costs are not excessive and prohibitive to construct these facilities.

B. Provide public restrooms, initially, with the following major investments, and work with partnering agencies to determine the need and ability to design, construct and maintain public restrooms in additional high-use stations or multi-modal facilities:

   1. Northgate Light Rail Station
   2. Bellevue Transit Center
   3. King Street Station in downtown Seattle
   4. Everett Multi-Modal Station
   5. Tacoma Dome Transit Center
   6. On board the Sounder Commuter Rail trains

C. In addition, Sound Transit shall:

1. Evaluate Light Rail, Multi-modal Stations and Transit Centers to determine appropriate areas to make provisions of space for self-contained or permanent future restrooms.
2. Implement restroom facilities when funding, staffing, and maintenance arrangements can be made that do not affect Sound Transit's goal to meet budgets and schedules outlined in *Sound Move*. These arrangements may include partnerships with other agencies, funding by advertising, or other revenue sources.
3. Consider self-contained restrooms in conjunction with other agencies, including providing space at Sound Transit facilities for these units.
4. Predicate joint use development agreements on the need for public restrooms to be built and maintained by the developer.
5. Strongly encourage any transit-oriented development to also provide public restrooms.

D. All Sound Transit Public Restrooms shall:

1. Be located in a safe and secure area of the facility.
2. Provide CCTV security in entry areas.
3. Be constructed with durable, easily cleanable, and vandal-resistant materials, including lighting.
4. Not conflict with the facility operations or general flow of traffic.

Drinking Fountains:

With respect to drinking fountains, Sound Transit shall:

Provide drinking fountains at facilities where water and sewer utilities will be provided for other uses, such as restrooms or concessions, and continual on-going maintenance will be possible.

Adopted by the Board of the Central Puget Sound Regional Transit Authority at a regular meeting thereof on the 10th day of September 1998.

Paul Miller
Board Chair

ATTEST:

Marcia Walker
Board Administrator

SOUND TRANSIT

MOTION NO. M98-67

Station/Facility Design Issues in Common For Commuter Rail, Link Light Rail, and Regional Express BACKGROUND AND COMMENTS

Meeting:	Date:	Type of Action:	Staff Contact:	Phone:
Board of Directors	9/10/98	Discussion/Possible Action	Betty Laurs, Commuter Rail Debora Ashland, Link Light Rail Linda Smith, Regional Express	206-689-7440 206-689-3309 206-689-4922

ACTION:

The adoption of Motion No. M98-67 is being requested of the Board pertaining to the incorporation of restrooms and drinking fountains in Sound Transit facilities. Our intent for this meeting is to further discuss the station design policy issues for public restrooms and drinking fountains and present staff recommendations. All Design Issues in Common will be incorporated into each Line of Business Design Criteria Manual.

BACKGROUND:

In order to proceed with design and engineering, Sound Transit's philosophy needs to be addressed, with respect to design, maintenance, and operation of facilities. This will set the standards for which design criteria can be established and create a basis for designers, engineers, and architects to begin their work on station design.

The three Lines of Business have been discussing design elements in common to ensure all of Sound Transit will work as a unified whole and to assist in the development and maintenance of integrated systems. The goal is to establish policy and criteria that will serve all Lines of Business and work with our partnering agencies in the region. We wish to determine the common thread of issues that applies to all facilities.

At the July 17, 1998 Executive Committee Meeting, we generally discussed many design elements. At the August 27, 1998 Board Meeting, we presented design elements in the following format to facilitate the policy discussion:

1. Description of Element
2. Background
   a. Others experiences
   b. Costs: construction, operating, maintenance, revenue
3. Options
4. Staff Recommended Approach
5. Policy Decisions
6. Criteria/Standards/Physical Requirements (to be developed in detail after policy decision)

This written material contains only staff recommendations for public restrooms and drinking fountains. Staff provided background information, including other systems experiences, costs, and options and

recommendations at the meeting on August 27, 1998. Discussion will continue at the September 10, 1998 Board Meeting with possible action. After policy decisions are determined, specific design criteria will be drafted for designing and developing Sound Transit facilities.

STAFF RECOMMENDATIONS FOR SEPTEMBER 10, 1998 BOARD MEETING:

Public Restrooms in Stations/Facilities

Our primary goal is to build an efficient transportation system for the Puget Sound area. The citizens of this region have designated specific dollar amounts to build the best transportation system possible. To do that, difficult choices are required to keep our costs intact and our focus on transportation. The topic of whether or not to provide public restrooms for our patrons is one of those difficult decisions. We must balance the obvious cost concerns, both short and long term, with the potential comfort of customers. There are added issues of security, potential vandalism, and long-term durability of these facilities. In weighing the issues, staff has determined that public restrooms should be provided where they will be most warranted; have the greatest security; where regular, effective maintenance can be provided; and where costs are shared with all agencies using that facility.

Staff conducted research and gathered information from local and national operators to develop background information and specific recommendations on public restrooms. This information was presented to the Board at the meeting on August 27, 1998 to initiate discussion on this important issue. Additional discussion will continue at the September 10, 1998 Board Meeting with possible action on this issue. Staff has recommended that public restrooms be included in some of the facilities in our region based on the type of facility and criteria outlined in the attached Motion. In addition, staff recommends working with partnering agencies to determine the need and ability to incorporate public restrooms in additional multi-modal facilities.

Drinking Fountains

At the Board Meeting on August 13, 1998, drinking fountains were added to the list of passenger amenities to be provided. Background information for drinking fountains was provided at the August 27, 1998 Board Meeting. Staff recommends that drinking fountains are provided in conjunction with restroom facilities, or where other uses are provided that require sewer and water utilities.

A separate motion is attached for review and possible action at the September 10, 1998 Board meeting.

RELEVANT BOARD POLICIES AND PREVIOUS ACTIONS TAKEN:

- Adoption of *Sound Move*, The Ten-Year Regional Transit System Plan (May 31, 1996)
- Resolution No. 98-3 (January 22, 1998), Light Rail Consultant Contract with PSTC
- Resolution No. 98-11 (April 9, 1998)
- Executive Committee Discussion on July 17, 1998 (No action)
- Board Meeting on August 27, 1998 (Discussion)

KEY FEATURES:

Staff recommendations for Station/Facility Design Issues for public restrooms and drinking fountains, as they pertain to design issues in common for all Lines of Business: Commuter Rail, Link Light Rail, and Regional Express, and in partnership with the other regional providers and jurisdictions.

ALTERNATIVES:

The following alternatives are available for Board action:

1. Adopt the design policy issues as presented above and as outlined in the attached Motion after discussion of all material.
2. Adopt a portion of the design policy issues as presented above to allow design work to continue and list specific items as needing further review and/or discussion.

CONSEQUENCES OF DELAY:

Agreement on the design criteria is essential to continuing the design phase for all three Lines of Business. We expect to have all the design criteria in place by the end of September 1998.

The Sounder staff is currently working with the cities and their Technical Advisory Committees to choose design teams for all stations between Tacoma and Seattle. The selection process has been completed and contracts are pending. Award of design contract is expected in September 1998 with the design period extending from September 1998 through January 1999.

Regional Express has awarded contracts for environmental review and preliminary design for several community connections and direct access improvement projects. Environmental analysis is underway and preliminary design will begin in the fall of 1998.

Link Light Rail has awarded design contracts to Puget Sound Transit Consultants (PSTC) for all stations. Conceptual design work will be completed in December 1998 with preliminary engineering finishing by December 1999.

Schedules for all three Lines of Business are based on the implementation plan adopted by *Sound Move* and allow little deviation. Delay in design criteria development will negatively affect the facility design schedule, which will negatively affect the overall construction schedule for all Lines of Business.

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SOUND TRANSIT

MOTION NO. M98-78

A motion of the Board of the Central Puget Sound Regional Transit Authority establishing bicycle policies which provide direction to staff on encouraging bicyclists to use Sound Transit services and facilities, and setting forth considerations for bicycle access in developing those services and supporting facilities.

Background:

Bicycling has become a primary means of transportation for tens of thousands of Puget Sound residents. This region's long-term commitment to the development of a regional trails network, on-street facilities and the integration of bicycling elements in Commute Trip Reduction programs and development codes have resulted in some of the highest levels of bicycle journey-to-work levels of any metropolitan area in the nation. This region also has the most comprehensive "bike on transit" program in the nation. King County Metro carried nearly one half million bicycles on its transit vehicles last year alone.

Sound Transit has made commitments to providing bicycle access to its services and facilities in *Sound Move*; in recently adopted station design policy, and in early decisions relating to vehicle design and operational policy. Early regional planning efforts developed a nationally recognized study paper outlining how a regional transit system can attract significant new by integrating bicycle transportation in its design and development.

The proposed motion outlines a strategy for Sound Transit to uphold its commitments and achieve the benefits of integrating bicycle access into its system. Over the past two months, Sound Transit staff has conducted focus groups with bicycle transportation advocates; with local, county, and state transportation agencies; and with our regional transit partners. On September 21, 1998, over one hundred citizens attended a workshop to provide input on how best Sound Transit can build on local program success, and how to take the fullest advantage of the successes of other transit systems in developing this market.

Motion:

It is hereby moved by the Board of the Central Puget Sound Regional Transit Authority that the bicycle policies substantially in the form of Attachment A be adopted. These policies include the following general bicycle guidelines for the development and implementation of Sound Transit services and facilities:

1. To the System – Getting bicyclists to Sound Transit services and facilities
   - Bicycle access will be a common method of access to and from Sound Transit facilities.
   - Sound Transit will work with local jurisdictions and communities to determine appropriate bicycle improvements within half mile of rail stations, park & ride lots, and transit centers.

2. On the System – Providing accommodations for bicyclists on Sound Transit Vehicles
   - Sound Transit will provide for bicycle access through provision of well-designed facilities on vehicles that:

- encourages general bicycle access
- minimizes conflict with other patrons
- achieves high compliance with adopted bicycle Rules of Conduct
- provides predictable and reliable access on vehicles

- Sound Transit shall strive to provide access to Link, Sounder and Regional Express during all hours of operation.
- Sound Transit's bicycle access programs will stress user responsibility and communication of accepted Rules of Conduct.

3. Through and Across Barriers – Protecting and enhancing bicycle access near Sound Transit facilities and right-of-way:
   - Impacts on existing non-motorized access and safety by the development and implementation of transit services shall be mitigated in cooperation with local agencies and with the active input of community organizations.
   - Sound Transit will incorporate a non-motorized access assessment element in the design process associated with all stations, park & ride lots, transit center, and corridor development.
   - Sound Transit will pursue opportunities to share transit and trail facilities within the same right-of-way where feasible, safe, and where access to transit will be improved.

4. At the System – On site facilities and programs which support bicycle access to Sound Transit:
   - Sound Transit shall provide an appropriate mix of bicycle facilities at all access points to the system.
   - Design of facilities will provide ample space and clearly identified pathways for bicycle circulation at the stations and on the platforms.
   - Sound Transit should aggressively pursue opportunities to develop services and facilities that can increase the numbers of bicyclists who use Sound Transit.

5. Low Cost, Efficient and Effective:
   - Sound Transit will emphasize the development of efficient connections with other transportation systems, including Washington State Ferries, King County Metro, Community Transit, Pierce Transit, Everett Transit, Amtrak, and SeaTac International Airport.
   - Sound Transit will pursue and support partnerships with other agencies, particularly in securing grant funds for non-motorized access projects through the TEA-21 Transit Enhancements program and other bicycle and pedestrian eligible grant funds.
   - Sound Transit will emphasize education and communication as an effective means of maximizing the benefits associated with improving bicycle access.
   - All design and development of access provisions for bicyclists should reflect a commitment to the best design practices available.

Approved by the Board of the Central Puget Sound Regional Transit Authority at a regular meeting thereof on the 22nd day of October, 1998.

ATTEST:

Marcia Walker
Marcia Walker
Board Administrator

Greg Nickels
Greg Nickels
Board Vice-Chair

SOUND TRANSIT

MOTION NO. M98-78

Bicycle Policies
BACKGROUND AND COMMENTS

Meeting:	Date:	Type of Action:	Staff Contact:	Phone:
Executive Committee	10/16/98	Discussion/Recommend Board Approval	Agnes Govern, Director, Regional Express	684-1673
Board	10/22/98	Approval	Barbara Gilliland, Program Manager, Systems Integration	684-1630

ACTION:

Approval of a motion to establish Sound Transit bicycle policies which provide direction to staff on encouraging bicyclists to use Sound Transit services and facilities, and setting forth considerations for bicycle access in developing those services and supporting facilities.

BACKGROUND:

Bicycling has become a primary means of transportation for tens of thousands of Puget Sound residents. This region's long-term commitment to the development of a regional trails network, on-street facilities, integration of bicycling elements in Commute Trip Reduction programs, and development codes have resulted in some of the highest levels of bicycle journey-to-work travel of any metropolitan area in the nation. This region also has the most comprehensive "bike on transit" program in the nation. King County Metro carried nearly one half million bicycles on its transit vehicles last year alone.

Sound Transit has made commitments to providing bicycle access to its services and facilities in *Sound Move*; in recently adopted station design policy, and in early decisions relating to vehicle design and operational policy. Early regional planning efforts developed a nationally recognized study paper outlining how a regional transit system can attract significant new ridership by integrating bicycle transportation in its design and development.

The proposed motion outlines a strategy for Sound Transit to uphold its commitments and achieve the benefits of integrating bicycle access into its system. Over the past two months, Sound Transit staff has conducted focus groups with bicycle transportation advocates, with local, county, and state transportation agencies, and with our regional transit partners. On September 21, 1998, over one hundred citizens attended a workshop to provide input on how Sound Transit can best build on local program success, and how to take full advantage of the successes of other transit systems in developing this market.

Why Bikes and Transit?

(From: Bicycles & Transit: A Partnership That Works
Federal Transit Administration, 1998)

There are several benefits from investing in and integrating transit and bicycle facilities:

For bicyclists, access to transit allows the opportunity to make longer trips to a greater variety of destinations from a greater range of trip origins than can be made on transit alone. Where physical conditions prevent a continuous bicycle trip, transit can provide a link to previously inaccessible destinations.

For transit providers, improving bicycle access attracts new riders. Bicycles expand transit's catchment area beyond what pedestrians can comfortably cover without depending on increased auto access. Bicyclists also represent an important weekend and off-peak market, when ridership is lower and capacity is typically underutilized. Providing secure parking for bicyclists is less expensive than providing parking for automobiles.

For livable communities, bicycles and transit together provide more mobility options to everyone, particularly those who because of age, disability or income are unable to drive. Less auto traffic through neighborhoods contributes to a safer, quieter and more pleasant environment.

For everyone, safe and convenient transit service and bicycle facilities attract more passengers and increase the viability of transit service. Fewer trips by automobile reduce polluting emissions. Increased use of transit and bicycle facilities can decrease traffic congestion

RELEVANT BOARD POLICIES AND PREVIOUS ACTIONS TAKEN:

- Adoption of *Sound Move*, the Ten-Year Regional Transit System Plan (May 31, 1996). *"Sound Move* will create a regional transit system that is easy to reach and use by everyone including pedestrians, bicyclists, people with disabilities and other public transportation customers.

  Sound Transit will work with local public transportation agencies, communities and local governments to place and design transit facilities that fit with local community plans. This will include making improvements within one-half mile of each station for safe, easy transit, pedestrian and bicycle access. Transit facility designs will be flexible; allowing each station to reflect and fit into the community it serves while providing standard features for customers such as:
  - Safety and security design standards
  - Consistent route and schedule information
  - Easy-to-read and consistent signs
  - Pedestrian-friendly design and full access for people with disabilities
  - Bicycle access and storage
  - Transit-friendly access to provide smooth transfers from one type of public transportation to another"

- Motion M98-58 (August 13, 1998) – Adopting station/facility design guidelines and providing general guidelines for the inclusion of bicycle facilities, circulation and potential for future expansion.

KEY FEATURES:

- Establishes policies defining Sound Transit's role in providing bicycle access to transit facilities, including coordination of off-site access within half mile of transit centers, stations and park & ride lots.
- Outlines alternative methods for carrying bicycles on each of the elements of Sound Transit - Link, Sounder and Regional Express – while establishing guidelines for accommodating demand for services at peak and crush load conditions
- Identifies strategies for mitigating the potential effects to existing bicycle facilities during transit system development, and actions for improving bicycle access by eliminating existing barriers through design and development of Sound Transit facilities.
- Provides more detailed policy direction on alternative means of meeting the needs of bicyclists at Sound Transit facilities, including an examination of new ideas designed to encourage bicycle parking and transfer to various elements of the system.
- Develops a policy framework for extending the benefits of a seamless system to bicycling customers, while also identifying coordination and funding strategies intended to make bicycling an increasingly viable means of taking full advantage of Sound Transit services.

FUNDING:

Funding for the implementation of these policies will be included in the design and construction of each transit facility and corridor alignment, and in the purchase of the vehicles required for operation. In addition, special grant resources have been identified in the TEA-21 legislation, which is earmarked specifically for developing bicycle access to transit. Federal match for these programs is 90-95%, depending on the funding source identified and project characteristics. Development of collaborative projects with other agencies and jurisdictions can extend the effectiveness of these funds.

ALTERNATIVES:

The Board could choose to revise the proposed motion to adopt only selected policies.

CONSEQUENCES OF DELAY:

Design and purchase of vehicles is already underway; any changes needed to those designs will need to be considered immediately. Design is underway for initial facilities and additional direction on the integration of bicyclists in those designs would be helpful.

LEGAL REVIEW:

Upon review of the background and comments and the motion, the Legal Department finds both documents to be legally acceptable.

Bicycle Access to Sound Transit:
A Policy Review & Recommendations

For Consideration by the Sound Transit Board of Directors

Summary of Policies

October 5, 1998

Introduction: Why Bikes and Transit?

There are several benefits to investing in and integrating transit and bicycle facilities:

For bicyclists, access to transit allows the opportunity to make longer trips to a greater variety of destinations from a greater range of trip origins than can be made on transit alone. Where physical conditions prevent a continuous bicycle trip, transit can provide a link to previously inaccessible destinations.

For transit providers, improving bicycle access attracts new riders. Bicycles expand transit's catchment area beyond what pedestrians can comfortably cover without depending on increased auto access. Bicyclists also represent an important weekend and off-peak market, when ridership is lower and capacity is typically underutilized. Providing secure parking for bicyclists is less expensive than providing parking for automobiles.

For livable communities, bicycles and transit together provide more mobility options to everyone, particularly those who because of age, disability or income are unable to drive. Less auto traffic through neighborhoods contributes to a safer, quieter, and more pleasant environment.

For everyone, safe and convenient transit service and bicycle facilities attract more passengers and increase the viability of transit service. Fewer trips by automobile reduce polluting emissions. Increased use of transit and bicycle facilities can decrease traffic congestion.

Bicycles & Transit: A Partnership That Works
Federal Transit Administration, 1998

TOTAL Access Service Concept and General Policies:

The vision to fully integrate bicycling and transit incorporates relatively simple goals with ambitious effort. For Sound Transit to meet its adopted goals and its commitment to the region's voters, it needs to incorporate the concepts of bicyclist access, mobility, and service throughout the different lines of business. One simple means to describe this vision is "TOTAL Access:"

TOTAL Access: Serving the region's bicyclists with integrated access:
To the system **O**n the vehicles **T**hrough and across barriers created by the system **A**t the stations **L**ow-cost, effective and efficient

The basic elements of TOTAL Access include:

- Safe and direct access to stations via both on-street and trail facilities
- Consistent and reliable system access on vehicles at all hours of operation
- Convenient means to secure bicycles where possible on vehicles that protect safety and convenience for all passengers/patrons
- Preserving bicycle access across newly established corridors, and investigating means to improve access across existing barriers through excellent design of new facilities
- Both short term and long term bicycle parking provisions that stress safety and security for both bicycles and bicyclists – at transfer centers, park & ride lots, and transit stations
- Station design and layout which accommodates both bicycle and pedestrian movement
- Sharing of Sound Transit right-of-way with trail facilities where appropriate and where existing facilities may be displaced by system development

This report will propose policies that emphasize the theme of TOTAL Access on the topics described above.

1.0 To the System – Getting bicyclists to Sound Transit services and facilities

1.1 Identification of Appropriate Off-Site Transit Access Projects Immediate Station Area Access to Rail Stations, Park & Ride Lots, and Transit Centers

Policy

Bicycling will be a common and encouraged method of access to and from Sound Transit facilities. Sound Transit will work with local jurisdictions and transit agencies to identify access projects that enable and encourage attractive non-motorized access to Sound Transit services.

The degree to which Sound Transit will participate in the development of off-site facilities will be based upon a qualitative and quantitative assessment of the project's potential to meet Sound Transit service and non-motorized access goals. Such projects must collectively demonstrate sub-area equity throughout the Sound Transit service area.

Sound Transit will work with local jurisdictions and communities to determine appropriate bicycle improvements within a half-mile radius of stations. Streets that are reconstructed as part of implementing *Sound Move* will be built to a standard that accommodates bicycle and pedestrian access consistent with locally adopted plans and federal and state adopted design standards.

Facilities which might meet the intent of this policy include (but are not limited to):

- Arterial bicycle lanes
- Widened outside travel lanes
- Paved road shoulders
- "Traffic-calmed" routes on local streets parallel to heavily traveled arterial routes
- Curb cuts
- Access paths to adjacent neighborhoods or land uses
- Regional trail linkages
- Facilities such as bridges or tunnels which correct barriers to bicycle access to planned stations and transit centers
- Trails within Sound Transit right-of-way where appropriate, safe and supported by local adopted non-motorized transportation plans
- Facilities (such as ped/bike bridges) which eliminate barriers to local non-motorized access created by the establishment of Sound Transit facilities, or that create access where none currently exists through modifications in the design of proposed Sound Transit facilities

2.0 On the System – Providing accommodations for bicyclists on Sound Transit vehicles

2.1 Comprehensive Approach to System Bicycle Access

Policy

Sound Transit will provide for bicycle access through provision of well-designed facilities on vehicles. Capacity for bicycle access will be based on current and projected patronage, and design considerations for future capacity. Design of services and facilities will emphasize ease of use and minimal delay and inconvenience to other passengers.

Keys to Success

Encourage general bicycle access by:

- Providing service capacity that is predictable and reliable
- Providing protected, high quality bicycle parking at stations
- Developing facilities at strategically located stations, which encourage bicyclists to store their bicycles and access transit as a pedestrian

Minimize conflict with other patrons by:

- Incorporating adequate access to train platforms
- Designating queuing space on platforms for bicyclists, where appropriate

Achieve high compliance with adopted bicycle Rules of Conduct through:

- Good visual information on system use by bicycle
- Development of Codes specific to a particular line of business
- Commitment to, and marketing of the program

Provide predictable and reliable full-time access on vehicles by:

- Providing well-designed bicycle storage areas and/or systems on vehicles
- Locating facilities on the vehicle which lessens impedance to other passengers
- Clearly communicating policies and program rules of conduct
- Developing flexible capacity which reflects user demand and provides reliable access
- Using demonstration programs and on-going assessment of program performance
- Soliciting feedback on program development from users, other passengers, and operators/drivers during design phase of system as well as after system start-up

2.2 Hours of Use and Access to Vehicles

Policy

2.2.1 Peak Hour Policy and Capacity Constraints

Sound Transit shall strive to provide access to Link, Sounder and Regional Express during all hours of operation, utilizing appropriate equipment to secure bicycles and to minimize any inconveniences and delays for other patrons. Because of the limited capacity on vehicles and high service demands, more restrictive peak hour policies may be put in place. Similarly, capacity may be increased on designated vehicles or scheduled runs to accommodate increased peak hour demand. Shared bicycle and ADA facilities should not be the only bike facilities available on any given vehicle.

2.2.2 Education and Rules of Conduct

Sound Transit's Bicycle Access Programs will stress user responsibility and communication of accepted Rules of Conduct. Access to Sound Transit vehicles will be clearly marked to facilitate ease in loading and safety to other users. Special bike permits will not be required to use Sound Transit services.

2.3 Regional Express System Bicycle Access

Policy

Regional Express will accommodate bicyclists on its regional routes in the same manner as provided by local transit agencies. Efforts will be made to address capacity issues on specific corridors in cooperation with local transit agencies and local, county and state transportation departments. Service should be seamless with other Sound Transit services, and efforts should be made to consolidate elements of program management with other local transit providers where appropriate.

<u>Keys to Success</u>

- Familiar, easy-to-use rack systems
- Involvement of bus operators in development of operating procedures
- Clearly communicated system instructions
- Active marketing of the program and education of all potential system users
- Participation with other agencies in addressing capacity and service limitations in shared corridors
- Ongoing feedback from users on potential system improvements
- Consolidation and collaboration with other transit agencies of common program elements (i.e. lost & found, procurement)
- Consistent system policies with local transit agencies

2.4 Link Light Rail Bicycle Access

Policy

Link services shall make provisions to encourage bicycle access on train vehicles, taking into account the safety, convenience, comfort of patrons, and with minimal impact on service. Sound Transit will design light rail vehicles that take into consideration securement for bicycles, capacity commensurate with goals, minimal impact to service, and other passengers.

Keys to Success

Link Bicycle Access:

- Provide a variety of high quality bicycle parking systems and other facilities at strategically located stations which encourage bicyclists to store their bicycles and access Link as a pedestrian
- Provide well-thought out bicycle storage areas and/or systems on vehicles
- Develop a range of service alternatives that provide desired capacity while preserving patron comfort, safety, and convenience
- Develop structured service options that address peak loading conditions
- Incorporate adequate space and access to train platforms identifying queuing areas for bicycle patrons which supports on-train access design
- Retain access during off-peak and reverse commute hours

A bicycle access policy for Link would have four central components

1. Vehicles Designed to Carry Bicycles

When vehicles are chosen and designed, the following issues will be addressed:

- Configuration and location of a designated area for bicycles
- Carrying capacity
- Identification of the bicycle storage areas
- Whether supplemental bicycle storage areas can be shared with ADA tie-downs and/or other storage locations
- Location and type of graphic designation for specific bicycle ingress

2. Demonstrate and Assess Feasibility of All Hour Access

The system should eventually support access during all hours of operation, including peak. This must be accompanied by policies and procedures to protect other patrons from inconvenience and/or delay. Such policies and procedures might include:

- Reduced maximum number of bikes during peak hour (i.e. 2 instead of 4 per car)
- Full time preference given to ADA patrons if bike use conflicts with ADA access

- Loading procedures
- Restricting bike access during peak to a particular car

Demonstration and Phase-In
Link off-peak and reverse peak hour bicycle service shall be initiated during system start-up. The feasibility of providing peak hour access to Link should be demonstrated during an initial trial period, after which an assessment shall be made of procedures, equipment,
customer comment, and operator input. This trial should commence no later than six months after service is introduced, and should last long enough to assess service impacts during periods when universities are both in and out of session.

3. Elevator Access to All Stations

~~Bicycles should not be allowed on escalators at any time. Bicycle access to platform and mezzanines should be by elevator. Stations dependant upon elevator access to the platform should have a specific elevator designated for bicyclists as well as other passengers.~~ (See Station Access Section)

Bicycle access to platforms and mezzanines should be, at a minimum, by elevator to those stations that require elevators or escalators. Stations dependant upon elevator access to the platform should have a specific elevator designated for bicyclists as well as for other passengers. The policy of allowing people to carry their bikes on escalators should be reviewed during the demonstration and phase-in of peak-period bicycle service. The escalator policy should also be evaluated during the development of the Rules of Conduct.

4. Full Tunnel Access (Assuming Coaches are displaced)

Operations in the Downtown Tunnel should accommodate bicycle access to transit if coaches no longer operate there. Specific access routes for bicyclists to station platforms will need to be identified on a station-by-station basis.

2.5 Sounder Commuter Rail Bicycle Access

Policy

Sounder services shall be designed to take advantage of both the increased mobility commuter rail provides to bicyclists. The policies should also increase the capture area and destinations that bicycling provides to commuter rail service.

Sounder services shall consider design features for bicycle access on vehicles, taking into account the safety, convenience, comfort of other passengers, and with minimal impact on service. Sound Transit will accommodate bicycles on board trains at a level that reflects anticipated user demand for the service.

Keys to Success

- Designing vehicles to carry bicycles
- Providing capacity which meets anticipated demand for the service, and which seamlessly accommodates system transfers from other agencies, including the Washington State Ferries
- Actively marketing the program and educating all potential users
- Providing well-thought out bicycle storage areas and systems on vehicles
- Clearly communicating system instructions and codes of conduct
- Designating waiting areas for bicyclists on platforms
- Soliciting ongoing feedback from users and other passengers on potential system improvements

A bicycle access policy for Sounder would have three central components:

1. Vehicles Designed to Carry Bicycles

When vehicles are chosen and designed, the following issues will be addressed:

- Configuration and location of a designated area for bicycles
- Manner of separation of the bicycle storage area from other patrons
- Determine the feasibility of a supplemental bicycle storage that can be shared with ADA tie-downs and/or other storage areas
- Location and type of graphic designation for specific bicycle ingress

2. Stations Designed to Minimize Conflict

- Determination of where on the platform bicyclists should wait for a train
- Adequate on site parking and access (Policy 4.0)
- Clearly communicated rules of conduct regarding loading policy

3. Carrying Capacity Per Car

- The current configuration calls for tie-down space for two bicycles per car or twelve bicycles per train during high demand hours. To be determined is whether additional bicyclists would be accommodated on a space-available basis in vehicle vestibules
- Tandems and other odd-dimensioned bikes can be accommodated during low-traffic hours in vehicle vestibules, and should be incorporated into off-peak system policy
- Additional capacity for bicyclists in each car is being explored through the use of a vertical rack system to be incorporated into the current vehicle design. Bike racks, which are adjustable and securely fasten both wheels of the bicycle, can hold at least four bikes in the floor space currently allocated for two bikes under this option, capacity could be increased to 4-6 bikes per car.

3.0 Through and Across Barriers – Protecting and enhancing bicycle access near Sound Transit facilities and right-of-way

3.1 Displacement and Trail Mitigation

Policy

Impacts on existing non-motorized access and safety by the development and implementation of transit services, shall be mitigated in cooperation with local agencies, and with the active input of community organizations. This includes impacts to on-street bicycle facilities affected by the introduction of increased bus traffic or dedicated curb lanes for transit access.

Sound Transit will mitigate any displacement or disruption of existing regional and local trails during construction, as a result of operation of the Sound Transit system.

3.2 Access Assessment and Barrier Identification

Policy

Sound Transit will incorporate a non-motorized access assessment element in the design process associated with all stations, park & ride lots, transfer centers, and corridor development. To be conducted with the input of local agencies, this assessment will evaluate existing access to the system within half mile of each station for safe, easy transit, pedestrian, and bicyclist access. This effort will identify a list of potential projects in cooperation with local jurisdictions. The identification of these projects shall also include an assessment of barriers to bicycle access and projects, which can correct these deficiencies.

Sound Transit will pursue opportunities to share transit and trail facilities within the same right-of-way where feasible, safe, and where access to transit will be improved. Every effort will be made to design appropriate facilities with safe separation of modes in conjunction with local agencies and with the active input of community organizations.

4.0 At the system – On site facilities and programs which support bicycle access to Sound Transit

4.1 Adopted Access and Design Policy (Adopted 8/13/98)

Motion M98-58:
The Board of the Central Puget Sound Regional Transit Authority hereby moves that the following items are adopted as policy for all three lines of business station/facility design:

B. Bicycles

With respect to bicycles at stations/facilities, Sound Transit shall:

- design facilities to provide ample space for maneuvering bicycles in and through stations and onto vehicles
- provide a mix of storage lockers and locking racks, based on projected patronage of facilities
- provide storage areas open to circulation, on direct paths from access points, and to not impede pedestrian and vehicular traffic flows
- designate areas, where possible, for storage expansion to accommodate bicycle ridership increases

4.2 Bicycle Parking

Policy

Sound Transit shall provide a variety of parking for bicycles at access points to the system. This parking should be provided in a variety of styles and types to meet the diversified needs of commuters, recreational riders, and visitors to the area.

The number of parking spaces available should be based on expected patronage, with the provison that 100% of bicyclists should have access to secure parking, and that the capacity of the system will be expanded as needed.

4.3 Additional Station Area Services

Policy

Sound Transit should aggressively pursue partnership opportunities to develop services and facilities that can increase the numbers of bicyclists who use Sound Transit. Such facilities might include staffed parking areas, repair shops, bike rental operations, and other initiatives that can take full advantage of opportunities presented by system location near popular trails and other bicycling facilities. While these additional services should not necessarily represent a system standard, they do represent a potentially very effective marketing tool for site-specific implementation. Such facilities potentially could involve joint development with other agencies and jurisdictions, franchise and/or vendor operations, or operating agreements with non-profit community organizations.

5.0 Low Cost, Efficient, and Effective

5.1 Efficient Connections with other systems

Policy

To maximize the potential for increasing bicyclist ridership throughout the system, Sound Transit will emphasize the development of efficient connections with other transportation systems, including the Washington State Ferries, King County

Metro, Community Transit, Pierce Transit, Everett Transit, Amtrak, and SeaTac International Airport (Port of Seattle). This effort will focus on consistent design of bicycle facilities and services, Codes of Conduct, and other customer service functions throughout the region.

5.2 Funding and Grants

Policy

Funding for the implementation of these policies will be included in the design, construction of each transit facility, corridor alignment, and in the purchase of the vehicles required for operation. Off-site access improvement projects within half mile of station facilities are an important part of the *Sound Move* commitment to bicycle access. Non-motorized access projects funded from local tax revenues must collectively demonstrate a benefit to all sub-regions served by Sound Transit.

In addition, Sound Transit will pursue and support partnerships with other agencies, particularly in securing grant funds for non-motorized access projects through the TEA-21 Transit Enhancements and other bicycle and pedestrian-eligible grant funds. Generally, grant revenues should be used to provide either for specific program initiatives with direct benefit to non-motorized access and services or to off-site access projects which provide improved access to Sound Transit facilities and services.

5.3 Education and Communication

Policy

Sound Transit will emphasize education and communication as an effective means of maximizing the benefits associated with improving bicycle access. This is particularly important in reinforcing adopted Codes of Conduct for access and facility programs throughout Sound Transit.

5.4 Reflecting Best Practices

Policy

All design and development of access provisions for bicyclists should reflect a commitment to the best design practices available, consistent with the ongoing commitment of local, county, and state agencies to develop their bicycle facilities to these same standards. Sound Transit should be a leader in the development of bicycle and pedestrian access to transit, and participate in organizations and programs that advance the effective design and operation of these facilities and programs.

REGIONAL TRANSIT AUTHORITY

RESOLUTION NO. 98-1

A RESOLUTION of the Board of the Regional Transit Authority for the Pierce, King and Snohomish Counties region establishing Sound Transit Art Program guidelines and adopting a budget policy.

WHEREAS, the Regional Transit Authority is a governmental entity vested with all powers necessary to implement a high capacity transportation system within its boundaries in King, Pierce, and Snohomish Counties as provided in RCW chs. 81.104 and 81.112; and

WHEREAS, Federal Transit Administration policy Circular 9400.1A encourages including art in mass transit projects in order to improve the appearance and safety of a facility, give vibrancy to public spaces, and make patrons feel welcome; and

WHEREAS, Sound Move, the Ten-Year Regional Transit System Plan adopted by the Board states that implementation of the Sound Transit system will include works of art that contribute to a positive experience for system users and affected communities.

NOW, THEREFORE, BE IT RESOLVED by the Board of the Regional Transit Authority that Sound Transit Art Program Guidelines, essentially in the form of the Attachment, are approved.

ADOPTED by the Board of the Central Puget Sound Regional Transit Authority at a regular meeting thereof held on the 22nd day of January 1998.

Bob Drewel

Bob Drewel
Board Chair

ATTEST:

Marcia Walker

Marcia Walker
Board Administrator

REGIONAL TRANSIT AUTHORITY

RESOLUTION NO. 98-1
BACKGROUND AND COMMENTS

Meeting:	Date:	Agenda Item:	Staff Contact:	Phone:
PGA Committee	1/16/98	No. 4	Barbara Dougherty, Communications Manager	206-684-1357
Board of Directors	1/22/98	No. 7C-1		

ACTION:
Board approval of Resolution No. 98-1, establishing program guidelines for Sound Transit Art and adopting an art budget policy.

BACKGROUND:
In Motion No. 40, adopted September 11, 1997 (copy attached) the Board committed to the integration of public art in the implementation of the Sound Transit system. Staff was directed to develop a master plan for art, establish an art advisory group, and prepare a resolution for adoption of an art budget**.**

RELEVANT BOARD POLICIES AND PREVIOUS ACTIONS TAKEN:
- Adoption of *Sound Move* (May 31, 1996)
- Adoption of 1998 Budget (December 11, 1997)
- Adoption of Motion 40 (September 11, 1997)

KEY FEATURES:
- Authorizes the initiation of Sound Transit Art (ST<u>ART</u>)
- Recognizes a wide range of opportunities for art within the Sound Transit system, from discrete artworks to artistic enhancements to functional elements.
- Commits to having artists work with the preliminary and final design teams on the development of the project design and on the integration of art into the system as a whole.
- Authorizes the establishment of a public art advisory task force to work with staff, consisting of representatives from each of the jurisdictions in which Sound Transit facilities will be built.
- Establishes a policy for calculating the art budget as 1% of capital construction costs, excluding the cost of tunneling.

FUNDING:
Sound Transit Art would not result in an addition to the budget for *Sound Move*, rather it would allocate 1% of the existing construction budget (exclusive of tunneling) for art. The distribution of construction budget to the subareas will be unchanged. Administration of the art program would be funded from the 1% allocation and assigned to the Communications and Marketing Division where it would become an element of community involvement In 1998, it is intended that the art program be administered through an agreement for part-time professional services with King County. The 1999 budget would include an FTE to fully administer the program.

ALTERNATIVES:

Establish another methodology for calculating the art budget and alternative guidelines for implementation of the art program.

Several other formulas for calculating a public art budget were considered. Examples include: 1% applied to station costs only; 1% of station costs plus .5% of visible and accessible non-station costs; .5% of all construction costs. The formula recommended was chosen because it provides funding for art throughout the system, not just in stations; is consistent with local practices; and is straightforward and easy to explain.

CONSEQUENCES OF DELAY:

The Board has committed to involving artists in the design of transit facilities and public spaces. The design phase has begun, and it is important to involve artists as soon as possible. Some local jurisdictions that have public art programs are eager to know what the Sound Transit art program will be so that efforts may be coordinated. One consequence of delaying action is that opportunities for integrating art and artistic enhancements will be missed.

FIRST STEPS:

The following steps would be taken in the first half of 1998 to initiate Sound Transit Art:

- Board approval of art program guidelines
- Convene Public Art Advisory Task Force
- Issue RFQ for lead design team artists
- Develop Sound Transit artist services contracts
- Convene selection panel to establish pool of qualified design team artists
- Consultants and communities select design team artists from pre-qualified pool
- Artists begin working with design teams and communities

REGIONAL TRANSIT AUTHORITY

RESOLUTION NO. 98-1

A RESOLUTION of the Board of the Regional Transit Authority for the Pierce, King and Snohomish Counties region establishing Sound Transit Art Program guidelines and adopting a budget policy.

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WHEREAS, Sound Move, the Ten-Year Regional Transit System Plan adopted by the Board states that implementation of the Sound Transit system will include works of art that contribute to a positive experience for system users and affected communities.

NOW, THEREFORE, BE IT RESOLVED by the Board of the Regional Transit Authority that Sound Transit Art Program Guidelines, essentially in the form of the Attachment, are approved.

ADOPTED by the Board of the Central Puget Sound Regional Transit Authority at a regular meeting thereof held on the _____ day of _____1998.

_____
Bob Drewel
Board Chair

ATTEST:

_____
Marcia Walker
Board Administrator

ST*ART*
SOUND TRANSIT ART
PROGRAM GUIDELINES
AND BUDGET POLICY

I. INTRODUCTION

It has long been recognized that the sensitive use of art and design in transit systems gives vibrancy to public spaces and presents an image of the local culture and architectural heritage. But more recently the power of art as a tool in establishing relationships with the community has been recognized. The artistic processes and review procedures of public art give citizens an avenue for participation in the project process. By becoming invested in a project, the community works toward implementing rather than opposing it. Through this process, the community also develops a sense of ownership and pride that can carry over beyond design and construction and make them partners in maintaining the facility.

Just as Sound Transit is building a regional transit system to link the communities of this region, it can structure a public art program that enhances these linkages.

A. Federal Policy

Federal Transit Administration policy Circular 9400.1A encourages including art in mass transit projects:

"The visual quality of the nation's mass transit systems has a profound impact on transit patrons and the community at large. Mass transit systems should be positive symbols for cities, attracting local riders, tourists, and the attention of decision-makers for national and international events. Good design and art can improve the appearance and safety of a facility, give vibrancy to its public spaces, and make patrons feel welcome. Good design and art will also contribute to the goal that transit facilities help to create livable communities."

B. National Examples

National examples of successful transit art programs include:

- Tri-County Metropolitan Transportation District of Oregon
- Los Angeles Metropolitan Transit Authority
- Dallas Area Rapid Transit Authority
- Massachusetts Bay Transportation Authority
- Atlanta Rapid Transit Authority
- Metro-Dade Transit Authority
- Greater Cleveland Regional Transit Authority
- King County Metro

C. Adopted Policy

On September 11, 1997 in Motion 40 the Board of the Central Puget Sound Regional Transit Authority made a commitment to the integration of public art in the Sound Transit system. The Motion states:

- Implementation of the Sound Transit system will include works of art that contribute to a positive experience for system users and affected communities.
- Artists will participate in the design of transit facilities and public spaces to maximize the opportunities for integrating art into construction.
- Affected communities will be involved in decisions regarding where and what type of art is appropriate in their communities, and in the selection of artists to execute the artwork.

In order to carry out the policy adopted by the Board and to initiate the Sound Transit art program – S*TART*, the following guidelines are established.

II. OPPORTUNITIES FOR ART

Transit agencies in this country have twenty years' experience in developing and refining art programs. Research into this experience reveals a wide range of ways in which art has contributed to enhancing the everyday act of commuting. Discrete artworks that celebrate the history, culture and people of the region are important and will be included in Sound Transit. However, the integration of art and architecture is essential because concerns regarding safety, operations, maintenance, vandalism, and pedestrian flow often preclude many of the opportunities for discrete art objects. In addition, many functional aspects of a transit system can be transformed and enlivened by the application of art and artistic ideas.

Following is a list of selected components that will be considered as possibilities for art or artistic enhancement .

A. Stations, P&R's, Transit Centers

1. Canopy/roof/column design
2. Paving – platform, parking, crosswalks
3. Wall-vertical materials-finishes
4. Lighting – station or site. Attachments to standard light poles
5. Windscreens
6. Landscaping, stormwater design, artwork integrated into landscaping
7. Fencing
8. Bicycle racks/storage
9. Seating
10. Railings
11. Kiosks
12. Signage – design, attachments, additions
13. Trash receptacles
14. Site-specific, free-standing artwork that serves as marker or community identifier
15. Clocks
16. Tree grates
17. Community connections
18. Art on shelter surfaces, i.e. paint, tile, terrazzo, metal

19. Art in shelter glass, i.e. sandblasting, placement of artwork on translucent film between two panes of glass
20. Attachments to shelter roofs, i.e. wind vanes

B. Along the Right-of-Way

1. Power poles – color, attachments, design
2. Finishes/coverings for mechanical sheds/boxes
3. Signage/markers
4. Landscaping
5. Lighting
6. Paving
7. Murals on buildings along the alignment
8. Sound walls
9. Fencing

C. Vehicles

1. Exterior & interior design of basic vehicle
2. Specially painted vehicles
3. Art in advertising spaces

D. Fare Cards

Artwork on fare cards.

E. Signage

1. Attachment/maker on top of standard poles, i.e. whirligigs
2. Specially designed poles to reflect the history/culture of the area

F. Access Ramps

1. Concrete form work
2. Railings
3. Landscaping
4. Markers/identifiers
5. Lighting
6. Paving
7. Design of columns/attachments to columns

G. Temporary Art During Construction

1. Installations
2. Displays
3. Performances
4. Publications

III. INVOLVEMENT OF ARTISTS

Sound Transit will involve artists in two ways, through a phased approach:

1. to collaborate with the preliminary and final design teams on the development of the project design and on the integration of art into the system as a whole.
2. to create a discrete artwork for a specific site or for a specific purpose.

Artists will be under contract to Sound Transit, which will determine their scopes of work, schedules for involvement and compensation.

A. Phase I

During conceptual development and schematic design, a team of lead artists will work with system designers to:

1. investigate possible systemwide approaches to and opportunities for art that could be incorporated into prototypical elements;
2. identify the prototypical elements that might be modified to give identity and focus to each station;
3. help communities articulate their aesthetic vision for their transit system and choose which art projects to implement.

B. Phase II

During final design, additional artists will be commissioned to carry out specific art projects approved during Phase I.

IV. COMMUNITY INVOLVEMENT

A. Advisory Task Force

To ensure that the Sound Transit art program truly represents the interests of the region, a Public Art Advisory Task Force will be formed. The task force will consist of representatives from each of the jurisdictions in which Sound Transit facilities will be built. The representatives will be primarily city and county staff responsible for public art programs in their own jurisdictions. The task force will:

1. Serve as liaison between Sound Transit and the local jurisdictions they represent on matters related to public art;
2. Advise Sound Transit staff on the implementation of the art program;
3. Provide advice to the Sound Transit Executive Director on the resolution to any disputes concerning public art.

B. Affected Communities

Affected communities will be directly involved in deciding where and what type of art is appropriate in their communities, and in selecting artists to execute the artwork. Sound Transit will work with local arts commissions to organize these selection processes.

V. FUNDING

A. Federal Policy

FTA policy recommends that funds spent on art for transit projects should be a minimum of one-half percent of construction costs and a maximum of 5 percent.

B. National Examples

Around the country there have been various formulas used to establish art budgets for transit projects

- Dallas Area Rapid Transit set aside 1% of construction costs in the bus system and $50,000 for each light rail station
- Tri-Met in Portland originally set aside 1% for art but recently raised the level to 1.5% to provide funding for non-station-specific elements of the art program
- Los Angeles County MTA sets aside .5% of all construction costs
- Downtown Seattle Transit Tunnel set aside 1% of the visible and accessible elements of the project (i.e. stations and surface improvements)

C. Regional Precedents

In the Sound Transit region, the most widely accepted practice is for public agencies to set aside 1% of construction costs for art.

D. Sound Transit Art Budget

Establishment of a Sound Transit art program will not result in an addition to the current Sound Transit budget.

In keeping with local precedents and FTA guidelines, the Sound Transit budget for art will be calculated as 1% of capital construction costs, excluding the cost of tunneling. The funds generated for art will be pooled within each subarea. Opportunities for integrating art will be evaluated for the system as a whole before determining where art is most appropriate and how much money should be allocated for art at specific locations within each subarea.

The 1% for art policy will allow the art program to begin without committing to specific dollar amounts until cost estimates for specific construction projects are more firmly established. Because it is anticipated that much of the art will be completely integrated into construction, determining the specific costs attributable to the art budget may not be possible. Costs will be reasonably assigned based on the best judgment of those collaborating on the Sound Transit art and design tasks.

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SOUND TRANSIT

MOTION NO. M2005-37

A motion of the Board of the Central Puget Sound Regional Transit Authority authorizing the Chief Executive Officer to execute a sole source contract amendment with Hatch Mott MacDonald in the amount of $9,077,591 and a 10% contingency in the amount of $907,759, for a revised total authorized contract amount not to exceed $25,935,350, to provide preliminary engineering and architectural design services for the Airport Link preferred alternative between South 154th Street in the City of Tukwila and the proposed Airport light rail station near South 176th Street in the City of SeaTac and to provide final design services for the Airport Link project to be selected for construction by the Sound Transit Board.

Background:

Airport Link is part of the Central Link Project defined in Sound Move. In its action identifying the Initial Segment on September 27, 2001, the Sound Transit Board directed the agency to work with the Port of Seattle and the Cities of SeaTac and Tukwila to extend the Initial Segment south beyond South 154th Street. In a subsequent action on November 29, 2001, the Board acknowledged that the delay in the POS's development plans, due in part to aviation security responses to the attacks of September 11, 2001 precluded construction of the LRT extension to the airport within the timeframe of the Initial Segment and authorized implementation of a work plan to evaluate alternatives to serve the airport by the year 2009.

In December of 2004, Sound Transit, the Port of Seattle (POS), and the City of SeaTac reached agreement on the preferred alternative for extending the Central Link Initial Segment from South 154th Street to a light rail station located at Sea-Tac International Airport's main terminal. The airport LRT (Airport Link) extension is planned to be completed by the end of 2009, just prior to the 2010 Winter Olympics in Vancouver, B.C.

Sound Transit and the POS collaborated to integrate the LRT extension with the Port's planned roadway improvements in the same corridor. This led to adoption of a common project schedule that fully integrates the design and construction of LRT facilities with the POS's roadway projects. This integration requires both agencies to maintain flexibility as their respective design efforts advance and led Sound Transit to combine preliminary civil engineering and final design within a single consultant contract.

The scope of this proposed amendment includes the civil engineering, architectural design, geotechnical explorations, and related professional services for both the preliminary engineering and final design for the Airport Link project, including approximately 1.7 miles of LRT guideway, an elevated station near South 176th Street, and a kiss-and-ride facility. Services to be provided under this proposed amendment would be authorized and performed as part of two distinct elements:

- Sound Transit would proceed to authorize performance of preliminary engineering and architectural services in an amount of $2,992,196 and a 10% contingency of $299,220 for a total amount not to exceed $3,291,416 that would be funded under the Adopted 2005 budget for Airport Link. Preliminary engineering and architectural services would commence in April 2005.

- Sound Transit would authorize performance of final design services only upon the Sound Transit Board's future adoption of the Airport Link project and completion of the National Environmental Policy Act (NEPA) and State Environmental Policy Act (SEPA) environmental reviews. Final design services would be funded through amendment of the Airport Link capital budget in conjunction with the project adoption. Final design services are anticipated to commence in the third quarter of 2005 and are scheduled to be completed in mid-2006.

The procurement of preliminary civil engineering and final design services for Airport Link through execution of a sole source contract amendment is justified under applicable procurement regulations and has been documented in accordance with Sound Transit's policies.

On November 18, 1999, the Board adopted Resolution No. R99-34 selecting the alignment, station locations, and the maintenance base to be built for the Central Link Project. The Board action was supported by the Central Link Light Rail Project Final Environmental Impact Statement (November 1999). On that same day, the Board agreed to evaluate an alternative route (Tukwila Freeway Route) through the City of Tukwila that had been proposed by the City. Draft and final supplemental environmental impact statements were prepared evaluating this route.

Resolution No. R99-34 included a route selection from the Tukwila International Boulevard Station to the South 200th Station. The proposed Airport Link project would modify the route and station locations in this segment from the alignments and station locations selected by the Board in November 1999. An Environmental Assessment (EA) under NEPA is being prepared to address these modifications to the project. This EA will also serve as a project Addendum under SEPA. Notice to proceed for final design will not be authorized until the EA and SEPA Addendum are complete, the Sound Transit Board has selected the Airport Link project to be constructed, and a NEPA environmental determination has been made by the FTA.

Motion:

It is hereby moved by the Board of the Central Puget Sound Regional Transit Authority that the Chief Executive Officer is authorized to execute a sole source contract amendment with Hatch Mott MacDonald in the amount of $9,077,591 and a 10 percent contingency in the amount of $907,759, for a revised total authorized contract amount not to exceed $25,935,350, to provide preliminary engineering and architectural design services for the Airport Link preferred alternative between South 154th Street in the City of Tukwila and the proposed Airport light rail station near South 176th Street in the City of SeaTac and to provide final design services for the Airport Link project to be selected for construction by the Sound Transit Board.

APPROVED by the Board of the Central Puget Sound Regional Transit Authority at a regular meeting thereof held on April 14, 2005.

John W. Ladenburg
Board Chair

ATTEST:

Marcia Walker
Board Administrator

SOUND TRANSIT

MOTION NO. M2005-101

A motion of the Board of the Central Puget Sound Regional Transit Authority adopting **SeaTac/Airport** as the final name for the Central Link Light Rail Airport Link station.

Background:

Sound Transit established a Systemwide Sign Design Manual in 1999 for all lines of business to provide consistency to customers using Sound Transit facilities. The Sign Design Manual includes the following criteria for naming passenger transit stations:

1. Names must reflect nature of environment such as; street names, landmarks, and geographical locations;
2. Names will be brief and easy to read;
3. Names must adhere to a 30 character limit to insure compliance with the American with Disabilities Act (ADA); and
4. Commercial names should be avoided since they can change and prove confusing to the public and costly.

The Sound Transit Board adopted names for the stations of the Central Link Light Rail Initial Segment on January 13, 2005. At that time, the Airport Link station was not adopted and was not included in the name nominations and review process. On July 14, 2005, the Board adopted the Airport Link station and preliminary engineering work is currently underway.

Temporary stickers could cover the signs showing the **SeaTac/Airport** station name when the Initial Segment is in operations, but service for the Airport Link station is not operating.

Although many of Initial Segment station names include a secondary cross street indicator, staff proposes no cross street indicator at the **SeaTac/Airport** station since the Airport Link station will be recognized as a regional facility and there are no secondary streets crossing the location of the station.

Motion:

It is hereby moved by the Board of the Central Puget Sound Regional Transit Authority to adopt **SeaTac/Airport** as final name for the Central Link Light Rail Airport segment station.

APPROVED by the Board of the Central Puget Sound Regional Transit Authority at a regular meeting thereof held on August 25, 2005.

Greg Nickels
Board Vice Chair

ATTEST:

Marcia Walker
Board Administrator

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SOUND TRANSIT

RESOLUTION NO. R2005-20

A RESOLUTION of the Board of the Central Puget Sound Regional Transit Authority modifying the preferred route, profiles, and station locations for the North Link Light Rail Project and identifying University Link as the preferred segment of North Link for purposes of the final supplemental EIS and for obtaining a New Starts rating from the Federal Transit Administration.

WHEREAS, a Regional Transit Authority, hereinafter referred to as Sound Transit, has been created for the Pierce, King, and Snohomish County region by action of their respective county councils pursuant to RCW 81.112.030; and

WHEREAS, on November 5, 1996, at a general election held within the Central Puget Sound Regional Transit Authority district, the voters approved local funding for Sound Move, the plan for high capacity transit in the Central Puget Sound Region, which includes an electric light rail line connecting SeaTac, Tukwila, and Seattle; and

WHEREAS, Sound Transit is implementing the Sound Move transit plan; and

WHEREAS, the light rail segment between Convention Place and Northgate (North Link) will provide congestion-free, high-capacity transit access to some of the state's largest employment and population areas and will triple Central Link's system-wide daily ridership to more than 150,000 in 2030; and

WHEREAS, on November 5, 1999, Sound Transit and the Federal Transit Administration (FTA) issued a final environmental impact statement (FEIS) for the Central Link Light Rail Transit Project to satisfy the requirements of the National Environmental Policy Act (NEPA) and the State Environmental Policy Act (SEPA); and

WHEREAS, on November 18, 1999, the Sound Transit Board (Board) approved Resolution No. R99-34, which selected the Central Link light rail alignment from the University District in Seattle to South 200th Street in the City of SeaTac to be built; and

WHEREAS, on July 27, 2000, the Board adopted Resolution No. R2000-11, which further refined the alternatives to be studied for the University District to Northgate light rail segment; and

WHEREAS, because of the changed and unforeseen circumstances set forth in Resolution No. R2001-16 on November 29, 2001, the Board approved Resolution No. R2001-16, selecting the 14-mile segment from Convention Place Station in downtown Seattle to South 154th Street in Tukwila, with connections to Sea-Tac Airport as the initial segment of the Central Link Light Rail Project to be constructed; and

WHEREAS, because Sound Transit is committed to completing the light rail segments from downtown Seattle to the University District and to Northgate, on September 27, 2001 the Board approved Motion No. M2001-104, which authorized a work plan including the engineering and environmental analysis required to evaluate light rail routes and station alternatives for Central Link light rail between Convention Place and Northgate (North Link); and

WHEREAS, the scoping process to evaluate the range of proposed actions, alternatives, and impacts to be discussed in the draft supplemental environmental impact statement (SEIS) for the North Link alternatives was completed in November 2001; and

WHEREAS, on February 14, 2002, the Board approved Motion No. M2002-13, which identified routes for inclusion in the North Link draft SEIS; and

WHEREAS, on May 23, 2002, the Board approved Motion No. M2002-69, which modified the route alternatives previously identified for study in the North Link draft SEIS; and

WHEREAS, on March 13, 2003, the Board approved Motion No. M2003-33, which directed staff to complete additional work to further develop the North Link route alternatives in order to better inform its decision-making; and

WHEREAS, on November 21, 2003, Sound Transit and the Federal Transit Administration issued a draft SEIS to satisfy the requirements of NEPA and SEPA. The draft SEIS stated that a purpose of the North Link project was to reduce costs and construction risk. The draft SEIS

included a detailed evaluation of the costs and impacts of the North Link route alternatives. The draft SEIS process included a 70-day public comment period and two public hearings; and,

WHEREAS, following consultation with the University of Washington, the Board approved Motion No. M2003-128 on December 11, 2003, which authorized study of a modified Montlake route; and

WHEREAS, in February 2004, Sound Transit issued an addendum to the draft SEIS. The addendum analyzed the impacts of a modified Montlake route through the University of Washington campus. The addendum process included a 30-day public comment period and a public meeting to discuss its contents. Over 300 letters and oral comments were received on the draft SEIS and addendum; and

WHEREAS, on May 20, 2004, the Sound Transit Board adopted Resolution No. R2004-08 identifying the preferred route and stations for the North Link Light Rail Project and authorizing staff to complete the final SEIS and other work on the preferred alternative and other alternatives in the draft SEIS; and

WHEREAS, on January 27, 2005, the Sound Transit Board adopted Resolution No. R2005-06 identifying the preferred Roosevelt route and station location for the North Link Light Rail Project; and

WHEREAS, based on new information and changed and unforeseen circumstances regarding the engineering, construction, and budget risks associated with construction of the First Hill Station, including the North Link risk assessment, the North Link Risk Assessment Technical Report (July 2005), the tunnel construction expert recommendation (July 2005), the lack of funding to address such risks, and the briefing at the July 14, 2005 Board meeting, it appears impractical to construct the First Hill Station because there is a substantial risk that the time and cost involved in attempting to solve the complex engineering and construction problems posed by construction of the First Hill Station could significantly delay completion of University Link and require funding needed to construct the remainder of the segment. Because it is in the best interest of Sound

Transit to allocate its limited resources in a manner that best achieves the goals of Sound Move, and in this case, the completion of University Link within the available budget and within a reasonable time, it appears impractical to accomplish construction of First Hill Station; and

WHEREAS, NEPA requires Sound Transit to identify its preferred alternative in the final SEIS; and

WHEREAS, identification of the preferred alternative will also enable Sound Transit to report a "Locally Preferred Alternative" to the FTA, pursuant to the requirements of 23 CFR 771.123; and

WHEREAS, in order to preserve eligibility for federal funding for North Link, Sound Transit must identify a preferred segment of North Link for purposes of obtaining a New Starts rating from FTA; and

WHEREAS, the identification of a preferred segment of North Link for purposes of obtaining a New Starts rating is not a final decision about the project phasing or financing. The Board will make a final decision on the North Link project, including each of these items (route, station locations, project phasing and financing) after publication of the final SEIS; and

WHEREAS, the Board's identification of the North Link preferred route and station locations is based on a review of the North Link draft SEIS, the addendum addressing a modified Montlake route, public comments from interested citizens, and other information submitted to Sound Transit; and

WHEREAS, to prepare for a ballot measure to seek voter-approval to expand the region's high-capacity transportation investment, Sound Transit issued a final supplemental environmental impact statement to identify and assess the impacts of proposed amendments to the Regional Transit Long-Range Plan; and

WHEREAS, on July 7, 2005, the Sound Transit Board approved Resolution No. R2005-14, adopting the Regional Transit Long-Range Plan to guide development of a mix of light rail, commuter rail, bus rapid transit, regional express bus, and other supportive high-capacity

transportation facilities and services to be considered for inclusion in the next regional transportation system plan, which will be presented to voters as a proposal to expand and complement the region's transportation facilities and services.

NOW, THEREFORE, BE IT RESOLVED by the Board of the Central Puget Sound Regional Transit Authority as follows:

Section 1: The preferred alternative for the North Link segment of the Central Link Light Rail Project shall consist of the following described alignment, station locations, and operational and service parameters:

A. From the Downtown Seattle Transit Tunnel (DSTT), the light rail route would cross under Interstate-5 and proceed east and then north to a cut-and-cover station beneath Nagle Place south of East John Street on Capitol Hill, serving the First Hill/Capitol Hill Urban Center.

B. The tunnel route would then cross the ship canal via the modified Montlake route with a cut-and-cover crossover track and station at Husky Stadium, serving the University of Washington campus and the surrounding neighborhoods.

C. The tunnel route would include a vent facility in the vicinity of East Roanoke Street and 22nd Avenue East (Hop-In Market site) in the Montlake neighborhood to meet operational and system requirements.

D. North from the University of Washington Station, the tunnel route would continue to a cut-and-cover station under Brooklyn Avenue NE south of NE 45th Street in the University District, serving the business district, surrounding residential neighborhood and north University of Washington campus.

E. North of the University District through the Roosevelt neighborhood, the light rail route would continue north in a tunnel to a cut-and-cover station just west of 12th Avenue NE between NE 65th Street and NE 68th Street. From the Roosevelt station, the tunnel route would continue

north and then northwest to a portal location inside Washington State Department of Transportation right-of-way immediately north of the Lake City Way interchange with Interstate-5.

F. North of Roosevelt, the light rail line would continue along the east side of Interstate-5 staying west of the parallel city streets to Northgate. The elevated Northgate station would be located east of 1st Avenue NE, spanning NE 103rd Street. This station would provide access to bus transfers at the Northgate Transit Center and to adjacent park-and ride facilities.

Section 2: Although the 1996 voter-approved Sound Move transit plan provided that the northern terminus of North Link be NE 45th Street in the University District unless additional funding became available, the Board again emphasizes the importance of extending light rail to Northgate as soon as possible. Northgate is an important urban center in the region that must be served by excellent transit. Building light rail beyond the University District to Roosevelt and Northgate would increase light rail boardings in 2030 by over 20,000 per day. Both stations are important and efficient collector points for bus riders from north Seattle and north King County that would reduce bus volumes in downtown Seattle.

Section 3: North Link light rail stations shall be developed to foster effective transit-oriented development, where practical. Consistent with Board policy, light rail station access considerations should include pedestrians, bus transit, passenger drop-off or pick-up, and bicycles to link the light rail line with surrounding neighborhoods. This shall include providing space near stations, where practical, for bus passenger facilities that facilitate easy transfers and bicycle storage.

Section 4: Sound Transit will identify appropriate measures to mitigate significant impacts of construction or operation of the light rail system in the North Link final SEIS, consistent with Board policy and will involve local jurisdictions, businesses, community groups, affected institutions, and citizens in its implementation. In addition, Sound Transit shall provide opportunities for affected neighborhoods to have input on the design of the North Link light rail stations and other project elements to ensure cost-effective, community-sensitive design solutions.

Sound Transit staff shall work with King County Metro to develop plans for bus feeder service to light rail stations to knit the light rail line into the surrounding neighborhoods and encourage light rail ridership.

Section 5: The work required to perform necessary analysis and engineering to complete the final SEIS for the preferred alternative and other alternatives in the draft SEIS, including preliminary engineering on the preferred route and stations, is authorized.

Section 6: The Board identifies "University Link" as the preferred segment of North Link for purposes of the final SEIS and for obtaining a New Starts rating from FTA. The University Link segment is defined as from the Downtown Seattle Transit Tunnel to University of Washington Station, consistent with the preferred route described in Section 1 A, B, and C above. Staff will brief the Board regularly on North Link progress, will seek Board review on appropriate North Link issues, and will return to the Board after the completion of the final SEIS to request a final decision on the North Link project to be built and funded.

Section 7: To the extent possible, the technical work required to develop a proposed regional transportation system plan to present to voters should continue on a schedule that enables any voter-approved plan to be implemented in conjunction with University Link.

ADOPTED by the Board of the Central Puget Sound Regional Transit Authority at a regular meeting thereof held on July 28, 2005.

Greg Nickels
Board Vice Chair

ATTEST:

Marcia Walker
Marcia Walker
Board Administrator

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SOUND TRANSIT
STAFF REPORT

RESOLUTION NO. R2005-20

Modify North Link Preferred Route and Identify "University Link" Segment for purposes of obtaining a New Starts Rating

Meeting:	Date:	Type of Action:	Staff Contact:	Phone:
Board	7/28/05	Discussion/Possible Action	Joni Earl, Chief Executive Officer Ahmad Fazel, Link Director	(206) 398-5450 (206) 398-5389

PROPOSED ACTION

- Modify the preferred route, profiles, and station locations for the North Link Light Rail Project.
- Identify "University Link" as the preferred segment of North Link for purposes of the final SEIS and for obtaining a New Starts rating from the Federal Transit Administration participation.

KEY FEATURES of PROPOSED ACTION

- Modifies the preferred route, profiles and station locations for the North Link portion of the Central Link Light Rail Project as follows:

  - From the Downtown Seattle Transit Tunnel (DSTT), the light rail route would cross under Interstate-5 and proceed east and then north to a cut-and-cover station beneath Nagle Place south of East John Street on Capitol Hill.

  - The tunnel route would then cross the ship canal via the modified Montlake route with a cut-and-cover crossover track and station at Husky Stadium.

  - The tunnel route would include a vent facility in the vicinity of East Roanoke Street and 22nd Avenue East (Hop-In Market site) in the Montlake neighborhood to meet operational and system requirements.

  - North from the University of Washington Station, the tunnel route would continue to a cut-and-cover station under Brooklyn Avenue NE south of NE 45th Street in the University District.

  - North of the University District through the Roosevelt neighborhood, the light rail route would continue north in a tunnel to a cut-and-cover station just west of 12th Avenue NE between NE 65th Street and NE 68th Street. From the Roosevelt station, the tunnel route would continue north and then northwest to a portal location inside Washington State Department of Transportation right-of-way immediately north of the Lake City Way interchange with Interstate-5.

  - North of Roosevelt, the light rail line would continue along the east side of Interstate-5 staying west of the parallel city streets to Northgate. The elevated Northgate station would be located east of 1st Avenue NE, spanning NE 103rd Street. This station would provide

access to bus transfers at the Northgate Transit Center and to adjacent park-and ride facilities.

- Identifies "University Link" as the preferred segment of North Link for purposes of the final SEIS and for obtaining a New Starts rating from FTA, from the Downtown Seattle Transit Tunnel to University of Washington Station, consistent with the preferred route described above.

- Staff will brief the Board regularly on North Link progress and will seek Board review on appropriate North Link issues.

- Technical work required to develop a proposed regional transportation system plan to present to voters should continue on a schedule to permit any voter-approved plan to be implemented in conjunction with University Link.

BUDGET IMPACT SUMMARY

Not applicable to this action.

BUDGET and FINANCIAL PLAN DISCUSSION

In order to preserve eligibility for federal funding for North Link, Sound Transit must identify a preferred segment of North Link proposed for a New Starts rating. A preferred alternative must also be identified in the final SEIS, consistent with NEPA. The identification of a segment of North Link for a New Starts rating is a statement of the Board's intent regarding the North Link project federal grant strategy; it is not a final decision about the project phasing or financing. The Board will make a final decision on the North Link project, including project phasing and financing after publication of the Final SEIS.

BUDGET TABLE

Not applicable to this action.

M/W/DBE – SMALL BUSINESS PARTICIPATION

Not applicable to this action.

PROJECT DESCRIPTION and BACKGROUND for PROPOSED ACTION

On November 18, 1999, the Sound Transit Board (Board) approved Resolution No. R99-34, which selected the Central Link light rail alignment from the University District in Seattle to South 200th Street in the City of SeaTac to be built.

After re-examining Central Link light rail project because of cost, schedule, and engineering issues, on September 27, 2001 the Sound Transit Board identified the preferred initial 14-mile light rail segment to be constructed and operated from Convention Place in downtown Seattle to South 154th Street. On November 29, 2001 the Board adopted Resolution No. R2001-16, selecting that Initial Segment of the Central Link Light Rail Project to be constructed and operated by 2009.

Also on September 27, 2001, the Board adopted Motion No. M2001-104, which authorized a work plan including the engineering and environmental analysis required to evaluate light rail

routes and station alternatives for North Link. The scoping process to evaluate the range of proposed actions, alternatives, and impacts to be discussed in the draft supplemental environmental impact statement (SEIS) for the North Link alternatives was completed in November 2001.

On February 14, 2002, the Board approved Motion No. M2002-13, which identified routes for inclusion in the North Link draft SEIS. On May 23, 2002, the Board approved Motion No. M2002-69, which modified those route alternatives previously identified for inclusion in the North Link draft SEIS.

The Board approved Motion No. M2003-33 in March 2003, which directed staff to complete additional work to further develop the North Link route alternatives in order to better inform its decision-making.

Sound Transit and the Federal Transit Administration issued a draft SEIS to satisfy the requirements of NEPA and SEPA on November 21, 2003. The draft SEIS stated that a purpose of the North Link project was to reduce costs and construction risks. The draft SEIS included a detailed evaluation of the costs and impacts of the North Link route alternatives. The draft SEIS process included a 70-day public comment period and two public hearings.

Following consultation with the University of Washington, the Board approved Motion No. M2003-128 on December 11, 2003, authorizing study of a modified Montlake route. In February 2004, Sound Transit issued an addendum to the draft SEIS, which analyzed the impacts of a modified Montlake route through the University of Washington campus. The addendum process included a 30-day public comment period and a public meeting to discuss its contents.

On May 20, 2004, the Sound Transit Board adopted Resolution No. R2004-08 identifying the preferred route and stations for North Link and directing staff to complete the final SEIS and other work on the preferred alternative and other alternatives in the draft SEIS. On January 27, 2005, the Sound Transit Board adopted Resolution No. R2005-06 identifying the preferred Roosevelt route and station location.

NEPA requires Sound Transit to identify its preferred alternative in the Final SEIS. Identification of the preferred alternative will also enable Sound Transit to report a “Locally Preferred Alternative” to the FTA. To preserve eligibility for federal funding for North Link, Sound Transit must identify a preferred segment of North Link proposed for a New Starts rating.

The identification of a preferred segment of North Link for a federal New Starts rating is a statement of the Board’s intent regarding the North Link project federal grant strategy; it is not a final decision about the project phasing or financing. The Board will make a final decision on the North Link project, including route, station locations, project phasing or financing after publication of the Final SEIS.

Based on new information and changed and unforeseen circumstances regarding the engineering, construction, and budget risks associated with construction of the First Hill station, including the North Link risk assessment, the North Link Risk Assessment Technical Report (July 2005), the tunnel construction expert recommendation (July 2005), the lack of funding to address such risks, and the briefing at the July 14, 2005 Board meeting, staff believe it is impractical to construct the First Hill Station because there is a substantial risk that the time and cost involved in attempting to solve the complex engineering and construction problems posed

by construction of the First Hill Station could significantly delay completion of University Link and require funding needed to construct the remainder of the segment.

Thus, this action represents Sound Transit's staff recommendation to modify the preferred North Link alignment and identify "University Link" as the preferred segment of North Link proposed for the final SEIS and for a New Starts rating, from the Downtown Seattle Transit Tunnel to University of Washington Station, consistent with the preferred route described in the Key Features section of this staff report.

Prior Board or Committee Actions and Relevant Board Policies

Motion or Resolution Number	Summary of Action	Date of Action
R2005-06	Identified the preferred Roosevelt route and station location for the North Link Light Rail Project.	1/27/05
R2004-08	Identified the preferred route, profiles, and station locations for the North Link Light Rail Project.	5/20/04
M2003-128	Authorized staff to conduct additional study of a modified Montlake route for future Board consideration as part of the North Link Supplemental Environmental Impact Statement process, including additional engineering and cost estimating work, environmental analysis, continued coordination with the University of Washington, and additional community outreach efforts.	12/11/03
M2003-33	Directed staff to complete additional work on North Link route alternatives in order to provide the Board with more comprehensive information for its North Link route decision-making process.	3/13/03
M2002-69	Authorized staff to modify the set of route alternatives previously identified to be included for study in the North Link Draft Supplemental Environmental Impact Statement.	5/23/02
M2002-13	Identified the route alternatives for inclusion and study in the North Link Draft Supplemental Environmental Impact Statement (Draft SEIS) and deleting less promising route alternatives from further study.	2/14/02
R2001-16	Selected the initial segment of the Central Link Light Rail Project to be constructed and operated by 2009.	11/29/01
M2001-104	Directed the Executive Director to evaluate Central Link Light Rail routes and station alternatives between Convention Place and Northgate (North Link).	9/27/01
M2001-103	Identified the preferred initial segment to be constructed and operated for Central Link Light Rail.	9/27/01
R99-34	Selecting the alignment alternatives and profiles, station locations, and vehicle maintenance base site alternative to be built for the Central Link Light Rail line.	11/18/99

CONSEQUENCES of DELAY

Delay in Board action to identify a preferred segment of North Link for the final SEIS and for a New Starts rating would result in a delay in the final SEIS and in the preliminary engineering, final design and FFGA award steps of the New Starts process. If Sound Transit does not submit a New Starts Report by August 15, 2005 then a one year delay would be incurred before Sound Transit could resubmit a report as part of the annual FTA evaluation and rating cycle used nationally for potential projects seeking FTA New Starts funding.

PUBLIC INVOLVEMENT

Throughout preliminary engineering, community outreach to the First Hill neighborhood has taken place through various efforts including a station design open house at Town Hall, mailing of project updates and involvement opportunities to ensure a widespread distribution of information, email notification to those subscribed to the North Link interested party list, briefing community organizations/groups on the project status, and holding one-on-one briefings with institutions, stakeholders and community members on First Hill. One-on-one and community briefings were held as recently as June and July of 2005.

Sound Transit staff has also contacted First Hill and other community stakeholders to explain the risk assessment and the Board discussion prior to and after the July 14 Board meeting, and informed them of the upcoming Board meeting discussions on July 28. Staff is also responding to individual emails, comments and questions that have been coming in through the website or customer service phone line. Staff is doing an informal briefing with the First Hill Improvement Association on Wednesday, July 27, to go through the Board materials.

LEGAL REVIEW

PW 7/26/2005

END APPENDIX A

APPENDIX B

SUMMARY OF REQUIRED MITIGATION MEASURES

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Record of Decision
ATTACHMENT C
Summary of Required Mitigation Measures

For the Airport Link Segment of the
Central Link Light Rail Transit Project

August 2005

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Introduction

This attachment lists the mitigation commitments made by the Federal Transit Administration (FTA) and Sound Transit for the Airport Link Segment[1] of the planned Central Link Light Rail Project. This list is provided in the Record of Decision (ROD) to facilitate the monitoring of the implementation of the mitigation measures and to give a sense of the nature of the mitigation actions and associated impacts.

The mitigation commitments identified for the Airport Link project in the FTA this ROD shall and must be implemented by Sound Transit if the project proceeds with FTA financial assistance. These mitigation measures are now incorporated into the definition of the project, and Sound Transit shall implement them, provide funding for their implementation, or ensure that other agencies fund and implement them (although this would not alleviate Sound Transit's overall responsibility for implementation). Sound Transit is prohibited from withdrawing or substantially changing any of the mitigation commitments identified in the ROD for the project without express written approval by FTA. In addition, any change to the project that may involve new or changed environmental or community impacts not yet considered in the existing environmental record must be reviewed in accordance with FTA environmental procedures (23 CFR Part 771) and approved by FTA.

Mitigation measures associated with the operation of the project are described first in Section 1 of this Attachment. Mitigation measures associated with the construction of the project are described in Section 2. Airport Link consists of two segments: Tukwila International Boulevard through the Airport Station and from Airport Station south to the S. 200th Station. Mitigation for impacts by subject area is discussed separately by segment. Mitigation associated with a particular segment will only be implemented with construction or operation of that particular segment. The program for monitoring the implementation of the mitigation measures is described at the end in Section 3.

1 Operational / Long-Term Mitigation

1.1 Transportation

1.1.1 Common to both segments

Parking

[1] The mitigation measures provided herein apply to the Airport Link Segment of the Central Link LRT System that is the subject of the ROD of August 2005 and runs from the Initial Segment Tukwila International Blvd. Station in Tukwila interim terminus to S. 200th Street in SeaTac. The unqualified term "project" used in this Attachment refers to this Airport Link Segment. Whenever the longer Central Link Light Rail Project that includes more than the Airport Link segment is the subject, the name of that larger Central Link LRT will be fully spelled out.

Sound Transit will work with the City of SeaTac to determine if and when measures to discourage on-street hide-and-ride parking in the vicinity of stations will be needed.

Off-street parking displacements due to partial property acquisitions will compensated or replaced according to section 1.3, Acquisitions, Displacements and Relocations below.

Non-motorized Transportation and Traffic

Sound Transit will work with the City of SeaTac and King County Metro to determine the need and, if needed, the inclusion of direct Airport Station access from the west side of International Blvd.

Sound Transit will work with the Port of Seattle to determine the need for a mechanized people-mover between the Airport Station and the SeaTac Airport terminal building and, if needed, its inclusion in the project.

1.1.2 Tukwila International Boulevard through Airport Station

No significant impacts have been identified during operation beyond potential hide-and-ride parking and no additional mitigation is necessary.

1.1.3 Airport Station south to the S. 200th Street Station

Traffic Operations

To mitigate impacts to the International Blvd./S. 200th Street intersection, Sound Transit will work with the City of SeaTac to determine appropriate improvements for mitigation. Possible improvements include:

- adding a second southbound left-turn lane by the year 2015 or when the extension to 200th is constructed if after 2015,
- adding a second westbound left-turn lane by 2030, and
- extending the left-turn pocket storage by approximately 500 feet to mitigate the queue lengths until the additional westbound left-turn lane is constructed.

Parking

Sound Transit will minimize airport passenger and employee use of the Tukwila International Boulevard and S. 200th Street Station park-and-rides through

- strict enforcement of a no overnight parking policy
- signage indicating that parking is for the exclusive use of light rail system patrons only, and
- closing the park-and-ride during late evening/early morning hours when there is no light rail service.

1.2 Land Use

Mitigation for land use and economic impacts would be provided through relocation assistance as described in section 1.2.3.

1.3 Acquisitions, Displacements and Relocations

1.3.1 Common to both segments

Sound Transit will contact all property owners whose property will be directly affected to answer questions and provide additional information about relocation assistance services, payments, and reimbursement eligibility. Sound Transit's relocation assistance advisory services will include, but not be limited to, measures or services necessary or appropriate to determine relocation needs and preferences of each household, business, and nonprofit organization to be displaced. Sound Transit will seek to provide current available information on the availability, purchase prices, and rental costs of comparable replacement dwellings.

Sound Transit will compensate affected property owners according to the provisions specified in Sound Transit's adopted Real Estate Property Acquisition and Relocation Policy, Procedures, and Guidelines. Sound Transit will comply with the appropriate provisions of the Federal Uniform Relocation Assistance and Real Property Acquisition Policies Act of 1970 and Uniform Relocation Act Amendments of 1987 and the State of Washington's relocation and property acquisition regulations (Washington Administrative Code [WA] 468-100). These benefits vary depending on the level of impact, available options, and other factors.

Private property owners whose entire or partial property is acquired by Sound Transit will receive just compensation for their land and improvements. Just compensation is an amount not less than the market value of the property acquired, including damages or benefits to the remaining property.

Sound Transit will pay for all normal expenses of sale, including escrow fees, title insurance, prepayment penalties, mortgage release fees, recording fees, and all typical costs incurred incident to conveying title. The sale will be exempt from real estate excise tax and no real estate commissions are involved. All funds remaining at the end of sale closing will be released to the seller. Other benefits and compensation may include, as appropriate, payment of residential moving expenses and replacement housing payments, nonresidential moving expenses, and reestablishment expenses.

Compensation for use of Port of Seattle and Washington State Department of Transportation property will be according to agreements between Sound Transit and those agencies. Port employees in the former bank building on International Boulevard will be relocated in coordination with the Port of Seattle under the terms and conditions specified in the MOA between Sound Transit and the Port of Seattle.

1.4 Neighborhoods

Specific mitigation for impacts to neighborhood quality of life, social interaction, and safety and security, are described in detail in other sections of this mitigation plan (transportation, displacements, visual resources, air quality, and noise).

1.5 Visual Resources and Aesthetics

1.5.1 Common to both segments

No significant impacts have been identified during operation and no mitigation is necessary.

1.6 Air Quality

No significant impacts have been identified during operation and no mitigation is necessary.

1.7 Noise and Vibration

1.7.1 Common to both segments

Sound Transit will provide reasonable and feasible noise mitigation in an effort to reduce noise levels at properties identified with noise impacts attributed to Airport Link to below the FTA or city of SeaTac criteria, as applicable. The main form of noise mitigation for transit projects is to install noise barriers along the elevated guideways or park-and-ride facilities in affected areas. In accordance with Sound Transit policy, if noise walls are not considered a reasonable and feasible form of noise mitigation, sound insulation of impacted structures may also be considered.

1.7.2 Tukwila International Boulevard through Airport Station

Sound Transit will install noise barriers along the elevated guideway structure adjacent to the Corinthian Apartments.

1.7.3 Airport Station south to the S. 200th Street Station

The noise impacts identified at a cluster of single family residences located immediately south of S. 192nd St. and at the swimming pool at the Hampton Inn will be mitigated through the installation of a noise barrier along the east side of the elevated structure along 28th Avenue S. A noise barrier will also be installed along the S. 200th Street Station park-and-ride west property line.

1.8 Ecosystems

No significant impacts have been identified during operation and no mitigation is necessary.

1.9 Water Resources

1.9.1 Common to both segments

Sound Transit will provide stormwater detention and water quality treatment facilities to meet the requirements of applicable federal, state, and local rules, regulations and permits.

1.9.2 Tukwila International Boulevard through Airport Station

Sound Transit will coordinate with the Port of Seattle on possible use of Port-owned existing or planned facilities for stormwater detention and treatment.

1.10 Energy

No significant impacts have been identified during operation and no mitigation is necessary.

1.11 Geology and Soils

No significant impacts have been identified during operation and no mitigation is necessary.

1.12 Hazardous Materials

1.12.1 Common to both segments

Sound Transit will comply with applicable federal and state regulations governing activities involving dangerous, hazardous, and toxic substances.

1.13 Electromagnetic Fields

No significant impacts have been identified during operation and no mitigation is necessary.

1.14 Public Services

1.14.1 Common to both segments

Sound Transit will implement its Safety and Security Management Plan (2001), which involves the continual development and reevaluation of safety and security procedures throughout project design, construction, and operation. Such evaluations include an assessment of the need to provide security personnel at stations and park-and-rides, and a determination of who would provide the service. Developing and implementing design criteria, training programs, and implementation procedures would be an ongoing process in concert with the Fire/Life Safety Committee, which includes representatives of the Port of Seattle, Port of Seattle police and fire departments, King County Metro, City of SeaTac police and fire departments, and Sound Transit safety and security specialists. Sound Transit will involve the Fire/Life Safety Committee throughout design, construction, and operation. The Fire/Life Safety Committee's work includes an evaluation of the need for specialized equipment and training to respond to emergencies and security concerns within the system. Crime prevention through environmental design (CPTED) features and security measures, such as closed-circuit television, minimizing the number of platforms, and providing alarm systems, will be incorporated into the project as necessary to minimize impacts. Light rail trains will be equipped with intelligent traffic control technology in coordination with local fire and transportation departments. Security personnel could also be provided to rove between stations.

1.15 Utilities

1.15.1 Common to both segments

Based on design measures and coordination with utility providers, impacts to utilities during light rail operation would be minimal. Sound Transit will continue to work with utility providers to minimize any potential service interruptions and conserve resources. Sound Transit will comply with applicable ordinances and procedures to prevent or minimize potential operational impacts on utilities.

1.16 Historic and Archaeological Resources

No historic or archaeological resources are affected within the project's Area of Potential Effect, and no mitigation is necessary during operation.

1.17 Parklands

No parklands are affected by the project, and no mitigation is necessary.

2 Construction / Short-Term Mitigation

2.1 Transportation

2.1.1 Common to both segments

Traffic Operations

Sound Transit will comply with local regulations governing construction traffic control and construction truck routing. Sound Transit will finalize detailed construction plans in coordination with the Port of Seattle, local jurisdictions, WSDOT, King County Metro, and other affected agencies and organizations as appropriate. Mitigation measures for traffic and freight impacts due to light rail construction will include the following practices.

- Coordinate with King County Metro Transit to minimize construction impacts and disruptions to bus facilities and service. Post informative signage before construction at existing transit stops that would be affected by construction activities.
- Follow standard construction safety measures, such as installation of advance warning signs, highly visible construction barriers, and the use of flaggers.
- Post signs prior to construction as appropriate in areas where surface construction activities would affect access to surrounding businesses.
- Coordinate street sweeping services in construction areas with construction activity, particularly areas with surrounding residential and retail development.
- Use lighted or reflective signage to direct drivers to truck haul routes to ensure visibility during nighttime work hours.
- Use temporary reflective truck prohibition signs on streets with a high likelihood of cut-through truck traffic.
- Cover trenches during non-construction hours, and use precast concrete barriers to protect drivers where appropriate.
- Develop a multimedia public information program to provide information regarding street closures, hours of construction, business access, and parking impacts.

Parking

- Provide construction workers designated parking on- or off-site, as possible, to minimize neighborhood parking impacts.
- Provide temporary parking to mitigate loss of private off-street parking due to construction staging or work activities, as appropriate.

2.2 Land Use, Economics, and Neighborhoods

2.2.1 Common to both segments

Sound Transit will develop and implement a construction outreach plan that will provide that local residents and businesses are informed about potentially major disruptions such as temporary street closures, out of the ordinary construction noise, vibration, light or glare; changes in transit service; and parking availability. In addition, Sound Transit will.

- minimize construction-related noise, vibration, dust, and dirt impacts through appropriate construction scheduling methods, particularly to minimize impacts during periods of increased sensitivity, such as evenings for residences and hotels
- provide business cleaning services as needed on a case-by-case basis and
- provide a project-specific 24-hour hotline monitoring center that provides telephone access for the public to get construction information and to make complaint and incident reports.

2.3 Visual Resources and Aesthetics

2.3.1 Common to both segments

Sound Transit will shield and aim construction light sources to block direct views from residential areas and reduce spillover lighting.

2.4 Air Quality

2.4.1 Common to both segments

Sound Transit will comply with applicable Puget Sound Clean Air Agency air quality regulations, which require using best available control technology to control fugitive dust emissions such as

- Using water spray as necessary to prevent visible dust emissions-particularly during demolition of brick or concrete buildings by mechanical or explosive methods.
- Minimizing dust emissions during transport of fill material or soil by wetting down, covering loads, or other measures.
- Keeping all construction machinery engines in good mechanical condition to minimize exhaust emissions.
- Covering materials, debris, and soil.

In addition, Sound Transit will

- promptly clean up spills of transported material on public roads by frequent use of a street sweeper machine.
- route and schedule high volumes of construction trucks to reduce delays to traffic during peak travel times as practical to reduce air quality impacts cause by a reduction in traffic speeds.

- evaluate additional mitigation such as more frequent cleaning or replacement of the building's air conditioning system filters or more frequent exterior dust and particulate control measures as appropriate where businesses with unusually high air quality requirements are located adjacent to high dust-generating construction activities.

2.5 Noise and Vibration

2.5.1 Common to both segments

Noise

Sound Transit will

- limit the operation of construction equipment, where feasible, near occupied dwellings at night (10:00 pm to 7:00 am) or on Sundays or legal holidays.
- use noise barriers as necessary around noise-generating equipment near sensitive receivers.
- require all engine powered equipment to have mufflers installed according to the manufacturer's specifications, and all equipment will be required to comply with equipment noise standards of the U.S. EPA.
- limit activities as practical that would produce the highest noise levels, such as hauling, jack hammering, and the use of demolition equipment, to daytime hours of 8:00 am to 5:00 pm near sensitive receivers or when disturbance to sensitive receivers would be minimized.
- schedule construction activities in an effort to limit impacts on residences and local area businesses and seek to avoid the most noise intensive construction techniques where possible.
- A variance will be requested from the city if construction activities exceeding nighttime noise regulations are needed.

Vibration

Sound Transit will include specifications in the construction contract that includes vibration monitoring of all activities that may produce vibration levels at or above 0.5 inches-per-second whenever there are structures or sensitive equipment located within 50 feet of the most intensive vibration-producing activity. In these locations, alternative construction approaches will be considered to minimize vibration.

2.6 Ecosystems

2.6.1 Common to both segments

Managing stormwater in accordance with applicable regulations will avoid ecosystem impacts.

2.7 Water Resources

2.7.1 Common to both segments

Sound Transit will employ best management practices (BMPs) to minimize water quality degradation from erosion and sedimentation and the release of pollutants during construction in accordance with applicable rules, regulations, and permits.

2.8 Energy

No significant impacts have been identified during construction and no mitigation is necessary.

2.9 Geology and Soils

No significant impacts have been identified during construction and no mitigation is necessary beyond those identified in sections 2.5.1 and 2.7.1.

2.10 Hazardous Materials

2.10.1 Common to both segments

- Sound Transit will comply with federal and state regulations governing activities involving dangerous, hazardous, and toxic substances.

- Sound Transit will require the contractor to provide a formalized health and safety plan and contaminated soil and materials handling plan before construction work begins.

2.12 Public Services

2.12.1 Common to both segments

- Sound Transit will require the contractor to provide advance notice to fire, police, and emergency medical services of construction plans, traffic detours, and road closures.
- Sound Transit will work with the Fire/Life Safety Committee to ensure reliable emergency access is maintained during project construction and alternate plans or routes are developed, as appropriate, to avoid significant delays in response times.
- Sound Transit and the contractor will coordinate with the fire department during water and other utility relocations to prevent supply disruptions.

2.13 Utilities

2.13.1 Common to both segments

- Sound Transit will repair or replace utilities inadvertently damaged during construction.
- Sound Transit and the contractor will coordinate with utility providers during construction to minimize potential service disruptions

2.14 Historic and Archaeological Resources

2.14.1 Airport Station south to the S. 200th Street Station

Sound Transit will conduct subsurface testing before construction and monitoring during construction in areas of high or moderate probability for archaeological resources. In the event resources are discovered during construction, an Archaeological Resources Monitoring and Treatment plan, prepared pursuant to the Central Link Light Rail Programmatic Agreement, will be implemented, as appropriate.

2.15 Parklands

No parklands are affected by the project, and no mitigation is necessary.

END APPENDIX B

APPENDIX C

TRANSIT SECURITY DESIGN CONSIDERATIONS

(FORMERLY CRIME PREVENTION THROUGH ENVIRONMENTAL DESIGN, C.P.T.E.D.)

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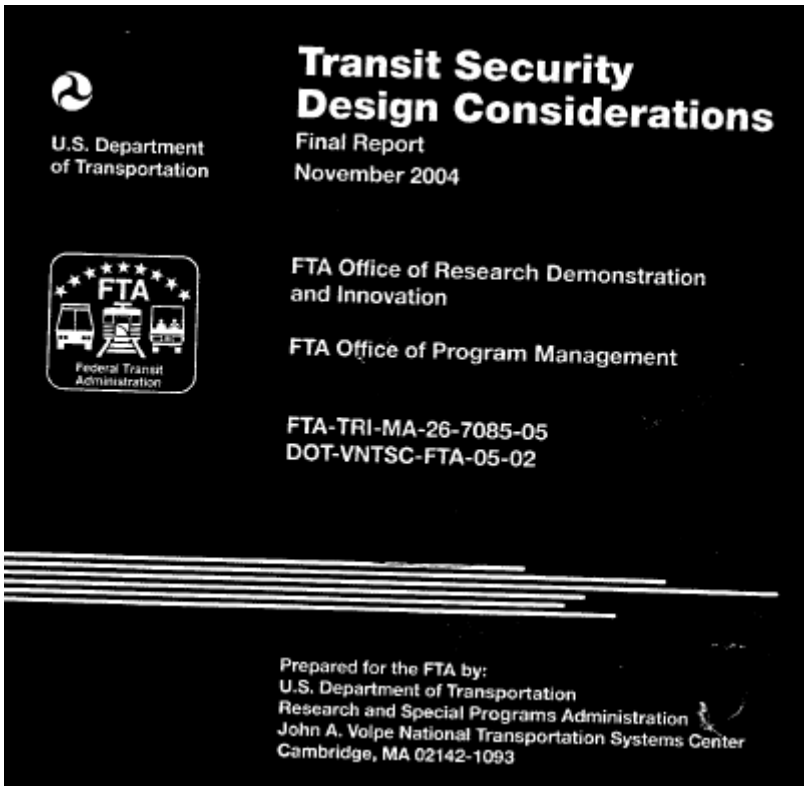
Per Sound Transit Safety & Security Department, the document titled, “Building Security into New Transit Systems with C.P.T.E.D. (Crime Prevention Through Environmental Design)”, presented by Bernard M. Jacobs, C.P.P, May 4, 1997, has been replaced by the following document:

“Transit Security Design Considerations, Final Report November 2004”, prepared by FTA.
FTA-TRI-MA-26-7085-05
DOT-VNTSC-FTA-05-02



END APPENDIX C