MASSACHUSETTS BAY TRANSPORATION AUTHORITY

SILVER LINE PHASE III

MANUAL OF DESIGN CRITERIA

REVISED OCTOBER 2007

URS DMJM HARRIS
A JOINT VENTURE

66 LONG WHARF, 2ND FLOOR
BOSTON, MA 02110

1.0 CIVIL

1.1 SCOPE

This chapter contains general civil criteria developed for the MBTA Silver Line Transitway system. These criteria govern the design of the tunnel alignment as determined by the tunnel roadway alignment for the bus rapid transit (BRT) vehicle, including consideration to not preclude the future conversion to a light rail transit (LRT) vehicle. This chapter also contains general criteria for the protection and relocation of existing utilities and the reconstruction of surface roadways. Included in this chapter is a summary of the codes and standards, and standard design criteria and practices that will be used during the project.

These criteria are intended to promote uniformity of design and standardization of civil elements and their application throughout the Transitway system.

1.2 STANDARDS, CODES AND GUIDELINES

The latest edition of the applicable standards, codes and guidelines of the following organizations shall be used for all designs unless otherwise required by this manual:

- Massachusetts Bay Transportation Authority (MBTA) Book of Standard Plans, Track and Roadway
- Massachusetts Bay Transportation Authority (MBTA) Guide to Access
- Massachusetts Bay Transportation Authority (MBTA) Standard Specifications - Construction
- American Association of State Highway and Transportation Officials (AASHTO) – A Policy on Geometric Design of Highways and Streets (the Green Book)
- American Railway Engineering and Maintenance-of-way Association (AREMA) Manual for Railway Engineering
- National Fire Protection Association (NFPA) National Fire Codes
- Massachusetts Architectural Access Board, 521 CMR
- The Americans with Disabilities Act (ADA), 28 CFR Part 36
- Boston Water and Sewer Commission (BWSC) Standard Drawings and Specifications
- Boston Transportation Department (BTD) Standard Drawings and Specifications
- Boston Street Lighting Section Standard Drawings and Specifications
- Boston Fire Department Construction Methods and Specifications
- Massachusetts Highway Department (MHD) Highway Design Manual
- Massachusetts Highway Department (MHD) Standard Specifications for Highways and Bridges
- Massachusetts Highway Department (MHD) Construction and Traffic Standard Details
- Verizon – New England Telephone, Manhole & Conduit Specifications
- NSTAR – Code 19 Underground Contractors (Manholes and Conduits)
- Dig Safe System, Inc.
- Keyspan Energy Delivery (to be obtained)
- Comcast – They use the same specifications as Verizon

The following Design Manuals and Reports contributed to or are referenced in the design criteria:

1. MBTA – South Boston Piers/Fort Point Channel Underground Transitway, Schematic Design Report MBTA Contract No. SOPS03, November 1992, Prepared by Stone & Webster.

2. MBTA – Silver Line Phase III Conceptual Design Report for The Tremont Street Alignment And Dewey Square to South Station Tunnel Segments, October 2001, Prepared by URS Corporation.

3. MBTA – Engineering Design Manual, Southwest Corridor Project, MBTA 065-018, (Chapter II.1.10, Green Line Operations) September 1978, Prepared by Kaiser Engineers, Inc./Fay, Spofford & Thorndike, Inc.

4. MBTA – Light Rail Accessibility Program, Green Line, Project Design Manual, MBTA Contract No. S5PS11, August 1995, Prepared by Gannett Fleming, Stull and Lee, Inc. et al.

5. Transportation Research Board, Transit Cooperative Research Program TCRP Report 57, "Track Design Handbook for Light Rail Transit" copy righted 2000.

1.3 TUNNEL ALIGNMENT AND GEOMETRY

1.3.1 Design Parameters

1. Design vehicle is the Neoplan Bus – Boston DMA, Low Floor for use in the Silver Line bus rapid transit (BRT) tunnel. The design shall accommodate ("not preclude") the conversion from BRT to Light Rail Transit (LRT) and the Light Rail Vehicle (LRV). The BRT vehicle path governs the overall dimensions, which is slightly wider than the LRV on curves. The BRT is assumed to be an unguided 60-foot long articulated bus with rubber tires and non-steering center and rear axles. The LRV is assumed to be a rail guided articulated vehicle. Vehicle diagrams are provided as Figure 1 and Figure 2.

2. Horizontal alignment consists of tangents joined to circular curves by Hickerson Clothoid Spiral curves. Circular curves are defined by the arc definition and specified by their radii (R) in feet, and their degree of curvature (D), in degrees. Double spiral transition curves between tangents are acceptable in restricted conditions where minimum circular curve and minimum length of spiral transition curve can not be attained.

3. Horizontal Design criteria are applied to the Horizontal Control Line (HCL). The HCL is the drivers' side curbline. This is the left curbline of the tunnel in the direction of operation.

4. Vertical design criteria are applied 7' – 0" from the HCL on tangent sections. This PGL is chosen to accommodate the future conversion to LRV as it aligns with the center of the LRV tracks on tangent. On horizontal curves the PGL follows the centerline of the LRV tracks. The centerline of the tracks shifts away from the HCL to accommodate the vehicle overhang. This offset varies with the radius of curvature.

5. The design speed is a maximum of 30 mph. Design speed is controlled by radius of curvature and superelevation particularly at sharp turns.

6. The Horizontal Datum is the North American Datum of 1983 (NAD83).

7. The project Vertical Datum is 100 feet below the National Geodetic Vertical Datum of 1929 (NGVD29).

1.3.2 Horizontal Design Criteria

1. Minimum radius –

   open conditions – 100 feet
   restricted conditions – 50 feet
   station platform (ADA) – 400 feet

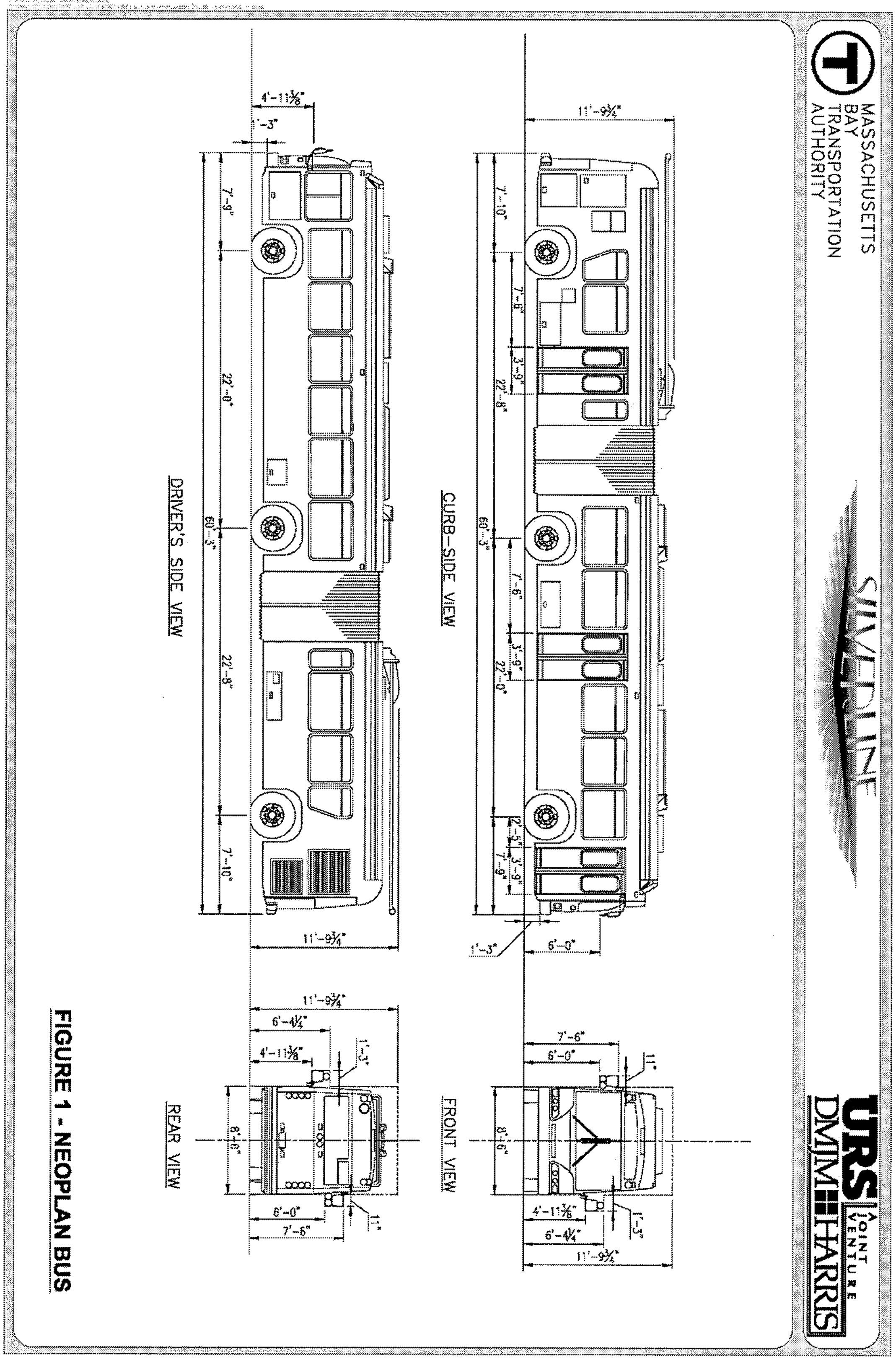

FIGURE 1 - NEOPLAN BUS

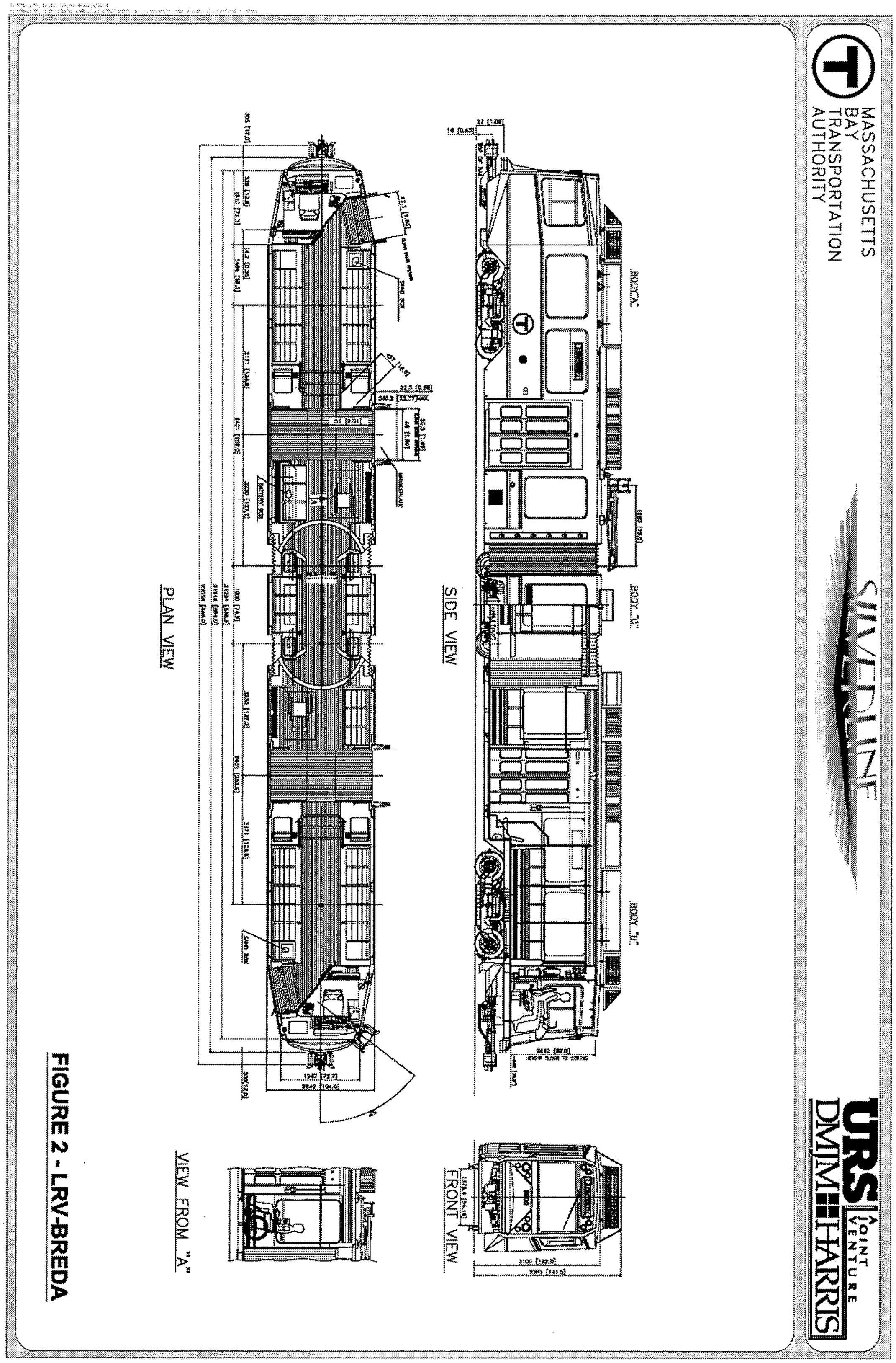

FIGURE 2 - LRV-BREDA

2. Minimum length of spiral, Ls = V(Ea)

   open conditions – 50 feet
   restricted conditions – 25 feet.

3. Minimum length of tangent. A minimum length of tangent shall separate reverse curves except on non-service loops.

   open conditions – 75 feet (equal to longest car that will traverse system)
   restricted conditions – 10 feet (with MBTA approval)

4. Minimum length of curve – (may include ½ of spiral length)

   open conditions – 50 feet
   restricted conditions – 25 feet

5. Superelevation – constant on circular curves; linear transition through spirals. Superelevation to be completely run off within spiral length.

6. Superelevation rate – BRT – AASHTO Exhibit 3-40.

   0.050 feet/foot for 50 ft radius
   0.050 feet/foot for 100 ft radius
   0.050 ft/ft for 200 ft radius
   0.020 ft/ft for 250 ft radius
   Normal crown for 300 ft radius

7. Superelevation rate – LRV –

   Ee = Equilibrium superelevation, inches; Ee = (4.011)V2 / R
   Ea = Actual superelevation, inches; max Ea = 3 inches
   Eu = unbalanced superelevation, inches; max Eu = 3 inches

8. Roadway widening on curves shall follow the vehicle path of the BRT. The swept path of the BRT governs the roadway width. A table of dimensions has been established using Autoturn Software and the vehicle dimensions, see Table 1.

1.3.3 Vertical Design Criteria

1. Maximum vertical tangent grade – 5.6%.

2. Maximum grade in stations – 2.0%.

3. Maximum grade at switches (for future conversion to LRV) – 0.5%.

4. Minimum Length of vertical curve – Sag - Lvc = (G)*V2/46.5/0.02g; for V = 30; G in percent (of grade in – grade out); Lvc = (G) * 30.

5. Minimum Length of vertical curve – Crest - Lvc = (G)*V2/46.5/0.03g; for V = 30; G in percent (of grade in – grade out); Lvc = (G) * 20.

6. Minimum Length of vertical curve – allowable Lvc = 30 feet.

7. Clearance between tunnels – 8 feet preferred; absolute minimum determined by geotechnical considerations at restricted locations.

TABLE 1

Curve Data - Left Curve					Radius of HCL	Curve Data - Right Curve				
(Direction of travel turning left, HCL on left)						(Direction of travel turning right, HCL on left)				
Radius of CL Vehicle path	**W** Curb to Curb Width	**U** Track width	**C** clearance per veh	**Z** allowance for diffclty on curve		**W** Curb to Curb Width	**U** Track width	**C** clearance per veh	**Z** allowance for diffclty on curve	Radius of CL Vehicle path
FT	**FT**	**FT**	**FT**	**FT**	**FT**	**FT**	**FT**	**FT**	**FT**	**FT**
60	23.33	17.33	4	2	50	25.86	19.86	4	2	40
65	22.74	16.74	4	2	55	25.09	19.09	4	2	45
70	22.22	16.22	4	2	60	24.33	18.33	4	2	50
75	21.79	15.79	4	2	65	23.75	17.75	4	2	55
80	21.35	15.35	4	2	70	23.15	17.15	4	2	60
85	20.98	14.98	4	2	75	22.61	16.61	4	2	65
90	20.62	14.62	4	2	80	22.12	16.12	4	2	70
95	20.31	14.31	4	2	85	21.65	15.65	4	2	75
100	20.03	14.03	4	2	90	21.28	15.28	4	2	80
105	19.78	13.78	4	2	95	20.92	14.92	4	2	85
110	19.54	13.54	4	2	100	20.59	14.59	4	2	90
120	19.14	13.14	4	2	110	20.01	14.01	4	2	100
130	18.79	12.79	4	2	120	19.53	13.53	4	2	110
140	18.51	12.51	4	2	130	19.12	13.12	4	2	120
150	18.23	12.23	4	2	140	18.78	12.78	4	2	130
154	18.13	12.13	4	2	150	18.43	12.43	4	2	143
164	17.91	11.91	4	2	160	18.16	12.16	4	2	153
175	17.69	11.69	4	2	170	17.97	11.97	4	2	162
186	17.51	11.51	4	2	180	17.75	11.75	4	2	173
196	17.38	11.38	4	2	190	17.57	11.57	4	2	183
206	17.24	11.24	4	2	200	17.44	11.44	4	2	192
216	17.11	11.11	4	2	210	17.3	11.30	4	2	202
226	16.99	10.99	4	2	220	17.15	11.15	4	2	212
247	16.78	10.78	4	2	230	17.04	11.04	4	2	222
247	16.77	10.77	4	2	240	16.93	10.93	4	2	232
256	16.69	10.69	4	2	250	16.85	10.85	4	2	242
267	16.61	10.61	4	2	260	16.73	10.73	4	2	252
277	16.53	10.53	4	2	270	16.67	10.67	4	2	262
287	16.46	10.46	4	2	280	16.59	10.59	4	2	272
297	16.39	10.39	4	2	290	16.51	10.51	4	2	282
307	16.33	10.33	4	2	300	16.43	10.43	4	2	292
318	16.30	10.30	4	2	310	16.36	10.36	4	2	302
328	16.25	10.25	4	2	320	16.31	10.31	4	2	312
338	16.16	10.16	4	2	330	16.26	10.26	4	2	321
348	16.14	10.14	4	2	340	16.23	10.23	4	2	331
358	16.09	10.09	4	2	350	16.15	10.15	4	2	341
408	15.90	9.90	4	2	400	15.96	9.96	4	2	391

TABLE 1

Curve Data - Left Curve (Direction of travel turning left, HCL on left)					Radius of HCL	Curve Data - Right Curve (Direction of travel turning right, HCL on left)				
Radius of CL Vehicle path	**W** Curb to Curb Width	**U** Track width	**C** clearance per veh	**Z** allowance for diffclty on curve		**W** Curb to Curb Width	**U** Track width	**C** clearance per veh	**Z** allowance for diffclty on curve	Radius of CL Vehicle path
FT	**FT**	**FT**	**FT**	**FT**	**FT**	**FT**	**FT**	**FT**	**FT**	**FT**
458	15.75	9.75	4	2	450	15.78	9.78	4	2	440
508	15.62	9.62	4	2	500	15.65	9.65	4	2	491
609	14.65	9.44	4	1.214	600	14.70	9.46	4	1.236	591
709	14.43	9.30	4	1.125	700	14.46	9.32	4	1.142	691
809	14.25	9.20	4	1.054	800	14.29	9.22	4	1.068	791
909	14.12	9.13	4	0.994	900	14.15	9.14	4	1.006	891
1009	14.00	9.06	4	0.944	1000	13.99	9.04	4	0.954	990
2010	13.45	8.78	4	0.669	2000	13.46	8.79	4	0.673	1990
3010	13.24	8.69	4	0.547	3000	13.24	8.69	4	0.549	2990
4010	13.09	8.62	4	0.474	4000	13.09	8.62	4	0.475	3990
5000	13.02	8.60	4	0.424	5000	13.02	8.60	4	0.425	5000
7500	12.92	8.57	4	0.346	7500	12.92	8.57	4	0.347	7500
10000	12.86	8.56	4	0.300	10000	12.86	8.56	4	0.300	10000

1.3.4 Station Design Criteria

1. Edge of platform clearance – 4'-9" from centerline of LRV = 10'-0" from HCL on Tangent sections.
2. Platform height – 8" above roadway surface.
3. Length of Platform – 220 feet minimum loading area.
4. Platform on tangent alignment where possible, minimum radius 400 feet.
5. Station Grades – Minimum 0.0%, Typical 0.5%, Maximum 2.0%.

1.3.5 Typical Section (See Figure 3)

1. Single tunnel on tangent – 1.75-foot wide median curb, 12-foot roadway, and 3.0-foot wide safety walk.
2. Single Tunnel on Curve – 1.75-foot wide median curb, a variable width roadway per Table A-1 and 3.0-foot safety walk.
3. Curb Height – 8".

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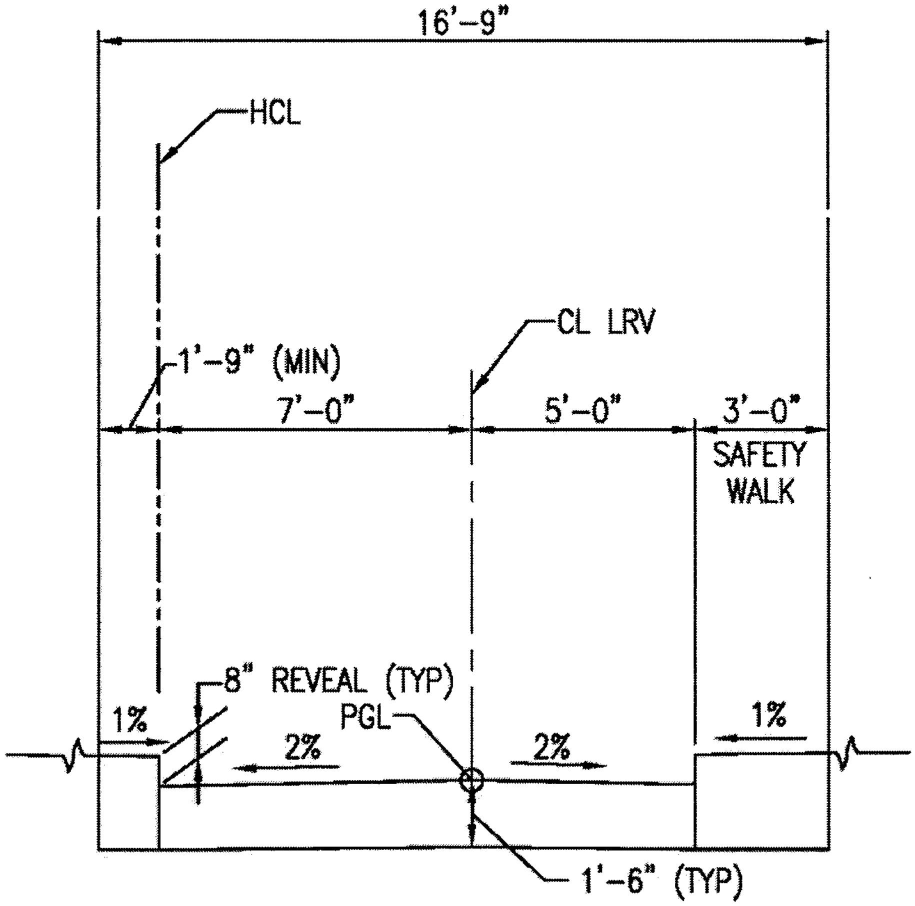
URS DMJM HARRIS A JOINT VENTURE



SINGLE ROADWAY TUNNEL
ON TANGENT
(LOOKING IN TRAVEL DIRECTION)

FIGURE 3 - TYPICAL ROADWAY SECTION

4. Median wall between parallel tunnels – 2 foot wide.

5. Roadway cross slope – 2% crowned about the PGL on Tangents.

6. Superelevated as required per HCL radii.

7. Walkway/curb cross slope – 1.0 max % towards roadway.

8. Minimum Vertical Clearance – Restricted – 15'-3" (14'-0" to contact wire plus 1'-3" to ceiling) measured from the PGL or high side of superelevated roadway. Due to the number of vertical restrictions and to reduce the overall depth of using stacked tunnels the 15'-3" tunnel clearance is used throughout.

1.3.6 Drainage Requirements

1. As far as practicable, drainage shall be by gravity flow.

2. Surface Runoff - Boat Section: Intercept all surface storm water runoff before and at the Portal entrance to Tunnel and lift (pump) storm water to City Storm Drain. Drainage facilities for the Boat Section to be sized for the 50-year Design Storm event.

3. Non- Tunnel Surface Runoff: Storm water runoff from surface areas such as parking areas will be intercepted, separate from tunnel related surface drains, and conveyed to existing City Storm Drains. Non-Tunnel related surface drainage facilities to be sized for the 10-year Storm Event.

4. Tunnel Runoff: Inclusive of Fire Flows, Subdrains and Areaway drains will be collected and conveyed to a single pump station and lifted to a surface Oil Water Separator before discharging into the City Sanitary Sewer System. The layout and design of all Tunnel Structure drains is considered to be plumbing. See Plumbing Design Criteria.

5. Minimum pipe slope – slope to provide minimum flow velocity of 2.5 feet/sec at design flow.

6. Drain inlet requirements – 100 foot minimum spacing; grate HS-25 vehicle loading capability.

7. Manhole requirement – 400 foot minimum spacing BWSC standard cover.

8. Implement Best Management Practices (BMPs) inclusive of deep sumps on all inlets, scheduled sweeping and regular inspections on all drainage systems.

1.4 SURFACE ROADWAYS

1.4.1 Roadway Reconstruction

1. The surface roadways along the tunnel alignment will be subjected to numerous surface penetrations for borings, soil stabilization improvements, utility relocations, access shafts for tunnel mining support activities and for Transitway station construction. All roadways along the alignment corridor will be reconstructed from back of walk to back of walk in accordance with City of Boston requirements. Material replacement will be in-kind except in areas where betterment arrangements have been agreed upon with the City or abutters.

1.4.2 Utility Relocation

1. There are numerous existing utilities located within the alignment corridor proposed Silver Line III. These existing utilities in most areas will be unaffected by the work due to the depth of the tunnel and associated mined construction operations. There are, however, several critical locations that will require extensive utility system support and protection as well as potential relocation. The Joint Venture will work in conjunction with the affected utility agencies to coordinate and design the support/protection and or the needed relocation of utilities to ensure minimal disruption of utilities. In many cases relocation of major utilities will require relocation contracts prior to the beginning of the tunnel project. The Joint Venture Utility Engineers will work closely with the various Utility Companies, the City and the Contractors to ensure that utility impacts associated with the project are properly mitigated.

   Final planning for utility relocation or support must coincide with the beginning of final design. In many cases where utilities must be relocated, the total time required could be several years. As soon as the final top down excavation locations are determined the utility mitigation process will begin.

   - Select design engineering team for utility mitigation.
   - Meet with utilities and identify affected utilities and evaluate their mitigation options.
   - Prepare preliminary engineering design cost estimates.
   - Coordinate final plans and specifications for construction of inclusion in tunnel construction specifications.

2. Major Utility Providers:

   - Keyspan Gas
   - Nstar Electric
   - Trigent Boston Energy (steam)
   - Boston Water and Sewer
   - Verizon Communications
   - City of Boston Street Light, Traffic, Fire Alarm
   - MFS cable

3. Design Requirements

   Each utility provider has particular design standards or guidelines that have been developed to ensure:

   1. Temporary and permanent services are to be maintained and not interrupted unless approved by the utility company.

   2. The utilities shall be supported and protected as required.

   3. Maintain the least disruption to each utility system and maintain its integrity.

   4. The work shall be performed by an approved contractor for the specific utility being worked on.

   5. The specific utility's standard materials shall be installed.

   6. Maintain an open avenue of communication with all of the utility companies.

7. Design so the water main(s) are above the sewer by a minimum of 18 inches vertically and if on the same level they shall have a minimum of a 4-foot separation.

8. Design to each utility company's standards.

9. NSTAR – Pipe-Type Cable – These are steel pipes that carry high voltage. The pipes are oil filled to keep the cables from getting over heated. They are always laid in pairs and only one of them is in service at a time,. The second pipe acts as a back – up. The cables can only be worked on in the spring or fall. This is due to the high volume use of air conditioners in the summer and the high volume use of heaters in the winter.

2.0 STRUCTURAL DESIGN CRITERIA – UNDERGROUND STRUCTURES

2.1 GENERAL

This chapter sets forth Structural Design Criteria (SDC) to design underground structures, including tunnels, below grade station structures, support excavation, and boat (transition) structures for the MBTA Silver Line, Phase III Project. The following Definitions apply to Chapters 2 and 3:

1. Cut-and-Cover Tunnel Structures: Reinforced cast-in-place concrete structure below finish grade.

2. Mined Tunnel Structures: Reinforced concrete structure constructed using primarily the Sequential Excavation Method (SEM); however other mining techniques such as drift tunneling and micro-tunneling are included in this criteria.

3. Below Grade Station Structures: The outer perimeter shell of the underground station and any part of the station elements required maintaining the structural integrity of the outer shell, such as the mezzanine levels.

4. Boat or Transition Structures: Reinforced concrete structure without a roof slab, conveying the line and grade of the alignment from the ground surface to a tunnel portal or headwall.

5. Slurry Walls: Reinforced concrete panel wall constructed under bentonite slurry methods. Typical wall panels will act as temporary support of excavation and will, eventually, be incorporated into the permanent completed tunnel/underground structure. Panels will be constructed using conventional reinforced concrete.

6. Secant Pile Walls: Similar to slurry wall construction, except the use is restricted to temporary support of excavation structure and constructed using conventional reinforced concrete or soldier pile reinforced. Used in areas requiring ground water control.

7. Deep Soil Mix Walls: Constructed using a cement slurry mix in existing ground, reinforced with WF sections at intervals determined by design. Deep soil mix walls are restricted to temporary support of excavation in areas where ground water control is required.

8. Portal Structures: The entrance or exit from a tunnel to a boat structure.

9. Approach Slab: A direct buried slab placed beneath the travel-way that facilitates the transition of the ground stiffness to that of the structure ahead. Typically used at the interface of boat structures to at-grade transitions.

2.2 DESIGN SPECIFICATIONS

2.2.1 CODES

Unless noted, or directed otherwise, the following codes will be used in the analysis and design of all structures and structural elements, as set forth in this chapter:

1. "Standard Specifications for Highway Bridges", 17th Edition, 2002, of the American Association of State Highway and Transportation Officials, referenced to in these criteria as the "AASHTO Code", as modified herein.

2. American Institute of Steel Construction (AISC), "Manual of Steel Construction", 13th Edition, applying the Allowable Strength Design philosophy, referenced in these criteria as the "AISC".

Where differences between the structural design criteria and codes noted in Section 2.2.1 occur, the design criteria shall govern the design and analysis of the structures. For seismic design, additional references are included in Chapter 3.

2.2.2 STANDARDS, REFERENCES AND GUIDELINES

Unless noted, or directed, otherwise, the following standards, references and guidelines shall be used:

1. "Annual Book of ASTM Standards", of the American Society for Testing and Materials, referenced to in these criteria as the "ASTM".

2. "Standard Specifications for Transportation Materials and Methods of Sampling and Testing" of the American Association of State Highway and Transportation Officials, Part I, referenced to in these criteria as the "AASHTO Materials", and Part II, referenced to in these criteria as the "AASHTO Testing".

3. American Railway Engineering and Maintenance of Way Association, "Manual for Railroad Engineering, 2002," referenced in these criteria as the "AREMA Code", as modified herein.

4. Massachusetts Building Code, 6th Edition, referenced as the "MBC Code".

5. American Concrete Institute (ACI), "Building Code Requirements for Structural Concrete - ACI 318–05," including its commentary, referenced to in these criteria as "ACI–318", as modified herein.

6. Underwriters' Laboratories, Inc. (UL), "Testing for Public Safety, Building Materials List," referenced to in these criteria as the "UL List"

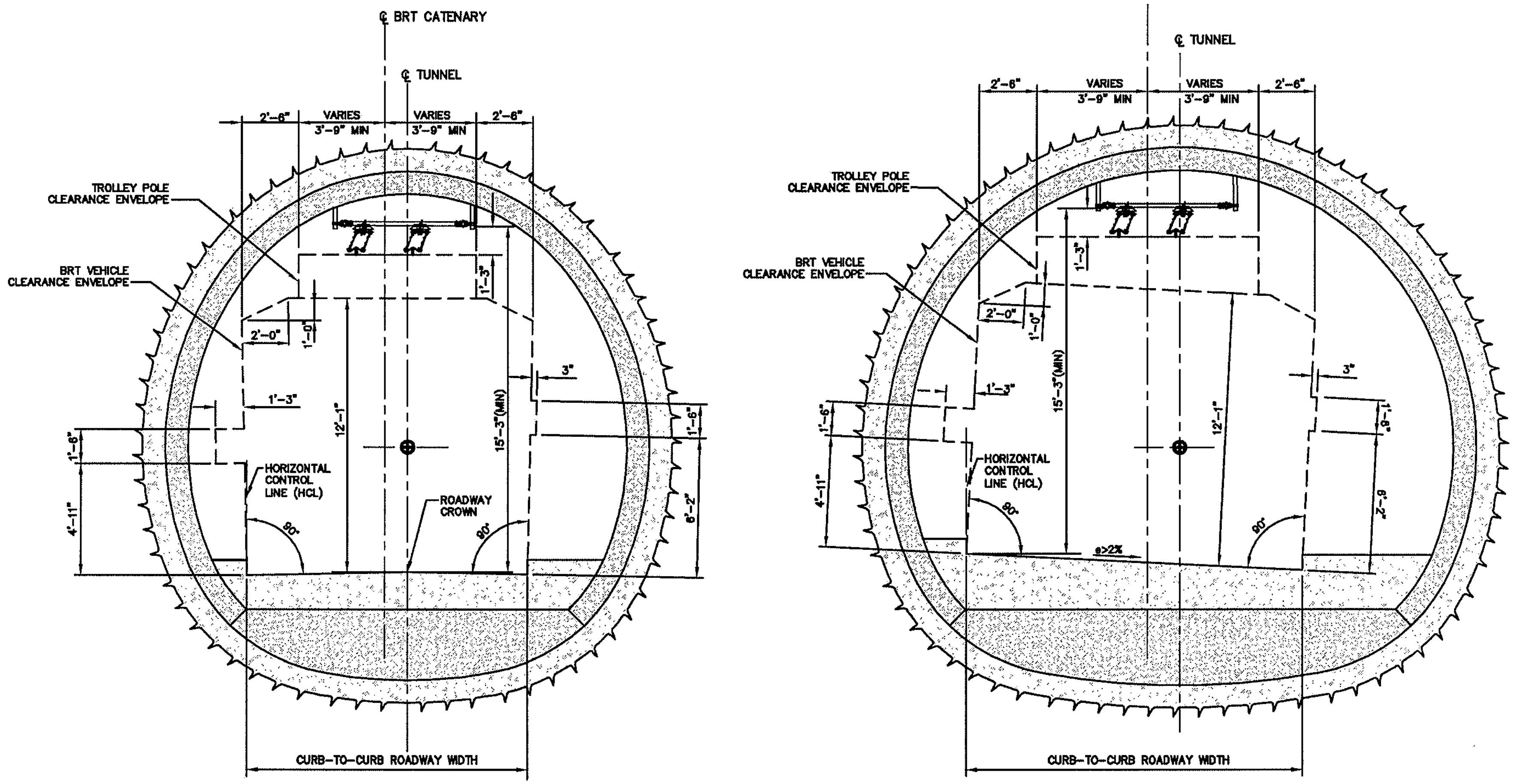
7. National Fire Protection Association, (NFPA), "Standard for Fixed Guideway Transit and Passenger Rail Systems, 2000 edition, referenced to in these criteria as the "NFPA 130".

The structural design criteria shall supersede all standards and references noted above in cases of conflict, unless directed specifically by the Structural Discipline Lead. For seismic design, additional references are included in Chapter 3.

2.2.3 CLEARANCES

1. The general arrangement of structures shall be shown on the contract documents.

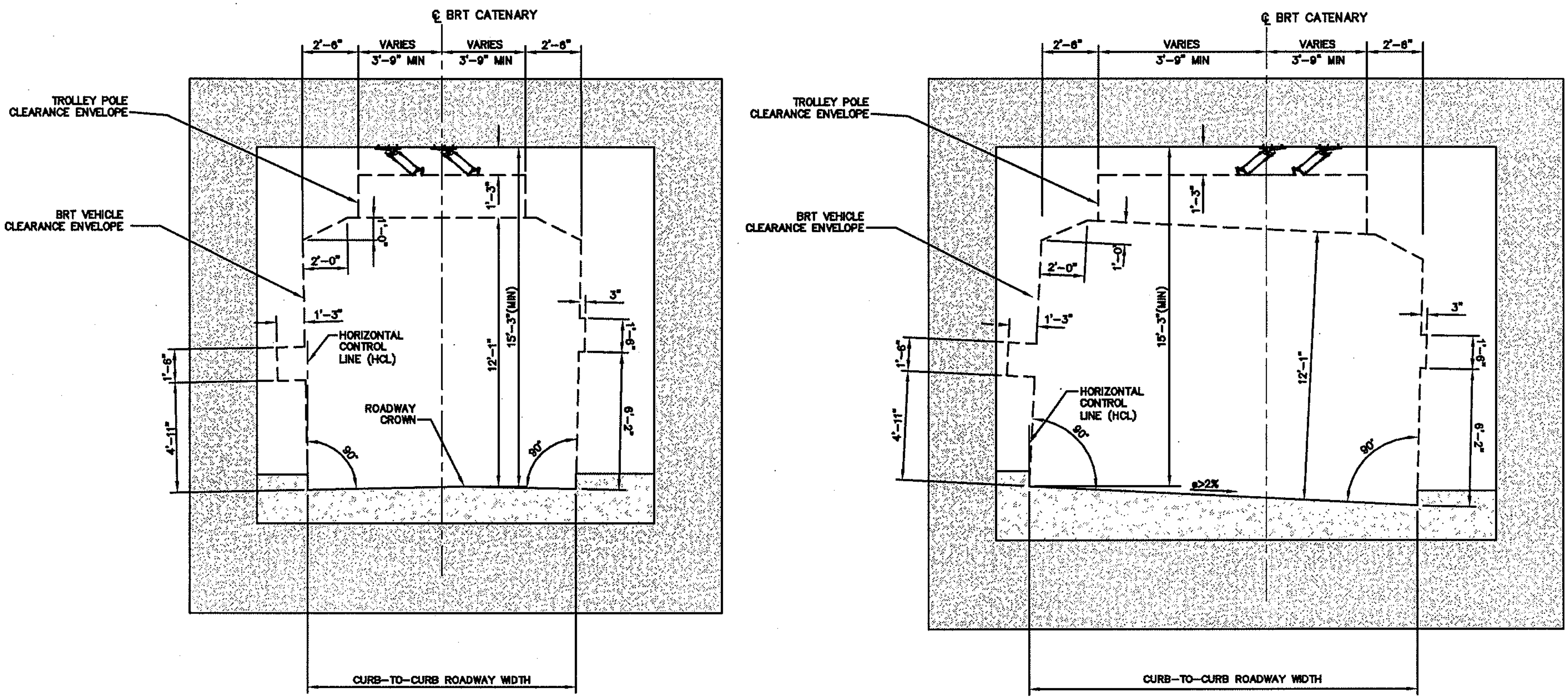
2. The governing minimum vertical and lateral clearances for the Bus Rapid Transit (BRT) are shown in Figures 2.3-1 and 2.3-2, as applicable to the structure, vehicle design speed and alignment configuration; the Light Rail Vehicle clearances are enveloped by the BRT clearances. Locations of utilities inside the tunnels, though not shown, shall be coordinated with different tunneling type sections.



Normal Crown Roadway
e = +2.0%, e= -2.0%

Superelevated Roadway

FIGURE 2.3-1: BRT (Neoplan Bus) CLEARANCE ENVELOPE FOR MINED TUNNELS



Normal Crown Roadway
e = +2.0%, e= -2.0%

Superelevated Roadway

FIGURE 2.3-2: BRT (Neoplan Bus) CLEARANCE ENVELOPE FOR CUT-AND-COVER TUNNELS

2.3 MATERIALS

2.3.1 CONCRETE

2.3.1.1 Cast-in-Place Concrete

Cast-in-place reinforced concrete shall have a minimum specified 28-day compressive strength, f'_c, as follows:

4 ksi	all structural concrete, unless noted otherwise below or on the drawings
5 ksi	all mined tunnel final liner
3 ksi	mud and protection slabs
1 - 2 ksi	lean concrete for filling cavities and for other non-structural miscellaneous use, where future excavation is not anticipated.

Flowable fill will also be used throughout the project. The strength of flowable fill shall range between 1 ksi to 2 ksi, project specifications for flowable fill will specify the required strength based on need. Use of flowable fill shall be limited to areas where future excavation is not anticipated.

2.3.1.2 Shotcrete

Unless otherwise specified, shotcrete shall have a 28-day minimum compressive strength, f'_c, of 5 ksi; a 7-day compressive strength of 3.5 ksi; a 24-hour compressive strength of 2.5 ksi.

Shotcrete shall be used for primary liner for the SEM construction technique; if warranted, its use may be extended to final liner as well

2.3.1.3 Precast – Prestressed Concrete

Unless otherwise specified, concrete for prestressed members, except for bored tunnel segments, shall have a 28-day minimum compressive strength, f'_c, of 5 ksi; at time of initial prestress, a minimum compressive strength, f'_{ci}, of 3.5 ksi.

2.3.2 STEEL

2.3.2.1 Reinforcing Steel

All reinforcing steel shall be AASHTO M31 (ASTM A615) Grade 60. All reinforcing bars shall be uncoated

2.3.2.2 Steel Fiber

Fiber reinforcement shall not be used.

2.3.2.3 Prestressing Steel

Prestressing steel reinforcement shall be one of the following:

1. High-strength steel wire. The high strength steel wire shall conform to AASHTO M204 (ASTM A421).

2. High strength seven wire strand. The seven wire strand shall conform to the requirements of AASHTO M203 9ASTM A416), Grade 270, low relaxation.

3. High strength alloy bars. High-strength alloy bars shall conform to the requirements of AASHTO M 275 (ASTM A722). Bars with greater minimum ultimate strength but otherwise produced and tested in accordance with AASHTO M 275 (ASTM A722) may be used provided they have no properties that make them less satisfactory than the specified material and that they are approved by the Owner.

2.3.2.4 Structural Steel

1. Unless otherwise specified, Structural Steel shall conform to AASHTO M270 (ASTM A709) Grade 50.
2. Steel Piping shall conform to ASTM A53, Grade B (Type E or S) with F_y = 35 ksi.
3. Structural Tubing shall conform to ASTM A500, Grade B, with F_y = 46 ksi.
4. High strength bolts for structural steel connections including suitable nuts and washers shall conform to AASHTO M164 (ASTM A325).
5. Anchor bolts shall conform to ASTM F1554.

2.3.3 UNIT WEIGHTS OF MATERIALS USED IN CALCULATIONS

Unless specified otherwise, unit weight of materials shall be as noted in Table 2.3-1. The unit weight given for soil is the total unit weight. When considering soil below groundwater level, effective soil density, γ_{total} - γ_{water}, shall be used, but not less than 60 pcf. The 60 pcf limit shall not apply to buoyancy analysis check, or when loading combination is intended to generate a minimum vertical load condition.

Material		Unit Weight pcf
Concrete	Reinforced	150
	Plain	145
Masonry	Brick	120
	Stone	150
Granite		165
Steel		490
Rock		150
Gravel		120
Pavement		150
Water		62.4

Material	Unit Weight pcf
Soils:	
Existing Fill	120
Structural Backfill	120
Organics	110
Glacial Till N < 50	140
Glacial Till N > 51	140
Marine Clay N < 15	117
Marine Clay N > 15	117
Stratified Sands	125
Bedrock RQD > 10%	150

Table 2.3-1: Material Unit Weight

2.4 DESIGN LOADS, LOAD AND GROUP FACTORS, AND LOAD COMBINATIONS AND CONSTRUCTION CONSIDERATIONS

As per the Structural Design Criteria, all structures shall support the loads identified in Section 2.4.1. All analysis shall incorporate appropriate load, β and group, γ factors identified in Section 2.4.2, in addition to the load combinations specified in Section 2.4.3.

In general and unless directed otherwise, working stress method shall be used for analysis and design of steel structural elements; ultimate strength method shall be used for analysis and design of concrete structural elements.

Where γ, β, and other strength reduction factors have been provided in this document, they shall be for use in analyzing and designing structural members and foundations in accordance with the Ultimate Strength Design Method.

2.4.1 DESIGN LOADS

2.4.1.1 Dead Load (D):

Dead load includes the self weight of the structure being analyzed and all of its associated components. The dead load shall consist of the estimated weight of the entire permanent structure, including, but not limited to: permanent walls, slabs, beams, columns and other fixed structural members.

2.4.1.2 Superimposed Dead Loads (DL):

Superimposed dead loads include loads that are applied on the structure after the structure has been completed. These loads shall be, by way of example and without limitations:

MaterialSystems	Unit Weight	Material/Systems	Unit Weight
Infill concrete	145 pcf	Wearing course (per 3.5 in)	40 psf
Railway tracks, etc.	200 plf	Future wearing course	12.5 psf / in
Partition walls	20 psf	Electrical systems	15 psf
Mechanical systems	15 psf	Signal/communication equipment	10 psf
Safety walk	150 pcf	Signs and supports	5 psf
Light fixtures	5 psf	Handrails	10 plf
Walls (non-structural)	150 pcf	Poles and utility services	20 plf

2.4.1.3 Live Loads (L)

Vehicular Loads
The following vehicle loads shall be used in the design of all tunnels and station structures:

Silverline Bus Rapid Transit (BRT) vehicle
Light Rail Vehicle (Types 7 and Type 8 – Breda)
MBTA Green Line Crane Vehicle

For axle spacing, axle loading and vehicle spacing see Figures 2.4-1 through 2.4-4 showing the front and driver side views.

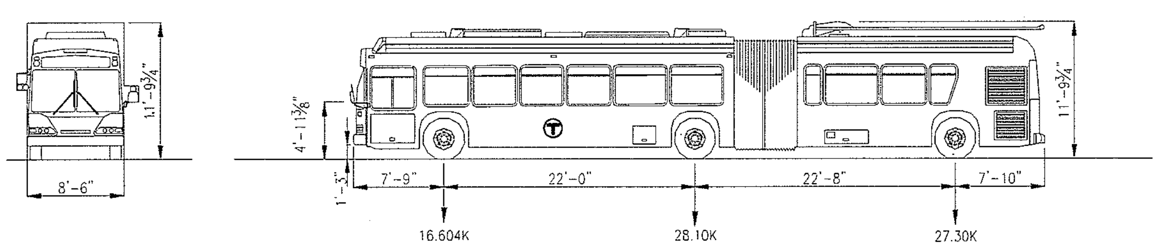


Figure 2.4-1: Silverline BRT Vehicle with Apparent Axle Loads

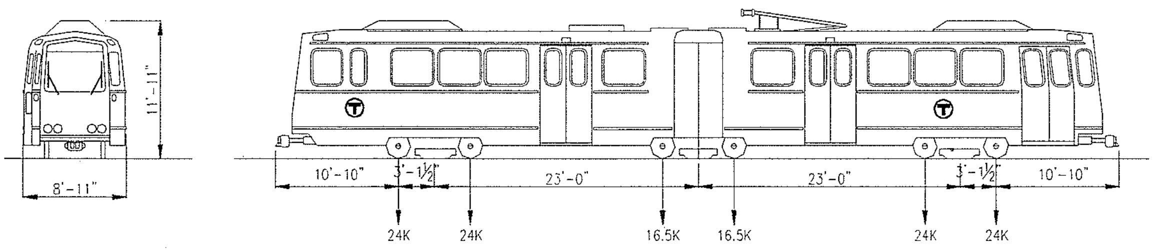


Figure 2.4-.2: MBTA LRV Type 7 Vehicle with Apparent Axle Loads

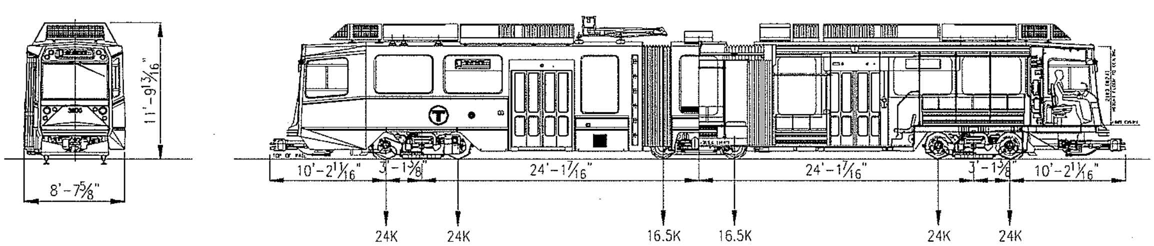


Figure 2.4-3: MBTA LRV Breda Type 8 Vehicle with Apparent Axle Loads

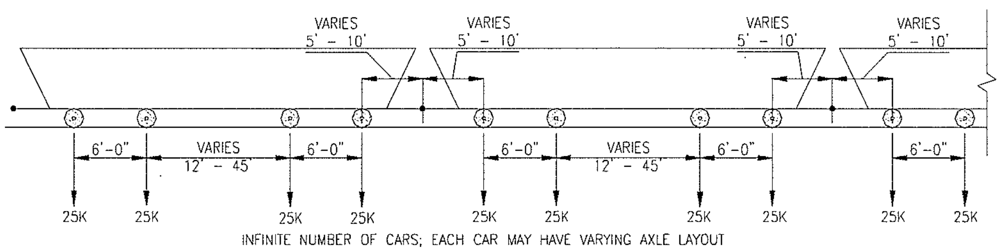


Figure 2.4-4: MBTA Crane Vehicle with Apparent Axle Loads

These vehicular loads shall be used for all stress and deflection calculations, either as single-vehicle units or as multi-vehicle units. For all structural elements being analyzed and designed, the designer shall determine the vehicle type and configuration, spacing and arrangement that will produce the most critical conditions for axial, bending, and shear stresses, and deflections.

Impact Load

Impact loading shall be considered by the designer, as per applicable code.

The impact load shall be added to the vehicle live load as a percentage of, and distributed the same way as the axle load.

Non-vehicular Service Loads

Uniformly Distributed (U) and concentrated (C) non-vehicular service loads, defined in Table 2.4-1, shall be used as minimum loads to design structural members. Concentrated load shall be positioned so as to produce the most critical condition for axial, bending and shear stresses, and for deflections.

Listed below are notes on Table 2.4-1:

1. In designing elevated columns, use one-half of the uniformly distributed live load.
2. For one-way or two-way floor slabs or floor beams, use the uniformly distributed live load over the entire floor area, or a pattern loading, plus the concentrated live load in a location that would produce maximum stresses on the member. Pattern loading shall be applied to induce the maximum positive and negative stresses.
3. Non-vehicular loading is to be used for under platform exhaust fan rooms, fan chambers, fan work areas and other areas supporting similar size fans.
4. The design live load must be determined for each location in consultation with the mechanical design discipline. The equipment live load shall be increased to include impact. A minimum uniformly distributed live load of 150 psf shall be used on all floor areas designated as mechanical rooms or areas.
5. Design live loads given are for escalators with a maximum rise of 33 feet. For longer escalators, note 4 shall apply.
6. Design live loads must be determined on the basis of maximum hydrostatic pressure and external earth pressure, where applicable.
7. This design live load applies to quarters for personnel such as, foreman, dispatchers, trackmen, as well as tool rooms, work shops and "light" storage rooms.
8. Passageways and other areas on which equipment is to be temporarily supported must be designed for the live load of the appropriate rooms.

No.	Description	U psf	C kips	Note
1	Canopy roof	30		1
2	Service walk	150		1
3	Stairs, on horizontal projection	150		1
4	Platforms and mezzanines	150		
5	Chiller room	150	15	2
6	Air cooling unit room	150	1	2
7	Fan area	150	5	2,3
8	Control room	150		
9	Elevator machine room			4
10	Elevator pit			4
11	Escalator machine room	150	2	2,5
12	Escalator pit	150		5
13	Ejector room	150	1	2
14	Pump room	250	2	2
15	Sump room			6
16	Circuit breaker house	200	2	2
17	Electrical distribution room	250	5	2
18	Electrical panel room	150		
19	Relay room	150	1	2
20	Central instrument room	150	1	2
21	Signal tower control room	150	1	2
22	Communication room	150		2
23	Telephone compartment room	150		
24	Compressor room	150		
25	Substation – Transformer area	300	15	2
	Substation – Circuit breaker platform	300	6	2
26	Track lubrication room	150		
27	Various quarters	150		7
28	Subway storage space	400		
29	Maintenance service rooms & duct manholes	150		
30	Passageways	150		8

Table 2.4-1: Non-Vehicular Service Loads

The floors and supporting structural members in substations, switch rooms, electrical or mechanical plant rooms or other areas containing switch gear or machinery, shall be designed for the following conditions:

1. The full live load as per Table 2.4-1, or the full dead load of the assembled piece of equipment at any reasonable position on the structure likely to be positioned during of after installation, plus 150 psf on the floor area outside the equipment footprint, whichever produces maximum stresses.

2. In addition, ancillary areas such as electrical/mechanical rooms, pump rooms, substations, etc., shall be designed for a superimposed dead load to account for attachments supported to the underside of floor slabs and beams as given in Table 2.4-2

Floor Area Range	Uniform Load
< 100 ft^2	40 psf
100 ft^2 through 300 ft^2	30 psf
> 300 ft^2	20 psf

Table 2.4-2: Additional Ancillary Area Loads

Roadway Live Load on Underground Structures

Roadway live loads over tunnels shall be based on the HS25-44 Truck Loading (HS 20-44 Truck Loading increased by 25%) of the AASHTO Code and AASHTO Military Loading as defined by AASHTO 3.7.4, whichever produces a more onerous design. The distribution of wheel loads through earth fills shall be as follows:

1. If depth of fill is less than 2 feet: wheel loads shall be applied as concentrated loads directly on the structure.

2. If depth of fill is greater than 2 feet: wheel live loads shall be distributed over a square area, the sides of which are equal to 1.75 times the depth of fill. When distribution areas overlap, the total load shall be uniformly distributed over an area defined by the outside limits of the individual areas.

Impact on Underground Structure

Impact due to roadway live load through earth fills shall be as given in Table 2.4-3.

Slab on grade shall not be subject to impact loading consideration.

The depth of fill shall be measured from the top of ground or pavement to the top of the underground structure.

Depth of fill	Impact (I)
< 1.00 ft	30 %
1.00 ft through 2.00 ft	20 %
2.01 ft through 3.00 ft	10 %
> 3.00 ft	0 %

Table 2.4-3: Impact Factor Based on Fill

Rubber Wheel Load Distribution (BRT)

Distribution of BRT wheel loads to the structure shall be in accordance with AASTHO Section 3.23 "Distribution of Loads to Stringers, Longitudinal Beams, and Floor Beams" and Section 3.24 "Distribution of Loads and Design of Concrete Slabs", as they may apply. The tire contact area shall be assumed as a rectangle with an area in square inches of 0.01 P and a length in direction of traffic/width of tire ratio of 1/2.5, in which P is the wheel load in pounds (per AASHTO Section 3.30).

Direct Fixation (LRV)

Where wheel loads are transmitted to a slab through rail mountings placed directly on the slab, longitudinally, the wheel load shall be assumed as uniformly distributed over three feet of rail, plus twice the effective depth of the slab, limited, however, by axle spacing.

This load may be distributed transversely by the width of the rail fastener pad, plus the effective depth of the concrete slab section.

Ballasted Track (LRV)

Where wheel loads are transmitted to a slab through ballasted sections, longitudinally, the wheel load shall be assumed as uniformly distributed over a length of three feet of rail, plus the depth of the ballast under the tie, plus twice the effective depth of the slab, limited by the axle spacing.

This load may be distributed transversely over the length of the track tie, plus the depth of the ballast and the effective depth of the concrete slab section.

Vehicular Live Load on Gratings

Ventilation shaft gratings on the roadway or sidewalk shall be designed to carry the HS25-44 Truck loading (HS 20-44 Truck Loading increased by 25%) of the AASHTO code and AASHTO Military Loading as defined by AASHTO 3.7-4, whichever produces a more onerous design. Gratings protected from vehicular traffic shall be designed for a uniform load of 250 psf. Gratings that may be subjected to loading from out-of-control vehicles shall be designed for HS25-44 loading.

2.4.1.4 Hydrostatic (H) and Buoyancy (B) Loads:

Tunnels and other underground and transition structures shall be designed for the maximum and minimum groundwater levels, as noted below, to ensure that the most adverse hydrostatic loading conditions have been considered.

In addition, tunnels, station and transition structures shall be checked for buoyancy or floatation conditions. This is a stability, not strength, check and shall be based on groundwater elevations noted below.

Essex Street:	Design Maximum Groundwater Elevation	108 ft
	Design Minimum Groundwater Elevation	94 ft
Boylston Street	Design Maximum Groundwater Elevation	108 ft
	Design Minimum Groundwater Elevation	94 ft
Charles Street:	Design Maximum Groundwater Elevation	108 ft
	Design Minimum Groundwater Elevation	94 ft
Tremont Street:	Design Maximum Groundwater Elevation	108 ft
	Design Minimum Groundwater Elevation	94 ft
100 yr. Design Flood Elevation		110.3 ft
500 yr. Design Flood Elevation		111.2 ft

Resistance to buoyancy shall be based on the dead weight of the structure, without internal super imposed dead loads.

With the exception of the extreme 500 yr. flood, Factor of Safety against buoyancy shall neglect sidewall friction, and shall be as specified in Table 2.4-4.

Design Condition	Factor of Safety	Note
Design	1.1	Including Interior Finish
Design	1.05	Excluding Interior Finish
Flood (100 year)	1.05	Including Interior Finish
Flood (500 year)	1.0	Including Interior Finish & Sidewall Friction

Table 2.4-4: Factor of Safety Against Bouyancy

2.4.1.5 Thermal (T) and Shrinkage (S) Effects:

When calculating stresses and strains induced in concrete sections due to overall thermal expansion or contraction, the following shall apply:

1. The range of temperature variation during concrete construction and, also, during normal operations, with respect to the baseline ambient temperature of 55°F will be as follows:

   Temperature rise/fall – during construction: .... ± 25 °F
   Temperature rise/fall – post construction of interior structural members:.................... ± 20 °F
   Coefficient of Thermal Expansion, Concrete .... 6.0×10^{-6} / °F
   Coefficient of Thermal Expansion, Steel.................... 6.5×10^{-6} / °F

2. For calculating forces induced by shrinkage and thermal effects, the effective modulus of elasticity of concrete during early age will be taken as ½ the value of E_c given in AASHTO, Section 8.7.

3. The shrinkage coefficient will be taken as 0.00025 in/in

4. Special consideration will be given to the potential post construction temperature gradients in tunnel, transition, and station reinforced concrete elements. The gradient is formed between the buried face of concrete slabs (presumed to be constant at the ground ambient temperature of 55°F), while the ambient air temperature varies with the season. This gradient induces flexural stresses, which can develop into cracking. Consider a temperature variation of ± 10°F on all members.

2.4.1.6 Earth Loads (E)

Horizontal Earth Loads (EH)

Horizontal earth loads on tunnel and rigid transition (boat) structure walls shall be computed using the "at-rest" earth pressure coefficient, Ko, as recommended by the Geotechnical Consultants and noted in Table 2.4-5.

Horizontal earth loads on flexible transition (boat) structure walls shall be computed using "Active" earth pressure coefficient, Ka, as recommended by the Geotechnical Consultant and noted in Table 2.4-5. A wall to be classified as flexible must meet the rotation requirements of AASHTO Table 5.5.2A.

If finite element analysis is not used to generate forces for the design of the initial and final liners, then K_o values shall be used to calculated the applied earth loads on the structure for the final liner; K_a values shall be used to calculate the applied earth loads on the structure for the initial liner.

Vertical Earth Loads (EV)

Vertical earth loads on underground structures shall be computed using the depth of soil cover times the effective unit weight of the soil, as recommended by the Geotechnical Consultants and noted in Table 2.3-1. For calculation of effective unit weight of soil, see Section 2.3.3.

Material		Drained Properties						
		Friction Angle (ϕ)	K_o	K_a	K_p	E (ksf)	Poisson's Ratio (ν)	MSR* (tcf)
Existing Fill		30	0.5	0.33	3	30 ksf per foot depth	0.33	40
Structural Backfill		32	0.47	0.31	5	50 ksf per foot depth	0.33	40
Organics		30	0.5	0.33	3	20	0.33	10
Glacial Till N < 50		35	0.43	0.27	7	1000-2000	0.33	500
Glacial Till N > 50		38	0.38	0.24	8	2000-3000	0.33	1000
Marine Clay N < 15		30	0.5	0.33	3	20 (normally consolidated)	0.33	50
Marine Clay N > 15		30	0.5	0.33	3	100 (pre-consolidated)	0.33	50
Stratified Sands		32	0.47	0.31	5	50 ksf per foot depth	0.33	100
Weathered Bedrock	Moderate to Severely	42	0.33	0.2	12	3000-10,000	0.33	800
	Slightly to Moderately	47	0.27	0.2	16	10,000-20,000	0.33	2000

** For additional information on use of Modulus of Subgrade Reaction (MSR), see Section 2.5.1.1*

Material		Undrained Properties				
		Shear Strength	Unconfined Compression Strength (psi)	E (ksf)	Poisson's Ratio (ν)	MSR* (tcf)
Organics		400		120	0.49	10
Marine Clay N < 15		1000 - 2000		600 - 1200	0.49	400
Marine Clay N > 15		2000 - 4000		1200 - 2400	0.49	400
Weathered Bedrock	Moderate to Severely		100 - 500	3000-10,000	NA	NA
	Slightly to Moderately		500 - 3000	10,000-20,000	NA	NA

** For additional information on use of Modulus of Subgrade Reaction (MSR), see Section 2.5.1.1*

Table 2.4-5: Geotechnical Parameters (Drained and Undrained) for Various Soils

Differential Settlement

Differential settlement will be considered and designed for in the longitudinal analysis of the tunnel, if applicable.

At a minimum, a longitudinal beam model on elastic foundation must be analyzed, based on the actual ground profile.

2.4.1.7 Surcharge Loading (S)

Vertical Surcharge (S_V)

For tunnel roofs, minimum vertical surcharge loading of the intensity shown in Table 2.4-6 shall be applied to simulate conditions during future construction and other undefined miscellaneous surface loading.

Additionally, areas where future development is anticipated, future air right loads shall be considered as additional design loads.

Depth ft	**Intensity psf**
< 5	600
5 through 20	600 - 40 (Depth - 5ft)
> 20	Zero Intensity

Table 2.4-6: ES_v Intensity Based on Depth

Horizontal Surcharge (S_H)

For underground and boat structures, ES_H due to a vertical surcharge load will be applied on all below grade structure walls. The value of ES_H shall be based on equation noted below.

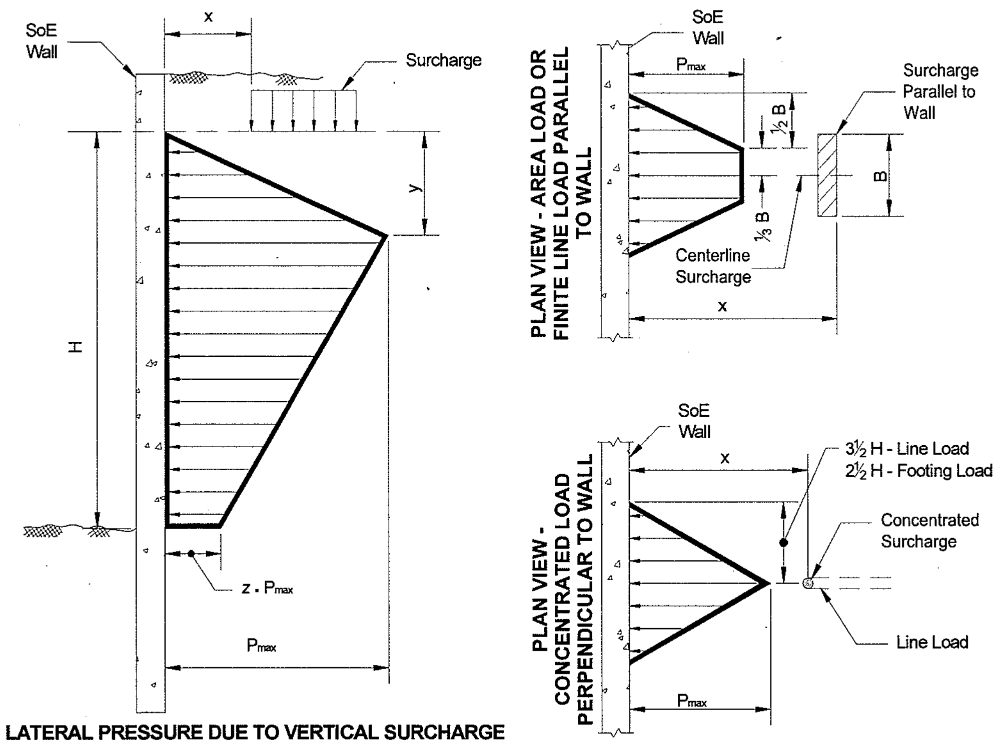
$$ES_H = K \bullet ES_V \quad \text{EQ 2.4-1}$$

Where, K is the earth pressure coefficient, as defined in 2.4.1.6

ES_v is the vertical surcharge, as defined by 2.4.1.7.

Building Surcharge

Building surcharge loads shall be those that are anticipated to continue to act on the structure post-construction activities. These, typically, include surcharge loads from other structures in vicinity of the structure being designed. Surcharge loading shall be determined by using Figure 2.4-5 and Table 2.4.7; and shall be appropriately added to the vertical or horizontal surcharge noted above.



If building foundations are underpinned, then the transfer of building load to a lower level should be considered in evaluating resultant lateral pressure using procedures acceptable to the geotechnical engineer

Symbols:

B	Length of area loaded parallel to wall
H	Vertical distance between the horizontal loaded plane and bottom of excavation
P_{max}	Calculated lateral pressure due to surcharge; for surcharge of existing buildings, use ½ the calculated value
Q	Vertical surcharge intensity
X	Distance from wall to footing or parallel line load or to leading edge of ara loaded or perpendicular line load

Figure 2.4-5: Surcharge Pressure Diagrams

Load Case	y	z	P_{max}
Isolated (individual) footing considered as point load	0.6 • H	0.4	$\{2.1 - 1.8 \bullet x) \bullet Q / H^2$
Continuous footing – line load parallel to wall	0.4 • H	0.25	$\{1.1 - 0.5 \bullet x) \bullet Q / H$
Area load	0.4 • H	0.25	$\{0.8 - 0.5 \bullet x) \bullet Q / H$
Continuous footing – line load perpendicular to wall	0.6 • H	0.4	$\{1.4 - 1.2 \bullet x) \bullet Q / H^2$

Table 2.4-7: Coefficients for Surcharge Loading for Figure 2.4-7

2.4.1.8 Derailment Load (DR):

The vertical derailment load shall be that produced by the LRV vehicle, including 30-percent impact, placed with its longitudinal axis parallel to the track and two feet from the centerline of track at each side, or to the nearest obstruction.

The horizontal force due to derailment shall be taken as 40% of the dead load of a single fully loaded vehicle acting two feet above top of rail and normal to the barrier wall for a distance of 10 feet along the wall.

2.4.1.9 Earthquake Load (EQ):

When analyzing any and all structures for design, designer shall incorporate seismic analysis procedures in addition to static analysis. See Section 2.6

2.4.1.10 Tunnel Flooding (F)

The tunnel flooding case will apply an equal hydrostatic pressure in and outside the tunnel. However, the joint between the mined or bored underground structure and any cut-and-cover or open cut structure shall be designed to accommodate differential movements of ± ¼ inches.

2.4.2 GROUP AND LOAD FACTORS

Design of structures for Silver Line Phase III shall be based on AASHTO Code. All reinforced concrete structures shall be designed using the Ultimate Strength method; all steel structures shall be designed using Working Stress method – for additional discussion, see Sections 2.5.2 and 2.5.3. Group and Load factors are discussed in the Sections 2.4.2.1 and 2.4.2.2; additionally, load combinations are discussed in Section 2.4.3. Section 2.4.2 shall be read in conjunction with Section 2.4.3, Load Combinations and Construction Considerations.

2.4.2.1 Group Factors, γ

For all Static group analysis, γ shall be taken as 1.3.

2.4.2.2 Load Factors, β

The β values are tabulated in Tables 2.4-8 and 2.4-9, for ultimate and working stress design, respectively.

	LOAD											
	GROUP	COMBINATION Figures 2.4-10 through 2.4-12	TYPE									
			D	SD	H	B	L	SH	SV	EH	EV	S/T
Ultimate Strength Design	A	1	1.00	1.00	1.00	1.00	1.67	❖	1.00	❖	1.00	
		2	0.75		1.00			❖		❖		
		3	1.00	1.00			1.67		1.00	0.50	1.00	
		4, 5	1.00	1.00	1.00	1.00	1.67		1.00	0.50	1.00	
		6	1.00	1.00	1.00	1.00	1.67	❖	1.00	❖	1.00	
		7	1.00	1.00	1.00	1.00	1.67	✡	1.00	✡	1.00	
	B	1, 2	0.75		1.00	1.00		❖		❖		1.00
		3 through 6	1.00									1.00
	C	See Seismic Design Criteria										

❖ β = 1.30 for K_a β = 1.15 for K_o

✡ β = 1.15 for one wall; 0.67 for opposite wall

Table 2.4-8: β Factors for Load Combinations for Ultimate Strength Design

Working Stress Design	LOAD											
	GROUP	COMBINATION Figures 2.4-10 through 2.4-12	TYPE									
			D	SD	H	B	L	SH	SV	EH	EV	S/T
	A	1	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	
		2	1.00		1.00			1.00	1.00	1.00		
		3	1.00	1.00			1.00		1.00	0.50	1.00	
		4, 5	1.00	1.00	1.00	1.00	1.00		1.00	0.50	1.00	
		6	1.00	1.00	1.00	1.00	1.00	0.50	1.00	0.50	1.00	
		7	1.00	1.00	1.00	1.00	1.00	◆	1.00	◆	1.00	
	B	1, 2	1.00		1.00	1.00		1.00		1.00		1.00
		3 through 6	1.00									1.00
	C	See Seismic Design Criteria										

◆ β = 0.85 for one wall; 0.5 for opposite wall

Table 2.4-8: β Factors for Load Combinations for Working Stress Design

2.4.3 DESIGN LOADING COMBINATIONS AND CONSTRUCTION CONSIDERATIONS

The general loading combinations are set out in the equations below. These equations are a minimum and other load groups may be added. In addition to the balanced load conditions, unbalanced load conditions shall be evaluated. Under this load combination, one side of the tunnel is subject to maximum effective earth and hydrostatic loads, while the opposite wall is subject to ½ effective earth load and a hydrostatic load with a 10" 0" head differential; the lowered hydrostatic head shall be applied on the ½ effective earth load side. This unbalanced condition may yield stresses that are higher than the balanced load cases. The equations noted below are applicable to the unbalanced load cases.

The structural design shall consider the following permanent loading groups:

Group A:

$$\gamma \bullet \left\{\beta_D \bullet D + \beta_{SD} \bullet SD + \beta_E \bullet (E_V + E_H + S_V + S_H) + \beta_L \bullet L + \beta_H \bullet H + \beta_B \bullet B\right\}$$

Group B:

$$\gamma \bullet \left\{\beta_D \bullet D + \beta_{SD} \bullet SD + \beta_{EV} \bullet EV + \beta_{EH} \bullet EH + \beta_{SV} \bullet SV + \beta_{SH} \bullet SH + \beta_L \bullet L + \beta_H \bullet H + \beta_B \bullet B + \beta_{S/T} \bullet (S+T)\right\}$$

Group C:

$$\gamma \bullet \left\{\beta_D \bullet D + \beta_{SD} \bullet SD + \beta_E \bullet (E_V + E_H + S_V + S_H) + \beta_H \bullet H + \beta_B \bullet B + \beta_{EQ} \bullet EQ\right\}$$

Temporary and construction conditions, in addition to final conditions shall be analyzed. Various load combinations are developed based on tunnel construction staging and serviceability considerations. These are outlined in Figures 2.4-6 through 2.4-7; design shall satisfy all appropriate load combinations noted for a particular type of construction.

Group B load combinations are not applicable to mined or bored structures since these structures are constructed within the existing grounds. For seismic (Group C) load combinations, refer to Chapter 3 – Seismic Design Criteria; to ensure a comprehensive design, Group C load combinations shall be part of structure analysis and design.

If, during final design, it is determined that additional load combinations are required to better represent the actual conditions, then these shall be brought to the attention of the design lead for consideration.

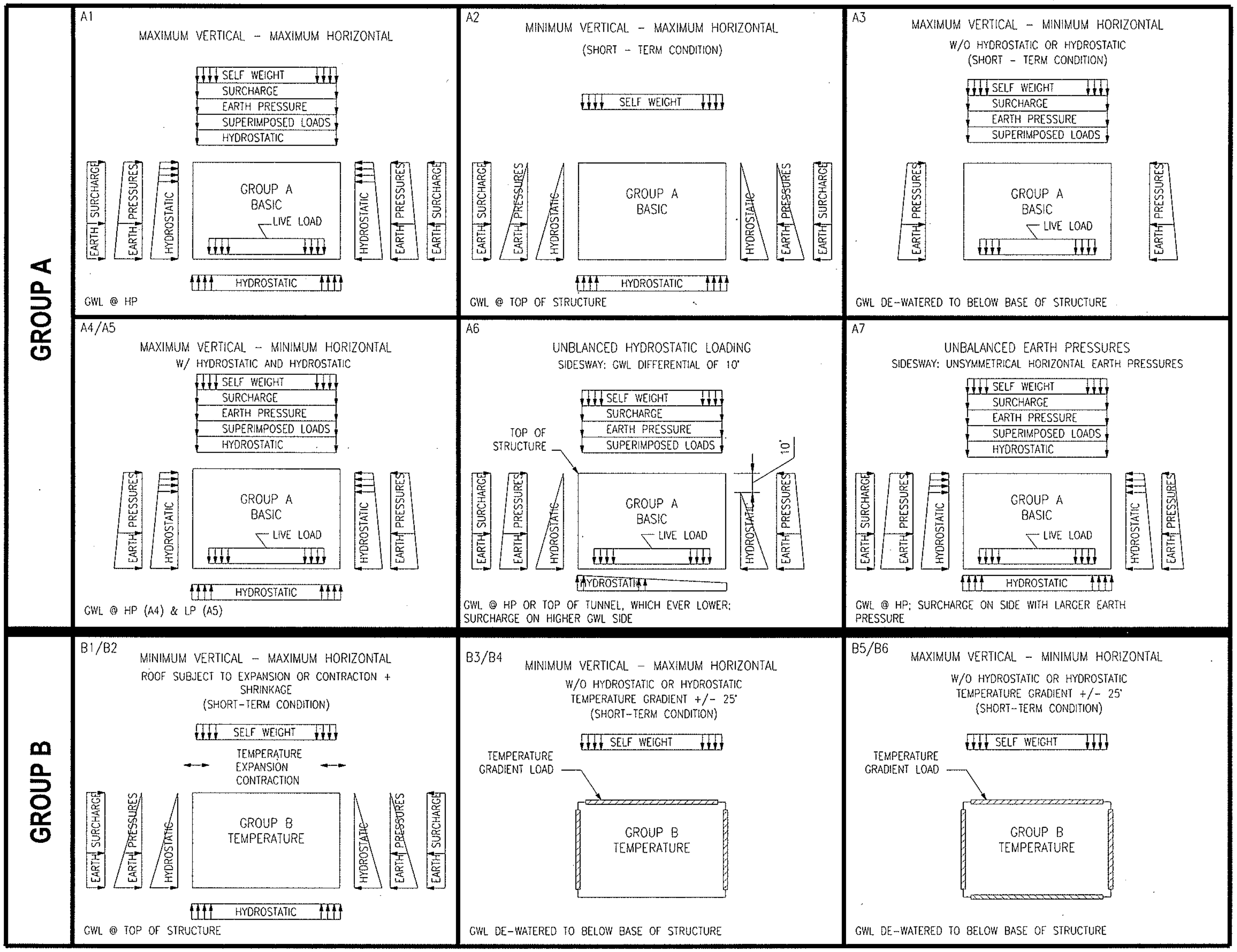


Figure 2.4-6: Group A and Group B Load Combinations for Cut-and-Cover Tunnel

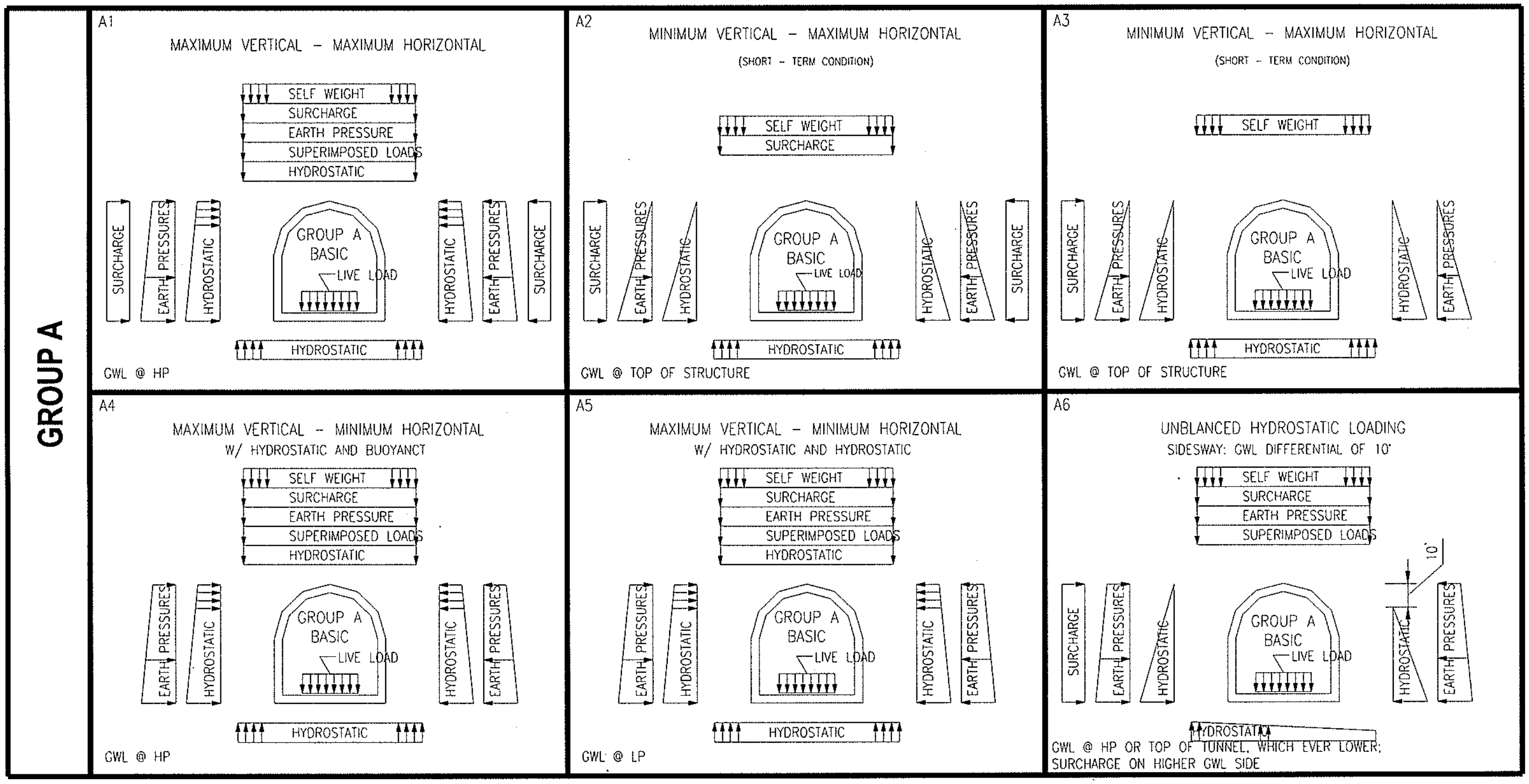


Figure 2.4-7: Group A Load Combinations for Mined Tunnel

2.5 METHODS OF STRUCTURAL ANALYSIS AND DESIGN

2.5.1 STRUCTURAL ANALYSIS

Structural analysis shall either employ computer or hand calculation analysis. Lateral earth pressures shall be based on effective values, as applicable. Hydrostatic pressures shall be applied acting orthogonally to the external face of the structure, or lining.

Unless finite element modelling tools are used to analyze the structure, all underground and above ground structures bearing on soil shall be analyzed as beam or slab on elastic foundation. An appropriate modulus of subgrade reaction (MSR) value, provided by the Geotechnical Consultant, shall be used in calculating the soil spring stiffness. For additional discussion on the MSR value, see Section 2.5.1.1.

When utilizing two-dimensional and three-dimensional finite element analysis involving soil structure interaction, the initial vertical stress condition shall be taken as equivalent to full overburden pressure; it shall be derived using appropriate K_o values.

For the purpose of concrete analysis and design, load and strength reduction factors shall be adopted in accordance with the appropriate code and the ultimate strength design method. If, however, working stress analysis is employed, then the structural design of concrete structures shall still be based on ultimate strength design method. To that end, the design forces generated by working stress analysis, shall be multiplied by an appropriate, but weighted, β factor that is consistent with the types and distribution of loads being applied to the structure and the applicable code under consideration.

For structural steel analysis and design, working stress method shall be employed.

2.5.1.1 Modulus of Subgrade Reaction (MSR)

MSR is a pseudo soil property that is dependent of a variety of soil parameters and profiles, and loading conditions. As such, a single or a set of MSR values, in a beam-on-an-elastic-foundation model, will not be sufficient to properly model the complexity of the soil structure interaction for a buried structure. Instead, an iterative process, involving the structural and the geotechnical discipline is critical.

Recommended values of modulus of subgrade reaction for use in soil-structure interaction analyses are given in Table 2.4-5. These values represent loading applied over a 1-foot by 1-foot area, and are applicable to horizontal and vertical loading conditions. For use in an analysis, the MSR values must be reduced based on the actual size and geometry of the loaded area; the subgrade modulus values for loadings applied over large areas are significantly lower than the values noted for 1 ft^2 area. The reduction required for the actual size and geometry of the loaded area may be different for horizontal and vertical loadings[1].

With the exception of clay as noted, the modulus values are provided for a drained loading condition. For the clay, the undrained values assume non-consolidated soil; the drained values assume fully consolidated soil. The undrained values shall be considered appropriate for short-term loadings where there is insufficient time for significant consolidation to occur. For long-term loadings, both the undrained and drained conditions should be checked to determine the more severe loading condition.

1 Terzaghi, 1955.

In addition, the recommended subgrade modulus values are principally based on the assumption that the contact pressures are less than one-half of the ultimate pressure based on bearing capacity theory or passive pressure theory, whichever is applicable to the type of loading condition being analyzed. This principal assumption must be validated by comparing the contact pressures, obtained from analyses using the provided MSR values, to the ultimate pressures based on bearing capacity or passive pressure theories, which ever is applicable. It should be noted that the subgrade modulus decreases significantly for contact pressures greater than one-half of the ultimate pressure. When the contact pressure reaches the ultimate bearing capacity or ultimate passive pressure, the soil experiences plastic yielding[2].

Alternatively, use of a finite element model, utilizing appropriately defined soil properties and profiles, can be used to obviate the need for MSR.

2.5.1.2 CUT-and-COVER PERMANENT STRUCTURES

The earth pressure to be used in design of the cut-and-cover permanent structures shall consider the short-term and long-term loading conditions. The soil pressure distribution on the walls and slabs shall be derived using a combination of maximum/minimum values of saturated/dry soil unit weight, together with the appropriate strength parameters.

All temporary construction staging consideration, such as, but not limited to, temporary intermediate bracing, partial backfilling, etc, shall be incorporated into the analysis.

2.5.1.3 SLURRY DIAPHRAGM OR SOLDIER PILE TREMIE CONTRETE (SPTC) WALLS AS PERMANENT STRUCTURE

For the design of slurry diaphragm walls used as part of the permanent structure, soil-structure interaction analysis shall be used. The analysis shall be performed using finite element analysis or finite difference analysis methods. The wall shall be assumed to be continuous.

The analysis shall consider staged construction that adequately models the proposed excavation and bracing sequence, as well as the sequence of constructing the permanent structure and removal of temporary bracing.

The analysis shall be performed using estimates of the actual soil and water pressures on the wall. The earth pressure distribution shall be appropriate to the proposed method of construction, the limit state being considered and shall account for all surcharge loads and compaction loads, where appropriate.

The soil pressure distribution on the walls and slabs shall be derived using a combination of maximum/minimum values of saturated/dry soil unit weight, together with the appropriate strength parameters. The wall shall be designed to resist the loads based on K_o (final long-term) conditions.

The design brace loads for the temporary struts and the permanent slab shall be based on the critical loads from the staged analysis. The permanent slabs shall be designed to resist the loads based on K_o (final long-term) conditions.

2.5.2 REINFORCED CONCRETE DESIGN

Reinforced concrete structures will be designed in accordance with the AASHTO Code, Section 8, Ultimate Strength Design Method, unless noted otherwise in this document.

[2] Condition where significant displacement is noted without an increase in contact pressure.

To promote water tightness and structural integrity and in view of the relatively uniform internal temperature in the main members of underground structures, expansion and construction joints shall be provided in accordance with the stipulations noted below:

1. To control shrinkage stresses in monolithically poured concrete slabs and walls and to minimize cracking, construction joints shall be provided at maximum spacing of 30 feet preferably and not to exceed 45 feet. Joints shall have continuous reinforcing steel, keys or other positive means of shear transfer. In all exterior elements in contact with the soil or rock, joints shall have nonmetallic water stops.

2. Expansion or contraction joints for cut and cover structures are only permissible at transition areas to differing construction types. In all cases, thorough consideration shall be given to water-tightness of the structure.

2.5.2.1 Shrinkage & Thermal Crack Control

Minimum longitudinal reinforcement requirements will be established for structures based on minimizing crack widths that can occur due to early-age thermal cracking.

2.5.2.2 Longitudinal Shrinkage

Structures will be designed to limit early-age thermal crack widths to values defined below. This is an estimated value based on ACI Committee 224, "Control of Cracking in Concrete Structures", Table 4.1 Tolerable Crack Widths, Reinforced Concrete for an exposure condition of humidity, moist air or soil.

Cut-and-cover, Open cut structures:	0.012 inches
Mined or Bored structures:	0.008 inches

For Concrete retaining structures, reinforcement required to control early-age thermal crack widths may be calculated from the following:

$$\rho = (f_{ct}/f_b)\,(\phi_{bar}/2w_c)\,(\alpha/2)\,(T_1+T_2) \qquad \text{EQ 2.5-1}$$

where,

- ρ = Steel ratio (total reinforcement in the face under consideration) based on the area of the surface zone at 10 inches deep maximum.
- f_{ct}/f_b = Ratio of concrete tensile strength to the average bond strength=0.67
- ϕ_{bar} = Reinforcing bar diameter
- w_c= Tolerable Crack width
- α = Coefficient of thermal expansion of concrete
- T_1 = Temperature Difference between peak heat of hydration and ambient temperature=52°F
- T_2 = Seasonal temperature variation, 45 °F

Ambient temperature shall be taken as 55 °F.

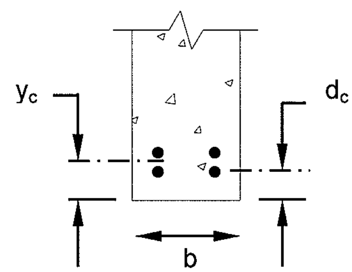
2.5.2.3 Transverse Shrinkage

Transverse shrinkage will be directly evaluated during analysis and design of the tunnel and transition structures, in accordance with the applicable codes and as specified herein (See article A3.3.4.1.5).

2.5.2.4 Flexural Crack Control

1. Flexural crack widths shall not exceed a maximum of 0.012 inches. In addition, the stress in the tension reinforcement at service load shall not exceed that given by EQN 2.5-2 taken from AASHTO Code, with the value of *z* being taken as 130 kip/in.

$$f_s = \frac{z}{\sqrt[3]{d_c A}} \leq 0.6 f_y$$



...EQ 2.5-2

where,

z shall be taken as 130 k/in.
d_c distance from extreme tension face to centroid of nearest transverse reinforcement, but ≤ 2.0 in.
y_c distance from extreme tension face to centroid of reinforcement group.

$$A = \frac{(2 \bullet y_c \bullet b)}{\text{Number of reinforcing bars}}$$

2. Minimum longitudinal reinforcement for soil supported tunnels, where significant heave and settlement may occur, shall be 1.2 times the cracking moment of the box structure in accordance with the AASHTO, Section 8.17.1.1. Elsewhere the smaller value of Section 8.17.1.2 will be used.

2.5.2.5 Reinforcement Cover Requirements

The following minimum cover dimensions shall apply for concrete:

1. Cast against and permanently exposed to earth[3]: ..... 3"
2. Pre-cast concrete tunnel lining segments, all faces: ..... 2"
3. Track bed, top face: ..... 2 ½"
4. Concrete slabs directly beneath railway surfaces:
   Top Reinforcement ..... 3"
5. For transition structure walls at rustication joints:
   Cover to Reinforcement at Rustication Joints ..... 1 ½"
6. Concrete surfaces exposed to earth or weather:
   Walls and slabs (except as per Items 2 & 3) ..... 2"
   Beams and columns
   Stirrups, ties and spirals ..... 2"
7. Concrete surfaces not exposed to weather or in contact with earth:

[3] Includes normal and slurry type construction.

Walls and Slabs (except as per Items 2 & 3) .... 1 ½"
Beams and Columns, Stirrups, ties and spirals .... 1 ½"

8. All other concrete cover requirements shall be in accordance with the AASHTO Code Section 8.22.

2.5.2.6 Longitudinal Reinforcement Placement

As a measure of protection against early-age shrinkage cracks, longitudinal reinforcing steel for tunnel and transition structures will be detailed directly inside the outermost transverse reinforcement layer.

2.5.2.7 Spacing of Reinforcement

Whenever possible, main reinforcing bars shall be spaced at 6 inch, 9 inch or 12 inch on center.

Exceptions to this rule include beams, columns, stairways and thin slabs. This requirement is intended to simplify design, checking of bar placement and field inspection. Spacing should also consider ease of concrete placement, space for embedded items and crossings of reinforcement.

2.5.3 STRUCTURAL STEEL DESIGN

Analysis and Design of underground steel structures, including SPTC walls, drilled soldier pile walls, roof and invert framing systems, columns, beams, etc. will be designed in accordance with the AISC code using the *Allowable Strength Design* philosophy, unless noted or directed otherwise.

2.5.4 BOAT SECTIONS AND RETAINING WALLS

Boat sections shall be analyzed as continuous structures on elastic foundation. Adequate provisions shall be made for resistance to hydrostatic uplift.

If at any station the two walls of the boat section are of unequal heights, then the factor of safety against sliding shall be a minimum of:

1. Without passive resistance of the soil 1.5
2. With passive resistance of the soil 2.0

Wall thickness for boat sections and retaining walls shall be designed by considering:

1. The at rest lateral earth pressure coefficient, as defined in Article 2.4.1.6
2. The hydrostatic pressure, as defined in Article 2.4.1.4
3. Surcharge effects, as defined in Article 2.4.1.7 and 2.4.1.8

2.5.5 APPROACH SLABS

Approach slabs shall be used to transition the stiffness of ballasted track onto boat section structures. Approach slabs will be subjected to vertical BRT or LRV loading and shall be designed as reinforced concrete slab construction.

The approach slab shall have a length of not less than 20 feet, nor less than the length computed from the following formula:

$$L = 1.5 \bullet H \bullet \tan(45° - \tfrac{1}{2}\phi) \qquad \text{EQ 2.5-3}$$

Where: L = Minimum length of approach slab;
H = Vertical distance from bottom of approach slab to bottom of boat structure invert slab;
ϕ = Angle of internal friction of backfill soil, in degrees.

The slab shall be assumed to receive no support from the backfill for a distance not less than 13.0 feet, nor less than $H \bullet \tan \bullet (45° - \tfrac{1}{2}\phi)$, measured from the end of the invert slab structure.

2.5.6 SEISMIC DESIGN

Group C loading considerations shall be included in analysis to adequately account for seismic effects.

Refer to Chapter 3, the Seismic Design Criteria.

2.5.7 SUPPORT OF EXCAVATION AND TEMPORARY DECKING

Support of excavation systems are defined as either flexible or rigid system. Flexible wall systems shall include: Interlocking sheet piles walls, soldier pile and lagging, or similar system; Rigid wall systems shall include: Reinforced concrete (slurry) wall, soldier pile tremie concrete walls; adjacent (tangent) or intersecting (secant) cast-in-place reinforced concrete pile walls, or similar.

Support of excavation walls intended as whole or part of, permanent structures shall be designed as rigid walls.

Analysis and design of all support of excavation systems and temporary decking shall conform to the design requirements noted in 2.5.7.2 and Table 2.5-1 and Table 2.5-2

Design of all support of excavation wall systems and temporary decking shall be based on the loading conditions provided in 2.5.7.2

For the design of the excavation support walls that will eventually become part of the permanent structure, the designer shall specify the bracing levels and the design requirement of the SOE walls. Design of the wales, struts and other non-permanent aspects of the SOE system shall be designed by the contractor.

2.5.7.1 Design Requirements

1. Bracing members and deck beams shall be of structural steel; tiebacks shall be of high strength tendons.

STRUCTURE	DESIGN LOADS: DEAD	LIVE: VERTICAL	LIVE: HORIZONTAL	EARTHQUAKE	COMBINATION
DECK BEAMS AND HORIZONTAL SUPPORTING FRAMEWORK	Self weight Weight of flooring Weight of utilities and supporting elements Weight of stored construction material and equipment	**Vehicle Loads** Basic loading (L) HS 20-44; see sections[a] 3.6, 3.7 and 3.11 Impact (I) loading; see section[a] 3.8 Reduction in load intensity not applicable; see section[a] 3.12 Operating loads from construciton equipment (L) as required by contractor **Other Loads:** Supported utility loads (L) - water and sewer Loads on Sidewalks and Other Deck Elements Without Vehicular Access: 100 psf	Longitudinal forces (LF); see section[a] 3.9 Wind load on live load (WL) 20 PSF on exposed area of vehicles and equipment, but not less than 100 plf of deck structure applied normal to the longitudinal direction Lateral earth and hydrostatic pressure	Horizontal force on each element of 7% of its weight applied at its center of gravity in any direction Additional horizontal load on any element of either 10 PSF on contributary deck area or a single concentrated load of 1 kip, whichever produced a more critical loading condition. This load is applied at the surface of the deck in any direction	Group I $D + L^c + I + E + H$ at 100% allowable unit stress Group II $D + L^c + LF + WL + E + H$ at 125% allowable unit stress Group III $D + L^c + E + H + EQ$ at 133% allowable unit stress
DECK FLOORING	Self weight	As noted above; also see sections[a] 3.25, 3.27 and 3.30			$D + L^c$ at 100% Allowable Unit Stress
RAILINGS[b]	Self weight	As noted above; also see section[a] 2.7 (L)	See Section[a] 2.7 (L)		$D + L^c$ at 100% Allowable Unit Stress
CURBS AND SAFETY CURBS	Self weight	Vehicle and equipment loads	See Section[a] 3.14.2 (L)		$D + L^c$ at 100% Allowable Unit Stress

Table 2.5-1: Temporary Decking Loads and Loading Combinations

[a] Section reference is to appropriate paragraphs in AASHTO
[b] Temporary Decking shall have railings on any and all sides with a grade differential to decking
[c] The value of L, live load, shall be the maximum total live load obtained by combining the various live loads that can exist at any given time

STRUCTURE	DESIGN LOADS: DEAD	LIVE: VERTICAL	LIVE: HORIZONTAL	EARTHQUAKE	COMBINATION
WALL SYSTEM[a] (ELEMENTS IN CONTACT WITH RETAINED EARTH)	Self weight Reactions from dead loads of deck structure and bracing system Weight of underpinned structures	Reactions from live load on deck structure (L), excluding impact load Walkways and incidental loads (L) Construction equipment (L) Vertical component of tie-back reaction Floor loads of underpinned buildings	Lateral earth pressure (E) due to soil and surcharge Hydrostatic pressure (H) Axial loads from end walls (E and H), where applicable	Effects of lateral force from buildings and soil	Group I $D + L^b + I + E + H$ at 120% allowable unit stress Group II $D + L^b + E + H + EQ$ at 150% of allowable unit stress
BRACING SYSTEM MAIN HORIZONTAL MEMBERS: STRUTS AND WALES	Self weight	As required by bracing design	Reaction from wall system (E and H) Axial loads from end walls (E and H), where applicable	Reaction from wall system	Group I $D + L^b + E + H$ at 120% allowable unit stress Group II $D + L^b + E + H + EQ$ at 150% of allowable unit stress
BRACING SYSTEM MAIN VERTICAL MEMBERS: STRUTS AND WALES	Self weight Reactions from dead loads of deck structure and bracing system	Reactions from live load on deck structure (L), excluding impact load Walkways and incidental loads (L) Construction equipment (L)	As required by bracing design	As required by bracing design	$D + L^b$ at 100% Allowable Unit Stress
CURBS AND SAFETY CURBS	Self weight	Axial load equal to 3% of the design axial load in the more heavily loaded adjacent bracing member (L)		As required by bracing design	Applicable bracing system loading

Table 2.5-2: Support of Excavation Loads and Loading Combinations

[a] Wall systems are classified as either flexible or rigid. By way of example and without limitations, flexible wall systems include interlocking sheetpile walls, soldier pile and lagging, and other similar By way of example and without limitations, rigid wall systems include reinforced concrete slurry walls, soldier pile tremie concrete (SPTC), tangent or secant piles, and other similar systems

[b] The value of L, live load, shall be the maximum total live load obtained by combining the various live loads that can exist at any given time

2. Steel deck beams shall not be considered as receiving lateral support from timber decking and shall be braced consistent with the analysis adopted.

3. Where the loading conditions on opposite sides of an excavation are not equal, the stability of the temporary retaining structure shall be analyzed and the structural members designed to take this condition into consideration.

4. The vertical distance between struts shall not exceed 12'-0". At no time shall the vertical distance from the centerline of the lowest installed struts to the bottom of excavation exceed 17'-0". The maximum horizontal centerline to centerline spacing shall not exceed 15'-0".

5. To account for concentration of soil pressure at strut locations, bending moments obtained from pressure diagrams (hydrostatic pressure excluded) may be reduced by 20% when calculating flexural requirements for vertical members of flexible wall systems only.

6. The slenderness ratio (KL/r) of struts shall not exceed 120. The maximum slenderness ratio of secondary bracing elements shall not exceed 200. Allowable axial stress in steel shall be determined in accordance with AASHTO Section 10.34.

7. All compression member connections, in addition to be designed for compressive loads, shall be designed for tension and shear equal to larger of 10% of the compressive load or actual tension and/or shear loads.

8. In the design of struts and their connections to wall and column elements, stresses due to temperature variations and to eccentricity from lateral loading, either laterally or vertically, shall be taken into consideration.

9. Temporary excavation support walls may either be designed as a series of simply-supported beams spanning between braces, or as a continuous beam with full continuity over supports at braced locations.

10. For simply-supported case, tributary load areas are assigned to each brace and to the reaction at the bottom of the excavation. Bracing loads are calculated by assuming that the wall acts as a series of simply-supported beams spanning between bracing points.

11. Walls shall be considered continuous over braced locations when:

    i. Geostatic, rather than apparent, pressure diagrams are used for analysis;
    ii. Walls that eventually become wholly, or part of, a permanent structure.

12. When calculating the required penetration of the wall system below the bottom of the excavation, the following criteria shall govern:

    a. *Simply Supported Wall Analysis*: The wall shall be embedded below the bottom of the excavation such that the moment of forces about the lowest brace shall be in static equilibrium, with a FoS of 1.5, assuming a hinge at the bottom brace. Embedment shall be as calculated, but not less than 10 feet.

    b. *Continuous Wall Analysis*: The wall shall be embedded such that when moments are taken about the bottom brace, the moment due to the passive pressure plus the allowable moment capacity of the wall itself shall have a FoS of 1.5 against the applied moments due to the soil, water and surcharge pressures located below the bottom brace.

c. Embedment shall also be designed to satisfy vertical bearing capacity, base stability and mass stability requirements.

d. Passive pressure, P_p, shall be calculated based on Section 2.5.7.2.

13. Available geotechnical data shall be used in the selection of the support of excavation systems.

2.5.7.2 Design Loads

The design loads shall be generated based on the category (flexible or rigid) retaining wall system being analyzed. The loading conditions are detailed in Section 2.5.7.2 and passive conditions are also detailed in Section 2.5.7.2.

To properly document the design loads, a comprehensive excavation sequence analysis shall be performed, consistent with the anticipated construction efforts; the maximum design loads for lateral bracing members shall be based on sequenced excavation analysis.

Flexible Wall Systems

Without limitation, interlocking sheet piles walls, and soldier pile and lagging walls are examples of a flexible earth retaining wall system. The load distribution shall be based on apparent pressure diagrams, as noted in Figure 2.5-1; and shall include the following loads:

Lateral ***active*** earth pressure
Lateral hydrostatic pressure
Lateral surcharge due to traffic and construction equipment
Lateral surcharge[4] due to building and other permanent conditions

SYMBOLS

γ_t Total Unit Soil Weight
γ_b Effective Unit Soil Weight
γ_w Unit Weight – Water
K_a Coefficient for Active Conditions
C_u Undrained Shear Strength

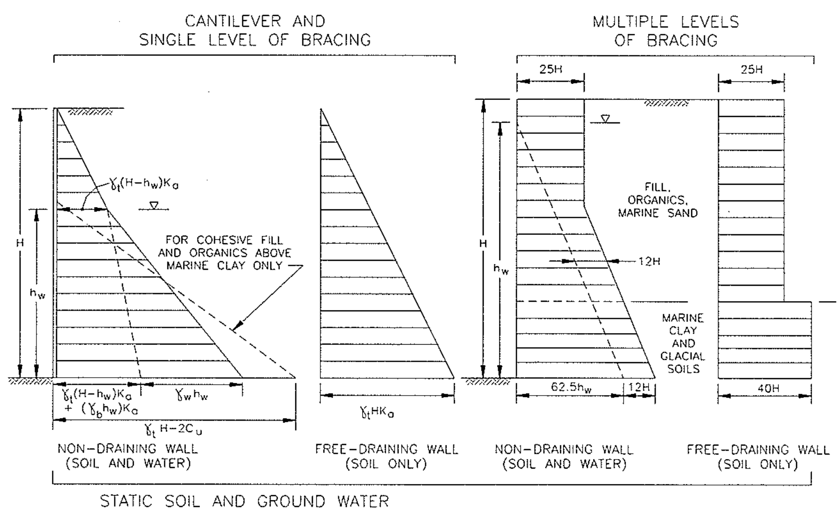


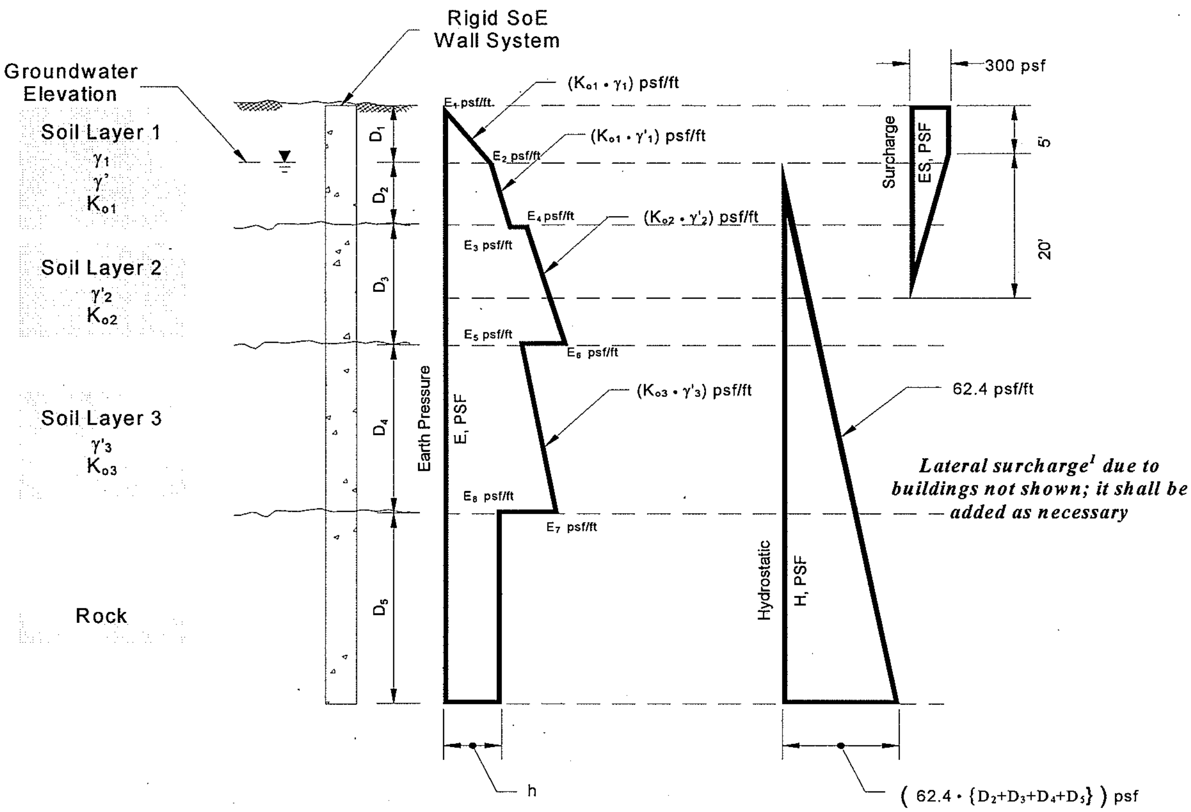
FIGURE 2.5-1: Lateral Load Pressure Diagram Flexible Wall Systems

[4] See Section 2.4.1.9

Rigid Wall Systems

Without limitation, reinforced concrete (slurry) wall, soldier pile tremie concrete walls; adjacent (tangent) or intersecting (secant) cast-in-place reinforced concrete pile walls, are examples of a rigid earth retaining wall system. The load distribution shall be based on geostatic pressure diagrams, as noted in Figure 2.5-2; and shall include the following loads:

Lateral ***at-rest*** earth pressure
Lateral hydrostatic pressure
Lateral surcharge due to traffic and construction equipment
Lateral surcharge[5] due to building and other permanent conditions



Designation	Lateral Pressure psf
E_1	0
E_2	$K_{o1}\ \gamma_1\ D_1$
E_3	$K_{o1}\ (\gamma_1\ D_1 + \gamma'_1\ D_2)$
E_4	$K_{o2}\ (\gamma_1\ D_1 + \gamma'_1\ D_2)$
E_5	$K_{o2}\ (\gamma_1\ D_1 + \gamma'_1\ D_2 + \gamma'_2\ D_3)$
E_6	$K_{o3}\ (\gamma_1\ D_1 + \gamma'_1\ D_2 + \gamma'_2\ D_3)$
E_7	$K_{o3}\ (\gamma_1\ D_1 + \gamma'_1\ D_2 + \gamma'_2\ D_3 + \gamma'_3\ D_4)$
E_8	Based on wedge analysis

FIGURE 2.5-2: Lateral Load Pressure Diagram and Table Rigid Wall

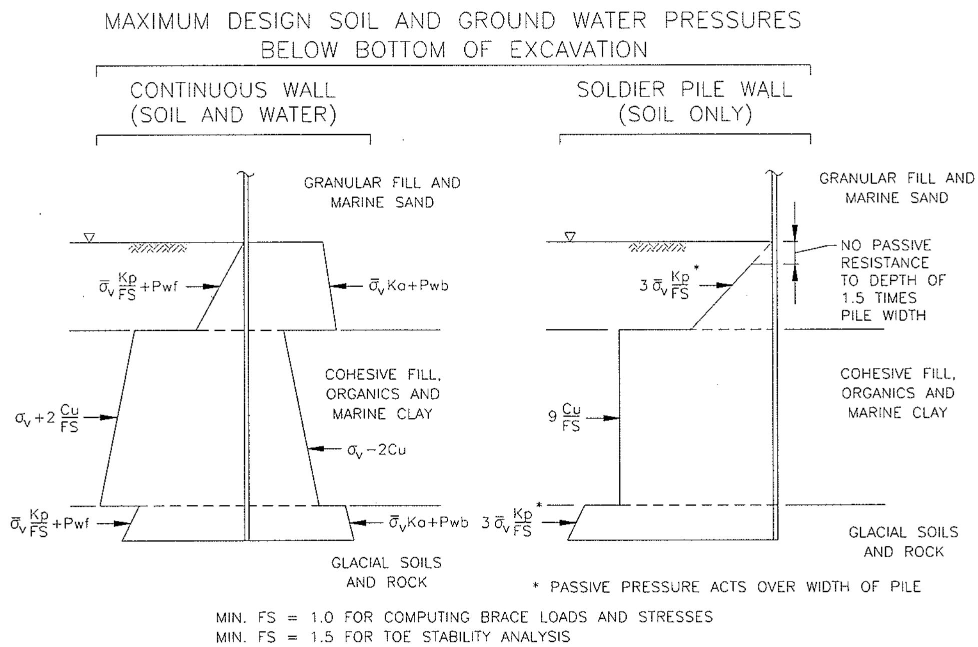
[5] See Section 2.4.1.9

Passive Pressure Distribution

Limits of passive pressures shall be determined in accordance with Figure 2.5-3. These resisting pressures are applicable for permanent and temporary conditions.

SYMBOLS

- σ_v Total Overburden Pressure
- $\bar{\sigma}_v$ Effective Overburden Pressure
- K_p Coefficient for Passive Conditions
- C_u Undrained Shear Strength
- FS Factor of Safety
- P_{wf} Hydrostatic Pressure (Front)
- P_{wb} Hydrostatic Pressure (Back)



FIGUR E 2.5-3: Below Bottom of Excavation Passive Pressure Diagram Flexible and Rigid Wall Systems

2.5.8 CONTROL OF DEWATERING

1. In areas, uncontrolled lowering of the groundwater for construction may cause settlement of buildings both adjacent to and some distance away from excavations. The GC shall prepare recommendations for construction and dewatering for these areas. Such limitations and control measures shall be incorporated in the design studies and shall be included as appropriate in the contract drawings.

2. In general, support of excavation rigid wall types shall serve as water cut-off to prevent lowering of the ground water level adjacent to the construction area.

3.0 STRUCTURAL SEISMIC DESIGN CRITERIA

3.1 GENERAL

This chapter sets forth the Structural Seismic Design Criteria (SSDC) for the design of cut-and-cover, mined and bored tunnels; stations; and other ancillary structures.

Only the general seismic design conditions that apply to the project are addressed in this section. It does not, however, address special design cases; such unique design considerations shall be appropriately addressed as needed, and on a case-by-case basis.

To address life safety concerns in the event of an earthquake, and because of importance of structures, a two-level earthquake hazard design approach has been adopted for the Silver Line Phase III (SL3) Project. The two-level earthquake hazard design approach considers the Operating Design Earthquake (ODE) and the Maximum Design Earthquake (MDE).

3.1.1 OPERATING DESIGN EARTHQUAKE – ODE

ODE is a seismic event that has a 10% probability of being exceeded in 50 years (approximately 500 year return period). An ODE event is expected to occur at least once during the design life of the structure. Design conforming to an ODE event shall ensure that structure is fully functional, and without interruption to service, before and after the seismic event. All structural elements shall be designed to behave in an elastic manner. Minor, though readily repaired, damage will be permitted to secondary structural and architectural elements. The structure shall be fully functional within a few hours after a safety inspection.

3.1.2 MAXIMUM DESIGN EARTHQUAKE – MDE

MDE is a seismic event that has a 2% probability of being exceeded in 50 years (approximately 2,500 year return event). MDE represents an event with a very small probability of exceedance during the design life of the structure. Upon occurrence of a MDE event, structure may behave in an inelastic manner; some interruption to service is acceptable. However, structure shall be designed with adequate strength and ductility to withstand loads and deformations imposed by the MDE event without catastrophic failure. Major structural repairs can be anticipated.

Bored and mined tunnel sections shall be designed as circular tunnel sections.

Cut-and-cover tunnel sections, regardless of depth of structure, shall be designed as shallow rectangular framed underground structures subjected to ground shaking.

The transition (boat) structures will be designed as gravity retaining structures subjected to ground shaking.

Liquefaction potential of the soil medium shall be evaluated by the Geotechnical Consultant (GC).

The GC shall perform site-specific SHAKE analyses along the SL3 alignment and provide a comprehensive report indicating results obtained from the SHAKE analysis[6]. The report will include, without limitations: Peak particle velocity and peak particle acceleration; and appropriate ground response velocities, accelerations, and displacements. In addition, GC shall identify locations of fault lines and potential for slip planes being developed.

[6] SHAKE analysis at each determined location shall be performed for ODE and MDE events.

Locations of representative SHAKE analyses will be established by the GC.

The Seismic Design Criteria shall be read in conjunction with the Silver Line Project Structural Design Criteria.

3.2 DESIGN SPECIFICATIONS

3.2.1 CODES

Unless noted, or directed otherwise, the following codes will be used in the seismic analysis and design of all structures and structural elements, as set forth in this chapter:

1. "Standard Specifications for Highway Bridges", 17th Edition, 2002, of the American Association of State Highway and Transportation Officials, referenced to in these criteria as the "AASHTO Code", as modified herein.

2. American Institute of Steel Construction (AISC), "Manual of Steel Construction", 13th Edition, applying the Allowable Strength Design philosophy, referenced in these criteria as the "AISC".

Where differences between the structural design criteria and codes noted in Section 3.2.1 occur, the design criteria shall govern the design and analysis of the structures.

3.2.2 REFERENCES

Unless noted, or directed otherwise, the following references shall be used for the seismic analysis and design of the structures.

1. St. John, C. and Zahrah, T. (1987), "Seismic Design of Underground Structures", *Tunneling and Underground Space Technology*, Vol. 2, No. 2, pp. 165-197.

2. Seed, H. and Whitman, R. (1970), "Design of Earth Retaining Structures for Dynamic Loads", *1970 ASCE Specialty Conference on Lateral Pressures in the Ground and Design of Earth Retaining Structures*, Cornell University.

3. Whitman, R. (1990), "Design of Earth Retaining Structures for Dynamic Loads", *1990 ASCE Specialty Conference on Lateral Pressures in the Ground and Design of Earth Retaining Structures*, Cornell University.

4. Y. M. A. Hashash, J. J. Hook, B. Schmidt, and J. I. Yao, "Seismic Design and Analysis of Underground Structures", *Tunneling and Underground Space Technology*, Vol. 16, No. 4, October 2001, pp. 247–293.

5. Ishihara, K., "33rd Rankine Lecture, Liquefaction and Flow Failure during Earthquakes", *Geotechnique* 43, No. 3, 1993 pp. 251–415.

6. *NEHRP Recommended Provisions for Seismic Regulations for New Buildings and Other Structures*, 2000 Edition

7. St. John, C. T. and Zahrah, "A Seismic Design for Underground Structures", *Tunneling and Underground Space Technology*, Vol 2, No. 2, 1987, pp. 166–197.

8. Andrus, R. D. and Stokoe, K. H., "Liquefaction Resistance of Soils from Shear-Wave Velocity", *Journal of Geotechnical and GeoEnvironmental Engineering*, ASCE, Vol 126, No. 11, 2000, pp. 1015–1025.

3.3 DESIGN GROUND MOTION PARAMETERS

Ground motion profiles, provided by the Geotechnical Consultant, shall be used for the design of underground structures. These profiles include acceleration, velocity and displacement and maybe updated, as necessary, by the GC.

Unless a site-specific shake analysis is performed for a particular structure, the seismic analysis of the underground and above ground structures shall be based on the ground accelerations noted in Table 3.3-1.

	ODE	MDE
Horizontal Acceleration	0.17g	0.24g
Vertical Acceleration	0.11g	0.16g

Table 3.3-1: Ground Acceleration Coefficient

Prior to commencement of analysis for final design, the most recent revision of the profiles and ground motion parameters shall be obtained from the GC for use. At all times, the most up-to-date parameters issued by the GC shall be used.

The design of the tunnel shall provide and assume the following:

1. Tunnel and boat structures shall behave within the elastic range under ODE earthquake conditions.
2. Vertical design acceleration motion will be taken as $^2/_3$ of the design horizontal ground acceleration.
3. Active earth pressures are assumed to be present during the design earthquake condition, unless conditions dictate otherwise.

3.4 SITE RESPONSE ANALYSES

A one-dimensional (1-D) site-specific response analyses shall be performed using the ground motions from the ODE and MDE described in Section 3.4. 1-D response analyses shall be performed to obtain the cyclic shear strains, shear stresses, spectral values and response spectrum for various dynamic soil profiles along the alignment. Dynamic soil properties shall be based on field investigations such as in-situ geophysical testing (down-hole, cross-hole, and seismic refraction), seismic cone penetrometer tests (SCPT), and correlation with Standard Penetration Test (SPT) N-values for non-cohesive soils

3.5 UNDERGROUND STRUCTURES

The general procedure for seismic design of underground structures shall be based on ground deformation approach and shall be specific to construction methodology.

In the event of an earthquake, ground deformation will induce structural deformations and/or displacements. The structure must accommodate deformation forces and/or displacements without jeopardizing structural integrity.

Group C load combinations shall be dependent on construction methodology and shall be taken as:

For cut-and-cover construction

$$C_{ODE} = 1.05\,(D + SD) + 1.3\,L + \beta_1\,(EV + H + B + EH) + 1.3\,EQ$$

$$C_{MDE} = D + SD + L + EV + B + EH + H + EQ$$

For mined or bored construction

$$C_{ODE} = 1.05\,(D + SD) + 1.3\,L + \beta_2\,(EX + B + H) + 1.3\,EQ$$

$$C_{MDE} = D + SD + L + H + B + EX + EQ$$

Where

- D - Dead Load
- SD - Superimposed Dead Load
- L - Live Load
- EV - Vertical Earth Load
- EH - Horizontal Earth Load
- EX - Excavation Load
- H - Hydorstatic Load
- B - Buoyancy Load
- EQ - Seismic Load
- $\beta_{1\text{ or }2}$ - Use 1.05 if extreme conditions are assumed for horizontal and vertical earth and hydrostatic loads; otherwise use 1.3

It should be noted that in some instances, a more onerous loading condition may be generated by omitting live loads. The engineer shall evaluate all such instances.

The forces generating structural deformation due to seismic events are the "EQ" values for use in the loading combinations defined in the loading combination above. The structure is acceptable for seismic loading conditions when the seismic forces plus the static forces meet the appropriate Group C loading requirements.

In considering "EQ" forces, following combinations must be utilized:

EQ = Full Horizontal Seismic Pressures ± 30% of Vertical Seismic Pressures;

EQ = 30% of Horizontal Seismic Pressure ± Full Vertical Seismic Pressures

3.5.1 CIRCULAR STRUCTURES

Circular structures include bored and mined tunnels constructed in soft and hard ground conditions. These types of tunnels are constructed using either precast concrete segmental lining, cast-in-place concrete lining, or cast-in-place shotcrete lining.

Circular structures experience three primary modes of deformation:

Ovaling – caused primarily by seismic waves propagating transversely to the longitudinal axis of the tunnel. The vertical propagating shear waves are generally considered to be the most critical type of waves for this mode of deformation.

Compression and tension – induced primarily by seismic waves propagating along the longitudinal axis of the structure.

Longitudinal bending – induced primarily by seismic waves propagating along the longitudinal axis of the structure.

3.5.1.1 Ovaling Deformation

Seismic ovaling deformations develop when there is a change in diameter of a circular tunnel due to seismic wave propagation in a direction perpendicular or nearly perpendicular to the tunnel axis. The stresses and strains induced in the lining are defined in terms of the change in tunnel diameter, ΔD_t. These dynamic stresses/strains shall be superimposed on the static state of stress /strain in the lining.

Calculating ΔD_t

From the SHAKE analysis, obtain the maximum free-field shear strain, γ_{max}, caused by vertically propagating shear waves.

1. For tunnels in rock or dense and stiff soils, the effects of the lining may be neglected; the ΔD_t shall be estimated as:

$$\Delta D_t = 2 \cdot \gamma_{max} \cdot (1 - \nu_m) \cdot D \qquad \text{EQN 3.5-1}$$

where:

ν_m = Poisson's ratio of the surrounding soil
γ_{max} = Free-field shear strain
D = Diameter of tunnel

2. If the structure is stiff relative to the surrounding soil, the effects of soil-structure interaction shall be taken into consideration. The stiffness of the tunnel structure is based on the flexibility, F, and the compressibility, C, ratios. These ratios measure the flexural and extensional stiffness of the structure and are expressed as:

$$F = \frac{E_m \cdot (1 - \nu_l^2) \cdot R^3}{6 \cdot E_l \cdot I_l (1 + \nu_m)} \qquad \text{EQN 3.5-2}$$

$$C = \frac{E_m \cdot (1 - \nu_l^2) \cdot R}{E_l \cdot t \cdot (1 + \nu_m) \cdot (1 - 2 \cdot \nu_m)} \qquad \text{EQN 3.5-3}$$

where:

E_m = Modulus of elasticity of the surrounding soil
ν_m = Poisson's ratio of the surrounding soil
E_l = Modulus of elasticity of the tunnel lining
ν_l = Poisson's ratio of the tunnel lining
R = Radius of tunnel lining
t = Thickness of tunnel lining
I_l = Moment of inertia of tunnel lining (per unit width)

The strain compatible elastic modulus of the soil, E_m, shall be derived using the strain compatible shear modulus, G_m, corresponding to the effective shear wave velocity.

The moment of inertia of the concrete lining, I_l, shall be determined based on the expected behavior of the selected lining under the combined seismic and static loads. In determining I_l, cracking in lining and joints between segments shall be considered, as appropriate.

The cracked section of concrete shall be used for bending stress as appropriate. Contact stresses along the edges of precast concrete lining shall be evaluated to ensure that concrete is not overstressed.

The change in tunnel diameter, ΔD_t, shall be estimated as:

$$\Delta D_t = \frac{K_1 \cdot F \cdot \gamma_{max} \cdot D}{3} \quad \text{EQN 3.5-4}$$

where:
- K_1 = Ovaling coefficient defined below
- γ_{max} = Maximum free-field shear strain
- F = Flexibility coefficient
- D = Tunnel diameter

The seismic ovaling coefficient is calculated as:

$$K_1 = \frac{12 \cdot (1 - \nu_m)}{2 \cdot F + 5 - 6 \cdot \nu_m} \quad \text{EQN 3.5-5}$$

where:
- ν_m = Poisson's ratio of the surrounding soil
- F = Flexibility coefficient

The resulting bending moment induced maximum fiber strain, ε_m, and axial/thrust strain, ε_t, in the final lining shall be derived as follows:

$$\varepsilon_m = \frac{t \cdot R^2 \cdot K_1 \cdot \gamma_{max}}{12 \cdot E_l \cdot I_l} \cdot \left(\frac{E_m}{1 + \nu_m} \right) \quad \text{EQN 3.5-6}$$

$$\varepsilon_t = \frac{K_2 \cdot \gamma_{max} \cdot E_m \cdot R}{2 \cdot E_l \cdot t \cdot (1 + \nu_m)} \quad \text{EQN 3.5-7}$$

where:
- K_1 = Ovaling coefficient
- E_m = Modulus of elasticity of the surrounding soil
- ν_m = Poisson's ratio of the surrounding soil
- E_1 = Modulus of elasticity of the tunnel lining
- γ_{max} = Maximum free-field shear strain
- R = Radius of tunnel lining
- t = Thickness of tunnel lining
- I_l = Moment of inertia of tunnel lining (per unit width)

The maximum thrust force, T_{max}, and bending moment, M_{max}, shall be computed as:

$$T_{max} = \frac{K_2 \cdot \gamma_{max} \cdot R \cdot E_m}{2 \cdot (1 + \nu_m)} \quad \text{EQN 3.5-8}$$

$$M_{max} = \frac{K_1 \cdot \gamma_{max} \cdot R^2 \cdot E_m}{6 \cdot (1 + \nu_m)} \quad \text{EQN 3.5-9}$$

where:

K_1 = Ovaling coefficient
K_2 = Ovaling coefficient, defined below
ν_m = Poisson's ratio of the surrounding soil
E_m = Modulus of elasticity of the surrounding soil
γ_{max} = Maximum free-field shear strain
R = Radius of tunnel lining

The equations for T_{max} and ε_t are based on a non-slip condition between the soil and the lining interface. In addition, K_2 is calculated as:

$$K_2 = 1 + \frac{F\,[(1 - 2\nu_m) - (1 - 2\nu_m)\,C] - \tfrac{1}{2}\,(1 - 2\nu_m)^2 + 2}{F\,[\,(3 - 2\nu_m) + (1 - 2\nu_m)\,C\,] + C\,(\,2.5 - 8\nu_m + 6\nu_m^2) - 8\nu_m + 6}$$

..... EQN 3.5-10

Figure 3.5-1 schematically shows the various forces and moments induced in a bored tunnel due to seismic activity.

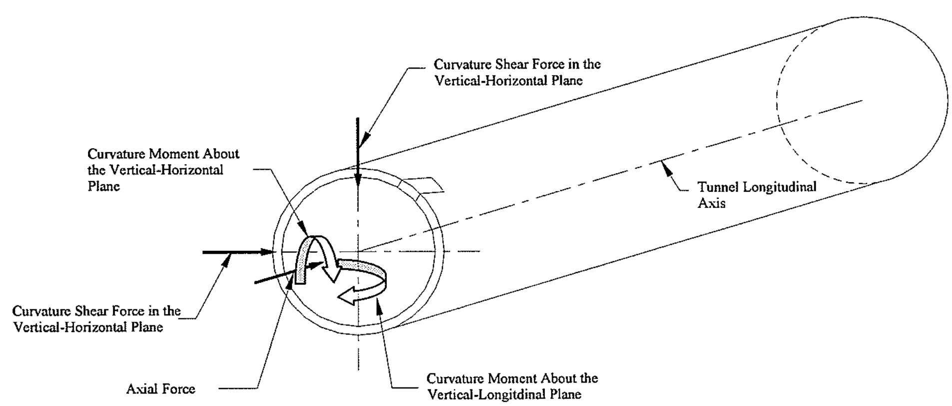


FIGURE 3.5-1: INDUCED FORCES AND MOMENT CAUSED BY SEISMIC

The seismic ovaling deformation shall be combined with deformations resulting from non-seismic loads defined under the Structural Design Criteria for cut-and-cover, mined or bored structures.

For the ODE level design, the non-segmental lining shall be designed to respond in an elastic manner; the combined axial and bending strains (ε_{max}) of the lining shall not exceed 0.001 and 0.002 for concrete and steel, respectively.

For a MDE event, inelastic deformation is permitted, but the combined axial and bending strains (ε_{max}) shall not exceed strains of 0.003 and 0.006 for concrete and steel, respectively. Concrete strain may be permitted to 0.004 provided that the strain is predominantly in flexural mode. Segmental lining shall be designed to accommodate static and seismic deformations.

Gaskets shall be designed to accommodate stresses and deformation associated with the MDE and ODE events, permitting only minor leakage.

The final lining shall also be designed to meet the strength requirements for the ODE event. The internal forces associated with the seismic ovaling deformation, ΔD_t, shall be derived by elastic analysis using the effective I_l value.

3.5.1.2 Axial and Curvature Deformation – Longitudinal Wave Propagation

The tunnel lining shall be designed to accommodate seismic strains caused by axial and curvature deformations of the ground. The strains due to combined axial and curvature deformations can be conservatively estimated using the formulas[7] for free-field elastic strain contained in Table 3.5-2. The angle of wave propagation, ϕ_{wp}, should be the value that maximizes the combined axial strains.

Wave Type		STRAIN			
		Longitudinal	Normal	Shear	Bending
P-Wave		$\varepsilon_{lm} = \frac{V_{max}}{V_{pe}}$ $\phi = 0^\circ$	$\varepsilon_{nmax} = \frac{V_{max}}{V_{pe}}$ $\phi = 90^\circ$	$\gamma_m = \frac{V_{max}}{2 \cdot V_{pe}}$ $\phi = 45^\circ$	$\varepsilon_{pmax} = \frac{R \cdot a_{max}}{2.6 \cdot V_{pe}^2}$ $\phi = 35.27^\circ$
S-Wave		$\varepsilon_{lm} = \frac{V_{max}}{2 \cdot V_{se}}$ $\phi = 45^\circ$	$\varepsilon_{nmax} = \frac{V_{max}}{2 \cdot V_{se}}$ $\phi = 45^\circ$	$\gamma_m = \frac{V_{max}}{V_{se}}$ $\phi = 0^\circ$	$\varepsilon_p = \frac{R \cdot a_{max}}{V_{se}^2}$ $\phi = 0^\circ$
Raleigh Wave	Compression Component	$\varepsilon_{lm} = \frac{V_{max}}{V_{pe}}$ $\phi = 0^\circ$	$\varepsilon_{nmax} = \frac{V_{max}}{V_{re}}$ $\phi = 90^\circ$	$\gamma_m = \frac{V_{max}}{2 \cdot V_{re}}$ $\phi = 45^\circ$	$\varepsilon_{pmax} = \frac{R \cdot a_{max}}{2.6 \cdot V_{pe}^2}$ $\phi = 35.27^\circ$
	Shear Component		$\varepsilon_{nmax} = \frac{V_{max}}{V_{re}}$ $\phi = 45^\circ$	$\gamma_m = \frac{V_{max}}{V_{re}}$ $\phi = 0^\circ$	$\varepsilon_p = \frac{R \cdot a_{max}}{V_{re}^2}$ $\phi = 0^\circ$

Particle Motion orthogonal to logitudinal axis of tunnel
ϕ - wave angle measured wrt to logitudinal axis of tunnel
V_{pe} = 2 Vse
V_{re} = 0.95 Vse

V_{pe}, V_{se} and V_{re} are effective wave propagation velocities
V_p = peak particle velocity
a_p = peak particle acceleration
R = Distance from NA to extreme fibre of structure

Strains are dimensionless number. Units used within the equations should be consistent to obtain dimensionless results

Table 3.5-2: Strain Equations for Various Wave Types

The shear wave velocities used in these equations shall be the strain-compatible values determined from the SHAKE analysis. The values of Raleigh wave velocity required for use in Table 3.5-2 can be conservatively taken as equal to 95 percent of the strain-compatible shear wave velocity for the appropriate soil profile and design earthquake level.

For the ODE event design, the longitudinal strains, ε_{lm}, due to the axial and curvature deformations shall be checked not to exceed strains of 0.001 for concrete and 0.002 for steel. For the MDE level design, the allowable strain condition shall be 0.003 and 0.006 for concrete and steel, respectively.

3.5.2 RECTANGULAR STRUCTURES

Rectangular structures include all types of cut-and-cover box shaped construction, mined stations, and transition structures. Design details for the seismic design of reinforced concrete box structures shall be in accordance with all provisions of the Project Structural Design Criteria and this criterion. Typically, analysis of such structures involves the following three methods:

Racking Analysis
Pseudo-static Stress Analysis
Dynamic Soil Pressure Increment Analysis

[7] Equations are for specified ϕ values, and are based on St. John, C. and Zahrah, T. (1987), "Seismic Design of Underground Structures", *Tunneling and Underground Space Technology*, Vol. 2, No. 2, pp. 165-197. For additional values of ϕ, refer to the referenced document.

All rectangular below grade structures shall be analyzed and designed based on the most onerous design force condition generated by either the racking or the pseudo-static stress methods of analyses.

All transition structures shall be analyzed using the dynamic soil pressure increment analysis method.

3.5.2.1 Racking Analysis

Seismic design of the transverse cross section of a structure includes the racking deformations due to the vertically propagating shear waves, which is similar to the ovaling deformations of a circular tunnel lining.

Racking deformations are defined as the differential sideways movement between the top and the bottom elevations of the box structures, shown as δ_r in Figure 3.5-2.

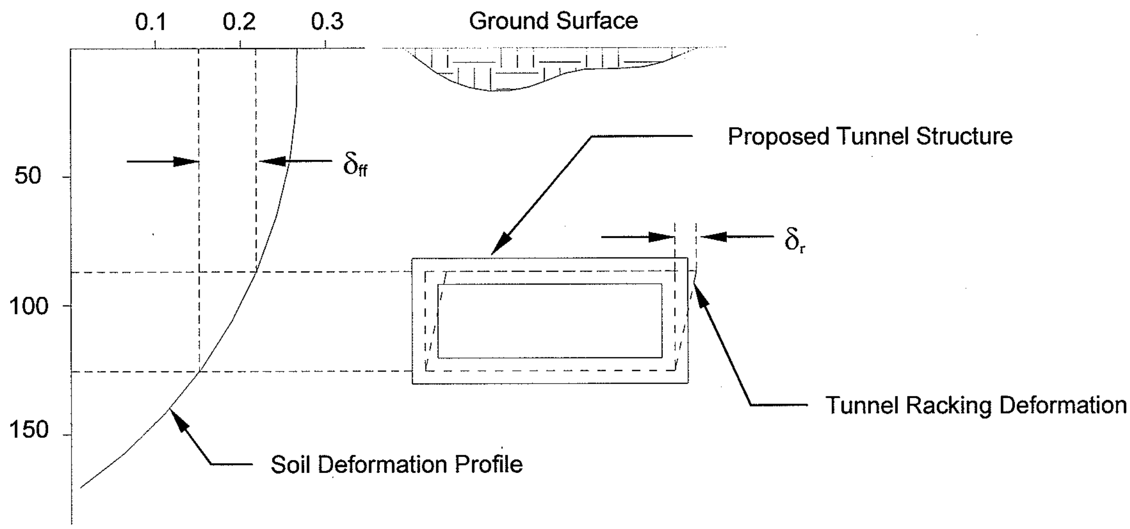


Figure 3.5-2: Racking Deformation of Rectangular Section

Racking deformation load, P, is based on a site-specific horizontal shear deformation profile, caused by vertically propagating shear waves. The horizontal shear deformation profiles will be obtained for ODE and MDE events. These profiles will be provided by the Geotechnical Consultant and shall be measured during the subsurface exploration. The most updated version of the profiles shall be utilized for calculation purposes. The procedure for calculating the racking deformation load is as follows:

- Calculate the free-field deformation, δ_{ff}. δ_{ff} shall be computed as the difference in horizontal shear deformation between the top and the bottom of the structure[8]. For analysis purposes, the top and bottom of the structure shall be considered as the model centerlines.

- Calculate the racking stiffness, K_r, of the proposed structure; it shall be determined from a structural frame analysis procedure. The K_r shall be computed using the displacement of the roof subjected to a unit lateral force (P_o) applied at the roof level, while the base of the structure is restrained against translation, but with the joint free to rotate. The ratio of the applied force to the resulting lateral displacement yields K_r. In performing the structural frame analysis, appropriate moment of inertia[9] values, taking into account the potential development of cracked section, shall be used.

[8] If the soil profile is varying within the vertical limits of the structure, then see Section 3.6.2.1-Vertical Limits of Structure Located in Multiple Soil Stratums.

[9] The racking stiffness can conservatively be based on I_g; alternatively, a more detailed analysis can utilize $I_e = \omega^3 \cdot I_g + [1-\omega^3] \cdot I_{cr}$, where ω is the ratio of cracking moment, M_{cr}, to service moment, M_a.

$$K_r = \frac{P_o}{\delta_{ro}}$$ EQN 3.5-11

Where:
P_o = Unit lateral force applied at the roof level
δ_{ro} = Displacement due to P_o

- The flexibility ratio, Fr of the proposed design of the structure shall be determined by the following equation:

$$F_r = \frac{G_m \cdot w}{K_r \cdot h}$$ EQN 3.5-12

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. (G_m shall be derived from the strain compatible, effective shear wave velocity, for 1-D response analysis)
H = height of box

- The racking deformation of the structure, dr, shall be determined by using the following relationship:

$$\delta_r = R_r \cdot \delta_{fl}$$ EQN 3.5-13

Where:
δ_{ff} = Free-field deformation of the soil
R_r = Racking reduction coefficient given as:

$$R_r = 4 \cdot \frac{(1 - \nu_m)}{1 + \left(\frac{3 - 4 \cdot \nu_m}{F_r}\right)}$$ EQN 3.5-14

- The seismic demand in terms of internal forces as well as material strains shall be calculated by imposing a force, P, such that the desired deformation, δ_r, is achieved – as shown in Figure 3.5-3; P is calculated as:

$$P = \delta_r R_r$$ EQN 3.5-15

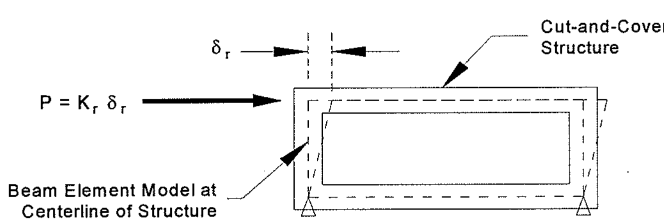


Figure 3.5-3: Racking of a Rectangular Structure

Vertical Limits of Structure Located in Multiple Soil Stratums

It is impractical to assume that multiple soil stratums shall influence the deformation of a rigid structure consistent with the dynamic soil properties of each of soil stratum. To that end, if the soil deformation characteristics are not consistent due to varying soil profile within the vertical limits of the structures, a modified approach is necessary to evaluate the δ_{ff}.

The modified approach shall either be based on a detailed 1-D response analysis integrating the peak shear strains in each layer from the bottom to the top of the profile; or, a simplified weighted-average free-field displacement.

In either case, the ODE conditions will ensure elastic behaviour of the structure; for MDE conditions, plastic analysis will be permitted, provided a failure mechanism does form in the structural member.

a. *Detailed 1-D Response Analysis*
This soil deformation shall be input into a generalized finite element (or difference) program with the side boundaries being set to deflect by the same amount as δ_{ff}. Additionally, a pseudo-static horizontal acceleration shall be applied to the soil mass, such that the soil deflects laterally the same amount as that indicated by the 1-D response analysis.

After establishing horizontal acceleration in the model to obtain deformed shape, an analysis shall be carried out with the underground structure in place with the determined horizontal acceleration in the soil mass. This analysis will provide a more realistic assessment of the induced shear force and moment in the structures due to the earthquake ground motion can be determined.

b. *Simplified Weighted-Average Free-Field Displacement*
In this approach, a secant line, originating at the bottom of the structure, is drawn for each of the soil layer enveloping the bottom and the top of the structure. A δ_{ff} is calculated for each of the two soil layers, based on the secant lines drawn. A weighted δ_{wff}, is then derived, based on the soil layer depth influencing the structure and the δ_{ff} for the respective soil layer.

By way of example, the procedure for calculating the weighted average free field deformation, δ_{wff}, is as noted below:

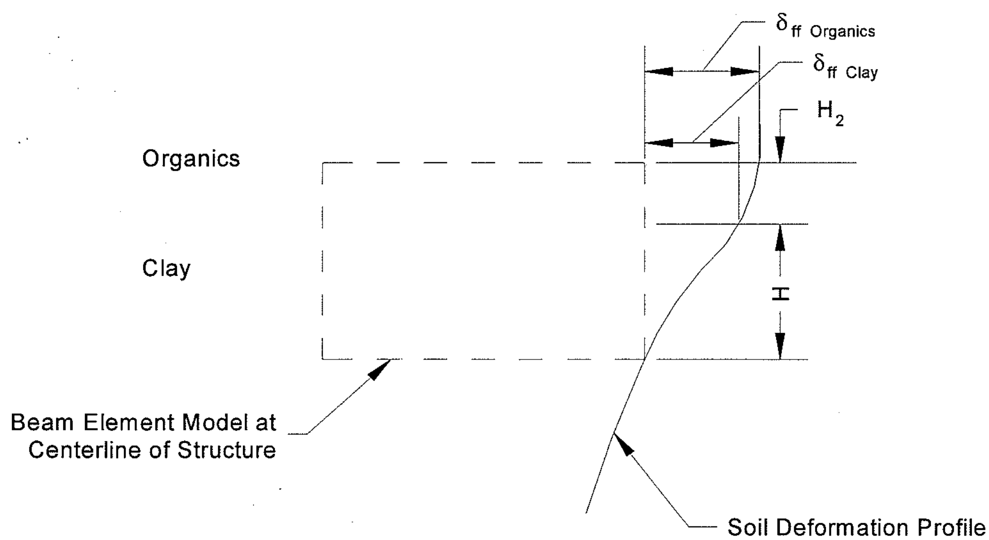


Figure 3.5-4: Free-field Deformation of Rectangular Structure

$$\delta_{wff} = \frac{\delta_{ff\ clay} \bullet H_1 + \delta_{ff\ organics} \bullet H_2}{H_1 + H_2} \quad \text{EQN 3.5-16}$$

3.5.2.2 Dynamic Soil-Pressure Increment (DSPI) Analysis

1. The DSPI loading is applicable to transition structures only. Tunnels and underground stations shall not be analyzed using the DSPI method.

2. Seismic design of the transition structures for the DSPI loading will be performed using either the Mononabe–Okabe (MO) or the Woods methods of analyses. The applicable procedure is dependent on the soil structure interaction – classification of either a flexible or rigid wall system[10].

3. If the structure is considered rigid, then Woods method of analysis is applicable; if the structure is "flexible", then the MO method is to be used for developing seismic pressures.

4. The effects of stratified soil, groundwater, and overburden soil surcharge will be included in the analysis. All DSPI methods will be performed using average soil friction angles and the effective soil stresses.

5. DSPI is ultimately intended to be a means of imposing a seismic racking displacement on the structure, and, as such, does not transmit horizontal shear to the foundations.

6. For either method used, the analysis will consist of solving for the dynamic, incremental forces on the structure wall during an earthquake based on the failure plane of the sliding wedge necessary to develop the dynamic soil-increment loading.

7. The average acceleration, within the limits of the structure, shall be determined from the SHAKE analysis results and use to determine the active dynamic soil-pressures and design forces.

8. **Methods of Analysis:**

   MO method of analysis is essentially an extension of the classic Coulomb's theory for static loading conditions; developed to determine the lateral pressures on gravity retaining wall with dry homogenous backfill. MO method has inherent assumptions regarding a seismic event:
   1. The failure in soil takes place along a plane wedge.
   2. The retaining structure is flexible enough to initiate active/passive conditions
   3. The active wedge behind the retaining structure acts as a rigid body.
   4. At failure, full shear strength along the failure palne is mobilized.
   5. The shear strength of the dry cohesionless soil can be given by the equation $s = \sigma' \tan(\phi)$.

   For most part, the assumptions can be taken for granted, except that listed as item 3. The active wedge condition must be verified based on the amount of displacement experienced by the wall.

   The general MO equation is given as EQN 3.5-17 defines an inverted triangular shaped pressure diagram. The pressure at the bottom of the structure is zero and maximum pressure at the top of the structure. This equation defines the seismic and the active soil pressure effects.

$$\gamma \bullet H \bullet K_{ae} \bullet a_{gh} \qquad \text{EQN 3.5-17}$$

   The term γ is the $\gamma_{total} - \gamma_{water}$; H is the structure height; a_{gh} is the horizontal ground acceleration; and the term K_{ae} is defined as:

$$K_{ae} = \frac{\cos^2(\phi - \theta - \beta)}{\cos(\theta)\cdot\cos^2(\beta)\cdot\cos(\delta + \beta + \theta)\cdot\left(1 + \sqrt{\dfrac{\sin(\phi + \delta)\cdot\sin(\phi - \theta - i)}{\cos(\delta + \beta + \theta)\cdot\cos(i - \beta)}}\right)^2}$$

... EQN 3.5-18

10 Refer to AASHTO Table 5.5.2A; alternatively, if the structure deforms or displaces more than 0.005 • H, then it shall be considered flexible for the sole purpose of calculating soil pressures.

The total active and seismic pressure force is calculated as EQN 3.5-19.

$$\frac{1}{2} \bullet \gamma \bullet H^2 \bullet K_{ae} \bullet a_{gh} \qquad \text{EQN 3.5-19}$$

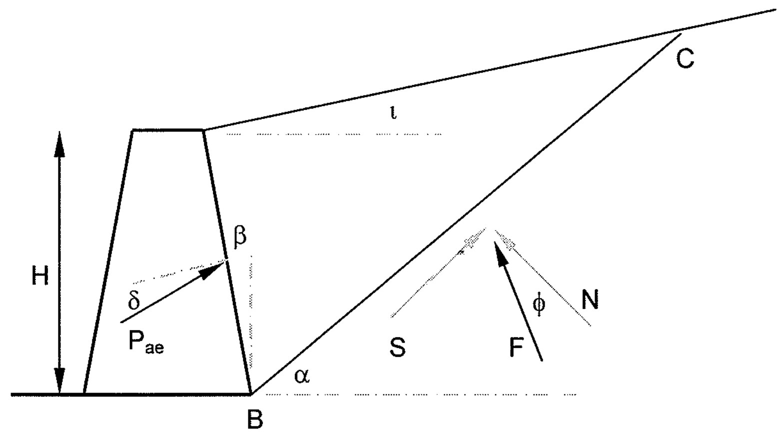


Figure 3.5-5: Schematic Representation of Mononabe-Okabe Pressure Wedge

The point of application of P_{ae} can be estimated by the following procedure:

1. Calculate the active pressure force, $P_a = \frac{1}{2} \bullet \gamma \bullet H^2 \bullet K_a$.
2. Calculate the active plus seismic pressure force, $P_{ae} = \frac{1}{2} \bullet \gamma \bullet H^2 \bullet K_{ae} \bullet a_{gh}$.
3. Calculate the net seismic effect, $\Delta P_{ae} = P_{ae} - P_a$.
4. Apply P_a at $^1/_3 \bullet$ H from the base; apply P_{ae} at $^3/_5 \bullet$ H from the base.

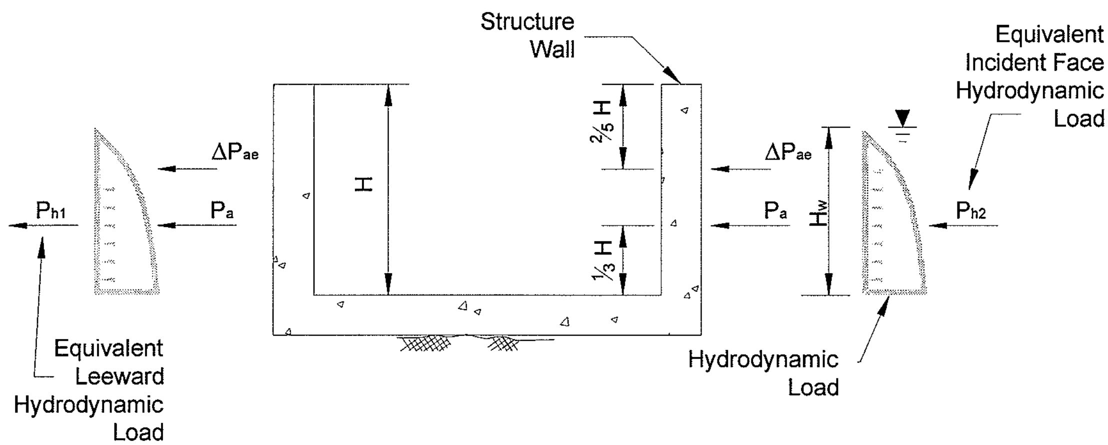


Figure 3.5-6: Application of Mononobe-Okabe Forces on Transition Structure

Wood's method of analysis considers a rigid non-yielding wall, with a uniform horizontal body force representing the soil inertia triggered by ground shaking. The pressure distribution is trapezoidal.

The applicable pressure, located at the top of the structure, for Wood's analysis are given by EQN 3.5-20. The pressures at the bottom of the structure are ½ the value of the pressures given by EQN 3.5-20; the transition from maximum pressure to minimum pressure commences at mid-height of the structure – as noted in Figure 3-7. If the structure is located within varying layers of soil stratum, then a weighted soil density, based on the height of the structure, shall be used.

$$p_{max} = \gamma_{avg} \bullet H \bullet a_{gh} \qquad \text{EQN 3.5-20}$$

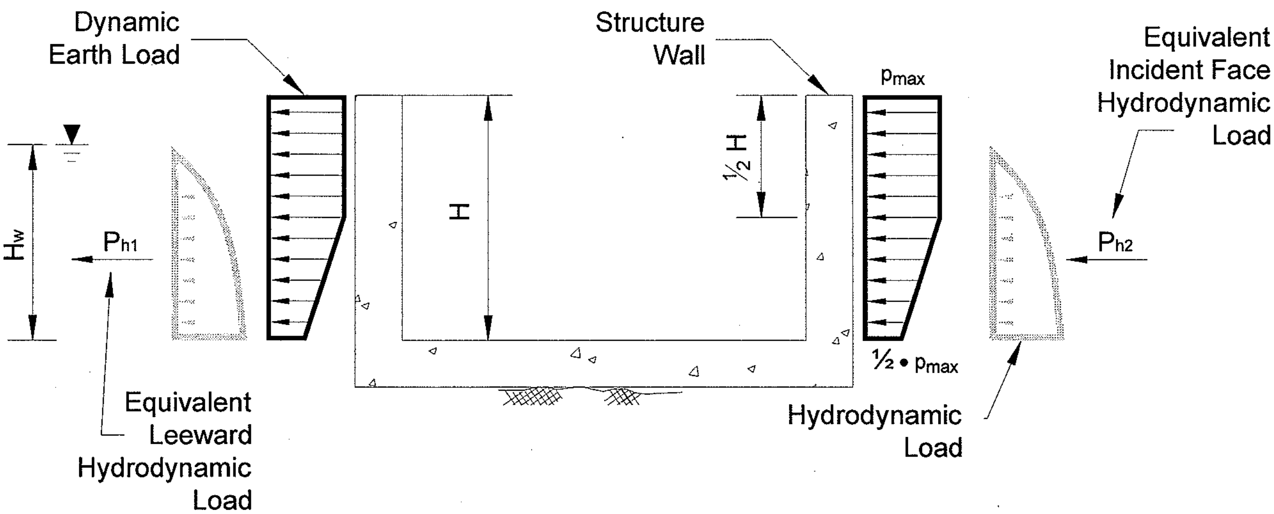


Figure 3.5-7: Application of Woods Forces on Transition Structure

9. For both methods of analysis, dynamic water pressures must also be considered. The correct distribution of the water pressure is parabolic (maximum pressure at the base) over the height of the structure; however, for expediency, a triangular application is sufficient, provided the total pressures are comparable to the parabolic distribution.

10. For both methods of analysis, the dynamic pressure (earth and water) are applied, in the ***same global*** direction, to all ***external*** walls shown in a transverse section. Consequently, there will be a need to limit the appropriate dynamic pressure on the wall opposite the incident side of the structure to the corresponding static pressures. In essence, dynamic pressure cannot exceed the corresponding static pressure on the side opposite the incident wall.

Hydrodynamic Load

Hydrodynamic loads are based on the following equations:

$P_{h1} = {}^{7}/_{12}\, a_{gh}\, \gamma_w\, H_w^2$ Leeward Side EQN 3.5-21

$P_{h2} = {}^{2}/_{5}\, a_{gh}\, \gamma_w\, H_w^2$ Incident Side EQN 3.5-22

The point of application is at 3/5Hw, from the base of the pressure diagram.

3.5.2.3 Pseudo-Static Analysis

1. The free-field state, or the pseudo-static strain, method shall be omitted from the analysis procedure for structures designed using Ultimate Strength Method. This procedure evaluates the longitudinal, normal, shear and bending strains on the tunnel structures and compares the results to allowable strains; the analysis imposes the deformation of the soil on the structure neglecting the soil-structure interaction effects. Inherently, this procedure is inconsistent with the Ultimate Strength Design Method that utilizes ultimate strains.

2. Further, experience has consistently indicated that the strain analysis will invariably fail; obviating the need for the actual exercise. However, the equations for calculating strains are noted in Table 3-2.

   Instead, the structure can more reasonably be analyzed using simplified soil-structure interaction (SSI) in accordance with formulas noted in Table 3-3. The structure is acceptable for pseudo-static analysis when the SSI calculated stresses plus the static stresses meet the Group C loading requirements.

3. For design of structures using Working Stress Method, the pseudostatic allowable strain values are:

Seismic Type	**Material**	$\varepsilon_{allowable}$
ODE	Concrete	0.003 in/in
ODE	Steel	0.002 in/in
MDE[11]	Concrete	> 0.003 in/in
MDE[10]	Steel	> 0.002 in/in

4. If, under ODE conditions, a structure designed to working stress method, experiences strains greater than allowable, then the structure shall be reanalyzed using the simplified soil-structure interaction equations noted in below.

Normal Stress

$$\sigma_n = (E_m + M_m)\,\varepsilon_{nmax} \qquad \text{EQN 3.5-23}$$

$$M_m = \frac{E_m (1 - \nu)}{(1 + \nu)(1 - 2\nu)} \qquad \text{EQN 3.5-24}$$

Transverse Shear Stress

$$\tau_v = \frac{4 E_m d D (1 - \nu)}{A (3 - 4\nu)(1 + \nu)} \qquad \text{EQN 3.5-25}$$

$$\tau_h = \frac{E_m d D (1 - \nu)}{2 A (1 - \nu)(1 + \nu)} \qquad \text{EQN 3.5-26}$$

Longitudinal Stress

$$\sigma_l = \frac{4 E_m d D (1 - \nu)}{A (3 - 4\nu)(1 + \nu)} \qquad \text{EQN 3.5-27}$$

[11] The total strain may exceed the allowable, provided a failure mechanism does not develop in the structural member.

Bending Stress

$$\sigma_b = \frac{M_{hor/ver}\, y}{I} \qquad \text{EQN 3.5-28}$$

$$M_{hor} = {}^1/_3\ D \sqrt[3]{4\,Ec\,I \left[\frac{4\,E_m\,d\,(1-\nu)}{(3-4\nu)\,(1+\nu)}\right]^2} \qquad \text{EQN 3.5-29}$$

$$M_{ver} = {}^1/_3\ D \sqrt[3]{4\,Ec\,I \left[\frac{E_m\,d}{(3-4\nu)\,(1+\nu)}\right]^2} \qquad \text{EQN 3.5-30}$$

where,

E_m	Soil medium modulus of elasticity equals $2(1+\nu)\,\rho\,C_{se}^2$	C_{se}	Shear wave velocity
		d	Largest dimension of structure (width or height)
M_m	Constrained modulus of elasticity of soil	**D**	Maximum displacement amplitude of soil medium **A**
	Section cross-sectional area	σ_l	Longitudinal stress
$\tau_{v/h}$	Vertical/Horizontal shear stress	**I**	Moment of inertia of structure
σ_b	Bending stress	**y**	distance to either extreme face from neutral axis
$M_{ver/hor}$	Maximum vertical/horizontal bending stress induced in tunnel section		

3.5.3 VERTICAL SEISMIC LOADS

Loads due to the vertical seismic motions on cut-and-cover structures shall be considered by applying a vertical static load, equivalent to a fraction of the slab and the overburden material weight. This load shall be applied in the positive and negative vertical direction to generate the most onerous seismic loading condition. These forces shall be determined as:

$$Q_v = a_{g\ ode}\,(DL + E_v) \qquad \text{EQN 3.5-31}$$
$$Q_v = a_{g\ mde}\,(DL + E_v) \qquad \text{EQN 3.5-32}$$

Where

$a_{g\ ode}$ – Vertical acceleration under ODE event
$a_{g\ mde}$ – Vertical acceleration under MDE event
DL – All dead loads
E_v – Vertical earth loads

The vertical acceleration coefficients shall be established using free field site response analyses based on the appropriate dynamic soil profiles. These acceleration coefficients will vary along the alignment.

For mined and bored below grade structures, E_v corresponds to loads due to weight of the loosened zone above roof and shall be established taking into consideration the proposed construction methods and sequences.

3.5.4 VENTILATION AND ACCESS SHAFTS

The seismic designs of vertical shaft structures are similar to those for the line circular tunnel structures. In general, curvature strains and shear forces of the lining resulting from vertically propagating shear waves will govern design. Force and deformation demands may be critical in cases where shafts are embedded in deep but soft deposits. In addition, potential stress concentrations at the following critical locations along the shaft shall be properly accounted for:

- Abrupt changes of the stiffness between two adjoining geologic layers, such as soil-rock interface.
- Shaft/tunnel or shaft/station interfaces
- Shaft/surface building interfaces

In poor ground conditions, flexible connections shall be used between any two structures in that have dramatically different stiffness or mass.

3.5.5 LATERAL LOADS FROM EXISTING STRUCTURES

Lateral loads from existing buildings shall be considered in the design of underground structures. The dynamic horizontal building force shall be taken as $M_{building} \bullet S_a$. S_a is obtained from the response spectra for 5% damping computed for the ODE and MDE earthquakes.

The fundamental period of the structure, T_a, shall be determined by the following relationship:

$$T_a = C_T \bullet h_n^{0.75} \qquad \text{EQN 3.5-33}$$

Where

C_T – Building period coefficient

h_n – Building height-above the base to highest level

The T_a for moment resisting frame buildings can be approximated as $0.1 \bullet N$, where N is the number of stories in the building, provided that the building has a maximum of 12 stories, with a minimum of 10 feet per story height.

3.5.6 INTERFACE JOINTS

Interfaces between structures in soil and bedrock and between bored tunnels and 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 differential movements. The design differential movements shall be established.

3.5.7 SURFACE STRUCTURES

Seismic design of surface building structures and/or other non-building surface structures shall meet all requirements of the Massachusetts Building Code. The effects of surface buildings on tunnels, expressed in terms of base shears and/or rocking moments, shall be added to the ground deformation effects on tunnel structures. The ground deformation effects shall be evaluated in accordance with the procedures presented in this chapter.

3.5.8 NON-STRUCTURAL COMPONENTS AND EQUIPMENT SUPPORTED BY STRUCTURES

Permanent non-structural components and their attachments, and the attachments for permanent equipment, including mechanical and electrical systems, supported by a structure shall be designed in accordance with the Massachusetts Building Code.

3.6 LEVEL GROUND LIQUEFACTION

Level ground liquefaction assessments shall be performed using one or a combination of the following three different methodologies:

- Shear Strain Approach, Dobry, et. Al., 1982.
- Shear Stress Approach, Youd & Idriss, 2001.
- Shear Wave Approach, Andrus & Stokoe, 2000

Level ground liquefaction assessments shall be performed for ODE and MDE events.

The first two methods require that a 1-D, level ground site-specific dynamic soil response analysis is performed for dynamic soil profiles representative of each segment of the alignment. The profiles shall be developed based on soil properties obtained from the results of in-situ geophysical testing, seismic cone penetrometer tests and correlation with SPT Test N-values.

Laboratory tests shall also be performed to evaluate index properties such as Atterberg Limits, gradation, and unit weight necessary to develop the soil profiles.

The objective of these analyses is to evaluate average cyclic shear strains and cyclic shear stresses with depth. To obtain these strains and stresses, a 1-D level ground liquefaction assessment shall be performed.

The third method requires that the in-situ shear wave velocity be measured.

3.6.1 SHEAR STRAIN APPROACH

In this approach, the average cyclic shear strains induced in the soils by the earthquake motions are compared to the threshold strain, γ_t, level of 10^{-2} percent. If the cyclic shear strains are less than or in the proximity of the threshold strain level, soils are not susceptible to liquefaction, Dobry, et. al., 1982.

The cyclic strain approach consists of the following steps:

1. The cyclic shear strain, γ_c, versus depth is determined; $\gamma_c = 0.65\ \gamma_{c\ max}$. The factor of 0.65 represents an averaging over the time history. These strains are determined by a site specific one-dimensional response analysis.

2. Induced cyclic shear strain levels are compared to the threshold strain. If the threshold shear strain is not reached, excess pore pressures will not be generated and level ground liquefaction is not an issue.

3. Pore water pressure generation is evaluated. If the cyclic shear strains induced are higher than the threshold cyclic shear strain, the cyclic pore water pressure generation is to be evaluated using Figure 3.6-1.

4. A determination shall be made whether pore pressures generated will cause initial liquefaction ($u = \sigma_{vo}$). If the pore pressures generated are equal to the total vertical stress, then liquefaction will occur.

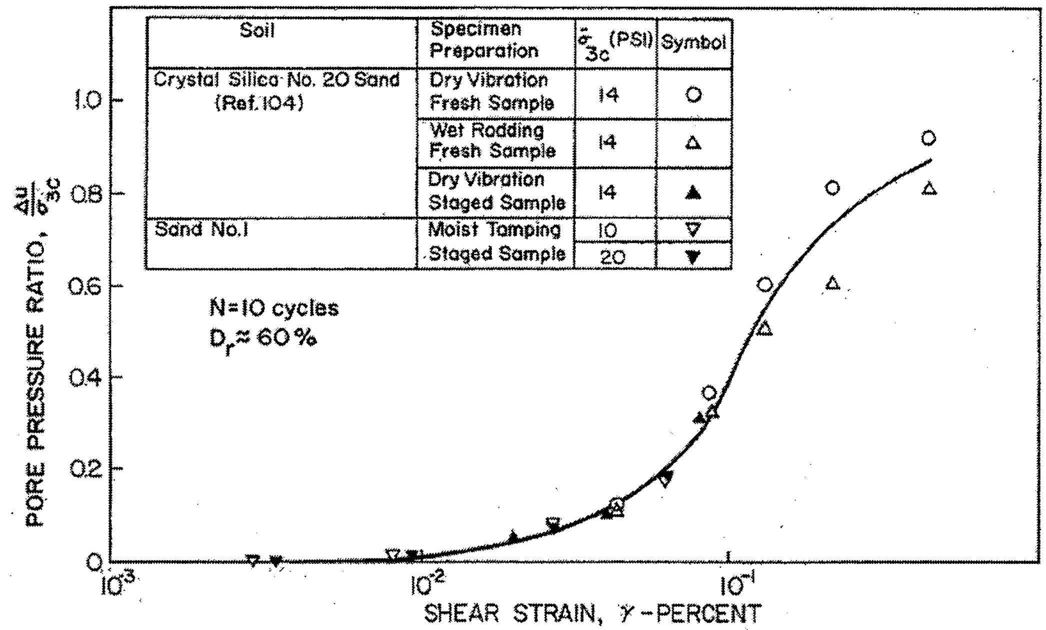


Figure 3.6-2: Measured Pore Pressure in Saturated Sands after 10 Loading Cycles; Strain Controlled Cyclic Triaxial Tests

3.6.2 SHEAR STRESS APPROACH

In this method, horizontal shear stresses generated by the earthquake are compared with the resistance available to prevent liquefaction. The "demand" shear stress is expressed in terms of Cyclic Stress Ratio (CSR); the "capacity" shear stress in terms of a Cyclic Resistance Ratio (CRR). The procedures used here were published by Youd and Idriss, 2001.

$$CSR = 0.65 \bullet \tau_{peak}/\sigma'_{v\ init} \qquad \text{EQN 3.6-1}$$

Where:

τ_{peak} - Peak horizontal sheet stress due to seismic event
$/\sigma'_{v\ init}$ - Initial vertical effective stress

The 0.65 factor represents the average over the time history; the CRR is found from a cone penetration test (CPT), performed as part of the field investigation. A plot of the CRR versus $(N_1)_{60}$, which is the SPT "N" value corrected for 60 percent energy efficiency and for a vertical effective stress of 1 tsf is also required for determining CRR.

It is also necessary to correct for fines content larger than 5%. This is done using the following expression:

$$(N_1)_{60\ corrected} = \alpha + \beta \bullet (N_1)_{60\ uncorrected} \qquad \text{EQN 3.6-2}$$

α:	0.0	$FC \leq 5\%$	β:	0.0	$FC \leq 5\%$
	$e^{1.76 - 190\ FC^{-2}}$	$5\% < FC < 35\%$		$0.99 + 0.001\ FC^{1.5}$	$5\% < FC < 35\%$
	5.0	$FC \geq 35\%$		5.0	$FC \geq 35\%$

The correction for the vertical effective stress is achieved by:

$$C_N = \frac{2.2}{1.2 + \frac{\sigma'_v}{2088}} \le 1.7 \quad \text{EQN 3.6-3}$$

The factor of safety against liquefaction is calculated as:

$$FS = \frac{Capacity}{Demad} = \frac{CRR}{CSR} \cdot MSF \cdot K_\sigma \quad \text{EQN 3.6-4}$$

MSF is a magnitude scaling factor to account for the fact that the magnitude at which the empirical factors were calibrated is 7.5. The formula given by MSF = $10^{2.24} \bullet M^{-2.56}$. K_σ varies between 0.5 and 1.7, as a function of the overburden stress according to charts presented by Youd and Idriss, 2001.

3.6.3 SHEAR WAVE THEORY

In this method, the measured shear wave velocity is corrected for overburden using the following equation, Andrus and Stokoe, 2000:

$$V_{s1} = V_s \cdot \left(\frac{2088}{\sigma'_v}\right)^{0.25} \quad \text{EQN 3.6-5}$$

The CRR can then be determined using Figure 3.6-2.

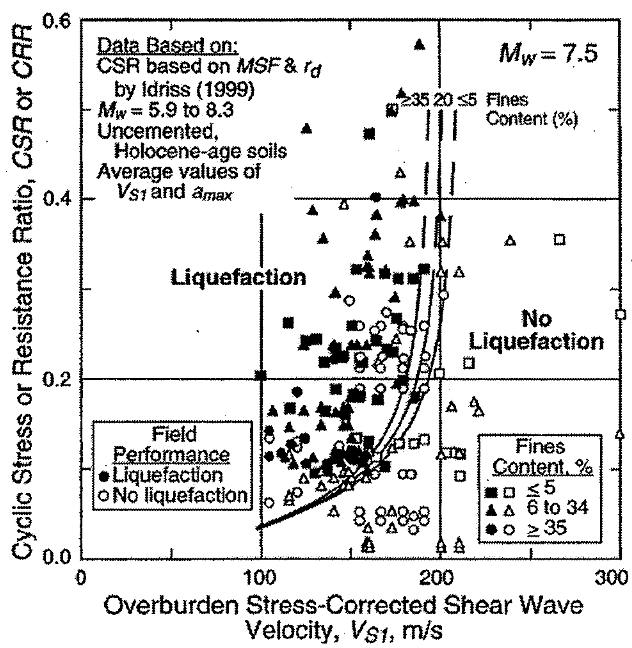


Figure 3.6-2: Simplified Base Curve Recommended for Calculating CRR from SPT Data along with Empirical Liquefaction Data (modified from Seed et al., 1985)

The factor of safety against liquefaction is computed from the EQN 3.6-6

3.6.4 OTHER CONSIDERATIONS

The effects of liquefaction on the design of the foundations as well as structures shall be comprehensively investigated. These effects shall include, but shall not be limited to, the following:

$$FS = \frac{\text{Capacity}}{\text{Demad}} = \frac{CRR}{CSR} \cdot MSF \qquad \text{EQN 3.6-6}$$

- Downdrag and lateral/vertical resistance of deep foundations
- Loss of bearing capacity and settlements of shallow footings
- Post-liquefaction (post-earthquake) stability and deformation of embankments
- Increased lateral pressures and buoyancy forces on walls and underground structures
- Lateral spreading along gentle slopes

If the liquefaction impact analysis yields unacceptable performance of the structures, mitigation measures shall be incorporation into the design.

3.7 DYNAMIC ONE-DIMENSIONAL SETTLEMENT

Dynamic settlement shall be estimated using empirical relationships between volumetric strain, SPT N-values (corrected for overburden), and the factor of safety against liquefaction. For soils above the prelatic surface, the approach developed by Tokimatsu and Seed, 1987, shall be used, which is based on relationships between the volumetric strain and the cyclic shear strain and SPT N-values. The peak shear strain computed from the one-dimensional response analysis and the SPT corrected N-value at that point shall be entered into the Tokimatsu and Seed relations to yield the volumetric strain. For saturated soils beneath the phreatic surface, the methodology proposed by Ishihara, 1993 shall be used; it gives relations for volumetric strain as a function of the factor of safety against liquefaction and the corrected N-value. The total settlement shall then be obtained by integrating these volumetric strains as a function of depth.

4.0 ARCHITECTURE

4.1 INTRODUCTION

This chapter contains general architectural criteria developed for MBTA Silver Line phase III stations. These criteria govern the design of the stations with regard to the discipline of architecture, including formulas, methods and a program to ensure quality of design and efficiency of passenger circulation and safety. This Chapter is intended to promote uniformity of design and standardization of architectural elements and their application throughout the system.

4.2 REFERENCED CODES, STANDARDS, AND GUIDELINES

The following codes and standards are to be adopted and used for quality assurance as well as conformity to local statutes. The active edition of each code and MBTA guideline will establish the actual criteria that must be followed. The specific contents of these codes and standards will not be addressed in this document- refer to current applicable documents as necessary.

- Massachusetts State Building Code 780 CMR, Sixth Edition
- Massachusetts State Elevator Code 524 CMR, 2003
- NFPA 101 Life Safety Code, 1994
- NFPA 130 Standard for Fixed Guideway Transit Systems, 1995
- Massachusetts Architectural Access Board 521 CMR, 2002
- ASME A17.1 Safety Code for Elevators and Escalators, 2000
- MBTA Elevator Design Standard, Rev. 17 September, 2007
- MBTA Guidelines & Standards, 1977
- MBTA Guide to Access, 1990
- APTA Guidelines (American Public Transportation Association), 1981
- ADA Architectural Guidelines (in connection with Uniform Federal Accessibility Standards), 2002
- Transit Capacity and Quality of Service Manual, TCRB Report, 1999
- Pedestrian Planning and Design, Dr. John Fruin, Second Edition 1987

4.3 DESIGN PARAMETERS

The intent of the design parameters is to establish certain absolutes that are inherent to and dictated by the overall system and its technologies. While not all of the parameters are empirical, they can be assigned a certain level of quality that must be met.

4.3.1 QUALITATIVE DESIGN GOALS

4.3.1.1 Efficient Passenger Circulation

- Design vertical circulation elements to meet passenger demand.
- Provide adequate queuing areas at all escalators, stairs, elevators, and fare lines.
- Provide an orderly hierarchy of decision points.
- Avoid cross flows of pedestrian traffic at all escalators, elevators, stairs, and entry-ways.
- Avoid reverse directions en-route to minimize travel time.

4.3.1.2 Design Principles

- Employ functional design combined with simplicity of form and incorporate an expression of structure to create a uniform and comprehensive station design.
- Create multi-volume spaces to enhance passenger experience and orientation.
- Utilize a design that supports ease of station maintenance.

4.3.1.3 Clarity of Circulation

- Provide the most direct route possible from entrance to platform.
- Develop a logical progression of spaces to promote intuitive circulation routes.
- Employ openness and transparency in layout and elements to achieve unified station concept in which destinations are readily discerned.

4.3.2 PHYSICAL (TECHNICAL) PARAMETERS

4.3.2.1 Operational

- Platform Length is established at 220 feet, in order to accommodate a potential conversion to LRV, which would utilize a 3-car vehicle.
- Provide pedestrian transfer connections to all existing adjacent entries and platforms for alternate modes of MBTA transit systems (i.e. Green Line and Orange Line).
- *Level of Service (LOS):* Passenger circulation within the station is evaluated under the quality of service provided to the patrons, a quality which is quantified in LOS guidelines in the Transit Capacity and Quality of Service Manual. For the Silver Line III stations, a LOS "C" has been established as the practical capacity.
- *Service Standard:* The length of time targeted to clear the platform and vertical circulation elements (VCEs) of passengers after the train arrives. The service standard is based on parameters of customer comfort and vehicle boarding safety from the moment passengers alight until they enter the mezzanine/paid lobby and vice-versa. The service standard has been established as one-half the headway time as prescribed in the Silver Line operating plan.

4.3.2.2 Ridership/ Passenger Load

The following criteria have been established for determining passenger loads used to quantify all passenger circulation elements throughout Silver Line III stations:

- All circulation demands shall be derived from current and accurate ridership forecasts as provided by the Regional Travel Model administered by Central Transportation Planning Staff (CTPS). The latest version of CTPS ridership forecasts, made available in Spring 2008, will be the basis for design of Horizontal and Vertical Circulation Elements. The highest volume *peak hour* data (either AM or PM) shall be used at each platform.
- The peak hour data is divided into four 15 minute blocks- in which the actual peak 15 minute period contains a surge factor of 1.5 times the remaining three periods. The distribution of peak hour passenger volume into fifteen minute blocks is 22%-33%-22%-22%.
- The peak (surge) fifteen minute period is then broken down into equal headways as established by the operating plan. The passenger load per vehicle can be derived directly by dividing the number of passengers within the surge 15 minute period by the number of headways.
- This number of passengers per headway, including boardings, alighting, transfers and line volume shall be used to determine level of service requirements as well as life safety/ egress requirements.

4.3.2.3 Alignment

- Side Platforms are to be located outboard of the bus-ways where vehicles operate in normal right-hand side of bus-way. Per the Silver Line Phase 3 design vehicle, passengers exit from the right side of the vehicle only.
- Catenary protection in the form of architectural elements (i.e. glass panels) is required at all areas of potential conflict with pedestrians, including stairways and elevated walkways/mezzanines.
- Station design shall not preclude a system conversion to light rail vehicles (LRV).

4.4 HORIZONTAL CIRCULATION ELEMENTS

.4.1 PLATFORMS

The design of the platform shall support the function of the platform as both a queuing area for passengers waiting for a transit vehicle to arrive and as a circulation area for both departing and arriving passengers. Platform width requirements should be calculated with peak hour passenger volumes.

A side platform layout is based on independent platforms servicing each direction. Each platform includes waiting area in the front (next to curbside) and circulation space in the back (parallel to platform back-wall). Passenger routes to and from the platforms are direct and specific, with the other end of the route being a mezzanine space in a paid zone. A variation of a side platform configuration is a horizontally staggered layout. Regarding platform width, the horizontally staggered layout requires, practically, similar computations to a layout of separated side platforms.

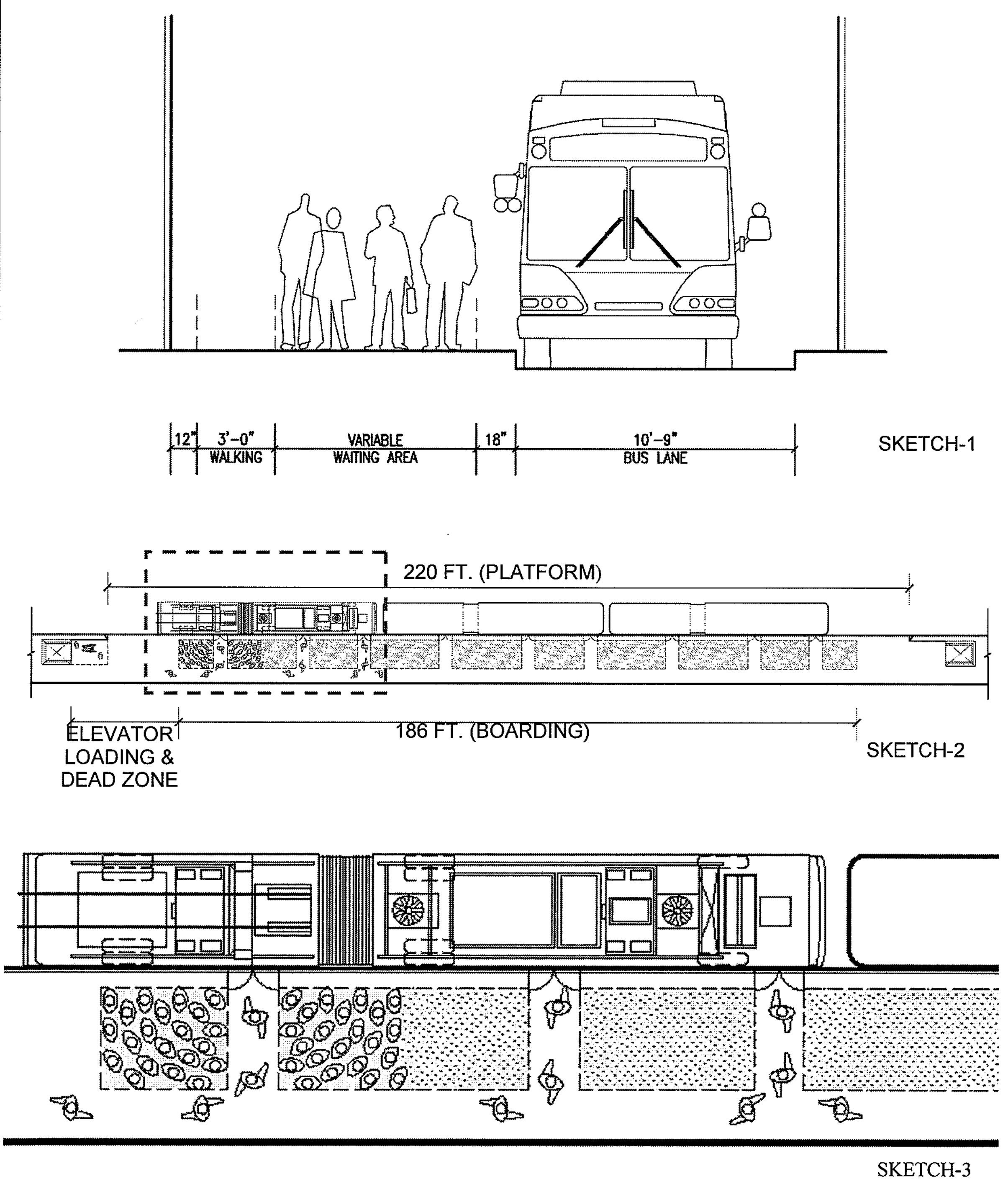
4.4.1.1 Level of Service for Side Platforms

The required platform width (**W**), from platform edge to back wall, is a function of the number of waiting passengers (**P**) to board according to projected ridership and their density while waiting to board the BRT, a density (**D**) established at **D = 7sqf/p** per LOS "C". The actual (net) loading length (**L**) for the 220 ft long platforms is obtained through the following assumptions and requirements:

- Dead Zone: Walking and waiting do not occur evenly over the platform area. Some areas are used primarily for walking (e.g., near entry/exit locations and along the back edge of the platform) while other areas are used primarily for waiting (e.g., loading areas). Areas that are generally not used by passengers are termed "dead areas." These areas are typically present between buses at a bus terminal or in front of or behind a train at a rail terminal. Dead areas should be taken into consideration when choosing the size and configuration of a platform.
- Silver Line III platforms (at 220 feet) will accommodate three 60-foot articulated at the same time. The gross loading length for three platooned 60 foot articulated buses is 186 ft. (This takes into account "dead zones".)
- Exit paths located at each door are considered to be 3 feet wide. Each bus contains three doors resulting in total exit width of 27 feet (9 doors in total).
- The net length of queuing areas **L = 159 ft.** (186 – 27)
- An additional 2-foot wide tactile edge is required along the entire length of the platform and will not be included in the queuing area

The following diagrams illustrate various "zones" within the platform:

Side Platform Width



SILVER LINE III - Design Criteria

- An additional 3-foot wide circulation path is required for movement along the platform.
- An additional 1-foot buffer zone is required along the back wall.

For side platforms, the following formula is used to determine the overall platform width:

$$W = \frac{P \times D}{L} + 2\text{ ft.} + 3\text{ ft.} + 1\text{ ft.}$$

W =	$\frac{P \times D}{L}$	+ 2 ft.	+3 ft.	+1 ft.
Overall platform width		Tactile edge	Circulation for alighting passengers	Buffer zone from platform back-wall

- Minimum clearance: A 6 foot clearance is required from platform edge to obstructions (i.e. columns and station amenities) along the platform proper.

4.4.1.2 Egress

Two exits from the platform proper, remote from one another and either one located within a range of 300 ft. from any point on the platform.

4.4.1.3 Accessibility

- Slope: Longitudinal and cross slopes shall be 0.5% for new stations.
- Width: The minimum platform width to accommodate two handicapped persons, one on a parked wheelchair and the other on a moving wheelchair, is 7'-0".

4.4.2 WALKWAYS

4.4.2.1 Level of Service

The required width (**W**) of walkways is computed at peak conditions, with concurrent occupation of the space by boarding and alighting passenger flows. One direction is considered being the peak direction while the other one is producing minimal reverse-flow demand. The following formula combines peak flow (**F**) (passengers per minute) and LOS "C" density (**D**) established at 10 to 15 p/wf/m (passengers per foot of width per minute).

$$W = \frac{F}{D} + 3\text{ ft.} + 2\text{ ft.}$$

W =	$\frac{F}{D}$	+ 3 ft.	+ 2 ft.
		Circulation for contra-flow	Buffer zones (1 ft on either side)

- The peak flow may be found in the boarding direction, and thus calculated from the ridership data, assuming that passengers arrive evenly to the platform. Or, it may be in the alighting direction, at which time the alighting passengers (**P**) and the service standard (**T**) (the time established as a threshold to clear the platform and the walkways of arriving passengers) combine to produce the alighting flow **F= P/T**.

4.4.2.2 Egress

Exit corridors and ramps shall be a minimum of 5'-8" wide.

4.4.2.3 Accessibility

If the walkway is part of the accessible route, then the minimum width is 6'-0" (two handicapped passengers on wheelchairs crossing each other)

4.4.3 MEZZANINE

The configuration of the station Mezzanine will organize spaces for movement, for queuing and for incidental waiting, in a way that conflicts are minimized and adequate run-off space is provided in front of escalators, elevators and the fare line. Depending on the volume of transfer connections, the mezzanine layout must differentiate the direction to the Unpaid Lobby from platform connections.

4.4.4 FARE LINE

The capacity (**C**) of a fare gate is determined by the minimum time required by each pedestrian to pass through. Type of fare collection system must be established at the time of station design. Based on projected ridership, the number (**N**) of fare gates needed to accommodate the peak flow (**F**) in the peak demand direction will be calculated. Furthermore, at least two gates will need to be added to this number, one for reverse flow and one for the possibility of a malfunctioning unit. At least one of the fare gates must be ADA compliant.

$$\mathbf{N = Round\left(\frac{F}{C}\right) + 2}$$

4.4.5 UNPAID LOBBY

4.4.5.1 Level of Service

The design of the Unpaid Lobby will organize the spaces for movement, for queuing and for incidental waiting of patrons and each of these activities carries a LOS standard with it.

For spaces of movement, an analysis similar to walkways would ensure that the patrons have the comfort and flexibility to enter/exit the Unpaid Lobby without interfering with waiting passengers. The LOS "C" standard is 15p/wf/m.

Queuing spaces will be found around the following elements:

- Doors or stairs/escalators to grade should be able to accommodate the flow of boardings and alightings within the established service standard (**T**).
- Fare line is discussed independently.
- Elevator is discussed in Accessibility
- Fare Vending Machines (FVM), each typically servicing 3-4 p/m, require 5 ft. deep queuing area in front of them at minimum.
- Station Assistant requires a space of 40 sq ft in front, at minimum (for 4 patrons at a density of LOS "C")

Waiting space for those patrons expecting to meet a party, use amenities such as benches, phones, subway maps, etc. will be located aside from the above spatial requirements and designed to convey openness, comfort and quality.

4.4.5.2 Accessibility

In the case of underground stations, such as Boylston and Chinatown, access for disabled persons from street level to the station must be provided with an Unpaid Zone elevator.

4.5 VERTICAL CIRCULATION ELEMENTS

4.5.1 STAIRS

All stairs must comply with MAAB 521 CMR and MSBC 780 CMR and there will be a minimum of two stairs to serve each platform below grade.

4.5.1.1 Level of Service

Due to the reduced role of stairs to supplemental circulation elements based on the presence of escalators, stairs may operate on a LOS "D" density, which assumes 10 to 13 p/wf/m (persons per foot of width per minute) for ascending and descending and 5 sq. ft./person for queuing at top and bottom. A standard stair unit is planned as 5'-9" wide and will have the following characteristics:

- Risers shall be of uniform height 7 inches maximum, closed and with nosing.
- All treads shall be a uniform width of 11 inches minimum.
- Landings shall have a minimum length of 4'-6" and a width equal to the width of the stair.

4.5.1.2 Egress

Number of stairs and their width shall be determined on the basis of NFPA 130 exiting analysis, with minimum width 44 inches.

4.5.1.3 Accessibility

For stairs that are part of the accessible route, an ascending/descending lane of 48 inches minimum clearance between handrails is required.

4.5.2 ESCALATORS

In stations whose depth from the surface is substantial, movement upwards and downwards is primarily served by escalators. The number of escalators is generally determined by the demand for vertical circulation and the quality of the service that the station provides to the passengers. The current specification that the authority maintains, is a nominal 48-inch wide (40-inch clear step) heavy-duty transit escalator with internal drive configurations.

4.5.2.1 Level of Service

- At minimum, escalators must be provided for all vertical movements greater than 12 feet upwards, and 24 ft. downwards.
- The 48-inch wide (40" step) escalator provides a capacity of 70 passengers per minute at speed of 90 feet per minute. To calculate the required queuing area (**A**) for those taking the escalator, the following formula is a function between the projected circulation demand expressed as peak flow (**F**) (passengers per minute) and the density (**D**) under a LOS "C", **D** = 10 sq ft/p (square foot per waiting passenger).

$$\mathbf{A = (F - 70ppm)D}$$

The peak flow may be found in the boarding direction, and thus calculated from the ridership data, assuming that passengers arrive evenly to the platform. Or, it may be in the alighting direction, at which time the alighting passengers (**P**) and the service standard (**T**) (the time established as a threshold to clear the platform and the walkways of arriving passengers) combine to produce the alighting flow **F= P/T**.

- The number (**N**) of escalators required for the 90 percent of peak hour passengers (**P**) to clear or access each station's platform within the service standard is a function of the peak flow (**F**) (passengers per minute) and capacity (**C**) of the standard escalator (70 passengers per minute).

$$N = \text{Round} \quad \frac{F}{C}$$

The peak flow may be found in the boarding direction, and thus calculated from the ridership data, assuming that passengers arrive evenly to the platform. Or, it may be in the alighting direction, at which time the alighting passengers (**P**) and the service standard (**T**) combine to produce the alighting flow **F= P/T**. The remaining 10 percent of these passengers have the option of either waiting more than the service standard to leave the platform, or of using a staircase.

- The escalator run-off distance (for passengers getting off each unit) is 30 ft from the working point of the escalator to an obstruction and 25 feet to another escalator queuing area running in the same direction.

4.5.2.2 Egress

Escalators and stairs are part of the egress route, and as such, their combined widths play an important role in the station evacuation. The Station egress report is a document that sets forth stair design parameters that supplement the egress function of escalator based on code (general-use stairs or emergency stairs).

4.5.3 ELEVATORS

4.5.3.1 Location

- All passenger transfers and surface connections should be able to occur by use of an elevator. In deep stations, it is recommended that one additional elevator per platform is included in the vertical circulation station scheme. A number of transit authorities have recently adopted such course of action in order to ensure a constant accessible service even during periods of elevator stoppage/maintenance.
- A minimum of 7 feet 6 inches clearance is required between hoistway and edge of platform, assuming that the elevator doors do not open towards the platform.
- Preferred location of paid zone elevators serving platforms is at the end of platform.
- Close proximity of all elevators (those within paid zone and unpaid zone) to fare lines is preferred to obtain shortest possible travel distances.
- Unpaid zone: From each accessible station surface entrance to each unpaid lobby.
- Paid zone: From each paid lobby to each platform.

4.5.3.2 Design Features

- Adhere to design and performance standards developed by APTA.
- Type of Drive is dependent on travel height of hoist-way:
  - Direct Acting Hydraulic: travel of up to 40 feet (low-rise, secondary preferred drive)
  - Traction: travel of 40 feet and above (high-rise)
  - MRL Elevator: travel up to 100' (primary preferred drive technology)
- Queuing/discharge: space should be at a minimum of 1.5 times the depth of the car or 10 ft., whichever larger and located so as to not interfere with the main flow of passengers.

- Hoistway and car design should utilize materials/ construction to promote transparency and maximum visibility. Hoistway size will be determined by product manufacturer's specifications.
- Pass through cab configurations with side opening doors are the preferred configuration for elevators. Specific minimum configuration requirements for pass through cab systems are:
  Minimum Cab Width: 60" (1524 mm) wall to wall
  Minimum Cab Depth: 80" (1829 mm) door to door
- Machine room doors: Refer to elevator code for minimum sizing and clearance requirements after consulting manufacturer on selected equipment. Machine room door to be minimum 3'-6" wide for machine access. In certain cases when manufacturers supply large elevator machine units pre-assembled before the installation, a larger door size will be required.
- Machine Room size: A machine room layout showing all the required electrical, HVAC and elevator equipment - using actual equipment sizes - must be developed early in the process by the station designer. The layout must indicate the required code and manufacturer's clearances for each component within the room. Regarding the 7'-0" minimum ceiling height that code requires, the station designer shall increase the ceiling height as necessary for specific equipment installation and necessary maintenance of that equipment to a minimum of 9'-0" in the area surrounding a hydraulic drive unit. Refer to MBTA Elevator Design Standard for MRL Elevator Machine Room requirements.
- Emergency access: Refer to CMR 524 for requirements.
- Provide for stand-by power supply so that elevators can return to a designated landing position during a power outage.

4.5.3.3 Accessibility

- Emergency Medical Service (EMS) gurney (sized as 24"x83") to be accommodated in the minimum cab size.
- Although the minimum elevator door width is 3'-6" for an EMS car, as per several codes and regulations, a 4'-0" wide door opening would allow two lanes of passenger movement in and out of the cab, thus effectively reducing the waiting time.
- Americans with Disabilities Act Architectural Guidelines (ADAAG) compliant for communication and control features.

4.6 STATION ENTRY-WAYS

Station entrances provide the link between the station, the city, and the surrounding streets, and their design must reflect the distinct requirements of each. Entrances must provide convenient access and egress for passengers and fit appropriately within the surrounding urban context and community.

4.6.1 LOCATION

Where space is a factor—as in most urban environments, station entrances should be positioned beyond the public way to preserve space for pedestrian circulation on the public sidewalks. Toward this end, entrances should be located within buildings and in public plazas where possible. Factors influencing the location of entry-ways are:

- The physical constraints of the surrounding structures and streets
- Proximity to high-density land uses and potential trip generators
- The availability and cost of real estate, especially in cases of historic buildings and their landmark status.
- Visibility within the surrounding urban context
- Ease of inter-modal transfer, including bus-routes
- Existing open land use, particularly sidewalks, plazas, and parks
- Pedestrian network and access to destinations
- City of Boston's urban design plans addressing sidewalk congestion and safety in and around the entry-way

4.6.2 SIZE

The station entrance size is largely determined by the number and size of the circulation elements (both vertical and horizontal) located within it, as well as other programmatic requirements. Factors that affect the design of entry-ways are:

- Configuration of the circulation elements that lead to the platform
- The established level of service desired for the entry, and emergency egress requirements for the above configuration
- Weather protection from weather conditions specific to the location
- Spaces for several communication equipment and emergency and security panels as per state regulations and ADAAG

4.6.3 ACCESSIBILITY AND SAFETY

By use of the new automatic fare collection (AFC) equipment, the Authority is offering more entrance options to its patrons in heavily used downtown stations. The fare collection enhancement is paired with the installation of expanded communication and security devices in the entrance lobbies. Both improvements are intended to facilitate passenger movement and orientation in and out of the station. From this perspective, new stations with substantial boardings will not include any exit-only ways. From a life-safety perspective, stations usually provide for a minimum of two separate street exits. The combination of the above suggests that the new Silver Line III stations should provide for a main and at least one secondary entry-way. The entry-ways need to be carefully sized and evaluated as to the portion of passengers expected to use each one during peak demand hours.

- Provide an accessible route from the sidewalk to the station unpaid zone elevator(s)
- Elevator to be located at maximum service areas and to provide the optimum functional connection to the unpaid lobby (i.e. either as part of the entrance proper or further down the street)
- Provisions for fire department access during an emergency
- Safety and security, ease of surveillance, no obstacles or hidden spaces
- Floor area requirements for an unobstructed passenger flow out of the station during an emergency, especially in the presence of entry doors

4.6.4 IDENTIFICATION

- Station identity and visibility at a distance, but at the same time sympathetic to the scale and character of surrounding structures
- Art, signage and lighting characteristic of a portal to public transit
- Use of materials that convey an openness and transparency of the transit environment, as well as durability and ease of maintenance
- For specific signage design standards, refer to MBTA Guidelines and Standards, 1977,Part V - Graphics

4.7 PROGRAM OF NON-PUBLIC SPACES

The following program lists the general station support spaces required for a stand-alone Silver Line III station to function properly. In certain instances, such as at Chinatown Station and Boylston Station, in which the Silver Line station can be seen as an addition, certain rooms may not be required and must be reviewed on a case-by-case basis.

The information in the program is for space planning purposes only. Actual room requirements shall be coordinated between disciplines as necessary.

Table 4.7-1: Station Controller Room

Room Description		Quantity	Size	Egress	Fire Rating
Houses communication equipment associated with fare lines		1 per fare line	8'x8'	1	2hr
Location	Adjacent to fare lines				
Design Criteria	• HVAC – positive pressure • Direct fresh air intake from street level • Supply and return shafts from/to street				

Table 4.7-2: Rest Rooms (Staff)

Room Description		Quantity	Size	Egress	Fire Rating
Semi-private restrooms for employee/emergency use		2	7'x10'	1	2hr
Location	Locate at lobby level				
Design Criteria	• Conform to 521 CMR • Provide hose bib (Source: MBTA Non-Public Space Station Requirements Meeting of 19 Oct 07) • Provide heat (Source: Section 11.2.6 - Heating) • Provide exhaust ventilation shaft/s to street (Source: MBTA Fax of Ancillary Space Design Criteria 09 Nov 07; Item 1 and MBTA Facility Design Preferences; Subway Stations; Mechanical; Item 3.I) • Sinks to be cast iron, not china (Source: MBTA Facility Design Preferences; Subway Stations; Mechanical; Item 3.P)				

Table 4.7-2a: Rest Rooms (Public) (Source: MBTA Non-Public Space Station Requirements Meeting of 19 Oct 07)

Room Description		Quantity	Size	Egress	Fire Rating
Public restrooms for employee/public use		2	7'x10'	1	2hr
Location	Locate at lobby level				
Design Criteria	• Conform to 521 CMR • Provide hose bib (Source: MBTA Non-Public Space Station Requirements Meeting of 19 Oct 07) • Provide anti-vandalism fixtures (Source: MBTA Non-Public Space Station Requirements Meeting of 19 Oct 07) • Avoid the use of ceramic fixtures (Source: MBTA Facility Design Preferences; Subway Stations; Section 15400 – Plumbing Systems; Item 9) • Provide heat (Source: Section 11.2.6 - Heating) • Provide exhaust ventilation shaft/s to street (Source: MBTA Fax of Ancillary Space Design Criteria 09 Nov 07; Item 1 and MBTA Facility Design Preferences; Subway Stations; Mechanical; Item 3.I) • Sinks to be cast iron, not china (Source: MBTA Facility Design Preferences; Subway Stations; Mechanical; Item 3.P)				

Table 4.7-3: Starters Booths

Room Description		Quantity	Size	Egress	Fire Rating
Houses MBTA system monitoring personnel		1 per platform	8'x8'	1	
Location	Locate at end of platform				
Design Criteria	• HVAC – positive pressure				

Table 4.7-4: Communication Room

Room Description		Quantity	Size	Egress	Fire Rating
		1	20' x 20' (Source: MBTA e-mail of 14 Nov 07)	1	2hr
Location	Either end of station at Silver Line level(s)				
Design Criteria	• HVAC – positive pressure • Clean agent fire extinguishing system • Direct fresh air intake from street level • Supply and return shafts from/to street				

Table 4.7-5: Signal Room

Room Description		Quantity	Size	Egress	Fire Rating
		1	16'x16'	1	2hr
Location	Either end of station at Silver Line level(s)				
Design Criteria	• HVAC – positive pressure • Clean agent fire extinguishing system • Direct fresh air intake from street level • Supply and return shafts to/from street				

Table 4.7-6: Storage/ Lamp Room

Room Description		Quantity	Size	Egress	Fire Rating
Storage space		1	12'x18'	1	2hr
Location	Silver Line level				
Design Criteria	• Ventilation (exhaust fan with louver at door) • Provide heat (Source: Section 11.2.6 - Heating)				

Table 4.7-7: Elevator Machine Room

Room Description		Quantity	Size	Egress	Fire Rating
Houses elevator machine equipment		1 per elevator	10'x10'	1	2hr
Location	Adjacent to elevator at lowest level				
Design Criteria	• HVAC • Hydraulic oil heat exchanger & fresh air intake • If elevator machine room is not vented into hoist-way, a 2hr smoke exhaust system to grade is required				

Table 4.7-8: Emergency Tunnel Ventilation Fan Room

Room Description		Quantity	Size	Egress	Fire Rating
Houses emergency tunnel ventilation fan equipment *(room size is based on horizontal side-by-side fan configuration)*		2	40'x60'	2 min	2hr
Location	Locate at both ends of stations				
Design Criteria	• Air transfer openings to tunnel to be located at least 100' from ends of platforms • Provide heat • Monorail at ceiling for rigging fan/ motors • Street level exhaust considerations • Equipment access for damper and actuators at one end of fan plants • Large air ducts required to street level • Ceiling height considerations based on fan configuration • Access for motor and fan blades replacement				

Table 4.7-9: Motor Control Rooms – Emergency Tunnel Ventilation Fans

Room Description		Quantity	Size	Egress	Fire Rating
Houses fan motor control systems		2	12'x20'	2	2hr
Location	One control room required adjacent to each emergency fan room				
Design Criteria	• Positive pressure direct intake from street level • Ventilation (unconditioned) • Supply and return shafts to/from street level				

Table 4.7-10: AC Unit Substations

Room Description		Quantity	Size	Egress	Fire Rating
Houses power equipment for operations & emergency tunnel ventilation fans		2	30'x60'	2	3hr
Location	Locate at both ends of station				
Design Criteria	• Equipment access and replacement • Isolation from break dust • Ventilation (unconditioned) • Positive pressure direct intake from street level • Substation duct banks from street level • Supply and return shafts to/from street level • 14' min. ceiling height • Provide heat (Source: Section 11.2.6 - Heating)				

Table 4.7-11: Battery Room (not needed) - delete

Room Description		Quantity	Size	Egress	Fire Rating
Houses emergency backup power equipment		1	10'x10'	1	2hr
Location	Close proximity to electrical rooms				
Design Criteria	• Continuous exhaust with louver at door • Provide exhaust ventilation shaft/s to street (Source: MBTA Fax of Ancillary Space Design Criteria 09 Nov 07; Item 1)				

Table 4.7-12: Emergency Electrical Rooms

Room Description		Quantity	Size	Egress	Fire Rating
Houses emergency electrical equipment		2	8'x12'	1	2hr
Location	1 room at each Silver Line platform level adjacent to electrical room				
Design Criteria	• Positive pressure – direct fresh air intake from street • Supply and return shafts to/from street • Provide heat (Source: Section 11.2.6 - Heating)				

Table 4.7-13: Electrical Rooms

Room Description		Quantity	Size	Egress	Fire Rating
Houses low voltage panels		2	15'x12'	1	2hr
Location	1 room at each Silver Line platform level				
Design Criteria	• Positive pressure – direct fresh air intake from street • Supply and return shafts to/from street				

Table 4.7-14: Generator Room

Room Description		Quantity	Size	Egress	Fire Rating
Houses emergency generator		1	18'x24'	2	2hr
Location	Either end of station – as beneficial for connection to street utilities or fill point				
Design Criteria	• Supply & exhaust radiator ventilation to street • Provide H & V • Engine exhaust to street level • Possible storage room needed if diesel generator (storage tank, etc) • Contact MBTA insurance carrier FMG for oil/diesel fuel storage tank containment enclosure fire rating, ventilation guidelines, etc.) (Source: MBTA Fax of Ancillary Space Design Criteria 09 Nov 07; Item 3)				

Table 4.7-15: Generator Storage Tank Room

Room Description		Quantity	Size	Egress	Fire Rating
Houses fuel storage tank (660 gallons) for emergency generator		1	10'x10'	1	2hr
Location	Adjacent to or directly above generator room				
Design Criteria	• Fuel/vent lines from street to storage tank • Ventilation (room) • For fuel tank, vents for tank and storage required direct to street • Fill point at street (diesel/oil) • Contact MBTA insurance carrier FMG for oil/diesel fuel storage tank containment enclosure fire rating, ventilation guidelines, etc.) (Source: MBTA Fax of Ancillary Space Design Criteria 09 Nov 07; Item 3)				

Table 4.7-16: Platform Ventilation Fan Rooms

Room Description		Quantity	Size	Egress	Fire Rating
House fans for station ventilation		2	18'x18'	1	2hr
Location	1 fan room located at or near each Silver Line platform				
Design Criteria	• Vents required to pull hot air/bus fumes from platform and vent to street level • Fresh air to be provided by open station design (open stairwells and escalators). • A shaft from street level is required in the event of a new Silver Line station being located beneath or adjacent to, and connecting to, an existing station which would result in air being drawn from another station's platform. • Exhaust ventilation shaft to street level • Verify room size and provide a detailed design criteria for review (and compliance with codes and standards) (Source: MBTA Fax of Ancillary Space Design Criteria 09 Nov 07; Item 2)				

Table 4.7-17: Mechanical Room / Valve Room

Room Description		Quantity	Size	Egress	Fire Rating
Houses fire alarm valves & water meter		1	10'x15'	1	2hr
Location	Locate at main lobby level				
Design Criteria	• Heating and ventilation				

Table 4.7-18: Sewer Ejector Rooms

Room Description		Quantity	Size	Egress	Fire Rating
Houses sewer ejector pump and services for floor drains and porters rooms		2	10'x10'	1	2hr
Location	Locate at both ends of stations at lowest level				
Design Criteria	• Heating and ventilation o Ventilation at ten (10) air changes per hour (Source: MBTA Facility Design Preferences; Subway Stations; Mechanical; Item 3.L) • Provide exhaust ventilation shaft/s to street (Source: MBTA Fax of Ancillary Space Design Criteria 09 Nov 07; Item 1)				

Table 4.7-19: Homeland Security Hub

Room Description		Quantity	Size	Egress	Fire Rating
Houses security monitors with system connections		1	15'x20'	1	2hr
Location	Locate at main lobby level at major key stations				
Design Criteria					

Table 4.7-20: Vendor Storage Room

Room Description		Quantity	Size	Egress	Fire Rating
Location	Locate near head house				
Design Criteria	• Storage room for vendors (Source: MBTA Facility Design Preferences; Subway Stations; Item C. Headhouses)				

Table 4.7-21: Janitor's Closet

Room Description		Quantity	Size	Egress	Fire Rating
Location	Locate near headhouse				
Design Criteria	• Provide slop sink • Sinks to be cast iron, not china (Source: MBTA Facility Design Preferences; Subway Stations; Mechanical; Item 3.P) • Provide ventilation (Source: MBTA Facility Design Preferences; Subway Stations; Mechanical; Item 3.J) • Should be separate from restrooms (Source: MBTA Facility Design Preferences; Section 15400 - Plumbing; Item 1) • Storage room for vendors (Source: MBTA Facility Design Preferences; Subway Stations; Item C. Headhouses)				

Table 4.7-22: Traction Power Substation

Room Description		Quantity	Size	Egress	Fire Rating
Houses power equipment (DC) for the OCS (Source: Section 8.3)		1	65'x65'	2	3hr
Location	Surface (if land area exists) or at existing MBTA facility				
Design Criteria	• 2 floors • 14' min. ceiling height • Ventilation fans or air conditioning and unit heaters (Source: Section 8.6.6)				

Table 4.7-23: Break Room(s) (Porter's Room)

Room Description		Quantity	Size	Egress	Fire Rating
For drivers (Source: MBTA e-mails 12 Nov 07 & 14 Nov 07); also for general storage at portal area (Source: MBTA Non-Public Space Station Requirements Meeting of 19 Oct 07)		1	TBD	TBD	TBD
Location	TBD				
Design Criteria	• HVAC • Conduit & wiring from communications room for telephones, data and video • Include bathroom (if possible) • Include replacement/used lamp storage (Source: MBTA e-mail of 22 Oct 07) • Storage for ice removal equipment, sand, other maintenance items at portal (Source: MBTA Non-Public Space Station Requirements Meeting of 19 Oct 07)				

5.0 ELECTRICAL SYSTEMS

5.1 INTRODUCTION

The purpose of this section is to summarize the codes and standards, and standard design criteria and practices that will be used during the project. The general electrical design defined herein form the basis of the design for the electrical components and systems of the project. More specific design information will be developed during detailed design to support equipment and other discipline designs. It is not the intent of this section to present the detailed design information for each component and system, but rather to summarize the codes, standards, and general criteria that will be used.

5.2 STANDARDS, CODES AND GUIDELINES

The design and specification of all work shall be in accordance with all applicable laws and regulations of the MBTA, the State of Massachusetts, and applicable codes and ordinances. A listing of the codes and industry standards to be used in design and construction follows:

- National Electric Code (NEC)
- Massachusetts Electrical Code (MNESC)
- National Electrical Safety Code (NESC)
- Massachusetts Building Code
- American National Standards Institute (ANSI)
- National Electrical Manufacturers Association (NEMA)
- Institute of Electrical and Electronic Engineers (IEEE)
- Insulated Cable Engineers Association (ICEA)
- National Fire Protection Association (NFPA)
- Underwriters Laboratories (UL)
- Illuminating Engineering Society (IES)
- Occupational Safety and Health Act (OSHA)
- National Association of Corrosion Engineers (NACE)

Particular references shall be made to the following sections of NFPA

- NFPA 70 National Electrical Code
- NFPA 72 Fire Alarm and Security Systems
- NFPA 101 Life Safety
- NFPA 110 Standards for Emergency and Standby Power Systems
- NFPA 130 Fixed Guideway Transit Systems

In addition to the above codes and standards, the design of the electrical system will comply with the regulations imposed by the MBTA, NSTAR Electric, City of Boston and the Commonwealth of Massachusetts.

Also the following specific standards will be utilized:

- Cable, Low Voltage Power, Control and Instrument
- ASTM B-3 & B-8 –Annealed copper wire for Electrical Purposes
- ICEA S-68-516, NEMA WC-8 –Ethylene-Propylene-Rubber-Insulated Wire and Cable for the transmission and distribution of electrical code
- NFPA 258 –Standard Test Method or Measuring the Smoke
- ANSI/UL 44-Safety for Rubber Insulated Wires and Cable
- UL Standard 1424 Thermoset-Insulated Wires and Cables

- UL Standard 1685-Vertical –Tray Fire Propagation and Smoke Release Test for Electrical and Optical –Fiber Cables
- MBTA Wire and Cable Specifications as found in Technical Appendix TA-1
- ASQC Standard C11968
- MBTA Specification S-104 C
- MBTA Standard Cable Specification No. S114-B
- MBTA Specification C-65

- Cable, Medium Voltage Power
- ICEA Ethylene Propylene Rubber Insulated Shielded Power Cables, Rated 5 to 69 kV
- ASTM B8 –Concentric Lay-Stranded Copper Conductors, Hard, Medium-Hard, or Soft
- ASTM B3-Bare Soft or Annealed Copper Wire for Electrical Purposes
- ICEA S-66-524-Cross Linked-Thermosetting, Polyethylene-Insulated Wire and Cable
- ICEA S-68-516-Ozone-Resistant Ethylene-Propylene Rubber Insulation for Power Cable
- ICEA S-19-81, NEMA WC3 Rubber Insulated Wire and Cable
- MBTA Specification P-148-15 KV 1/C Cables
- MBTA Specification P1CN30-15KV 3/C Cables

- Cable Tray
- Nema GP0-2 Cable Tray Systems
- ASTM D1532-67T

- Circuit Breakers, High Voltage
- ANSI/IEEE C37.04-Rating Structure for AC high voltage circuit breakers
- AMSI/ C37.06-Preferred Ratings and related required capabilities for AC High Voltage Circuit Breakers
- ANSI / IEEE C37.09 Test Procedure for AC High Voltage Circuit Breakers
- ANSI/IEEE C37.010 Application Guide for AC High Voltage Circuit Breakers
- ASNI C37.11-Requirements for Electrical Control for AC High Voltage Circuit Breakers

- Conduit
- UL 6, ANSI C80.1 Rigid Steel Conduit
- UL 514 ANSI C80.4 All fittings
- UL 1684 FRE (Fiberglass reinforced epoxy) Conduit
- UL 886-Hazardous Area Fittings
- UL 360-Flexible Liquid –tight Conduit
- MBTA Standard Specification P-138E

- Distribution Panels
- NEMA AB1-Molded Case Circuit Breakers
- NEMA PB1-Panelboards
- UL 50-Electrical Cabinets and Boxes
- UL 67-Panelboards
- NEMA ICS –Industrial Controls and Systems
- NEMA KSI-Enclosed Switches

- Grounding
- ASTM B8-Specifications for Concentric –Lay Stranded Copper Conductors
- NEC-National Electric Code
- NEMA CC-1-Electrical Power connectors for substations
- IEEE 80—IEEE Guide for safety in AC substation grounding
- UL 467-Quality assurance
- UL 486 A and UL 486 B-Bonding and grounding requirements
- IEEE 81-Two point test method

- Lighting Fixtures
- NFPA 101 / UL924 Compliance for visibility and luminance requirements for exit signs
- NEMA FA1-Outdoor Floodlighting Equipment
- NEMA LE1-Fluorescent Luminaries
- UL 57- Standard for Safety, Electric Lighting Fixtures
- UL 924-Standard for Safety, Emergency Lighting Equipment
- ANSI/IEEE C62.11-Surge Arresters for AC Power Circuits

- Secondary Unit Substations
- ANSI C37.13 Low Voltage AC Power Circuit Breakers
- ANSI C37.16 Preferred Ratings Requirements and Application Recommendation
- ANSI C37.35 Guide for the Application, Installation, Operation and Maintenance of High Voltage Air Disconnecting and Load Interrupted Switches
- ANSI C37.17 Standard for trip devices for AC and General purpose DC Low-Voltage power circuit breakers
- ANSI C37.20.1 Switchgear Assemblies
- NEMA CC-1-Electrical Power Connectors for Substations

- Motor Control Centers
- NEMA ST-20-Dry Type Transformers for NEMA General Purpose Applications
- NEMA AB-1-Molded Case Circuit Breakers
- UL 845 Motor Control Centers
- NEMA ICS-1 General Standards for Industrial Controls and Systems

- Motors, Low Voltage
- NEMA MG1-Motors and Generators
- AFMBA 9/ANSI B3.15-Antifriction Bearing Manufacturer Association
- NEMA MG13-Frame Assignment for AC HP Induction Motors
- Transformer, Dry-Type
- ANSI U1-General Requirements for Dry-Type and Power Transformers
- NEMA ST20-Dry-Type Transformers for General Applications
- UL 506 –Standard for Safety, Specialty Transformers

Other recognized standard will be utilized as required to serve as design, fabrication, and construction guidelines when not in conflict with the above listed standards.

The codes and industry standards used for design, fabrication, and construction will be the codes and standards, including all addenda, in effect as stated in equipment and construction purchase or contract documents.

5.3 ELECTRICAL DESIGN CRITERIA

5.3.1 UNIT SUBSTATION

The Unit Substation shall be built to MBTA standards. The substations shall be located at each station and supply the loads for each station and a portion of the Tunnels. The following items shall be considered the general criteria for the Unit Substation:

- General Criteria:
- Unit substation shall serve the associated fan plants and jet fans
- Secondary sections should have full draw-out capabilities to allow maintenance of circuit breakers without shutdown of systems.

- The main-tie to main system should be auto selective so that a failure of one transformer will automatically signal opening of the associated main breaker and closing the tie breaker to allow operation of all loads from one transformer during emergency condition.
- Transformer sizing should be based on a maximum of 10% voltage drop during motor start-up, assuming all fan plants are on line except one that is starting.
- Services –two primary medium 13.8 kV services
- Enclosure- Nema 3R, gasketed
- Communications-shall be wired for MBTA SCADA system
- Seismic requirements -of BOCA for Zone 2A application
- Sound level-shall not exceed ANSI C89.2 and NEMA ST-20
- Environment –designed for operation in 0- 40 degrees C ambient temperature
- Phase -3 phase
- Wire – 4wire and Ground
- Ground- copper ground bus shall extend the length of the switchgear
- High Voltage Bus and Ground Bus- hard temper, per ASTM B187

- Load Break Switch
- Nominal three phase rating of associated switchgear- 750mva
- Rated maximum voltage -15 kV
- Basic Impulse Level -95 kV
- Contact Interrupt Rating, minimum -600A

- Medium Voltage Transformers
- Dry Type epoxy cast coil
- Insulation Class-220 degree C
- Cooling System- IEEE Standard C57.12.01, Class AA/Fused
- Insulation Temperature Rise: 80 degree C maximum rise above 40 degree C
- High Temperature Alarm
- High Voltage Surge arresters -15kv class, per NEMA Standard LA 1
- Windings- Two winding type

- Low Voltage Switchgear Section
- All breakers shall be 600 volt rated
- Main and Tie Circuit Breakers shall be 3 pole, draw out power circuit breaker
- Circuit Breakers shall be equipped with solid state tripping devices.
- Circuit Breakers shall be UL listed
- Provide undervoltage, phase sequence, transformer thermal relay and lockout relay.
- Continuous current not less than the full load current (FA rating) of the transformer to which it is connected with 100 percent rated neutral.
- Bus system minimum ANSI 4-cycle short-circuit to withstand rating of 100,000 amperes symmetrical.
- System shall interconnection for automatic closing and opening main/tie breakers

The main switchgear shall be metal enclosed and equipped with draw-out type circuit breakers on the main incoming service.

All circuit breakers shall be electrically operated.

Space heaters shall be provided in each cubicle compartment.

Space shall be allocated for provision of future expansion.

The switchgear lineup shall be 480/277 Volts, 60 Hertz with ground bus.

The switchgear shall be sized for 25% spare capacity above estimated peak demand load.

All circuit breakers shall be equipped with electronic trip units.

Ground fault protection of the main incoming service feeder shall be provided, if necessary, in accordance with the NEC.

The integrated protection of the switchgear shall be a fully rated selectively coordinated system, i.e., the circuit breaker closest to the fault will trip first, thus isolating the faulty circuit.

- Low Voltage Transformers

- The transformers shall be standard dry-type, 60 Hertz, ventilated, with drip-proof enclosure.
- Primary full capacity taps shall be provided.
- The maximum average sound level shall be in accordance with NEMA ST-20.
- The transformers shall be constructed in accordance with NEMA, ANSI, UL, and IEEE standards.
- Transformers shall be equipped with vibration dampening mounts.
- Primary and secondary conductors shall be installed in flexible conduit at transformer locations.
- Transformers shall be mounted away from corners of walls or ceilings, thereby minimizing the potential for sound transmission. Otherwise, use sound absorbing material on walls and ceilings to eliminate sound reflection.

- Panelboards

- Panelboards shall be rated for industrial application.
- All circuit breakers shall be bolt-on type.
- All panelboards shall be designed with 25% spare capacity above estimated demand load. Spare breakers shall be provided.
- Circuit breakers shall be industrial type.
- Panelboards shall be selected for a particular NEMA designation based on application.
- All panelboards shall have typed circuit directories prepared by construction personnel subsequent to termination of wiring.

5.3.2 GENERAL MOTOR DESIGN CRITERIA

These paragraphs outline basic motor design guide parameters for selection and purchase of electric motors.

The following design parameters shall be considered:

- Motor Manufacturer
- Environment, including special enclosure requirements
- Voltage, frequency, and phases
- Running and stating requirements, limitations and duty cycle
- Motor type (synchronous, induction, dc, etc) and construction
- Power factor
- Service factor
- Speed and direction of rotation
- Insulation
- Bearing construction, rating life of rolling elements, and external
- Ambient noise level
- Termination provisions for power, grounding and accessories
- Installation, testing and maintenance requirements
- Special features (shaft grounding, temperature and vibration monitoring)
- Motor space heater requirements
-

<u>Safety Consideration for Motors</u>- The motors shall adhere to the OSHA personnel protection requirements. Belt guards shall be specified for personnel safety and guard screens will be provided over motor enclosure openings that would allow direct access to rotating parts. All motors shall be adequately grounded. Motors located in hazardous areas shall meet all applicable regulatory requirements and be UL labeled.

<u>Electrical Design Criteria Special Application Motors</u>- Special requirements for individual motors and specifications for special application motors will be included in individual specification technical sections.

- **Rating** – Motors shall be selected to permit the connected load to develop its specified output continuously without encroaching on the service factor under normal operating conditions. Motors will be designed for full voltage starting and frequent starting where required and will be suitable for continuous duty in specified ambient conditions.
- **Temperature Considerations**-Integral horsepower motors will be designed for an ambient temperature of 40 degree C. Motors located in areas where the ambient temperature exceeds 40 degree C will be designed for that ambient condition.
- **Windings and Insulation**- All motors shall be assumed to be NEMA Class M that exhibit high in-rush characteristics during starting. All insulated stator winding conductors and would rotor motor secondary windings will be copper. Where required, the windings will be treated with a resilient, abrasion resistant material.
- **Overspeeds**-The squirrel cage and wound rotor induction motors, will be so constructed that in an emergency of short duration, they will withstand, without mechanical injury, overspeeds above synchronous speed in accordance with NEMA MG1-12.48
- **Space Heaters**-if required, will be sized as required to maintain the motor internal temperature above the dew point when the motor is idle. Motor space heaters will not cause winding temperature to exceed rated limiting values or cause thermal protective device over temperature indication when the motor is not energized. In general, all motors 200 horsepower (hp) or larger will have 120 volt single-phase, 60 hertz, space heaters.
- **Nameplates**- All motor nameplate data will conform to NEMA MG1-20.60 requirements.
- **Environment**-The location of individual motors within the plant will determine ambient temperature, corrosive environment, hazardous environment and humidity to be experience by the motors.
-

5.3.2.1 Motor Control Centers/ Motor Starters

In general, circuit breaker combination starters in a motor control center construction shall be used for the 480-volt motors. However, individually mounted circuit breaker combination starters may be used where practicable. Starters shall be magnetic, full-voltage start, single-speed and non-reversing, except where the equipment characteristics or power company limitations require other types. Each starter shall be equipped with a 120-volt control transformer and three thermal overload relays. In general, enclosures shall be NEMA Type 12, except where environmental conditions make other types more suitable. Refer to “Mechanical,” of this manual for specific requirements. Control centers shall be mounted on raised concrete steel sills located in clean, dry locations which are not subject to flooding. Reduced voltage starting of the closed transition (auto transformer type) type shall be used on all motors whose in-rush is excessive.

5.3.2.2 Full-Voltage Starters

A squirrel cage motor draws high starting current (inrush) and produces high starting torque when started at full voltage. These values can differ based on the different motor designs, the typical NEMA Design B motor, the inrush will be approximately 600 percent of the motor full load amperage (FLA) and the starting torque will be approximately 150 percent.

Table 5-1: 480 VOLT 3 PHASE MOTOR BRANCH CIRCUIT REQUIREMENTS

Motor HP	Motor FLA	OCPD	OCPD	SWITCH SIZE	FUSE SIZE	STARTER NEMA SIZE	BRANCH CIRCUIT REQUIREMENTS
		C/B	FUSE				
½	1.1	15	15	30	15	00	¾" C W/3#12,1#12 G
¾	1.6	15	15	30	15	00	¾" C W/3#12,1#12 G
1	2.1	15	15	30	15	00	¾" C W/3#12,1#12 G
1 ½	3	15	15	30	15	00	¾" C W/3#12,1#12 G
2	3.4	15	15	30	15	0	¾" C W/3#12,1#12 G
3	4.8	15	15	30	15	0	¾" C W/3#12,1#12 G
5	7.6	20	15	30	15	1	¾" C W/3#12,1#12 G
7 ½	11	25	20	30	20	1	¾" C W/3#10,1#10 G
10	14	35	25	30	25	2	¾" C W/3#10,1#10 G
15	21	50	35	60	35	2	¾" C W/3#10,1#10 G
20	27	70	45	60	45	2	1" C W/3#8,1#8 G
25	34	80	60	60	60	3	1" C W/3#6,1#8 G
30	40	100	70	100	70	3	1" C W/3#6,1#8 G
40	52	125	90	100	90	3	1 ¼" C W/3#4,1#6 G
50	65	150	110	200	110	4	1 ¼" C W/3#3,1#6 G
60	77	200	125	200	125	4	2" C W/3#1,1#6 G
75	96	250	170	200	170	4	2" C W/3#1/0,1#4 G
100	124	300	200	200	200	5	2" C W/3#3/0,1#4 G
125	156	400	275	400	275	5	2 1/2"CW/3#4/0,1#3G
150	180	450	300	400	300	5	3"CW/3#300MCM,1#2G
200	240	600	400	400	400	5	3 1/2"CW/3#500MCM,1#1G
250	302	750	500	600	500	6	2 sets of 2 ½"c w/3#4/0, 1#1/0
300	361	900	600	600	600	6	2 sets of 3"c w/3#300mcm, 1#2/0 G
350	414	1000	700	800	700	-	2 sets of 3"c w/3#350mcm, 1#2/0 G
400	477	1200	800	800	800	-	2 sets of 3.5"c w/3#500mcm, 1#3/0 G
450	515	1200	900	1200	900	-	2 sets of 4"c w/3#600mcm, 1#3/0 G

5.3.2.3 Reduced Voltage Starters

When a motor is started at reduced voltage, the current at the motor terminals is reduced in direct proportion to the voltage reduction, whereas the torque is reduced by the square of the voltage reduction. If the typical Nema B motor is started at 70 percent of line voltage, the starting current would be 70 percent of the full-voltage (i.e. .70 x 600% =420% FLA). The torque would then be (.70 X .70) or 49 percent of the normal starting torque (i.e.; .49 x 150% = 74% full voltage torque.

Table 5-2: Reduced-Voltage Starter Selection Table

Application	Need: Smooth Acceleration	Need: Minimum Line Current	Comments
High Inertial Loading	1. Solid State 2. Autotransformer 3. Primary Resistor 4. Wye Delta 5. Part Winding	1. Autotransformer 2. Solid State 3. Wye Delta 4. Part Winding	
Long Acceleration Time	1. Solid State 2. Wye Delta 3. Autotransformer 4. Primary Resistor	1. Solid State 2. Wye Delta 3. Autotransformer 4. Primary Resistor	-acceleration greater than 5 sec Requires non –std resistors -part winding not suitable less than 2 sec
Frequent Starting	1. Solid State 2. Wye Delta 3. Primary Resistor 4. Autotransformer	1. Solid State 2. Wye Delta 3. Primary Resistor 4. Autotransformer	-part winding is unsuitable for frequent starts
Flexibility in Selecting Starter Characteristics	1. Solid State 2. Autotransformer 3. Primary Resistor 4. Part Winding	1. Solid State 2. Autotransformer 3. Primary Resistor 4. Part Winding	-primary resistor, resistor change required -starting concern for wye-delta starters

5.3.3 POWER AND CONTROL WIRING

Medium Voltage Cable- All 13.8 kV system cable shall meet or exceed MBTA specification requirements. This should be in strict conformance with the latest MBTA standard specification section P-73E and Specification P-148.

- General Criteria:
- Conductors shall be stranded copper construction with 15 kV rated insulation
- Conductors shall be provided with an insulating level of 133 percent
- Cables installed underground in duct and manhole system shall be 3/C impregnated paper insulated, lead covered (PILC), PVC jacketed cable
- Cables installed in panels, stations or other structures shall be ethylene propylene rubber (EPR) insulated, PVC jacketed cable.
- EPR cables shall terminated in stress cones
- PILC cable shall be terminated in pot heads
- All medium voltage cable test shall include, but not limited to; 1)Continuity test 2)Insulation resistance test 3) High potential test
- Conductor shall be Class B Copper
- Shielding Copper tape, helically applied over extruded semiconducting insulation screen with 12.5 percent minimum overlap.

Low Voltage Conductors (600 volts and less) - In general conductors for this project shall conform to NFPA 130, Standard for Fixed Guideway Transit and Passenger Rail Systems. All general wire and cable shall be stranded copper, RHH-RHW rated (heat and moisture resistant) flame retardant and color-coded as follows to distinguish phases and voltage:

- 120/208 or 120/240 Volt Systems
- Phase A-Black

- Phase B-Blue
- Phase C-Red
- Neutral-White

- 277/480 Volt Systems
- Phase A-Orange
- Phase B-Yellow
- Phase C-Brown
- Neutral –Off-White

- Ground wire shall be colored green
- Wiring (except traction power) –shall be capable being subject to temperatures up to 932 F for one hour and shall not support combustion under the same temperature condition.
- All conductors shall be insulated
- Insulations no lower than 194 F degrees
- Cable shall meet UL 1581, section 1160 (Low Smoke)
- Cable shall meet ASTM E 662
- Cable shall meet UL 1685
- Conductors (except radio antennas) shall be enclosed in armor sheaths, conduits, or enclosed raceways, boxes, and cabinets except in ancillary areas or other nonpublic areas.
- Conductors in conduits or raceways shall be permitted to be embedded in concrete or electrical duct banks.
- Conductors for emergency lighting and communication shall be protected from physical damage and fire 1) embedment/encasement 2) routing of such conductors external to the interior underground portions of the transit system facilities.
- All control wires shall be multi-stranded copper. No. 12 awg size minimum.

Miscellaneous / Special Cable - If other types and construction of cable are required as design progresses, they will be designated and routed as required. The special cable will include cable supplied with equipment, prefabricated cable, coaxial cable, communication cable etc. This cable will normally be supplied by a particular supplier.

- Testing Requirements
-

Pre-operational tests will be performed on insulated conductors after installation

1. Insulated conductors with insulation rated 5,000 volts and above will be given a field dc insulation test after installation as specified in ICEA Standards S-68-516 and S-66-524.

2. Low voltage cables will be either insulation resistance tested prior to connecting cables to equipment or functionally tested (at equipment operation voltage) as part of the checkouts of the equipment system.

3. All cable / wire shall conform to MBTA standards.

- Installation

Cable installation will be in accordance with the following general rules

1. Cables will be routed as indicated in a circuit list or on the drawings.

2. The pulling tension of cable will not exceed the maximum tension recommended by the cable supplier, and the pulling tension in pounds at a bend will not exceed the cable supplier's recommendations for sidewall pressures. Minimum bend radii shall not exceed the supplier's recommendations.

3. Care will be exercised during the placement of all cable to prevent tension and bending conditions in violation of the supplier's recommendation.

4. All cable supports and securing devices will have bearing surfaces located parallel to the surfaces of the cable sheath and will be installed to provide adequate support without deformation of the cable jackets or insulation.

5. Nylon ties will be used to neatly lace together conductors entering panelboards, control panels and similar locations after the conductors have emerged from their supporting raceway and before they are attached to terminals.

6. The electrical contractor will identify both ends of all circuits.

7. All spare conductors of a multi-conductor cable will be left at their maximum length for possible replacement of any conductor in the cable. Each spare conductor will be neatly coiled and taped to the conductors being used.

8. In addition to the above requirements, cables will be installed in accordance with supplier's and MBTA requirements and recommendations.

5.3.4 GENERAL ENGINEERING CONSIDERATIONS

The following general design criteria shall be followed in the design of electrical systems:

1. Panelboards shall be designed with 5% spares and 20% breaker spaces for future loads as a minimum.

2. Feeder and bus capacity shall include 25% of estimated initial demand for future loading.

3. Molded case circuit breakers, in panelboards fed from switchgear shall be selected for the required interrupting capacity.

4. Provide expansion joints in long runs of conduit and where crossing all expansion joints.

5. Provide for protection from lightning and switching surges.

6. Guide for use in calculating maximum demands:

Table 5-3 list the Demand factors:

Table 5-3: Demand Factors

SERVICE	DEMAND FACTORS
Lighting and Signs	100% of Connected Load
Emergency Lighting	100% of Connected Load
Escalators	80% of Connected Load
Elevators	50% of Connected Load
Ventilation Equipment	100% of Connected Load
AC Equipment	100% of Connected Load
Heating	0% if
Convenience Outlets	1.5 Amps per Duplex Receptacle
Drainage Pumps and Ejectors	70% of Connected Load
Bus Control Equipment	70% of Connected Load
Communications Equipment	80% of Connected Load

5.4 SERVICE TO FACILITIES

5.4.1 PASSENGER STATIONS

The normal electrical service to each passenger station will be supplied from the MBTA 15kV system, which will be connected to a Double Ended Substation with the necessary switches and distribution breakers that will provide power for Station and Tunnel. The Proposed Substations at Chinatown and Boylston stations shall be supplied by two 15 kV feeders .Each 15 kV feeder cable shall be sized to supply the entire station electrical load including operation of all tunnel smoke ventilation fans. The failure of one 15 kV feeders, or its removal from service for maintenance or testing, will not diminish the capability of the electric service at each station to supply full loads.

In addition, standby generators shall be located at each Station for Emergency and Standby power requirements.

5.4.2 ELECTRICAL AND AUXILIARY ROOMS

The Electrical Rooms shall be designed per the Massachusetts Building Code and National Electrical Code Fire Resistant Ratings. The rooms shall be sized to meet the necessary requirements for installation, operation, maintenance, egress purposes, and spare capacity for both design and future requirements.

Table 5-4 is a breakdown on the electrical rooms / closets area requirements for a typical MBTA station arrangement.

Table 5-4: Electrical Rooms/Closets Area Requirements

Area Designation	Quantity	Size	Rating	Notes
AC Unit Substation Room Components (Typical) -2 Dry Cast Transformers -6 Medium Voltage Switches -10 Distribution Breakers	1	30 x 80	3 hr	-No Fire Protection System required-only Fire Alarm System (Notification and Signal) Only. -HV system Electric-positive pressure system. -Minimum two exits -Minimum clearance for removal of transformers and switchgear (10ft x 12ft) typical -2500 kva -Weight >25,000 lbs -Light Level -50 fc-70 fc -Emergency Lighting -Dedicated Phone line. -NEC clearances around and above switchgear. -6ft
Emergency/Standby Generator Room	1	24ft x 18ft	2 hr	-No Fire Protection System required-only Fire Alarm System (Notification and Signal) Only. -HV system Electric-positive pressure system. (Positive ventilation for Engine batteries -Light Level 50 fc -70 fc -Emergency Lighting -Dedicated Phone Line -Provisions for containment/storage system if diesel fuel. -Critical Silencer
Communication Room	1	16 x 16	2 hr	-Inert Gas System-similar to FM200 -HV system Electric-positive pressure system. -Light Level 50 fc -70 fc -Emergency Lighting
Signal Room	1	16 x 16	2 hr	Inert Gas System-similar to FM200 -HV system Electric-positive pressure system. -Light Level 50 fc -70 fc -Emergency Lighting
Emergency Electrical Room / Emergency Electrical Closet	2 2	12 x 18 10 x 10	2 hr 2hr	No Fire Protection System required-only Fire Alarm System (Notification and Signal) Only. -HV system Electric-positive pressure system. -Light Level 50 fc -70 fc -Emergency Lighting -Room -2Hour Rated -NEC clearances 3ft in front, below and above electrical panels. -6ft
Electrical Room Electrical Closet	2 2	20 x 18 10 x 10	2 hr 2 hr	No Fire Protection System required-only Fire Alarm System (Notification and Signal) Only. -HV system Electric-positive pressure system. -Light Level 50 fc -70 fc -NEC clearances 3 ft front, 6ft below and above

5.4.2.1 Additional Electrical Room Design Criteria Notes:

- The size, weight, and penetrations required for the electrical equipment shall be coordinated with the architect and structural engineer.
- Dry Type Transformers Installed Indoors- 112.5 Kva or less shall have a 12 inch separation from combustible material unless separated from combustible material by fire resistant, heat insulated barrier.
- Dry Type Transformers Installed Indoors- Over 112.5 Kva shall be installed in a transformer room of fire resistant construction. Exceptions, 1) Class 155 or higher insulation systems and separated from combustible material by a fire-resistant, heat-insulating barrier or by not less than 6ft horizontal

and 12ft horizontal. 2) Class 155 or higher insulation system and completely enclosed except for ventilating openings.

- The penetrations shall be sealed with UL rated material and the material shall meet Room Hour ratings.
- Layout of electrical distribution equipment and egress doors shall be in accordance with the NEC, Article 110.
- Seismic calculations shall be provided for all Electrical Equipment connected to walls and ceilings.

5.4.3 CLASSIFICATION OF ELECTRICAL LOADS

The loads for the Silver Line shall be identified as normal and emergency loads. The power interruption on emergency loads shall be limited to the normal transfer time of automatic transfer equipment. The Silver Line Phase III shall receive power from a Unit Substation which shall be installed at each Station. The Unit Substation shall be supplied by two 15kV Feeders per Substation. In the event of loss of power of one of the feeders, the other feeder shall supply power to the Normal Loads. In the event of loss of power on both feeders, the Generator shall supply power to the loads classified as Emergency Loads. Nonessential loads will not affect safety and system operation if power is interrupted for short periods of time, these loads do not require a back up power source. (See Table 5-5)

Table 5-5: Type of Load Power Source and Requirements

Type of Load	Load	Power Requirements	Power Source
Normal/Emergency	Tunnel Lighting	480 volt, 3ph delta	480/277V-Substation Electrical Room / Emergency Generator
Normal/ Emergency	Elevators / Supervisory Panel	480 volt, 3ph	480V-Substation –Electric Room / Emergency Generator
Normal	Escalators	480 volt, 3ph	480V-Substation-Electric Room
Normal	Electric Heating / Air Conditioning	480 volt, 3ph	480/277-Substation-Electric Room
Normal/Emergency	Signals& Communication	480 volt/120, 3ph, transformer at signal com room	480/277V/-Substation –Electric Room
Normal	Ventilation Fans	480 volt, 3ph	480 V Motor Control Center
Normal	Stormwater Pumps	480 volt, 3ph	480 V Motor Control Center
Normal /Emergency	Low Point Pump Station	480 volt, 3phase & 600 volt dc	480 V Motor Control Center 600 V DC system
Normal/Emergency	Station and Egress Lighting	277 Volt and 120 Volt, 1ph	480/ 277 V & 208/120V Panel-Electric Room
Normal/Emergency	Fire Alarm System	480 volt/120, 3ph, transformer at com room	480V-Substation –Electric Room / Emergency Generator
Normal	Leased Areas	120/208, 3ph,4wire	Separate Metered Service
Normal	Receptacles	120 V, 1PH	480/277&208/120-Panel-Electric Room

5.4.4 PROTECTIVE RELAYING

The selection and application of protective relays are discussed in the following paragraphs. The relays protect equipment in the Silver Line System, MBTA Distribution System and Emergency Generator System and electrical loads powered from these systems.

The following general requirements apply to all protective relay applications:

1. The protective relaying scheme will be designed to remove or alarm any of the following abnormal occurrences:

Three Phase, Phase to Phase to Ground Electrical faults
Over current
Under voltage or over voltage
Frequency variations
Over temperature
Abnormal pressure
Open Circuit and unbalanced current
Abnormal direction of power flow
Failure to operate

2. The protective relaying system will be a coordinated application of individual relays. For each monitored abnormal condition, there will exist a designated primary device for detection of that condition. A failure of any primary relay will result in the action of a secondary, overlapping scheme if possible to detect the effect of the same abnormal occurrence. The secondary relay may be the primary relay for a different abnormal condition. Alternate relays may exist which detect the initial abnormal condition but which have an inherent time delay so that the alternate relays will operate after the primary and secondary relays. Similar to secondary relays, the alternate relays may be primary relays for other abnormal conditions. All protective relays will be selected to coordinate with protective devices supplied by suppliers of major items and the thermal limits of electrical equipment, such as transformers and motors.

3. Secondary current produced by current transformers will be in the 5-ampere range, and voltage signals produced by potential transformers will be in the 120-volt range.

Generator Protective Relays

- Protective relay packages will be provided to minimize the effects from the following faults and malfunctions:
  - Generator phase faults
  - Generator stator ground faults
  - Stator open circuits and unbalanced currents
  - Loss of excitation
  - Backup protection for external system faults
  - Reverse power
  - Generator potential transformer circuit monitoring
  - Under frequency / over frequency
  - Breaker failure

Equipment furnished with the generator's excitation equipment will provide the following additional protection:

- Under excitation
- Over excitation
- Generator field ground faults
- Excessive volts per hz.

Additional generator protective monitoring equipment will be provided to protect against the following:

- High-bearing temperatures
- Over speed conditions
- Excessive vibrations
- Generator overheating

5.5 LIGHTING

Artificial lighting shall be provided for safety and aesthetics and in accordance with the recommendations of the IES and all local codes having jurisdiction. The average maintained foot-candle values and uniformities are indicated in Table 4.2. The lighting system for the Silver Line tunnels and station will include fluorescent, metal halide, low pressure and high pressure sodium fixtures. Illumination levels will be in accordance with the Design Criteria, MBTA Standards, IES, MSBC and APTA recommendations. Lighting is one of the means by which a comfortable, secure and pleasant atmosphere is established. These criteria are intended as a guide to photometric performance, component design, and selection of lighting equipment to achieve the desired environment. These criteria cover lighting systems for the proper illumination of tunnel, passenger stations, miscellaneous lighting and emergency lighting. Consideration should be given to location and arrangement of lighting circuits and panel configuration to accommodate automated energy control devices.

The design criteria are a guide to minimum illumination levels considered acceptable in operating properties for passenger / personnel safety and convenience. After thorough evaluation by the designer, a standardized lighting fixture arrangement might be adopted, because of economic or architectural consideration, which could create illumination levels above or below the general range suggested. However, a minimum lighting level must be maintained to promote safety. A brightly lit station with a minimum of dark corners or narrow, circuitous passageways facilitates surveillance and tends to discourage crime. Adequate lighting is particularly important to facilitate system use by visually handicapped individuals.

Attention should be paid to passenger station entrance areas. Lighting should provide for a comfortable transition from street to station entry area. Illumination levels should be increased during daylight hours to minimize the otherwise abrupt change from outdoor to indoors. The use of photoelectric cells for the operation of additional lighting fixtures should be considered as an option of achieving this problem.

The standardization of lighting levels for the similar areas throughout the system is desirable. The standardization of Phase II with Phase III will be necessary to achieve this consistency.

General illumination should not be designed on the basis of a uniform level throughout the station, but rather with variations in level as may be required by the particular station layout.

Lighting calculations that are submitted for review and analysis shall use the “point by point” method to determine the minimum – maintained foot-candle levels and the “zonal cavity lumens” method for determining the average maintained foot-candles.

Illumination designs shall incorporate energy efficient procedures. All equipment shall be selected and located to optimize visibility, aesthetic design criteria, cost and ease of maintenance.

- Lighting Systems include sub-systems as:
- Tunnel lighting
- Station and miscellaneous lighting
- Emergency Lighting

5.5.1 TUNNEL LIGHTING

The average maintained illumination levels are detailed in Table 5-6. The average maintained illumination level for the interior zone shall between 7 foot-candles to 10 foot-candles. The daytime average maintained illumination levels at the portals entrances will need to be illuminated significantly to eliminate the black hole effect. This can be controlled with the addition of the necessary fixtures at the portal locations.

Table 5-6: Recommended Illumination Levels

Location	Average Foot-candles Maintained Uniformity Range (Between)				Uniformity	
	Open	Closed	Day	Night	Avg: Min	Max: Min
Tunnels Except first 100'-00" from each Tunnel Station						
Transitway		7 -10	7-10	7-10	3:1	10:1
Sidewalks		2 -5	2-5	2-5	3:1	10:1
Walls		5-10	5-10	5-10	3:1	10:1
Tunnels Within 100'-00" to each Tunnel Station						
Transitway		14 -20	14 -20	14-20	3:1	10:1
Sidewalks		2-5	2-5	2-5	3:1	10:1
Walls		10-20	10-20	10-20	3:1	10:1
Tunnels In Turn Around Loop						
Centerline		3-5	3-5	3-5	3:1	10:1
Transitway		5-10	5-10	5-10	3:1	10:1
Sidewalks		2-5	2-5	2-5	3:1	10:1
Walls		5-10	5-10	5-10	3:1	10:1
Tunnels To Washington Street Exit						
Transitway	14-20	14-20	14-20	14-20	3:1	10:1
Sidewalks	2-5	2-5	2-5	2-5	4:1	10:1
Barrier Walls	10-20	10-20	10-20	10-20	3:1	10:1
Tunnel Entrance Areas		50- 60	50-60	10-20	4:1	10:1
Park-and Ride Areas						
General parking: 5.0 5.0* 4:1 10:1	2.5	5.0	5.0	5.0	4:1	10:1
Ramps and corners:		10	5.0	5.0	4:1	10:1
Entrance and Exit Roads	3.0				4:1	10:1
Pedestrian Walkways:	10				4:1	10:1
Brt loading zone	15	15	15	15	4:1	10:1
Entrance to stations	20				4;1	10:1
Escalators and stairways:	25	25	25	25	4:1	10:1
Platforms		30	30	30	4:1	10:1
Passageways		40	40	40	4:1	10:1
Mechanical and Electrical Spaces		20	20	20	4:1	10:1
Storage rooms		15	15	15	4:1	10:1

Notes:

* Values shown in horizontal foot-candles. Vertical foot-candles should be similar in value measured 6 ft above finished floor or surface.

** Recommended range of sign luminance =42 to 65 candles/square ft.

*** A light loss maintenance factor of 65% (MF=.65) or less shall be used to calculate maintained illumination levels.

The lighting fixtures within the tunnels shall be equivalent to existing High Pressure Sodium Fixtures installed during Phase II. A light loss maintenance factor of .65% or less shall be used to calculate maintained illumination levels.

5.5.2 STATION AND MISCELLANEOUS LIGHTING

Lighting will be provided to station facilities including platforms, staircases, entrances, rest rooms, electrical rooms, mechanical rooms, generator room, communication rooms, and mechanical fan rooms utilizing MBTA listed standard lighting fixtures attaining recommended illuminations levels for all the areas based on IES, APTA and MBTA guidelines.

Fluorescent lamp lighting fixtures will be used through out this design. A light loss maintenance factor of 65% or less shall be used to calculate maintained illumination levels.

The calculation for the Coefficient of Utilization (CU) Factor using the Zonal Cavity Method, the following Zonal Cavity Reflectance Values should be used for passenger stations. (Does not apply to Tunnels)

- Floor Cavity = 20 maximum reflectance
- Wall Cavity =30 maximum reflectance
- Ceiling Cavity =50 maximum reflectance

5.5.3 EMERGENCY LIGHTING

Emergency lighting will be provided to permit passenger egress from the station and tunnels during loss of normal power. Emergency lighting will be provided throughout the platform, stairs, and tunnels. Emergency and egress lighting for the new platform, tunnel walkways, and exit stair should provide a minimum of at least one (1) foot-candle average measured at floor level (NFPA 101).

Exit and emergency lights that are sufficient to permit safe exit from buildings in which the public may congregate should be supplied from an emergency power source. When the emergency lighting units are not used under normal conditions, power should be immediately available to them upon loss of the normal power supply. When the emergency lights are normally in service and served from the normal power supply, provisions should be made to transfer them automatically to the emergency power source when the normal power supply fails.

Sufficient lighting should be provided in stairs, exits, corridors, and halls so that the failure of any one unit will not leave any area dark or endanger persons leaving the building. Adequate lighting and rapid automatic transfer to prevent a period of darkness is important in public areas. Public safety is improved and the chance of pilfering or damage to property is minimized. ANSI / NFPA 101 (Life Safety Code) requires that emergency power for lighting be capable of carrying their connected loads for at least 90 minutes. A 2 to 3 hour capacity is more practical and in many installations, a 5 to 6 hour or even several day capacity is provided. The MBTA standard is normally a several day capacity minimum.

Table 5-7 is the breakdown on the following emergency illumination foot-candle requirements: Minimum illumination Levels (fc)

Table 5-7: Emergency Illumination Foot Candle Requirements

MBTA (Massachusetts Bay Transit Authority)	APTA (American Public Transit Association) Guidelines	Massachusetts Building Code	Area
4 fc	1 fc	1 fc	Egress path and exits
4 fc	1 fc	1 fc	Passenger stations areas including platform, mezzanines, ticketing, areas, passageways and entrances.
4 fc[1]	1-2 fc	1 fc	Stairs and escalators
4 fc	5 fc	1 fc	Fare collection kiosks
1.5 fc	.25 fc	1 fc	Underground track areas

Notes:
1. 5 fc at step surface per A17.1

5.6 EMERGENCY POWER SYSTEM

5.6.1 REQUIREMENTS

Emergency power shall be provided for emergency lighting exit signs, elevators, fire alarm systems, communications and signal equipment located at the Station Platform and Tunnel locations, as required. The emergency power systems shall consist of 1) Natural Gas or Diesel Generator 2) Battery / charger inverter unit, sized accordingly. The emergency system shall be connected to an Automatic Transfer Switch located in an Emergency Electrical Room separate from the Normal Electrical Equipment per Massachusetts Electrical Code. Emergency systems are intended to supply electric power to equipment essential for safety to human life, upon interruption of normal supply. Included in this classification would be illumination in areas of assembly, to permit safe exiting and panic prevention and such other vital functions as fire detection and alarm systems, elevators, fire pumps, public address and communication and orderly shutdown of maintenance of hazardous processes.

The following is a breakdown on the emergency / standby power requirements for Silver Line Phase III.

Table 5-8: Emergency/Standby Power Requirements

Item	Equipment	Task	Standby Power	Emergency Power
1	Ventilation Fans	Tunnel Smoke Removal	YES	NO
2	Ventilation Fans	Station Ventilation	YES	YES
3	Light Fixtures	Normal Lighting	YES	NO
4	Light Fixtures	Normal/Emergency Lighting	YES	YES
5	Fire Alarm Panel & Aux. Devices	Fire Alarm System	YES	YES
6	HVAC	Critical rooms HVAC systems	YES	[1]YES
7	CCTV	Closed Circuit Television Surveillance	YES	YES
8	PA/Signage	Public Address and Signage Systems	YES	YES
9	Signals	Tunnel Signals	YES	YES
10	Escalator Status Panel [2]	Vertical Transportation	YES	NO
11	Elevators/Supervisory Panel	Vertical Transportation	YES	[1]YES
12	Radio Systems	Wireless Communication	YES	YES
14	Intrusion Alarms	Security Alarms	YES	YES
15	Pumping Stations	Hydraulic System	YES	[1]YES
16	Emergency Phone & Intercoms	Communication Systems	YES	YES

1. Specific equipment quantities shall be connected to emergency power system
2. Escalators do not require stand-by power. Escalator Status Panel on stand-by power.

5.6.1.1 Generator

All generators shall be diesel or natural gas powered prime movers, 3 phase, 4 wire, 60 Hertz, 480/277 Volts with provisions for mounting indoors.

The exhaust system shall be equipped with a critical silencer.

The storage tank for a diesel powered unit shall be mounted under the generator on skids.

Generators shall be equipped with vibration dampers.

The generators shall be sized for 25% spare capacity.

The generator system shall be equipped with batteries/rack/cables, battery charger, controller, auto transfer switch, and generator breaker.

The generators and associated electrical and mechanical systems shall be constructed and installed in accordance with NFPA 110 “Emergency and Standby Power Systems”, and NFPA 70 (NEC), Article 700.

5.6.1.2 Batteries

Batteries are the fundamental and most commonly used standby power source. They are typically in the form of unitized equipment (wallpacks) consisting of a rechargeable storage battery, automatic charger, floodlight-type lamps, and automatic transfer relay. Batteries provide a low-cost option as an emergency source, but have a **1.) relatively high maintenance cost and 2.) limited capacity**. These are two of the main factors in which battery systems are not usually recommended for the MBTA. There are other factors that would confirm battery systems not being recommended for the Silver Line Phase III, 3) Environmental Conditions 4) Vandalism and Security Issues.

There are some locations that Battery Systems are currently used in Phase II of the Silver Line, 1) Switchgear breaker DC control power 2) Fire Alarm Control Panel Batteries, and 3) UPS (uninterruptible power supply) for communication systems. The specifications and the design of these systems will need to minimize any potential problems.

5.6.1.3 Automatic Transfer Switch

An automatic transfer switch shall transfer the load of the emergency panel from the normal power to the emergency power within 10 seconds. The transfer switch shall provide an indication of transfer to the supervisory control system. When the trouble has cleared, the transfer switch shall automatically retransfer the emergency panel load from the emergency power back to the normal power after 15 minutes.

Some of the other design criteria items:

- Comply with NFPA 110
- Comply with Massachusetts Electrical Code
- Comply with the UL1008, and shall meet the 3-cycle short circuit closing and withstand as follows:

Table 5-10: RMS Symmetrical Amperes 480 VAC

Amperes	Closing and Withstand	Current Limiting Fuse Rating
100 - 400	42,000	200,000
600 - 800	65,000	200,000
1000 -1200	85,000	200,000
1600 - 4000	100,000	200,000

The electronic components of the transfer switch shall meet the following requirements:

- Storage conditions- 25 degrees C to 85 degrees C.
- Operations conditions – 20 degree C to 70 degrees C ambient
- Humidity 0 to 99 percent relative humidity, non-condensing
- Capable of withstanding infinite power interruptions
- Surge withstand per ANSI/IEEE C-37, 90A-1978

5.7 GROUNDING

The National Electrical Code (NEC) and Institute of Electrical and Electronic Engineers (IEEE) publications identified in this section contain regulations pertaining to system and equipment grounding applicable to the station and equipment to be installed. The station's electrical systems will be grounded and designed so that a circuit protective device will remove any faulty circuit from the system regardless of the type of fault. Each of the conductors will be sized so it can safely pass the maximum ground fault current without melting or fusing before the circuit breakers or protective relays disconnect the source of the fault current.

For convenience, grounding systems are defined as :

- System Neutral Ground
- Equipment Ground
- Building Structural Ground

- Critical Power System Grounding

5.7.1 SYSTEM NEUTRAL GROUND

Three-Phase AC secondary systems for distributions shall be wye connected with neutral grounding at the source.

1. A system neutral and a ground conductor shall be run throughout. An exception is the 15 kv feeders serving primaries of load center substations. Generators shall be wye-connected. Transfer switches on wye-systems shall be four-pole type.
2. Neutral deriving equipment is normally solidly grounded.
3. The secondary wye neutral point of these equipments shall be connected to the primary source equipment ground, where applicable, the secondary equipment ground bus, and to two separate points of the building structural ground system.
4. The electric service usually included a grounded neutral conductor and/ or a ground mat of some type. Where this occurs at the point of service to a facility, the service ground shall be solidly interconnected via the equipment ground system and where feasible, the building structural ground system.

5.7.2 EQUIPMENT GROUND

1. The equipment ground is established at each secondary transformer winding or generator winding at the same point that the system neutral originates.
2. The equipment ground conductor is distinct and separate from the system neutral ground conductor and shall not be used as a load current carrying conductor. The function of the equipment ground conductor a) provide a low impedance path for line to line ground fault current b) to bond all non-current carrying enclosures together, including raceways, fixtures, panels, controls, motors, disconnect switches, switchgear and light fixtures enclosures, c) to provide a return path for ground fault equipment operation
3. The equipment ground conductor shall be electrically and mechanically continuous from the source of supply to the equipment to be grounded.
4. The equipment ground conductor shall be provided inside each raceway system.
5. Multi-conductor power cables shall be specified with equipment ground conductors constructed inside the cable sheath in the interstices of the cable The equipment ground conductors constructed in multi-conductor power cables are normally bare with a current-carrying capacity equal to 50% of the phase conductors.
6. Wiring channels, cable trays, and all metallic conduit, including rigid, electrical metallic tubing, and flexible conduits, shall be connected at each end to the equipment ground conductor utilizing a conduit bushing O-Z type B or approved equal.
7. Lighting fixtures shall be securely connected to the equipment ground conductor. A continuous row of fixtures mechanically joined to provide good electrical contact may be considered as one fixture with the equipment ground conductor connected at only one point.

8. Motors shall be connected to the equipment ground conductor with a conduit grounding bushing and with a bolted solderless lug connection on the metal frame. Bolts, nuts and washers shall be bronze, cadmium plated steel, or other non-corrosive material.

9. The equipment ground conductor shall be continuous throughout the system connecting all transformers neutrals, all non-current carrying enclosures, building structural grounds and equipment.

5.7.3 BUILDING STRUCTURAL GROUND

1. # 4/0 awg copper ground bus loop shall be buried a minimum of 24 inches below finished grade and 24 inches outside the structural footing around the entire perimeter of the building.

2. A minimum of two-ground electrode shall be provided with maximum 60 feet spacing between electrodes, measured along the perimeter of the building. Connect each electrode to the ground bus loop with # 4/0 awg bare copper conductor. Ground electrodes shall be ¾ inch by 10-foot copperweld ground rods driven 30 feet deep. The top of the ground electrode shall be 24 inches below grade and located outside of the building structure. Where soil conditions make it impossible to drive the ground rods minimum 10 feet deep, provide three 10-foot ground rods spaced 10 feet apart in an equilateral triangle and interconnected with #4/0 awg copper conductor. Other types of ground electrode installations for special field conditions shall be determined as encountered. Make all below grade connections utilizing exothermic type process.

3. Steel columns in exterior walls shall be connected to the ground bus loop at intervals not to exceed 60 feet. The # 4/0 awg bare copper connection shall utilize exothermic or pressure bolted fittings at the steel column. Connection shall be made 18 inches above the finished floor in the web of the column.

4. Steel columns inside the building shall be connected to the ground bus loop on each side of the building, with continuous # 4/0 awg bare copper conductors at intervals not to exceed 100 feet.

5. In buildings using materials other than steel for columns and where the roof structure is steel, the steel roof beams shall be grounded to the ground bus loop similar to the above methods.

6. Domestic and fire protection metallic water pipes shall be connected to the ground bus loop with # 4/0 awg bare copper conductor at a minimum of two points.

7. Miscellaneous metal objects, including piping, vessels and structural shapes, within 10 feet of electrically grounded metallic objects shall be interconnected to the ground system with a minimum #6 awg bare copper conductor to protect personnel should a current imbalance occur.

5.7.4 GENERAL GROUNDING CONSIDERATIONS

Ground rods will be minimum ¾' –inch diameter by 10 feet in length, copper clad steel. Rods will be connected to the grid by the exothermic welding process.

1. Grounding conductors between the ground electrode system and the grounded system will be insulated copper wire. The conductor will be sized to preclude fusing under the maximum fault current for that equipment but in no case smaller than permitted by the NEC.

2. Transformer cases and alternating current distribution panels and panel boards for auxiliary power will be grounded to the facility ground system using copper grounding conductors.

3. Raceways for lighting and power feeders to motor, lighting and receptacle loads will contain a separate green safety insulated grounding conductor. Each branch circuit will have a safety-insulated grounding conductor extended from the ground bus of the panel board to the device it is serving.

4. Fences will be grounded in accordance with the National Electrical Safety Code and American National Standards Institute (ANSI).

5. The non-current carrying parts of all electrical equipment, devices, panelboards and metallic raceways will be connected to the ground bus.

5.8 EXPOSED CONDUIT WIRING METHODS

5.8.1 ALLOWABLE APPLICATIONS

In general, exposed conduit for wiring within facility areas shall be galvanized Rigid Steel Conduit (RGS) and Fiberglass Reinforced Epoxy Conduit (FRE). Cable trays may be used in areas where approved.

5.8.1.1 Conduit and Raceway Systems

Rigid Galvanized Steel (RGS) Conduit shall be used for all exposed applications above ground.

Fiberglass (FRE) Conduit and Fittings constructed of the highest grade rated for 130 degree C, UL listed, as approved by the Engineer, and which conforms to the requirements of MBTA standard Specification P-138E.

Cable Trays shall be open ladder type, constructed of aluminium or other suitable materials commercially available with support spacings, strength, and material characteristics equal to or greater than aluminium.

MC cable may be used above ceilings, within rooms, for connection between junction boxes and lighting fixtures. The length of cable shall be a maximum of 6 feet.

Flexible metal conduit shall be used for final connection to equipment. Connection shall not exceed 3 feet.

Equipment located in wet areas, kitchens, mechanical rooms, and exterior locations shall utilize liquid-tight connectors, and PVC jacketed flexible conduit.

Conduit supports shall be fastened to building structure, and surfaces in accordance with code practices.

Adequate clearance shall be maintained between piping and conduit. A minimum clearance of 12 inches shall be maintained between conduit and surfaces with temperatures exceeding 104 degrees Fahrenheit.

All rigid steel conduit shall be hot-dipped galvanized.

Table 5-11: Minimum Radius Bends in Conduit

90 Degree		45 Degree		22 Degree	
SIZE	**RADIUS**	**SIZE**	**RADIUS**	**SIZE**	**RADIUS**
3 inch	36 inch	3 inch	36 inch	3 inch	36 inch
4 inch	36 inch	4 inch	36 inch	4 inch	36 inch
5 inch	48 inch	5 inch	48 inch	5 inch	48 inch

5.8.2 CONDUIT SIZE

Exposed conduit smaller than 3/4 in electrical trade size shall not be used.

5.8.3 INSTALLATION CRITERIA

Expansion fittings or liquid-tight metallic flexible conduit shall be used where conduits cross structural expansion joints, and as required by the thermal expansion and contraction in a length of conduit.

Conduit shall be grounded and bonded to assure electrical continuity and the capacity to safely conduct any fault current likely to be imposed.

Materials manufactured for use as conduits, raceways, ducts and their surface finish will conform to the National Electrical Code (NFPA 700, National Electrical Manufacturers Association (NEMA), American National Standards Institute (ANSI) Standards, and the Underwriters Laboratories, (UL) Inc. listed.

5.9 EMBEDDED CONDUIT WIRING METHODS

5.9.1 ALLOWABLE APPLICATIONS

Embedded conduit for wiring within facility slabs and underground shall be rigid non-metallic conduit, and FRE conduit is acceptable rigid non-metallic compositions for embedded conduit installations.

Rigid Galvanized Steel (RGS) Conduit shall be used for all exposed applications above ground.

Fiberglass (FRE) Conduit and Fittings constructed of the highest grade rated for 130 degree C, UL listed, as approved by the Engineer, and which conforms to the requirements of MBTA standard Specification P-138E.

Cable Trays shall be open ladder type, constructed of aluminium or other suitable materials commercially available with support spacings, strength, and material characteristics equal to or greater than aluminium.

MC cable may be used above ceilings, within rooms, for connection between junction boxes and lighting fixtures. The length of cable shall be a maximum of 6 feet.

Flexible metal conduit shall be used for final connection to equipment. Connection shall not exceed 3 feet.

Equipment located in wet areas, kitchens, mechanical rooms, and exterior locations shall utilize liquid-tight connectors, and PVC jacketed flexible conduit.

Conduit supports shall be fastened to building structure, and surfaces in accordance with code practices.

Adequate clearance shall be maintained between piping and conduit. A minimum clearance of 12 inches shall be maintained between conduit and surfaces with temperatures exceeding 104 degrees Fahrenheit.

5.9.2 CONDUIT SIZE AND SPARES

Embedded conduit smaller than 1 inch electrical trade size shall not be used.

In order to provide for spare capacity, the total number of embedded conduits specified shall, in general, be a minimum of 50 percent more than the number of conduits required by design. However, the total spare capacity shall also be assessed on a case-by-case basis and account for relevant site-specific conditions. This requirement shall be applicable to each run, or duct bank, of conduits.

5.9.3 INSTALLATION CRITERIA

Expansion fittings shall be used where embedded conduit passes through structural expansion joints. Expansion fittings shall be installed perpendicular to the expansion joints. In general, expansion fittings are not required for embedded conduit installations where underground temperatures are relatively constant. However, due to the large change in length per degree change in temperature exhibited by non-metallic conduit, such installation shall be backfilled or concrete-encased immediately.

Minimum cover requirements shall meet or exceed the requirements of NEC for the conduit composition and voltage class of wiring installed. Areas subject to heavy vehicular traffic shall have a minimum cover of 2'-0" with a 3 inch concrete encasement.

Where multiple conduits or ducts are run as a duct bank, plastic spacers shall be used to support the rows of conduit and to maintain a clear separation of 2 inch between conduits. The maintained separation provides space for backfill or concrete aggregates; permits the mounting of end bells or bushings at terminations; and facilitates heat dissipation.

Duct banks shall be laid out in as straight a line as possible with a slope of 0.50 percent to 1 percent toward drain points. Where bends are required, large-radius field bends are preferable. The minimum conduit-bending radius shall not be less than that permitted by the NEC. Small-radius conduit bends should generally be constructed with factory-made fittings. The total number of bends in one run of conduit shall not exceed the equivalent of four-quarter bends (360 degrees total).

Conduits shall be cleaned with a mandrel or rod after installation and before cable installation. If cable is not to be installed immediately, a pull-string shall be installed in the conduit.

Vertical conduit turn-ups from embedded conduit shall be installed with rigid galvanized steel conduit.

5.10 MANHOLES AND HANDHOLES

Manholes and handholes are located in underground duct banks to provide cable pull-points and junction points and to accommodate splices. Manholes should be large enough to accommodate the depth and cross-sectional area of the duct banks entering and to provide a minimum horizontal workspace of 3 ft clear of cable supports and a minimum vertical dimension of 6'-10".

Manhole openings provide both access and cable-installation space. Round access openings shall be a minimum 2'-2" in diameter. Rectangular access openings shall not have dimensions less than 1'-10"-by-2'-2". Grade adjustment rings can be installed around manhole openings to accommodate the depth of the duct banks.

Manholes shall be provided with sumps, and the floor shall be sloped toward the sump. Portable sump pumps can be used to pump out accumulated water.

Handholes shall be a maximum 3'-6" in depth and shall be covered with a removable or hinged checkered plate.

5.11 MECHANICAL/ELECTRICAL INTERFACE CRITERIA

HVAC equipment and pumps shall be provided with integral motor starters, and control devices when feasible.

HVAC equipment and pumps grounding shall be in accordance with the NEC.

All thermostats, H-O-A switches, Start-Stop pushbuttons, thermal switches, etc. for operation of the HVAC equipment and pumps shall be furnished and installed by the mechanical contractor.

Equipment branch circuit ampacity, interrupting capacity, overload protection, etc. shall be in accordance with the NEC, Article 440.

Mechanical equipment schedule indicating power requirements for both heating and cooling stages shall be provided for all HVAC equipment. Power requirements shall indicate volts, amps, horsepower, kilowatts, and number of phases.

Manufacturers' shop drawings, and cut sheets shall be provided for all HVAC equipment. These documents shall include wiring diagrams for power and control circuits.

HVAC equipment shall have protective devices as required by the NEC.

Electrical heating equipment shall be UL listed.

Emergency ventilation systems shall be supplied power from the emergency bus.

Sewage ejector and sump pumps shall be on the emergency power system.

5.12 FIRE DETECTION AND ALARM SYSTEM

The design of the Fire Detection and Alarm system will comply with the City of Boston Fire Alarm Code 93-01, the State of Massachusetts Building Code 780-CMR-9.00, and the applicable National Codes. The Fire Detection and Alarm System will include a Fire Alarm Control Panel, manual fire alarm pull stations, horn/strobes, etc. The Fire Alarm Control Panel will be connected to the Boston Fire Department and 45 High Street for alarm response and monitoring purposes.

The Fire Detection and Alarm system will be electrically supervised, closed circuit, selectively coded, and continuously self –monitoring. System components will conform to applicable codes and standards.

Install initiating and alarm devices as required by NFPA 72 Fire Alarms and A17.1 for vertical transportation equipment.

Installation shall be in compliance with ADA regulations, local codes and MBTA standards.

Table 5-12: TBM Estimated Electrical Load

Tunnel Size	Load	Voltage	Reliability
19.5 ft	4212 hp 3674 kva	13.8 kv to machine 480 v to equipment	High - minimum of two 13.8 kv services.
Load Breakdown			
Machine			
6 @ 250 hp		1500 hp	
1 @ 200 hp		200 hp	
1 @ 150 hp		150 hp	
2 @ 30 hp		60 hp	
Total Machine HP		1910 hp	

Ventilation Motors 3@ 400 hp	1200 hp
Conveyor / Auxiliary Systems	400 hp
Estimated Total	3510 hp
20% margin	
Estimated Total + Margin	4212 hp
Estimated KVA	3674 kva

5.14 ELEVATORS AND ESCALATORS ELECTRICAL CRITERIA

The electrical design shall be in accordance with the NEC and ASME A17.1, 2000 Edition as modified by the Massachusetts State Elevator Code 524 CMR 2003.

Electrical design requirements for the elevators and escalators pits shall comply with the NEC and ASME A17.1, 2000 Edition as modified by the Massachusetts State Building Code.

The power source for the elevators and escalators shall be the 480/277 Volt Normal Power. The elevators shall be planned to be connected to the Generator for Standby Power per National Electrical Code 701.

A disconnect switch within sight of the elevators' and escalators' controllers shall be the limits of the design. Wiring and accessories from the disconnect switches to the elevators and escalators shall be the responsibility of Elevator Manufacturer.

Elevator disconnect switches shall be installed no more than 18 inches from the lock jamb side of the machine room entry door.

Escalator disconnect switches shall be installed adjacent to the escalator controller.

6.0 TRANSIT OPERATING SYSTEMS

6.1 OVERHEAD CONTACT SYSTEM REQUIREMENTS

6.1.1 SYSTEM DESCRIPTION

This section identifies the system requirements for the overhead contact system (OCS) design for the both the underground and street level portion of the Phase III Silver Line. The design shall include the overhead line supports, wires, cables, hardware, assemblies and electrical equipment that will make up the traction power distribution system. A fully elastic pendulum system will be utilized to match the system used in phase II. The OCS system components may include, but are not limited to the following specific catenary items:

1. Catenary structures, foundations, poles, anchors, guys, small part steelwork, brackets and associated structural assemblies, which act to support the OCS including attachments to tunnel structures and portal walls.

2. Insulated cantilever support and registration assemblies, tubular frames and arms.

3. Bare wires and /or insulated cables, together with all electrical connectors, taps, insulators, terminations, miscellaneous conductors, line equipment and hardware that make-up the OCS.

4. Parallel traction power feeder and distribution cables, supports, hardware, taps, feeders and other equipment that are connected to the OCS including the insulated traction power supply cables.

5. Special insulated supports and system attachments, which are mounted to overhead tunnel structures.

6. Bonding, grounding and protection systems, devices and similar equipment, which ensure the safe and reliable operation of the OCS, that are connected to poles, foundations, wires, conductors and associated electrical equipment.

7. Ancillary system cable cross-arms, supports and hardware for any locations where pole-mounted aerial support is utilized for parallel signal power, communications or control conductors.

The Previously constructed Silver Line Phase II system, previously identified as Phase 1 of the Transitway project consists of both negative and positive 4/0 bronze 80 trolley wires, each supplied by one (1) 1000 kcmil parallel feeder. The new Phase III OCS shall be designed to have compatible interfaces with the existing active system. The Phase III system will also be designed to address lessons learned in the construction of the existing Phase II system.

All catenary assemblies, components, hardware and related equipment shall be designed to be fabricated by an experienced OCS manufacturer, such that equipment may be supplied from a standard product catalogue. The design shall also facilitate installation by an experienced electrification construction contractor.

6.1.2 GOVERNING CRITERIA

OCS electrical system shall comply with but not be limited to the MBTA, The Commonwealth of Massachusetts, the City of Boston regulations, and the following codes and standards:

- American Concrete Institute referred to in these criteria as "ACI"

- American Institute for Steel Construction “AISC”
- American National Standard Institute “ANSI”
- American Railway Engineering and Maintenance-of-Way Association, Manual for Railway Engineering 2002 “AREMA”
- American Society for Testing and Materials “ASTM”
- American Welding Society, Standard D.1.1 - Structural Welding Code “AWS”
- Institute of Electrical and Electronics Engineers “IEEE”
- National Electrical Safety Code, referred to in these criteria as “NESC”.

The latest edition of each code or standard shall be applied as applicable to the design.

6.1.2.1 Pendulum System

The suspension of the trolley wires in both tunnel and street sections should utilize a fixed termination, variable tension pendulum system as selected in Phase II. The pendulum system represents an elastic system designed to reduce wear on both the wire and trolley shoes.

6.1.2.2 OCS Tensions, Sags and Spans

OCS technical sheets shall be developed to quantify the catenary design. The sheets shall define the overhead conductor particulars, tensions, equivalent and maximum spans, climatic conditions variations, technical alignment data, sags and line loadings to be used for the final design. A tension-adjustment table or graph shall be provided to facilitate construction at a range of ambient temperatures other than the design condition.

6.1.2.3 Section insulators

Section insulators will be required to electrically isolate sections of the overhead system to facilitate work on the trolley wire while maintaining operation on other portions of the system. The section insulator must be capable of providing the require isolation while being able to be traversed in either direction by trolley shoes. A section insulator with a protective system should be used to preventing bridging and allow freedom in the placement of section insulators.

6.1.2.4. Insulation

The OCS shall be designed as a double-insulated system whose components are capable of withstanding a maximum continuous voltage of 1500 VDC and voltage spikes of 3000 VDC without damage.

6.1.2.5 Switches

In all cases, the switch used shall be dependant upon location, speed, and operating conditions. The trolley wire switch shall be designed to facilitate the removal of sections of the under-runners without altering the tension in the trolley wire. Remote inductive control devices located on the trolley buses and controlled by the driver shall provide command for trolley frog actuation.

6.1.2.6 Climatic Conditions

The OCS design shall meet the requirements of AREMA and the NESC and vehicle parameters for the climate conditions of the design including temperature changes, wind and ice loading. The following conditions shall be used in load combinations as specified in the NESC.

- Tunnel Section
- Temperature Range: 30°F to 90°F

- No Ice in tunnel
- No Wind in tunnel

- Street Level
- Temperature Range: -20°F to 110°F
- Radial Ice Thickness: ½"
- Wind Speed: 90 Mph

6.1.2.7 Trolley Overhead System - Tunnel

Tunnel sections include all underground portions of Phase III, including stations, cut and cover, and bored tunnels. The traction power will be a 650VDC system consisting of two trolley wires spaced 30" apart and suspended from the tunnel roof by an embedded single strut insert. Twin 1000 kcmil HD Cu parallel feeders will supply the trolley wires (One feeder for each trolley wire). Feeder cables will be located at least 4 ft. to the side of each trolley wire.

In the event of a de-wire incident, a space of 10'-6" above the bus shall be clear of equipment to minimize damage. This includes the 2'-6" spacing between the trolley wires, and the 4 foot clearance to the feeder wires. This clear area will be modified as necessary for super-elevated sections that occur on curves in the tunnel. Feeders will be connected to the trolley wires by means of attachment to the embedded Uni-Strut channel. Feeder cables will be installed in conduit to provide protection from de-wirement.

A blockout shall be included every 48 feet to allow for the crossing of the tunnel roof by pipes and cables without interfering with the trolley wires. The blockout will be covered to protect the equipment in the block-out from a de-wire incident and to provide a smooth ceiling finished appearance.

- Trolley wire specifications:
- Two (2) 4/0 AWG bronze alloy 80 – positive and negative wires.
- Solid grooved, bare.
- 0.482" diameter.
- Maximum trolley wire wear of 30%.
- Normal trolley wire tension of 1395 Lb at 68°F.
- Minimum height of trolley contact wires at midspan = 13'.
- Nominal height at support points = 14'.
- Minimum height to structure = 15'-3".

- Pull off wire
- 5/16" Galvanized steel
- 7 strand high strength
- 0.372" diameter

- Tangent Section Support:
- The trolley wire will be supported every 48 feet with pendulums.
- Jumpers will be installed in every span between the feeder cable and trolley wires.
- The feeder cables will be supported every 8 feet at a nominal tension of 500 lbs.

- Curve sections
- The trolley wire will be supported on pendulums for curves at 8, 16 or 24 feet dependant on the curve radius.
- Jumpers will be installed every 48 feet.
- The feeder cables will be supported every 8 feet at a nominal tension of 500 lbs.

6.1.2.8 Trolley Overhead System – Street level

If the design incorporates above ground electrification over any distance, the following OCS criteria will be used. The traction power will be a 650 VDC system consisting of two trolley wires spaced 30" apart and supported using either cantilever structures or a cross span wire arrangement with connections to poles or directly to existing buildings through eye bolt attachments. For 90-degree turns, 3, 4, or 5 curve segments will be used with pull off wires to transfer tensile loads to pole supports. The number of curve segments used will depend upon the degree of the turn and the speed with which the vehicle will operate. 1000 kcmil HD Cu parallel feeders will supply the trolley wires and be located in ducts in the sidewalks as needed.

- Trolley wire specifications:
- Two (2) 4/0 AWG bronze alloy 80 – positive and negative wires
- Solid grooved, bare
- 0.482" diameter
- Maximum trolley wear of 30%
- Normal trolley wire tension of 1395 Lb at 68°F.
- Minimum height of trolley contact wires at midspan = 18'.
- Maximum trolley wire height at supports = 20'.
- Polarity shall generally place the positive wire towards the street center and the negative towards the curb.

- Cross-span wire
- 5/16" galvanized steel
- 7 strand high strength
- 0.372" diameter

- Pull off wire
- 5/16" Galvanized steel
- 7 strand high strength
- 0.372" diameter

- Tangent / Light Curve Section Support:
- The trolley wire will be supported with pendulums with an angular deviation up to 4 degrees. This is acceptable in curves with a radius of 700 feet or greater on a 100 ft. span.
- Jumpers will be installed in every span between the feeder cable and trolley wires.

- Curve sections
- For sharp curves with low speeds, slanting pendulums with curve rails or clamp type curve segments will be utilized.
- Jumpers will be installed every 48 feet.

6.1.2.9 Overhead Line Loadings

Overhead loadings will be based on the requirements for Grade B construction and conform to the Heavy Loading District criteria as defined by the "National Electrical Safety Code."

6.1.2.10 Street Supports

The OCS system at street level shall be designed using cross span wires and pull off wires connected to structural supports. Where possible, it is economically and visually advantageous to use anchors in existing buildings rather than constructing new poles. Where poles are required, a tapered steel pole with architectural treatment and street light mounts should be used to replace existing street lighting and minimize visual impacts where possible. New poles should match the existing lighting poles in appearance, be of sufficient height for cross span attachment, and be capable of withstanding the loads applied by the cross span system. Alternatively, single cantilever poles may be considered on either side of the roadway.

6.1.2.11 Foundations

Foundation design for OCS poles shall conform to local requirements and the guidelines of the IBC? And the design shall be in accordance with the ACI Code and established civil and structural engineering practice. All foundations and anchors shall be capable of supporting the loads incurred during construction and of withstanding a broken wire failure event without foundation damage.

6.1.2.12 Steel Structures

Steel structures including poles and supports shall be designed in accordance with "Section F. Overhead Line Loadings". All poles shall be designed to withstand a broken wire failure event without major damage and be in accordance with AISC.

6.1.2.13 Bonding and Grounding

The OCS, related equipment and poles shall be grounded and protected per NEC and NESC. When possible, an earth grounding system will be provided at individual structures to provide a resistance of not more than 24 ohms.

Foundation design shall include a 10-foot ground rod with an insulated copper jumper cable exothermically connected to the steel reinforcement. An appropriate length of jumper shall extend out of the foundation to connect to the pole grounding stud.

Steel poles shall have a ground nut welded to their baseplate and shall be manufactured with a cable lug and stud for connection to the previously mentioned ground jumper.

All grounding and bonding shall be tested after installation to verify the indicated ground resistance.

7.0 ELECTRICAL TRACTION POWER

7.1 SCOPE

These criteria include functional and design requirements for the supply and supervision of electric power for the dual mode Bus Rapid Transit (BRT) vehicles.

The electrical system shall supply power to the transit facilities to provide safe, efficient and continuous operation of the system. Design of the electrical system shall be coordinated with the requirements of the power companies providing primary power to the system, the existing Phase II power supply system and any other elements of the MBTA Light and Heavy Rail system.

7.2 STANDARDS, CODES AND GUIDELINES

The latest edition of the following standards, codes and guidelines shall be used for the traction power system design:

- American National Standards Institute (ANSI)
- Institute of Electrical and Electronic Engineers (IEEE)
- Insulated Cable Engineers Association (ICEA)
- National Electric Code (NEC)
- National Electrical Manufacturers Association (NEMA)
- National Electrical Safety Code (NESC)
- Underwriters' Laboratories (UL)
- American Association of Railroads (ARR)
- OSHA
-

7.3 SYSTEM

1. Traction power system shall include: Traction power supply system providing electrical power to the overhead contact and power distribution system (the OCS) for electric traction motor propulsion and vehicle auxiliary power;

2. Substations required for the conversion and supply of power to the OCS, including high-voltage switching, protective apparatus, transformers, rectifiers, switchgear, control and supervision;

3. Sectionalizing to permit flexibility during normal and contingency vehicle operations;

4. Supervisory control and indication interfaces for supervision, protection and control of the substation and OCS equipment that are essential to continuous operation of the traction power system. For all remote control and indication capabilities at the OCC, the substation equipment shall interface to the Supervisory Control and Data Acquisition (SCADA) system, which shall be provided in accordance with the requirements of "Communications System," section. The interface shall occur via an intelligent remote terminal unit (RTU) or programmable logic controller (PLC) located in each substation and master controller in the OCC. The field RTU or PLC shall be connected to the adjacent substations and the OCC via the fiber optic Carrier Transmission system.

   In addition to providing remote supervision and control functions, the SCADA shall also provide the following features:

Local annunciation within each substation;
Communication with adjacent substations for transfer-trip of selected direct current (dc) feeder breakers;

Communication with all wayside motorized disconnect switches for remote control and supervision (the signals to or from these disconnect switches shall be terminated in the nearest substation RTU/PLC cabinet).

7.4 TERMINOLOGY

7.4.1 STANDARD TERMINOLOGY

Definitions that are specifically applicable to dc traction power, ac power and supervisory control functions shall conform to the following standards, unless otherwise stated in this manual:

- ANSI C42.100, "Dictionary of Electrical and Electronic Terms"
- ANSI C37.100, "Definitions for Power Switchgear"
- ANSI C37.2, "Electrical Power System Device Function Numbers and Contact Designation"
-

Electrical terms used in these criteria that are not defined in the appendices or the above references shall be interpreted according to normal usage.

7.4.2 SPECIAL TERMINOLOGY

The following definitions of special terms shall apply:

1. Anode bus: An assembly of rigid conductors with associated connections, joints and insulated supports connecting the output of a rectifier transformer to a rectifier.

2. Direct current main breaker (cathode breaker): A dc circuit breaker protecting the positive-output side of a rectifier.

3. Cathode bus: An assembly of rigid conductors with associated connections, joints and insulated supports carrying positive dc from the output side of a rectifier to a cathode breaker, and from a cathode breaker to one or more direct current feeder breakers.

4. Direct current feeder breaker: A dc circuit breaker with associated load-sensing devices, which energizes or de-energizes a section of the OCS and protects the substation equipment from faults.

5. Rectifier transformer ac feeder breaker: A primary-voltage ac circuit breaker protecting the line side of a rectifier transformer.

7.5 TRACTION POWER

7.5.1 GENERAL

The BRTs will be propelled by electric traction motors that are driven by electric traction power supplied to the vehicle through the OCS.

Two contact wires will be installed over each traveling direction, under which trolley poles on each vehicle will maintain contact.

The OCS, and associated cabling, shall be capable of maintaining voltage no lower than 420 volts at the BRT.

Direct current traction power shall be provided by rectifier substations with a rated voltage output of 650 volts at 100-percent load. Maximum voltage output under no load at the substation bus shall not exceed 720 volts, corresponding to 6-percent regulation. Rectifier-inherent voltage regulation shall be approximately linear from no load to 100-percent load, and shall be as linear as technically feasible from 100-percent load to 450-percent load.

7.5.2 OVERHEAD CONTACT AND POWER DISTRIBUTION SYSTEM

Traction power shall be distributed via the OCS as described in "Overhead Contact and Power Distribution System," section. At each substation, sectionalizing gaps shall be provided in the inbound and outbound OCS to create power zones. The distribution system serving the inbound direction shall be electrically separate from that serving the outbound direction. The system shall be designed to permit isolation of each power zone by opening the appropriate feeder circuit breakers.

7.5.3 MAINLINE SECTIONING

To the extent feasible, substation locations are to be optimized to satisfy sectionalizing requirements. Where substations are located in the vicinity of OCS sectionalizing gaps, which in turn are determined in conjunction with operations, the substation breakers shall be used to isolate OCS sections or zones. Additionally, each sectionalizing gap will be provided with a tie-switch. The switches shall be manually operated no-load-break type, depending on the location and operational needs.

Each substation circuit breaker shall be provided with protective devices, including instantaneous and time-delay over-current relay, rate-of-rise relay and load measuring and automatic reclosing relay.

All circuit breakers shall normally be operated remotely from OCC using the SCADA system. Local controls shall be provided to allow local manual operation of all circuit breakers within each substation. During local operation, supervisory control for each device operated locally shall be inhibited and indicated at OCC.

7.5.4 DIRECT CURRENT POWER CABLES

Direct current traction power cables shall be insulated single conductors, with a non-shielded, external non-metallic jacket suitable for use in wet or dry locations and rated 2000-volt, dc and 90 degrees C (194 degrees F) conductor temperature for normal operation; 130 degrees C (266 degrees F) for emergency operation; and 250 degrees C (482 degrees F) for short circuit conditions. The conductors shall be copper, with Class B stranding.

Traction power cables connecting the dc feeder breakers to the OCS to the negative bus shall be sized to carry the maximum root-mean-square (rms) currents and maximum theoretical fault currents, with temperature rise not exceeding safe insulation design limits of the cables. Cables shall also be de-rated for installation in an underground duct bank or any other configuration selected during the design process.

Feeders shall be standardized on a single conductor size (1000 Kcmil) by using multiple conductors for different ampacities. The cables shall have sufficient ampacity to carry the maximum rms current imposed by the worst-case operating scenario. Negative cables shall be provided between the substation negative bus and the running rails, with the ampacity determined by the total substation rms load under the worst-case operating scenario.

7.5.5 CABLE SUPPORTS

Traction power positive cables from the dc feeder breaker connections and negative cables from the negative bus connections shall be laid or run in appropriate raceways, such as fiberglass cable trays, non-metallic conduit, or in concrete-encased duct banks using PVC (schedule 40) conduit. Raceways shall provide adequate cross-sectional area to permit a neat alignment of the cables and avoid crossing or twisting.

Cables in manholes shall be supported on non-metallic racks and secured by porcelain or fiberglass cable support insulators. Such supporting arms or racks shall be spaced to avoid excessive weight or pressures on the cable insulation. The cables shall be arranged in not more than one layer.

Conduit stub-ups shall be protected against damage during construction. Conduit and cable seals shall be used to prevent water ingress into the substation facility.

7.6 TRACTION POWER SUBSTATIONS

7.6.1 BASIS FOR RATING

Traction power substations shall be rated to provide adequate power to the vehicles in meeting the demand of the operating schedule during maximum traffic periods. The system shall be capable of supplying the maximum rms loads.

Each substation shall include two transformer-rectifier units, with associated ac and dc switchgear and auxiliary equipment. These substations shall be fed from dual, medium-voltage utility feeders with associated ac switchgear for transferring from one incoming utility feed to another. The equipment ratings shall be adequate to support the rms load of the vehicles during peak-period operation, including contingency operations, and shall maintain minimum vehicle voltages as indicated below:

1. **Normal Conditions**: With all substations energized, the equipment shall maintain an average of 650 volts and a minimum of 420 volts to vehicles during peak-hours of operation with vehicle operating at predetermined headways. The simultaneous starting of two vehicles, one each on the inbound and outbound directions of a passenger station midway between two substations, shall also be possible.

2. **Contingency Operations**: Maintain 420 volts minimum to vehicles with any one new double transformer-rectifier unit substation out of service, or one rectifier-transformer unit out of service in an existing double-ended substation.

During the above condition at any single unit substation, the dc bus at the failed substation shall be considered energized and the substation treated as a tie-breaker. It shall be possible to start one vehicle at a passenger station adjacent to the failed substation.

If a substation outage occurs at the end of the line, one vehicle start should be possible at reduced performance, which may be by way of reduced acceleration or power draw.

7.6.2 SUBSTATION POWER SUPPLY

The substation feeds shall be 13.8-kV, 3-phase, 60-Hz ac supplied by Boston Edison or from the MBTA distribution system. Substation shall have double-units, with two feeds. Incoming ac service to the substations shall include metal-clad, indoor switchgear rated for nominal operation at 13.8-kV, 3-phase, 60 Hz.

The capacity of each power company circuit shall be sufficient to support the kilovolt-ampere (kVA) load of the installed substation and the peak loads associated with vehicle starts.

7.6.3 SUBSTATION EQUIPMENT

Substations shall be equipped with medium-voltage ac switchgear; metering; two transformer-rectifier units; dc switchgear and protective devices; auxiliary transformer; signal power transformer and associated switching devices; local annunciator; power panels; and SCADA interface (RTU or PLC).

Substations and equipment shall be designed to operate unattended. Controls shall be provided to operate all switchgear from the OCC or from local control switches on the equipment. All indications shall be displayed locally, as well as at the OCC.

Provisions shall be made for entry of cables and termination in appropriate switchgear.

Rectifier-transformers shall be indoor, metal enclosed, open ventilated, natural convection cooled, dry type with cast coils, using building air for cooling under ambient conditions. Transformer connections shall be suitable for input to a 12-pulse rectifier.

Silicon-diode rectifiers shall be natural convection-cooled, with 12-pulse output. Rectifiers shall deliver rated output (including overloads) with any one diode out of service in each phase leg. Loss of a diode shall be monitored locally.

The feeder breakers shall be metal-enclosed, draw-out, 750-volt dc, single pole, high-speed type. The main dc breaker (cathode breaker) shall be suitable for protecting the feeders in case of failure of feeder breakers, and shall also protect the rectifier from internal fault.

Direct current disconnect switches shall be no-load break and either manually operated or motorized type, depending on the application. The switches shall be rated 750-volts dc with appropriate current rating.

Auxiliary equipment shall include lightning or surge protection; interconnecting buswork; 125-volt control power battery (rated for 12 hours) and charger; provision for stray-current corrosion control drain cables and provision for SCADA interface.

Substation interconnecting buses shall be copper. Buses shall be sized to limit the temperature rise on the basis of applicable standards. Buses shall be adequately supported to withstand available short-circuit forces.

Lifting devices, or other means, shall be provided in the design to permit changing out of feeder breakers or any large draw-out equipment.

7.6.4 EQUIPMENT ARRANGEMENT

Substation structures shall have adequate area to accommodate the electrical equipment and ancillary components. Relative spacing and positioning of each transformer-rectifier unit shall permit the removal, replacement, or maintenance of the unit without moving other equipment. The arrangement of the equipment shall permit doors to be opened, panels to be removed and switchgear to be withdrawn. Ceiling heights and structural openings shall permit entry and removal of the largest components that will be installed in the structure.

7.6.5 SUBSTATION ENCLOSURES

The environmental considerations, including noise criteria, are indicated in the "Environmental Issues," section of this manual. The ambient temperature varies from -30 degrees C (-22 degree F) to 35 degrees C (95 degree F).

The enclosures shall be fabricated from "galv-annealed" (galvanized and annealed) sheet steel, mounted on a structural steel base and provided with internal and external paint finishes to prevent corrosion over the life of the substation.

The walls shall be provided with thermal and acoustic insulation. Sound levels measured at 50 feet in any direction from the substation in accordance with the limits specified in the "Environmental Issues" section. Electrical insulation shall be provided in places such as floors and walls to provide a dielectric strength of 300 volts/mil.

7.6.6 VENTILATION AND HEATING

Each substation enclosure shall be provided with ventilation fans or air-conditioning and unit heaters to maintain the required air-changes, temperature and humidity within the maximum permissible limits recommended by the equipment manufacturers.

Additional information regarding climatic data is provided in "Overhead Contact and Power Distribution System," and "Mechanical," sections.

7.6.7 LIGHTING AND AUXILIARY ELECTRICAL SYSTEMS

7.6.7.1 Lighting

Lighting shall be provided by fluorescent fixtures. Design shall provide for minimum maintained lighting levels of 20 foot-candles. The lighting shall be located to provide sufficient illumination of the vertical surface of switchgear, rectifiers, etc. Lighting fixture locations shall be coordinated to avoid interference with overhead raceways or other major wiring, and shall not be positioned directly above switchgear, rectifiers, or transformers.

Photo-controlled exterior lighting shall also be provided for visibility and security.

Exterior lighting may comprise mercury or sodium fixtures, and shall be weather - and thermal-resistant.

7.6.7.2 Emergency Lighting

Each substation unit shall be provided with emergency lighting powered from a rechargeable battery and battery charger, with one or more lamps mounted on the equipment and a relaying device arranged to automatically energize the lamps on failure of the ac power. The battery shall have capacity to supply the rated load for 1.5 hours at not less than 87 percent nominal battery voltage.

The designer shall consider the concept of using one battery system for both control power and emergency lights.

7.6.7.3 Convenience Outlets

Duplex convenience outlets shall be placed in the substation to allow use of hand tools and small equipment. One 20-amp duplex outlet shall be fed from a dedicated circuit to allow the use of a heavy-duty vacuum cleaner, a portable air compressor of up to 1.0 horsepower, or other hand tools.

The design shall include 120-volt, 60-Hz, 20-ampere circuits for ac and dc switchgear heaters. To preclude grounded circuits, dc switchgear heaters shall be fed via isolation transformers.

7.7 MEDIUM VOLTAGE POWER CABLES

7.7.1 GENERAL

Cables for incoming service to traction substations will be furnished and installed by the utility company up to the incoming line terminations in the ac switchgear. The substation equipment shall conform to the following requirements:

1. The minimum cable size shall be based on a 750-MVA fault-availability for a 13.8-kV system.
2. Cable ratings shall be based on the 100-percent load factor and two-hour rating of the rectifier transformer.
3. The sizes of high-voltage cables installed in air or in raceways shall be based on appropriately de-rated current carrying ratings.
4. The sizes of medium-voltage cables installed in underground embedded raceways shall be based on a 25° C earth temperature with appropriate de-rating factors applied for the number of loaded circuits in the underground duct bank.

7.7.2 15-KV AND 35-KV CLASS CABLES

Cables shall be three-conductor, shielded, with insulated copper conductors, designed for a 100-percent insulation level, cabled together with a bare copper grounding conductor in a common overall jacket. The cables shall have low-smoke Halogen-Free jackets and shall be suitable for use in wet or dry locations and rated 90° C conductor temperature for normal operation; 130° C for emergency operation; and 250° C for short-circuit conditions.

7.8 TRACTION SUBSTATION MISCELLANEOUS SYSTEMS

7.8.1 TRACTION SUBSTATION AUXILIARY POWER

An auxiliary transformer shall be provided for transforming the medium-voltage supply to 480 Y/277 volts. The transformer shall be of sufficient capacity to provide the total auxiliary power requirement for the substation, such as lighting, convenience outlets, switchgear heaters, and building heating, ventilation and air conditioning (HVAC).

7.8.2 SUBSTATION CONTROL POWER

A battery and charger system shall be provided to supply dc control power for all substation equipment. The battery shall be maintenance-free, lead-calcium type, sized to handle dc loads for a minimum of three hours.

7.8.3 INTRUSION AND FIRE ALARM

Intrusion alarm and smoke detectors shall be provided in each substation. The alarms shall enunciate locally and at the OCC upon activation.

7.8.4 COMMUNICATIONS

Each substation shall be provided with an emergency telephone connected to the OCC and a local-service telephone.

7.8.5 SCADA INTERFACE

Remote supervision and control of substation equipment shall be provided by the SCADA system. For this purpose, SCADA PLCs or RTUs shall be provided in each substation. These units shall interface with the communication link for remote control and supervision from the OCC.

7.9 SUBSTATION GROUNDING

Each substation shall be equipped with a 2" x ¼" copper ground bus and necessary extension cabling to a substation ground grid, as required, to obtain a maximum resistance to earth of 2 ohms.

Non-current-carrying metal enclosures or parts of ac equipment, including ac apparatus and rectifier-transformers, shall be securely grounded to the ground grid.

The dc traction power distribution shall be operated as an ungrounded system. Enclosures for traction power rectifiers, dc switchgear and dc busways shall be installed insulated from ground on their support surfaces. A high-resistance ground and hot-structure protective system shall be provided that shall enunciate when the dc enclosure is grounded, and shall trip and lock out the dc breakers when the enclosure is energized. Adequate insulated sections shall be provided where metallic structures interconnect grounded and ungrounded equipment, (e.g., the bus connection between rectifier and rectifier-transformer).

A solid state automatic grounding switch shall be provided for safety to monitor the running rail-to-ground potential during train operation, or catenary-to-ground fault. This switch shall automatically connect the running rail to the substation ground bus if the voltage rises above a preset value of 35 volts (to be confirmed during final design).

7.10 CORROSION CONTROL

TBD

8.0 SIGNALING

8.1.1 SCOPE

This chapter establishes design criteria for the busway signal system and equipment required for safe and efficient vehicle operation throughout Silver Line Phase III territory including the tunnel section between Boylston St. and the Phase II portal in South Boston; as well as all Phase III areas where conflicting moves can occur.

8.1.2 STANDARDS, CODES AND GUIDELINES FOR BOTH OPTIONS

The latest edition of the following standards, codes, and guidelines shall be used for design, installation, and testing of the signal system:

- American Railway Engineering and Maintenance-of-Way Association (AREMA), "Communication & Signal Manual of Recommended Practice"
- Federal Railroad Administration (FRA), where applicable
- Federal Highway Administration, "Manual of Uniform Traffic Control Devices" (MUTCD)
- National Electric Code
- National Electrical Safety Code
- Insulated Cable Engineers Association
- American Society for Testing and Materials
- American National Standards Institute
- Underwriters' Laboratories, Inc.
-

8.1.3 SYSTEM DESCRIPTION

The signal system shall be based on line-of-sight. The system shall be compatible and capable of operating with the existing Silver Line Phase II system and environment.

The system will include wayside signals providing the vehicle operator with an indication of route conditions ahead.

8.1.4 DESIGN OBJECTIVES

The signal system shall ensure safe vehicle operation by utilizing fail-safe principles and shall perform the following functions:

1. Prevent rear-end collision;
2. Prevent head-on collision by vehicles in opposing routes;
3. Detect the presence or absence of vehicle on any portion of the busway with potential conflicting routes;
4. Prevent conflicting signal indications from being established.

All equipment will be designed to operate reliably and without damage over a temperature range of minus 40 degrees C to plus 70 degrees C.

The major signaling equipments will be designed to be located as follows:

1. Way side:

   - Wayside signals; vehicle-to-wayside loops/antennas; microprocessor modules; power supplies; cable entrance terminals and local control panels.

2. Vehicle Equipment:

   - Vehicle-to-wayside transponders and control panel

8.1.5 SYSTEM SAFETY

Safety shall be the prime consideration in design of the signal system and in the selection of their components and equipment. All safety-related functions shall be designed using fail-safe principles. All circuits and systems shall be protected from all the types and effects of external interference, such as cross-talk, low-resistance ground paths, power transients of any kind, radio-frequency interference, arc transient and similar effects. In no case shall such interference cause unsafe operation of either system.

The following requirements govern the design of all portions of the system or subsystems which affect vehicle safety:

1. Only components with high reliability and predictable failure modes or rates that have been proven in conditions similar to the projected service will be utilized.

2. Components will be combined in a manner that ensures a restrictive rather than a permissive condition will result from component failure.

3. All circuits not confined to one housing, and that affect safety, will be double-wire, double-break.

4. The design will be based on closed-circuit principles.

5. Component or system failures will cause a more restrictive signal indication than that permitted with no failure. Built-in fault-detection and alarm-generation capability is preferred.

6. System safety design will be such that any single independent component or subsystem failure will result in a safe condition. Failures that are not independent will be considered in combination as a single failure and will not cause an unsafe condition.

7. Electronic-circuit design will ensure the following types of component failures have a restrictive rather than permissive effect:

Two terminal devices: open; short; partial open or short
Multi-terminal devices: combination of opens, shorts, partial opens and/or partial shorts

1. Wherever possible, built-in checks will be included to impose a restriction and/or activate an alarm whenever a device required assuming its most restrictive position, fails to do so.

2. Redundant design by itself will not be considered an acceptable method of achieving design safety.

8.1.6 HEADWAYS AND BLOCK LAYOUT

The signal system shall be capable of supporting a minimum of 74 vehicles per hour traveling in the section tunnel between Boylston St. and the Phase II portal in South Boston with an average headway of approximately 48 seconds.

8.1.7 WAYSIDE SIGNALS AND SIGNS

Wayside signal heads shall be standard railroad type, complete with doublet outer lens, color inner lens, blank cover plates, and all mounting hardware. The signal heads shall include adjustable lamp transformer in each control wire circuit, and two single-contact candelabra two-pin bayonet bases. Signals shall be capable for tunnel-wall and mast-mounted installations. Signals will be located to the right side of busway. Each wayside signal will be identified by a signal number. Signals will be lit by ac energy directly. Double-filament lamps shall be used.

Signals shall be located along the dedicated busway. Signals shall be installed at both ends of station platforms, at intermediate location and at locations with limited line of sight.

Signal displays shall be as follows:

Aspects	Indication
Red	Stop and Stay
Flashing Yellow	Proceed with caution (with maximum of speed 10mph)
Yellow	Proceed

Fixed reflective wayside signs shall be installed in both traffic directions and shall provide information on the speed and condition of route ahead.

8.1.8 SIGNAL EQUIPMENT HOUSING

Housings for signal equipment shall be of weathering steel or aluminium construction and shall be equipped with shelves, racks, doors and all associated hardware to properly secure the equipment. Signal equipment housings shall provide sufficient space to house signal equipment with 20% spear space. Signal equipment housings shall be pre-wired and prefabricated to the greatest possible extent. To facilitate maintenance, all racks shall be accessible both front and back (hinged racks permitted for wall-mounted racks).

8.1.9 SIGNAL CABLE

Stranded wire and cable of standard sizes will be used for interconnection of signal apparatus. External signal cable shall be of rugged construction suitable for direct burial, and shall have insulating and jacketing materials capable of a 40-year average service life. Within tunnels and station platforms locations, low-smoke, non-toxic cables shall be provided. Cables shall be suitable for use in the environments encountered in the Boston Bay area and shall be certified for continuous operation at 90 degrees C in wet or dry locations. All signal cables supplied shall meet or exceed the requirements and applicable standards of ICEA, ASTM and AREMA. A minimum of 10-percent spare conductors shall be provided in each cable.

8.1.10 POWER SOURCES AND SYSTEMS

All signal equipment shall require electrical service no greater than 120 VAC, 60 Hz. Batteries will be used for wayside equipment where recommended by the manufacturer.

8.1.11 VEHICLE TO WAYSIDE COMMUNICATIONS (VWC)

The VWC shall be utilized to provide the following data functions: vehicle identification, automatic routing, data transmission, sign display and vehicle tracking, with a minimum of 10-percent spare bits The vehicle-carried portion of the VWC system will consist of transponders and control units. The wayside portion will consist of antennas and a wayside transceiver. The car-borne transponder will transmit a message identifying the car number, vehicle number, route number and other information.

Wayside traffic controllers will be used to analyze AVI detection information for appropriate signal displays. The signal displays will indicate route occupancy ahead and will provide authorization for vehicle entrance to the areas with limited line of sight; including the loop areas and merge points.

The AVI and the traffic controller data will also be used for monitoring the tunnel area vehicle movements, from a remotely located control center.

The signaling system will integrate with the Traffic Management System and station Passenger Information System to provide vehicle arrivals and destinations information.

The signaling system will be capable of providing automatic vehicle dispatching at station areas with the ability of local manual operation. The vehicle dispatching functions will facilitate optimal utilization of platform capacity for timely embarking and disembarking of passengers and minimize vehicle queuing near station platforms as well as vehicle dispatching during emergencies.

9.0 COMMUNICATIONS SYSTEMS DESIGN CRITERIA

9.1 SCOPE

This document is a compilation of design criteria for the communications system of the Phase III of the Silverline Bus Rapid Transit Project. This document provides a list of applicable standards as well as basic functional and performance requirements of the communication system. It is however not intended to prescribe specific technologies or approaches nor is it intended to preclude continued investigation of new technologies.

9.2 CODES, STANDARDS, AND SPECIFICATIONS

Unless otherwise specified herein, the design shall be governed by the standards, policies, guidelines and specifications listed below with all the addenda, supplements and revisions thereto. Where applicable standards conflict, the most stringent shall apply.

- National Intelligent Transportation Systems (ITS) Architecture, U.S. Department of Transportation ITS Joint Program Office (version 5.0 or latest),
- National Transportation Communications for ITS Protocol (NTCIP)
- American Association of State Highway and Transportation Officials (AASHTO).
- American Society for Testing and Materials (ASTM)
- Institute of Transportation Engineers (ITE)
- National Electrical Manufacturers Association (NEMA)
- Society of Automotive Engineers (SAE)
- National Intelligent Transportation Systems (ITS) Architecture, U.S. Department of Transportation ITS Joint Program Office
- Intelligent Transportation Systems Architecture for the Metropolitan Boston Region, Massachusetts Highway Department, 2003
- American National Standards Institute (ANSI)
- Electronic Industries Association (EIA)
- EIA Standard RS-603 Land Mobile FM and PM Communications Measuring and Performance Standard
- MIL-STD 810 C&D Rugged Environment Standards
- Federal Communication Commission (FCC) 49 CFR
- Institute of Electrical and Electronics Engineers (IEEE) standards.
- National Fire Protection Association (NFPA)
- All applicable Underwriters' Laboratories, Inc. (UL) Standards
- Electrical, fire and safety codes of applicable local jurisdictions
- National Electric Code (NEC)
- Americans with Disability Act (ADA) of 1990
- Telecommunications Industry Association (TIA)

9.3 COMMUNICATIONS SYSTEMS

9.3.1 GENERAL

The fundamental objective of the Silver Line Phase III communications system is to provide a secure, high-speed and reliable platform for transmission of voice, data and video to support operations and security functions of the Silver Line.

- Due to the phased deployment of the Silver Line, the technologies and design approaches selected by the designer must be compatible with the existing systems to the extent possible with allowance for substantial expansion and technology migration.
- The design of communications system shall incorporate, to the extent possible and desirable, existing communications systems, components, and protocols from the Silver Line Phase I and II communications systems.
- The design shall provide operators at the OCC on 45 High Street with direct access to control and monitor the security, facilities and ITS components of the entire Silver Line.
- The design shall allow partial access and limited control on the selective security, facilities and ITS operations to agencies as authorized by MBTA.
- The design of the communications system shall be consistent with all applicable standards and protocols of standard setting agencies such as IEEE, FCC, NTCIP, and NEC etc.
- The communications network must be fashioned on "best practices" of the communications industry and should be considered for any new investments. The network should be:
- ***Needs Based***: Across all disciplines that require communications between facilities and/or devices;
- ***Reliable***: Meet industry standard performance parameters;
- ***Scalable***: Can be expanded and augmented seamlessly;
- ***Flexible***: Can serve a multitude of applications and interface requirements;
- ***Dimensional***: Provides the capacity to meet current and future requirements;
- ***Standards Based***: Equipment and system specifications must meet industry ubiquitous standards consistent with all applicable standards and protocols of standard setting agencies such as IEEE, FCC, NTCIP, and NEC etc.;
- ***Maintainable***: Equipment and systems are maintainable utilizing universal network management applications;
- ***Cost Effective***: Equipment and systems are cost effective and universally available from multiple suppliers.

9.3.2 FUNCTIONAL REQUIREMENTS

The communications system component provides the audio, video and data links to integrate the various ITS, security and facilities components at the stations and in the tunnels.

The communications backbone network shall be designed to support secure, high-speed packet based communications between network elements and shall be designed for high reliability.

Transmission path diversity shall be provided throughout the network to ensure a single point of failure in the network does not result in loss of communications.

High up-time goals shall be supported by path diversity. The alternate paths shall be designed to either be used concurrently with the primary path or as a 'standby' that is continually monitored for its readiness.

The design should allow switchover to and from the alternate path to occur without operator's intervention, without loss of information, and with the appropriate change-of-status report to the operator. The performance should not degrade as a result of using alternate paths.

The system shall also be self-monitoring by providing automatic tests and diagnostics to alert the operator of malfunctioning equipment and status of the line and equipment information.

The network shall be designed to allow equipment moves, adds and changes to the end-user equipment configuration with minimal new circuit provisioning.

The Operations Control Center (OCC) at 45 High Street shall be provided with direct access and control to the surveillance systems, telephone and radio trunks to all points through out the network.

9.4 VOICE NETWORK

The voice network is comprised of two main components:

1. Fixed telephone circuits for MBTA administrative, operations, emergency assistance, passenger assistance and public address purposes.

2. Mobile communications system that supports communication with the vehicle operator during regular vehicle operations and interagency communications during an emergency.

9.4.1 TELEPHONE NETWORK

A packet based network shall be designed to transmit voice signals for administrative and station operation purposes. This network shall support inter station, station to OCC communication, public address operation and public telephone systems. The system shall be designed to support both voice over data channel communications and integration with legacy circuit switched network elements.

A dedicated network shall be designed to provide non-dialled point-to-point direct voice communications to agencies listed below for emergency operations:

- MBTA Police
- Boston Fire Department
- State Police
- Boston Emergency Medical Service
- MBTA
- Massachusetts Highway Department
- Boston City Police

9.4.2 RADIO SYSTEM

The radio system shall be designed to facilitate voice communications within the tunnel for a mobile to mobile and mobile to Operations Control Center communications for the following services:

- Vehicle operator communication
- Police
- Emergency medical services
- Tunnel operation and maintenance personnel

The command and control radio system for the MBTA utilizes an 821MHz, trunked, digital radio system operating on 20 channels. It uses 5 dedicated channels for polled CAD/AVL data and the remaining 15 channels for voice communications. One complete set of base stations, covering all 20 channels, shall be located in one of the communications rooms. These radios shall be fully compatible and interoperable with the MBTA's existing 821 MHz system.

The RF signal for the trunked radio system shall be generated by these base stations, using audio and control signals from the control center. The RF signals shall undergo an E/O conversion and shall be distributed to the other Silver Line communications rooms over the fiber optic cable installed under this contract.

The signals shall undergo an O/E conversion in the communications room. The "electrical" RF signal shall then be conveyed to directional antennas located in the tunnels using low loss coaxial cable. The location of these directional antennas shall be dictated by the tunnel dimensions to facilitate the use of the tunnel itself as a radio wave guide.

This system shall also be capable of transmitting and receiving signals for first responder agencies such as Boston Police Dept., Boston Fire Dept., and Boston EMS. This may be accomplished through the use of parallel systems, using each of the agencies frequencies or and IP based "back room" network that is capable of translating frequencies an nullifying the effects of proprietary coding schemes used by many radio system manufacturers. Such a "back room" solution shall provide a virtual open air interface that will provide full interoperability for all users.

The method chosen must provide full interoperability and shall be demonstrated to, and approved by the MBTA prior to final design and implementation.

9.4.3 RADIO PROPAGATION STUDIES:

A radio propagation study shall be conducted for all of the surface areas of the Silver Line, using the MBTA's existing 821 MHz, System Wide Radio. The study shall ensure that radio coverage from the existing radio system is adequate to cover all Silver Line corridors.

If adequate cover does not exist, additional sites shall be planned to provide the necessary coverage.

Normal propagation models are not suitable for predicting signal levels in the tunnel sections so calculations shall be submitted to support the placement and signal levels for all antennas. The design signal level shall provide a minimum of –100 dBm inside the vehicle for a design margin of 15 dBm.

All mobile units shall be designed in accordance with applicable MIL standards and are required to provide identification codes at the beginning of each transmission, and be fully compatible and interoperable with the existing 821 MHz trunked radio backbone.

All tasks undertaken in relation to the mobile communication system shall comply with Federal Communications Commission (FCC) and Institute of Electrical Engineers (IEEE).

9.4.4 VIDEO NETWORK:

The video network shall support transmission of video from cameras located in the tunnel and stations for security and operation purposes.

The video network shall be packet based and shall be designed to support transmission of packet video (example: IP video) and integration with legacy switched network elements.

To the extent possible and desirable, the video network shall interface with the existing video system components from the Silver Line Phase I and II at the OCC.

The surveillance network images along with Camera ID, date and time-of-day information shall be available at all times to the operator at the OCC. The operator shall be able to view images from any camera on any monitor and observe real-time video for any duration of time.

The system shall be designed to achieve video quality at the control center to meet or exceed RS-250C medium haul specification. The design shall require that CCTV video quality be measured over the entire video path, from camera through links and switches to monitor.

The video network shall also support video distribution and provide control to agencies across the interagency network as designated by the MBTA.

9.4.5 NETWORK

The data network supports control and monitoring of ITS/security equipment and other facilities such as ventilation, climate control, fire detection and power systems.

The status of these devices shall be available at all times to the operator at the OCC. The operator shall be able to monitor and observe the real-time status of these devices continuously.

The data network shall also allow access to control and monitor selective devices by other agencies authorized by the MBTA.

- Some other items that might need addressing:
- SCADA SYSTEM
- Bandwidth requirements
- Risk of obsolescence of existing network technology
- Current and future applications to be supported
- Interfaces needed to support applications
- Emerging technologies

9.5 INTELLIGENT TRANSPORTATION SYSTEMS (ITS)

9.5.1 SCOPE

This chapter describes the Intelligent Transportation Systems (ITS) components of Silver Line Phase III and system-wide upgrades for the full-build operation.

The purpose of the Silver Line ITS components is to support safe, reliable, robust, and efficient BRT service through the use of coordinated and integrated monitoring and control infrastructure that:

- Uses data collection and monitoring systems to maintain consistent service headways under normal operating conditions;
- Supports incident response and dispatch functions under abnormal or emergency operations;
- Provides maximum utilization of infrastructure to support surveillance, security, and safety requirements;
- Provides accurate, real-time passenger information to support pre-trip, in-station, and in-vehicle information needs;
- Is compatible, to the extent possible and desirable, with existing Silver Line ITS infrastructure designed for Phases I and II;
- Interfaces with MBTA-wide ITS systems, including the fare collection system and website;
- Supports information, video, and voice data exchange with external entities that are critical to Silver Line operations and safety, including the MBTA police and numerous city and state transportation and emergency response agencies;

This document represents design criteria for the full-build ITS system. ITS and communications components designed for the beginning of revenue service shall include the flexibility, scalability, and robustness to support all system functionality described herein.

9.5.2 STANDARDS, CODES, AND GUIDELINES

The latest editions of the following standards, codes, and guidelines shall be used, as applicable, for the design and implementation of Silver Line ITS:

- National Intelligent Transportation Systems (ITS) Architecture, U.S. Department of Transportation ITS Joint Program Office (version 5.0 or latest), http://itsarch.iteris.com/itsarch/
- National Transportation Communications for ITS Protocol (NTCIP), (AASHTO (American Association of State Highway and Transportation Officials); ANSI (American National Standards Institute); ASTM (American Society for Testing and Materials); IEEE (Institute of Electrical and Electronics Engineers); ITE (Institute of Transportation Engineers); NEMA (National Electrical Manufacturers Association); SAE (Society of Automotive Engineers)), www.itsstandards.net.
- National Transit Communications Interface Protocol (TCIP) (NTICP 1400:2000-1408:2000), (AASHTO (American Association of State Highway and Transportation Officials); ITE (Institute of Transportation Engineers); NEMA (National Electrical Manufacturers Association)).
- National Intelligent Transportation Systems (ITS) Architecture, U.S. Department of Transportation ITS Joint Program Office (latest version)
- Intelligent Transportation Systems Architecture for *the Metropolitan Boston Region*, Massachusetts Highway Department et. al., 2003
- American National Standards Institute (ANSI)
- Electronic Industries Association (EIA)
- EIA Standard RS-603 Land Mobile FM and PM Communications Measuring and Performance Standard
- MIL-STD 810 C&D Rugged Environment Standards
- Federal Communication Commission (FCC) 49 CFR
- Institute of Electrical and Electronics Engineers (IEEE)
- National Fire Protection Association (NEPA)
- All applicable Underwriters' Laboratories, Inc. (UL) Standards
- Electrical, fire and safety codes of applicable local jurisdictions
- Americans with Disability Act (ADA) of 1990
- Telecommunications Industry Association (TIA)

9.5.3 INTELLIGENT TRANSPORTATION SYSTEMS

9.5.3.1 General Requirements

The Silver Line ITS system shall support phased deployment through a modular and scalable design, permitting implementation or upgrade of ITS systems, hardware, or software, either during construction OR at any time during the operating life of the Silver Line;

The Silver Line ITS system shall incorporate system redundancies that maintain, to the fullest extent possible, normal operations, monitoring, and security levels during the failure of individual systems or components;

The Silver Line ITS system shall allow all ITS systems to be controlled from a single operator console through a customized integrated user interface;

The Silver Line ITS system shall, to the extent possible, allow individual ITS devices or components to support multiple ITS functions (e.g., combined operations and security cameras);

The Silver Line ITS system shall be consistent with MBTA, Regional, State, and National ITS Architectures, as well as national ITS standards and protocols.

The Silver Line ITS System shall utilize open architecture design principles to the fullest extent possible without compromising system functionality, security, scalability, or robustness.

The Silver Line ITS System shall interface with existing and planned MBTA-wide ITS systems, standards, and protocols (e.g., fare collection and website).

The Silver Line ITS System shall incorporate, to the extent possible and desirable, existing ITS systems, components, and protocols from the Silver Line Phase I and II ITS Systems.

9.5.3.2 Headend Systems/Operations Control Center (OCC)

System design shall permit complete operation and control of the Silver Line ITS system from a single operator console located in the Operations Control Center (OCC) at 45 High Street via secure dedicated networks.

The system shall also permit full or partial operations from remote locations to be specified by the MBTA, such as the MBTA Mobile Command Center and the Massachusetts Emergency Management Agency (MEMA) headquarters in Framingham.

The Silver Line ITS system shall support sharing of relevant emergency management and traffic management video, data, and voice communications with the following entities:

- MBTA Police Department
- City of Boston Police Department
- City of Boston Fire Department
- Boston Transportation Department (BTD)
- Massachusetts Highway Department (MassHighway)
- Central Artery/Tunnel (CA/T)
- Massachusetts Turnpike Authority (MTA)
- Massachusetts Port Authority (Massport)

The availability of this system (functionality and coverage) shall be not less than 99.9% of the time the system is in use.

9.5.3.3 CCTV Video Surveillance

The Silver Line ITS System shall provide system-wide Closed Circuit Television (CCTV) video surveillance to support operations, security, emergency/incident management, and facilities management functions.

The video surveillance system shall provide video surveillance coverage the following areas:

- Public areas within underground stations, including:
- Station platforms
- Station fare lines
- Station manager booths
- Elevators and escalators
- Corridors, stairways, and passageways
- Lobbies and mezzanines
- Headhouses
- Access-controlled locations, including:
- Secured doorways
- Power substations
- Safe rooms

- Communications and equipment rooms
- Pumping stations
- Critical tunnel segments
- Tunnel merges and intersections
- Vehicle staging areas
- Mode change locations
- Portal areas and transition "boat" sections
- Critical roadway segments with mixed-traffic operations (e.g. intersections, pedestrian crosswalks)
-

In areas identified as critical to Silver Line security, operations, emergency/incident management, and/or facilities management, redundant video coverage shall be provided, such that no single point of system failure results in a loss of video coverage.

In areas outside of MBTA-controlled rights of way (e.g., city streets), the video surveillance system may provide coverage via video sharing from other agencies where available.

Video images shall be integrated with the Silver Line OCC Graphical User Interface (GUI) such that real-time video images can be viewed through a fully integrated software interface.

The system shall support sharing of real-time video images with external entities via secure networks to support security, traffic management, and incident/emergency management functions, as outlined previously in this document.

The system shall support both static and pan-tilt-zoom (PTZ) hardware, as dictated by functional requirements and field conditions at each camera location. Control of PTZ cameras shall reside at the Silver Line OCC at 45 High Street, with the capability to transfer this control to alternate locations to be determined.

Optical requirements, resolution, filters, environmental requirements, etc. shall be determined based on the field conditions at each camera location.

Onboard surveillance capability shall be provided on all Silver Line coaches used for revenue service. Internal and external cameras shall provide sufficient coverage of the bus exterior, the passenger compartment, doors, and the farebox area, as dictated by MBTA policy. At least one interior camera view (preferably farebox view) shall include the MBTA-assigned vehicle number.

Video images from onboard surveillance shall be continuously recorded (utilizing a digital onboard recording device) from all cameras for a minimum of 72 hours. If a Silver Line Operator activates the silent alarm, recorded video shall be write-protected from the time of that alarm forward.

When a Silver Line Operator activates the vehicles' silent alarm, the OCC Dispatcher shall assume control of the onboard video surveillance system, with the ability to transfer control to emergency response personnel.

The system shall support wireless download of video images from Silver Line coaches anywhere in the Silver Line tunnel, on-street route, and non-revenue service areas (e.g. maintenance garages and routes thereto).

The availability of this system (functionality and coverage) shall be not less than 99.0%. Higher availability may be mandated for security- or operations-sensitive locations.

9.6 AUTOMATIC VEHICLE LOCATION (AVL)/AUTOMATIC VEHICLE IDENTIFICATION (AVI)

The Silver Line ITS System shall provide the functional capability to locate Silver Line revenue and non-revenue vehicles at any location above ground and anywhere within the Silver Line Tunnel using Automatic Vehicle Location (AVL) and Automatic Vehicle Identification (AVI) technology.

AVL/AVI systems shall be capable of identifying individual vehicles and interfacing with mobile data terminals (MDTs) and computer aided dispatch (CAD) software to determine driver identification, route, schedule adherence, and other related information.

AVL/AVI systems shall be capable of interfacing with tunnel signal, traffic signal, and portal security systems to provide positive identification and authentication of vehicles and drivers, and to support traffic signal priority, tunnel signal control functions, portal access, and passenger information.

Coverage of the Silver Line AVL/AVI system shall be at least 99% along the Silver Line Full-Build Alignment (all service routes), and at least 95% within the boundaries of the City of Boston.

The accuracy of vehicle location systems on the surface and within the tunnel shall be within +/- 3.0 meters of actual location.

The availability of this system (functionality and coverage) shall be not less than 99.0% during revenue and non-revenue operations. Higher availability may be mandated for sensitive locations.

9.6.1 PASSENGER INFORMATION SYSTEM

The Silver Line ITS System shall incorporate a Passenger Information System to support traveler information, safety, and security functions.

The Passenger Information System shall be designed to permit maximum dissemination of Silver Line information among a wide variety of devices to support pre-trip, en-route, and onboard information requirements of passengers. Devices may include, but are not limited to:

- In-station Variable Message Sign (VMS) displays;
- In-station Public Address Systems;
- On-Board Public Address/Variable Message Sign (PA/VMS) systems;
- Third-party information service providers, e.g., SmarTraveler;
- Traveler Information Kiosks
- MBTA and External Websites;
- MBTA Customer Information Telephone and regional "511" traveler information Interactive Voice Response (IVR);
- Web-enabled devices such as personal digital assistants (PDAs) and cellular phones;
- Other internal notification techniques including email, pager, and fax messaging.

The Passenger Information System shall utilize a set of rules to determine the priority of message display/announcement when a device receives multiple information requests. Where possible, scrolling or loop formats shall be utilized to permit conveyance of multiple messages.

Message display/announcement priority shall be as follows:

- Emergency/evacuation/alarm messages (highest priority)
- Real-time service announcements

- Static Silver Line service announcements
- Static MBTA-wide service announcements

The Silver Line passenger information system shall permit exchange of information with MBTA-wide and External systems in accordance with relevant ITS architectures.

The passenger information system shall utilize standard MBTA, NTCIP, and/or TCIP protocols as appropriate to permit maximum portability and exchange of Silver Line information among ITS systems and with MBTA-wide and external passenger information systems.

Passenger Information Systems shall be compliant with the Americans with Disabilities Act (1990) and subsequent revisions.

The availability of this system (functionality and coverage) shall be not less than 99.0% of the time the system during revenue service hours.

9.6.2 PUBLIC ADDRESS/VARIABLE MESSAGE SIGN (PA/VMS)

The Silver Line ITS System shall support a Public Address/Variable Message Sign (PA/VMS) system to disseminate Silver Line, MBTA, and emergency public announcements. The PA/VMS system shall consist of both Passenger Station and Onboard components.

The station PA/VMS system shall allow the announcement and display of the following information types in Silver Line Passenger Stations:

- Real-time vehicle arrival estimates (via interface with CAD/AVL system)
- Silver Line service announcements (from OCC or station manager)
- MBTA-wide service announcements
- Emergency management/evacuation

The onboard PA/VMS system shall allow the announcement and display of the following information types on Silver Line Vehicles:

- Station arrival announcements (via interface with CAD/AVL system)
- Route identification
- Silver Line service announcements (from OCC or station manager)
- MBTA-wide service announcements
- Emergency management/evacuation announcements

The PA/VMS system shall be fully integrated with other elements of the passenger information system to ensure consistency and completeness of information provided.

The PA/VMS system shall be compliant with the Americans with Disabilities Act (1990) and subsequent revisions.

The availability of this system (functionality and coverage) shall be not less than 99.0% during revenue service hours.

9.6.3 AUTOMATIC PASSENGER COUNTERS (APCS)

The Silver Line ITS System shall incorporate an Automatic Passenger Counting (APC) system to support load management, emergency management, and data collection for service planning.

Automatic Passenger counting equipment shall be provided to allow accurate determination of the following passenger tallies:

- Onboard passengers (each vehicle)
- Passengers on platform (at each station, in each direction)
- Number of passengers entering and existing stations (for each fareline)

The APC system shall provide minimum 99% accuracy for onboard passenger and station fareline counts, and 95% accuracy for station platform counts. The system shall have sufficient accuracy to meet MBTA and National Transit Database (NTD) reporting standards without manual intervention.

The APC system shall incorporate an automatic periodic re-calibration feature, not less than once per day, to "zero" passenger counts to eliminate cumulative errors.

Technologies utilized for the APC system shall be operable in all revenue service conditions (weather, lighting, etc.) and shall provide the required passenger count accuracy in the presence of normal passenger objects such as guide dogs, carts, parcels, etc.

The availability of this system (functionality and coverage) shall be not less than 99.0% during revenue service.

9.6.4 TRAFFIC SIGNAL PREEMPTION

The Silver Line ITS System shall incorporate a traffic/transit signal pre-emption priority system to regulate the movement of Silver Line vehicles and general traffic in the following areas:

- Mixed-traffic intersections of surface Silver Line Routes;
- Silver Line tunnel portal entrances;
- Special conflict areas, e.g., Emergency vehicle priority areas.

Operations protocols for traffic/transit signal priority systems shall be determined in consultation with the MBTA, the City of Boston Transportation Department, and emergency management agencies, as in accordance with specific field circumstances.

Traffic/transit signal priority systems shall be integrated with the Silver Line CAD system at the OCC to support schedule adherence functionality.

Where possible and desirable, traffic/transit signal pre-emption priority system shall be compatible with existing systems utilized by the Boston Transportation Department, police, fire, or EMS agencies.

Operations protocols for traffic/transit signal priority systems shall be determined in consultation with the MBTA, the City of Boston Transportation Department, and emergency management agencies, as in accordance with specific field circumstances. This includes, but is not limited to: protocol for initiating traffic/transit signal priority requests, threshold conditions, authorization by the Boston Transportation Department, and emergency vehicle override provisions.

The availability of this system (functionality and coverage) shall be not less than 99.0% during revenue service. Higher availability may be mandated for sensitive locations.

9.6.4.1 Portal Pedestrian Safety System

The Silver Line ITS system shall incorporate active pedestrian safety devices in the areas of pedestrian-vehicle conflict, including portals, station platform areas, crosswalks, and subterranean vehicle staging areas.

Pedestrian Safety Devices shall be vehicle actuated to provide warning of the presence of Silver Line vehicle(s) in the vicinity. Additionally, vehicle operators shall have the capability to manually activate pedestrian warning signals.

Pedestrian Safety Systems shall be integrated with traffic signal, traffic signal pre-emption, portal security, and/or tunnel signal systems that regulate the movement of Silver Line vehicles in and around pedestrian conflict zones.

Portal area pedestrian safety devices shall be compliant with the Americans with Disabilities Act (ADA) of 1990 by providing a combination of audio, visual, and/or tactile warnings to pedestrians.

Warrants for pedestrian warning devices shall be determined in accordance with Institute of Transportation Engineers (ITE) standards where applicable.

The availability of this system (functionality and coverage) shall be not less than 99.0% during all revenue and non-revenue vehicle operations.

9.7 Fare Collection Systems

Fare collection systems (e.g., turnstiles, fareboxes, vending/replenishment machines) shall be designed in accordance with MBTA system-wide fare collection design standards, including but not limited to: acceptable fare media; fare validation; revenue management; data collection; communications; and security.

9.8 LANE ASSIST VEHICLE GUIDANCE

Lane Assist technologies are under evaluation for the purposes of 1.) preventing collisions with the tunnel wall and 2.) allowing higher running speeds within the tunnel. Silver Line ITS and communication systems shall be designed to accommodate future implementation of electronic Lane Assist technologies (magnetic, optical, etc.)

9.8.1 PRECISION DOCKING

Precision Docking technologies are under evaluation to minimize vehicle-platform gaps to a range typical of fixed rail systems (approx. 2" or less), thereby decreasing passenger/wheelchair boarding and alighting times. Silver Line ITS and communication systems shall be designed to accommodate future implementation of electronic Lane Assist technologies (magnetic, optical, etc.)

9.8.2 ONBOARD VEHICLE SYSTEMS

Onboard equipment and electronics (e.g., Vehicle Logic Units, Mobile Date Terminals, Automatic Vehicle Identification (AVI)/Automatic Vehicle Location (AVL), fareboxes, engine sensors, surveillance cameras, alarms, communications systems, etc.) shall be designed to support the Silver Line system functionality described within the ITS and other pertinent Design Criteria.

Similarly, onboard sub-systems and components shall feature adequate robustness, scalability, and interoperability to support future upgrade of systems and individual hardware and software components by more than one vendor/vehicle manufacturer.

It is assumed that additional information on onboard systems shall be presented in the Dual Mode Articulated Vehicle Specification for Phase III.

Other Notes:

- Material assumed to be provided by others, not incorporated here:
- Fare Collection
- Signal System
- Security Systems, incl. portal safety devices, access control, alarms

Major onboard electronics (MDT, VLUs, vehicle stat monitoring, etc) have been excluded pending confirmation of the ITS contents of the Neoplan vehicle specification.

9.9 TRANSIT SERVICE DESIGN AND OPERATING CRITERIA

9.1 SCOPE

This section identifies functional and performance requirements for Silver Line Phase III Bus Rapid Transit service, as well as applicable guidance. It is intended to guide the design of system elements, not to set forth specific service plans (e.g. routes and service frequencies) for any particular design year.

9.2 DESIGN GUIDANCE

Design guidance from the following documents applies as indicated:

- MBTA *2004 Service Delivery Policy* as referenced in section X.3;
- Part 1 of the TRB *Transit Capacity and Quality of Service Manual*, 2nd Edition, for the definition of 'vehicle capacity'.
- Part 3 of the TRB *Transit Capacity and Quality of Service Manual*, 2nd Edition, for the definitions of 'coefficient of variation of headways' and 'standing passenger area'.

9.3 TRANSIT OPERATING CRITERIA

Service plans for the Silver Line Phase III shall be developed so as to satisfy the criteria in this section. Service plans shall include: route identification, stop or station locations, and both running times and frequency of service by time of day for each BRT route operating in or through the Silver Line III tunnel section.

9.3.1 STANDARD TRANSIT VEHICLE

The standard bus rapid transit (BRT) vehicle for the determination of capacity in section X.3.3 shall have the following characteristics:

- A bumper-to-bumper length not exceeding 61 feet;
- A vehicle width no greater than 104 inches;
- A minimum of 53 passenger seats;
- A minimum of 125 square feet of standing passenger area.

9.3.2 CUSTOMER LEVEL OF SERVICE

On sections of BRT route operating outside the tunnel, service levels shall be designed to meet the MBTA's *2004 Service Delivery Policy* for 'key' bus routes. For BRT services in the tunnel section:

- The coefficient of variation of headways for a specific BRT service over a three-hour peak period in either direction shall not exceed 0.40 times the scheduled service interval for that route at any time of day at any platform in either direction, both measured in minutes.
- The coefficient of variation of headways for a specific BRT service over the late evening period at any platform in either direction shall not exceed 0.25 times the scheduled service interval, both measured in minutes.
- Average portal-to-portal travel time in the slower direction shall not exceed 8.5 minutes in the late evening period
- Portal-to-portal tunnel average travel times in peak periods in either direction shall not exceed 11 minutes.
- Average transit vehicle occupancy in the three-hour peak periods through the tunnel (Boylston to World Trade Center stations inclusive), as measured by total person-miles in both directions divided total vehicle-miles in both directions, shall not exceed the number of seats on standard vehicles as defined in section 9.3.1
- Average transit vehicle occupancy at the maximum load point in the heavier travel direction in the tunnel during either the AM or PM peak hours shall not exceed 80 on standard vehicles as defined in section 9.3.1.

9.3.3 THROUGHPUT AND CAPACITY

The Silver Line Phase III tunnel shall be, in conjunction with Silver Line elements already in place under normal conditions, able to sustain operations carrying the required design peak period passenger loads for both the AM and PM peak periods while meeting the customer level of service requirements for peak periods in section 9.3.2. This design throughput requirement will be proportional to projected peak passenger volumes at the most heavily-travelled tunnel segment.

The vehicle capacity past any point in the Silver Line Phase III tunnel shall not be less than 25 percent greater than the design throughput.

10.0 MECHANICAL

10.1 SCOPE

This chapter contains mechanical criteria developed for the MBTA Silver Line Transitway system, excluding vehicles, yard and shop equipment. These criteria govern the functional requirements, operation and control of the heating systems, ventilation systems, air conditioning systems, water and sewerage systems, drainage facilities (except at-grade sections) and fire protection systems.

These criteria are intended to promote uniformity of design and standardization of equipment and its location through out the Transitway system.

10.2 STANDARDS, CODES AND GUIDELINES

The latest edition of the applicable standards, codes and guidelines of the following organizations shall be used for all designs unless otherwise required by this manual:

- Air-Conditioning and Refrigeration Institute (ARI)
- Air Movement and Control Association International (AMCA) Standard 210, "Laboratory Methods of Testing Fans for Rating Purposes"
- AMCA Standard 300, "Test Code for Sound Rating Air Moving Devices"
- AMCA Standard 301, "Methods for Calculating Fan Sound Ratings from Laboratory Test Data"
- American National Standards Institute (ANSI)
- American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc. (ASHRAE)
- American Society of Mechanical Engineers (ASME)
- American Society for Testing and Materials (ASTM)
- American Water Works Association (AWWA)
- American Public Transport Association (APTA), Rail Transit Committee, "Guidelines for Design of Rapid Transit Facilities", 1981
- Department of Transportation (DOT), "Recommended Emergency Preparedness Guidelines for Rail Transit Systems"
- International Building Code
- International Mechanical Code
- International Plumbing Code
- International Standardization Organization (ISO)
- Manufacturer's Standard Society (MSS)
- Massachusetts Architectural Access Board , 521 CMR
- Massachusetts State Building Code, Chapter 13 –" Energy Conservation"
- Massachusetts Uniform State Plumbing Code
- National Electrical Manufacturer's Association (NEMA)
- Occupational Safety and Health Act (OSHA)
- Safety Code for Mechanical Refrigeration
- Sheet Metal and Air-Conditioning Contractors' National Association (SMACNA)
- Underwriter's Laboratories, Inc. (UL)
- U.S. Department of Commerce, "Subway Environmental Design Handbook"
- The Americans with Disabilities Act (ADA) , 28 CFR Part 36
-

Particular references shall be made to the following sections of NFPA:

- NFPA Standard 10, "Portable Fire Extinguishers"
- NFPA Standard 13, "Installation of Sprinkler Systems"
- NFPA Standard 14, "Standpipe, Private Hydrant, and Hose Systems"
- NFPA Standard 20, "Installation of Stationary Pumps"

- NFPA Standard 54, “National Fuel Gas Code”
- NFPA Standard 70, “National Electrical Code”
- NFPA Standard 90A,”Installation of Air-Conditioning and Ventilating Systems”
- NFPA Standard 101, “Life Safety Code”
- NFPA Standard 130, “Fixed Guideway Transit and Passenger Rail Systems”
- NFPA Standard 204, “Smoke and Heat Venting”
- NFPA Standard 496, “Purged and Pressurized Enclosures for Electrical Equipment”
- NFPA Standard 502, “Standard for Road Tunnels, Bridges and Other Limited Access Highways”
- NFPA Standard 750, “Water Mist Fire Protection Systems”
- NFPA Standard 820, “Fire Protection in Wastewater Treatment and Collection Facilities”
- NFPA Standard 1963, “Fire Hose Connections”
- NFPA Standard 2001, “Clean Agent Fire Extinguishing Systems”

10.3 AIR CONDITIONING

10.3.1 SCOPE

The air conditioning concepts described in these criteria are applicable to the final configurations of the areas served, with mechanical equipment rooms located where indicated on the drawings. When subsequent configurations and equipment room locations vary from these design layouts, the systems shall be designed to adapt these concepts to suit special configurations or situations. This section covers the following areas:

Air conditioning systems, equipment, operation and controls for the following:

- Collector’s Booth (if used)
- Communications Room
- Elevator Machine Room
- Police Room
- Signal Room
- Starter’s Booth

10.3.2 DESIGN CONDITIONS

Cooling loads and system design shall be based on the following:

Location: Boston, MA.:

1. Outside summer design-conditions:

    - 87 degrees F dry bulb, 71 degrees F wet bulb (1 percent occurrence) in all air conditioned areas.
    - For air-cooled condenser sizing design, dry bulb temperature shall be 90 degrees F.

2. Inside design conditions coincident with outside, summer design-conditions:

    - 78 degrees F dry bulb, 55 percent relative humidity in all air conditioned areas.

10.3.3 SYSTEM CONCEPTS

Air conditioning systems, where the outside air supply is required, shall be designed so that air handling units can modulate from minimum outside air required for ventilation to 100-percent outside air.

System concepts shall be based on the Massachusetts State Building Code energy conservation guidelines.

Mechanical equipment and systems shall be designed so that the maximum noise levels generated and transmitted by the systems do not exceed allowable limits for interior or outdoor noise levels.

10.3.3.1 Air Handling Equipment

Air Handling Units

Air handling units shall include the following components:

1. Mixing plenum.

2. Opposed-blade motor-operated outside-and-return air dampers.

3. Replaceable filter section.

4. Direct-expansion and electric heating coil section.

5. Fan section: Fans shall be double-inlet, double-width (DIDW), or single-inlet, single-width (SISW), with non-overloading air-foil-type blades. Each fan shall be complete with: adjustable pitch V-belt drive, electric motor, vibration isolators for mounting of fan and motor base, belt guard, magnetic starter, local hand-off-auto fan switch, space thermostat. Electric motors for each fan unit shall be selected so that the fan power requirement at any point of the fan power-capacity curve does not exceed the horsepower rating of the motors. Fan outlet velocity shall not exceed 2,200 ft/min.

6. In determining the input power for fans, an air density of 0.0807 lbs per cubic foot (lbs/ft3) at 32 degrees F and 14.7 PSI shall be used.

7. Access to air-handling unit shall be provided for maintenance of fans, coils and filters.

10.3.3.2 Split Ductless Air Conditioning Units

Split ductless air conditioning units shall include the following components:

1. Indoor, wall mounted, direct expansion fan coil unit consisting of a cooling coil, fan, fan motor, electrical controls, microprocessor control system, integral temperature sensing, all mounted in an unit cabinet.

2. Air cooled outdoor unit with a propeller fan, hermetic type compressor, outdoor coil, refrigeration components, controls and safeties, all installed in an unit cabinet.

3. Field installed accessories, such as low ambient temperature kit, winter start control.

10.4 AIR DISTRIBUTION SYSTEMS

10.4.1 Design Air Velocities

Design velocities shall be selected to suit system performance requirements and to minimize noise, drafts and intake of dust particles. The maximum recommended velocities in air distribution systems are:

- Sheet Metal Ducts
- Branch supply duct: 1,200 ft/min

- Fresh-air intake duct: 1,200 ft/min
- Main exhaust and return ducts: 1,600 ft/min
- Branch exhaust and return ducts: 500 ft/min
- Transfer duct: 250 ft/min
- Air Outlets and Intakes
- Supply registers and diffusers: Size for throw and noise criteria
- Exhaust and return grilles: 500 ft/min over gross area
- Transfer grilles: 250 ft/min over gross area
- Transfer louvers: 250 ft/min over gross area
- Intake and discharge louvers: 500 ft/min over gross area

10.4.2 Ductwork

Ducts shall be sized by the static regain method, or for an equal pressure drop of 0.1-in.water gauge (w.g.) per 100 ft of duct, as appropriate. Maximum velocities shall not exceed those specified. Sheet metal ducts shall be constructed of galvanized steel, designed for medium air pressure operation with airtight joints, and sufficiently stiffened and supported to avoid sagging and vibration.

10.4.3 Supply Air Diffusers

Supply air diffusers shall be selected to provide the required throw and spread with the least amount of draft and noise. Supply air diffusers shall be provided with opposed blade damper, adjustable from the face of the diffuser.

10.4.4 Exhaust and Return Grilles

Exhaust and return air grilles shall be sized for the velocities indicated in this subsection. They shall be equipped with fixed, non-see-through blades or louvers, or the duct behind them shall be painted black. Grilles shall be equipped with opposed-blade, adjustable-volume dampers, key-operated through the face.

10.4.5 Volume Dampers in Branch Ducts

Adjustable volume dampers shall be provided for all branch ducts serving more than one outlet. The dampers shall be equipped with locking quadrants, and blades sufficiently stiffened at the edges to effectively close off the duct with no vibration under any condition of operation.

10.4.6 Splitter Dampers in Duct Fittings

Splitter dampers may be used in multiple duct fittings for initial balancing, instead of individual, opposed-blade volume dampers in each branch at the multiple duct fitting. These splitters shall be adjustable through quadrants, and shall be of the single-blade type with edges sufficiently stiffened to avoid vibration under all conditions of operation.

10.4.7 Fire Dampers

Fire dampers shall be provided in ducts where required by NFPA, International Building Code (IBC) and/or local codes, whichever is more stringent. Fire dampers shall be Type B and have UL approval.

10.4.8 Backdraft and Relief Dampers

Backdraft dampers shall be used on all exhaust fans. Weighted relief dampers shall be used in exhaust ducts and openings where positive pressure must be maintained by forced air supply and gravity exhaust.

Backdraft and relief dampers shall be of the multi-blade, gravity type with neoprene or felt cushioning on blade edges.

10.4.9 Extractors

Air extractors may be used in branch duct connections and for registers and diffusers where there is inadequate space for installing multi-blade volume dampers. Use moveable-blade, pivoted air extractors.

10.4.10 Turning Vanes

Elbows shall have a centerline radius of at least 1.5 times the width of the duct. Where full-radius curves are not feasible, provide elbows with single-thickness extended-blade turning vanes.

10.4.11 Dampers and Louvers

Dampers and louvers are to be rated in accordance with the latest revision of AMCA Standard 500, "Test Method for Louvers, Dampers and Shutters." Exterior wall louvers shall be storm-proof with maximum water penetration of 0.01 oz/sq ft at 650 fpm velocity.

10.4.12 Access Doors in Ducts and Plenums

Access doors shall be provided in ducts and plenums to allow servicing of dampers, duct heaters, coils, instruments, fire detectors, etc. Access doors in plenums of air conditioning systems shall be hinged and furnished with latches operable from both inside and outside. Edges shall rest against neoprene or felt for airtight closure. Access doors in ducts shall rest against felt or neoprene gaskets, and be fastened with sheet metal screws.

10.4.13 Flexible Duct Connectors

Flexible duct connectors shall be used to connect HVAC equipment to ductwork. Select the length of each joint to accommodate both horizontal and vertical deflections of the equipment. All flexible duct connectors shall be mechanically secured to HVAC equipment and ductwork to provide airtight joints.

10.4.14 Air Filtration

Replaceable media filter sections shall be arranged in banks. Filter media shall have a Minimum Efficiency Reporting Value of MERV 8 when evaluated under the guidelines of ASHRAE Standard 52.2-1999.

The filter media shall have an average dust spot efficiency of 25-30% when evaluated under ASHRAE Standard 52.1-1992. Minimum dust holding capacity when evaluated under this Standard shall be no less than 170 grams. Initial resistance to airflow shall not exceed 0.25-in.w.g. at a velocity of 500 ft/min.

The air filter material shall be classified by Underwriters' Laboratories as UL Class 2.

10.5 REFRIGERATION SYSTEM

Local direct-expansion refrigeration equipment with air-cooled condensing units shall serve air-conditioned areas as required. Air-cooled condensers shall be located as close as possible to the direct-expansion coils served.

10.5.1 Air-Cooled Condensing Units

Each unit shall have semi-hermetic reciprocating compressor, direct-expansion condensing coils with integral sub-cooling, supporting casing with stand, direct drive propeller fans, motors, and head pressure control. Units shall be factory-packaged, cleaned, dehydrated, sealed and leak-tested and shipped with a holding charge. Saturated suction temperature shall be 40 degrees F and condensing temperature 120 degrees F, with 90 degrees F dry bulb entering condenser and 17 degrees F sub-cooling.

10.5.2 Temperature Control System

Utilize room thermostat to cycle the exhaust fan in order to maintain the maximum air temperature setting in the room.

Single zone air handling units shall be controlled by a room thermostat activating either heating or DX cooling coil based on the temperature setting.

Where multiple zones are served from a single air-handling unit, single temperature control shall be provided in the most critical room. Where multiple critical zones are served from a single air handling unit, provide each zone with a thermostat and VAV box.

10.6 HEATING

10.6.1 Scope

These criteria cover the heating systems and equipment for the following typical areas:

1. Signal and Communications Room, Porter's and Starter's Room, Police and Collector's Booth
2. Fan Rooms
3. Sewage Ejector Rooms
4. Toilets
5. Mechanical Rooms
6. Emergency Generator Room
7. Emergency Electrical Rooms
8. Elevator Machine Room
9. Storage and Maintenance Rooms
10. AC Unit Substation Room
11. Pumping Station

10.7 DESIGN CONDITIONS

Heating loads and system design shall be based on the following:

10.7.1 Outside Winter Design Conditions

- 7 degrees F dry bulb;
- 5634 annual degree days;
- 25 mph wind velocity;
- 42.37° latitude;
- 30 ft elevation above sea level.

Table 10-1: Inside Winter Design Conditions

	Temperature (°F)	Relative Humidity (%)
1. Offices		
a) Starter's Room	70	N.C.
b) Signal and Communications Room	70	N.C.
c) Police Booth	70	N.C.
d) Collector's Booth	70	N.C.
2. Fan Room	60	N.C.
3. Sewage Ejector Room	60	N.C.
4. Porter's Room	60	N.C.
5. Toilets	70	N.C.
6. Mechanical Room	60	N.C.
7. Emergency Electrical Room	60	N.C.
8. Elevator Machine Room	60	N.C.
9. Storage and Maintenance Room	60	N.C.
10. AC Unit Substation Room	60	N.C.
11. Pumping Station	60	N.C.

* N.C. indicates "no control" of relative humidity in winter.

10.8 SYSTEM CONCEPTS

Design concepts shall be based on the following criteria:

10.8.1 Starter's, Communications and Signal Room, Police and Customer Service Booth

Electric heating coil(s) in an air conditioning system.

10.8.2 Fan Room, Sewage Ejector, Porter's, and Elevator Machine Room:

Where possible, these ancillary rooms shall be heated by transferring secondary air from adjacent heated areas. Where additional heating is required, electric baseboard heaters shall be utilized. In case a central heating and ventilating unit is provided, electric coil heating unit shall be utilized.

10.8.3 Toilets

Where possible, toilets shall be heated by transferring secondary air from adjacent heated areas. Where additional heating is required, electric baseboard heaters shall be provided.

10.8.4 Mechanical, Storage, Maintenance and Electrical Rooms:

Where possible, the rooms shall be heated by transferring secondary air from adjacent heated areas. Where additional heating is required, electric heaters shall be provided.

10.9 HEATING EQUIPMENT

Heating equipment shall comply with the following:

1. Electric heating equipment shall be thermostatically controlled and have protective devices as required by the NEC.
2. Electric duct and unit heaters shall be controlled with a 120-volt remote thermostat. Electric baseboard and convector heaters shall be controlled with an integral thermostat (120-volt or 277-volt).
3. Electrical heating equipment shall be UL-listed.
4. Electric-resistance heating equipment shall have high limit controls.
5. Duct heater coils shall be of the resistor type, and designed to slide into ducts. Duct heaters shall be interlocked with supply fans so they do not operate when the fan is off, and equipped with pressure airflow switches wired into the control circuit. Duct heaters shall be sized so that the air velocity through the coil complies with the heater manufacturer's recommendation.

10.10 VENTILATION

10.10.1 Scope

These criteria cover the Tunnel Emergency Ventilation and Station Ventilation including the associated Tunnel Ventilation shaft structures and equipment.

10.10.2 Design Parameters

The following design parameters shall apply to the selection of ventilation equipment and in the design of ventilation systems.

Ventilation capacities for emergency ventilation systems and station ventilation in subsurface sections in the subway area shall be verified by the Subway Environmental Simulation (SES) computer program.

10.10.2.1 Station Ventilation Systems for the Chinatown and Boylston Street Stations:

For normal operation, main distribution ductwork (trunks) shall be sized for maximum velocities of 2,200 fpm in sheet metal, and 2,500 fpm in concrete. Branch ducts shall be sized for pressure losses not exceeding 0.1-in. w.g. per 100ft. of straight length duct. An aspect ratio of five to one (5:1) will be used for the design of ductwork except where physical constraints prevent conformance.

Station ventilation fans shall be of the axial flow type, with internally mounted, direct drive motor. Fans shall have adjustable-pitch blades, or variable frequency drive units fitted to permit changes in the fan-operating characteristic for either system balancing or future system modification.

Each fan shall be provided with modular sound attenuators on both the inlet and discharge sides of the fan. Additional sound lining shall be provided as required so that maximum noise levels from ventilation systems do not exceed allowable limits.

Any fans and motors required to operate during smoke evacuation in the Stations shall be capable of operating in an ambient temperature of 482 °F for a minimum of one hour unless engineering analysis determines that the temperature at the fan during a fire event would be less than 482 °F. In no case shall the fan operating design temperature be less than 300 °F for one hour. Flow rates in main distribution ductwork during an emergency event may exceed the values previously listed for normal operation.

Fan power curve shall not exceed 100 percent of the motor rating at any point. Any fan dampers required shall be heavy duty, industrial type with parallel blade design. The dampers shall be capable of operating in an ambient temperature of 482 °F for a minimum of one hour. End/limit switches shall be provided for each fan damper section to allow remote monitoring of the “closed” and “open” damper positions.

10.10.2.2 Emergency Ventilation Systems for the Tunnels:

Emergency ventilation fans shall be of the axial-flow type, with internally mounted, directly driven motor. Fans shall be reversible, to one or both tunnel bores. Fans shall have adjustable-pitch blades, or variable frequency drive units fitted to permit changes in the fan-operating characteristics for either system balancing or future system modification. The minimum acceptable reverse (supply) flow capacity shall be 90 percent of the forward (exhaust) flow capacity.

Fans shall be selected to have a total efficiency of not less than 60 percent in the forward (exhaust) flow mode.

Jet fans shall be of the vane-axial type, and shall have at least 95% capacity in reverse mode. Jet fans shall be provided with appropriate sound attenuators.

Unless engineering analysis determines that the temperature at the fan during a fire event is less than 482 °F, emergency ventilation fans, motors and jet fans shall be capable of operating in an ambient temperature of 482 °F for a minimum of one hour. In no case shall the fan operating design temperature be less than 300 °F for one hour.

Fan power curve shall not exceed 100 percent of the motor rating at any point. The brake horsepower for reverse (supply) flow shall not exceed the brake horsepower for forward (exhaust) flow.

Any dampers required shall be heavy duty, industrial type with parallel blade design. The dampers shall be capable of operating in an ambient temperature of 482 °F for a minimum of one-hour and a static pressure reversal from plus three inches w.g. to minus three inches w.g. occurring during a maximum 30-second time interval. Any damper component shall be capable of operating in an ambient temperature of 482 °F for a minimum of one hour and a static pressure reversal from plus 4-in. to minus 4-in. occurring during a maximum of a 30 second time interval. End/limit switches shall be provided for each fan damper section to allow remote monitoring of the "closed" and "open" damper positions.

During SES simulation studies for proposed (future) tunnel segments, the following design and acceptance criteria shall be applied:

Table 10-2: Outside Ambient Conditions (Boston, MA)

Description	Data	Source	Comment
Summer dry bulb design temperature	87.0 °F	ASHRAE Fundamentals	1% occurrence
Summer wet bulb design temperature	71.0 °F	ASHRAE Fundamentals	1% occurrence
Summer average daily temperature range	15.3 °F	ASHRAE Fundamentals	
Winter dry bulb design temperature	7.0°F	ASHRAE Fundamentals	99.6% design value
Ambient barometric pressure	14.68 psi	ASHRAE Fundamentals	

Table 10-3: Air Temperature Design Criteria

Tunnel - Normal Operation	
Preferred Maximum Temperature	95°F
Maximum Average Temperature	104°F
Maximum Peak Temperature	113°F
Tunnel - Congested Operation	
Maximum Temperature for train A/C and electrical equipment	102°F
Maximum Local Peak Temperature	113°F
Tunnel - Emergency Operation	
Maximum 6 min average Temperature in Evacuation Pathways	120°F

Table 10-4: Air Velocity Criteria

Location	Description	Velocity
Public Areas of Station	Maximum velocity	1,000 fpm
Exterior inlets and outlets	Piston Relief and Mechanical Ventilation During Congested or Emergency Operation	2,000 fpm
Main Shafts and Ducts – normal operation	All materials	2,200 fpm normal/2,500 fpm max
Tunnels	Emergency Operation – Smoke Control	Critical velocity – varies for each tunnel section
	Emergency Operation - Maximum	2,200 fpm in areas where passengers may be present

10.10.2.3 Pressure Wave Criteria at Stations

Pressure waves are generated by the bus moving through a tunnel and propagate along the tunnel at the speed of sound. These pressure waves reflect at portals, at cross passages and from other buses and continue to pass over the bus for the duration of its transit through the tunnel. As a consequence, a passenger on the bus is typically subjected to fluctuations in ambient pressure which may cause aural discomfort. The extent of this discomfort varies considerably between individuals.

Table 10-5: Normal and Congested Operation

Normal and Congested Operation	
Maximum Isolated Pressure Pulse Not to Exceed Within a Period of 4 seconds	12 inches w.g.
Maximum Repeated Pressure Pulses Not to Exceed Within a Period of 1.7 seconds	2.8 inches w.g.

Table 10-6: Design Fire Data

Location	**Max. Fire Size**	**Growth Rate**	**Max. Flame Temp.**
Tunnels	68.2 MBtu/hr (20 MW)	Fast Fire	1,800° F

10.10.2.4 Noise Criteria:

Noise criteria shall comply with the Guidelines for Design of Rapid Transit Facilities as listed by the Rail Transit Committee, American Public Transit Association (APTA), 1981.

Table 10-7: Ventilation Equipment Noise Limits

Area	**Target Noise Level (NC)**
Platforms	45
Mezzanines	45
Station Booths	40
Retail	45
Emergency Operation	70

During emergency operations, the tunnel ventilation noise shall not exceed L_{max} 85 dB(A) within the tunnel, and combined with the station ventilation noise must not exceed NC 70 as measured within the station.

External Building Equipment Noise Criteria

External noise level restrictions affecting the Silver Line Transitway system are listed below.

Noise level restrictions are contained in the Regulations for the Control of Noise in the City of Boston, adopted by the Air Pollution Control Commission of the City of Boston. The noise from all station equipment will be included in the predicted level and will be determined at the lot line of any lot, depending on the Zoning District.

Table 10-8: Zoning District Noise Standards

Maximum Allowable Octave Band Sound Pressure Levels, dB(A) re 2 x 10-5 Pa						
Octave Band Center	**Residential**		**Residential/ Industrial**		**Business**	**Industrial**
Frequency of Measurement (Hz)	**Daytime**	**All Other Times**	**Daytime**	**All Other Times**	**Anytime**	**Anytime**
31.5	76	68	79	72	79	83
63	75	67	78	71	78	82
125	69	61	73	65	73	77
250	62	52	68	57	68	73
500	56	46	62	51	62	67
1,000	50	40	56	45	56	61
2,000	45	33	51	39	51	57
4,000	40	28	47	34	47	53
8,000	38	26	44	32	44	50
Signal Number Equivalent	60 dBA	50 dBA	65 dBA	55 dBA	65 dBA	70 dBA

Restrictions on Noise Emitted from Construction Sites

Any construction device or devices on any construction site shall not emit noise, measured at the lot line of affected property, in excess of the values shown in the following table. With the exception of impact devices, a construction device operating at any street excavation, grading or repair, utility street work installation or repair, shall not produce a noise level exceeding 86 dBA at a distance of 50 ft. from the device.

Lot Use of Affected Property	L10 level	Maximum Noise Level
Residential or Institutional	75 dBA	86 dBA
Business or Recreational	80 dBA	-
Industrial	85 dBA	

The same noise level applies to any public way as applies to an industrial use. Measurements should not be taken closer than 50 ft. from the nearest active construction device on the construction site.

The L10 level shall be determined from one hundred (100) A-weighted noise level observations measured on the sound level meter on "slow" response. The L10 level shall be that level that is equal to the tenth highest level recorded.

The hours allowed for construction, such as excavation, erection, demolition, alteration or repair of any building, are from 7:00 a.m. to 6:p.m. on weekdays. At residential lot lines, any construction devices operating on any construction site between the hours 6:00 p.m. and 7:00 a.m., shall not emit noise in excess of 50 dBA, measured at the lot line. The exceptions are provided only to Public Utility Companies in emergencies and to constructions that are in the interest of public safety or welfare, upon issuance of a permit.

10.11 SYSTEM CONCEPTS

10.11.1 Emergency Situations

To minimize the response time for determining and implementing the proper ventilation mode for a given emergency, the permutations of cause and effect must be predetermined. This will be achieved through the use of an automated control system providing guidance through interactive software. The installations would be redundant and would include a screen to guide the operator in proper activation of the required ventilation elements. In essence, this control system would function as follows:

1. Input information (voice communication at the scene of the incident) would advise the operator of the location of the vehicle in the system, the relative location of the fire, and the proposed evacuation route. For this purpose, appropriate wayside signage is extremely important.

2. The operator at the emergency ventilation console would input these three points of information into the control system.

3. In response, the control system would display on the screen the following:

Input information inserted by the operator.
A schematic display of the tunnel system indicating all of the ventilation elements to be activated and their mode of operation.
Sequence button to be energized in order to achieve the displayed modes of operation of each of the elements.

4. Upon examination of the display by the operator to assure the reasonableness of the displayed decision, the operator will energize the designated sequence button which in turn will control each of the displayed ventilation elements to function in the manner as indicated.

   It is not intended to have the screen display and the control system fully automate the emergency operation of the ventilation system, but rather to minimize the effective response time by programming the decision-making process.

10.11.2 Ventilation Shafts and Terminals at Grade

All ventilation shafts and terminals at or above grade shall be sized and designed in accordance with the following criteria. Such criteria shall be applicable to exhaust shafts if no supply shafts are provided on the system.

1. Supply and exhaust shafts shall be smoothly expanded to terminals and tunnels.

2. For emergency ventilation, the maximum intake and exit air velocity at terminals of ventilation supply and exhaust shafts, based on gross area of terminal gratings or louvers, shall be 1,200 fpm (net air velocity not to exceed 2,000 fpm).

3. For normal ventilation the maximum intake and exit air velocity at terminals of ventilation supply and exhaust shafts, based on gross area of terminal or louvers, shall be:

Exhaust discharge gratings in sidewalks or in area where people will be affected by the discharge of air and supply intake gratings in sidewalks, medians, or off-street properties where dust, debris, and snow may be entrained: 500 fpm.

Exhaust discharge gratings in medians or off-street properties where people will not be affected by the discharge of air: 1,000 fpm.

Louvered supply or exhaust terminals ten feet or more above grade: 1,200 fpm, provided that net velocity (across free area) does not exceed 2,000 fpm.

1. Shafts shall be designed to avoid unnecessary turns, offsets, area changes, and obstructions. Streamlining of obstructions and shaft passages shall be undertaken where required.

2. Each ventilation shaft shall be designed so that the inlet flow to the fan and the outlet flow from the fan will be compatible with the proper operation of the fan. Where these conditions are not feasible, air-straightening devices shall be provided.

3. Shaft locations shall be as follows unless other factors, such as availability of real estate or requirements of local jurisdictions, dictate otherwise:

Shaft openings at grade shall be located to avoid pedestrian and vehicle crossing and to minimize the danger of flooding. Vent-shaft gratings in sidewalks shall be located near the curb; their width shall not exceed 50 percent of the sidewalk width but in no case shall they exceed 6 ft.

Where possible, shaft openings shall be located in median strips or off-street locations and be suitably screened with plants or other decorative treatment. Shaft openings shall not be located in roadways. Supply air ventilation shaft openings for station shall be located at grade or above grade in areas relatively free of vehicular traffic and contaminants.

Exact shaft locations recommended by the Engineer shall be approved by the MBTA.

1. Surfaces adjacent to shafts terminating at grade shall be sloped away from gratings to minimize the flow of water into the shafts.

10.11.3 Ventilation of Ancillary Rooms

Ventilation of ancillary rooms shall be based on following:

1. Toilets only: Larger of 75 cfm per fixture or l0 air changes per hour, operating when associated lighting is energized

2. Custodial Rooms: 3 cfm/sqft in continuous operation

3. Sewage Ejector Room: 3 cfm/sqft in continuous operation.

4. Storage and Porter's Room: As required to maintain a temperature below 85 °F (controlled by room thermostat).

5. Mechanical, Electrical and Fan: As required to maintain a temperature

6. Rooms below 104 °F: Mechanical equipment rooms in the buildings with air conditioning units may be ventilated with supply and return air from the specific unit.

10.12 PLUMBING

10.12.1 Pipe and Fittings

Pipes and fittings shall be as follows:

1. Waste and soil pipe shall be heavy weight cast iron pipe with bell and spigot fittings, below ground, and service weight, no hub, above ground. Soil pipe from fixtures shall have a slope of 1 percent in the direction of flow for pipe 3-in. and larger.

2. Vent pipes within structures shall be galvanized steel threaded pipe or no-hub service-weight cast iron pipe and fittings.

3. Hot and 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.

4. Force mains shall be ductile iron pipe with grooved joints or standard-weight galvanized steel pipe with joints of a size and type and as approved by the local authority having jurisdiction.

5. Water service entrances shall be ductile iron grooved joint pipe, over 2-in. size and hard drawn copper type K for pipe 2-in. and smaller.

6. Hose bibs shall be anti-siphon freeze-proof type.

7. The minimum diameter of waste pipe installed underground shall be 4-in.; the minimum diameter of waste pipe installed in structural slabs shall be 3-in.

8. Dielectric couplings shall be provided for the connection of pipes of dissimilar metals, and in all metallic piping entering a facility.

9. Corrosion control measures shall be provided for buried pipes and pipes contained in the tunnel subject to DC stray currents.

10. Isolation and drain valves shall be located so they are easily accessible.

10.12.2 Water Service

The domestic water-service connection shall have a minimum diameter of 2-in. and shall be metered. Fire water-service connections shall have a minimum diameter of 4-in. and shall not be metered. Each service shall have a main shut-off valve immediately inside the structure wall. Backflow preventor shall be provided to conform to local code requirements.

Minimum fixture service requirements shall be calculated from the following fixture unit values:

1. Flush valve water closet: 12

2. Flush valve urinal: 6

3. Lavatory: 1

4. Service sink: 2

The service requirements of outlets that are likely to impose continuous demand, such as hose connections, shall be estimated separately and added to the above fixture service requirements to determine the required total-service connection capacity.

The application for backflow preventer indicating the size of water supply line shall be submitted to Boston Water and Sewer Commission (BWSC) for approval.

10.12.3 Hot Water Service

Hot water shall be supplied to all toilet rooms and custodial rooms.

Water heater capacities shall be based on 100 degrees F recovery, and sized to meet the demands of the fixtures to be served by each heater. In systems with a hot water demand of 19 gallons per minute (gpm) or less, an instantaneous electric water heater shall be used.

Combination pressure-temperature relief valves shall be provided in accordance with code requirements, and piped to the indirect waste system.

A recirculation system shall be provided where the supply piping is more than 100 ft. long.

10.12.4 Insulation and Freeze Protection

The following piping shall be insulated:

1. Portions of water piping subject to freezing;
2. Portions of drainage and cold water piping subject to sweating.

Electric-resistance tape shall be used where required for freeze protection.

10.12.5 Plumbing Fixtures

Certain mechanical features of plumbing fixtures are prescribed in this manual, as follows:

1. Water closets shall be wall-hung, of the siphon-jet, elongated-bowl type, and shall have a flush valve.
2. Urinals shall be wall-hung, of the siphon-jet type, and shall have a flush valve.
3. Lavatories shall be wall-hung.
4. Service sinks shall be of monolithic pre-cast terrazzo, 36-in.by 24- in. and shall be equipped with a stainless steel rim guard.
5. Water supplies to fixtures shall have key-operated service valves.
6. The connection shall be designed for the pressure recommended by the fixture manufacturer; the pressure, however, shall not be less than 15 psi for flush valves, and not less than 8 psi for other fixtures.
7. The water supply to lavatories and flush-valve fixtures shall have water shock-absorbing provisions.
8. Vacuum breakers shall be installed on all outlets with hose bib connections and submerged inlets.

9. Where service water pressure is above 60 psi at the water service room, reducing valve assemblies shall be provided that includes a reducing valve, three-valve bypass and strainer.

10.12.6 Sewage Ejector

The Contractor shall provide package sewage ejector with duplex electric motor-driven centrifugal pump units completely assembled and tested at the factory.

Sewage ejector shall be selected on the following basis:

1. The ejector rating shall be based on the fixture units for water service.

2. The ejector head shall be consistent with the static and friction heads, and shall be calculated on the basis that only one ejector is operating.

3. Receiver shall be of cast iron and designed for an operating pressure of 50 psi. The receiver shall be hermetically sealed and provided with a 16-in. dia. manhole in the top.

4. Level control shall be of the mechanical type. A high-level alarm shall be provided for monitoring where directed.

5. Electrical Characteristics: Motors shall be drip-proof, non-overloading at normal operating conditions and operative on 480-volt, three-phase, 60-hertz power. Provide across-the-line magnetic starters, hand-off-auto automatic selector switches, and an adjustable, automatic pressure switch and circuit breaker disconnect.

6. Sewage ejector shall discharge to the nearest sanitary sewer, and have a minimum diameter of 2-in. Force main discharge velocity shall be 2.5 fps minimum and 7.0 fps maximum.

7. Valves: Check and gate valves shall be provided in the discharge piping from the sewage ejector.

8. Ejector operation shall be such that each pump cycles automatically. Normal operation shall be one pump running. At High Water Level the system will alarm. At High-High Water Level both pumps will run at the same time.

10.12.7 Eyewash Facilities

The capability for eye clearing shall be provided by a portable eyewash apparatus in the Emergency Generator Room.

10.12.8 Hose Bibs and Floor Drains

Hose bibs and floor drains in stations shall be provided in accordance with the following instructions:

Porter's Room

Plumbing provisions shall include a hot- and cold-water single spout, a mop sink drain and a floor drain.

Toilet Rooms

Toilet rooms shall be provided with a single cold-water hose bib and a means of drainage.

Water Heaters

A floor drain shall be provided at each water heater location to remove wastewater produced by maintenance procedures and relief valve actuation.

10.12.9 Sanitary Facilities

All sanitary waste lines shall be run to sewage ejector pits containing duplex sewage pumps. The discharge shall then be pumped to the nearest city main.

10.13 DRAINAGE

10.13.1 General

The criteria of this Section pertain to the design of the Tunnel drainage facilities. The following guidelines related to the location of drains, selection of piping materials, drainage volume and flow, and design of pump stations apply.

10.13.2 Location of Drains

1. Drainage shall be provided from the low point in each escalator pit and elevator pits. Elevator and escalator pits shall be provided with high water alarm reporting to 45 High Street.
2. Drainage pumps shall be provided at all low points not drained by gravity.
3. Tunnel drainage inlets shall be provided at the maximum interval of 350 ft.
4. Stations drainage inlets shall be provided at a maximum interval of 120 ft. along each busway.
5. Clean-outs shall be provided along all drainage lines at maximum intervals of 50 ft. for pipes 4-in. and smaller and 100 ft. max. for pipes larger. A clean-out is required for each 90 degree bend and for each two 45 degree bends.

10.13.3 Drainage Fittings

The following fittings shall be provided:

6. Drain Inlet
7. Drainage shall be provided at each inlet, with a connection to the main tunnel drain.
8. Scupper Drain
9. A scupper drain shall be provided at the drain inlet from fan shafts and vent shafts.
10. Clean-Out

Clean-outs shall be provided where access to the drainage piping is required for clean out purposes only. Avoid locating cleanouts in the roadway.

10.13.4 Drainage Piping

1. Drainage piping for the busway tunnel shall be designed in accordance with these criteria.

2. The drainage piping for sub-surface sections shall be selected from the following:

Diameter (in.)	Material	Use
4	Ductile Iron Pipe	Drain connections in structural walls and floors
6	Ductile Iron Pipe	Drain connections in structural walls and floors
6	Ductile Iron Pipe	Branch connections in roadway slab and underground
8	Ductile Iron Pipe	Main track drain
12	Ductile Iron Pipe	Track drain manhole to pumping station

10.13.5 Drainage Volumes

The volumes of water to be handled by each drainage system shall be calculated as follows:

1. Open Areas Draining into the Sub-Surface Drainage System

   Drainage volumes from decks, entrances, ventilation shafts and similar openings draining into the sub-surface drainage system shall be calculated by means of the formula:

   $Q = Aci$

   Where: Q = Volume, in cubic feet per second
   A = Drainage area, in acres
   c = Coefficient of runoff (Section 6)
   i = Intensity for 50 year frequency from duration rainfall curves established by the local jurisdiction.

2. Drainage volume for subsurface guideways shall be designed for a 750 gpm flow from the fire protection standpipe systems.

10.13.6 Flow Formula

Flow and velocity in drainage piping shall be calculated using Manning's formula. In the use of this formula, the following factors for "n" shall be used:

$n = 0.013$ for ductile iron pipe for 8-in. pipe

Note: Maintain minimum scouring velocity in the pipe

10.13.7 Grades

1. Drainage piping shall have the following minimum grades:

   Pipe Size (in.) Minimum Grade

3	2%
4	1%
6	1%
8	1%
10	1%

Grades may be reduced as required, with the approval of the MBTA, to keep the piping system within structural slabs or to maintain clearances.

2. For the design of main drains, the Section 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 tunnel profile.

3. Main drain lines shall be designed in such a manner the grades produce a minimum velocity of 2.5 fps with the pipe flowing at 50% full.

10.13.8 Low Point Pump Station

1. The pumps shall be fully sealed to exclude moisture, abrasive material, corrosive gases, and all other matter that may contribute to wear.

2. The pump station shall be designed on the following basis:

    a. Minimum Number of Pumps: 4

    b. Pump Rating: Two (2) smaller pumps, each sized for 100% of drainage volume; two (2) larger pumps (AC and DC power), each sized for the flow from three (3) fire departments Siamese connections (750 gpm). Pump Head: To suit static and friction heads of each installation. Friction head calculated with two pumps operating.

    c. Pump Type: Nonclog sewage type.

    d. Check Valves: Swing type with weighted outside control.

    e. Level Controls shall be of the mechanical type.

    f. Pump Clearances: Pump clearances shall be adequate to pass 2-in.

    g. Pump Speed: The pump speed shall be minimum 1750 rpm.

    h. Motor Selection: Motors shall be of the non-overloading type.

    i. Calculations for pump discharge piping pressure losses shall include an allowance for future deterioration Use ration of the interior surface of the piping, i.e., C=100 (Williams and Hazen Formula) or equivalent.

3. In determining the pump head, an investigation of the 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.

4. A high-water level alarm shall be provided for monitoring and indication where directed.

5. Provide fire alarm and intrusion alarm detectors.

6. Pumping station shall discharge into oil/water separator and a storm sewer. The designer shall design a system to treat pump discharge to meet federal, state, and local regulations. The discharge water will likely contain the following requirements: suspended solids, oil, and grease.

7. Pump Room

   a. Provide an enclosed pump room heated as required to maintain a minimum room temperature of 50°F and ventilated to provide 6 air changes per hour when room temperatures exceeds 90°F.

   b. Pump station wet well and dry well are subject to build up and ignition of flammable gases and vapors and therefore the entire area is classified under Class I, Group D, Division 2. If dry well is pressurized in accordance with NFPA 496, the area is unclassified.

   c. Walls and doors must be able to withstand reversing transient air pressures to 70 psf where required by structural design criteria. Access is to be provided from the tunnel section.

   d. Pumps are to be supported independent of discharge piping.

   e. Discharge line to be ductile iron with quick-connection coupling to pumps.

   f. The pump sets to have separate discharge to oil / water separator

   g. Provide permanent provisions for removal of pumps, including overhead hoisting system.

   h. Pump controls to be of weighted-float type with automatic alternation of pumps after each pumping cycle.

   i. Electrical equipment to be in dust-tight enclosures and installed at least 18- in. above the pump room floor.

   j. Fourth pump shall be 600 volt DC permanent stand-by for automatic use.

8. Pump Room shall be provided with portable fire extinguisher and an alarm. Wet well shall be provided with combustible gas detection system.

10.13.9 Storm Water Pump Station

1. Storm water pump station shall be factory built below ground automatic type. All components of the pumping station shall be factory tested for vibration, leaks and correct operation. Pump station shall be completely wired, except for the power feeder lines and entrance light switch.

2. The pump station shall consist of a fiberglass reinforced polyester resin pump chamber with fiber glass entrance tube and an access ladder.

3. In addition to the pump station enclosure, main components shall include two horizontal, self priming centrifugal sewage pumps with suction and discharge piping.

4. The pumps shall be provided with an electric motor with V-belt drive, motor control panel, automatic level control system and internal wiring. Each pump shall be sized to deliver 900 gpm at 30' TDH.

5. Motor control panel shall include magnetic starters, circuit breakers and overload protection on all phases. Automatic level control shall be mounted in the face of the panel and shall include high water alarm, low water alarm, on/off and lead /lag control features.

6. Storm water pump station shall be also provided with lighting, vent fan, dehumidifier, heater and sump pump kit.

7. Alarm horn and alarm light shall be furnished for field mounting.

10.13.10 Oil/Water Separator

1. General: The oil/ water separator shall be a special purpose factory assembled unit which is the standard product of a manufacturer regularly engaged in the production of such equipment with similar units operating for a minimum period of ten years.

2. The separator shall be designed in accordance with Chapters 3 and 5 of the American Petroleum Institute (API) Manual on Disposal of Refinery Wastes (Volume on Liquid Wastes, Latest Edition) and with API Bulletin No.1630, First Edition, May 1979.

3. Construction and thickness of the separator shall be in strict accordance with Underwriters Laboratories UL 58 Standard for Steel Underground Tanks for Flammable and Combustible Liquids or UL 142 Standard for Steel Above Ground Tanks for Flammable and Combustible Liquids. Separator shall bear Underwriters Label.

4. Underground corrosion control system of the oil/water separator shall be applied by a licensee of the Steel Tank Institute and the separator shall bear the STI-P3 Coating Specification Label, 30-year limited warranty. Sacrificial type cathodic protection shall be provided by the manufacturer of the oil/water separator.

5. The oil/water separator shall be designed for intermittent, variable or continuous gravity flows of water, oil and/or any combination of non-emulsified oil/water mixtures.

6. The oil/water separator shall process uncontrolled surges of water, oil or oil and water mixtures ranging from zero flow up to 100% of maximum hydraulic capacity and provide water effluents which meet continuous discharge requirements of 10 ppm or less of oil and grease. The oil/water separator shall meet all Federal, State and Local codes and other requirements.

7. Electrical equipment shall be explosion proof and the controls shall be intrinsically safe and suitable for a Class 1, Division 1 installation.

8. If oil/water separator is subjected to freezing conditions, then freeze protection shall be provided as called for on the plans.

9. Construction of the Unit: The oil/water separator be a prepackaged, pre-engineered, ready to install cylindrical unit consisting of:

    a. Influent and effluent connection, internal influent nozzle, diffusion baffle, sediment chamber, sludge baffle, and oil/water separation chamber.

    b. Fittings for vents sensors oil pump discharge, sampling and gauge.

    c. Two (2) twenty four (24) inch diameter manholes with accessories.

d. Lifting lugs and hold down straps.

e. Corrosion Protection System STI-P3.

f. Automatic waste oil pump out system.

g. Identification plates affixed in prominent locations.

10.14 FIRE PROTECTION

10.14.1 Fire Protection Systems

The following fire protection systems will be employed:

1. Sprinkler systems, wet and dry
2. Dry standpipe systems
3. Portable fire extinguishers
4. Smoke and heat detection systems
5. FM-200 or similar

10.14.2 Sprinkler Systems

Sprinkler systems shall include a main water supply, fire department inlet connections, alarm check valve, piping from inlet connections and water supply mains to the sprinkler heads, sprinkler heads (with spares), drain lines, provisions for remote alarm devices, pipe fittings, valves, hangers, inserts, sleeves, and appurtenances. Sprinkler systems shall conform to the requirements of NFPA 13. Dry-pipe sprinkler systems shall be installed in unheated areas and where the provision of freeze protection is not practical.

Where not more than six sprinkler heads are required for any isolated hazardous area, they may be connected to the cold-water piping of the domestic water system having sufficient capacity. Include flow switches in the piping to the sprinkler heads to allow remote monitoring of water flow at the High Street facility. If the sprinkler system is designed to connect to the domestic water supply, care shall be taken so that the domestic water flow does not activate the alarm system.

10.14.3 Standpipe Systems

Standpipe systems shall include fire department inlet connections, piping from inlet connections to supply main, hose valves, fire hose cabinets, drain lines, pipe fittings, control valves, hangers, inserts, sleeves, and appurtenances. Standpipe systems shall conform to the requirements of NFPA 14 and NFPA 130.

10.14.4 Portable Fire Extinguishers

Portable fire extinguishers shall be installed in accordance with NFPA 10 and as modified by these design criteria.

Install portable fire extinguishers of types appropriate to the areas being protected in the following areas/facilities:

1. General Areas.
2. Electrical rooms.
3. Tunnels.
4. Passenger Station Platforms.

10.14.5 Smoke and Heat Detection Systems

Smoke and heat detection systems shall be provided as required by the applicable NFPA Standard and MBTA Guidelines.

10.14.6 Fire Hydrants

10.14.6.1 Fire Hydrant Location

A fire hydrant of a type approved by the local authority with jurisdiction shall be provided at each of the following locations (if one is not already present):

1. Within 50 ft. of each portal.
2. Within 100 ft. of each fire department connection to a standpipe system;
3. Within 100 ft. of the fire department connection to each sprinkler system.

The 100-foot limits listed above are maximum and may be exceeded pending the AHJ's approval.

10.14.6.2 Water Supply

The adequacy of the water supply shall be supplied from records of the agency owning the water supply system.

Street mains (i.e., the mains of the local authority supplying water service for fire protection) shall be sized to carry the design flow, but in no case shall have a diameter less than 6-in. The capacity of the connected water supply must be adequate for the supply of only the sprinkler portion of the fire protection systems. The standpipe systems will be charged by local fire departments after their arrival on the scene.

Where both sprinkler and standpipe systems are served, the building fire main shall not be less than 6-in. in diameter when feeding tunnel standpipe systems.

No pressure-regulating valves shall be used in fire water-supply mains, except by special permission of the local authority with jurisdiction. Meters shall not be installed in fire water-supply mains to MBTA facilities.

Where connections are made to a public water system, it may be necessary to guard against possible contamination of the public water supply. The requirements of BWSC shall be determined and met.

Submit the application for backflow preventer indicating the size of water supply line to BWSC for approval.

10.14.7 Fire Department Connections

All fire protection systems shall be provided with Siamese connections through which the fire department can pump water into the sprinkler, standpipe, or other system furnishing water for fire extinguishing.

There shall be no shut-off valve in the fire department connection.

An approved silent check valve shall be installed in each fire department connection, located as close as practicable to the point where it joins the system.

The pipe between the check valve and the outside hose coupling shall be equipped with an approved automatic drip, arranged to discharge to a proper place.

Hose connections shall be approved by the local fire department and shall be of a listed type in accordance with NFPA codes.

Hose coupling threads shall conform to those used by the local fire department. American National Standard fire-hose coupling screw threads shall be used wherever they fit the local fire department hoses.

Hose connections shall be at the access road side of buildings and be located and arranged so that hose lines can be readily and conveniently attached to the inlets without interference with any nearby objects, including buildings, fences, posts, or other fire department connections.

Fire department connections shall be designated by a sign with raised letters, at least one inch in size, cast on a plate or fitting reading: "Automatic Sprinkler," or "Standpipe," whichever is appropriate for the station or tunnel. The sign shall also indicate the buildings or structures, or parts thereof, served by the connection. The Authority's logo shall be provided at each fire department connection for identification.

10.15 SYSTEM WIDE ELEMENTS

10.15.1 General

Provisions shall be made for the system wide elements as described in other sections of this manual.

10.15.2 Fire Life Safety

1. Egress Spacing required By Code

   NFPA 130 (Section 3-2.4.2) states that emergency exit stairways shall be provided throughout the tunnels and spaced such that the distance to an emergency exit shall not be greater than 1,250 ft unless cross passages are provided. In a continuous tunnel section, this means that the exit stairways can be as much as 2,500 ft apart. For the proposed tunnels for the Silver Line all of the tunnel segment lengths between adjacent stations, and between the portals and stations are less than this maximum distance. It is therefore recommended that the emergency exits be located at each new station and portal. At this stage it is not anticipated that there will a requirement for additional stairways linking the tunnels to surface. Stairways, where provided shall be designed in accordance with NFPA 101.

2. Requirements for Cross Passages

   NFPA 130 (Section 3-2.4.3) allows cross passages to connect one tunnel to the other, in lieu of the emergency stairways. These cross passages have to be spaced no further apart than 800 ft. National Safety Council (NSC) code does not require that cross passages be installed. However, depending on the location and tunnel alignment, the local fire authority may request that cross passages be installed to reduce the overall egress lengths and to facilitate access to the point of the fire by fire fighting personnel.

3. Walkway Width Requirements

   The minimum unobstructed width of egress facilities located within or directly adjacent to the trainway shall be 24 inches measured at the walkway surface and 30 inches measured at a height of 56" above the walkway surface (NFPA 130 Section 6.2.6.11)

   For emergency egress stairways and passages, the minimum emergency walkway width shall be in accordance with NFPA 101 (Life Safety Code Section 7.3.4.1). Walkways shall be designed for an open walkway width of 36 in. min.

   All emergency walkways, including tunnel walkways shall be designed to provide a headroom of not less than 7 ft 6 inch with projections from the ceiling not less than 6 ft 8 inch above the finished walkway surface (per Section 7.1.5 of NFPA 101).

   According to direction from the MBTA and Boston Fire Department, it may be possible to reduce the walkway width to match that of the existing system as approved by the Authority, in consultation with the Fire Marshall. This shall also be supported by an engineering analysis of egress time.

4. Configuration of the Walkways

   In accordance with NFPA 130, walkways shall be provided, with uniform, slip-resistance walking surfaces (Section 3-2.6). In areas that cross passages are provided, the walkways shall be provided on the cross passage side of the busway. Walkway continuity shall be maintained at special sections such as crossovers. Raised walkways shall include a handrail that will not obstruct egress from the bus.

   Based on these code requirements and the requirements for ADA egress in an emergency, it is recommended that a raised continuous walkway be provided throughout all the tunnel sections. In those areas where the walkway has to switch sides, or cross switch areas, the walkway should be continued at bus level. All active tunnels should be provided with a dedicated walkway.