Green Line Extension Project

Design Criteria Manual

Revision 2

January 2014

GLX

MBTA Green Line Extension Design Criteria Manual

Revision History

Date	Issue	Changes	Notes
September 2012	Draft Rev. A	Initial Draft	
January 2013	Revision 0	Incorporation of Comments (FTA< OR, AECOM|HNTB)	
August 2013	Revision 1	Revisions by the AECOMIHNTB Team	
January 2014	Revision 2	Revisions by the AECOMIHNTB Team	Revisions Reflect Responses to APE Submittal Comments

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ATTACHMENTS

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Acronyms and Abbreviation

A	Amperes
AAI	all-appropriate inquiry
AAR	Association of American Railroads
AASHTO	American Association of State Highway and Transportation Officials
AC	Alternating Current
AC&ID	access control & intrusion detection
ACI	American Concrete Institute
ACSM	American Congress on Surveying and Mapping
ADA	Americans with Disabilities Act
ADAAG	Americans with Disabilities Act Architectural Guidelines
AFC	automated fare collection
AFTC	Audio Frequency Track Circuit
AGD	automatic grounding device
AI	analog input
AISC	American Institute of Steel Construction
ALTA	American Land Title Association
AMCA	Air Movement and Control Association
APTA	American Public Transportation Association
AREMA	American Railway Engineering and Maintenance of Way Association
ASCE	American Society of Civil Engineers
ASD	allowable stress design
ASHRAE	American Society of Heating, Refrigerating, and Air Conditioning Engineers
ASTM	American Society of Testing Materials
ASQC	American Society for Quality Control
AUL	activity and use limitation
AVI	automatic vehicle identification
AWS	American Welding Society
AWG	American Wire Gauge
BDA	Bi-Directional Amplifier
BCIL	Boston Center for Independent Living
BHL	bus hold lights
BIL	basic impulse insulation level
BMP	best management practices
BSP	Book of Standard Plans
BSTP	Book of Standard Trackwork Plans
BWA	Balance Weight Assembly
BX	AC signal power
CA/T	Central Artery/Tunnel
CBD	Central Business District
CCTV	closed circuit television
CE	clearance envelope
CFD	Cambridge Fire Department
CFR	Code of Federal Regulations
CIH	central instrument house
CM/GC	Construction Management/General Contractor
CMR	Code of Massachusetts Regulations
CMT	construction and maintenance tolerances
CMU	concrete masonry units

C.R.	curve radius
CRDSM	Commuter Rail Design Standards Manual
CSO	combined sewer overflow
CS	curve to spiral
CTPS	Central Transportation Planning Staff
CU	coefficient of utilization
CW	chorded wall construction factor
CWD	Cambridge Water Department
CWR	Continuously Welded Rail
D_a	degree of curvature
DC	Direct Current
DEIR	Draft Environmental Impact Report
DI	digital input
DO	digital output
DOJ	Department of Justice
DPW	Department of Public Works
E_a	actual superelevation value
EA	Environmental Assessment
EB	eastbound
EF	equipment factor
EIA	Electronic Industries Association
EMS	Emergency Medical Service
EPA	Environmental Protection Agency
E_q	total superelevation
ESA	Environmental Site Assessments
E_u	unbalance superelevation value
FACP	fire alarm control panel
FG	fare gate
FHA	Federal Highway Administration
FMP	Fire Management Panel
FRA	Federal Railway Administration
FRE	fiberglass reinforced epoxy
FTA	Federal Transit Administration
FVM	Fare Vending Machines
GFI	ground fault interrupters
GLX	Green Line Extension
HID	high intensity discharge
HMCS	Hub Monitoring and Control System
HVAC	heating, ventilation, and air conditioning
HSCB	High Speed Circuit Breaker
IBC	International Building Code
IEEE	Institute of Electrical and Electronics Engineers, Inc.
IES	Illuminating Engineering Society
IPCEA	Insulated Power Cable Engineers Association
ISA	International Symbol of Accessibility
LCP	local control panel
LDD	luminaire dirt depreciation factor
L_{dn}	day-night sound level
L_{eq}	existing peak hourly equivalent sound level
LED	light emitting diode
LEED	Leadership in Energy and Environmental Design
LFD	load factor design
LLD	lamp lumen depreciation factor
LLF	light loss factor

L_{max}	maximum noise levels
LOS	level of services
LRFD	Load and Resistance Factor Design
LRT	Light Rail Transit
LRTMSS	LRT Track Maintenance and Safety Standards
LRV	Light Rail Vehicle
LSP	Licensed Site Professional
LVC	length of vertical curve (feet)
LVPS	Low Voltage Power Supply
MAAB	Massachusetts Architectural Access Board
MassDEP	Massachusetts Department of Environmental Protection
MassDOT	Massachusetts Department of Transportation
MBC	Massachusetts State Building Code (also MSBC)
MBCR	Massachusetts Bay Commuter Railroad
MBTA	Massachusetts Bay Transportation Authority
MCP	Massachusetts Contingency Plan
MEC	Massachusetts Electric Code
MGL	Massachusetts General Law
MassHighway	Massachusetts Highway Department
MPA	Mid-Point Anchor
mph	miles per hour
MRL	Machine Room Less
MSBC	Massachusetts State Building Code (also MBC)
MUTCD	Manual on Uniform Traffic Control Devices
NDS	National Design Specification
NEC	National Electrical Code
NEMA	National Electrical Manufacturers Association
NFPA	National Fire Protection Association
NPDES	National Pollution Discharge Elimination System
NRSWA	New Roads and Street Works Act
NVR	networked video recorders
NVPLC	Non-Vital Programmable Logic Controllers
OCS	overhead contact system
OCC	Operations Control Center
OHM	Oil and/or Hazardous Materials
OSHA	Occupational Safety and Health Administration
OWF	other wayside factors
PA	public address
PC	point of curvature
PE	polyethylene
PLC	programmable logic controller
PoE	Power over Ethernet
PPV	peak particle velocity
PROWAAC	Public Rights of Way Access Advisory Committee
PSN	Public Switched Network
PT	point of tangency
PTC	positive train control
PTZ	pan, tilt, and zoom
PVC	polyvinyl chloride
PV	photovoltaic
R	radius of curvature (ft)
RAO	Response Action Outcome
RC	running clearances
REC	recognized environmental conditions

RGS	rigid galvanized steel
RI/O	remote input/output
rms	root mean square
ROS	Remedy Operation Status
ROW	Right of Way
RTN	release tracking number
RTU	Remote Terminal Unit
SC	spiral to curve
SCADA	Supervisory Control and Data Acquisition
SCAT	Simple Catenary, Auto Tensioned
SCFT	Simple Catenary, Fixed Termination
SCU	station control unit
SMACNA	Sheet Metal and Air Conditioning Design Consultant's National Association, Inc.
SMDC	Stormwater Management Design Criteria
SPD	special project designation
ST	Spiral to tangent
SWFT	Single Wire Fixed Termination
SWPPP	Stormwater Pollution Prevention Plan
SZO	Somerville Zoning Ordinance
TCRP	Transit Cooperative Research Program
TES	Traction Electrification System
TMDL	total maximum daily load
TPS	traction power system
TPSS	traction power substation
TS	tangent to spiral
TSCS	surveillance and control system
TWFT	trolley wire with fixed termination
UL	Underwriters Laboratories
UPS	uninterruptible power supplies
VCE	Vertical Circulation Elements
VdB	vertical vibration velocity in decibels
VDC	volts direct current
VDE	vehicle dynamic envelope
VDH	vehicle dynamic envelope
VF	voltage to luminaire factor
VLAN	virtual local area network
VMIS	vital microprocessor interlocking systems
VMS	variable message system
VMSF	Vehicle Maintenance and Storage Facility
VoIP	voice over internet protocol
WAN	wide area network
WB	westbound
XLPO	cross linked polyolefin

1 Civil, Track, Community Path and Utilities

Chapter 1

1.1 General

This chapter sets forth criteria required for designing roadways, intersections, traffic control improvements, track alignment, community path, and utility relocation for the MBTA Green Line Extension (GLX) project.

1.2 Roadways

1.2.1 General

This subchapter sets forth criteria required for designing roadways, as part of the MBTA Green Line Extension project.

1.2.2 Codes, Standards, References, and Guidelines

Unless noted, or directed otherwise, the following standards, codes and guidelines shall be used in the design of all roadways and roadway elements, as appropriate, and as set forth in this chapter. Design element-specific references will be described in the appropriate design element subchapters.

1. The latest edition, including revisions, amendments and supplements, of the following publications:

   - MassHighway Project Development and Design Guide
   - MassHighway Department of Conservation and Recreation Historic Parkway Preservation Treatment Guidelines (for parkways only)
   - MassHighway Bridge Manual
   - Massachusetts 250 Code of Massachusetts Regulations (CMR) 6.00 Procedural and Technical Standards for the Practice of Land Surveying
   - 2011 Minimum Standard Detail Requirements for American Land Title Association (ALTA)/ American Congress on Surveying and Mapping ACSM Land Title Surveys
   - United States National Map Accuracy Standards
   - MassHighway Construction and Traffic Standard Details
   - MassHighway Standard Specifications for Highways and Bridges
   - MassHighway Storm Water Handbook for Highways and Bridges
   - MassHighway Building Better Bicycling Manual
   - MassHighway Standard Traffic Management Plans
   - MassHighway Standard Drawings for Traffic Signals and Highway Lighting

- Massachusetts Amendments to the Manual on Uniform Traffic Control Devices (MUTCD) and the Standard Municipal Traffic Code
- Massachusetts State Building Code (MSBC)
- National Fire Protection Agency 502 Manual

2. Current versions of the following relevant policies, procedures and directives:

   - MassHighway Engineering Directives
   - MassHighway Policy Directives
   - MassDOT Highway Division Engineering Directives
   - MassDOT Highway Division Policy Directives

3. Standards, guidelines, circulars, policies, and procedures of the following organizations:

   - Federal Highway Administration (FHA)
   - Federal Transit Administration (FTA)
   - American Association of State Highway and Transportation Officials (AASHTO)
   - Transportation Research Board
   - United States Access Board
   - Massachusetts Architectural Access Board (MAAB)
   - American Nursery and Landscape Association
   - American Railway Engineering and Maintenance-of-Way Association
   - American Society of Testing Materials (ASTM) International
   - City of Cambridge, Somerville, and Medford

1.2.3 Design Criteria

The design criteria for roadways shall be in accordance with the MassDOT Project Development and Design Guide (2006), AASHTO – A Policy on Geometric Design of Highways and Streets, 6th Edition (2011), and Manual on Uniform Traffic Control Devices for Streets and Highways (2009), with Massachusetts Amendments.

1.3 Roadway Intersections

1.3.1 General

This subchapter sets forth Civil Design Criteria to design roadway intersection improvements, as part of the MBTA Green Line Extension project.

1.3.2 Design Methodology

Intersections shall be designed in accordance with MassDOT Highway Division, AASHTO, and Architectural Access Board (AAB) and the Americans with Disabilities Act (ADA) standards, as well as any locally applicable design standards.

1.3.3 Design Criteria

The design criteria for roadways shall be in accordance with the MassDOT Project Development and Design Guide (2006), AASHTO – A Policy on Geometric Design of Highways and Streets, 6th Edition (2011), Manual on Uniform Traffic Control Devices for Streets and Highways (2009), with Massachusetts Amendments, 521 Code of Massachusetts Regulations(CMR) – Rules and Regulations of the Architectural Access Board and the Americans with Disabilities Act Accessible Rights-of-Way: A Design Guide (2006), and any locally applicable standards from the Cities of Cambridge, Somerville, and Medford.

1.4 Pedestrian Improvements

1.4.1 General

This subchapter sets forth criteria required for designing pedestrian improvements, as part of the MBTA Green Line Extension project.

1.4.2 Design Methodology

Pedestrian improvements shall be designed in accordance with MassDOT Highway Division and Transit Division (MBTA) and MAAB/ADA standards.

1.4.3 Design Criteria

The design criteria for roadways shall be in accordance with the MassDOT Project Development and Design Guide (2006), Manual on Uniform Traffic Control Devices for Streets and Highways (2009), with Massachusetts Amendments, 521 CMR – Rules and Regulations of the Architectural Access Board and the Americans with Disabilities Act Accessible Rights-of-Way: A Design Guide (2006).

1.5 Traffic Control Improvements

1.5.1 General

This subchapter sets forth criteria required for designing traffic control improvements, as part of the MBTA Green Line Extension project.

1.5.2 Design Methodology

Traffic control improvements shall be designed in accordance with MassDOT Highway Division and Manual on Uniform Traffic Control Devices for Streets and Highways (2009), with Massachusetts Amendments, standards, as well as any locally applicable standards.

1.5.3 Design Criteria

The design criteria for roadways shall be in accordance with the MassDOT Project Development and Design Guide (2006) and the Manual on Uniform Traffic Control Devices for Streets and Highways (2009), with Massachusetts Amendments, as well as any relevant standards from the Cities of Cambridge, Somerville, and Medford.

1.6 Track Alignment and Geometry

1.6.1 Commuter/Freight Rail Geometrics

1.6.1.1 Commuter Rail Track Alignment and Vehicle Clearance

1.6.1.1.1 General

This section addresses the minimum standards and design policies governing the horizontal and vertical geometry and clearance requirements for MBTA commuter rail track and roadway.

This section also addresses minimum standards and design policies as they apply to freight railroad traffic on the MBTA Lowell and Fitchburg Lines.

Except for specific requirements established in these criteria for this project, the design shall be in conformance with the following documents:

1. MBTA Railroad Operations "Commuter Rail Design Standards Manual" Revision No.1 April 19, 1996 (CRDSM).
2. MBTA Railroad Operations "Book of Standard Plans, Track and Roadway", March 18, 2008 Revision. (BSP)
3. The American Railway Engineering and Maintenance of Way Association (AREMA), 2012 Manual for Railway Engineering and Portfolio of Trackwork Plans.
4. Applicable Federal, State, and local statutes.

1.6.1.1.2 Design Speed

Track alignment shall be designed to accommodate a maximum design speed of 70 miles per hour (mph) for commuter and Amtrak passenger trains and 40 mph for freight trains. Physical constraints along various portions of the system, together with other design limitations may preclude achievement of this objective.

All efforts shall be made to design spiral lengths and curves so as not to preclude future commuter rail maximum speeds of 80 mph.

1.6.1.1.3 Track Designation and Stationing

Engineering stationing shall increase in the outbound direction. Stationing values shall be equated to historical railroad valuation maps.

Table 1-1 Commuter Rail Track Designation and Stationing

Branch	Track	Designation
New Hampshire Main Line	Outbound	NH-T1 XXX+XX
	Inbound	NH-T2 XXX+XX
Fitchburg Line	Outbound	FL-T1 XXX+XX
	Inbound	FL-T2 XXX+XX

The outbound track (right track (T1) when looking up station) shall be the control track for each line. Each line shall be stationed independently along the centerline of the control (outbound) track. Stationing shall be continuous along the centerline of the control track and will be the basic control for locating commuter rail system facilities along the route.

Independent stationing will be required on the inbound track when tracks are neither parallel nor concentric, where widened track centers are required around curves, where parallel tracks have independent profiles, or where tracks are in separate structures. Where curvature results in different stationing at the end of a curve, the inbound track stationing shall be equated to the control track stationing at the spiral to tangent (ST) point of whichever track has the spiral which extends the furthest ahead station. Geometrics shall be developed for all tracks.

1.6.1.1.4 Commuter Rail Horizontal Design Criteria

1. Horizontal Design shall be in accordance with the CRDSM, Section I, Chapter 3 Geometric Design Criteria.

2. Compound Curve Combining Spirals: Minimum spiral lengths connecting compound curves shall equal or exceed the maximum value computed in the following formulas:

   - Ls (compound) =62 (Δ E_a); $V \leq 50$ mph
   - Ls (compound) =83 (Δ E_a); $50 < V \leq 80$ mph
   - Ls (compound) $\geq$ 1.22 (Δ E_u) V; (in "tight" situations)
   - Ls (compound) $\geq$ 1.63 (Δ E_u) V; (Wherever possible)

3. Accommodation of Freight Rail Traffic

   It shall be assumed that freight trains will operate on all sections of commuter rail track. Therefore, the following shall apply:

   A. Actual superelevation value (E_a) on commuter rail track shall be limited to a maximum value of 4" unless prior written approval is obtained from the MBTA.

   B. Maximum unbalance superelevation design value (E_u) for freight traffic shall be 3 inches.

1.6.1.1.5 Commuter Rail Vertical Design Criteria

1. Vertical Design shall be in accordance with the CRDSM, Section I, Chapter 3, Geometric Design Criteria.

2. Minimum length of vertical curves shall be the greatest length obtained by the following:

   A. Commuter Rail Criteria: As determined by Formulas 3.9, 3.10 and 3.11 in the CRDSM.

   B. Freight Rail Criteria: As determined by AREMA Chapter 5, Section 3.6 Vertical Curves (2002).

1.6.1.1.6 Special Trackwork

Special trackwork is defined as any type of turnout, crossover or rail crossing. All special trackwork shall be located in accordance with the CRDSM, Section I, Chapter 3 Geometric Design Criteria and be located on a horizontal tangent.

1.6.1.1.7 Clearances

1.6.1.1.7.1 General

1. Clearances shall be established in accordance with the CRDSM, Section I, Chapter 6, Clearance Criteria.

2. Deviation from clearances described in the CRDSM and in this criteria require prior written approval by the MBTA.

1.6.1.1.7.2 Track Spacing

1. Commuter Rail Track Centers: The minimum horizontal distance between commuter rail track centerlines shall be 13' - 0".

2. Commuter Rail/Light Rail Track Centers: The minimum horizontal distance between commuter rail track and light rail track centerlines shall be 16' - 0" as dictated for this project by Federal Railway Administration (FRA).

3. Commuter Rail/Adjacent Ladder Track Centers: The minimum horizontal distance between commuter rail track and yard ladder track centerlines shall be 17'-0" in accordance with BSP Dwg. No. 1018, Standard Track Centers & Side Clearance Increases for Curved Track.

4. Curve Widening: Track centers shall be widened in curves in accordance with the BSP Dwg. No. 1018, Standard Track Centers & Side Clearance Increases for Curved Track.

5. Concentric Curves in Multiple Tracks: Multiple tracks shall incorporate concentric curves in accordance with the methodology presented in the CRDSM.

1.6.1.1.7.3 Horizontal Clearance

1. Standard Side Clearances: Side clearance shall be in accordance with the CRDSM and the BSP.

2. Increased Side Clearances for Curvature: Side clearances shall be increased in curved track sections in accordance with the CRDSM and the BSP.

3. Minimum clearance from the track centerline to retaining and noise walls shall be 8'-6" and increased in curved track sections in accordance with the CRDSM and the BSP.

4. Freight Railroad Clearance: Initial guidance was to provide for Plate E clearance. See AREMA Chapter 28, Figure 28-2-6. Clearance criteria to be provided by Massachusetts Bay Commuter Rail (MBCR) during preliminary engineering.

1.6.1.1.7.4 Vertical Clearance

1. Minimum vertical clearance at overhead bridges shall not be less than 17'-3". Also see BSP Dwg. No. 1016.

2. If practicable, provide clearance in excess of 17'-3" to allow for raising of track during future track surfacing work.

3. For bridges with existing clearances of greater than 17'-3", maintain existing clearance if practicable.

4. Tracks that are superelevated under overhead structures must have their overhead clearances increased in accordance with BSP Dwg. No. 1016 and with CRDSM I.6.B.3.

5. Tracks that are in a vertical curve under overhead structures must have their overhead clearances increased in accordance with CRDSM I.6.B.4.

6. Bridges with less than 22'-6" clearance require approval by the MBTA and the Massachusetts Department of Public Utilities.

7. Freight Railroad Clearance: Provide for Plate E clearance. See AREMA Chapter 28, Figure 28-6-2.

1.6.1.2 Commuter/Freight Rail Trackwork

1.6.1.2.1 General

This section addresses the minimum standards and design policies governing trackwork for MBTA commuter rail track and roadway. These track and roadway sections might also support freight rail operations as applicable.

This section also addresses minimum standards and design policies as they apply to freight railroad traffic on the MBTA Lowell and Fitchburg Lines.

Except for specific requirements established in these criteria, the design shall be in conformance with the following documents:

1. MBTA Railroad Operations "Commuter Rail Design Standards Manual" Revision No.1 April 19, 1996 (CRDSM).

2. MBTA Railroad Operations "Book of Standard Plans, Track and Roadway", March 18, 2008 Revision. (BSP)

3. MBTA Railroad Operations, "Track Maintenance Standards", January 2, 2001.

4. AREMA, 2012 Manual for Railway Engineering and Portfolio of Trackwork Plans.

5. Applicable Federal, State, and local statutes.

1.6.1.2.2 Track System

The following track systems shall be used for commuter rail trackwork on the GLX project:

1. At Grade Track: Wood Tie and Ballast

2. Track on Railroad Bridges (Ballasted Deck): Wood Tie and Ballast

3. Mainline Crossovers: Wood Tie and Ballast

4. Mainline Lateral Turnouts: Concrete and/or Wood Tie and Ballast

1.6.1.2.3 Roadway

1. Roadway design shall be in accordance with the CRDSM, Section I, Chapter 5 Roadway Criteria.

2. Track Roadbed: Track roadbed shall be in accordance with the BSP Dwg. No. 1000, Typical Roadbed Section Double and Single Track on Tangent, and BSP Dwg. No. 1002 Typical Roadbed Section Double and Single Track on Curve.

3. Transition ties as shown on BSP Dwg. No. 1108, Transition Ties, may be omitted with prior written approval of the MBTA. Transition ties are required for crossovers as cited in 1.6.1.2.6-3, below.

4. Slopes: Slide slopes shall be 2H:1V maximum. Stabilized 1.5H:1V slopes may be used with prior written approval of the MBTA where steeper slopes are required to avoid right-of-way impacts or excessive earthwork. The stability of the proposed slopes, and soil conditions, shall be evaluated and evidenced to the satisfaction of the MBTA.

5. Retaining Walls: Retaining walls shall be used in sections where topography and right of way constraints do not allow for the installation of side drainage ditches. See Chapter 2 of this document for retaining wall criteria.

6. Drainage Structures: See Section 9.2 of this document for drainage criteria

7. Right of Way Fence: Fencing is required along the entire length of the right of way boundary except in areas where noise walls or system structures provide a barrier preventing unauthorized entry to the right of way. See Chapter 10, Landscape Architecture of this document for specific fencing criteria.

8. Intertrack Fence: Intertrack fence is required where commuter rail track is located adjacent to light rail track. Intertrack fence shall be 4'-0" high.

9. Right of Way Signs, Posts and Markers shall be in accordance with the CRDSM, Section I, Chapter 5 Roadway Criteria. Speed restriction signs shall be placed one-half mile prior to the start of the restriction.

1.6.1.2.4 Trackwork - General

1. Trackwork design shall be in accordance with the CRDSM, Section I, Chapter 4 Trackwork Criteria.

2. Rail: New rail shall be 132 RE and shall be head hardened standard AREMA chemistry rail with a minimum Brinell Hardness, HB of 370. See AREMA Chapter 4, Paragraph 2.1.4.2.

3. Track Gauge: Track gauge shall be 4' 8-1/2" measured 5/8" below top of rail on gauge face of the rail.

4. Rail Welding: Tee rail for tracks outside the limits of special trackwork shall be welded into continuous strings using the electric flash-butt pressure welding process. Thermite welds shall be used only where it is impractical to perform Pressure Welds (Production Flash Butt Welds), usually in the following locations: joining continuous welded rail strings, and for inserting insulated plug joints into welded strings.

5. Insulated Joints: Insulated rail joints shall be shop-manufactured per MBTA Drawing No. 1340, and shall conform to MBTA Commuter Rail Material Specification No. 9221 – Insulated Bonded Joint Plug Rail or MBTA Commuter Rail Material Specification No. 9224 – Insulated Joint Kit.

6. Rail Lubricators: Existing rail lubricators shall be verified with MBTA for relocation and update requirements.

1.6.1.2.5 Signaling/Train Control Coordination

The track design, including location of insulated joints at interlockings and crossovers shall be coordinated with the signal design.

1.6.1.2.6 Special Trackwork

1. Special trackwork design shall be in accordance with the CRDSM, Section I, Chapter 4 Trackwork Criteria.

2. Number 20 turnouts shall be used for mainline crossovers. Number 15 mainline crossovers shall be acceptable for use as part of the reconstruction of the existing Swift interlocking. Number 10 turnouts shall be used for low speed connections to the Main Line and for secondary track crossovers.

3. Proposed universal crossover on the New Hampshire Mainline shall be comprised of No. 20 turnouts on concrete ties utilizing movable point frogs. Timber approach/transition ties are required at transitions between main line wood tie track and concrete tie turnouts.

4. The design and location of turnouts shall be coordinated with the Track/Civil, Signals and Communications designs.

1.6.1.2.7 Noise and Vibration Mitigation

Areas in the GLX corridor that require measures to mitigate the potential effects of noise and vibration from the project are identified in the Environmental Assessment. Track design shall incorporate mitigation measures such as ballast mats and resilient rail fastening systems in the identified areas. Track design shall be coordinated with the noise and vibration engineer and with Chapter 8 of this document.

1.6.2 Light Rail Geometrics

1.6.2.1 Light Rail Track Alignment and Vehicle Clearance

1.6.2.1.1 General

This section of the Design Criteria Manual details minimum standards and design policies to govern the engineering, materials, and construction standards for light rail track alignment and its interfaces with other elements of the Green Line Extension project.

Interfacing elements of the system include track, stations, structures, traction power, communications, signal systems, drainage, and all other elements located within the guideway.

Except for the requirements established in these criteria, construction plans and specifications shall generally follow the AREMA Manual for Railway Engineering and Portfolio of Trackwork Plans modified as necessary to reflect the MBTA Maintenance of Way Division Book of Standard Trackwork Plans and the physical requirements and operating characteristics of the MBTA Green Line system.

Track construction and maintenance standards shall comply with the current addition of the MBTA Maintenance of Way Division Green Line Light Rail Transit Track Maintenance and Safety Standards.

1.6.2.1.2 Design Speed

Track alignment shall be designed to accommodate a maximum design speed of 50 miles per hour. Physical and operational constraints along various portions of the system, together with other design limitations may preclude achievement of this objective.

The civil design speeds shall be coordinated with the operating speeds used in the train performance simulation speed-distance profiles.

1.6.2.1.3 Track Designation and Stationing

Engineering stationing shall increase in the outbound direction. Stationing values shall be equated to the existing stationing placards on the Lechmere Viaduct.

Track designations shall be as follows:

Table 1-2 Light Rail Track Designation and Stationing

Branch	Track	Designation
Medford	Outbound	MB-EB XXX+XX
	Inbound	MB-WB XXX+XX
Union Square	Outbound	US-EB XXX+XX
	Inbound	US-WB XXX+XX

The outbound track (right track when looking up station) shall be the control track for each branch. Each branch shall be stationed independently along the centerline of the control (outbound) track. Stationing shall be continuous along the centerline of the control track and will be the basic control for locating light rail transit (LRT) system facilities along the route. Independent stationing will be required on the inbound track when tracks are neither parallel nor concentric, where widened track centers are required around curves, where parallel tracks have independent profiles, or where tracks are in separate structures. Where curvature results in different stationing at the end of a curve, the inbound track stationing shall be equated to the control track stationing at the ST point of whichever track has the spiral which extends the furthest ahead station. Geometrics shall be developed for all tracks.

1.6.2.1.4 Horizontal Track Alignment

The track alignment shall be designed to attain maximum permissible operating speeds and to maximize passenger ride quality.

1.6.2.1.4.1 General

Unless otherwise approved by MBTA, the horizontal alignment shall consist of tangent sections connected by circular curves with spiral transition curves.

1.6.2.1.4.2 Tangents

A. The minimum length of tangent between curved sections (except those with compound curves) shall be as follows:

Condition	Tangent Length (ft)
Desirable Minimum	3 times the design speed in mph
Minimum	60
Absolute Minimum	40

All tangent lengths less than minimum require prior written approval by the MBTA.

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

Condition	Tangent Length Beyond Ends of Platform (ft)
Desired Minimum	75
Minimum	45
Absolute minimum	25

Tangent lengths less than Minimum require prior written approval by the MBTA.

Where tangent platforms are not possible, curved platforms may be used subject to approval by MBTA.

Curved platforms shall be designed with clearances required to accommodate the future rising of platforms to provide for level boarding of vehicles. Approval of the planned alignment will be contingent on providing calculations illustrating that the design will have adequate clear distance between the vehicle body and the edge of platform and that the proposed platform gap will be no larger than 3 inches and will conform to ADA requirements.

1.6.2.1.4.3 Curves

A. Circular Curves

Circular curves shall be defined by the arc definition of curvature, and specified by their radius in feet. Degree of curve shall be converted to radius using the following formula:

$$R = 5{,}729.578/D_a$$

Where:

R = radius of curvature in feet

D_a = degree of curvature

Minimum circular curve radii are as follows:

Mainline Track:

Condition	Radius (ft.)
Desirable Minimum	500
Minimum	275
Absolute Minimum	150

Yard and Other Non-Revenue Track:

Condition	Radius (ft.)
Minimum	120
Absolute Minimum	50

All curves below Minimum radius require prior written approval by the MBTA.

Minimum circular curve lengths are as follows:

Condition	Minimum Length (ft.)
Desirable Minimum	3 times the design speed in mph
Minimum	40
Absolute Minimum	30

All circular curve lengths below Minimum require prior written approval by the MBTA.

For mainline multi-track layouts where two or more tracks follow the same general alignment, tracks shall be made concentric through the curves. In cases where track widening is required, the preferred method of creating concentric curves is to adjust the spirals of the inside track to a length where the spiral offset distance (p) relative to the outside track spiral offset distance is increased by an amount equal to the required track center increase, or in cases where no track widening is required, equal to the offset distance of the outside track.

The design speed for a given horizontal curve shall be based on its radius, the length of spiral transitions, and the actual and unbalance superelevation values assigned to the curve as described in the following sections.

B. Superelevation

Superelevation shall be constant through the circular curve. Superelevation shall be achieved by maintaining the top of the inside rail at the top of rail (TOR) profile and raising the outside rail by an amount equal to the track actual superelevation (Ea). The superelevation transition shall occur linearly at a uniform rate over the length of the spiral curve. For curves without spirals (limited to yard and non-revenue track), superelevation transitions, if required, shall occur at a uniform rate. The length of the transition shall be the minimum spiral length that would have been required for the curve as defined in Paragraph 1.6.2.1.4.3.C. The transition shall be distributed with 1/3 in the circular curve and 2/3 in the tangent.

Track superelevation shall be based on the following formula:

$$E_q = E_a + E_u = 4.011V^2/R$$

Where:

E_q = total superelevation required to balance the centrifugal force at a given speed in inches

E_a = actual track superelevation to be constructed in inches

E_u = unbalance superelevation in inches

V = design speed in mph

R = radius of curve in feet

Actual track superelevation (Ea) shall meet the following criteria:

Mainline Track (Excluding Station Approaches)

Condition	Actual Superelevation
Desirable Maximum	4 Inches
Absolute Maximum	6 inches

Condition	Unbalance Superelevation
Preferred Maximum	0 Inches
Maximum	½ Inch

Actual track superelevation shall be applied in ¼ inch increments.

Unbalance superelevation greater than the maximum shall not be used without prior written approval by the MBTA.

Mainline Track Station Approaches – Defined as the segment of track approaching a station platform where train speeds vary over the length of the approach segment.

Condition	Actual Superelevation
Desirable Maximum	4 Inches
Absolute Maximum	6 Inches

Condition	Unbalance Superelevation
Desirable Maximum	½ Inch
Absolute Maximum	1½ Inches

Ballast Yard tracks shall be superelevated if possible.

C. Spiral Curves

Spiral curves shall be provided between circular curves and horizontal tangents, and between adjacent circular curves of varying radius. Spirals shall be Talbot (clothoid) curves as defined by the AREMA Manual for Railway Engineering in which the following relationship pertains:

$$R * L = R_c * L_s$$

Where:

R = radius of curvature at the spiral at any given point between the TS and SC.

L = distance along the spiral from the TS to the given point.

R_c = radius of the circular curve, equal to R at SC.

L_s = length of the spiral curve from TS to SC.

The minimum length of spiral curve shall be the greatest length obtained from the following formulas:

$$L_s = 40E_a$$
$$L_s = 1.10E_aV$$

$L_s = 0.82\ E_uV$ Minimum
$L_s = 1.22\ E_uV$ Preferred

Absolute Minimum $L_s = 40'$

Where:

L_s = length of spiral in feet

E_a = actual superelevation for the circular curve in inches

E_u = unbalanced superelevation for the circular curve in inches

V = design speed in mph

Spirals shall be required on horizontal curves having a radius of less than 10,000 feet.

Yard and other non-revenue tracks do not require spiral curves if design speeds are 10 mph or less.

D. Reverse Curves

Minimum tangent lengths as specified in Section 1.6.2.1.4.2 above shall be maintained between all reverse curves.

E. Compound Curves

Compound circular curves may be used provided that they are connected by a spiral transition curve. The minimum length of spiral transition curve shall be the greatest length obtained from the following formulas:

$L_s = 31\Delta E_a$ Minimum
$L_s = 1.10\Delta E_a V$ Preferred

$L_s = 0.82\ \Delta E_u V$ Minimum
$L_s = 1.22\ \Delta E_u V$ Preferred

Absolute Minimum L_s = 40'

Where:

L_s	length of spiral in feet
ΔEa	difference of actual superelevation of the circular curves in inches
ΔEu=	difference of unbalanced superelevation of the circular curves in inches
V	design speed in mph

Yard and other non-revenue tracks with compound curves do not require spiral curves if design speeds are 10 mph or less.

1.6.2.1.5 Vertical Track Alignment

1.6.2.1.5.1 General

The vertical alignment shall be composed of constant grade tangent segments connected at their intersection by parabolic curves having a constant rate of change in grade.

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

In areas of curved horizontal alignment where the profile is given for only one track, the grade of the second track shall be adjusted uniformly to accommodate for the differences in length throughout the curve.

1.6.2.1.5.2 Grades

Grades shall not exceed the maximums specified below:

Condition	Grade
Maximum Sustained Mainline Grade: Unlimited Length	4.0%
Maximum Sustained Mainline Grade: up to 2500' Between PVIs	6.0%
Station Platforms: Desirable	0.0%
Station Platforms: Maximum	0.5%
Yard Tracks: Desirable	0.0%
Yard Tracks: Maximum	1.0%
Yard Storage and Pocket Tracks: Desirable	0.0%

Yard Storage and Pocket Tracks: Maximum	0.2%
Special Trackwork: Desirable Maximum	1.0%
Special Trackwork: Maximum	2.0%

1.6.2.1.5.3 Vertical Tangents

The minimum length of constant profile grade (vertical tangent) between vertical curves (PVC and/or PVT) shall be as follows:

Condition	Length
Desirable Minimum	The greater of 100 feet or 3 times the design speed (mph)
Absolute Minimum	40 feet

At station platforms, a vertical tangent shall extend for 40 feet beyond the ends of the platform.

1.6.2.1.5.4 Vertical Curves

Vertical tangents along the track shall be connected with parabolic vertical curves having a constant rate of change of grade.

A. Vertical Curve Lengths

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

Condition	Length
Desirable Length	LVC = 200A
Preferred Minimum Length	LVC = 100A
Absolute Minimum - Crest	$LVC = AV^2/25$
Absolute Minimum - Sag	$LVC = AV^2/45$

Where:

LVC = length of the vertical curve in feet

A = algebraic difference in the grades in percent

G_1 = percent grade of approaching tangent

G_2 = percent grade of departing tangent

V = design speed in mph

The minimum equivalent radius of curvature for vertical curves located on mainline tangent track shall not be less than 820 feet for crests and 1150 feet for sags. This equivalent radius of curvature can be calculated from the following formula:

$$R_v = LVC/0.01(G_1 - G_2)$$

Where:

Rv = minimum equivalent radius of curvature of a vertical curve in feet.

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

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

B. Reverse Vertical Curves

Reverse vertical curves may be used provided the minimum length of each vertical curve is not less than that defined in Section 1.6.2.1.5.4 A above, and prior MBTA written approval has been obtained.

C. Compound Vertical Curves

Compound or unsymmetrical vertical curves may be used provided the requirements of Section 1.6.2.1.5.4.A are met and prior MBTA written approval has been obtained.

D. Combined Horizontal and Vertical Curves

Where possible, areas of combined horizontal and vertical curves shall be avoided. Where a vertical curve must coincide with a horizontal curve, the absolute minimum length of the vertical curve shall be increased by 1.5 times the required length.

Absolute minimum horizontal curve lengths and vertical curve lengths shall not be used in the design of a combined geometry section.

1.6.2.1.6 Special Trackwork

Special trackwork is defined as any type of turnout, crossover or rail crossing. All special trackwork shall be located on horizontal and vertical tangents.

For special trackwork the horizontal and vertical tangent shall extend from the distance specified below preceding the point of switch to the end of the long ties.

The minimum length of tangent track preceding a point of switch shall be as follows:

Condition	Tangent Length
Desirable	45 ft
Minimum	30 ft
Absolute Minimum	12 ft

Tangent length less than 30 feet shall require prior written approval by the MBTA.

The desirable and maximum vertical gradients through special trackwork are given in Section 1.6.2.1.5.2 above.

1.6.2.1.7 Clearances

1.6.2.1.7.1 General

This section establishes the minimum dimensions required to ensure proper clearances between the light rail vehicles and transit structures or other obstructions and to establish a procedure for determining minimum track center distances. All designs shall meet or exceed the minimum clearance criteria as specified herein.

Designs shall include space for minimum 30" wide maintenance and emergency walkways on both sides of the LRT track bed wherever possible. MBTA written approval shall be obtained on a case by case basis where this condition cannot be met. Maintenance and emergency walkways shall not encroach on the static vehicle envelope per NFPA 130.

1.6.2.1.7.2 Clearance Envelope

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

$$CE = VDE + OWF + RC$$

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

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

1. Vehicle Dynamic Envelope Considerations for Determination

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

2. Dynamic Vehicle Outline

   The dynamic outline of the vehicle shall be defined as the extreme car body displacement that can occur for any combination of rotational, lateral and vertical car body movements that occur when the vehicle is operating on level, tangent track. These car body movements are due to truck suspension movements, spring action, allowable wheel and rail wear, and permitted tolerances in vehicle and track construction. The MBTA Maintenance of Way Division Standard Drawing 160, "LRT Track Standard Dynamic Clearance Envelope – Composite LRV" (LRV – light rail vehicle) defines the dynamic vehicle outline to be used for the Green Line Extension project.

3. Vehicle Inswing/Outswing

   In addition to the dynamic car body movements described above, car body overhang in horizontal curves also increases the lateral displacement of the dynamic outline relative to the track centerline. For design purposes, both mid-car inswing and end-of-car outswing of the vehicle shall be considered. The amount of mid-car inswing and end-of-car outswing depends primarily on the truck spacing and end overhang of the vehicle and on the radius of track curvature. Mid-car inswing and end-of-car outswing shall be based on the single-articulated MBTA Type 7 Vehicle as shown on MBTA Light Rail

Equipment Engineering Drawing, “Data Sheet No. 7 Surface rail Car NOS. 3600 – 3699” Drawing Number 47667 Rev A.

4. Superelevation Effects

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

5. Cross Level Deviation Effects

   The effect of cross level deviation shall also be taken into account in developing the Vehicle Dynamic Envelope. Allowable cross level deviation is dependent upon track maintenance requirements set by the MBTA. Cross level deviation effects shall be limited to the vehicle lean induced by the difference in elevation between the two rails of a track and shall be considered independently of other effects on the dynamic outline. In determining cross level deviation effects, the shape of the dynamic outline shall not be altered. Rather, the dynamic outline shall be rotated about the centerline of the top of the high rail an amount equal to the allowable cross level deviation set by the maintenance practice of the MBTA.

   Clearance calculations shall be based on a cross level deviation value of 2-1/8”.

D. Vehicle Dynamic Envelope

With the dynamic vehicle outline developed and the effects of track curvature and superelevation determined, the VDE can be calculated.

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

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

E. Other Wayside Factors

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

OWF = CMT + CW

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

Construction and Maintenance Tolerances (CMT)	
Construction tolerance along soldier pile and lagging walls and mechanically stabilized walls	6 Inches
Construction tolerance along all other proposed structures	2 Inches
Construction tolerance at OCS poles or signal equipment	1.5 Inches
Track construction and maintenance tolerance for mainline ballasted track	2.25 Inches
Track construction and maintenance for yard tracks	2.25 Inches
Allowance for acoustical treatment, where required	3 Inches

Chorded Wall Construction Factor (CW)	
Additional width for chorded construction of walls to be added on the outside of curves only	See Figures 1-1 & 1-2

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

a. Track Construction and Maintenance Tolerances

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

b. Construction Tolerances along Proposed Structures

Where the facility adjacent to the trackway is a structure, or part of a structure, the minimum horizontal construction tolerance shall be provided on the assumption that the structure, or part thereof, may be misplaced during construction by a dimension of that magnitude. It is emphasized that the term "structure" as used in this subsection applies to any facility to be constructed alongside the LRT system and above the top of rail.

c. Acoustical Treatment

The need for this allowance shall be investigated in cases where noise produced from the LRT system operations may be found in excess of tolerable limits for a given area.

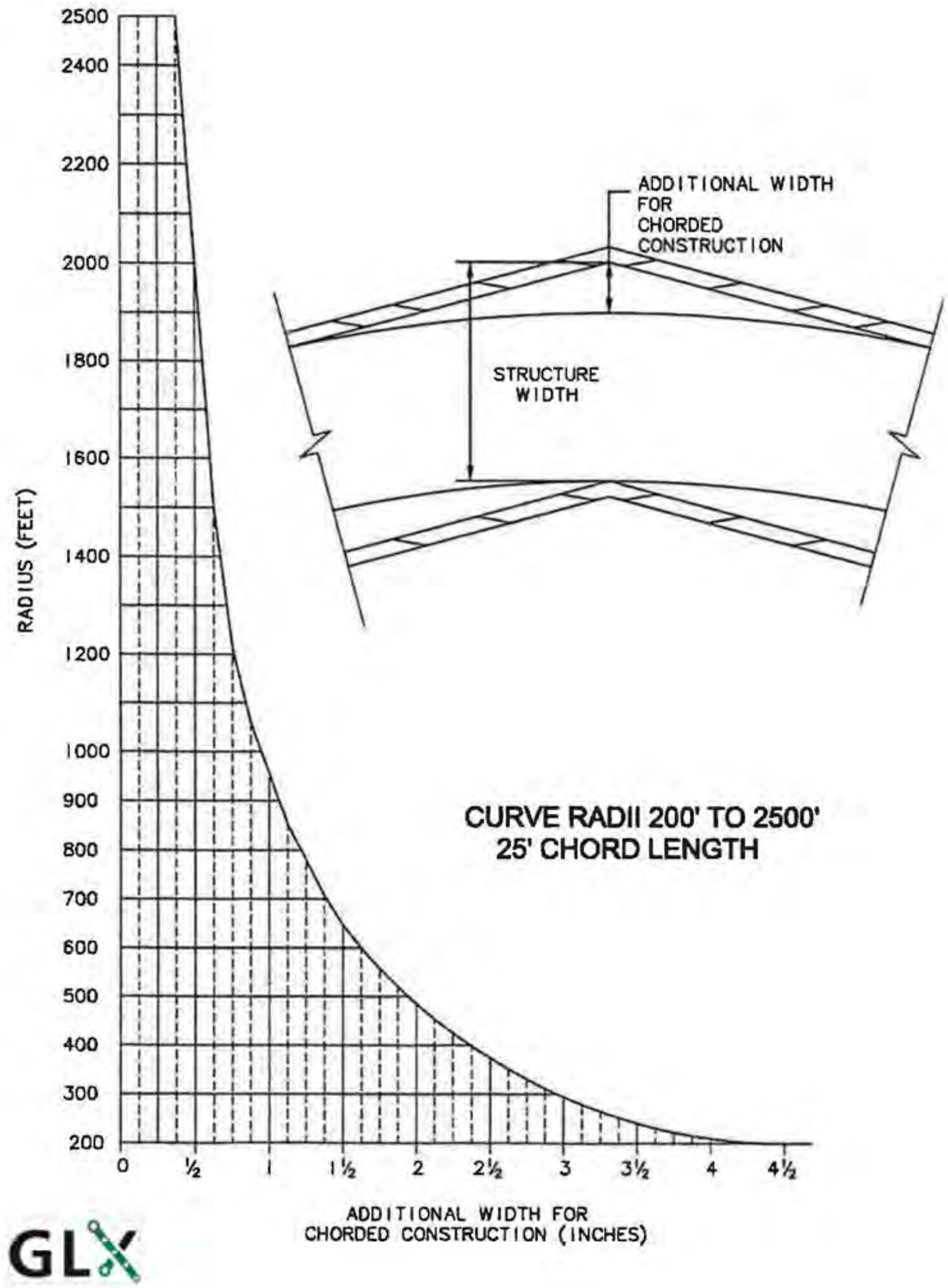
d. Running Clearances

In addition to the VDE and other wayside factors, the CE includes an allowance for RC. The following define the running clearances to be included in the horizontal component of the CE.

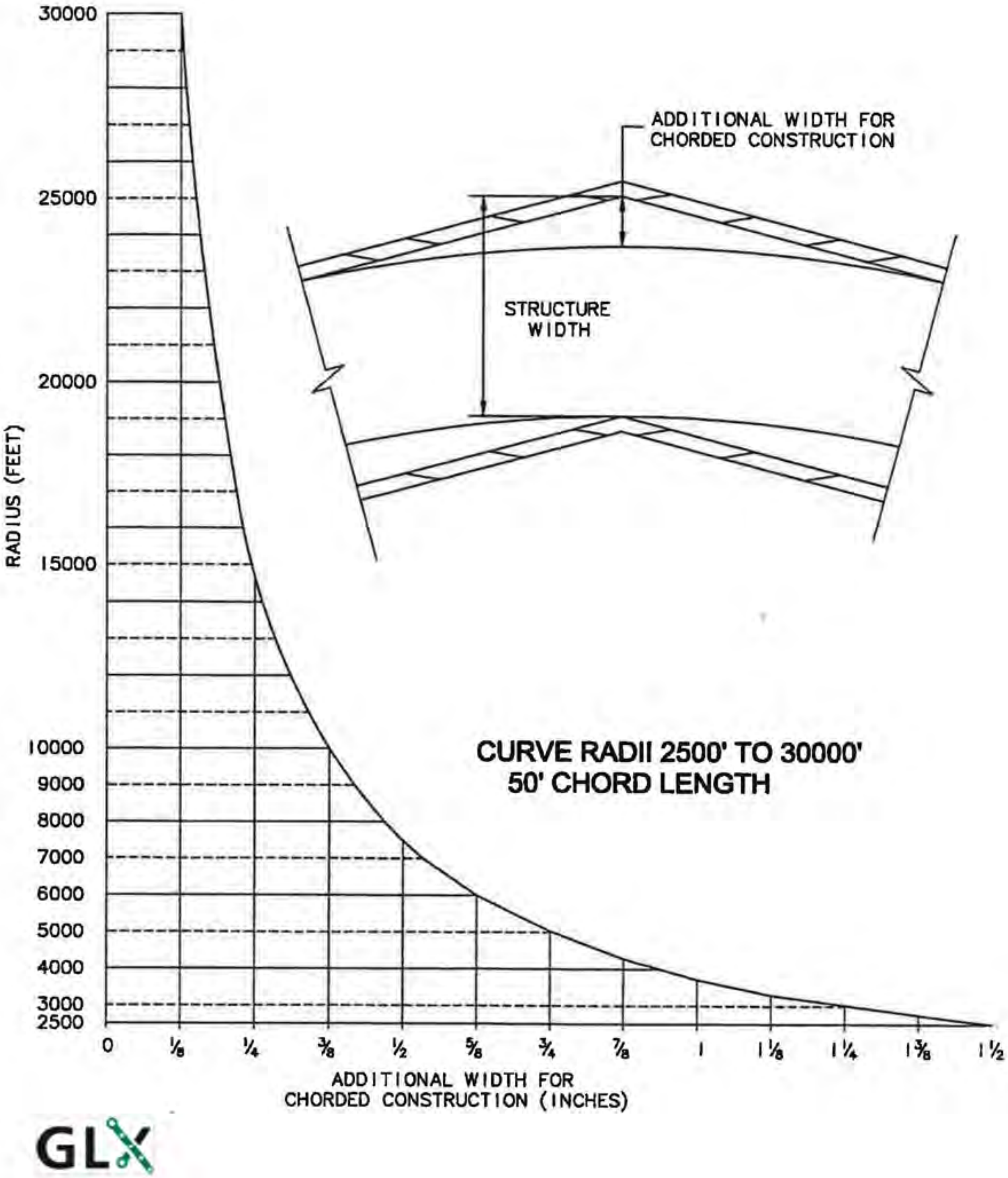
<table>
<tr><th colspan="2">Running Clearance (RC)</th></tr>
<tr><td>Running clearance at OCS poles, signals, signs and other non-structural members</td><td rowspan="3">3 Inches Min.

6 Inches Preferred</td></tr>
<tr><td>Running clearance along soldier pile and lagging walls and other structures which are normally constructed with liberal construction tolerances.</td></tr>
<tr><td>Running clearance along cast-in-place, pre-cast, and masonry walls and other structures which are normally constructed with strict construction tolerances</td></tr>
<tr><td>Running clearance for adjacent light Rail Vehicles (Total between
vehicles)</td><td>6 Inches</td></tr>
</table>

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



<u>**Figure 1-1 Additional Width for Chorded Construction with 25' Chord Length**</u>



<ins>Figure 1-2 Additional Width for Chorded Construction with 50’ Chord Length</ins>

1.6.2.1.7.3 Special Clearance Situations

In addition to the CE requirements described above, the following special clearance situations warrant further definition.

A Vehicle Interface at Station Platforms

The distance from the centerline of the track to the edge of platform shall be 4'-9**" for** platforms located on tangent track. The distance from centerpoint of track to the edge of platform for platforms located in curved track shall be modified to account for the effects of vehicle inswing and outswing. See section 1.6.2.1.4.2 for additional requirements for curved platforms.

Station platform shall be located 8" above top of rail plane.

Platform construction tolerances shall be coordinated with the station architectural and structural designs to ensure compliance with ADA requirements.

The vehicle/platform interface shall be designed to accommodate raising station platforms in the future to allow for level boarding of vehicles in conformance with current ADA requirements.

B. Retaining Walls

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

1. Cut Sections

   The preferred minimum clearance from the centerline of track to the near face of a retaining wall shall be 9'-0". Where required, maintenance and emergency evacuation paths shall be provided. The absolute minimum clearance from the centerline of track to the near face of a retaining wall shall be no less than that required to clear the CE plus the maintenance and emergency exiting width where required. The width of maintenance and emergency walkways shall be a minimum of 30", and the walkway envelope is defined at 80" above the walkway surface, per National Fire Protection Association (NFPA) 130.

2. Fill Sections

   The top of retaining wall shall be located at the same elevation as the top of rail adjacent to the wall for ballasted track. The preferred minimum distance from the centerline of track to any fencing or hand railing on top of the wall shall be a minimum of 9'-0". The absolute minimum clearance from the centerline of track to the face of wall, fencing or hand railing shall be no less than that required to clear the Clearance Envelope plus the maintenance and emergency exiting width where required. The width of maintenance and emergency walkways shall be a minimum of 30", and the walkway envelope is defined at 80" above the walkway surface, per NFPA 130.

3. Catenary and Signal Poles

   Preferred minimum clearance to catenary and signal poles, including any equipment or other attachments to the pole shall be 8'-6" from the track centerline for tangent track. Minimum clearance shall be 6'-6" and shall not be reduced without prior written approval by the MBTA.

4. Safety Niches

Safety niches shall be provided at all locations where side clearances do not include space for maintenance and emergency walkways on both sides of the LRT track bed over a total distance along the track of 20 feet or greater.

Maximum distance between niches shall be 20'-0" on center. The dimensions of niches will be in accordance with the MBTA Commuter Rail Standards.

The use of niches requires prior written approval by the MBTA.

1.6.2.1.7.4 Vertical Clearances to Overhead Structures

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

Location	Minimum Vertical Clearance
At overhead bridges	21 feet 6 inches, preferred minimum 15 feet 0 inches, minimum 14 feet 7 inches, absolute minimum

B. Absolute minimum vertical clearances shall be coordinated with the MBTA and OCS designs as required to identify specific local conditions which may affect the clearance. Use of vertical clearances less than the minimum require prior written approval by the MBTA.

1.6.2.1.7.5 Track Spacing

Track spacing shall vary depending upon the curvature and the type of construction used for the particular section of line. Minimum track centers are as follows (without center catenary poles):

Condition	Track Centers
Mainline: Preferred Minimum	12' - 0"
Mainline: Absolute Minimum	11' - 0"
Yard: Preferred Minimum	13' - 4"
Yard: Absolute Minimum	12' - 0"
Yard: Absolute Minimum with Center Walkway	18' - 0"

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

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

Where:

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

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

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

OWF = other wayside factors, in inches

RC = running clearances, in inches

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

$$d = \frac{Tt + Ta + 2\,(OWF + RC) + P}{12}$$

Where:

d	minimum allowable spacing between track centerlines, in feet.
T_t	dynamic half width of vehicle towards curve center, in inches
T_a	dynamic half width of vehicle away from curve center, in inches
OWF	other wayside factors, in inches
RC	= running clearances, in inches
P	maximum allowable OCS pole diameter (including deflection)

1.6.2.2 Light Rail Trackwork

1.6.2.2.1 General

Trackwork shall be designed in accordance with:

1. MBTA Maintenance of Way Green Line - LRT Track Maintenance and Safety Standards (LRTMSS)
2. MBTA Maintenance of Way Division - Book of Standard Trackwork Plans (BSTP)

1.6.2.2.2 Track System

The following track systems shall be used for light rail trackwork on the GLX project:

1. At Grade Guideway: Wood Tie and Ballast
2. Track on Viaducts: Wood Tie and Ballast
3. Track on LRT Bridges: Wood Tie and Ballast
4. Shop and Yard Tracks: Wood Tie and Ballast

1.6.2.2.3 Roadbed

1. Roadbed shall be designed in accordance with BSTP Dwg. No. 125 LRT Track Typical Roadbed Section (Tangent), and Dwg. No. 130 LRT Track Typical Roadbed Section (Curved).
2. Subgrade: Subgrade shall be analyzed to determine whether it has both the uniform stability and the strength needed to carry the expected loadings. Existing track beds shall be evaluated to determine if subgrade conditions are adequate or if remedial measures will be required. Coordinate with the Geotechnical group to determine

areas and limits where standard section(s) cannot be used and alternative subgrade designs may be required.

3. Subballast: Minimum subballast depth shall be 8”. Subballast material shall be in accordance with the MBTA Commuter Rail Material Specification No. 9251 - Subballast.

4. Asphalt Underlayment: Underlayment is required for all at grade mainline turnouts and special work. Underlayment shall be in accordance with MBTA Railroad Operations Book of Standard Plans Dwg. No. 1030 Asphalt Underlayment at turnouts. Asphalt underlayment is not normally required for turnouts located within the vehicle maintenance facility yard unless subgrade conditions or heavy use dictate otherwise.

5. Ballast: Ballast shall conform to Section LRT213.103, Ballast of the LRTMSS. Minimum ballast depth shall be 12” minimum below the bottom of tie. A minimum ballast shoulder of 18” from end of tie to top of slope is required. A 12” to 18” shoulder may be used in extenuating circumstances with the prior written approval of MBTA. Ballast shall be AREMA No. 4.

6. Crossties: Timber crossties shall be used for track construction and conform to Section LRT213.109, Crossties of the LRTMSS and with BSTP Dwg. No. 200 Standard Wooden Crosstie, and Dwg. No. 201 Anti-Splitting End Plate for Wooden Cross-Ties.

7. Switch machine timbers shall be made of Azobe Hardwood Timbers.

8. Crosstie Spacing: Spacing shall conform to BSTP Dwg. No 210 Standard Tie Spacing, Usage and Spiking Patterns.

9. Transition ties and approach slabs are required at the ends of all bridges and shall conform to BSTP Dwg. No. 215 Transition Tie Spacing.

10. Station Platform: A field side rubber crossing panel is required between the station platform and the near rail at all platform locations. Reference Accessible (low-floor) Platform Detail on BSTP Dwg. No. 140 LRT Track Typical Roadbed Section, Double Track with Station Platforms. Detail may be modified to provide for easy removal and installation of panels to perform track maintenance and as required to coordinate with GLX station platform detail.

11. Right of Way Fencing: Fencing is required along the entire length of the right of way boundary except in areas where noise walls or system structures provide a barrier preventing unauthorized entry to the right of way.

1.6.2.2.4 Rail

1. 115 RE section rail conforming to the current AREMA “Specification for Steel Rails” shall be used for all tracks on the LRT system.

2. Except as required in the following paragraphs, Rail shall be standard AREMA chemistry rail with a minimum Brinell Hardness, HB, of 310 (See AREMA Chapter 4, Paragraph 2.1.4.2.).

3. All new rail shall be head hardened standard AREMA chemistry rail (Head Hardened Rail) with a minimum Brinell Hardness, HB, of 370 (See AREMA Chapter 4, Paragraph 2.1.4.2.).

1.6.2.2.5Restraining Rail

1. Track having a centerline radius of less than or equal to 1000 feet, and greater than 100 feet, shall have restraining rail added to the inside running rail.

2. Track having a centerline radius equal to or less than 100 feet shall have restraining rail added to both running rails.

3. Restraining rail shall be 132 RE installed in accordance with the BSTP and supplemental detail provided by the MBTA. Restraining rail assembly shall extend beyond each end of a guarded simple curve (no spirals) a minimum distance of 10 feet before the curve and 30' after the curve based on the normal direction of travel. Where the track geometrics include a spiral, the curve guarding shall extend a minimum distance of 10 feet before the spiral and 30' after the spiral based on the normal direction of travel.

1.6.2.2.6 Emergency Guard Rail

1. Emergency guard rails (2) are required between the running rails (fully guarded) in the following locations:

   Bridge Decks
   Elevated Structures and Viaducts
   Adjacent to Station Structures
   Adjacent to Station Emergency Egress Structures
   Adjacent to Fill Retaining Walls and Slopes
   Bridge Abutments and Piers
   On Grades of 3% or greater (regardless of location)

2. Guard Rail shall conform to BSTP Dwg. No. 900 Bridge Guard Installation Details and Dwg. No. 905 Resiliently Fastened Bridge Guard Rail.

3. Emergency guard rail shall extend 100 feet ahead of the area being protected on the approach end and extend 50 feet beyond the area being protected on the departure end.

1.6.2.2.7 Track Gauge and Flangeway Width

1. Design values for track gauge shall conform to Section LRT213.53, Gauge of the LRTMSS.

2. Flangeway Width shall conform to Section LRT213.54, Flangeway Width of the LRTMSS.

1.6.2.2.8 Traction Power and Signaling/Train Control Coordination

1. The track design, including bonding and cross-bonding for the traction power negative return system, shall be coordinated with the Traction Power System design.

2. The track design, including location of insulated joints at interlockings, crossovers, and station platforms, shall be coordinated with the signaling and Communication System designs.

1.6.2.2.9 Corrosion Control/Stray Current Mitigation

1. Mainline running rails, including special trackwork, grade crossings and all ancillary system connections, shall be designed to minimize the corrosive effect of stray current. See Section 5.10 of this document for specific requirements.

1.6.2.2.10 Derails

Hand thrown sliding block derails are required on all tail tracks and yard leads to prevent out-of-control rail vehicles from inadvertently entering mainline track or fouling adjoining or adjacent tracks

Derails shall be located so as to derail equipment in the direction away from the main track. Derail installation shall be coordinated with the MBTA Signals and Communication Group.

Derails shall not be used to protect pocket tracks located between main lines due to the potential of a derailed train fouling the main line. Special trackwork accessing pocket tracks shall be configured so that switches can be lined in such a manner that will prevent a train from inadvertently accessing either of the main line tracks. The special trackwork configuration shall be coordinated with the MBTA Signals Department.

1.6.2.2.11 Light Rail Special Trackwork

1. Special trackwork shall be designed and constructed in strict accordance with MBTA standards and standard drawings.
2. Special trackwork shall be located on horizontal and vertical tangents unless otherwise approved by the MBTA.
3. All joints in primary track special trackwork shall be welded except at insulated joint locations.
4. Frogs in mainline track turnouts shall be designed to eliminate all bolted joints in running surfaces.
5. Jump frogs shall be used on mainline track turnouts that are not used for normal train operations. For example, the pocket track at Lowell Street.
6. Flange bearing frogs are required for all yard turnouts.
7. No. 8 turnouts are the preferred minimum size for mainline use on this project. No. 6 turnouts may be used with prior written approval of the MBTA.
8. All mainline turnouts shall be constructed with hot mix asphalt underlayments. Underlayment shall conform to MBTA Railroad Operations Standard Drawing No. 1030 Asphalt Underlayment.
9. Provisions shall be made during the design of special trackwork for the installation of switch heaters. All switches shall be designed to accommodate switch heaters regardless of the location of the specific installation within the system or the need for switch heaters at that location.
10. Special trackwork shall be located so as to reduce the exposure of pedestrians to the operating or movable mechanisms and to minimize requirements for special catenary and signal structures.
11. The limits of any trackwork design or construction contract shall not be located within a special trackwork unit.
12. Special trackwork design and location shall be coordinated with MBTA Operations, Traction Power, and Signal and Communication Groups.
13. The design of all mainline power operated and hand throw turnouts shall allow for a 4 ½” point opening measured 6” from tip of point, including point guards. Connecting rods shall be adjustable vertical rods, including #1 and #2 rods.

1.6.2.2.12 Miscellaneous Track Appurtenances

1. Bumping posts shall be installed at the ends of all stub-end tracks. Bumping posts shall be designed to engage the anticlimber of the LRT vehicle.

1.6.2.2.13 Storage and Maintenance Yards - Additional Requirements

1. Effective length of storage tracks shall be measured between 11.0’ clearance points of converging tracks.
2. Storage length of each single-ended track shall include 30’ buffer beyond the length of the LRV to provide space for parking overruns and to prevent hitting end-of-

track bumping posts. Storage length of double-ended track shall include 30' buffer beyond the calculated length of stored LRVs on the track to provide space for parking overruns. The buffer may be reduced with prior written approval by MBTA.

3. Yard Turnouts:

   Preferred: 150' curve radius (C.R.) Turnout, Fully Guarded.

   Minimum: 100' C.R. Turnout, Fully Guarded, with prior written approval of the MBTA.

4. Overlapping turnouts may only be used with prior written approval of the MBTA.
5. Yard tracks shall use standard MBTA ballasted track construction with timber crossties placed at 24" centers.
6. Walkways are required between vehicle storage tracks and shall be paved.
7. Hand thrown sliding block derails are required on shop lead tracks.
8. Yard leads shall have a positive grade (yard to mainline direction of travel) to prevent vehicles from inadvertently rolling onto the mainline.
9. Yard grade crossings and shop approaches shall be asphalt with rubber rail seal.
10. Yard track layout and design shall be coordinated with MBTA Operations, Traction Power, Signal and Communications, and Vehicle Groups.

1.6.2.2.14 Noise and Vibration Mitigation

Areas in the GLX corridor that require measures to mitigate the potential effects of noise and vibration from the project are identified in the Environmental Assessment. Track design shall incorporate mitigation measures such as ballast mats and resilient rail fastening systems in the identified areas. Track design shall be coordinated with the noise and vibration engineer and with Chapter 8 of this document.

1.7 Somerville Community Path

1.7.1 General

This chapter sets forth criteria required for designing the Community Path located adjacent to the MBTA Green Line Extension project. There are two distinct portions of the Community Path as follows: (1) the at-grade path and (2) the elevated structure also known as the Red Bridge Crossing (RBC), which will be defined separately below.

The intent of the community path is to provide a connection from the proposed terminus of the City of Somerville's community path at the Lowell Street extension (for which a groundbreaking ceremony was held in May 2013) to the North Point multi-use path in Cambridge. The City of Somerville has decided not to pursue construction of a spur connection to the Inner Belt Road area as part of this project.

Type of facility:	Multi-use path for pedestrians (including users of mobility aids), bicyclists, joggers, skaters, strollers/carriages
Operator:	City of Somerville 'City' will maintain and operate facility (MBTA will not be responsible for operations or maintenance). The community path will be available for use 24 hours per day, 7 days per week.
Right-of-way:	Where possible, City or private lands will be used. Where there is excess MBTA right-of-way (ROW) not needed for the commuter rail and Green Line Extension, the City of Somerville will seek to acquire that excess ROW for the purpose of the community path. Wherever private land is needed for construction and

maintenance of the path, this land will be acquired by the City for the Community Path.

Accessibility Variances: City of Somerville requires that all roadway crossings meet the current ADA/MAAB Standards. Any deviation from these standards will require relief from the appropriate agencies. The MBTA will obtain such relief, where possible, via the resources of the GLX project.

Approvals: City of Somerville will obtain all permitting approvals, including but not limited to MEPA, NEPA, MassDOT, MassDEP and Environmental. The Green Line Extension team will develop plans, specifications and estimates to support these approvals.

1.7.2 Regulatory Requirements and Other Design Guidelines

- U.S. Department of Justice (DOJ), ADA Standards for Accessible Design (September 15, 2010)
- US DOJ, Guidance on the 2010 ADA Standards for Accessible Design (September 15, 2010)
- United States Access Board, Proposed Accessibility Guidelines for Pedestrian Facilities in the Public Right-of-Way (PROWAG) (July 26, 2011)
- Massachusetts Architectural Access Board Regulations (521 CMR) (2006)
- American with Disabilities Act and Architectural Barriers Act - Accessibility Guidelines for Outdoor Developed Areas (36 CFR Part 1195) (2009)
- Federal Highway Administration, Designing Sidewalks and Trails for Access, Part II of II: Best Practices Design Guide (September 2001)
- AASHTO, Guide for the Development of Bicycle Facilities, 4th Edition (2012)
- Federal Highway Administration, Manual on Uniform Traffic Control Devices (MUTCD) (2009 with all revisions)
- United States Access Board ADA Accessibility Guidelines (ADAAG) (2004)
- Massachusetts Department of Environmental Protection (MassDEP) Stormwater Management Standards
- Massachusetts Department of Transportation (MassDOT) , Shared Use Paths and Greenways
- City of Somerville, Planning and Zoning Ordinances, and the City's Parks Specifications, and Department of Public Works (DPW) permits
- City of Cambridge, Planning and Zoning Ordinances, and Department of Public Works (DPW) permits

1.7.3 Geometrics – At Grade Community Path from Lowell Street to Washington Street

Design Speed: 20 mph for bicycles; 30 mph for steep downgrades (over 4%)

Load Capacity: To meet AASHTO Guidelines, maximum design weight of 12 kips. The City of Somerville's DPW vehicles have a Gross Vehicle Weight Ratings (GVWR) less than 10, 000 pounds for snow removal and other maintenance activities.

Path Pavement width: 12 foot (preferred)

8 foot minimum (at pinch points)

Vertical Clearance:	8 feet minimum, 10 to 12 feet if possible preferred
Turning Radius:	Maximum turning radius of 12 foot
Cross slope:	Less than 2% -- 1% recommended in AASHTO
Grades:	5% maximum (4.85% used for design to allow for construction tolerances)
Curvature:	Design Speed 20 mph – 100 feet minimum radius (desired) Design Speed 30 mph – 225 feet minimum radius (desired) Where these criteria cannot be achieved due to site constraints, appropriate signage will be incorporated.
Sight Distance:	Minimum Stopping Sight Distances and minimum lengths of vertical crest curves for various design speeds, vertical, and horizontal curves will be calculated using methods described in AASHTO and will be considered in the final design.
Shoulders:	2 foot each side (preferred) (grass or non-paved material) – additional shoulder/clearance width should be provided where obstruction are adjacent to path
Roadway Crossings:	Provide City of Somerville roadway crossing detail, where possible Specialty material type roadway crossing Crossing type at non-ADA compliant situations
Surfacing / Pavement:	Bituminous Concrete
Subbase:	See Attachment 5 - Typical Cross Sections for the At Grade Community Path.
Drainage:	Comply with MassDEP Stormwater Management Standards. Recommend pitching pavement to grass shoulders along path or using an inlet and conveyance pipe system. Catch basins should be flush with surface located outside of path with bicycle-safe grates.
Striping:	6-inch retro reflective single yellow centerline stripe, plus stop lines, per MUTCD and MassDOT amendment to the MUTCD.
Signage:	Traffic signage per MUTCD

1.7.4 Other Features – At Grade Community Path from Lowell Street to Washington Street

Fencing:	Fencing to separate path from MBTA operating ROW: 8 foot high, tight mesh (1”) security, no barbed wire. Verify with MBTA requirements for arc flash protection and heavier duty fencing. Fencing along station areas may be 8 foot decorative fence subject to the direction and approval of the MBTA. Fencing separating the community path from private land will be 6 foot high, black vinyl extruded knuckled end fence, no barbed wire. Private land fence types may vary per the City’s discussions with property owners and final agreement by MBTA. Gates and/or access connections (steps/ramps) from private land onto the community path will be discussed by the City during meetings with the adjacent property owners and placed with agreements between the City and each property owner prior to Final Design. Fence foundations will be designed to be a minimum depth of the regional frost depth as expressed in the Massachusetts Building Code.

Benches: Provide at periodic intervals where space and grade allow. City of Somerville standard bench type on concrete pad: Custom Fabrication Inc. Harpursville NY Part No. CFPB-010-01 Park Bench with Back. The bench concrete pad will be 6 inches of 4000 psi concrete with 12 inches of compacted stone or gravel base, the pad will slope at a ½ percent slope or crown from the center to the edges to eliminate any wet spots, brushed finish. The bench will have all steel pieces phosphate washed, primed with zinc rich primer, and painted with exterior grade polyester powder coat, color will be 'Black'. Wood will be painted with exterior grade enamel Sherwin Williams 'Black'.

Trash Receptacle: A single style of trash receptacle and recycling receptacle will be used for the entire Community Path Extension to maintain consistency, ease of maintenance and replacement. Locations of these shall be placed near or at roadway intersections along the pathway. City of Somerville standard trash receptacle enclosure type on concrete pad with standard padlock (provided by the City): Custom Fabrication Inc. Harpursville NY Part No. CFTR-020-01 Style 55 Gal Heavy Duty. Specify that each trash receptacle will contain a standard 55 gallon drum upon installation. Trash receptacle concrete pad will be 6 inches of 4000 psi concrete with 12 inches of compacted stone or gravel base, the pad will slope at a ½ percent slope or crown from the center to the edges to eliminate any wet spots, brushed finish. The receptacle will have all steel pieces phosphate washed, primed with zinc rich primer, and painted with exterior grade polyester powder coat, color will be 'Black'.

Lighting: Lighting fixtures shall match the work being done by others for the City of Somerville, as described below. Lighting in proximity to an MBTA station should conform to MBTA lighting standards. Consideration must be given to location and arrangement of lighting circuits and panel configuration to accommodate automated energy control devices and ease of maintenance. Panel locations subject to approval of the MBTA and the City of Somerville. Solar power fixture will be considered, but will meet the above reference lighting standards. City of Somerville standard lighting fixture on concrete base: Philips Lumec Light Head S55-65W49LED4K-ACDR-LE3-VOLT-SFX-BKTX and pole RA54-13.5-GFII-PH7/120-BKTX. Lighting foundations will be designed to meet MassDOT requirements. The lighting pole will have all steel pieces phosphate washed, primed with zinc rich primer, and painted with exterior grade polyester powder coat, color will be 'Black'.

Lighting under Bridges/Tunnels: Lighting fixtures shall provide lighting for safety and security of users of the community path. Lighting in tunnels will meet standard lighting requirements for tunnels and placed to reduce potential for vandalism. Pole and/or handrail mounted lighting fixtures options will be evaluated in Final Design. Consideration will be given to location and arrangement of lighting circuits and panel configuration to accommodate automated energy control devices and ease of maintenance.

Emergency Equipment: Emergency call boxes shall be installed at regular intervals as coordinated with the City's emergency responders. Emergency signage shall be highly visible and available in multiple languages. City of Somerville's standard emergency call box type with concrete call box terminal foundation: L.W.Bills Company, Georgetown MA, Signal/Communications/Solar Powered/Radio Fire Alarm Box DTS L1R1 – P104 (DTX Solar Powered Radio Box), for button for 'Fire' and stickers 'Emergency', and Signal

	Communications Corp. Woburn MA Call Box Terminal Foundation, Drawing No. 1000-0436-4 Typical Foundation Installation. Emergency call boxes concrete foundation will be designed to meet MassDOT requirements, the foundation will slope at a ½ percent slope or crown from the center to the edges to eliminate any wet spots. Placement of the solar powered emergency call boxes will consider the location to provide maximum opportunity for a clear path (radio transmission) from the unit radio antenna to the reception point. Emergency call box foundations will be designed to extend at least to the minimum regional frost depth.
Bollards:	Lockable, removable bollards will be placed at all access points of the path to prohibit unauthorized vehicle access. Bollards should be a single style high visibility type and should be consistent with those installed throughout the Minute Man Bike Path and the City of Somerville Community Path Extension. A minimum 36" clear width should be maintained.
Guard Rails:	Required where vehicular access may be permitted on the track side of the path. Reinforced supplemental hand / bicycle 'rub rail' shall be placed along the trackside fence to prevent pedestrian or bicycle traffic from entering the track corridor. Curb rail may be utilized as necessary along the top edge of retaining walls where the path is above the tracks.
Railings:	Continuous railings to be provided full length of community path where the path is at a retaining wall above tracks or is a tiered situation. The minimum height of 42 inches with bicycle rub rail at a height of 36 inches. Openings in the railing shall be designed to meet AASHTO requirements.
Signage:	Signage for the Community Path Extension shall conform to the Federal Highway Administration, 'Manual on Uniform Traffic Control Devices (MUTCD) (2009 with all revisions), AASHTO, Guide for the Development of Bicycle Facilities, 4th Edition (2012), and the City of Somerville's requirements. Signage shall be placed as so not to interfere with the user's safety or their approach to roadway intersections with the path. Signage shall consist of warnings, regulations, wayfinding devices, movements and controls, and other information signage to inform users of places of interest in the community.
Bicycle Storage Racks:	Bicycle storage racks will be provided at each of the Green Line Extension stations along the Community Path.
Other Amenities:	To be determined in consultation between MassDOT and City of Somerville.

1.7.5 General – Community Path Red Bridge Crossing Elevated Structure

This section sets forth criteria required for designing the Community Path Red Bridge Crossing located adjacent to the MBTA Green Line Extension project. This section pertains to specifically to the elevated structure portions of the path. Portions of the Red Bridge Crossing path that are constructed on-grade shall be in accordance with the requirements of *Green Line Extension Design Criteria Manual*, Sections 1.7 through 1.7.4.

Type of facility:	Multi-use path for pedestrians (including users of mobility aids), bicyclists, joggers, skaters, strollers/carriages
Operator:	City of Somerville 'City' will maintain and operate facility (MBTA will not be responsible for operations or maintenance). The community path will be available for use 24 hours per day, 7 days per week.

Right-of-way:	Where possible, excess MBTA right-of –way (ROW), not needed for the commuter rail or Green Line Extension, will be used for the Red Bridge Crossing. The City of Somerville will either seek to acquire the excess ROW or acquire easements/rights from the MBTA. Private land needed for construction and maintenance of the elevated path will need to be acquired by the City There is no City land available for use in the Red Bridge area.
Approvals:	City of Somerville will obtain all permitting approvals, including but not limited to MEPA, NEPA, MassDOT, MassDEP and Environmental. The Green Line Extension team will develop plans, specifications and estimates to support these approvals.

1.7.6 Regulatory Requirements and Other Design Guidelines

- U.S. Department of Justice (DOJ), ADA Standards for Accessible Design (September 15, 2010)
- US DOJ, Guidance on the 2010 ADA Standards for Accessible Design (September 15, 2010)
- United States Access Board, Proposed Accessibility Guidelines for Pedestrian Facilities in the Public Right-of-Way (PROWAG) (July 26, 2011)
- Massachusetts Architectural Access Board Regulations (521 CMR) (2006)
- American with Disabilities Act and Architectural Barriers Act - Accessibility Guidelines for Outdoor Developed Areas (36 CFR Part 1195) (2009)
- Federal Highway Administration, Designing Sidewalks and Trails for Access, Part II of II: Best Practices Design Guide (September 2001)
- AASHTO, Guide for the Development of Bicycle Facilities, 4th Edition (2012)
- Federal Highway Administration, Manual on Uniform Traffic Control Devices (MUTCD) (2009 with all revisions)
- United States Access Board ADA Accessibility Guidelines (ADAAG) (2004)
- Massachusetts Department of Environmental Protection (MassDEP) Stormwater Management Standards
- Massachusetts Department of Transportation (MassDOT) , Shared Use Paths and Greenways
- City of Somerville, Planning and Zoning Ordinances, and Department of Public Works permits
- City of Cambridge, Planning and Zoning Ordinances, and Department of Public Works (DPW) permits

1.7.7 Geometrics Elevated Community Path Red Bridge Crossing from Washington Street Somerville to West Boulevard Cambridge

Design Speed:	20 mph for bicycles; 30 mph for steep downgrades (over 4%)
Load Capacity:	To meet AASHTO Guidelines, maximum design weight of 12 kips. The City of Somerville's DPW vehicles have a GVWR less than 10, 000 pounds for snow removal and other maintenance activities.
Path width:	8 feet minimum, with a total clear width of 12 feet between railings, to allow for shoulders
Vertical Clearance:	8 feet minimum
Turning Radius:	Maximum turning radius of 12 foot
Cross slope:	Less than 2% -- 1% recommended in AASHTO sloped in one direction

Grades:	5% maximum (4.85% used for design to allow for construction tolerances)
Curvature:	Design Speed 20 mph – 100 feet minimum radius (desired) Design Speed 30 mph – 225 feet minimum radius (desired) Where these criteria cannot be achieved due to site constraints, appropriate signage will be incorporated.
Sight Distance:	Minimum Stopping Sight Distances and minimum lengths of vertical crest curves for various design speeds, vertical, and horizontal curves will be calculated using methods described in AASHTO and will be considered in the final design.
Shoulders:	Considered to be 2 feet each side to meet AASHTO Guidelines, (whether striped or not)
Surfacing:	Concrete
Drainage:	Comply with MassDEP Stormwater Management Standards. Recommend pitching pavement to grass shoulders along path or using an inlet and conveyance pipe system. Catch basins should be flush with surface located outside of path with bicycle-safe grates.
Striping:	6-inch retro reflective single yellow centerline stripe, plus stop lines, per MUTCD and MassDOT amendment to the MUTCD.
Signage:	Traffic signage per MUTCD

1.7.8 Other Features Elevated Community Path Red Bridge Crossing from Washington Street Somerville to West Boulevard Cambridge

Fencing:	Fencing will be used to separate path from MBTA operating ROW, and as a missile barrier on the outside edges of the bridge. The fence shall be 8 foot high, tight mesh (1”), no barbed wire.
Benches:	Will not be included within the elevated structure limits.
Trash Receptacle:	Will not be included within the elevated structure limits.
Lighting:	Lighting will be provided along the elevated structure. Pole and/or handrail mounted lighting fixture options will be evaluated in Final Design. Consideration will be given to location and arrangement of lighting circuits and panel configuration to accommodate automated energy control devices and ease of maintenance.
Emergency Equipment:	Emergency call boxes shall be installed at regular intervals as coordinated with the City’s emergency responders. Emergency signage shall be highly visible and available in multiple languages. Emergency call boxes shall be installed at regular intervals as coordinated with the City’s emergency responders. Emergency signage shall be highly visible and available in multiple languages. City of Somerville’s standard emergency call box type with concrete call box terminal foundation: L.W.Bills Company, Georgetown MA, Signal/Communications/Solar Powered/Radio Fire Alarm Box DTS L1R1 – P104, for button for ‘Fire’ and stickers ‘Emergency’, and Signal Communications Corp. Woburn MA Call Box Terminal Foundation, Drawing No. 1000-0436-4 Typical Foundation Installation. Placement of the solar powered emergency call boxes will consider the location to provide maximum opportunity for a clear path (radio transmission) from the unit radio antenna to the reception point.
Landscaping:	Will not be included within the elevated structure limits.

Bollards:	Lockable, removable bollards will be placed at all access points of the path to prohibit unauthorized vehicle access. Bollards should be a single style high visibility type and should be consistent with those installed throughout the Minute Man Bike Path and the City of Somerville Community Path Extension. A minimum 36" clear width should be maintained.
Railings:	Continuous railings to be a provided full length of structure with a minimum height of 42 inches with bicycle rub rail at a height of 36 inches. Openings in the railing to meet AASHTO requirements.
Signage:	Signage for the Community Path Extension shall conform to the Federal Highway Administration, 'Manual on Uniform Traffic Control Devices (MUTCD) (2009 with all revisions), AASHTO, Guide for the Development of Bicycle Facilities, 4th Edition (2012), and the City of Somerville's requirements. Signage shall be placed as so not to interfere with the user's safety or their approach to roadway intersections with the path. Signage shall consist of warnings, regulations, wayfinding devices, movements and controls, and other information signage to inform users of places of interest in the community.
Bicycle Storage Racks:	Will not be included within the elevated structure limits.
Other Amenities:	To be determined in consultation between MassDOT and City of Somerville.

1.7.9 Structural Design Elevated Community Path Red Bridge Crossing from Washington Street Somerville to West Boulevard Cambridge

Codes: Per *Green Line Extension Design Criteria Manual,* Section 2.5.

In cases where path structure is supported on extension of substructures of the adjacent rail viaduct, design of the substructure element shall be in accordance with *Green Line Extension Design Criteria Manual,* Section 2.3.

Design Vehicle:	The vehicle used for design will have a primary purpose of snow removal and maintenance. The maximum weight of the vehicle shall be 12 kips with a maximum turning radius of 12 feet. This maximum weight and turning radius are based on the assumption that a skid steer loader or a short wheelbase compact utility tractor will be used for snow removal. Accommodation of larger maintenance vehicles, pickup trucks, ambulances, or other emergency vehicles will not be considered in the design.
Placards:	All points of vehicular access to the elevated path shall incorporate a permanent metal placard with raised lettering that displays the design maximum weight limit for vehicles using the structure.

1.8 Utilities

1.8.1 Purpose

This section provides the design criteria for proposed relocation of existing utility lines within the railroad corridor, station footprints, areas attached to and/or crossing at bridges, roadway intersections, for new utility services for the proposed stations, and work on any other utilities as part of the MBTA Green Line Extension project.

1.8.2 Codes, Standards, References, and Guidelines

The following standards, codes and guidelines shall be used in the relocation/extension of utility lines (e.g., water, sewer, gas, fire alarm, electric, telecom, etc.) as part of construction for the Green Line Extension project for the rail corridor, proposed station footprints, bridges and roadway elements, as appropriate, unless noted, or directed otherwise. The design criteria will be set forth by the latest edition, including revisions, amendments and supplements, of the publications presented below and in the subsequent sections of this document. In the event there is a design criteria conflict between any of the design documents the more stringent conditions shall apply, unless otherwise directed by the MBTA.

Utilities located within the Corridor, the following documents shall govern.

- AREMA Part 5 Pipelines, which includes specifications for pipelines conveying flammable and non-flammable substances, uncased gas pipelines within the Right-of-Way, overhead pipelines crossings, and fiber optic construction on railroad Right-of-Way.

Massachusetts Bay Transportation Authority (MBTA) standards and guidelines -

- MBTA Railroad Operations Commuter Rail Design Standards Manual for Track and Roadway
- MBTA Commuter Rail Track and Roadway Book of Standard Plan
- MBTA Railroad Operations Commuter Rail Design Standards Manual for Bridges.
- MBTA Railroad Operations Directorate MBTA Manual of Guidelines and Standards
- MBTA Guidelines for Designing Barrier-Free Transportation Facilities
- MBTA Commuter Rail Station Access Guidelines
- MBTA Maintenance of Way Division Green Line – Light Rail Transit Track Maintenance and Safety Standards.

Utilities located within State Roads and/or located on Bridges, the following documents shall govern:

Massachusetts Department of Transportation (MassDOT) standards and guidelines -

- MassHighway Project Development and Design Guide
- MassHighway Design Manual
- MassDOT Highway Division Load and Resistance Factor Design (LRFD) Bridge Manual Design Guidelines
- MassDOT Highway Division Right of Way (ROW) Manual
- MassHighway Standard Specifications for Highways and Bridges
- MassDOT Highway Division Supplemental Specifications to the Standard Specifications for Highways and Bridges
- MassDOT Highway Division Standard Special Provisions
- MassHighway Construction and Traffic Standard Details
- MassDOT Highway Division Engineering Directives
- MassDOT Highway Division Policy Directives

Utilities owned by municipalities (including fire alarm), the following documents shall govern:

- City of Cambridge
- Construction and Operating Procedures
- City of Somerville
  - Refer to Section 1.8.4.2 of this document for utility definition information
- City of Medford
  - Refer to Section 1.8.4.3 of this document for utility definition information

Utilities owned by private utility companies, the following documents shall govern:

- Gas - National Grid
  - Blue Book Specifications and Requirements for Gas Installations
- Gas - NSTAR
  - Information and Requirements for Gas Service
  - Operating and Maintenance Procedures for NSTAR Gas Distribution
- Gas - Algonquin Gas (Spectra Energy)
  - Refer to Section 1.8.4.6 of this document for utility definition information
- Electric - National Grid
  - National Grid 2010 Specifications for Electrical Installations
- Electric - NSTAR
  - NSTAR Electric's D3820 "Construction, Material, and Work Specifications for New 15/25 kV Primary Underground Distribution Systems up to 200 Amps" (issued August 2009)
  - NSTAR Electric's "Information and Requirements for Electric Service" (revised 2009).
- Telecom - AT&T (Siena Engineering)
  - AT&T Specifications for Trenching, Conduit, Boxes and Manholes, Aerial Entrance Mast, Service Cabinets, Bonding and Grounding
  - AT&T's Guidelines for Access to AT&T Inc. and Operating Companies Structure (Issue 1, Oct 2000)
  - AT&T's Interstate (Long Lines) Specifications
- Telecom - Verizon
  - Verizon's Network Equipment Installation Standards (Information Publication IP7220, December 2009, Issue 4)
- Telecom - NSTAR
  - Shall be in accordance with the same design criteria and standards set forth by NSTAR Electric, per NSTAR Telecom
- Telecom - Comcast
  - 2004 Specifications and Installation Guide for Underground Service to Residential Developments
- Telecom, RCN
  - Refer to Section 1.8.4.13 of this document for utility definition information
- Telecom, AboveNet
  - Refer to Section 1.8.4.14 of this document for utility definition information
- Telecom, NextG, Lightower
  - Refer to Section 1.8.4.15 of this document for utility definition information

1.8.3 Permits and Regulatory Requirements

Proposed relocation of utility lines and new utility services for the proposed stations as part of the Green Line Extension project shall be in accordance with the requirements of each affected utility company as described in the following sub-sections. Proposed lines that cross or otherwise impact an existing Massachusetts Water Resource Authority (MWRA) easement or property will require an 8(m) permit prior to construction.

1.8.4 Design Criteria

This section discusses the design criteria for the relocation of several types of utility lines that belong to either municipalities or private utility companies.

1.8.4.1 Utilities: Water and Sewer, City of Cambridge

This section presents the City of Cambridge Construction and Operating Procedures that outline the Cambridge Water Department's minimum criteria for the construction of water utilities and infrastructure within the City limits. The following criteria should be considered when relocating or constructing new water lines in Cambridge as part of the MBTA Green Line Extension project, and shall be subject to the approval of the Cambridge Water Department (CWD):

- Pipes shall be cement lined, tar coated, Ductile Iron, Class 52. Water service pipes within a public way or a private way open to public travel shall be constructed in accordance with the CWD specifications. Water service pipes within private property shall be constructed in accordance with the latest version of the Massachusetts Plumbing Code and all CWD guidelines.
- The Cambridge Fire Department (CFD) and the Cambridge Water Department (CWD) shall approve hydrant location.
- Every hydrant shall be equipped with a 6-inch shut-off valve, bolted or anchored to the hydrant tee.
- Line valves shall be spaced at not more than 500 feet and as determined by the CWD.
- In new construction, every intersection shall be valved "(3) three-ways" if a tee is used; and "(4) four-way" if a cross is used.
- Dead ends shall be avoided by the looping of all water mains whenever practical.
- All water mains and service pipe shall be laid in a trench separate from any other utility. The horizontal distance between water mains or service pipe and any other utility (gas, electric, telephone, etc.) shall be at a minimum no less than two (2) feet, vertical distance shall be no less than (1) foot and no less than ten (10) feet from a sanitary sewer or surface water drain (MassDEP regulation #310CMR22.19 distribution system requirements).
- The minimum bury to burial depth shall be 5 feet for all water lines, unless approved by CWD.
- All material shall be in accordance with the "Material Standards" documentation from CWD.
- All material shall be new and shall be of the type currently used by the CWD.
- All construction shall be in accordance with the latest "Commonwealth of Massachusetts, Department of Public Works - Standard Specifications for Highways and Bridges", the "American Water Works Association Standards" and in accordance with the current practice of the CWD.

  The following criteria by the CWD for relocation and construction of new water mains in relation to sewers need to be considered when working in Cambridge as part of the MBTA GLX project:

  Horizontal Separation: Whenever possible sewers shall be laid at a minimum of at least 10 feet (3.0m), horizontally, from any existing or proposed water main. Should local conditions prevent a lateral separation of 10 feet, a sewer may be laid closer than 10 feet to a water main if:

  1. It is laid in a separate trench, or if;
  2. It is laid in the same trench with the water mains located at one side on a bench of undisturbed earth, and if;
  3. In either case the elevation of the top (crown) of the sewer is at least 18-inches (46cm below the bottom (invert) of the water main.

Vertical Separation: Whenever sewers must cross under water mains, the sewer shall be laid at such an elevation that the top of the sewer is at least 18-inches (46cm) below the bottom of the water main. When the elevation of the sewer cannot be varied to meet the above requirements, the water main shall be relocated to provide this separation or re-constructed with mechanical-joint pipe for a distance of 10 feet (3.0m) on each side of the sewer. One full length of water main should be centered over the sewer so that both joints will be as far from the sewer as possible.

When it is impossible to obtain horizontal and/or vertical separation as stipulated above, both the water main and sewer shall be constructed of mechanical-joint cement lined ductile iron pipe or other equivalent based on water-tightness and structural soundness. Both pipes shall be pressure tested by an approved method to assure water-tightness.

Other criteria for water lines in Cambridge include, but are not limited to the following:

System connections: Connections to the existing water distribution system must be approved by the CWD. This requires a Cambridge Water Works Construction Permit.

Contractor responsibilities: The Contractor shall not operate any hydrants, valves, curb stops or corporations, nor shall they draw any water from the system, without specific approval of the CWD. Only CWD personnel will operate valves, hydrants, corporations and curb stops unless otherwise directed by the CWD. This also requires an application for the Cambridge Water Works Construction Permit.

Fitting: Ductile iron fittings must be used and shall be cement lined. Fittings are required to be equipped with a mechanical joint restraint as specified in Article 1, Section 20 of the City of Cambridge "Construction and Operating Procedures," unless otherwise specified by the CWD. Mechanical joint fittings in sizes 4-inch through 12-inch shall be ductile iron compact fittings and rated for 350 psi working pressure. All nuts and bolts shall be of a type equal to ductile iron or KOR-10 steel T-bolts and nuts.

Gate Valves: Gate valves shall be resilient seated and shall meet the requirements of AWWA C-509. Valves shall be rated for *200 psi* minimum working pressure. Valves shall be iron body, bronze mounted, resilient seated, non-rising stem type fitted with "O" ring seals. The operating nut shall be 2-inches square. Bolts on the bonnet and stuffing box shall be stainless steel (316-stainless steel). Valves shall have mechanical joint ends and shall be equal to ANSI/AWWA C11/A21.11. Valves shall open right (clockwise). Extensions shall be provided for all gate valves that the depth exceeds 6 feet to the top of the operating nut.

Please refer to the City of Cambridge Construction and Operating Procedures for a complete listing of construction and material standards.

The following are some of the procedures involved in the extension, relocation, and construction of new water mains in the City of Cambridge:

- An applicant may propose an extension, replacement or relocation of public water mains to serve new or rehabilitated buildings. All proposed extensions, replacements or re-locations, including any tests, studies, investigations and inspections required for design, shall be subject to the approval of the CWD. All expenses, including all engineering, legal permitting, construction and inspection expenses involved in applying for and constructing an extension, replacement or relocation shall be borne by the applicant.
- Before commencing work on any public water main extension, replacement or relocation, a contractor working for the CWD or for an owner on city-owned property or easement shall file a bond with the DPW in an amount acceptable to the DPW, and the contractor must be approved by the CWD (a deposit may be required by CWD).

- After approval of a proposed extension, replacement or relocation of a water main and after the intended construction has been approved by the CWD, the applicant shall transfer ownership of the extended, replaced or relocated water main to the CWD through a Release Agreement form prescribed by the CWD.
- If an applicant requests a new water service pipe or fire pipe which, in the judgment of the CWD will impose a demand in excess of the capacity of the existing main, it may be necessary to replace the existing main with one of appropriate size. The full cost thereof, the applicant shall pay including any tests, studies, investigations and inspections required for design and construction.
- When the CWD must reasonably secure professional engineering and legal reviews for major development projects, the applicant shall pay for such engineering or reviews up to a reasonable limit.

1.8.4.2 Utilities: Water and Sewer, City of Somerville

Presently, Somerville Water and Sewer Department does not have any specific design criteria for replacement/relocation of utilities within the City limits. The City recommends any utility work in the City as part of the Green Line Extension project be in accordance with the criteria set forth by the City of Cambridge and the State of Massachusetts with the exception of fire hydrants. Check on the status of an official standards/manual with the City of Somerville and verify the standards for fire hydrants with City Engineer. New water and sewer connections shall provide pipe sizing calculations signed and sealed by a registered professional engineer.

Based on the Excavation and Trench Safety Regulation set forth by the state of Massachusetts, all construction-related trenches (subsurface excavation greater than three feet in depth, and fifteen feet or less between soil walls as measured from the bottom) on public ways, public property, or private property require a trench permit. All municipalities must designate a permitting authority to issue required permits for trenches on private property within the municipality. The permit can be obtained by the contractor and/or utility company through the City of Somerville Public Works Department designee in the Engineering Department. For state property, the relevant state authority will issue the permits.

1.8.4.3 Utilities: Water and Sewer, City of Medford

Presently, Medford Water and Sewer Department does not have any specific design criteria for replacement/relocation and new construction of utilities within the City limits. The City recommends that any utility work in the City as part of the Green Line Extension project be in accordance with the criteria set forth by the State of Massachusetts. A City-wide standards/manual for utilities is expected to be published by the end of 2012.

Based on the Excavation and Trench Safety Regulation set forth by the state of Massachusetts, all construction-related trenches (subsurface excavation greater than three feet in depth, and fifteen feet or less between soil walls as measured from the bottom) on public ways, public property, or private property require a trench permit. All municipalities must designate a permitting authority to issue required permits for trenches on private property within the municipality. The permit can be obtained by the contractor and/or utility company through the City of Medford Public Works Department designee in the Engineering Department. For state property, the relevant state authority will issue the permits.

All excavators must obtain a trench permit for each trench site, which requires information such as a licensed drain layer, the name of excavator, the location of trench, certificate of insurance, $5,000 cash bond, and the Dig-Safe number. The fee for this permit is $150.00

(Note: The excavation and trench permit is a Massachusetts State regulation and applicable for all 3 municipalities and all public/private utility companies.)

1.8.4.4 Utilities: Gas, National Grid

The relocation of gas lines owned by National Grid shall be in accordance with the design criteria and specifications outlined in the National Grid Blue Book Specifications and Requirements for Gas Installations. (Note that the criteria listed below have been obtained from the National Grid Blue Book (New York Version), Revision 7, 2009 and the National Grid Blue Book (Rhode Island Version), Revision 0, 2010). This book presents specifications and requirements relating to the connection and use of natural gas supplied from facilities. It contains the minimum acceptable standards for gas piping installation. The following are some of the specifications and requirements as listed from the Blue Book:

National Grid Equipment on Private Property: All National Grid equipment located on the customer's premises, such as the gas service line, meter, regulators, meter piping, etc., remain National Grid property, and may be removed by National Grid in the event such equipment is no longer needed.

Gas Service Line(s)/Lateral(s) Location Requirements: National Grid will install gas service piping in areas free of paved driveways or other paved areas. If it becomes necessary to locate a gas service line where it will be under a driveway or walk, the contractor shall not pave the driveway or walk until the gas service line has been installed. Alternately, the customer may opt to install a polyvinyl chloride (PVC) sleeve a minimum of 18" below grade in the area to be paved through which the gas service can be installed after the paving installation. This should first be discussed with National Grid who will advise the correct size sleeve and location, and obtain approval for the installation.

National Grid shall designate the exact location of the meter and service riser.

Clearance Requirements: National grid requires 18-24" clearance between the gas main line and the top of wall/footing. The major consideration with constructing a footing beneath the existing gas main would be that the main and surrounding soil would need to be supported during construction. In addition, protective full depth vertical steel sheeting and clearance (24" minimum) between gas line and adjacent work is required. National Grid also requires that a foreign opening inspector be present on-site during work to inspect and monitor excavation and advise with regard to impact on National Grid facilities.

Customer-owned Gas Piping System:

General Requirements: Before proceeding with the design and installation of gas piping systems, contractors are advised to refer to the International Fuel Gas Code. Review the State requirements to ensure that the proposed installation is in compliance with local codes.

High-Pressure Gas Pipelines:

Any construction/relocation activity as part of the Green Line Extension project that occurs in the vicinity of National Grid high pressure gas pipelines (above 7 bar gauge) and associated installations shall be in accordance with the National Grid criteria provided in the "Specification for Safe Working in the Vicinity of National Grid High Pressure Gas Pipelines and Associated Installations – Requirements for Third Parties T/SP/SSW/22" published in August 2007. These specifications should also be observed when carrying out work in the vicinity of intermediate pressure mains (pipelines operating between 2 and 7 bar gauge), which may be relaxed but only with the prior agreement of National Grid. This ensures that individuals planning and undertaking work take appropriate measures to prevent damage. It is the responsibility of the contractor to ensure that any work carried out conforms to the requirements of the Construction and Design Management Regulations and all other relevant health and safety legislation.

The following are some of the specifications for carrying out work in the vicinity of National Grid high pressure gas pipelines:

Formal Consent: No work shall be undertaken in the vicinity of the pipeline without the formal written consent of National Grid. Any documents handed to contractors, or other individuals undertaking work, on site by National Grid, shall be signed for by the site manager.

Within an Easement: The promoter of any works (see Section 2 of National Grid's document T/SP/SSW/22) in the Vicinity of National Grid High Pressure Gas Pipelines and Associated Installations) within an easement shall provide National Grid with details of the proposed works including a method statement of how the work is intended to be carried out. On acceptance of National Grid's requirements the promoter of the works shall give National Grid 7 working days' notice, or shorter only if agreed with National Grid, before commencing work on site.

Within the Highway: Work shall be notified to National Grid in accordance with the requirements of The New Roads and Street Works Act (NRSWA) and HS(G)47. The promoter of any works within the highway should provide National Grid with details of the proposed works including a method statement of how the work is intended to be carried out. This should be submitted 7 working days before the planned work is to be carried out or shorter, only if agreed with National Grid. If similar works are being carried out at a number of locations in close proximity a single method statement should be adequate.

Pipeline Locating: Where formal consent to work has been given, the third party should give 7 working days' notice or shorter, only if agreed with National Grid, to ensure that the pipeline is suitably located and marked out by National Grid prior to the work commencing.

Previously agreed working practices should be reviewed and revised based on current site conditions. Any changes shall be agreed by the National Grid responsible person.

The requirements for trial holes to locate the pipeline or determine levels at crossing points shall be determined on site by the National Grid responsible person. The excavation of all trial holes shall be supervised by the National Grid responsible person.

Slabbing and Other Protective Measures: No protective measures including the installation of concrete slab protection shall be installed over or near to the National Grid pipeline without the prior permission of National Grid. National Grid will need to agree to the material, the dimensions and method of installation of the proposed protective measure. The method of installation shall be confirmed through the submission of a formal written method statement from the contractor to National Grid.

Where permanent slab protection is to be applied over the pipeline National Grid will normally carry out a survey (Pearson Survey) of the pipeline to check that there is no existing damage to the coating of the pipeline prior to the slab protection being put in place.

Excavation Requirements:

In Proximity to a Pipeline in an Easement: Third parties may excavate, unsupervised, with powered mechanical plant no closer than 10 feet (3 meters) to the National Grid located pipeline and with hand held power tools no closer than 5 feet (1.5 meters).

1.8.4.5 Utilities: Gas, NSTAR

The relocation and/or protection of gas lines owned by NSTAR in the vicinity and within the limits of the Green Line Extension project shall be in accordance with the following documents:

"Information and Requirements for Gas Service"
"Operating and Maintenance Procedures for NSTAR Gas Distribution"

Any relocation of underground gas mains owned by NSTAR will be performed by NSTAR. The gas main will be installed after the water, sewer or septic, drains, electrical crossovers, and electrical main conduit are in place and prior to paving. Upon completion of the gas main and crossover installations, the main is tested and natural gas will be immediately installed into the new main. All road excavation shall be completed at the time the new main is installed.

The relocation of gas main, if any, will be sited by the NSTAR Gas Planning Department. With some exceptions, installation generally adheres to the following: the gas line should run parallel to the water, sewer, and electric services. In addition, the drain, water, and sewer are in the "paved way"; electrical, telephone and cable are on one side of the road, and the natural gas main will be on the opposite side of the road, in the grass strip, or underneath the sidewalk.

A typical trench for gas pipe is 36 inches deep and 12 inches wide. Installation of #10, solid core, yellow wrapped, copper wire is placed in the bottom of the trench. Approximately 6 inches of sand is placed over the wire (sand utilized shall be free of any stone and will be of masonry quality). Plastic pipe is then installed and another 6 inches of sand is placed on top of the pipe. A yellow terra tape is placed approximately 1 foot below finished grade to indicate the gas main location. Plastic pipe, wire and tape are considered facilities of NSTAR Gas and can only be installed by designated contractors or by qualified NSTAR Gas personnel. NSTAR Gas must size all gas lines up to the new or existing meter fit from the gas main, but will not size internal piping systems for a plumber or heating contractor.

The separation criteria for gas mains from other services or systems should conform to NSTAR's requirements. Underground services shall have a horizontal separation of at least 3 feet from all other services or systems. In case of unavoidable crossing, the gas service shall be kept at least 6 inches away from other services or systems. Some municipalities do not allow crossing of utilities.

The request for relocation of any existing NSTAR gas meters must be addressed to the relevant NSTAR gas representative. The contractor needs to contact NSTAR's Technical Services Department at 508-305-6890 or 508-305-6887. A meter relocation request by the contractor will be performed by NSTAR at the contractor's expense after a distribution foreman visits the site, and assesses work to be performed.

If in the judgment of NSTAR any existing gas meter installation may be subject to damage, the contractor may be required to provide suitable protection or enclosures for the meter equipment or relocate the equipment at their expense.

The relocation of NSTAR gas lines shall be in accordance with the Damage Prevention Criteria as listed in section 4.2.0 of the Operating and Maintenance Procedures Manual. The purpose of these criteria is to establish a program to prevent damage to the pipeline by excavation activities. "Excavation activities" include excavation, blasting, boring, tunneling, backfilling, the removal of above ground structures by either explosive or mechanical means, or other earth moving operations.

According to NSTAR's Operating and Maintenance Procedures Manual, the contractor is required to notify DIGSAFE whenever digging, trenching, blasting, demolishing, boring, backfilling, grading, pile driving, landscaping, or other earth moving operations are anticipated. DIGSAFE shall not be used for miscellaneous requests to relocate, lower or remove facilities. The contractor needs to refer to Section 4.2.2 of the Operating and Maintenance Procedures Manual for guidance on how DIGSAFE requests from third party should be handled.

All excavation, backfilling and safety practices shall be in accordance with Section 4.3.0 of NSTAR's Operating and Maintenance Procedures Manual, Department of Transportation, Title 49, Part 192, Massachusetts Department of Labor and Industries, Bulletin 12 and U.S. Department of Labor, OSHA, Title 29, Part 1910 and revisions thereto. Relocation of NSTAR transmission lines and pipelines, if any, in the project site or its vicinity shall be in accordance with the criteria listed in Section 4.5 of the Operating and Maintenance Procedures Manual.

Relocation of NSTAR gas mains, if any, in the project site or its vicinity shall be in accordance with the criteria listed in Section 4.6 of the Operating and Maintenance Procedures Manual. Specific criteria for lowering a Polyethylene (PE) gas main shall be in accordance with section 4.6.10 of the manual.

1.8.4.6 Utilities: Gas, Algonquin Gas (Spectra Energy)

Algonquin requires that for gas lines crossing below railroad tracks it is standard practice to encase the line in a steel casing. Algonquin will execute this work. A typical duration of this type of project including the notification process, permitting, planning, and physical work could take anywhere between 9 and 12 months to complete.

1.8.4.7 Utilities: Electric, National Grid

The relocation of electric lines owned by National Grid shall be in accordance with the design criteria and specifications outlined in the National Grid 2010 Specifications for Electrical Installations that cover National Grid service areas in MA, NH, NY, and RI. These specifications may be revised or amended from time to time in keeping with developments and progress of the industry. The Contractor should check for the latest official version of this document at National grid's website: **http://www.nationalgridus.com/electricalspecifications**. The following are some of the specifications and requirements as listed from the National Grid Specifications for Electrical Installations:

Relocation of Service Laterals Requirements: When electric service relocation is at the request of the Customer, all costs associated with the relocation of the service lateral on both private and public land shall be borne by the Customer.

When the service lateral relocation is the result of an order by a public authority, the Customer shall pay for that portion of the cost associated with the service lateral movement on private property. In some instances, the public authority may compensate the Customer for this expense.

When the pole from which a customer-owned underground service lateral originates must be replaced it is the Customer's responsibility to move its service lateral to the new pole location at its sole expense.

For a customer-owned electric service lateral needing relocation, it is the Customer's responsibility to arrange with its contractor to move its service lateral. This responsibility includes coordination of this relocation with National Grid and inspection of the newly relocated service lateral by an authorized electrical inspector. National Grid-owned facilities involved with any relocation will be the responsibility of National Grid.

Right-of-Way Requirements: Rights-of-way and easements must be cleared of any obstructions at no charge to National Grid. The Contractor shall grade the right-of-way or easement to within six inches (150 mm) of final grade before National Grid commences construction, and must maintain National Grid's clearance and grading requirements.

Electric Meter Clearances: Electric meters shall not be located above or below gas regulating vents and must maintain a minimum 36" horizontal distance from a gas regulating vent. In all cases, the Gas Service Provider should be consulted regarding the location of gas meters near electric meters or electrical equipment.

Temporary Service Requirements: For temporary service requirements, refer to section 4.1.10 of the 2010 National Grid Specifications for Electrical Installations.

Overhead Service Line Requirements: Relocation of National Grid overhead service line as part of the Green Line Extension project shall be in accordance with clearance requirements of the National Electrical Safety Code, National Grid's Overhead Construction Standards, and section 4.2.4.1 for General Overhead Service Clearances set forth in the 2010 National Grid 2010 Specifications for Electrical Installations.

1.8.4.8 Utilities: Electric, NSTAR

The relocation of electric lines, owned by NSTAR, as part of the Green Line Extension project shall be in accordance with the design criteria and standards set forth NSTAR Electric's D3820 "Construction, Material, and Work Specifications for New 15/25 kV Primary Underground Distribution Systems up to 200 Amps" (issued August 2009) and NSTAR Electric's "Information and Requirements for Electric Service" (revised 2009). The Contractor should check for the latest official version of these documents from NSTAR.

Any relocation or construction activities that involve underground NSTAR electric lines shall be contingent on fulfillment of the requirements set forth in "Section III Prerequisites" given in NSTAR Electric's D3820 "Construction, Material, and Work Specifications". Specific clearance requirements during relocation of NSTAR electric lines shall be in accordance with "C3802 Clearance Requirements from Equipment Buildings, Landscaping, or Traveled Way".

Relocation, extension or new construction of NSTAR electric lines shall be in accordance with "Section VII Construction Standards and Issues" given in NSTAR Electric's "Construction, Material, and Work Specifications". The Contractor should refer to this section for general requirements for cable and conduit system, and conduit design layout requirements. Specifically, for the Lechmere/Cambridge area where the existing and proposed via-ducts may impact the NStar Systems along O'Brien Highway, Water and East Streets, the foundation/piers should be at least 2-3 feet away from primary ducts and secondary piping.

Trenching and backfilling activities related to relocation of NSTAR electric lines shall be in accordance "Section VII Construction Standards and Issues" given in NSTAR Electric's D3820 "Construction, Material, and Work Specifications".

1.8.4.9 Utilities: Telecom, AT&T (Siena Engineering)

The relocation of telecom lines, owned by AT&T (Siena Engineering), as part of the Green Line Extension project shall be in accordance with the design criteria and standards set forth in "AT&T Specifications for Trenching, Conduit, Boxes and Manholes, Aerial Entrance Mast, Service Cabinets, Bonding and Grounding", "AT&T's Guidelines for Access to AT&T Inc. and Operating Companies Structure" (Issue 1, Oct 2000), and AT&T's Interstate (Long Lines) Specifications. According to the AT&T Specifications, the Contractor should verify the location of AT&T utility structures and buried facilities two days prior to excavation. Construction of trench and placing/relocation of substructures shall be in accordance with AT&T plans and specifications.

Any new conduit shall be installed and functional prior to the shutdown and disconnect of any existing conduit. PVC pipe buried to a depth of approximately 48" is the AT&T standard for underground conduit. Underground conduits require 18" of clearance horizontally between drainage, and in some cases may allow 12" of clearance. AT&T (Siena Engineering) requires 36" clearance horizontally between power systems (such as OCS), and should not be within the same duct system as OCS. Steel pipe is the AT&T standard for conduit above ground, overhead, and strapped to bridges. No concrete encasement is required for the conduit along the track. The Contractor should plan relocation of AT&T (Siena) utilities such that it may take up to two (2) months to organize a splicing crew in the event that an AT&T conduit has to be permanently relocated.

1.8.4.10 Utilities: Telecom, Verizon

Relocation of telecom lines owned by Verizon shall be in accordance with Verizon's Network Equipment Installation Standards, Information Publication IP7220, December 2009, Issue 4. All cable and wire installed should be Verizon-approved, and a three-inch clearance must be maintained under all building constructions. The minimum vertical clearance required for aerial lines owned by Verizon is 18 feet. The typical cover required over underground conduit is approximately 36 inches, which could be up to 5-6 feet at manholes. The standard manhole dimensions for Verizon telecom lines are 12'x6'x7 (interior).

Verizon prefers to locate their utility within the web of the bridge structure for protection, but would also allow their system to be mounted to the exterior edge if required. For conduits that are buried in sand, the minimum clearance between pipes is 12 inches. If the conduit is encased in concrete, the minimum clearance between pipes is 6 inches. Cable TV lines and telephone lines can be located in the same trench since they are both considered as low voltage lines. Specific issues related to the design and spacing of bridge hangers and extension joints as part of any proposed relocation of Verizon lines will be handled by the American Utel Contracting Company.

1.8.4.11 Utilities: Telecom, NSTAR

Relocation of any telecom lines owned by NSTAR shall be in accordance with the same design criteria and standards set forth by NSTAR Electric, per NSTAR Telecom.

1.8.4.12 Utilities: Telecom, Comcast

Relocation of telecom lines owned by Comcast shall be in accordance with the "2004 Specifications and Installation Guide for Underground Service to Residential Developments". Typically, Comcast requires approximately two months to perform utility relocations (including proper coordination and notification).

Any relocation of a Comcast overhead utility line in the MBTA Right-of-Way (ROW) requires a prior application for an aerial easement. Due to conflict with catenary lines along the corridor, aerial lines crossing the corridor should be relocated. The minimum overhead clearance required for Comcast aerial lines is 28 feet. If a Comcast line is underground in the MBTA ROW, Comcast prefers to leave this underground. The typical sequence of utility relocation is NSTAR, fire alarm, Comcast, and Verizon.

Relocation criteria of underground Comcast lines related to layout and grading, trenching, backfilling, inspection, conduit installation, transformer or switch vault, and riser poles shall be in accordance with the "2004 Specifications and Installation Guide for Underground Service to Residential Developments" for Comcast.

1.8.4.13 Utilities: Telecom, RCN

Specific design criteria related to relocation of RCN telecom lines is not available. Requests have been issued to RCN to get the latest version of their criteria, so that relocation of any RCN line as part of the Green Line Extension project shall be done in accordance with their criteria. No more than 2-90 degree bends may be allowed in any RCN line. The majority of RCN cable is coaxial and copper is being phased out. It is also required by RCN that the number of conduits pulled out during construction has to equal at least the number of conduits replaced, even if they are empty.

1.8.4.14 Utilities: Telecom, AboveNet

The relocation of lines owned by AboveNet as part of the Green Line Extension project shall be in accordance with the design criteria for relocation set forth by AboveNet. Specific design criteria for AboveNet was not available. AboveNet requires that any AboveNet line with less than 48" of cover requires steel plating.

1.8.4.15 Utilities: Telecom, NextG, Lightower

These companies typically lease conduit from other utility companies. For example, NextG leases within the AboveNet conduit which runs subgrade along Washington Street. In this case, proposed relocation of the NextG line shall be determined by the design criteria used by AboveNet for relocation of their lines. In general, relocation of utility lines that belong to NextG or Lightower shall be in accordance with the design criteria set forth by their respective parent lessor company at the respective proposed relocation sites.

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2 Structural

Chapter 2

2.1 General

This section sets forth structural design criteria required for designing above- and below-ground structures, including roadway, light rail, commuter/freight rail and pedestrian bridges, retaining walls, and noise barriers for the MBTA Green Line Extension project.

2.1.1 Definitions

The following definitions apply to this chapter:

1. Roadway Bridge: A bridge structure above ground carrying non-track mounted vehicles.
2. Light Rail Bridge/Viaduct: A b ridge or other aerial structure carrying only light rail, track-mounted vehicles.
3. Commuter/Freight Rail Bridge: A bridge or other aerial structure carrying commuter rail and/or freight rail only, or in combination with light rail, track-mounted vehicles.
4. Pedestrian Bridge/Ramp: A bridge or ramp structure carrying pedestrian live load and a maintenance vehicle load.
5. Retaining Wall: A wall structure utilized for restraining soil and/or vehicular loads in locations where there is not enough room to provide earth slopes between changes in grade.
6. Noise Barrier: A wall or other barrier structure utilized to reduce the propagation of sound.

2.1.2 Codes, Standards, References, and Guidelines

Unless noted, or directed otherwise, the following standards, codes and guidelines shall be used in the design of all bridge and wall structures and structural elements, as appropriate, and as set forth in this section. Design element-specific references will be described in the appropriate design element subsections.

1. LRFD Bridge Manual, Parts I and II, the latest edition, of the MassDOT, referenced in these criteria as the "MassDOT Bridge Manual".
2. AASHTO LRFD Bridge Design Specifications, the latest edition, of the AASHTO, as supplemented by the FHWA 2010 Drilled Shaft Manual, referenced in these criteria as the "AASHTO LRFD Specifications".
3. AASHTO Guide Specifications for LRFD Seismic Bridge Design, the latest edition, of the American Association of State Highway and Transportation Officials, referenced in these criteria as the "AASHTO Seismic Guide Specs".
4. MBTA Guide Specifications for Structural Design of Rapid Transit and Light Rail Structures, October 2005 of the Massachusetts Bay Transportation Authority (MBTA), referenced in these criteria as the "Light Rail Code".

5. American Railway Engineering and Maintenance-of-Way Association (AREMA) Manual for Railway Engineering, the latest edition, referenced in these criteria as the "AREMA Manual".
6. Standard Specifications for Highway Bridges, 17th Edition - 2002 with latest Interim Revisions, of the American Association of State Highway and Transportation Officials, commonly referred to as "AASHTO Standard Specifications".
7. MBTA Guidelines for Load Rating Transit Bridges, April 2003 of the Massachusetts Bay Transportation Authority (MBTA), referenced in these criteria as the "Light Rail Load Rating Code".
8. "Annual Book of ASTM Standards", the latest edition, of the American Society for Testing and Materials, referenced in these criteria as the "ASTM".
9. "Standard Specifications for Transportation Materials and Methods of Sampling and Testing", the latest edition, 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 in these criteria as the "AASHTO Testing".
10. American Institute of Steel Construction (AISC) "Manual of Steel Construction", the latest edition, referenced in these criteria as the "AISC Manual".
11. American Concrete Institute (ACI), "Building Code Requirements for Structural Concrete - ACI 318", including its commentary, the latest edition, referenced in these criteria as "ACI–318".
12. American Concrete Institute (ACI), "Manual of Concrete Practice", the latest edition.
13. National Fire Protection Association, (NFPA), "Standard for Fixed Guideway Transit and Passenger Rail Systems", the latest edition, referenced in these criteria as the "NFPA 130".
14. LRFD Guide Specifications for the Design of Pedestrian Bridges, the latest edition, of the American Association of State Highway and Transportation Officials, referenced in these criteria as the "AASHTO LRFD Pedestrian Bridge Specifications".
15. Standard Specifications for Highways and Bridges, 1988 with the latest supplemental specifications and Standard Special Provisions, of the Massachusetts Highway Department, commonly referred to as the "MHD Specifications".
16. MBTA Railroad Operations - Book of Standard Plans - Track and Roadway, the latest edition.
17. MBTA Railroad Design Construction Standard Specifications, the latest edition, commonly referred to as the "MBTA Specifications".
18. MBTA Railroad Operations - Commuter Rail Design Standards Manual, the latest edition, commonly referred to as the "MBTA Standards".
19. MBTA Standard Line Items, the latest version.
20. Massachusetts State Building Code, of the Commonwealth of Massachusetts, the latest edition, commonly referred to as the "Massachusetts Building Code".
21. ASCE/SEI 7-xx Minimum Design Loads for Buildings and Other Structures, the latest edition, of the American Society of Civil Engineers, commonly referred to as the "ASCE-7".
22. The Bridge Welding Code – ANSI/AA AWS D1.5 (AWS D 1.5) of the American Welding Society (AWS), the latest edition.
23. National Design Specification (NDS) for Wood Construction, the latest edition, of the American Forest & Paper Association, commonly referred to as "NDS Specifications".
24. CSX Transportation Criteria for Overhead Bridges, Sept. 2007 & CSX Transportation Criteria for Ballast Deck Railroad Bridges, Oct. 1999 commonly referred to as the "CSX Specifications".

25. Manual for Bridge Evaluation, the latest edition, of the American Association of State Highway and Transportation Officials.
26. International Building Code (IBC), the latest edition, of the International Code Council.
27. Code of Standard Practice for Steel Buildings and Bridges, the latest edition, of the American Institute of Steel Construction.

Where differences between the structural design criteria and codes noted in Section 2.1.2 above occur, the more stringent requirement shall govern the design and analysis.

2.1.3 Clearances

1. The general arrangement of structures shall be shown on the Advanced Conceptual Design drawings.
2. See Section 1.6.1.1.7 and 1.6.2.1.7 of this document for the governing minimum static and dynamic vertical and lateral clearances for the Green Line Extension project. The minimum vertical clearance for roadways under bridges shall be no less than the existing vertical clearance for the replacement of the existing bridges and a minimum of 14'-6" vertical clearance is preferred; and shall be 16'-6" minimum per MassDOT requirements for new bridges.

2.2 Roadway Bridges

2.2.1 General

This subsection sets forth structural design criteria required for designing Roadway Bridges. The structures governed by this subsection are as follows:

- Medford Street Bridge (Somerville)
- Lowell Street Bridge (Somerville)
- School Street Bridge (Somerville)
- Broadway Bridge (Somerville)
- College Avenue Right-turn-lane Bridge (Medford)

2.2.2 Codes

Unless noted, or directed otherwise, the following standards, codes and guidelines shall be used in the design of all structures and structural elements, as appropriate, and as set forth in this subsection.

1. LRFD Bridge Manual, Parts I and II, of the Massachusetts Department of Transportation, the latest edition, referenced in these criteria as the "MassDOT Bridge Manual".
2. AASHTO LRFD Bridge Design Specifications, the latest edition, of the American Association of State Highway and Transportation Officials, as supplemented by the FHWA 2010 Drilled Shaft Manual, referenced in these criteria as the "AASHTO LRFD Specifications".
3. AASHTO Guide Specifications for LRFD Seismic Bridge Design, the latest edition, of the American Association of State Highway and Transportation Officials, referenced in these criteria as the "AASHTO Seismic Guide Specs".
4. Standard Specifications for Highways and Bridges, 1988 with the latest supplemental specifications and Standard Special Provisions, of the Massachusetts Highway Department, commonly referred to as the "MHD Specifications".

2.2.3 Design Methodology

Roadway bridges shall be designed in accordance with MassDOT and AASHTO standards, using the Load and Resistance Factor Design (LRFD) methodology. In cases where conflicts exist, the MassDOT guidance shall govern.

2.2.4 Materials

Materials for roadway bridges shall be in accordance with MassDOT and AASHTO requirements. The materials for major bridge components are listed as the follows:

Cast-in-Place Concrete
Cement shall be Portland cement, ASTM-C150, Type II or IIA.

Substructure:	4000 psi – 1 ½" – 565# cement concrete masonry for abutment stems, piers, wingwalls and approach slabs, etc. 4000 psi – ¾" – 610# cement concrete masonry for backwalls, keeper blocks and curtain walls, etc.
Superstructure:	4000psi – ¾" – 585# HP cement concrete masonry for typical deck slabs, etc. 5000psi – ¾" – 685# HP cement concrete masonry for concrete barriers and sidewalks, etc.

Precast/Prestressed Concrete
Unless otherwise specified, concrete for prestressed members shall have a 28-day minimum compressive strength (f'_c) of 6,500 psi; at time of initial prestress, a minimum compressive strength (f'_{ci}) of 4,500 psi. Higher concrete compressive strengths may be acceptable, but require prior approval of the MassDOT Director of Bridges and Structures.

Steel Reinforcement
All reinforcing steel, including ties and spirals, shall conform to AASHTO M31 (ASTM A615) Grade 60 requirements. Epoxy coated bars, when specified, shall satisfy the requirements in ASTM A775 except where specifically noted otherwise.

Prestressing Steel
0.6" diameter, AASHTO M203, Grade 270, uncoated, low relaxation steel strands.

Structural Steel
AASHTO M270, Grade 50W.

2.2.5 Design Loads

The design loads for roadway bridges shall be in accordance with the MassDOT Bridge Manual, AASHTO LRFD Specifications, and the AASHTO Seismic Guide Specifications.

2.2.6 Load Combinations

The design load combinations for roadway bridges shall be in accordance with the MassDOT Bridge Manual, AASHTO LRFD Specifications, and the AASHTO Seismic Guide Specifications.

2.3 Light Rail Bridges/Viaducts

2.3.1 General

This subsection sets forth structural design criteria required for designing Light Rail Bridges/Viaducts.

The structures governed by this subsection are as follows:

- Lechmere Viaduct (Cambridge)
- Medford Branch Viaduct (Somerville)
- Yard Lead Flyover Viaduct (Somerville)
- Union Square Yard Lead Viaduct (Somerville)
- Union Square Westbound Viaduct (Somerville)
- Union Square Eastbound Viaduct (Somerville)

2.3.2 Codes

Unless noted, or directed otherwise, the following standards, codes and guidelines shall be used in the design of all structures and structural elements, as appropriate, and as set forth in this subsection:

1. MBTA Guide Specifications for Structural Design of Rapid Transit and Light Rail Structures, October 2005 of the MBTA, referenced in these criteria as the "Light Rail Code".
2. MBTA Guidelines for Load Rating Transit Bridges, April 2003 of the MBTA, referenced in these criteria as the "Light Rail Load Rating Code".
3. Standard Specifications for Highway Bridges, 17th Edition - 2002 with latest Interim Revisions, of the American Association of State Highway and Transportation Officials, commonly referred to as "AASHTO Standard Specifications".
4. AREMA Manual for Railway Engineering, the latest edition, of the American Railway Engineering and Maintenance-of-Way Association, referenced in these criteria as the "AREMA Manual".
5. MBTA Railroad Design Construction Standard Specifications, the latest edition, commonly referred to as the "MBTA Specifications".
6. AASHTO LRFD Bridge Design Specifications, as supplemented by the FHWA 2010 Drilled Shaft Manual, most recent edition.

2.3.3 Design Methodology

The light rail bridges shall be as specified in Articles 3 of the Light Rail Code unless otherwise directed by the MBTA.

2.3.4 Materials

Materials requirements for light rail bridges shall be as specified in the applicable materials sections of the Light Rail Code, the MBTA Specifications, the AASHTO Standard Specifications and the AREMA Manual.

The materials for major bridge components are specified as the follows:

Concrete
Cast-in-place concrete shall have a minimum specified compressive strength of 4,000 psi at 28 days. Cast-in-place concrete for bridge decks shall have a minimum specified compressive strength of 4,500 psi at 28 days. Precast concrete shall have a minimum specified compressive strength of 5,000 psi at 28 days.

Steel Reinforcement
Steel reinforcement, including ties and spirals shall conform to ASTM A615 Grade 60 requirements. Epoxy coated bars, if specified, shall satisfy the requirement in ASTM A775.

Prestressed Concrete
Unless otherwise specified, concrete for prestressed members shall have a minimum compressive strength of 6,000 psi at 28 days, and a minimum compressive strength at time of initial prestress of 4,000psi.

Prestressing Reinforcement
Prestressing reinforcement shall be high strength steel wire (ASTM A421), uncoated, seven wire, low-relaxation steel strands (ASTM A416, Grade 250 and Grade 270) or uncoated high strength steel bars (ASTM A722, Grade 150).

Prestressing Strand, Uncoated
Low-relaxation 7-wire strand, Grade 250 or 270

Prestressing Bars, Uncoated
Deformed high-strength bars, Grade 150
Structural Steel
Structural steel shall conform to ASTM Standard Specification A709, Grade 50 and 50W.

Bolts
High strength bolts for structural connections shall conform to ASTM A325. All nuts shall be heavy hex type and shall conform to the requirements of ASTM A563 Grade DH. All bolts, nuts and washers shall be hot-dipped galvanized in accordance with the requirements of ASTM A153.

Anchor bolts shall conform to ASTM F1554, Grade 55. Anchor bolts, nuts and washers shall be hot-dipped galvanized in accordance with the requirements of ASTM A123 and A153.

2.3.5 Design loads

The design loads for light rail bridges shall be as specified in Article 4 of the Light Rail Code. In addition to the Green Line transit revenue car loads included in Article 4.3.1 of the Light Rail Code, Green Line Cars Type 8 and 9 loadings will be provided by the MBTA and also shall also be analyzed.. Note that the Light Rail Code also includes design live load information for non-revenue vehicles.

For viaducts supporting noise barriers, loads from noise barrier shall be determined as specified in the AASHTO LRFD Specifications.

2.3.6 Load Combinations

Load combinations for light rail bridges shall be as specified in Article 5 of the Light Rail Code.

2.4 Commuter/Freight Rail Bridges

2.4.1 General

This subsection sets forth structural design criteria required for designing bridges that support Commuter Rail and/or Freight Rail operations.

The structures governed by this subsection are as follows:

- MBTA over Medford Street (Somerville)
- MBTA over Washington Street (Somerville)

- MBTA over Harvard Street (Medford)
- Community Path Tunnel under tracks at Washington Street Station

2.4.2 Codes

Unless noted, or directed otherwise, the following standards, codes and guidelines shall be used in the design of all structures and structural elements, as appropriate, and as set forth in this subsection:

1. AREMA Manual for Railway Engineering of the American Railway Engineering and Maintenance-of-Way Association, the latest edition, referenced in these criteria as the "AREMA Manual".
2. MBTA Guide Specifications for Structural Design of Rapid Transit and Light Rail Structures, October 2005 of the MBTA, referenced in these criteria as the "Light Rail Code".
3. MBTA Guidelines for Load Rating Transit Bridges, April 2003 of the MBTA, referenced in these criteria as the "Light Rail Load Rating Code".
4. LRFD Guide Specifications for the Design of Pedestrian Bridges, the latest edition, of the American Association of State Highway and Transportation Officials, referenced in these criteria as the "AASHTO LRFD Pedestrian Bridge Specifications".
5. Standard Specifications for Highway Bridges, 17th Edition - 2002 with latest Interim Revisions, of the American Association of State Highway and Transportation Officials, commonly referred to as "AASHTO Standard Specifications".
6. MBTA Railroad Design Construction Standard Specifications, the latest edition, commonly referred to as the "MBTA Specifications".

2.4.3 Design Methodology

Structural steel elements shall be designed using the Allowable Stress Design methodology.

Concrete elements shall be designed using the Strength Design methodology.

2.4.4 Materials

Materials requirements for heavy rail bridges shall be as specified in the applicable materials sections of the Light Rail Code, the MBTA Specifications, the AASHTO Standard Specifications and the AREMA Manual.

The materials for major bridge components are specified as the follows:

Concrete
All cast-in-place concrete shall have a minimum specified compressive strength of 4,000 psi at 28 days.

Steel Reinforcement
Steel reinforcement, including ties and spirals shall conform to ASTM A615 Grade 60 requirements. Epoxy coated bars, if specified, shall satisfy the requirement in ASTM A775.

Structural Steel
All structural steel shall conform to ASTM Standard Specification A709, Grade 50, painted.

Bolts
High strength bolts for structural connections shall conform to ASTM A325. All nuts shall be heavy hex type and shall conform to the requirements of ASTM A563 Grade DH. All bolts, nuts and washers shall be hot-dipped galvanized in accordance with the requirements of ASTM A153.

Anchor bolts shall conform to ASTM F1554, Grade 55. Anchor bolts, nuts and washers shall be hot-dipped galvanized in accordance with the requirements of ASTM A123 and A153.

2.4.5 Design Loads

The design live loads for bridges or portions of structure supporting commuter rail and/or freight rail shall be the Cooper E-80 or the Alternative Live Load as specified in AREMA Chapter 15, Section 1.3.3, which ever produces the greater stresses.

The design loads for portions of structure supporting light rail trains shall be in accordance with Light Rail Code. In addition to the Green Line transit revenue car loads included in Article 4.3.1 of the Light Rail Code, Green Line Cars Type 8 and 9 loadings will be provided by the MBTA and also shall also be analyzed.

The design loads for portions of structure supporting the Community Path at Washington Street shall be in accordance with the AASHTO LRFD Pedestrian Bridge Specifications.

2.4.6 Load Combinations

The design load combinations for portion of structure supporting commuter rail and/or freight rail trains shall be in accordance with the AREMA Manual.

The design load combinations for portion of structure supporting light rail trains shall be in accordance with Light Rail Code.

The design load combinations for portions of structure supporting the Community Path at Washington Street shall be in accordance with AASHTO Standard Specifications.

2.5 Pedestrian Bridges/Ramps

2.5.1 General

This subsection sets forth structural design criteria required for designing Pedestrian Bridges/Ramps.

The structures governed by this subsection are as follows:

- Burget Avenue Pedestrian Bridge (Medford)
- Community Path Ramps at Washington Street (Somerville)

Note that the pedestrian tunnel at Washington Street Station is included in Section 2.4 above.

2.5.2 Codes

Unless noted, or directed otherwise, the following standards, codes and guidelines shall be used in the design of all structures and structural elements, as appropriate, and as set forth in this subsection:

1. AASHTO LRFD Guide Specifications for the Design of Pedestrian Bridges, the latest edition, referenced in these criteria as the "AASHTO LRFD Pedestrian Bridge Specifications".
2. AASHTO LRFD Bridge Design Specifications, the latest edition, of the American Association of State Highway and Transportation Officials, as supplemented by the FHWA 2010 Drilled Shaft Manual, referenced in these criteria as the "AASHTO LRFD Specifications".
3. MBTA Guide Specifications for Structural Design of Rapid Transit and Light Rail Structures, October 2005 of the MBTA, referenced in these criteria as the "Light Rail Code".

4. LRFD Bridge Manual, Parts I and II, of the Massachusetts Department of Transportation, the latest edition, referenced in these criteria as the "MassDOT Bridge Manual".
5. Standard Specifications for Highways and Bridges, 1988 with the latest supplemental specifications and Standard Special Provisions, of the Massachusetts Highway Department, commonly referred to as the "MHD Specifications".
6. MBTA Railroad Design Construction Standard Specifications, the latest edition, commonly referred to as the "MBTA Specifications".

2.5.3 Design Methodology

Pedestrian Bridges/Ramps shall be designed in accordance with AASHTO, MBTA and MassDOT standards, using the Load Factor and Resistance Design (LRFD) methodology.

2.5.4 Materials

Materials for Pedestrian Bridges/Ramps shall be in accordance with MassDOT, MBTA and AASHTO requirements. The materials for major bridge components are listed as the follows:

Cast-in-Place Concrete
Cement shall be Portland cement, ASTM-C150, Type II or IIA.

Substructure:	4000 psi – 1 ½" – 565# cement concrete masonry for abutment stems, piers, and wingwalls, etc.
	4000 psi – ¾" – 610# cement concrete masonry for backwalls, keeper blocks and curtain walls, etc.
Superstructure:	4000 psi – ¾" – 610# cement concrete masonry for typical deck slabs, etc.

Precast/Prestressed Concrete
Unless otherwise specified, concrete for prestressed members shall have a 28-day minimum compressive strength, f'_c, of 6,500 psi; at time of initial prestress, a minimum compressive strength, f'_{ci}, of 4,500 psi. Higher concrete compressive strengths may be acceptable, but require prior approval of the MBTA.

Steel Reinforcement
All reinforcing steel, including ties and spirals, shall conform to AASHTO M31 (ASTM A615) Grade 60 requirements. Epoxy coated bars, when specified, shall satisfy the requirements in ASTM A775 except where specifically noted otherwise.

Prestressing Steel
0.6" diameter, AASHTO M203, Grade 270, uncoated, low relaxation steel strands.

Structural Steel
AASHTO M270, Grade 50W and 50.

2.5.5 Design Loads

The design loads for Pedestrian Bridges/Ramps shall be in accordance with the AASHTO LRFD Pedestrian Bridge Specifications, Light Rail Code, AASHTO LRFD Specifications, and the MassDOT Bridge Manual.

2.5.6 Load Combinations

The design load combinations for Pedestrian Bridges/Ramps shall be in accordance with the AASHTO LRFD Pedestrian Bridge Specifications, Light Rail Code, AASHTO LRFD Specifications, and the MassDOT Bridge Manual.

2.6 Retaining Walls

2.6.1 General

This subsection sets forth structural design criteria required for designing Retaining Walls.

2.6.2 Codes

Unless noted or directed otherwise, the following standards, codes, and guidelines shall be used in the design of all retaining walls as appropriate, and as set forth in this subsection.

1. MBTA Guide Specifications for Structural Design of Rapid Transit and Light Rail Structures, October 2005 of the MBTA, referenced in these criteria as the “Light Rail Code”.
2. AREMA Manual for the Railway Engineering, 2010, referenced in these criteria as “AREMA Manual”
3. Standard Specifications for Highway Bridges, 17th Edition - 2002 with latest Interim Revisions, of the American Association of State Highway and Transportation Officials, commonly referred to as “AASHTO Standard Specifications”.
4. Massachusetts State Building Code, of the Commonwealth of Massachusetts, 2008, commonly referred to as the “Massachusetts Building Code”.
5. IBC International Building Code, the latest edition as referenced in the Massachusetts Building Code, of the International Code Council.
6. American Institute of Steel Construction (AISC) “Manual of Steel Construction”, 13th Edition, referenced in these criteria as the “AISC Manual”.
7. American Concrete Institute (ACI), "Building Code Requirements for Structural Concrete - ACI 318", including its commentary, 2008, referenced in these criteria as "ACI–318".
8. American Concrete Institute (ACI), "Manual of Concrete Practice”, 2013.
9. Standard Specifications for Highways and Bridges, 1988 with the latest supplemental specifications and Standard Special Provisions, of the Massachusetts Highway Department, commonly referred to as the “MHD Specifications”.
10. MBTA Railroad Design Construction Standard Specifications, the latest edition, commonly referred to as the “MBTA Specifications”.

2.6.3 Design Methodology

Retaining Wall stability and bearing pressure calculations shall utilize the Allowable Stress Design (ASD) methodology. Concrete components of retaining wall shall be designed using the Load Factor Design (LFD). Structural steel components of retaining wall shall be designed using the ASD.

2.6.4 Materials

Material requirements for retaining walls shall be as specified in the applicable materials sections of the Light Rail Code, the MBTA Specifications, the MHD Specifications, the AASHTO Standard Specifications, and the AREMA Manual.

The materials for major retaining wall components are specified as the follows:

Structural Steel
Structural steel, except Sheet Pile, shall be galvanized and shall conform to ASTM Standard Specification A709, Grade 50. Sheet Pile Sections shall be designed in excess of strength requirements where corrosive soil is present.

Cast-in-Place Concrete
Cast-in-place concrete shall have a minimum specified compressive strength (f'c) of 4,000 psi at 28 days.

Pre-Cast Concrete
Pre-cast concrete shall have a minimum specified compressive strength (f'c) of 5,000 psi at 28 days. **Steel Reinforcement**
Steel reinforcement shall conform to ASTM A615, Grade 60, un-coated bars unless otherwise noted.

Prestressing Reinforcement
Unless otherwise specified, prestressing reinforcement shall confirm to high strength steel wire (ASTM A421), high strength strand wire (ASTM A416, Grade 270), or high strength alloy bars (ASTM A722).

Structural Timber
Structural timber shall confirm to Light Rail Code Article 9.6 and AREMA.

2.6.5 Design Loads

The design loads for retaining walls shall be as follows:

Lateral Earth Pressure
Lateral earth pressure loads shall be in accordance with AREMA, Light Rail Code and AASHTO Standard Specifications and geotechnical recommendations.

Surcharge Loads

1. For retaining walls supporting light rail, surcharge loads shall be as specified in Article 4 of the Light Rail Code, and in accordance with AREMA.

2. For retaining walls supporting commuter/freight rail, surcharge loads shall be in accordance with AREMA.

3. For retaining walls supporting vehicular and pedestrian loadings, surcharge loads shall be in accordance with AASHTO Standard Specifications.

4. For retaining walls supporting surcharge loading due to buildings, surcharge loads shall be in accordance with the Massachusetts State Building Code.

Noise Barrier Loads
For retaining walls supporting noise barriers, loads from noise barrier shall be determined as specified in the "AASHTO LRFD Specifications" and AASHTO Guideline Specifications for the Structural Design of Sound Barriers.

Seismic Loads

1. For seismic loads of retaining walls supporting light rail loadings, loads shall be determined as specified in Article 4 of Light Rail Code, and in accordance with AASHTO Standard Specifications.
2. For seismic loads of retaining walls supporting commuter/freight rail shall be determined in accordance with AREMA and AASHTO Standard Specifications:

a. Seismic Acceleration Coefficients shall be determined in compliance with AREMA

b. Seismic earth pressures, including inertial effects, shall be determined in accordance with AASHTO.

3. For seismic loads of retaining walls supporting vehicular loadings, loads shall be determined in accordance with AASHTO Standard Specifications.

4. Seismic Loads for Retaining Walls that are not covered under Items 1 through 3 above will be determined on the basis of the Project Memorandum "Load Generation for Retaining Walls, Seismic Loading", April 23, 2014, Calculation Number GLX-RW-GEN-03.

2.6.6 Load Combinations

Load combinations for retaining walls shall be as follows:

1. For retaining walls supporting light rail loadings, load combinations including earth pressure shall be as specified in Article 4 of Light Rail Code.
2. For retaining walls supporting commuter/freight rail loadings, load combinations including earth pressure shall be in accordance with the AREMA Manual.
3. For retaining walls supporting building loadings, load combinations including earth pressure shall be in accordance with the Massachusetts State Building Code.
4. For retaining walls supporting vehicular loadings, other non-rail and non-building loadings, load combinations including earth pressure shall be in accordance with AASHTO Standard Specifications.

2.7 Noise Barrier

2.7.1 General

This subsection sets forth structural design criteria required for designing Noise Barriers.

2.7.2 Codes

Unless noted or directed otherwise, the following standards, codes and guidelines shall be used in the design of all noise barriers as appropriate, and as set forth in this subsection.

1. AASHTO LRFD Bridge Design Specifications, the latest edition, of the American Association of State Highway and Transportation Officials, as supplemented by the FHWA 2010 Drilled Shaft Manual, referenced in these criteria as the "AASHTO LRFD Specifications".
2. Standard Specifications for Highways and Bridges, 1988 with the latest supplemental specifications and Standard Special Provisions, of the Massachusetts Highway Department, commonly referred to as the "MHD Specifications".

2.7.3 Design Methodology

Noise barriers shall be designed using the LRFD methodology.

2.7.4 Materials

Materials for Noise Barriers shall be in accordance with MassDOT, MBTA and AASHTO requirements.

The materials for major noise barrier components are specified as the follows:

Structural Steel
Structural steel shall conform to ASTM Standard Specification A709, Grade 50. Structural Steel shall be galvanized.

Cast-in-Place Concrete
Cast-in-place concrete shall have a minimum specified compressive strength (f'c) of 4,000 psi at 28 days.

Pre-Cast Concrete
Pre-cast concrete shall have a minimum specified compressive strength (f'c) of 5,000 psi at 28 days.

Steel Reinforcement
Steel reinforcement shall conform to ASTM A615, Grade 60, epoxy coated bars except for foundations and drilled shafts which will have uncoated bars.

Structural Timber
Structural timber will not be used.

2.7.5 Design Loads

The design loads for noise barriers shall be in accordance with the AASHTO LRFD Specifications.

2.7.6 Load Combinations

The design load combinations for noise barriers shall be in accordance with the AASHTO LRFD Specifications.

2.8 Transit Stations

2.8.1 General

List of structures governed by this chapter:

There are seven (7) stations included in this project. They are as follows:

1. Lechmere Station
2. Washington Street Station
3. Gilman Square Station
4. Lowell Street Station
5. Ball Square Station
6. College Avenue Station
7. Union Square Station

2.8.2 Codes

The following references are applicable for the design of the transit stations:

1. MBTA Guide Specifications for Structural Design of Rapid Transit and Light Rail Structures – October 2005
2. 780 CMR: Massachusetts State Building Code, 8th Edition, referred to below as “MBC” or “780 CMR”.
3. International Building Code – 2009, referred to below as “IBC”.

4. ASCE 7-05, Minimum Design Loads for Buildings and Other Structures
5. AREMA Manual for the Railway Engineering – 2010 Edition
6. AISC Steel Construction Manual 13th Edition – 2006
7. ACI-318-10 Building Code Requirements for Structural Concrete – 2010
8. ACI-530-08 Building Code Requirements for Masonry Structures – 2008
9. AASHTO LRFD Bridge Design Specifications, as supplemented by the FHWA 2010 Drilled Shaft Manual, the latest edition.

2.8.3 Design Methodology

The transit stations shall be designed using the following design methods in accordance with the corresponding design code:

- Steel elements shall be designed by the Allowable Stress Design (ASD) or Load and Resistance Factor Design (LRFD)
- Concrete elements shall be designed by the Ultimate Strength Method
- Masonry elements shall be designed by the Allowable Stress Design method (Allowable Stress)
- Wood elements shall be designed by ASD or Load and Resistance Factor Design (LRFD)

2.8.4 Materials

Structural steel:

Structural W and WT Shapes..ASTM A992
Plates, Bars, Angles and Channels ....ASTM A36
Structural HSS..ASTM A500, Grade B
Baseplates..ASTM A36
High Strength Bolts..ASTM A325

All steel members exposed to the environment shall be hot dip galvanized.

Reinforced concrete:
All cast-in-place concrete shall have a minimum specified compressive strength (f'c) of 4,000 psi at 28 days.

Precast concrete:
All precast concrete shall have a minimum specified compressive strength (f'c) of 5,000 psi at 28 days.

Reinforcing steel:
All reinforcement shall conform to ASTM A615, Grade 60, uncoated bars

Masonry:
Concrete masonry units (CMU) shall meet the requirements of ASTM C145 and C90, Grade N, Type 1, normal weight and shall have a minimum compressive strength of 2,000psi on the net-bedded area.

Mortar:
Mortar for CMU shall meet the requirements of ASTM C270, Type M.

Grout:
Grout for CMU shall have a minimum compressive strength of 2,500 psi at 28 days.

Welded Wire Reinforcement:
All welded wire reinforcement shall meet the requirements of ASTM A185, Grade 70.

Timber:
Wood framing shall be glued laminated timber. Wood decking shall be glued laminated timber decking. Timber framing exposed to the environment shall be treated to improve durability (pressure treated, Wolmanized®, etc.)

2.8.5 Design Loads

The design loads for the transit stations shall be in accordance with Chapter 16 of the MBC. For portions of the stations that are underground, in addition to the design loads from Chapter 16 of the MBC, the following loads must also be considered:

- **Live Loads:**
  - Public Spaces = 150 PSF per MBTA Guide Specifications
  - Non-Public Spaces = 50 PSF per IBC office loading
  - Plaza Live Load = AASHTO H20 loading
  - All other = Per 780 CMR
- **Train Loads:**
  - Vertical Loads:
    - Green Line Train = 137,000 LBS per MBTA Guide Specifications
    - Commuter/Freight Rail = AREMA Cooper E80
  - Horizontal Loads:
    - Green Line Train = 40% of single car load applied 2 feet above the top of track
    - Commuter/Freight Rail = per AREMA
  - Also refer to the memorandum titled "Review of Structure Protection for Stations and Plazas" that is included as an appendix to the Design Definition Document
- **Snow Loads:**
  - Per 780 CMR
- **Soil Loads:**

  Per Mass Building Code, including:
  - Vertical earth pressure loads (temporary and permanent)
  - Horizontal earth pressure loads (temporary and permanent)
  - Hydrostatic loads (normal water and flood elevations shall be provided in the Geotechnical Design Report referenced in the Design Definition Document)
  - Surcharge loads (vertical and horizontal)
  - Thermal loads:
    - Normal temperature shall be taken as 55°F for underground structures
    - The coefficient of expansion shall be 0.0000060 in/in/°F for concrete and 0.0000065 in/in/°F for steel
  - Buoyancy
  - Seismic load per 780 CMR 1610.2

2.8.6 Load Combinations

The load combinations for design shall comply with American Society of Civil Engineers (ASCE) 7-05 Chapter 2.

2.8.7 Serviceability Requirements

The structural components shall comply with the maximum deflections below.

- Floor Framing
  - Live Load Deflection = L/360
  - Total Load Deflection = L/240
- Roof Framing
  - Live Load Deflection = L/240
  - Total Load Deflection = L/180
- Lateral System
  - Wind Load Deflection = L/400
  - Seismic Load Deflection = Per ASCE 7-05 Section 12.12
- Plaza Framing
  - Live Load Deflection = L/800

2.9 Maintenance Facility Complex and Traction Power Substations

2.9.1 General

List of structures governed by this chapter

There is one (1) maintenance facility complex – consisting of a vehicle maintenance facility , a transportation building, an employee parking deck, and grade separation retaining walls - to be constructed as part of this project.

There are three (3) traction power substations in this project. Red Bridge will feed the storage maintenance yard, one will be located at Ball Square, and the other at Gilman Square.

2.9.2 Codes

The following references are applicable for the design of the traction power substation structures:

- Massachusetts State Building Code (MBC) 8th
- AISC Steel Construction Manual 13th Edition – 2006
- ACI-318-08 Building Code Requirements for Structural Concrete – 2008
- ACI-530-08 Building Code Requirements for Masonry Structures – 2008

The following references are applicable for the design of the maintenance facility complex structures:

- IBC 2009 - International Building Code
- Massachusetts Building Code 8th Edition – 780 CMR State Board of Building Regulations and Standards – Massachusetts Amendments to the International Building Code
- ASCE 7-05 – Minimum Design Loads for Buildings and Other Structures
- ACI 301-99 – Specifications for Structural Concrete

- ACI 318-08 – Building Code Requirements for Structural Concrete
- ACI 530-08 – Building Code Requirements for Masonry Structures
- AISC 360-05 – Specifications for Structural Steel Buildings
- AISC 341-05 – Seismic Provisions for Structural Steel Buildings, including Supplement 1 dated November 16, 2005.
- AISI S100-07 - Specification for the Design of Cold Formed Steel Structural Members
- AWS D1.1-08 – Structural Welding Code - Steel
- AWS D1.3-08 – Structural Welding Code – Sheet Steel
- AWS D1.4-05 – Structural Welding Code – Reinforcing Steel
- MBG 531-09 – Metal Bar Grating Manual 7th Edition
- NFPA-101-06 – Life Safety Code
- Preliminary Geotechnical Report – Vehicle Maintenance Facility, Parking Deck and Transportation Building MBTA Green Line Extension Project – Advance Preliminary Engineering and Final Design January 2013, Nobis Engineering, Inc.
- AREMA 2012 – Manual for Railway Engineering, The American Railway Engineering and Maintenance-of-Way Association
- AASHTO Standard Specifications for Highway Bridges 17th Edition 2002
- MassDOT LRFD 2009 Bridge Manual Parts 1 & 2
- Commuter Rail Material Specifications 1992, MBTA Railroad Operations
- Commuter Rail Design Standards Manual 1996, MBTA Railroad Operations
- Book of Standard Plans – Track and Roadway 1992, MBTA Railroad Operations
- Guide Specifications For Structural Design of Rapid Transit and Light Rail Structures 2005, Gannet Fleming for MBTA

2.9.3 Design Methodology

The maintenance facility complex and the traction power substations will be designed using the following design methods in accordance with the corresponding design code:

- Steel elements shall be designed by the Working Stress Method (Allowable Stress)
- Concrete elements shall be designed by the Ultimate Strength Method
- Masonry elements shall be designed by the Working Stress Method (Allowable Stress)
- Live load deflections, fatigue, crack control and vibration characteristics shall be investigated under service loadings to assure serviceability and durability.

2.9.4 Materials

Structural steel:
All structural steel HP shapes shall conform to ASTM Standard Specification A572, Grade 50. All structural steel W shapes shall conform to ASTM A992. All structural steel plate, channel and angle shall conform to ASTM A36.

Reinforced concrete:
All lean/fill concrete shall have a minimum specified compressive strength (f'c) of 2,500 psi. All other cast-in-place concrete shall have a minimum specified compressive strength (f'c) of 4,000 psi at 28 days.

Reinforcing steel:
All reinforcement shall conform to ASTM A615, Grade 60, uncoated bars; except where required by analysis for ductility and/or welding requirements, reinforcing steel shall conform to ASTM A706, Grade 60, uncoated bars.

Masonry:
Concrete masonry units (CMU) shall meet the requirements of ASTM C145 and C90, Grade N, Type 1, normal weight and shall have a minimum compressive strength of 2,000psi on the net-bedded area.

Mortar:
Mortar for CMU shall meet the requirements of ASTM C270, Type S above grade and Type M below grade.

Masonry Joint Reinforcement:
Masonry joint reinforcement shall conform to ASTM A951.

Grout:
Grout for CMU shall have a minimum compressive strength of 2,500 psi at 28 days.

Structural Grout:
Structural Grout shall have a minimum compressive strength equal to 4,000 psi. Non-shrink and packaged dry grout with 7,000 psi minimum compressive strength shall be used for grouting between foundations and base plates of structural steel columns.

Structural Steel Tubing:
All structural tube steel (HSS)shall meet the requirements of ASTM 500, Grade B. Structural Steel Tubing will only be used with the permission of the MBTA.

Steel Pipe:
All steel pipe shall meet the requirements of ASTM A501.

Welded Wire Reinforcement:
All welded wire reinforcement shall meet the requirements of ASTM A185, Grade 70.

2.9.5 Design Loads

The design loads for the traction power substations shall be in accordance with Chapter 16 of the MBC.

Design loads for the maintenance facility complex structures are provided in Attachment 3A "Green Line Extension Project, Vehicle Maintenance Facility Complex Structural Design Criteria, Supplemental Details and Requirements".

2.9.6 Load Combinations

For steel design, the load combinations for the traction power substations shall be in accordance with Articles 1616.2 and 1616.3 of the MBC.

For reinforced concrete design, the load combinations for the traction power substations shall be the governing load cases from either Articles 1616.2 or 1616.3 of the MBC, or Chapter 9 of ACI-318-10.

For masonry design, the load combinations for the traction power substations shall be the governing load cases from either Articles 1616.2 or 1616.3 of the MBC or Chapter 9 of ACI-530-05.

Load combinations for the maintenance facility complex structures are provided in Attachment 3A "Green Line Extension Project, Vehicle Maintenance Facility Complex Structural Design Criteria, Supplemental Details and Requirements".

2.10 The Protection of Station Supports

2.10.1 General

At all seven proposed Green Line Stations, supports for structures above the track level are located in close proximity to the Green Line Tracks and would be vulnerable to damage from a light rail vehicle derailment. The issue of the appropriate protection for these supports has been reviewed; memoranda regarding this issue are included as Attachment 4 "The Protection of Station Supports".

2.10.2 Codes

The MBTA Guide Specifications for Structural Design of Rapid Transit and Light Rail Structures does not include any specific provisions for the protection of supports located within the right of way due to a light rail vehicle derailment. Determinations have been made about the method of protection that is appropriate based on the specific types of supports that will occur at the stations. All Codes that relate to the design of Transit Stations, as described in Section 2.8 "Transit Stations" will apply to this work.

2.10.3 Design Methodology

The supports vulnerable to a Light Rail Vehicle Derailment will be designed using the following protective approaches:

- **Guard Rails:** All Station Supports will be protected by Guard Rails as described in Section 1.6.2.2.6 "Emergency Guard Rail".
- **Free Standing Supports:** There will be no Free Standing Supports. All supports will be part of continuous rows of columns.
- **Columns for the Support of Concourses, Headhouses, and Other Station Elements:** The typical station configuration will involve a platform at grade level with station related structures above the Platform Level. The Columns for the Support of Concourses, Headhouses, Passageways, Pedestrian Bridges, Entrance Areas, Plazas, and Other Station Elements will be in continuous rows of columns adjacent to the tracks. The columns will support a variety of occupied levels above. The columns will be founded on continuous reinforced concrete foundation walls. The foundation walls will extend far enough above the top of rail to elevate the column bases above the point where a derailment impact would occur so that the derailment impact will occur at the continuous foundation wall rather than at individual columns. The foundation walls will be designed to withstand a superimposed impact load based on light rail vehicle equipment and operational characteristics. The superimposed impact load will be 55 kip applied at two feet above the top of rail and distributed over a distance of 10 feet. The height of the wall will be a matter of detailing.
- **Columns at the Elevated Lechmere Station**: The columns for the support of the two headhouses at elevated Lechmere Station will be in continuous rows of columns adjacent to the tracks. These columns will support a roof level above the platform level. These columns will be protected from a derailment impact by a continuous reinforced concrete barrier that will interconnect and encase the columns so that the impact will occur at the continuous barrier rather than at individual columns. The barrier will be designed to withstand a superimposed impact load of 55 kip applied at two feet above the top of rail and distributed over a distance of 10 feet. The height of the barrier will be a matter of detailing.
- **Surfaces Supporting Vehicle Loads:** The supports for any section of a station that may potentially support a vehicle load will be designed with support protection in conformance with AREMA

standards for Pier Protection. The standards require reinforced concrete walls at least 2'-6" thick, at least 12' -0" long, and with a minimum height of 12'-0". The walls will be anchored to footings and must extend at least 4'-0" below the surrounding grade.

2.10.4 Materials

Material for Foundation Walls and Barriers will be Reinforced Concrete with a minimum compressive strength of 4,000 psi at 28 days and Reinforcing Steel that will conform to ASTM A615, Grade 60, Uncoated Bars.

2.10.5 Design Loads

The Design Loads to account for a possible train derailment impact will be as indicated in Section 2.10.3 Design Methodology.

2.10.6 Load Combinations

The Design Loads to account for a possible train derailment impact will be applied in accordance with the Massachusetts State Building Code in Load Combinations with all other applicable loads described in Section 2.8 "Transit Stations".

2.10.7 Serviceability Requirements

There will be no additional Serviceability Requirements beyond those described in Section 2.8 "Transit Stations

3 Stations

Chapter 3

3.1 General

This chapter contains general architectural criteria developed for the MBTA Green Line Extension project. These criteria govern the design of the stations with regard to the discipline of architecture. They include calculations (egress as required), accessibility, level of service (LOS) determination and a program that ensures an efficient design of passenger circulation and safety. This section is intended to add clarity to the project goals, design intent and issue understandings.

3.2 Standards, Codes, and Guidelines

The following codes and standards are employed for consistency with local and state requirements, as well as MBTA / Transit standards and guidelines.

- Massachusetts State Building Code 780 CMR, Eighth Edition
- Massachusetts State Elevator Code 524 CMR
- NFPA 101 Life Safety Code
- NFPA 130 Standard for Fixed Guideway Transit Systems
- Massachusetts Architectural Access Board 521 CMR
- ASME A17.1 Safety Code for Elevators and Escalators
- MBTA Guidelines & Standards, 1977
- MBTA Standard Contract Specifications
- MBTA Guide to Access, 1990
- APTA Guidelines (American Public Transportation Association)
- ADA and MAAB Accessibility Guidelines for Buildings and Facilities
- Transit Capacity and Quality of Service Manual, Transit Cooperative Research Program (TCRP) Report 100
- Pedestrian Planning and Design, Dr. John Fruin
- Boston Center for Independent Living Agreement (BCIL)
- Association of American Railroads (AAR)
- Public Rights-of-Way Access Advisory Committee (PROWAAC)

3.3 Design Considerations

The intent of the design considerations is to create an environment that is consistent with current priorities for station design, MBTA needs, and while maintaining a lasting level of design quality.

- Utilize a design that supports ease of station maintenance, including no use of sealant dependent joints.
- Employ functional design combined with simplicity of form and to incorporate an expression of structure to create a unified expression of project components. Within this framework, it is expected that the public elements of the stations will have the ability to adapt to specific urban design forces to produce a comprehensive station design.
- Create spaces to enhance passenger experience and orientation, incorporating local input from the project's Design Working Group.

3.3.1 Qualitative Design Goals

The transit station stands as a link between its neighborhood and the train system that enables its citizens to connect with the rest of the city. It should represent both its function as a connecting part of a larger transit system and its relationship with its environment. It should be clear to passers-by that the structure is part of a system, which enables them to access the rest of the city. The design of the station should be an asset to the community, and enhance its environment. The design should also provide user comfort, and afford access to persons with disabilities.

- Stations should provide a civic architecture that is permanent, functional and pleasant. It should express the system's character while contributing to its context -- one that is not entirely a derivative of the transit system, but of the neighborhood and community of which it is a part, yet maintains an overall line recognition and system identity.
- Develop a family of station parts and furniture that are interchangeable and allow for the individual character of each neighborhood or community as appropriate.
- The concourse and platform elements are intended to be similar at all stations. The exteriors are detailed as a rain screen system of metal plate panels. The color and material of this panel system will vary with individual stations, as necessary to assist in passenger wayfinding.
- Protect transit passenger from adverse weather conditions (snow, rain, and wind and summer sun) and vehicular traffic. Provide seating at shelters and other protected locations on the platform.
- Make transit a safe, secure, friendly and enjoyable experience and accessible to all, including persons with disabilities.
- Related function – Accessible Drop Off, within 100 feet of a station entry with direct line of sight connection between "The Ride" driver and the station entry point.
- It is the station's Headhouse entrances that provide the physical interface between the property, its surrounding streets, and the neighborhood. Headhouse entrances must provide convenient access for passengers and fit appropriately within the surrounding urban context and community.

Among the required qualitative characteristics for a station are the following:

- Efficient Passenger Circulation
  - Provide vertical and horizontal 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.

- If possible, avoid cross flows of pedestrian traffic at all escalators, elevators, stairs, and entryways. Track alignment dimensions will establish the overall dimensions of the station at track level. The arrangement of circulation elements is fundamentally tied to these limiting dimensions. Review of critical circulation dimensions-ADA and egress- must be rigorously checked against changes to track layout.
- Avoid reverse directions en-route to minimize travel time.

- Design Principles
  - Employ functional design combined with simplicity of form and organization, incorporating an expression of structure, to create a comprehensive station design.
  - Create multi-volume spaces to enhance passenger experience and orientation as a component of the station's wayfinding strategy.
  - Utilize a design (includes detailing and material selection) that supports ease of station maintenance.
- 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 from users within the station and to outside observers

The stations need to be carefully sized and evaluated as to the portion of passengers expected and to the proportions of the site and the surrounding neighborhood. Dimension between track centerlines will determine the maximum available dimensions.

Some design considerations to be considered are as follows:

- Station identity and visibility at a distance needs to be considered.
- Sight lines from the neighborhoods to the station need to be reviewed in order to locate station identity elements and to determine overall station massing relative to the context of the neighborhood.
- Stations need to be sympathetic to the scale and character of the surrounding area.
- Art, signage and lighting are an important aspect to the station design.

Use of materials that convey an openness and transparency of the transit environment, as well as durability and ease of maintenance should be considered.

3.3.2 Physical (Technical) Parameters

The station geometry should address dimensional criteria concerning station needs (trains, patrons, entry, etc.) to accommodate all users and requirements. The following criteria have been established as a basis for defining station physical characteristics:

- Platform Length is established at 225 feet, in order to accommodate a single three-car LRV .The design also provides for a 75 foot platform extension to 300' to accommodate a single four-car LRV or two two-car LRVs. The platform length for Lechmere Station, an elevated station where future extensions could not readily be accommodated, will be established at 300' initially.
- Provide pedestrian transfer connections to entries/exits where needed for alternate modes (i.e. bus, automobile accessible drop-off, etc.).

- *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.
- *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 following criteria have been established for determining passenger loads used to quantify all passenger circulation elements for each of the Green Extension project 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 highest volume peak hour data (either AM or PM) shall be used at each platform. Detailed passenger load forecasts are available in the project's Environmental Assessment document.
- The peak hour data is divided into four fifteen minute blocks in which the actual peak 15 minute period contains a surge factor of 1.5 times the remaining three periods.
- The peak (surge) 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 will be used to determine level of service requirements as well as life safety/ egress requirements.

3.3.2.1 Stair Width

For stairs that are part of an accessible route for the public, the width shall be 48 inches minimum. The Massachusetts State Building Code shall govern the spacing of handrails.

3.3.2.2 Location

Station entrances should be positioned alongside the public right-of-way to provide a sense of user-friendliness while still preserving space for pedestrian circulation on the public sidewalks. Toward this end, entrances should be located within public plazas where possible.

Factors influencing the location of entryways are:

- The physical constraints of the surrounding structures and streets
- Accessible path from neighborhoods served.
- Visual connection to accessible drop-off
- 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

3.3.2.3 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 entryways 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
- Bridge geometry which determines accessible entry

3.3.2.4 Elements

The design elements used for the station need to be as durable as possible. Transparency into the transit station helps provide a sense of security and aids in intuitive way finding, however, it is important to balance station transparency with issues of maintenance and light spillage into the neighborhood. Harmony with the surrounding neighborhood is the intended goal.

Equipment design and installation must comply with MBTA insurance carrier (FM Global) guidelines. Design drawings must be submitted to FM Global for review and comment prior to construction.

3.3.2.5 Sustainable Design

The "Leading by Example Program" has been developed to guide state agencies in meeting the mandates set forth in Executive Order 484. At the time of writing this document, the program has published a set of "tips" aimed to reduce overall environmental impacts of state government operations. "Tips" relevant to the design of the Green Line Extension stations, in addition to several best practices in sustainable design can be summarized as follows:

Green Construction:

- Use products made of low maintenance, renewable resources and recycled materials with a proven track record in station construction.
- Reclaimed asphalt will be reused as a substrate for newly paved areas.
- Construction procedures, which are green and considered practical in the construction industry of Boston Region.
- Use of green materials with low embedded energy.
- Consider long-term operating and maintenance costs when developing finish material templates
- Efficient design, minimizing land use and construction material
- Stormwater to be directed to holding tanks under station platforms before discharge. Lechmere Station, an elevated station, will not have holding tanks beneath its platforms.
- Locally-made materials and resources should be given priority consideration.

Energy Efficiency:

- Use compact fluorescent lamps instead of incandescent lights.
- LED lighting may be used where appropriate in areas other than platforms and in those areas of concourses and headhouses where the MBTA has approved their use.

- Maximize use of natural lighting
- Maximize use of natural ventilation with louvers located at bottom and top of station glazing.
- Use building elements to shade interior spaces during summer.
- Use light-emitting diode (LED) exit signs.
- Install motion sensors in the ancillary rooms.
- Install computer power management in personal computers (PCs) located in the automated fare collection (AFC)/Communications Room.
- Introduce light wells to daylight lobbies and combine with the use of daylight sensors in the station lighting.
- Do not use "Green Roofs" without approval from the MBTA. It is thought that the required maintenance of these elements outstrip their viability.
- Use light colored roof ballast to cover built-up-roofing materials to aid in reducing roof temperatures and to add long term protection to roof surfaces.

Water Use Reduction:

- Achieve a high performance in stormwater treatment per MassDEP regulations
- Landscaping choices to have minimum to zero irrigation needs from potable water, while attempting to restore site vegetation
- Direct rainwater from the roof to recharge the aquifer or to supply moisture to planted areas.
- Install low-flow toilets and faucet aerators in sinks in the station bathrooms.

3.4 Public Circulation

The journey to the platform includes Horizontal and Vertical Circulation Elements located in the public spaces of the station. Each of the circulation elements is defined by a set of operational requirements: (a) function per pedestrian Level of Service (LOS) standards as defined in TCRP-100, (b) emergency egress and (c) accessibility.

3.4.1 Platforms

The design of the platform shall support two functions: (a) queuing areas for passengers waiting to board a transit vehicle and (b) circulation area for departing and arriving passengers. Platform width requirements should be calculated on the basis of peak hour passenger volume at a pedestrian LOS [Level of Service] "C". LOS "C" is decribed in the "Transit Capacity and Level of Service Manual", 3rd Edition, Transportation Research Board, October 2003. Platform width is controlled by available track alignment dimensions.

The center platform layout combines the spatial needs for both the inbound and outbound service in one area. When passenger peak demands are offset in direction within the day, the center platform becomes a better choice: a portion of the non-peak direction platform can be used for the peak direction demand. Moreover, the center platform provides for a single pedestrian route and destination for system users and, consequently, improves passenger wayfinding and reduces the amount of vertical circulation and signage required. Both these conditions allow for a more intuitive understanding of the station configuration. Because circulation is simplified, emergency egress is also simplified. Finally, the center platform allows for a continuous "right hand" pedestrian circulation, limiting the amount of circulation crossovers.

The required platform width is a function of the number of waiting passengers to board according to projected ridership and their density while waiting to board the train. The actual (net) loading length for platforms is obtained through the following operational assumptions and requirements:

- Green Line Extension stations are designed with single end-loaded platforms.
- Platform length is 225 feet with a potential extension to 300 feet. The platform length for Lechmere Station, an elevated station where future extensions could not readily be accommodated, will be established at 300' initially.
- Edge of platform is located 4'-9" from centerline of the light rail track.
- Platform floor elevation is currently designed at 8" above top of rail at the edge. In the future, the platform will be lifted to 14" above top of rail to accommodate level boarding into the Type 9 LRVs. Elevators, stairs, and escalators shall be set at the future 14" elevation with transition ramps down to the current platform height.
- Station Grades are set as: minimum and preferred 0.5%, maximum 2.0%.
- The platforms will drain towards the track.
- A 2-foot wide tactile edge is required along the entire length of the platform and will not be included in the platform width calculation (for safety, this zone is considered off limits).
- Each station will have an emergency egress that will provide an accessible way to a point of safety (in the public right-of-way) from the end of the platform.
- For width clearances, a 6-foot minimum clearance is required from platform edge to obstructions (i.e. columns and stations amenities) along the platform proper (MBTA guideline).
- Refer to Platform/Canopy documents for design intent and arrangement of required functional elements.

3.4.2 Walkways

Walkways are connecting paths between the different functional areas as, for example, between the entrance and platform. The required walkway widths are based on level of service "C" during the 15-minutes peak pedestrian demand, per TCRP-100.

- Minimum width for accessibility is 6 feet clear and unobstructed. Unless limited by available track alignment dimension
- Design will use defensible space criteria to establish passenger safety.
- Standard waiting and walking spatial criteria apply when walkways lead to elevators outside of the main path of travel.

In addition, design of walkways should consider principles of Crime Prevention Through Environmental Design (CPTED) as outlined in Crime Prevention Through Environmental Design: Applications of Architectural Design and Space Management Concepts (2nd ed.) by Timothy D. Crowe, published by Butterworth, Boston 2000.

3.4.3 Track Crossings

As a means to ensure safety and separation between vehicles and passengers circulation paths, for this project MBTA policy does not consider the use of track crossings as a means of routine access or egress for platforms. For means of emergency egress only, the following will apply:

- The route surface from the platform shall be level and flush with the rail top at the outer edge and between rails, except for a maximum 2 ½" gap on the inner edge of each rail to permit passage of wheel flanges. Where gap reduction is not practicable, an above-grade or below-grade accessible route shall be provided. Any horizontal gap in the surface paving greater than ½" can trap a wheelchair wheel but smaller gaps than 2 ½" can cause a train to derail.
- Newly constructed emergency pedestrian paths should intersect rail crossing at right angles.

- Where the pedestrian crossings are not separated by curbs, railings or other elements from the vehicular way, a continuous boundary of 36 inches wide detectable warning will be provided.

3.4.4 Ramps

Exterior ramps will be required for means of emergency egress when a track crossing cannot be provided. The Office of System wide Accessibility will be consulted during the coordination of accessible route location, ramp design and construction tolerances.

- Refer to the current MBTA Guide to Access for detailed requirements for slopes, widths, landings, surfaces and handrails beyond those required by the ADA.
- Handrails along ramps shall be designed as per MBTA Guide to Access. Handrails should be made of stainless steel but galvanized steel is permitted.
- Current MBTA access guidelines state that if a ramp serves as the accessible entrance or egress to the station it will need to be covered. Assume all egress ramps require roofs and all other required systems, such as lighting and communication devices. Lighting shall be designed with shielding so as to not impact adjacent structures or properties.
- The design of the egress ramps should use the same material palette as the adjoining station.
- All ramps must comply with MAAB 521 CMR and Massachusetts State Building MSBC 780 CMR.

3.4.5 Escalators

In stations whose depth from the surface is substantial, movement upwards and downwards is primarily served by escalators and elevators. A standard specification shall include a nominal 48-inch wide (unless noted otherwise) (40-inch clear step) heavy-duty transit escalator with internal drive configurations. All escalators shall be based on APTA standards.

- Escalator balustrades shall be heavy gauge stainless steel.
- At minimum, escalators must be provided for all vertical movements greater than 12 feet upwards.
- Refer to Station documents for proposed location of escalators.

3.4.6 Stairs

All stairs must comply with MAAB 521 CMR and MSBC 780 CMR and where stairs are required; there will be a minimum of one stair per platform when escalators and elevators are also provided. A public stair unit will have the following characteristics:

- Risers shall be of uniform height 7 inches maximum, closed and perforated conditions, and with contrast/reflective nosing firmly attached to the stair structure
- All treads shall be a uniform width of 11 inches minimum.
- Landings shall comply with MAAB 521 CMR and MSBC 780 CMR.

3.4.7 Elevators

3.4.7.1 Location

All passenger transfers and surface connections should be able to occur by use of an elevator. Redundant elevators will be required in all stations.

3.4.7.2 Design Features

The BCIL agreement includes several provisions for the design of the elevator shaft and the detailing of the elevator cab and the performance of the equipment.

- Type of Elevator will be heavy duty, electrical traction, Machine Room Less (MRL) with a 3,000 Lbs capacity and an operating speed of 200 fpm.
- Queuing/discharge space should be at a minimum of 10 feet, and located so as to not interfere with the main flow of passengers. A queuing/discharge space of 1.5 the depth of the car is preferred where achievable but in no case shall the queuing/discharge space be less than ten feet.
- Hoistway and car design should utilize materials/ construction to promote transparency and maximum visibility. Hoistway size will be determined by product manufacturer's specifications.
- Control room sizing and clearance requirements will be developed after consulting several manufacturers on selected equipment.
- 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.
- The construction type of the hoistway will adhere to the station's construction type.
- Provide heating, ventilation, and air conditioning (HVAC) to control rooms to maintain room between 60°F and 90°F as per code.
- Provide smoke transfer duct between the control room and shaft. Provide smoke venting at the top of the elevator shaft.

3.4.7.3 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.
- The cab shall have minimum dimensions of 60"x80" such that the longer dimension is perpendicular to the door face (BCIL agreement).
- ADAAG compliant for communication and control features.

3.5 Entrances

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.

3.5.1 Accessibility and Safety

By use of the new automatic fare collection (AFC) equipment, the Authority is offering convenient entrance options to its patrons in the 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.

- 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 area or further down the street).
- Provisions for fire department access during an emergency.
- Safety and 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.
- Customer Assistance Areas (CAAs) must be incorporated into platform designs in accordance with standards currently under development by the MBTA. CAAs include a call box, a bench, and increased lighting levels, denoted by tactile surface materials.
- Where allowed by code, Areas of Rescue Assistance must be identified in station designs drawings.

3.5.2 Identification

- Station identity and visibility at a distance, but at the same time sympathetic to the scale and character of surrounding structures.
- MBTA standard "lollipop sign to be used as required at all stations.
- 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.

3.5.3 Fare Collection

3.5.3.1 Fare Gates

The capacity (**C**) of a fare gate is dependent on the time required by each pedestrian to pass through. 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 one gate shall be added to this demand number, for reverse flow and the possibility of a malfunctioning unit. Two of the total fare gates must be ADA compliant. The minimum number of gates per station is three.

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

The working capacity of the S&B fare gates currently considered by the MBTA for the Green Line Extension is:

- in the exiting direction: 20 people per minute
- in the entering direction: 10 people per minute

The egress capacity of fare gates is set by NFPA 130 and shall be used in the egress calculations of each station.

Fare Vending Machines (FVM), each typically servicing 1-2 people per minute, require a queuing area in front of them at minimum 5-foot deep. FVMs are typically organized in banks of three (a standard unit, a standard with VMS and a cashless unit)

- Location of FVMs shall be proximate to the entrance doorways and the accessible route. An FVM and its associated queuing area shall not block the accessible route or path of egress.

- Low-traffic stations can be serviced with one bank of FVMs; otherwise provide two banks or in the case of dual entrances, include one in each unpaid lobby.

3.6 Elements

The MBTA provides station amenities to enhance user comfort and to meet accessibility requirements. Consistency in the design of most of these elements will present a cohesive appearance helping to orient users of the rail system and reinforce the overall Green Line identity. At most surface stations, new site furnishings will be installed. All station entrances shall be accessible, and entrance signage must indicate the accessible route. The signage and wayfinding design will adhere to the MBTA's signage guidelines. The primacy of the accessible route shall be principal consideration.

3.6.1 Signage and Wayfinding

Signage provides location, wayfinding, route and schedule information to passengers both in the station and on transit. Stations need to be identified as part of the MBTA transit system, along with the station name and its accessibility provisions.

- Station identification signs are mounted on poles-(MBTA standard lollipop signage) - so they can be viewed from the street, and are internally lighted.
- Station name signage is normally 8'-0" to 12'-0" long with a 6" color strip with white lettering for the station name above a 6' white strip with black lettering indicating the train direction. This station name mounted on the station entrance wall shall be clearly visible from the adjacent sidewalks and street intersections.
- Stations, which are accessible, are designated with the International Symbol of Accessibility (ISA). The ISA symbol is located within the directional white strip.
- Tactile signs are required for all stations and for all the rooms therein. These signs must include Braille and raised lettering. Tactile signs should be placed at a height of 60" to the centerline of the Braille sign. Tactile signs shall have raised lettering of 1/32", upper case only. The font style shall be sans serif or simple sans serif. The raised characters in the tactile signs shall be at least 5/8" high, but no greater than 2" high. The same message must be in Grade 2 Braille.
- Station area maps should also be provided at each station for use in passenger orientation and wayfinding.
- The quantity and location of bus schedule cases must be coordinated with MBTA bus operations.

3.6.2 Canopies and Platform Shelters

Canopies are provided in order to protect transit users from the elements. In addition to existing MBTA guidelines concerning issues such as geometry, height and materials, there are a few access guidelines and construction directions worthwhile mentioning:

- Canopies should be continuous along the platform and their supports shall be integrated into the overall platform design. Refer to Platform documents. Future platform extension to a 4 car length shall provide for the extension of the canopy system.
- Canopies shall have roofs that project out at least 5'-0" from the post, where clearance permits, to account for a wheelchair turning radius.
- The layout allows for at least 2 wheelchair areas (this is an MBTA Guide to Access recommendation).
- Canopy structures shall be designed to be as open and lightly framed as possible. Bird "proofing details are required to be incorporated into the structural design of the canopy frame to discourage the nesting and socializing of birds.

- Platform wind screens shall have transparent back and wing walls. Wing walls should be coordinated with station glazing module for standardization of elements.

3.6.3 Informational and Cultural Panel Program

At each station information panels, which could have a map and points of interest and history of the surrounding area, have been provided. Refer to Platform Documents Some considerations for the information panels are the following:

- MBTA graphic design group will assist in the selection of images.
- Panels should be similar in design to other panels on the Green Line.
- There should be no obstructions in front of the panels to block the view of persons in wheelchairs, or visually impaired.
- Panels should be at a height, which is easily readable from all eye levels.
- Braille should be incorporated to accommodate the blind.

3.6.4 Benches

Benches provide places for people to sit, rest, and to lay down heavy packages. Some considerations for bench location and design are the following:

- Benches should be located near waiting areas, platform shelters, and in paid and unpaid areas if space permits.
- Benches on platforms shall be protected from the elements, and be located no greater than 200 feet apart.
- Benches should have high back and armrest. This design helps people with limited strength and mobility, and provides comfort.
- Benches shall be sloped for drainage.
- A 30-inch by 48-inch clear ground space for a wheelchair has been provided at all benches on each platform.
- The typical platform bench is shown as a 4x4 Ipe wood plank seating and back structure. The planks are separated with a half inch space as indicated on the platform documents. Armrest elements should be stainless or galvanized steel elements spaced so as to discourage lounging.

3.6.5 Trash Receptacles

It is recommended that one style of trash receptacle be used for the Green Line stations to maintain consistency, ease of maintenance and replacement. Some considerations for location and design of trash receptacles are:

- Trash receptacles should be located outside, but adjacent to path of travel, near entrances to stations, at canopies and at the entrance to pedestrian overpasses.
- A minimum of one trash receptacle per platform should be provided, but enough to prevent overflowing between trash removals.
- The MBTA should be consulted for blast/explosion proof issues.
- The height of a receptacle should be 3 feet maximum to the opening.
- Needs to be easily accessible for maintenance and vandal proof.
- Refer to Platform drawings for suggested locations.

3.6.6 Bicycle Racks

Each station has specific needs for enclosed and open bike storage. On-going research will determine the bicycle storage requirements for each station. Some considerations for location and design of the bike rack are:

- Enclosed and open bike storage shall be provided at surface stations, and shall be located away from major circulation.
- The number of bike spaces, at each station, is based on meeting the EA document requirements at a minimum. It is encouraged to exceed these capacity minimums.
- Bike racks should be located near station entrance and will be highly visible so they can be observed by MBTA personnel or commuters.
- Space for future bike rack expansion should be considered.
- Bike racks will be stacked and, made of galvanized steel. Colored galvanized steel could be a consideration. The MBTA is in the process of developing a standard racking system.

3.6.7 Sand Storage Bins

Snow covered pavement can be hazardous in the winter. All surface stations must have at least one sand and one salt storage bin per each station platform. Some considerations for location and design for this element are:

- Bins should be located in areas of the platform not used by passengers, and away from entrances and boarding areas.
- Bins should be located outside of required accessibility route, but easily accessible for MBTA maintenance workers.
- The size of the bin is approximately 2'-6" wide, 2'-6" high and 3'-0" long.
- At this time the MBTA is using painted wooden boxes, constructed by the MBTA for their own use. A manufactured fiberglass container should be considered for sand storage-Color-Light Grey

3.6.8 Fare Machine Installations

The design criteria for the fare vending machine installations need to be based on discussions with the MBTA for new requirements and guidelines. The installations will be designed on a case by case basis; each station will be evaluated independently. A typical installation includes the following: fare vending machines, fare media validators, lighting, closed-circuit television (CCTV) and benches.

3.7 Lighting

3.7.1 Headhouses

Artificial lighting shall be provided for safety and aesthetics and in accordance with the recommendations of the Illuminating Engineering Society (IES) and all local codes having jurisdiction. The lighting system can include fluorescent, metal halide, and low pressure and high-pressure sodium fixtures. LED lighting will be used for Exit Lights, Emergency Lights, and for non-platform lighting in areas where approved by the MBTA. 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 platform, 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. A minimum lighting level must be maintained to promote safety. A brightly-lit station with a minimum of dark corners and narrow, circuitous passageways facilitates surveillance and tends to discourage crime. Ample lighting is particularly important to facilitate system use by visually impaired 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 outdoors to indoors. The use of photoelectric cells for the operation of additional lighting fixtures should be considered as an option of mitigating this problem. The standardization of lighting levels for the similar areas throughout the system is desirable.

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:

- Station and miscellaneous lighting
- Emergency lighting

3.7.2 Station and Miscellaneous Lighting

Passenger station lighting will be provided within station facilities including platforms, stairs, ramps, pedestrian overpass, elevator areas and entrances, utilizing MBTA listed standard lighting fixtures attaining recommended illuminations levels for all the areas based on IES, APTA and MBTA guidelines.

All reasonable efforts must be employed to minimize light "spill" onto adjacent properties.

Fluorescent lamp lighting fixtures will be the primary lighting source used throughout 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

3.7.3 Emergency Lighting

Emergency lighting will be provided to permit passenger egress from the station during loss of normal power. Emergency lighting will be provided throughout the platform, stairs, ramps, pedestrian overpass, elevator areas, and entranceways. Emergency and egress lighting for these areas 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 platforms 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, ramps, pedestrian overpass, elevator areas and exits, so that the failure of any one unit will not leave any area dark or endanger persons leaving the platform. 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 days of capacity is provided. The MBTA standard is normally a several day capacity minimum.

3.8 Materials and Finishes

3.8.1 Performance Characteristics

Materials should be durable, easily maintained and well designed, employing the following guidelines. Special attention should be directed to strategies to avoid exterior rusting, detrimental contact of dissimilar materials, deleterious reaction to contact with salt, and use of field welded details. See Attachment 1 of this document for the MBTA design preferences for various building components and systems.

3.8.2 General

- Proven technologies
- Noncombustible
- Durable
- Low maintenance
- Reflective Lighting
- Type of materials should convey openness and transparency of the transit environment.
- All material shall comply with ADA guidelines
- Exterior Rain screen systems are recommended for exterior wall system.
- Weather resistant (freeze-thaw cycles).
- Integrate lighting and signage systems.
- Convey transit environment with respect to its surrounding.
- Mold resistant materials and proactive detailing to resist water penetration.

3.8.3 Floors

- High wear resistance.
- Materials which are consistent throughout their body.
- Low moisture absorption rate.
- Slip resistant ADA compliant.
- Non-stainable.
- All floors within the stations shall be cast in place concrete. Control joints shall be saw cut. Colored and/or etched surface treatments are permitted. The use of Carbon Black agents, to reduce glare, are encouraged. Minor areas of decorative materials are permitted with MBTA approval. Floor pours need careful execution to eliminate areas of ponding and reduce long term cracking.

3.8.4 Walls

- High impact and wear resistant finishes.
- Corrosion resistant.
- Low moisture absorption rate.

- In public areas, heavy gauge stainless steel panels and ceramic tile are recommended. Granite base at walls and at Headhouse glazing systems are indicated on the drawings.
- In Back of House areas, painted CMU is recommended.

3.8.5 Railings

- Picket style guard rail and hand rail assembly consisting of a rectangular-bar stock primary frame filled in with a smaller dimensioned field of rectangular bar-stock pickets.
- Hand rails to be 1 ½" diameter Heavy wall stainless tubing.
- The design intent is a railing system that is visually simple, minimal, and extremely strong and durable. Refer to drawings.
- All railing materials to be Grade 316 Stainless steel with #4 finish.

4 Mechanical and Electrical

Chapter 4

4.1 Mechanical

4.1.1 General

This section describes the design criteria to be used for the mechanical systems for the project. These requirements are intended to provide the performance based design criteria while allowing the Design Consultant the ability to be innovative during the final design and construction of the project.

4.1.2 Scope of Work

The scope of work specified in this section consists of: the design, preparation of plans and specifications; the furnishing, installation and construction; testing and commissioning of the mechanical systems and the other related ancillary facilities. The project mechanical systems include, but are not limited to, the following: heating/ventilating and air conditioning (HVAC), plumbing and drainage, and fire protection systems as deemed necessary for this project.

4.1.3 General Administrative Requirements

4.1.3.1 Codes, Standards, Guidelines and References

The mechanical systems shall be designed in accordance with all applicable MBTA Standards, American Society of Heating, Refrigerating, and Air Conditioning Engineers (ASHRAE) standards, National Electrical Code (NEC) Standards, NFPA standards and the Massachusetts Building Code. Other standards included by reference also are applicable, and the most stringent criteria shall govern where differing requirements exist.

4.1.3.2 Coordination Meetings

Coordination meetings for design, construction, fire/life safety and other issues will occur as necessary throughout the design and construction of the project. These meetings may include the following participants: State Fire Marshal's Office, Municipal Fire Departments, Water & Sewer Departments, Fire Rescue Departments, Police Departments, Telecommunications, other state & federal environmental agencies, and other agencies as necessary, and may supplement listed criteria.

4.1.4 Mechanical Systems for Facilities

This section establishes the design and construction criteria to be used for the mechanical systems including HVAC, plumbing & drainage, and fire protection systems, as required for the project facilities.

The mechanical systems shall be designed in accordance with all applicable MBTA Standards, ASHRAE standards, NEC Standards, NFPA standards, and the Massachusetts Building Code. Other standards included by reference also are applicable MBTA Standards, and the most stringent criteria shall govern where differing requirements exist.

The facilities mechanical systems shall include a Life Cycle Cost Analysis as required per Massachusetts Energy Modeling Program. The design of the HVAC systems shall place an emphasis on energy conservation and the energy consumption and efficiency requirements of the Massachusetts Building Code shall be met.

4.1.4.1 Space Design Requirements

Table 4-1 is a guide for the application of HVAC systems for types of ancillary spaces anticipated for the project.

Table 4-1 Space Design Requirements

Space Description	Heating	Ventilation	Air Conditioning	Other
Battery Rooms		X		
Electrical Equipment Rooms		X	2	
Fire Pump Room	X	X		
Generator Room		X		
Janitor Rooms	X	X		
Mechanical Equipment Rooms	X	X		
Pump Control/Utility Rooms	X	X		
Pump Stations	X	X		
Switchgear Room	X	X	2	
Toilet Rooms	X	X		
UPS Room	X	X		
Workshop/Storage Room	X	X		

Notes

1. Qty of air changes shall be determined based upon the Massachusetts Building Code requirements and occupancy either by personnel or equipment within the space.

2. Ventilation or air conditioning as required maintaining a maximum temperature of 104 ºF within the space.

3. The Contractor shall coordinate with the MBTA's to determine and confirm that the MBTA's Control room systems and equipment can meet the environmental requirements of the Contractor's control room equipment that will be located in the MBTA's Control room.

4. The table above represents general room types. Final design may not require use of all room types.

4.1.4.2 Environmental Design Criteria

The following ambient outdoor design conditions shall be used and are based upon the Climatic Design Information provided by ASHRAE Handbook, Fundamentals, 2009 Edition for Boston's Logan Airport location. The data assumes 0.4% summer and 99.6% winter, annual frequency of occurrence.

- Summer design dry bulb temperature: 90.8 ºF
- Summer design wet bulb temperature: 73.3ºF
- Summer average daily temperature range: 15.3ºF
- Winter design dry bulb temperature: 7.4ºF
- Ambient barometric pressure: 29.7" Hg

The following indoor design conditions shall be used:

Summer season/air conditioned spaces:

- Control rooms: 72 ºF db, 45% relative humidity (RH)
- Electrical rooms: 104 ºF db maximum

- Battery rooms: 88 ºF db
- Equipment/storage/janitor rooms: 104 ºF db
- Toilets rooms: Ambient Temperature

Summer season/ventilated spaces:

- Pump stations: 104 ºF db

Winter season:

- Control rooms: 70 ºF db, 45% RH
- Electrical rooms: 55 ºF db
- Battery rooms: 55 ºF db
- Equipment/storage/janitor rooms: 55 ºF db
- Toilets rooms: 70 ºF db
- Pump Stations: 55 ºF db

4.1.5 Heating, Ventilating and Air Conditioning (HVAC) System Duct Design

4.1.5.1 General Requirements

Sheet metal ducts in the building HVAC system shall be constructed of lock formed quality galvanized steel with joints that are air tight. Duct gauges and fabrication methods shall comply with the Sheet Metal and Air Conditioning Design Consultant's National Association, Inc. (SMACNA) Duct Construction Standards Metal and Flexible as applicable. The ducts shall be sized by the static regain method or for an equal pressure drop of not more than 0.10 in wg per 100 foot of duct.

4.1.5.2 Fire Dampers

Fire dampers shall be provided in ducts passing through fire rated partitions or walls. Fire dampers shall be Underwriters Laboratories (UL) listed. Fire dampers shall be the automatic operating type accepted for the protection of openings in the fire rated walls and partitions. Automatic dampers shall be dynamic and 2-hour or 3-hour rated as required by code.

4.1.5.3 Supply Air Registers and Diffusers

The supply air registers and diffusers shall be selected to provide the required throw and spread with the least amount of draft and noise. Registers shall be provided with adjustable and double deflection louvers and opposed-blade adjustable volume dampers. Ceiling diffusers shall be square, rectangular, circular or linear type with adjustable throw opposed-blade adjustable volume dampers. The volume dampers shall be key operable through the face of the diffuser.

4.1.5.4 Exhaust and Return Grill and Registers

Exhaust and return air grills and registers shall be equipped with fixed non-see-through blades or louvers.

4.1.5.5 Deflectors

Deflectors shall be provided in all duct mounted supply outlets, takeoff or extension collars to supply outlets. Air deflectors shall be factory fabricated and factory or field-assembled units.

4.1.5.6 Louvers

Louvers shall be provided for installation in exterior walls. Louvers shall be double draining, storm-rated type, designed in accordance with the requirements of Air Movement and Control Association (AMCA) Standard 500-L, latest edition. Louver blades shall be fabricated from anodized aluminum or galvanized steel sheets and protected with a weather-resistant protective coating. Louvers shall be provided with bird screens.

Elbows shall have full centerline radius of at least 1-1/2 times the width of the duct. Where full radius curves are not feasible, elbows shall be provided with single wall turning vanes.

4.1.5.7 Variable Air Volume Terminals

Variable volume, single duct, low and medium pressure terminal units shall be provided with a calibrated air volume sensing device, damper, actuator and accessory relays. Units shall control air volume to within 5 percent of each set point volume.

4.1.6 Heating Systems Design

Electric unit heaters shall be provided to heat individual spaces. The heaters shall be the industrial type and shall meet all the requirement of the National Electrical Code (NEC). The heaters shall be UL listed. Suitable stationary or rotating air deflectors shall be provided to assure proper heat distribution. The electric unit heaters shall be provided with a built in or surface mounted high limit thermostat interlocked electrically so the heater cannot be energized unless the fan and fan motor are running. The heaters' operation shall be controlled either by a built in or remote thermostats and have protective devices as required by the NEC.

4.1.7 Ventilation System Design

Ventilation systems shall be provided where necessary to maintain the desired environment for equipment operation and maintenance personnel. The system shall consist of air supply and/or exhaust fans and ductwork as required. Ventilation systems shall incorporate duct systems as appropriate and shall consider nearby intake/exhaust areas, neighboring facilities, and maximum sound levels permitted in the area. Fan ratings shall be based from test performed in accordance with the test code of the Air Movement and Control Association (AMCA) and shall bear the AMCA label.

4.1.8 Air Conditioning System Design

Air conditioning systems shall utilize distribution ductwork when not providing spot cooling for Electrical/IT or Elevator Machine Rooms. The use of wall or window air conditioning units is not acceptable. Console floor mounted units with outdoor air capabilities shall be acceptable at manned booths. Air conditioning units shall be capable of operating from the minimum outside air required to 100% outside air. The air conditioning equipment shall be capable of managing low sensible cooling loads at high humidity conditions. As such, air conditioning systems shall be provided with pre-dehumidification of any outside air. Variable air volume systems may be used where appropriate. The air conditioning unit cooling capacity shall meet the sensible and total heat requirement for the areas served by the unit. The air conditioning units shall be selected to maintain the space environmental design temperature, humidity, and air change requirements. The units shall be selected to produce the required air volume at the fan total pressure.

The air handling units shall include a fan/coil section, mixing box, pre-dehumidification coil, dampers, filters condensate drip pan, and the appurtenances for heating and dehumidification. The air filters shall be replaceable, 4" nominal thickness with an efficiency of 25-30% based upon ASHRAE standards. The filter rating shall be based upon a velocity of 500 feet per minute and an initial pressure drop of 0.25 in wg. The air filter material shall have a UL Class 1 rating.

The condensing unit shall be of the air cooled type, self-contained, complete with casing, fans, heat rejection coils and accessories, ready for full capacity operation. Split packaged units shall be provided with all interconnecting refrigeration piping, electrical power and control wiring between the condenser and the evaporator units.

4.1.9 Fuel Oil Storage, Transport, and Leak Detection

The Contractor shall install a fuel oil storage system using a direct buried double-walled fiberglass tank complete with fill and inspection ports. A fuel oil transport system shall include transfer pumps to be controlled off of the generator's day tank level controls. A fuel oil leak detection system shall be supplied for both the tank and piping systems.

4.1.10 HVAC Systems Construction

The HVAC systems shall be procured installed and constructed in a complete manner and shall include all of the components necessary to provide a complete and operable system that is in accordance with the criteria specified in this performance specification. The HVAC systems include, but are not limited to, fans, filters, sound attenuators, air conditioners, air handling units, unit heaters, associated piping, cabling, wiring, conduits, inlets, control systems, equipment, miscellaneous appurtenances, hardware, etc., and other components systems as necessary. The HVAC system must be installed and constructed with the requirements of other related performance specifications as applicable that are a part of the Contract Documents.

4.1.11 HVAC Systems Commissioning

The commissioning plan shall consist of individual equipment performance and quality assurance tests, as well as a complete installation testing and commissioning plan that assures that the system functions and operates as intended. This shall be submitted to the MBTA for review prior to commencement of any testing.

4.1.12 Plumbing and Drainage

The plumbing and drainage shall be designed in accordance with the requirement of the Massachusetts State Building Code. The plumbing systems shall be capable of supplying the required quantity of domestic (hot and cold) water for the various utilities, provide disposal of sanitary waste and storm water, and shall include any sanitary water treatment if necessary. The plumbing system shall include various plumbing fixtures, piping, valves, backflow preventers, water meters, hose bibs, strainers, domestic water heaters and other accessories as needed for a complete and operable system that meets the Massachusetts State Building Code requirements and the requirements of the State Plumbing Inspector. Prior to completion of the construction documents, a meeting with the State Plumbing Inspector is required.

4.1.13 Plumbing and Drainage Construction

The plumbing and drainage systems shall be procured, installed, and constructed in a complete manner and shall include all of the components necessary to provide a complete and operable system that is in accordance with the criteria specified in this performance specification. The plumbing and drainage system include, but are not limited to, piping, hangers, brackets valves fittings, pumps, plumbing fixtures, equipment, miscellaneous appurtenances, hardware, etc., and other components systems as necessary. The plumbing and drainage must be installed and constructed with the requirements of other related performance specifications as applicable that are a part of the design criteria documents.

4.1.14 Plumbing and Drainage Commissioning

The commissioning plan shall consist of construction inspections and quality assurance tests, as well as a complete installation testing and commissioning plan that assures that the system functions and operates as intended. This shall be submitted to the MBTA for review prior to commencement of any testing.

4.1.15 Fire Protection Systems

The design, construction and testing of the fire protection systems for the ancillary facilities are subject to the review and approval of the Massachusetts State Fire Marshal's Office. Prior to completion of the construction documents, a meeting with the local fire department is required to review the design approach.

The facility fire protection systems shall be comprised of sprinkler and standpipe systems, clean agent systems, and portable fire extinguishers.

4.1.15.1 Sprinkler and Standpipe Systems

The standpipe and sprinkler systems for the buildings and facilities shall conform to the requirements of NFPA 13, NFPA 14, and the Massachusetts Building Code. Ancillary Building/Facility sprinkler systems shall include at a minimum, the following components: main water supply; fire department inlet connections; piping from inlet connections and water supply mains to the sprinkler heads; sprinkler heads (including spares); drain lines; provisions for remote alarm devices; pipe fittings; valves; hangers; inserts; sleeves; and appurtenances as necessary to provide a complete, code compliant, and functional system. Flow switches shall be provided with suitable outputs to facilitate remote monitoring of water flow in the systems. Supervisory and/or alarm monitoring outputs shall be monitored remotely at the local and remote operations support facilities. The fire department hose connections shall be approved by the City Fire Department. The capacity of the connected water supply must be adequate for the supply of only the sprinkler portion of the fire protection systems.

4.1.15.2 Clean Agent Systems

Clean agent fire suppression systems shall be provided for communications rooms, and critical electronic equipment rooms. The system shall be provided in accordance with the requirements of NFPA standards 72 and 2001, and the Massachusetts Building Code.

The system shall include discharge nozzles, control panels, extinguishing agent containers, detection devices, manual release stations, alarm devices, and piping. The clean agent shall be supplied from high pressure storage cylinders that are manifolded. The system shall include reserve cylinders with 100% spare supply of gas and a main to reserve switch to ensure uninterruptible protection. All elements of the system shall be UL listed or Factory Mutual Research Corporation (FM) approved.

Should special conditions exist that may adversely affect the extinguishing efficiency (such as unclosable openings, etc.), additional quantities of the clean agent shall be provided to compensate for these factors. Activation of the clean agent systems shall be by cross zoned smoke detectors installed in the protected space. Activation of a single detector shall result in an alarm but shall not cause a clean agent discharge. Two detectors installed on separate electric circuits shall be activated in order to cause clean agent discharge. Prior to clean agent discharge, all HVAC systems and fans serving the protected area shall automatically shut down and all HVAC dampers shall be closed.

Protected rooms shall be provided with audio/visual alarms and signs to warn occupants of the suppression system operation and the necessity to evacuate the room immediately. Each clean agent system shall be equipped with a time delay evacuation relay to allow personnel sufficient time for evacuation. The system shall include emergency backup power. Upon loss of the normal power, the system shall automatically transfer to a standby battery. The battery shall be sized for 24 hours of supervision and be capable of discharge and operation of all alarms for 15 minutes at the end of the 24 hour standby period.

A minimum of two cabinet enclosed, self-contained breathing apparatus, each with a 30 minute air supply shall be provided immediately outside of the rooms protected by the clean agent fire suppression system.

4.1.15.3 Fire Extinguishers

Portable fire extinguishers shall be provided for each space in accordance with the requirements of NFPA Standard 10, and the Massachusetts Building Code.

4.1.16 Fire Protection Systems Construction

The ancillary facility fire protection systems shall be procured installed and constructed in a complete manner, and shall include all of the components necessary to provide a complete and operable system that is in accordance with the criteria specified in this performance specification. The ancillary facility fire protection systems include, but are not limited to, fire pumps, piping, sprinklers, hangers, miscellaneous appurtenances, hardware, etc., and other components systems as necessary. The ancillary facility fire protection systems must be installed and constructed with the requirements of other related performance specifications as applicable that are a part of the design criteria documents.

4.1.17 Fire Protection Systems Commissioning

The commissioning plan shall consist of individual equipment performance and quality assurance tests, as well as a complete installation testing and commissioning plan that assures that the system functions and operates as intended and in accordance with all applicable codes and standards. This shall be submitted to the State Fire Marshal and the MBTA for review and approval prior to commencement of any testing.

4.2 Electrical

4.2.1 General

This section describes the design criteria to be used for the electrical systems for the Green Line Extension project. These criteria are intended to provide design requirements.

The basic design criteria for the electrical systems to be installed for the Green Line Extension project address the following:

- Utility services
- Primary distribution system
- Transformers
- Utilization voltage switchgear
- Panelboards
- Motor controls
- Standby power system
- Uninterruptible power supplies (UPS)
- Grounding systems
- Building lighting
- Lighting controls
- Exterior lighting
- Outlets and receptacles
- Power to surveillance and control system (TSCS) equipment
- Power to 'Charlie' Card Systems
- Wire and raceway systems
- Underground raceway systems
- Lightning protection
- Power factor correction
- Communications systems (telephone, radio systems)
- Fire alarm and detection systems

- Intrusion detection and access control
- Provision for supervisory control and data acquisition (SCADA) Requirements
- Passenger Information Systems (Public Address, Variable Message Signs)
- CCTV System cameras and locations
- Fare Collection Systems (Fare Vending Machines, Fare Gates)
- Vehicle Maintenance Facility Communications and Security Systems
- Miscellaneous systems

4.2.1.1 Codes, Standards, and Specifications

The electrical systems shall be designed in accordance with all current applicable MBTA Standards, ASHRAE standards, NFPA standards and the Massachusetts Building and Electrical Codes. Other standards included by reference also are applicable, and the most stringent criteria shall govern where differing requirements exist.

4.2.1.2 Service and Utilization Services

Electrical energy for the project will be obtained from the local electric utility or MBTA sources where applicable.

4.2.1.3 Design Calculations

The design calculations prepared shall be checked and include: purpose, basis, references, methodology, and example use of equations, data, results, conclusions, and summary. The calculations shall be submitted to the MBTA for review and comment. This requirement shall apply to both manual and computer generated calculations.

Documentation of computer programs used in the preparation of calculations shall also be submitted to the MBTA. Documentation shall include, as a minimum:

- Verification procedures and test cases
- Description of limitations and intended use
- Algorithms used as basis of calculations
- Utilization procedures

The design of the electrical systems and the selection of circuit interruption devices shall be fully coordinated throughout and include ARC-flash analysis with equipment labeling. Design calculations shall include the preparation of coordination curves for all power distribution systems from point of service to each panel and motor control center.

4.2.1.4 Temporary Power and Lighting

Temporary power and lighting shall be designed for project buildings, and structures. This design shall be complete, to include equipment, raceway, and cable, and shall conform to all applicable electrical and safety codes.

4.2.1.5 Coordination of Design

The design of the electrical systems shall be coordinated with the design of other disciplines as necessary, such that the design performance and assumptions are not compromised, impacted, or degraded by the interaction with other systems.

4.2.2 Electrical Distribution System

Electrical power for the passenger stations will be supplied by the local electric utility or MBTA sources at these locations, through secondary feeders operating at 480/277 volts. The electric utility will provide the service cables and duct systems to designated interface locations. All design Work relating to the utility services shall be performed in accordance with the prevailing electric utility requirements. The back-up service to the stations will be via diesel fueled generators, through automatic transfer switches, at each location.

For the yard and shop areas, the load(s) will be served from two independent medium voltage utility circuits, via double-ended substations, which transform the voltage down to 480/277V. Both the primary and secondary busses will be of the main-tie-main configuration, assuring essentially uninterrupted power, except for the automatic switch-over time.

4.2.2.1 Specific Design Calculations

Design calculations shall be provided to the MBTA in sufficient detail to permit evaluation of the specified electrical equipment and the systems' designs. Design calculations shall include, but not be limited to, the following:

- Load evaluations for switchboards, panelboards, motor control centers, and transformers
- Fault current calculations as a basis for selection of circuit interruption devices and electrical equipment withstand ratings.
- Overcurrent protective device short-circuit study
- Incoming and feeder wiring selection
- Power factor evaluations and power factor correction selection basis
- Relay and overcurrent device settings and coordination curves
- ARC-flash analysis
- Voltage drop calculation
- Harmonic analysis

4.2.3 Secondary Distribution Systems

This section establishes the basic design criteria for secondary distribution systems, i.e. electrical distribution systems operating at a voltage level of 480/277or 208/120. Included herein are the criteria for utilization voltage switchgear, panelboards, motor controls, outlets and receptacles, raceway systems and wiring.

4.2.3.1 480/277 Volts Switchboard

480/277 Volt switchgear shall consist of circuit breakers positioned in a metal-enclosed, free-standing enclosure together with all associated meters, relays, instrument transformers, heaters, control power transformers, breaker handling mechanism, and other accessories as required to provide a complete and operable switchboard assembly. Main-tie-main circuit breakers shall be draw-out type. Switchboard bus shall be fully rated copper.

The switchboard shall comply with the latest applicable standards of ANSI, National Electrical Manufacturers Association (NEMA) and Institute of Electrical and Electronic Engineers, Inc. (IEEE). Provisions shall be included in the design to accommodate the required SCADA functions of remote operation of selected breakers, and remote monitoring and alarming of electrical system conditions and breaker positions.

Electrical interlocks shall be provided as required to fulfill operational conditions. In addition, mechanical interlocks shall be provided to ensure personnel safety under all conditions of operation and maintenance. Indoor switchboards shall be installed within an area of the building set aside for electrical switchboards and assured of a supply of filtered air, free of excessive moisture, to maintain an ambient temperature of 40 degrees Centigrade (104 degrees Fahrenheit) or less.

4.2.3.2 Panelboards

Panelboards for 480/277 Volt AC, 208/120 Volt AC, and 250/125 Volt DC services shall be circuit breaker type. The interrupting rating of the breakers shall be selected so as to safely interrupt the calculated fault currents. Type of enclosure shall be suitable for the installation environment. Circuit directories shall be provided for each panelboard. Panelboards located within architecturally finished spaces shall generally be flush mounted; panelboards located within unfinished spaces may be either flush or surface mounted. Panelboard bus shall be fully rated copper.

4.2.3.3 Motor Controllers and Control Devices

Solid-state or reduced voltage starters shall be provided for larger horsepower poly-phase motors where the minimum voltages on buses serving motor loads will, during start, otherwise decrease below 80 percent of the voltage before the motor starts.

Starters shall generally be grouped in floor mounted NEMA 1 or 12 assemblies of one or more metal enclosed vertical sections having a horizontal common power bus and principally containing combination motor control units (starters), identified by the industry and NEMA Standards as "Motor Control Centers." The motor control center(s) shall be installed within an interior area provided with sufficient filtered air, free of moisture and dirt, to maintain an ambient temperature not in excess of 40 degrees Centigrade (104 degrees Fahrenheit).

When used with a pressure, float or similar automatic type control device or maintained contact switch, the controller shall be provided with a "HAND-OFF-AUTO" selector switch. Connections to the selector switch shall be such that only the normal automatic regulatory control devices will be bypassed when the switch is in the "HAND" Position. All safety control devices, such as low and high pressure cut-outs, high temperature cut-outs, and motor overload protective devices, shall be connected in the motor control circuit in both the "HAND" and the "AUTOMATIC" position. Provisions shall be included in the design to accommodate the required SCADA functions associated with motor controls.

4.2.3.4 Dry – Type Distribution Transformers (600 volts and below)

Transformers shall be UL listed, two winding, low voltage, dry type suitable for indoor application and step down of the primary 480 Volts to a 208Y/120 Volt secondary level. Transformers shall generally be provided with a NEMA 1 enclosure. However, the enclosure shall be compatible with the installation environment. Transformer winding shall be copper.

4.2.3.5 Power and Convenience Outlets

In general, buildings shall be provided with a sufficient number of convenience type receptacles spaced around the perimeter of the interior walls, mounted on columns or otherwise located in such a manner as to meet the power requirements of portable equipment such as small hand tools, drop lights, vacuum cleaners, small blowers, small pumps, supervisory equipment, etc., connected to a 50 foot maximum length portable cord.

Outlet receptacles shall be heavy grade with stainless steel covers.

4.2.3.6 Raceway Systems

Wiring within structures for power, control, indication, alarm and lighting systems shall be installed in metal raceways for physical protection as described below. The basic raceway system shall be conduit, either exposed or embedded. Other raceway systems, such as cable trays or heavy duty wireways, may be used where application of these systems is more economical, provides a better means of cable protection or support, or is otherwise required due to physical constraints or equipment layout. Raceway systems are addressed later in this document. Rigid galvanized steel conduit shall be used for all runs embedded in floor or ceiling slab and for exposed conduit runs, indoor and outdoor, where there is a potential for physical damage. Liquid-tight flexible metal conduit shall be provided for final connections to recessed lighting fixtures and equipment subject to vibration, noise transmission or movement. Fiberglass reinforced epoxy (FRE) type rigid non-metallic conduit shall be used for installations below grade and below ground floor slab. Conduit below grade and below floor slab shall be encased in a minimum of two inches of concrete. FRE conduit shall be connected to rigid steel conduit before rising through floor slab.

Conduit runs within finished areas shall be concealed in floor slab, walls, ceiling slab or hung ceilings. Wiring devices shall be flush mounted. Embedded conduit runs for power and lighting shall be one inch minimum. Embedded conduit runs for signal and control wiring shall be 3/4 inch minimum. Spare sleeves shall be capped with a suitable fire rated material and identified on the drawings. Empty conduits shall be provided with plastic pull wire having not less than 200 pound tensile strength. Embedded conduits crossing expansion joints shall be provided with suitable watertight expansion fitting(s) and bonding jumpers.

Cable trays may be provided in lieu of conduit predominantly for installation of multi-conductor control cables in locations such as substations, mechanical equipment rooms, and electrical equipment rooms. Cable trays shall not be used for installation of medium voltage wires and cables in any location, nor shall they be used for installation of 600 volt wires and cables.

4.2.3.7 600 Volt Wires and Cables

All conductors shall be copper. Conductors No. 10 AWG and smaller may be solid; No. 8 AWG and larger shall be stranded. Minimum size conductors shall be No. 12 AWG for feeders and branch circuits; No. 14 AWG for control, signal, and alarm circuits, and for fixture wire.

All wire and cable shall pass the flame propagating criteria of IEEE 383. For purposes of design, the ambient temperature shall generally be assumed to be 30 degrees Centigrade. Where maximum ambient temperatures may exceed 30 degrees Centigrade, the current carrying capacity of the cable shall be de-rated accordingly.

Branch circuit wiring from lighting panels shall consist of wiring from the panels to terminal pull boxes and then to the lighting fixtures. Branch circuit wiring from a lighting panel to a terminal pull box shall not exceed No. 1 AWG. Wiring from the terminal pull box to the lighting fixtures and within lighting fixture raceways shall be No. 10 AWG.

Transducer output wiring shall be twisted pair, shielded cable, meeting the requirements for sound, communications and instrumentation wiring applications. Wiring for the following low voltage systems shall be as defined in the design criteria for each of the respective systems:

- Fire detection and alarm systems
- Communications systems
- Surveillance and control system (TSCS)

4.2.4 Standby Power Systems

This section establishes the basic design criteria for providing standby power from engine generators to selected loads to ensure continued operation if all normal utility power fails. The provision of uninterruptible power supplies (UPS) for selected loads that would be adversely affected by even a momentary switching outage is covered in "Uninterruptible Power Supplies."

The standby power systems shall consist of standby generators, switchboards, transfer switches, fuel supply and storage, accessories, and wiring as required providing standby power to the following loads, as a minimum.

- Egress stair lighting*
- Drainage system
- Fire protection pumps

- TSCS equipment*
- Communications, supervisory control and data acquisition, and fire detection and alarm systems*
- Signal Systems
- Selected building lighting*
- Selected receptacles in switchboard rooms, generator rooms, mechanical rooms, rest rooms, stairways, and offices.

(*- Systems also provided with battery-supported UPS for which standby power will provide long term backup.)

System design shall be based upon ANSI/IEEE Standard 446 and the criteria defined herein.

UPS units shall be connected to draw power from a standby source if normal power fails. Standby power switchboards may be located in the same room as the generators, such room to be provided with adequate ventilation and relatively dust free air. Transfer switches shall be located where it is most advantageous based upon access for operation, economic reasons, and other governing factors. Transfer switch shall be connected to SCADA System.

4.2.4.1 Standby Generator Units

Standby generators shall be gas fired. Diesel Engine Driven Generators will not be allowed. Generator output shall be 480/277 Volts, 60 Hertz, three phase, four wire, and kW capacity as determined by the design calculations. Both prime mover and the generator shall be capable of operating satisfactorily while supplying a load ten percent in excess of the net continuous rated generating capacity for two continuous hours out of any 24 consecutive hours. The rated net capacity for each standby generating unit shall be defined as the gross electrical power output of the generator minus total electrical power requirements of electric motor driven engine accessories included on the engine assembly.

In general, one standby generator at each facility should be sufficient to supply the load.

The system shall conform to NFPA 30 and NFPA 37. Fuel type shall be such that exhaust emissions comply with environmental standards. If located within a building, the cooling system shall be designed to discharge heat outside of the building within which the standby generator is to be installed. The generators shall be provided with appropriate silencers.

The design shall provide a means for periodic testing of standby diesel-generators at a minimum load equal to at least 40 percent of the generator nameplate kW rating. Loading may be achieved either by providing for means of applying normal/standby loads to the generator output, or by operating a load-bank provided for that purpose. Generators shall be designed to start up and be capable of accepting applied load within 10 seconds after initiation of start-up. The prime mover shall be started electrically, drawing power from a starting battery which shall serve no other purpose than engine starting. Standby generators shall be designed to start up by either manual initiation or automatically. The loss of normal power at the automatic transfer switch shall cause the associated standby generator(s) to start up automatically and assume the load if the normal power interruption continues. Where required, loads shall be arranged for sequential starting.

Automatic transfer switches shall be mechanically held, electrically operated by a single-solenoid mechanism energized from the source to which the load is to be transferred. They shall conform to UL 1008 and be rated for all classes of loads when installed in an unventilated enclosure. Accessory features shall be selected to best suit each application. The units shall be provided with manual bypass-isolation switches. Automatic transfer switches shall include neutral poles with "make-before-break" operating characteristics. Grounding shall be in accordance with MEC requirements.

4.2.4.2 Standby Switchboard

480/277 Volt standby switchboard shall be indoor type, metal-enclosed, self-supporting structure. Switchboard shall be of compartmentalized design with individually mounted devices in the distribution sections. It shall accommodate the various low voltage protective devices, such as molded case circuit breakers and draw-out type air circuit breakers together with all associated meters, relays, instrument transformers, control power transformers and other accessories to provide a complete and operable assembly. The switchboard shall comply with all applicable provisions of UL 891 and NEMA PB-2. Switchboard bussing shall be fully rated copper.

Design for the standby power systems shall include the auxiliary devices (transducers, contacts, interposing relays, etc.) necessary to interconnect the required monitoring, control and alarm functions to the SCADA system.

4.2.4.3 Specific Design Calculations

Design calculations of expected emergency and standby loads shall be prepared allowing an additional percentage for future loads. Design calculations shall be prepared for sizing the standby generator taking into account non-linear loads and "worst case" starting sequence of large motors. Design calculations shall also be prepared for the following:

- Selection and sizing of automatic transfer switches with fault current evaluations;
- Generator starting and running load evaluations;
- Battery and battery charger sizing;
- Relay settings and coordination curves;
- Fuel consumption/capacity evaluation including day tank duration and transfer pump capacity.

4.2.5 Uninterruptible Power Supplies

This section establishes the basic design criteria for the application and selection of uninterruptible power supplies (UPS) for selected loads. UPS units shall provide uninterruptible electrical power to designated loads. The following are typical loads that are connected to UPS systems:

- Communications, supervisory control and data acquisition system, access control, CCTV cameras and systems, fare collection systems and fire detection and alarm systems
- Selected utility room, and egress lighting
- Selected building lighting

Without exception, the "normal" electrical power service to loads which are provided with UPS shall be backed-up by a "standby power system" as described under “Standby Power Systems” preceding. The UPS units shall be designed to operate "on line" such that when normal power fails, the batteries will provide power for a designated period through the inverter output. If a UPS malfunctions, a static switch shall automatically connect the load directly to the normal supply while simultaneously opening the inverter-output circuit breaker. A maintenance by-pass shall be provided to manually transfer the load to the normal supply for routine service or maintenance of the UPS.

The UPS shall be sized for the specific type of connected loads including non-linear loads. Individual dedicated UPS shall be provided for lighting, building TSCS equipment, and roadway TSCS equipment. Harmonic distortion of the output wave form from the UPS shall be less than the maximum harmonic distortion acceptable to the equipment served. Each UPS storage battery shall be of the sealed, maintenance free type, and have sufficient capacity to supply rated output for the designated period following loss of "normal" power. The UPS equipment enclosure shall be suitable for the environment in which it is to be installed, recognizing that heat buildup and moisture act to diminish the reliability of a UPS unit.

UPS units shall, wherever feasible, be located in spaces which are relatively dry and adequately ventilated with clean air. This criterion must be weighed against the desirability of locating UPS units as close as possible to the load served, so as to reduce to a minimum the length and exposure of DC wiring and the UPS output wiring. Provision shall be made for the required monitoring, control and alarm functions to the SCADA system.

The UPS system shall provide power during those periods which the other power sources are unavailable or unstable. The UPS systems shall be sized accordingly for approximately 20-30 minutes.

4.2.5.1 Specific Design Calculations

Design calculations shall be prepared for each UPS application. The calculations shall establish the UPS rating, and battery size, battery charger size, and also identify significant parameters affecting the proper selection of the UPS unit for the intended load.

4.2.6 Grounding and Lightning Protection

This section sets forth the basic criteria for systems and equipment grounding and lightning protection provisions to be incorporated into the design.

Each substation and electrical load center shall be grounded to provide safety for personnel and to provide fast, reliable relaying. Grounding shall be coordinated with corrosion control requirements.

4.2.6.1 Systems Grounding

480 Volt, three-phase, 60 Hertz systems supplied from 480/277 Volt transformers shall have the transformer neutral solidly grounded at the transformer per NFPA 70.

480/277 Volt three-phase, four-wire systems shall be solidly grounded at their source (transformer secondary, standby generator neutral, or UPS neutral) per NFPA 70.

208/120, Volt three-phase, four-wire systems shall be solidly grounded at their source (transformer secondary or UPS neutral) per NFPA 70.

A connection of the system to earth shall be provided at each substation. The connection to earth shall have a sufficiently low resistance to permit prompt operation of the circuit protective devices in the event of a ground fault, and to provide the required safety from shock to personnel who may be in the vicinity of equipment frames, enclosures, conductors, or the electrodes themselves. The connection to earth shall consist of a number of individual driven ground rods connected together by buried, bare, stainless steel conductors, or driven ground rods connected to a grid system. The grid system shall consist of buried conductors forming a network of squares or rectangles. Buried conductors shall be interconnected at each crossover point by an exothermic welding process. The ground grid shall be connected to ground rods as required. Grids shall be buried in filled trenches or laid on earth and overlaid with at least 18 inches of backfill. Grid locations shall be coordinated with underground utilities and sewer installations to avoid any direct electrical connection to these systems. The connection to earth shall be designed in such a way that the system resistance measured at the main ground bus in the switchgear room will not exceed 2 ohms.

4.2.6.2 Equipment Grounding

The equipment grounding system shall be interconnected by means of equipment ground conductors to a ground bus in each distribution equipment enclosure such as switchboard, panelboard, motor control center and load center. Every feeder, circuit and branch circuit shall contain an equipment ground conductor within the same raceway with the phase and neutral conductors. The equipment ground conductor shall be 600 Volt insulated copper, sized to comply with applicable code requirements. The equipment ground conductor shall be continuous throughout the system, connecting all non-current carrying enclosures, building structural grounds, and equipment and machinery grounds.

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

Building steel structures shall be grounded at each column base and jumpers provided for, if required, maintaining ground continuity throughout.

The grounding lugs of exterior lighting poles, bases, and luminaires shall be connected to the system and local grounding conductors.

4.2.6.3 Grounding for Personnel Safety

Grounding for personnel safety shall be provided to minimize shock hazards as follows:

All exposed structural metalwork such as doors, handrails within reach of electrical equipment (5'-0"+), and all stairways shall be bonded to the nearest local ground bus.

In all manholes, handholes, and pull boxes, the ground conductors shall be connected to all exposed metal surfaces including cable racks, frames and covers, and ladders. In addition, in manholes and handholes, a ground conductor shall further be connected to the ground mat installed in the base of each manhole and handhole or to a local ground electrode for the express purpose of providing for personnel safety. Where the ground mat or local grounding electrode cannot be installed, a bare grounding conductor coil looping around the manhole or handhole can be used as the local ground.

In remote electrical installations, exposed metallic structures such as fences, handrails, lighting poles and bases, luminaires, and equipment supports and enclosures shall be bonded and grounded to the grounding electrode system. Flexible jumpers shall be provided at gates to ensure continuity. Fences shall be grounded in accordance with the National Electrical Safety Code.

4.2.6.4 Grounding Equipment

Driven ground rods shall be sectional type 316 stainless steel rods, each 3/4-inch by 10 feet long, coupled and driven to the required total depth.

Buried grounding conductors used to form the ground grid or used to connect the individual ground rods shall be stranded type 316 stainless steel bare cable. Equipment and system grounding conductors shall be stranded copper covered with green 600 Volt insulation and be of minimum size in accordance with NFPA 70.

Ground bus shall be copper. Wall mounted grounding bus shall be copper bars, ¼” x 2”, mounted on insulators approximately 24 inches above the floor.

Ground connections of stainless steel cable to ground rods, stainless steel cable to building steel, and stainless steel cable-to-cable shall be exothermically welded. Ground connections of copper cable to copper cable or to building steel shall be brazed or thermite welded. Exothermically welded connections shall be coated with coal tar epoxy or equivalent waterproof coating to prevent corrosion of the connection.

Connections of ground cable to equipment ground lugs shall utilize two-bolt lugs.

4.2.6.5 Lightning Protection

Lightning protection systems and equipment shall be installed, where required, to provide protection of persons, equipment and facilities against the hazards posed by lightning. The lightning protection system shall comply with the requirements of a UL “Master Label System” and NFPA 78, “Lightning Protection Code.”

The placement of air terminals and routing of conductors shall consider appearance as well as protection requirements. Air terminals shall be placed to take advantage of any protection afforded by adjacent structural features. On a flat-top building protected by air terminals, all metallic parts and equipment projecting higher than the air-terminals, such as heating, ventilating, and air-conditioning equipment, shall be bonded to the lightning protection system.

4.2.7 Lighting Systems

This section establishes lighting design criteria for the ancillary exterior areas such as parking facilities, ramps, and walkways.

The following general requirements shall be incorporated in the design of the lighting for each area:

- The lighting system installation shall be designed to minimize initial capital costs, as well as, frequency and expense of maintenance.
- Lighting shall be designed to satisfy security requirements and to provide a pleasant environment.
- Lighting fixture locations shall permit accessibility for re-lamping and periodic cleaning.
- Any required illumination shall be arranged and wired so that the failure of any single lighting unit or circuit shall not leave the area in total darkness.
- Lighting shall be designed to avoid "spill" light and objectionable glare and light trespass.

Luminaires are required to be stainless steel whenever possible. Linear fluorescent luminaires shall include solid frame, gasketed vandal proof diffuses hinged on one side (i.e., not removable).

4.2.7.1 Illumination Levels

Minimum maintained illumination levels for various areas shall be provided as shown in Table 4-2, "Recommended General Illumination Levels". The normal method for calculating these levels shall be in accordance with the IESNA Lighting Handbook with modifications or other requirements stated in this section. The "Point-By-Point" method of computing illumination shall be used to verify or confirm illumination and uniformity levels.

Table 4-2 Recommended General Illumination Levels

Location Type	**Average Maintained Illumination Level** (Footcandles at the finished floor or unfinished grade)
Parking Lot Revenue Collection	20
Automobile Parking Lot	5
Outdoor Plazas	10
Bus Loading Zone	15
Pedestrian Walkways	10
Outdoor Entrance to Escalator Stairway	35
Passageways	40
Stairways and Entrances	45
Entrance Lobbies	55
Vending Machines	65
Fare Collection Array	65
Fare Collection Booth-continues dimming floor?	5-50
Platforms	55
Waiting Area - Interior	45
Waiting Area - Exterior	30
Starter's Room	40
Concession Area	40
Mechanical and Electrical Spaces	40
Toilets	40
Storage Rooms	25
Bus Parking	5
Task lighting at actual work station	100

Design calculations shall be prepared, for each area, space or room indicating luminaire types, mounting methods, height above finished floors or grade, lamp type, wattage and lumens, light loss factors, designed and actual number of fixtures, and all applicable surface reflectances (wall, floor, ceiling).

4.2.7.2 Lighting Fixtures and Control

The building lighting system(s) shall be designed to incorporate all available energy conservation measures. These shall include, but not be limited to, the use of the most energy efficient lamps and ballasts, point of use controls and, in areas where applicable, occupancy sensors. Lighting controls shall provide means to automatically turn off 30% of station interior lighting between hours of 01:00 to 05:00. Occupancy sensors are not permitted in public spaces; time clocks are to be used for control of luminaires in public areas, including sidewalk and parking lot areas.

4.2.7.3 Fluorescent Industrial

Fixtures shall be ceiling or pendant mounted industrial type fluorescent having porcelain enamel finish with a minimum reflectance of 90 percent, 10 percent maximum up-light component and equipped with low temperature electronic ballasts and 4000K T8 lamps.

The following descriptions define the luminaires that should be used:

4.2.7.4 Enclosed and Gasketed

Where required, fixtures shall be a ceiling mounted fluorescent type, enclosed and gasketed (vapor-tight) one piece injection-molded, high impact thermoplastic design. Luminaire to be equipped with low temperature electronic ballasts and 4000K T8 lamps. Two sources of power shall be provided for stairway fixtures.

4.2.7.5 Recessed/Surface

Fixtures shall be recessed or ceiling mounted commercial low brightness lensed fluorescent type, suitable for mounting in the ceiling being provided, equipped with prismatic, 1/8 inch thick virgin acrylic lens and energy efficient cool white lamps. In rooms where glare is an issue, use 3" deep parabolic 18 cell louvers. All luminaires shall include electronic ballasts and 3500K T8 lamps.

4.2.7.6 Emergency Lighting

Emergency lighting will be provided to permit passenger egress from the station during loss of normal power. The system shall utilize a select number of lighting fixtures provided as part of the general illumination and be connected to an uninterruptible power supply (UPS) system. Emergency lighting will be provided throughout the platform, stairs, ramps, pedestrian overpass, elevator areas, and entranceways. Emergency and egress lighting for these areas 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 platforms 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, ramps, pedestrian overpass, elevator areas and exits, so that the failure of any one unit will not leave any area dark or endanger persons leaving the platform. 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 days of capacity is provided. The MBTA standard is normally a several day capacity minimum.

4.2.8 Exterior Lighting System

Design of the exterior lighting system is based on providing a uniform nighttime illumination on the parking lot.

4.2.8.1 Design Illumination Levels

The design criteria shall meet both the illuminance and luminance design methods as defined in ANSI/IES RP-8-00. Using the illuminance method, the design level shall be not less than 0.6 and not more than 0.8 average maintained horizontal lms/ft^2 (6 to 9 lux) on the pavement surface. The minimum horizontal level at any point along the pavement surface shall be 0.2 lms/ft^2 (2 lux). Average to minimum illumination levels shall be no greater than 3 to 1.

Using the luminance method, the design level of the average maintained luminance shall be not less than 0.4 to 0.6 candelas/m^2. The ratio of average to minimum shall be no greater than 3.5 to 1, with a maximum to minimum luminance ratio of 6 to 1.

The ratio of veiling luminance to average pavement luminance shall not exceed 0.3 to 1 (for all pavement types). These values are based on an asphalt surface with dark aggregates which provides a moderately diffuse to specular reflectance's (AASHTO Road Classifications), and for the condition when the lamp is at or near the end of its rated life.

All lighting fixtures and pole placements, along with pole elevations must account for light trespass. As defined in IES-TM-11-00, the environmental zone classification for this project shall be considered to be "E2" such that a 0.3 lms/ft^2 pre-curfew limitation and a 0.1 lms/ft^2 post-curfew limitation are accounted for.

4.2.8.2 Lamps and Ballasts

In general, high pressure sodium lamps will be used. Lower wattage lamps shall be used where mounting heights are severely restricted. As a rule, the design is to utilize the fewest lamp types possible throughout the project.

Ballast shall be outdoor type, integral with the luminaire, and compatible with the lamp size and system voltage. Ballasts shall be high power factor and regulate the lamp wattage to plus or minus 2 percent at plus or minus 5 percent line voltage variation.

All fixtures shall include fusing and quick disconnect for ballast tray removal without the use of tools. Lamp sockets shall be porcelain enclosed, heavy duty, and anti-vibration type, with mogul bases only.

4.2.8.3 Luminaires – IENSA Distribution Types

Luminaires with IES Type I, II, III or IV, and full cut-off classifications for lateral and vertical light distribution/control shall be used for this project. Additional shielding may be required to control light trespass.

4.2.8.4 Poles, Foundations, Bracket Arms and Miscellaneous Hardware

Paint color or anodizing finish shall match the color of the galvanized steel pole finish selected by the Architects. Color galvanized steel poles shall be used for all exterior lighting systems. The exterior lighting system shall be carefully integrated into the overall design theme of the project.

Poles for at-grade shall be 30 feet nominal.

Pole foundations shall be reinforced concrete, with anchor bolts. They shall extend 36 inches above grade. All poles shall be provided with base vibration pads and internal vibration dampening devices. Bracket arms shall be the same material as the pole with standard 4'-0", 6'-0", 8'-0" or 10'-0" overhang.

Poles and foundations shall be designed in accordance with AASHTO Standards for wind loading in the Boston area.

4.2.8.5 Light Loss Factors (LLF)

The light loss factor used in calculating the in-service illumination takes into consideration temperature and voltage variations, dirt accumulation on luminaires, lamp depreciation, maintenance procedures and ambient conditions. The LLF for this project shall be computed based on the following formula:

LLF = (LLD) x (LLD) x (EF) x (VF) x (LT)

Where:

LLD = Lamp lumen depreciation factor = 0.90 for high intensity discharge (HID) lamps

LDD = Luminaire dirt depreciation factor = 0.80 based on Category V very dirty atmosphere, no annual cleaning

EF = Equipment factor = 0.95 to 0.90

VF = Voltage to luminaire factor = 0.98

LT = Luminaire ambient temperature factor = 1.0 for high pressure sodium lamp

Hence:

LLF = 0.67 for HID fixtures

4.2.8.6 Load Centers, Contact, and Control

Load centers shall be 480/277 Volt, three phase, 60 Hertz, outdoor type, pad mounted, with main fused disconnect switches, dry type transformers, lighting distribution panels, and photo cells for group control of luminaires. Lighting panel shall have a main contactor and secondary three pole branch circuit breakers. Contactors shall be rated for the associated roadway lighting loads and controlled by photoelectric or light sensitive switches. Cadmium sulfide photo cells shall have standard "ON/OFF" foot-candle levels of 1.5/4.5. Light sensitive window shall face north or be turned in the direction of the greatest amount of natural or ambient light at those locations where the visibility is obstructed. Light sensitive windows shall be installed to prevent interference for high artificial light sources.

Load centers shall have SCADA interfaces and remote monitoring capabilities.

Exterior parking lot lighting system control shall be photocell controlled with time clock override.

4.2.9 Exterior Raceway Systems

This section establishes the basic design criteria for raceway systems.

The raceway systems shall consist of duct lines encased in concrete, and provided with manholes, handholes or pull boxes as the means of accessibility for cable installation and subsequent maintenance. All electrical conductors within such accessible enclosures shall be completely fireproofed. The raceway systems shall consist of separated sets of duct runs for different service classifications. This will permit alternate service cable to be installed with the assurance that if one cable fails, service can be maintained on the other. The raceway system(s) shall comply with the more stringent requirements of NFPA 70, ANSI C2, all pertinent MBTA Manuals and Guidelines, and all applicable local codes.

4.2.9.1 Design Requirements

Duct lines shall have a continuous slope downward toward manholes, handholes, or pull boxes, and away from buildings, with a pitch of not less than three inches in 100 feet. Where grades are flat or crest between manholes, a single slope will usually require too much depth in one of the manholes. In this event, slope the ducts from the crest area to both manholes. The duct lines shall be constructed of individual conduits encased in concrete. Conduits shall be separated by a minimum concrete thickness of two inches. Reinforcement of the duct bank shall be provided where required.

Raceways shall be routed in straight lines to the maximum extent possible. Bends, where required, shall be of the long radius type, consistent with other determining factors. Include a minimum of 50 percent spare ducts for future expansion and/or required modifications. Spare ducts shall be provided with a pulling wire. Dead end ducts shall be capped and left with sufficient length to allow for future continuation.

4.2.9.2 Materials

Raceways encased in concrete shall be fiberglass reinforced epoxy (FRE) conduit. All non-encased raceways shall be rigid galvanized steel (RGS) conduit. All conduits crossing expansion joints shall be provided with suitable water-tight expansion or expansion/deflection fitting(s) and bonding jumpers. Fittings shall be suitable to be encased in concrete applications. Empty conduits shall be provided with non-smoking plastic pull wire having not less than 200 pound tensile strength.

4.2.9.3 Manholes, Handholes, and Pull Boxes

Manholes, handholes and pull boxes may be pre-cast or cast-in-place. Pre-cast manholes shall be of a design which, upon assembly or placement, offers integrity against water intrusion equal to that of cast-in-place manholes. Concrete for manholes, handholes and walkway pull boxes shall be designed for a minimum 28-day compressive strength of 3,000 psi. Manholes, in general, should have minimum dimensions of six feet wide, eight feet long, and six feet inside clear height. Actual dimensions and shape shall be as required for each application. Manholes may be applied on any underground raceway system. Manholes shall be designed for a minimum of HS-20 truck loading per AASHTO.

Handholes and/or walkway pull boxes may be used for utilization voltage systems and for alarm, communications and signal systems. Handholes shall be designed for heavy duty traffic loading. Frames shall be designed to accept round covers wherever feasible, 27-1/2 inch diameter access minimum. Rectangular covers, where required, shall be equipped with flush hinges. Frames and covers shall be waterproof type designed to support heavy duty traffic loading. Covers shall have "MBTA.", and the service ("POWER", "COMMUNICATIONS", etc.), cast into the upper surface. All metal covers shall be bonded to their frames.

Manholes, handholes and pull boxes shall be designed to include a full complement of hardware, e.g. racks and hooks, cable support insulators, pulling eyes, and grounding provisions, all suitably bonded. Raceways shall enter manholes, handholes and pull boxes at right angles wherever possible, and terminate in end bells. Consideration should be given to the desirability of providing a drain in each manhole, handhole and pull box. Alternatively, provide a sump pocket in each manhole. Two adjacent manholes serving different raceway systems shall be nested to the extent feasible by abutting adjacent walls.

Embedded pull boxes and junction boxes can be employed in the following raceway systems:

- Low voltage systems (480/277 Volts and below)
- Alarm, communication and signal systems.

The environmental conditions for each such application shall be noted and a design shall be provided that is compatible with the expected exposure. The design of embedded pull and junction boxes shall fulfill the following requirements:

Sized to facilitate installation and removal of wires and cables, and allow for sufficient cable slack to accommodate cable expansion and contraction.

Covers shall be designed to prevent entrance of liquids that may impinge upon or collect on the cover.

Covers shall be sectionalized, if necessary, to facilitate removal and replacement, with due consideration given to the location of the respective boxes and the means of access thereto.

4.2.9.4 Specific Design Calculations

The raceway systems shall be designed such that cable pulling tensions and sidewall pressures are not exceeded in any run. Calculations shall be prepared for pulling tension and sidewall pressure for each run. Where acceptable limits on tension or sidewall pressure are exceeded under certain conditions of installation, the design shall clearly indicate the installation method by which acceptable values are to be achieved; e.g.:

- Use of pulling eyes instead of pulling grips
- Pulling cable into a duct bank from a designated direction
- Shorten distance between manholes, or pull boxes

- Increase bend radius of ducts.

Cable manufacturer's stated values of maximum tension and sidewall pressure are not to be exceeded.

For installation of three single conductor cables of equal diameter, the "jam ratio" of duct inside diameter to single conductor cable outside diameter shall be considered. A ratio from 2.8 to 3.0:1 shall be avoided.

4.2.10 Power Systems and Studies

This section specifies the furnishing of short circuit studies, protective device evaluation studies, protective device coordination studies and relay settings. The studies shall be certified by an independent registered professional electrical engineer registered in the Commonwealth of Massachusetts. The studies shall include, but not be limited to, portions of the electrical distribution system including the 480V distribution system, and down to the 120VAC panelboard level. Normal system connections and those which result in maximum fault current conditions shall be included in the study. Study shall include ARC-flash analysis and associate NFPA 70 labeling of equipment.

The studies shall be submitted to the MBTA for review. A load flow study and voltage drop to the farthest point on the system shall be performed.

The design shall include consideration of the MBTA and various local utility short-circuit data.

4.2.10.1 Short Circuit Study and Protective Device Evaluation Study

The short circuit study shall be performed with the aid of a digital computer program and shall be in accordance with applicable IEEE and ANSI standards. The study input data shall include the power company's short circuit contribution, resistance and reactance components of the branch impedances, the X/R ratios, base quantities selected, and other source impedances.

Short circuit close and latch duty values and interrupting duty values shall be calculated on the basis of assumed 3-phase and single phase bolted short circuits at each switchgear bus, low voltage motor control center, distribution panelboard, pertinent branch circuit panel and other significant locations throughout the system. The short circuit tabulations shall include symmetrical fault currents, and X/R ratios. For each fault location, the total duty on the bus, as well as the individual contribution from each connected branch, shall be listed with its respective X/R ratio.

A protective device evaluation study shall be performed to determine the adequacy of circuit breakers, molded case switches, and automatic transfer switches, and fuses by tabulating and comparing the short circuit ratings of these devices with the calculated fault currents. Appropriate multiplying factors based on system X/R ratios and protective device rating standards shall be applied. Problem areas or inadequacies in the equipment due to short circuit currents shall be corrected, at no additional cost to the MBTA.

4.2.10.2 Protective Device Coordination Study

A protective device coordination study shall be performed to provide the calculations and logic decisions required to select or to check the selection of power fuse ratings, protective relay characteristics and settings, ratios and characteristics of associated current transformers, and low voltage breaker trip characteristics and settings. The studies shall be in accordance with applicable IEEE and ANSI standards, and satisfy the requirements of the National Electrical Code.

The coordination study shall include, but not be limited to, medium and low voltage classes of equipment from the utility service connection protective devices to and including the largest rated device in the low voltage motor control centers, panelboards, down to typical 120VAC branch circuits. The phase and ground over-current protection shall be included, as well as settings of adjustable protective devices.

The time-current characteristics of the specified protective devices shall be drawn on log-log paper. The plots shall include complete titles, representative one-line diagram and legends, significant motor starting characteristics, complete parameters of transformers, and complete operating bands of low voltage circuit breaker trip curves and fuses. The coordination plots shall indicate the types of protective devices selected, proposed relay taps, time dial and instantaneous trip settings, transformer magnetizing inrush and ANSI transformer withstand parameters, cable thermal over-current withstand limits, and significant symmetrical and asymmetrical fault currents. All restrictions of the National Electrical Code shall be conformed to and proper coordination intervals and separation of characteristic curves shall be maintained. The coordination plots for phase and ground protective devices shall be provided on a system basis. A sufficient number of separate curves shall be used to indicate the coordination achieved.

The selection and settings of the protective devices shall be provided separately in a tabulated form listing circuit identification, IEEE device number, current transformer ratios and connection, manufacturer and type, range of adjustment, and recommended settings. A tabulation of the recommended power fuse selection shall be provided for medium voltage fuses where applied in the system.

Discrepancies, problem areas, inconsistencies or inadequacies shall be corrected.

4.2.10.3 Protective Device Coordination Study

A preliminary report shall be submitted to the MBTA for review and comment. The results of the power system studies shall be summarized in a final report.

The report shall be prepared and stamped by a professional electrical engineer registered in the Commonwealth of Massachusetts. Six bound copies of the final report shall be submitted to the MBTA for review and comment. The report shall include the following sections:

- Description, purpose, base and scope of the study, and an overall single line diagram of the power system which is included within the scope of the study.
- Tabulations of circuit breaker, fuse and other protective device ratings versus calculated short circuit duties, and commentary regarding the same.
- Protective device time versus current coordination curves, tabulations of relay and circuit breaker trip settings, fuse selection and commentary regarding the same.
- Fault current calculations including a definition of terms and guide for interpretation of computer printout.
- Load flow study.
- Voltage drop to the furthest point shown on the drawings.
- One copy of the final report shall be submitted to the various local utilities for their review.

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5 Systems

Chapter 5

5.1 General

These criteria provide the functional and design requirements for a traction power system (TPS) that will provide electric power to the LRVs that will operate along the GLX project. In addition, the final sections of this chapter provide criteria required for designing communications system elements to be installed along the corridor.

Power to drive the LRV traction motors shall be supplied to the LRVs by wayside traction power substations (TPSSs) that are interconnected through a traction power distribution system consisting of substation feeder cables; right-of-way parallel feeder cables; ductbanks, conduits and manholes; feeder disconnect switches; overhead power cables and the OCS. The OCS shall consist of a messenger wire and a contact wire installed above each of the LRV tracks. A pantograph atop each of the LRVs shall provide the interface between the LRV and the OCS as the collector of electrical current for the vehicles. The LRVs will return this current to the TPS via the running rails of each train track, with rail/signal bonds and cables providing the return electrical path back to the substations.

The entire TPS network should be located in close proximity to the Green Line alignment, and within its right-of-way (ROW) to the greatest extent possible. The GLX's new TPSSs convert electric power at given AC voltage levels from the local electric utility to the appropriate DC levels required to allow the LRVs to operate sufficiently. The specific elements of the TPS are the following:

- Utility AC supply feeders from their respective points of service with metering.
- Each TPSS, shall be completely integrated and comprised of AC and DC switchgear, DC power converter packages (rectifier and rectifier transformer and associated bus ducts); a negative equalizer bus and drainage board consisting of rectifier negative switches, equalizer bus , and drainage contactors; a substation auxiliary power system consisting of auxiliary power transformers and double ended low voltage switchboard, a control power battery system (power supply & charger, batteries, battery rack and 125 volt power distribution panel, etc.); protective devices (relays, etc.) mounted in their respective equipment; equipment controls (switches, meters, panels, etc.);, annunciators or Programmable Logic Controllers(PLCs)/Human Machine Interfaces (HMIs), a supervisory terminal box; and ancillary features (eye wash, lighting, etc.).
- Complete DC traction power distribution network including TPSS feeder cables and connections, ROW parallel DC power cables, OCS including sectioning devices (disconnect switches, section insulators and/or air breaks), and balance weight assemblies.
- Negative return system for double track circuit signal system, including connections to signal bonds, running rails and cross bonding cables.
- In addition, the TPSSs shall also function as 13.8 kV AC switching stations supplying power to the GLX passenger stations with two 13.8 kV AC feeders from each substation.

The TPS design shall provide sufficient and safe electrical power to the Green Line OCS to allow the LRVs to meet their operating requirements. In so doing, the TPS shall be designed to comply with accepted industry standards and practices (see Section 6.2 of this document) to do the following:

- Operate in an efficient and safe manner
- Be unerringly compatible with all other interfacing systems and subsystems
- Minimize interference from (or to) other systems, including those of utility companies in the vicinity of the Green Line alignment and ROW
- Minimize the effects of stray current

The design of TPS shall also be coordinated not only with the local electric utility companies and affected other local utility companies, but also with interfacing disciplines/systems as well (Track, Civil Works, LRVs, Signaling & Communications, Train Command and Control, etc.) to ensure system-wide compatibility. The Traction Power System shall conform to all pertinent MBTA Power Department Standards, Specifications, and established proven operating procedures.

5.2 Green Line Design Standards

Comply with all applicable engineering codes and standards and all life-safety codes and standards developed by the various federal, state, and local jurisdictions that pertain to the design and operation of electric transit systems. This shall include, but not be limited to, the following:

- American Railway Engineering and Maintenance-of-Way Association(AREMA) 2012 Manual for Railway Engineering: :
- American Railway Engineering and Maintenance-of-Way Association (AREMA) Communications and Signal Manual.
- American Institute of Steel Construction (AISC) Specifications, Codes and Standards:
- American Concrete Institute (ACI) Codes and Standards
- American National Standards Institute (ANSI) Standards
- American Society of Civil Engineers (ASCE) Codes and Standards
- American Society of Testing Materials(ASTM) Standards
- American Welding Society (AWS) Codes and Standards
- Electronics Industries Alliance, EIA, (Formerly Electronics Industries Association) Standards
- Federal Transit Administration (FTA) Rules, Regulations, Guide Lines and Standards
- Federal Railway Administration (FRA) Rules, Regulations, Guide Lines, Standards and Recommended Practices
- Illuminating Engineering Society of North America(IES) Standards: IEEE
- Institute of Electrical and Electronics Engineers, Inc. (IEEE) Guides and Standards
- Insulated Cable Engineers Association (ICEA) Standards
- MBTA Standard Power Engineering Department Standards/Specifications(where available)
- National Electrical Manufacturers Association (NEMA) Standards
- National Electric Code (NEC)
- National Electrical Safety Code (NESC)
- National Fire Protection Association (NFPA) Standards
- International Electrical Testing Association Inc. (NETA)

- Occupational Safety and Health Administration (OSHA)
- Underwriters' Laboratory (UL)
- TCRP Report 57, Track Design Handbook for Light Rail Transit (Transportation Research Board)
- TCRP Report 71, Track Related Research Vol.1 –Broken Rail Detection
- Standards, Codes, Rules and Regulations of National, State, and Local Government Agencies or Government Authorized Agencies having Jurisdiction over the Project

Additionally, all designs developed for the Green Line Extension project shall adhere to those standards as listed in standard MBTA Specification Sections 16122, 16126, 16140, and 16203.

5.3 Green Line Traction Power and DC Feeder System

Traction power for the Green Line is provided by direct current through an overhead contact system (OCS). Each Green Line Light Rail Vehicle is equipped with a pantograph on the top of the vehicle. The pantograph is used to collect the power available from contact with the trolley wire of the overhead contact system.

Electrical power for the overhead contact system is received at 13.8 kV AC from the electric utility or from the MBTA distribution network. The AC power received is converted to direct current by transformer–rectifier units. The direct current is then supplied to DC Switchgear for distribution to the transit system. The DC power is provided to the overhead contact system from individual traction power substations positioned at designated locations along the right of way. Multiple feeder cables provide power to each power section of the overhead contact system.

The MBTA's traction power system is generally described as being a 600 VDC system. However, there are a number of voltages that are associated with system operation and planning. The system currently operates at a nominal 590 VDC but the MBTA would ideally like to increase this level to 650 VDC in the future. The transformer–rectifier units are designed with provisions to allow for operation at either of these nominal voltages. For the system as currently operated, the output voltage of the rectifiers is between 626 and 636 VDC at Light Load and is between 590 and 600 VDC at Full Load. If the system voltage is increased in the future, then the output voltage for the rectifiers will be between 689 and 700 VDC at Light Load and between 650 and 661 VDC at Full Load.

All DC Switchgear and associated equipment shall be rated for 750 VDC.

For either configuration, the new traction power substations shall be designed to maintain a minimum voltage of 450 VDC during peak operating conditions based on the following assumptions:

- AW3-loaded 3-car trains at peak hour headways, both inbound and outbound.
- Green Line Types 7, 8 and 9 LRVs reaching a peak propulsion current according to their established characteristics at or about 23 mph.
- Substation rectifier voltage regulation is 6% approximately linear to 300% of full load current, and rectifier light load voltage output is 626 V DC.
- Summer system operation with air conditioning in service (34 kW average auxiliary load per car) and with electrical conductor resistances calculated for summer ambient conditions.

5.4 Terminology

The following rail-related acronyms and abbreviations appear in various places throughout this document. They are defined as follows:

A	Amperes
AC	Alternating Current
AWG	American Wire Gauge
BIL	Basic Impulse Insulation Level
BWA	Balance Weight Assembly
CBD	Central Business District
CWR	Continuously Welded Rail
DC	Direct Current
HSCB	High Speed Circuit Breaker
HMI	Human Machine Interface
LRT	Light Rail Transit
LRV	Light Rail Vehicle
LVPS	Low Voltage Power Supply
MPA	Mid-Point Anchor
PLC	Programmable Logic Controller
ROW	Right-of-Way
RTU	Remote Terminal Unit
SAS	Substation Automation System
SCADA	Supervisory Control and Data Acquisition
SCAT	Simple Catenary, Auto Tensioned
SCFT	Simple Catenary, Fixed Termination
SWFT	Single Wire Fixed Termination
TES	Traction Electrification System
TPSS	Traction Power Substation
UPS	Uninterruptible Power Supply

5.5 Green Line Extension Traction Power System Design Ratings and Capacity

5.5.1 Operating Criteria

The Advanced Conceptual Design for the Green Line Traction Power System is based on the following Operating Criteria:

- The Traction Power System should support Green Line Extension Operation as outlined in the "Green Line Extension Project Operations Report" dated January 2011. The Report calls for operation of 3-Car trains from North Station to College Avenue Station and from College Avenue Station to North Station during peak hour with 5 minute Headways. Similarly, the Report calls for Operation of 3–Car trains from North Station to Union Square Station and from the Union Square Station to North Station during peak hours with 5 minute Headways.

- The Traction Power System shall support normal operations of trains as specified in the Operations Report with a TPS System Contingency Condition of one rectifier unit in any of the four traction power substations supplying power to the Extension out-of-service while maintaining a minimum voltage of 450 volts or above at the train. The Advanced Conceptual Design supports the Operation of 4-Car Trains on 5-minute headways with certain enhancements to the Traction Power System. This is based on extrapolation of 3-Car simulation scenarios. Detailed simulations with 4-Car trains and OCS evaluation are required to determine the enhancements required for 4-car train operation.

- The Advanced Conceptual Design provides for operating contingencies by electrically sectionalizing the OCS

- The 13.8 kV AC power supply to the passenger stations is supplied by two 13.8kV feeders from the 13.8 kV Switchgear in the four new traction power substations. The system is configured so that if a feeder from one of the substations is out-of-service, the passenger station loads normally supplied from that feeder can be supplied from the adjacent 13.8 kV feeder. The two supplies to each station shall emanate from different power sources. The routing of the supplies shall be independent such that damage to one feeder shall not impact the other.

- The Maintenance Facility in the Yard shall be provided with its own TPSS (Third Avenue) which shall be fed by two independent 13.8 kV utility feeders. A back up 13.8 kV feeder shall be available from the Red Bridge Traction Power Substation.

- DC Feeder Breakers shall be provided in the Yard DC Switchgear (at Red Bridge TPSS for technical storage tracks and in the 3rd Avenue TPSS) to facilitate the sectionalizing of the Yard and simplify to the extent possible, the OCS in the Yard. Yard leads in and out of the Yard, trains into and out of the Maintenance Building, and for movement of trains in the Yard shall be given high priority in the re-sectionalizing of the yard power sections.

- The AC Switchgear continuous rating and short circuit current rating shall match or exceed the Incoming Service ratings/characteristics, and shall comply with MBTA and utility requirements and standard specifications.

- The BIL of 13.8 kV ac Switchgear, Rectifier Transformer and the Substation Auxiliary Power Transformer shall be in accordance with MBTA specifications.

- The Use of reactors to reduce the short circuit levels on the 13.8kV & LV ac side and on the 650 Volt dc side is strictly prohibited

- All Major equipment for the new traction power substations including the draw-out circuit breakers provided under this project shall be inter- changeable, as detailed in the standard MBTA specifications.

- The switching surges (over voltages) generated due to the frequent operation of Vacuum Circuit Breakers shall not damage transformers connected to the circuit and verified to the satisfaction of the MBTA Power Division. Rectifiers shall be designed to contain a minimum of four diodes per phase leg. The removal of one diode from each phase leg of a rectifier shall not affect the normal operation of the rectifier's ability to carry overloads and withstand short circuits. In addition, the safe junction temperature of the remaining diodes in service shall not be exceeded.

- Rectifiers shall be protected against transient voltage surges caused by lightning, faults, switching operations and train movements. Cathode Circuit Breakers and Feeder Circuit Breakers shall be rated for the maximum peak short circuit current at their terminals.

- All safety interlocks specified for the 13.8 kV Switchgear, Rectifier and DC Switchgear shall be provided as specified.

5.5.2 Yard and Shop

A dedicated Traction Power Substation (3rd Avenue) shall be provided in the Yard Facility to supply traction power to the Yard. The Yard Substation shall contain two Rectifier-Transformer sets and shall operate in a similar manner to the Mainline Substations.

5.5.3 Light Rail Vehicle

The MBTA currently operates two types of LRVs. The No.7 Vehicle which is Kinki–Sharyo and the Breda No.8 Vehicle. The MBTA is in the process of acquiring Type 9 vehicles to augment the Green Line Fleet. Below are some pertinent characteristics of the Type 7, 8, and Type 9 Vehicles:

	Type 7 Car	**Type 8 Car**	**Type 9 Car**
Length over couples	73 ft.	74 ft.	74 ft
Width	104 in.	104 in.	104 in.
Height – rail to roof	11 ft.	11 ft.	11 ft.
Pantograph Operating Range	12 ft. - 6 in. to 19 ft.	12 ft. to 19 ft. 1	12 ft. - 6 in. to 19 ft.
Weight	85,400 lbs	86,000 lbs	86,000 lbs
Service Acceleration on Tangent Track	28 mphps	28 mphps	28 mphps
Service Brake Level on Tangent Track	35 mphps	35 mphps	35 mphps
Maximum Design Speed	55 mph	55 mph	60 mph
Maximum Operating Speed	52 mph	55 mph	60 mph
Voltage	650 Volts DC	650 Volts DC	650 Volts DC
Drop Out Voltage	400 Volts	400 Volts	400 Volts

Detailed Characteristics of Type 7, 8, and type 9 vehicles can be obtained from the MBTA Project Office and the Riverside Maintenance Facility.

5.6 Green Line Substation Make-up

The TPSSs will be the interface between the utility providing AC electric power and the DC Green Line distribution system. The substation equipment design shall utilize standard sizes and configurations wherever possible to minimize parts & equipment inventory, and allow for compatibility and interchangeability of equipment between the individual TPSSs. The TPSSs shall be designed to operate autonomously, unattended, and with a minimum of regular maintenance. Local controls and alarms shall be provided that include provisions for remote control, monitoring and data gathering through a SCADA/PLC system. Each TPSS shall be designed as a complete unit, with electrical equipment coordinated and integrated to function as a single substation. The substation shall be designed for extra heavy duty traction power service (according to NEMA RI-9) including the following major elements:

- **Medium Voltage Switchgear**: shall be freestanding, indoor, metal-clad, vacuum circuit breaker type, suitable for use as service entrance equipment on a nominal 13.8 kV three-phase, three-wire, 60 Hz grounded neutral service, and shall be in conformance with the latest ANSI and IEEE Standards. The switchgear shall have voltage, current and short circuit withstand ratings suitable for operating on the incoming service from the electrical utility without use of any external devices to reduce the utility service short circuit levels. The switchgear shall be designed utilizing standard construction methods, equipped with protective and operating devices, and be provided with functional and operational features similar to the switchgear in the existing MBTA substations which are operating satisfactorily. Power circuit breakers shall be 15kV Class, suitable for operation on nominal 13.8 kV, 3 phase AC from the electrical utility (N-Star or N-Grid), designed for operation on 60Hz and rated on symmetrical current basis, in accordance with ANSI C37.06. The circuit breakers shall be draw-out type, 3-pole, motor-charged, spring-operated type, provided with overload, over-current, and under-voltage protective relays, fully coordinated with incoming service protective devices. Switchgear and circuit breaker continuous-current and short-circuit ratings shall match or exceed the incoming service requirements. Switchgear and transformer basic impulse insulation levels (BIL) shall be in accordance with MBTA and NSTAR specifications. If required, lightning arrestors (station class) with appropriate ratings shall be provided on the high voltage side of the rectifier transformer, solidly grounded to the TPSS ground system (with MBTA approval) as an added protection to the rectifier transformers and station service transformers. The transient overvoltages produced by frequent switching operation of the vacuum circuit breakers in the TPSSs shall not affect or harm the rectifier transformers, station service transformers and auxiliary transformers that are supplied by the vacuum circuit breakers. This shall be clearly demonstrated to MBTA with supporting calculations and tests. MBTA review and approval shall be obtained for the switchgear specifications and design at every stage of design submittal. AC switch gear shall conform to MBTA Power Department specifications.
- **Power Conversion Package**: The Power Conversion Package shall mainly consist of the rectifier transformer, rectifier, anode and cathode bus ducts (if required), and the negative disconnect switch. All the Power Conversion Package equipment, including the rectifier transformer and accompanying rectifier, shall be matched units designed for extra heavy duty traction service in accordance with NEMA RI-9. . Overall efficiency of each conversion unit shall be at least 97.5% at continuous rating. The rectifiers and rectifier transformers shall be suitable for interchanging with other rectifiers and rectifier transformers that are provided under this project – with the exception of the Yard Substation transformers which shall be 1500 kW units.
- **Rectifiers**: The Rectifiers shall be 12-phase multiple double-way, ANSI C34.2A circuit No. 31. Rectifiers shall be of the silicon-diode type (redundant and hermetically sealed), in free-standing high-resistance-grounded metal frames and with natural air convection cooling, and installed indoors. Diode over-current protection shall be via fast-clearing semiconductor fuses having trip indicators. Electrical interlocks shall be provided to trip the DC cathode breaker and the AC Rectifier-Transformer breaker upon opening the rectifier enclosure door. Rectifiers shall be designed for parallel non-attended operation. Each rectifier shall function as an integrated unit with the associated rectifier transformer AC circuit breaker, rectifier transformer, DC switchgear, and the negative disconnect switch. The rectifier negative shall be disconnected by a manually operated negative disconnect switch located in the Negative Return Bus and Drainage Cabinet. The maximum average audible sound level produced by the entire rectifier unit under no-load condition shall not exceed 55 decibels.

  Each rectifier shall have an output rating of 3000 kW at full load voltage of 590 volts at an ambient temperature of 40 degrees C. The voltage at 0.5 percent full load shall be 636 to 626 volts and the voltage at full load shall be 600 to 590 volts. Rectifiers will be configured for a future operating voltage of 650V DC. The rectifier shall be capable of carrying the overload requirements of extra heavy traction service with one diode removed from service in each phase leg of the rectifier without exceeding the safe junction temperature of the remaining diodes, and the loss of one diode in each phase leg shall not affect the ability of the rectifier to withstand short circuit.

Rectifier unit assembly shall be metal enclosed, provided with self-supported, welded steel structure. Each assembly shall consist of silicon diode power rectifier section and a control/auxiliary section to form a free standing unit. The control/auxiliary section shall be completely isolated from the power rectifier section, as shall instruments and devices required for control and monitoring of the rectifier transformer, rectifier and the rectifier DC main breaker. All control and supervisory circuit devices located in the control/auxiliary section are operated on 125 volt DC or 120 volt AC. All doors of the rectifier assembly containing/operating 590/650 volt DC positive potential buses and devices shall be provided with interlocks designed to prevent energization of the rectifier while any of the doors are open, and to de-energize the rectifier when any of the doors are opened while the rectifier is in operation. Rectifier internal buses shall be of copper with appropriate barriers to separate positive and negative buses. Diode heat sinks can be of aluminum. The rectifier unit assembly shall be secured to the insulated epoxy floor with insulated epoxy anchors.

Rectifiers shall be designed so that the diodes and other rectifier elements are protected against overcurrent and fault currents by phase and ground instantaneous and time over current relays located within the AC Switchgear. The overcurrent relays shall be selective with individual diode fuses so that the fuses shall not blow on a through-fault. Diode fuses shall blow on diode shorting only. Rectifier heat sinks shall be provided with thermal devices that will take the rectifier out of service when there is loss of complete protection to the rectifier from the overcurrent relays. Each rectifier unit assembly shall also be protected against transient surge voltages caused by lightning, faults or switching operations and DC spikes caused by operation of trains.

The details of design and construction features of the rectifier unit assembly shall be subject to the approval of MBTA. Rectifiers shall conform to MBTA Power Department specifications.

- **Rectifier transformers**: The Rectifier Transformers shall preferably be outdoor, fluid filled, natural convection cooled. Alternatively, if required due to constraints at a specific location, a Rectifier-Transformer may be indoor, metal enclosed, open ventilated natural convection cooled dry type units with epoxy cast primary and secondary coils and provided with non-load tap changer on the primary side. Transformers shall conform to the Power Division's latest standards and specifications. Transformers shall be suitable for operation at 40 degrees C ambient temperature and with the rectifier continuous load and overloads as required for the extra-heavy duty traction service for which the associated rectifiers are designed. The kVA rating of rectifier transformer shall be commensurate with its associated rectifier. Audible sound level of the rectifier transformer shall not exceed 60 decibels with no load and excitation on the transformer when measured in accordance with applicable ANSI Standard and OSHA regulation. The average temperature rise by resistance for the two hour overload cycle as specified shall not exceed 65 degrees C over an ambient temperature of 30 degrees C and maximum ambient temperature of 40 degrees C during a 24 hour period with Class F winding insulation rated for a total temperature of 155 degrees C or better. High voltage winding shall be copper, three-phase, 60 Hz, 13.8 kV nominal, delta connected, suitable for effective grounded system. High voltage winding insulation class shall be 15kV, rated for a basic impulse level (BIL) of 110kV, minimum. The secondary side of the transformer shall have two three-phase low voltage copper windings: one delta connected, the second wye connected, arranged in accordance with ANSI Circuit No.31, as defined in ANSI C34.2A, to provide 6 phase AC power to a twelve pulse , multiple delta-wye, double-way rectifier. Voltage and related characteristics of the low voltage windings shall be commensurate with associated rectifier. Low voltage insulation class shall be 1.2 kV, rated for BIL of 45 kV, minimum. The impedance of the transformer shall be as low as possible, consistent with good design and shall be determined by the DC conversion package requirement of voltage regulation, no load voltage and to limit the fault current within the ratings of rectifier/diode and DC breaker ratings. The no load tap changer shall have rated tap and four- 2.5% taps above and four-2.5% taps below normal tap. The transformer shall be provided with protective devices, meters, and control terminal required to monitor ensure safety of the equipment and trip the circuit breaker in the event of high winding temperature. The displacement power factor shall be 0.95 or greater from 25% to full-load at rated AC voltage. The details of design and construction features of the rectifier unit assembly shall conform with MBTA power Department specifications and subject to Department approval. Transformers shall also be capable of future operations at 650V DC and shall have a second set of no-load taps to facilitate this.

- **DC Switchgear**: The DC Switchgear Assembly shall be freestanding, indoor, metal enclosed, circuit breaker type and rated for 750 V DC traction service. The DC switchgear assembly shall conform to the ANSI Standard for switchgear assemblies and shall be suitable for operation with its structure high resistance grounded. Separate, steel-enclosed, compartments shall be provided for the circuit breaker, main bus, outgoing buses, feeder cables, and for relays, instruments and control devices. The width of individual circuit breaker unit in the DC switchgear shall not exceed 24 inches. Main bus and bus taps shall be of copper, sized to carry the full rated current of the switchgear bus and braced to withstand short circuit stresses as great as those for which the circuit breakers are designed. The busses shall be supported on high-strength, flame-retardant insulators designed to ensure adequate electrical clearances and to withstand the specified mechanical stresses. Each circuit breaker's housing shall be provided with protective shutters that close and block access to the positive bus and load terminals whenever the removable element of the circuit breaker is racked out from the cubicle. The circuit breaker housings shall be designed for easy racking of circuit breakers into and out of the cubicle. Barriers shall be provided at the side of cubicles to insulate the bus compartments of adjacent units. A completely isolated compartment, from other compartments in the same unit and also from the other unit shall be provided for the termination of outgoing power cables. The switchgear shall be securely attached to the insulated epoxy flooring by insulated epoxy anchors. DC switchgear shall conform to MBTA Power Department Specifications.
- DC circuit breakers shall be 750 volt DC minimum, single pole, air-break, motor-charged and spring-operated type. Both the main (cathode) circuit breaker and feeder circuit breaker shall draw-out type, truck-mounted, high-speed, certified for transit application, and rated for 750 V DC traction service. The circuit breakers conform to the applicable ANSI Standards and to the industry standards/practices. The circuit breakers shall have peak current, momentary current, short time current and short time current ratings for operation in a substation with two 3000kW extra heavy duty service rectifiers operating in parallel when supplied from a 13.8 kV, 60 Hz, 3 Phase Service capable of delivering maximum 600 MVA with an X/R ratio of 10. Application of reactors between the rectifiers and DC switchgear or between the rectifier and the negative equalizer bus, to limit the short circuit current seen by the circuit breakers, shall not be acceptable. These breakers shall be provided for all feeders and for the cathode of the rectifier. The cathode circuit breaker and the feeder circuit breakers shall be rated for the maximum peak short circuit levels available at their terminals. The cathode circuit breaker shall also be provided with reverse current protection. The feeder breakers shall also be provided with instantaneous, rate-of-rise and overload protection for close-in and remote faults, with supervised transfer trip backup protection. The breaker's protection scheme shall ensure that all breakers feeding a faulted section shall "trip open". Additionally, the feeder breakers shall be equipped with automatic reclosing and load-measuring devices. The cathode circuit breaker of DC switchgear receives power, either directly or through cathode bus duct, from the rectifier. The DC switchgear feeder circuit breakers, part of the DC switchgear, supplies power to the OCS through DC feeder cables. The details of design and construction features of the DC Switchgear shall conform with MBTA power Department specifications and subject to Department approval.
- **Negative Return Bus and Drainage Cabinet**: shall be freestanding metal enclosed, with a manually-operated (single pole, single throw) bolted pressure-type negative disconnect switch for each rectifier, and be designed in accordance with MBTA Specification Section 16311. This disconnect and the DC cathode circuit breaker shall be key interlocked so that the disconnect switch cannot be opened when the cathode breaker is closed and the cathode breaker cannot be closed when the disconnect switch is open. The voltage rise at the running rails shall be controlled by the use of paralleling feeders if required. The use of Automatic Grounding Devices is strictly prohibited. The AC Switchgear shall be connected to the negative return bus by way of a diode controlled drainage circuit. The Final Designer shall work with the Authority's Power Division in developing a method of using drain cables and their attachment to the substation and utilities.
- **Substation Control System/SCADA**: The substation shall be controlled using an automation control system. Each piece of main equipment and protection/relaying devices shall interface to the system by way

of an intelligent electronic device. Within the substation there shall be redundant networks to communicate to all devices. The network shall be controlled and monitored using hot standby, fully redundant PLCs. An HMI shall be provided to interface all communication and device status to the operator locally in the substation. The PLC may also operate as the substation SCADA RTU Device. The MBTA standard specifications indicate the points required to be available to SCADA. The AC Switchgear is typically controlled from a control panel separate from the AC Switchgear to avoid the operator being in close proximity to the equipment. This requirement also shall apply to the Substation HMI.

The MBTA will provide as a reference, specifications from recent procurements for substation equipment. These reference specifications will include substation equipment that generally corresponds with this Design Criteria. MBTA Engineering will also indicate the changes that are required to update the specifications based on present requirements.

The substation design shall not present any harmonic or other interference problems for public telephone system and Authority's two-way communication system and signal systems. Should such problems arise, remedial measures to eliminate the interferences shall be made available to the Authority immediately by the substation conversion equipment vendor. The substation design shall also include provision for installation of harmonic filters should the electrical utility supplying power requires it as the harmonics generated is affecting their power system.

Minor TPSS equipment shall include all necessary subsystems and devices for a fully-operable substation (auxiliary transformer, electrical and control panels, station battery system, disconnects, technical support equipment, etc.), and shall be designed in accordance with MBTA Standard Practices, and as required for specific substation installations. These shall include : Incoming 13.8 kV AC service and the 13.8 kV AC switchgear line-up including the number of feeder circuit breaker units, number of rectifiers and rectifier transformers, and the DC switchgear lineup with the number of main and feeder circuit breakers... The complete TPSS shall comply with the requirements of NFPA 130 including fire ratings and the MBTA Specification referred above with changes required by MBTA Engineering.

All substation electrical equipment, excepting fluid filled transformers, shall be housed within the buildings, shall be of the indoor type, and shall comply with relevant ANSI and NEMA standards (including the appropriate factory and type tests). DC switchgear and rectifier frames and enclosures shall be insulated from ground and from any grounded surface.

Incoming power to each TPSS shall include two independent 13.8 kV feeds from the local electric utility such as NSTAR or National Grid or through the MBTA Ring Feeder network if the same level of redundancy can be provided. Incoming power to the station shall be in an underground electrical duct bank. The general TPSS and equipment layout shall conform to existing MBTA standard substation design to the extent feasible. For example:

- The standard design of the substation building consists of two floors- operating floor with most of the equipment at grade level and full size basement with some equipment and all incoming and outgoing cables. Depending on the locations variations are possible subject to MBTA approval.
- The DC switchgear and rectifiers shall be installed on an epoxy insulated floor. There shall be a minimum of 6 feet of epoxy insulated floor around each piece of equipment. The DC switchgear and rectifiers shall be a minimum of 6 feet from any grounded enclosure or ground bar. Where this is not achievable, means such as installing plastic wall coverings or covers shall be used to maintain isolation.
- There shall be a minimum of 6 feet of clear space in front of the DC Switchgear to install and remove circuit breakers. There shall be a minimum of 8 feet of clear space in front of the AC Switchgear to install and remove circuit breakers.
- Adequate access shall be provided to remove equipment from the substation. Where equipment shall be accessed or removed using an access hatch, the hatch shall be a minimum of 8 feet by 8 feet. A suitable means of lifting shall be provided.
- Each substation building shall be provided with a loading dock to facilitate the delivery and installation of equipment and materials.

- Dry type cast coil transformers shall be located indoors on the operating floor for the substation auxiliary power. Fluid filled transformers shall be located outdoors.
- 13.8 kV switchgear, rectifiers, and 750 volt DC switchgear, batteries, chargers and DC distribution panels, as well as most other equipment (including cable trays for control cables) shall be located on the operating floor of the substation building.
- Auxiliary power switchgear for the substation, negative equalizer bus and drainage cabinets, DC feeder cable disconnect switches, cathode bus ducts (if required), negative bus ducts, cable racks for DC cables, all incoming and outgoing cables and conduits shall be located in the basement of the substation building.
- The buildings shall require minimal plumbing (rest room, roof drains, etc.).
- Each TPSS shall allow adequate space for a desk, filing cabinet, and storage closet.
- The Substation Auxiliary Power Switchgear shall provide the 480/277 volts power required for Ventilation System, Heating Units (Unit Heaters), and all auxiliary power requirements.
- The 208 V/120V transformers and distribution panels shall provide power to all the power and control loads requiring 208 volts and 120 volts.
- The traction power substation operating floor and the basement shall be provided with 125 volt dc emergency lighting supplied by the station battery and operated from a switch located inside the building easily accessible when the personnel entrance door is opened.
- The indoor lighting on the operating floor and basement shall have lighting levels required by MBTA Power Engineering. The lighting design shall be coordinated with the equipment and shall avoid glare in reading of meters on the equipment. The lighting design shall provide sufficient lighting levels to allow for cable replacement/maintenance on the equipment. All the switches for the indoor lighting shall be easily accessible.
- The outdoor lighting for the traction power substation shall be flood lights providing lighting to the parking lot, the substation and the utility equipment area. Wall mounted fixtures shall be provided on the sides and rear of the substation building to provide external lighting to the building. The entrance doors shall also be fully lit with a wallpack unit mounted on the side.
- The buildings shall require fire alarm systems with outside alarms and indications at the Control Center and Fire Station
- Each traction power substation shall be provided with an MBTA Standard Emergency Telephone and an analog telephone which operates on the Verizon Centrex System. Telephones shall be provided for the operating Floor, the Basement and at locations directed by MBTA Power Division.
- The door Security System shall be coordinated with and approved by the MBTA Power Division.
- The buildings shall require ventilation systems to remove the heat produced by the operating equipment, mainly the transformers and rectifiers. The MBTA's standard ventilation system for the substation buildings provides exhaust fans in the operating floor, quantity and size as required, with incoming fresh air motor-operated louvers with filters. Incoming air louvers open as the fan is switched on by the thermostat. The other method that has been used by MBTA is to install air-handling units with heating elements in the operating floor which can be used for both winter and summer.
- Heating for the building shall be provided with the use of electric unit heaters for both the operating floor and basement.
- Fenced space provision for the utility equipment for incoming utility service to be provided in the substation site as required by the utility
- The site shall be designed to allow for crane access to replace major components including transformers.

Appropriate access to distribution manholes near each TPSS shall also be provided.

5.7 Substation Size and Arrangement Details

Traction Power Study: The advanced conceptual design work and a traction power study to locate the necessary substations and to develop a traction power distribution system have been completed in consultation with the MBTA Power Department. The conclusion of the study was that the Green Line Extension project will require three new traction power substations along the rights of way in addition to the existing North Station Substation 14 in order to supply DC power to both the Medford Branch and the Union Square Branch. A substation for the Vehicle Maintenance Facility and Storage Yard is also required.

Required Traction Power Substations: These required substations are as follows:

- The Red Bridge Traction Power Substation along the right of way
- The Gilman Square Traction Power Substation along the right of way
- The Ball Square Traction Power Substation along the right of way
- The Third Avenue Traction Power Substation at the Yard Area

The Existing Adjacent Substation: The existing North Station Substation 14, which receives its 13.8 kV AC power from the MBTA Power System, provides traction power to the Lechmere viaduct. This substation will remain in service and will provide power to the new system in conjunction with the four new substations.

Study Methodology: The power study involved a simulation of the power demands of the proposed extension. The study determined (1) the number and locations of the required traction power substations and (2) the number and size of the power feeder cables needed to meet the service voltage requirements during peak conditions.

The AC Power Source for the Substations: The AC electric power will be provided by NSTAR. The electric power system supplying the new substations will be separate from the MBTA 13.8kV distribution network which powers the existing North Station Substation 14.

Power Input: All four new substations will be provided 13.8 kV, 3-phase, 60 Hz power. At each of the traction power substations, two incoming 13.8 kV AC feeds will be provided for redundancy. .

Interface with NSTAR: Space will be provided for the interface with NSTAR. The traction power substation layouts will provide the necessary space and infrastructure for any interconnection equipment. It is anticipated that the utility interface will be similar to that at other existing MBTA substations at which utility power cable is routed directly to the 13.8kV switchgear lineup. Substation design will comply with the utility company's requirements and regulations for service at the incoming voltage level. Service conductors shall be suitably protected against any potential overload, surge, lightning and short circuit faults.

5.8 Traction Power DC Cable and Feeder Network

The DC feeder system shall consist of positive cables, terminations, duct, and non-circuit breaker switching equipment to connect the TPSS DC switchgear breakers to the Green Line OCS. The system shall also include negative return cables and signal bonds (provided under signal requirements) to return TPS DC current back to the TPSSs or to equalize running rail voltages. The DC positive cables shall be single-conductor, non-shielded, copper, and insulated for minimum 1,000 V, jacketed and shall be in accordance with the MBTA Standard Specifications for DC positive cables. The DC negative return cables shall be single-conductor, non-shielded, copper, and insulated for minimum 1,000V, without jacket in accordance with the MBTA Standard Specification for the negative cables. These cables shall reach the ROW via a network of non-metallic ducts. Fiberglass reinforced conduits (FRE) shall be Schedule 40 minimum, except where exposed on OCS riser poles where Schedule 80 shall be used. All FRE conduit shall be five (5) inch low smoke conduit and conform to the Power Division's specification P138-E. The use of four (4) inch conduit will only be allowed after review and with the express consent of the Authority's Power

Division. All FRE conduits, conduit connections and manhole entrance ducts shall be epoxy sealed for strength and waterproofing. The network shall be designed to contain a minimum of 100% spare duct capacity where feasible, for future use. All fittings and hardware utilized in the designs developed for the Green Line Extension project shall adhere to MBTA Standard Specifications. The following are specific MBTA requirements that shall be met in the design process:

5.8.1 DC Feeder Cables

All DC cables utilized on this project shall be positive cables to ensure greater durability. The MBTA specifies positive cables as minimum 1,000 volt, single-conductor, EPR insulated, with cross linked polyolefin (XLPO) jacket in accordance with the latest issue of MBTA Specification P-120 for 2000 kcmil, P-118 for 1000 kcmil cables.. The cables shall also conform to the requirements of existing ASTM B-33 and B-8 Specifications and also to NEMA, ANSI and NFPA including NFPA 130 Standards as applicable.

5.8.2 DC Distribution to OCS

Traction power shall be fed from the substations to the overhead catenary system via 2,000 kcmil DC feeders in conduit along the viaduct part of the trackway. In the at-grade part of the trackway, the overhead contact system is fed from a combination of underground 2000 kcmil feeder or two overhead 1000 kcmil cables (OCS structure mounted), which are supplied from the underground feeders from the substations. .

5.8.3 Negative Return

The negative return current shall be carried through the Green Line running rails, which shall also be insulated from ground. At locations requiring insulated joints, signal bonds shall be used to maintain continuity of the DC negative return circuits. Cross-bonding between the tracks shall be required, and at a minimum shall be at negative returns to TPSSs and approximately midway between these TPSSs to control voltage rise in the running rails and excessive voltage drop to LRVs. The running rails shall be cross-bonded via signal bonds where necessary for signaling purposes, while maintaining strict traction power continuity.

The Green Line Extension negative return system shall include return through both running rails and through 2,000 kcmil cables, one for each track. These cables, parallel to the trackway, shall be installed exposed between the rails in the viaduct part of the trackway and shall be directly buried in ballast at a depth of one foot in the at-grade part of the trackway. Existing portions of the Green Line currently use a single rail dedicated to negative return, with the other rail being used for the signal system. Extending GLX signal system all the way to North Station will allow utilizing both rails of each track for the return.

5.8.4 DC Control Power

Station Battery, Battery racks, combination Power Supplies and Battery Chargers, and 125 Volt DC circuit Breaker Panels shall be provided for supplying nominal 125 volt DC for control and relay circuitry and to float charge the station batteries. The combined Power Supply and Battery Charger shall operate on 208 volt, three phase, 60Hz ac power supply. The unit shall have following operational features:

- Station batteries shall be of an approved pasted plate type and shall provide a minimum of 20 years of service with minimum maintenance.

- Each battery shall consist of 60 cells connected in series for a nominal 125 volt, ungrounded control power system.

- Battery sizing shall be subject to the approval of MBTA. The battery shall supply control power, with all loads connected, for a period of 12 hours without the aid from the power supply and battery charger.

- Spill containment and absorption system conforming to the requirements of Article 64 of the Uniform Fire Code and subject to the approval of MBTA shall be provided.

- To function as a power supply, the dc output voltage shall be adjustable between 127 volts and 140 volts and shall be capable of sharing the load with the battery, when needed.

- To function as a battery charger, the unit shall have two separate voltage adjustments, one for a float charge, adjustable between 122 volts and 138 volts, and the second for an equalizing charge adjustable between 128 volts and 144 volts.

- The charger shall be provided with current limiting circuitry to keep the output of the charger within the safe operating limit under all loading conditions and under severe overloads. A blocking diode shall be provided in the output circuit to prevent battery discharge through the charger in the event of ac power supply failure.

- The power supply shall be capable of concurrently carrying the constant load of the associated battery and fully charging the battery within six hours or less after it has been discharged to 1.75 volts per cell, and shall be able to carry the entire battery load in the event of battery failure.

- Battery racks shall be of the two-step rack type for mounting the individual cells of the station battery and making necessary connections.

- A 125 Volt DC Circuit Breaker Distribution Panelboard, shall be provided for distributing the 125 volt dc control power. Panel Boards and Circuit Breakers shall be UL approved, rated for operation on ungrounded 125 volt dc. Panelboard circuit breakers shall be two pole and shall have a minimum interrupting rating of 10,000 amps at 125 volt dc. The buses and Main circuit breakers in the panelboard shall have a continuous current rating of 125 percent of one minute rating of the battery. The branch circuit breaker ratings and specific construction features of the panelboard are subject to the approval of the MBTA Power Division.

5.8.5 Metering, Control & Indication

The Traction Power Substations provided under this Project will be operated unattended. The major equipment such as the ac and dc switchgear and rectifier units shall be provided with protective, control and interlocking features to safeguard various pieces of equipment and to permit both local and supervisory control in addition to providing the power dispatcher real time status indications of various devices programmed to be viewed through the SCADA system. The following is a typical list of protection, control, indication and measuring devices with their ANSI devise designations and is subject to approval of the MBTA Power Division:

DEVICE NO.	FUNCTION
1	AC circuit breaker local control switch
4	Rectifier master control relay
26R	Rectifier heat sink overtemperature device-alarm
26RX	Auxiliary relay for 26R
26RH	Rectifier heat sink overtemperature device-trip
26RHX	Auxiliary relay for 26RH
27A	Station 208/120 volt auxiliary supply undervoltage relay
27B 1,B2	15 kV Bus A/B differential relay DC supply undervoltage relay
27BA	Station battery charger AC input circuit undervoltage relay
27BB	Station battery charger DC output circuit undervoltage relay
27R	Rectifier lockout relay DC circuit undervoltage relay
27RA	Rectifier/transformer DC auxiliary circuit undervoltage relay
27RB	Rectifier/transformer reliable AC supply undervoltage relay
30	Annunciator
30X	Auxiliary relay for 30
32	Rectifier DC breaker directional instantaneous overcurrent trip device
32X	Auxiliary relay for 32
33	Rectifier compartment door safety interlock
43	AC breaker control mode selector switch
47A,47B	Phase sequence and undervoltage relay
47AX,47BX	Auxiliary relay for 47A, 47B
48	Rectifier incomplete sequence relay
49A	Auxiliary transformer winding overtemperature device-alarm
49TX	Transformer winding overtemperature device-alarm
49T	Rectifier transformer winding overtemperature device-alarm
49TH	Rectifier transformer winding overtemperature device-trip
50/51	Instantaneous and time overcurrent relay-phase
50N/51N	Instantaneous and time overcurrent relay-ground
51	Time overcurrent relay-phase
51C	Time overcurrent relay-cable overload
51 CX	Auxiliary relay for 51C
51N	Time overcurrent relay-ground
51R	Time overcurrent relay-rectifier overload
51RX	Auxiliary Tripping relay for 51R
52B	AC bus tie circuit breaker
52F	AC feeder circuit breaker
52FX	AC auxiliary feeder circuit breaker
59	Station battery charger DC output overvoltage relay
64R	Rectifier ground relay-hot structure-trip
64RX	Rectifier ground relay-grounded structure-alarm
67	Directional overcurrent relay-phase
67N	Directional overcurrent relay-ground
72R	Rectifier DC circuit breaker
74,74X	Alarm auxiliary relays

74F, 74FX	15 kV breaker auto-trip transfer relay
83	Reliable AC control supply auto transfer switch
83A	208/120 V AC power auto transfer switch
86	Rectifier lockout relay, hand reset
86B	Bus differential lockout relay, hand reset
86X	Rectifier conditional lockout relay, electrically reset
87B	Bus differential relay
89N	Rectifier negative lead disconnect switch
95D	Annunciator flasher and bell cutoff relay
99Y	Rectifier surge protection auxiliary circuit monitoring relay
101	DC circuit breaker local control switch
102	DC feeder reclosing cycle timer
102X	Auxiliary for 102
127	Reliable AC control supply undervoltage relay
129	DC feeder load measuring contactor
143	DC breaker control mode selector switch
150F	DC feeder rate-of-rise relay
150FX	Auxiliary relay for 150F
164S	DC switchgear ground relay-hot structure-alarm
164SX	DC switchgear ground relay-grounded structure-alarm
169	DC feeder permissive setup relay
172	DC traction feeder circuit breaker
176	DC feeder instantaneous series trip device
176X	Auxiliary relay for 176
176F	DC feeder instantaneous overcurrent relay
176FX	Auxiliary timing relay for 176F
182	DC feeder load measuring relay
183	DC feeder voltage measuring transfer relay
197X	DC feeder cable energized monitoring relay
201C	Supervisory interposing relay-close
201T	Supervisory interposing relay-trip
LMR	Load measuring resistor

The Designer shall familiarize himself with the existing operation of the MBTA substations and traction power system and prepare an operational write-up of current operations and recommendations for operation of the Green Line Extension's Substations/Traction Power System for review and approval by MBTA. The requirements of integrating the substation automation system with existing operations will be included.

5.8.6 Surge Arresters

Surge Arresters protect substation equipment both from external overvoltages caused by lightning strikes in overhead lines and from internal over-voltages produced by switching operations or earth faults and from DC spikes caused by the operation of the trains. Surge arresters of a suitable rating shall be provided for the equipment specified below. However, the Designer may propose as part of the surge arrester protection plan an alternative method of protection subject to the approval of the MBTA Power Division.

- Incoming Feeder Units of 13.8 kV AC Switchgear as recommended by the Utility providing the power
- Feeder Breaker units of 13.8 kV AC Switchgear feeding the Cast Coil Transformers (if required)
- Rectifier Units
- DC OCS Feeder Circuits

Surge Protection will follow current MBTA practices.

5.9 Substation Miscellaneous Subsystems

5.9.1 Power Sectionalization

Generally TPS is designed to be "power sectionalized" to accommodate the network's voltage drops over distance and to create a practical limit to the length of any one TPS section for efficient power distribution. However, the Green Line Extension TPS shall also be organized and segmented into a pre-planned series of electrified traction power sections to allow the system to be de-energized for maintenance or emergencies without having to de-energize the entire line. Disconnect switches utilized in these sectionalization designs shall adhere to data contained in standard MBTA Specification section 16126.

5.10 TPSS Bonding and Grounding

Bonding and grounding shall be provided for all TPSS and OCS-related facilities and their adjacent structures (both new and existing), as required by NESC standards and in accordance with standard MBTA Specification Section 16450. Additionally, TPSS grounding shall be in accordance with IEEE 80 to protect the equipment, installation and personnel from potential AC faults.

Each TPSS shall be equipped with a copper ground bus connected to the substation ground grid. All non-current-carrying metallic enclosures or parts of AC equipment in the substation shall be grounded by connecting to the ground bus. All other metallic objects (either within the building or just outside the building, such as fences and gates) shall also be connected to this grounding network. The AC Switchgear shall contain an isolated ground bus to which the shield of the feeder cables shall be connected. These shall be isolated from ground and connected by drainage diodes to the negative in a similar fashion to that used in recently constructed MBTA substations. All wire, fittings and hardware used in the grounding arrangements devised for the Green line Extension shall also adhere to data contained in standard MBTA Specification Section 16450.

5.11 Corrosion Control

The TPS for this project should be separated into two electrically isolated sections: the mainline and the yard. The TPS should include a separate DC traction ground electrode, which should also be electrically isolated from facilities in the substation. TPSSs shall be provided with access to the DC negative bus for stray current monitoring, utilizing corrosion control junction boxes.

At locations other than at aerial structures, electrical ground facilities for adjacent OCS support poles shall not be interconnected. This will be done to eliminate the possible transference of earth stray currents from one portion of the transit system to another because of an electrically continuous ground system.

5.11.1 Negative Distribution System

The following industry-accepted standards shall be included in the Green Line designs to provide an electrically isolated rail system to control stray current at the source:

- Continuously welded rail (CWR)
- Rail bond jumpers at mechanical rail connections for special track work
- Insulated rail fastening system for wood ties
- Ballast on at-grade sections
- Insulating direct rail fixation fasteners on any concrete aerial structures
- Cross-bonding cables installed between rails to maintain equal potentials on rails
- Insulation of switch machines at the switch rods
- Rail insulators to electrically isolate the main rails
- Impedance Bonds for crossbonding and bypassing insulated joints

Supplemental insulated negative return cables may also be provided where extensive utility installations exist or where major high pressure transmission pipelines are present.

5.12 Overhead Contact System (OCS) General Information

The OCS design shall include the conductor/wire system itself and the physical support system that accompanies the conductors. The OCS design shall be compatible with the LRV dynamic performance characteristics to ensure that current collection is maintained under all operating conditions. The design shall also be based on local climactic, environmental and aesthetic features of the area. The OCS design shall largely consist of an auto-tension catenary system, whose elements are described in the following subsections.

Traction power is distributed to the OCS through the DC cables and disconnects switches. Electrical continuity is provided in the OCS from substation to substation. At each substation, sectionalizing gaps shall be provided in the northbound and southbound OCS to create power zones. The distribution system serving the inbound track is electrically separate from that serving the outbound track. The system is designed to permit isolation of each power zone by opening the appropriate feeder circuit breaker and feeder disconnect switch.

Pole mounted, manually operated, DC disconnect switches shall be installed on the OCS feeder riser poles to allow isolation of electrical sections at specific locations in the system.

Jumper cables shall be provided for electrical continuity at all special track work locations where it is necessary to have separation in the OCS. At locations where jumper cables are used to provide electrical continuity, such cabling shall provide conductivity that does not reduce the circuit capacity. The design of the OCS system is subject to the review and approval of the MBTA Power Division.

5.12.1 Design Philosophy and Configuration Type

The OCS shall be designed to be compatible with the MBTA vehicle dynamic performance to ensure that the vehicle pantograph maintains contact with the OCS contact wire under all local, climate, and environmental conditions. Pantograph security shall be established by maintaining a minimum contact wire edge distance from the tip of the pantograph under the worst operating condition.

The mainline OCS shall be a simple catenary system comprised of two wires; a messenger and contact wire, which is supported over the track structure. The purpose of the OCS is to supply a positive electrical power source for utilization by the Light Rail Vehicle (LRV). The OCS shall be supplemented by parallel feeder cables, in underground conduits between the tracks to provide sufficient electrical current for the satisfactory operation of light rail vehicles.

The yard or maintenance facility shall be a single contact wire system (trolley) suspended over the yard track structures and under the parking deck.

The OCS is comprised of the following major components:

a. Catenary wires consisting of messenger and contact/trolley.
b. Feeder cables from substation to OCS and also running parallel to the OCS along the alignment.
c. Supports consisting of cantilever assemblies or cross-span wires.
d. In-span materials such as hangers, jumpers, insulators, splices etc.
e. Mid-point anchors consisting of tie wires and down guy assemblies.
f. Poles utilizing I-beams erected between tracks and on the outside of tracks.
g. Foundations consisting drilled shaft and ground connections.
h. Switch heater assemblies, including power supplies, switch boxes and connections.
i. Pole structure guying including termination and anchors.
j. Tensioning systems consisting of balance weight assembly with weights and pulleys, and/or spring type for special application such as cross-over tracks, when approved by MBTA.
k. OCS Protection devices such as lightning arrestors.
l. Sectionalization and de-energization with the means of insulated overlaps, section insulators, remote control and manual disconnect switches.

In the text below, the term “registering” refers to the function of locating of the catenary wires above the path of the LRV’s pantograph.

Requirements for the OCS messenger and contact wires are as follows:

- Contact wire: single AWG 4/0 bronze alloy 80 grooved, and adhering to standard MBTA Specification Section 16122
- Messenger wire: 4/0 19-strand copper weld type EK

5.12.2 Interfaces

The OCS is a part of the electrical distribution system that supplies electrical energy to the Light Rail Vehicles. The other components of the total electrical system are (1) the positive feeder cables that connect the DC power from the substations to the OCS; (2) the negative return cable system, which connects between the rails; (3) the negative bus within the traction power substation; and (4) the traction power substation, which supplies the electrical energy from the local utility. This complete electrical circuit system shall also require coordination with the TPSSs and train control/signaling systems for the use of DC drain/cross bonds for the traction power return.

5.12.3 OCS Configurations and Tensioning Systems

The catenary configurations are defined by the number of wires in the system and the way tensions is applied in the wires. The simple OCS is comprised of two (2) wires, a messenger and a contact wire, with hangers being used to support the contact wire from the messenger in a vertical plane.

The OCS shall be designed to utilize two different tensioning systems, depending upon location as follows:

1) Simple Catenary Auto Tensioned (SCAT) – For at-grade tracks and aerial, the OCS shall be equipped with a two-wire simple catenary auto-tensioned system, consisting of a contact wire vertically supported from a messenger by means of hangers. The tension on the wires is maintained with the use of balanced weight

assemblies and spring tensioning devices. The wire is fixed at mid-point so that movement at the mid-point of the tension length is restricted. The system shall be supported by I-beam poles located on the side of the track way (side poles). Where this arrangement is not possible due to property restriction, center poles located between tracks shall be used. In multi-track areas, a headspan or portal structure arrangement may be employed. The wire tension of a SCAT system remains constant over a specific range of climatic conditions; the approach is preferred over a Fixed Termination type of system that puts greater temperature stresses on fittings, poles, and other support elements and requires heavier components.

2) Trolley Single Wire with Fixed Termination (SWFT) – For yard tracks, a single wire fixed termination system shall be used except in certain areas where the use of a SCAT system is advisable Depending on the yard layout, the SWFT shall be supported either by a single or back-to-back pole mounted cantilever arms, portal structure and/or a cross-span arrangement. This system is a variable tension system, where the tension in the wires varies according to the climatic conditions. The tensioning is accomplished by installing the wires between two fixed points, according to the climatic conditions at the time of installation and/or final adjustment. Auto-tensioning will be used on main lines, at main line/yard interfaces, and in the yard at areas of high radius curves in situations where there will be high contact wire tension of greater than 3,000 pounds.

The OCS in the interlockings and crossovers shall also be a SCAT system whenever possible.

The maintenance yard and shop in the project shall be a trolley wire with fixed termination system (TWFT).

An interface overlap shall be established at both ends of a maintenance and storage facility to allow the transition between the mainline and yard systems.

5.12.4 Interface between Catenary Types

Appropriate transitions shall be designed between the two different types of OCS tensioning systems described when the use of a SWFT system is unavoidable. Transitions shall be accomplished by means of a full parallel wire overlap. Additional OCS supporting structures shall be required to support the fixed termination trolley wire system at the mid-span to reduce the OCS sag.

For a maintenance facility, Overhead Coiling Entrance Door, the contact wire will be terminated at a Door Bridge Assembly anchored to the building structure.

5.12.5 OCS Design Parameters

Ambient Temperature Range	-15°F to 120 °F
Auto Tension Temperature Range	-15°F to 120°F
Extreme Wind Speed	80 MPH
Heavy Ice Loading	0.5 inch radial ice on wire
Maximum Design Train Speed	50 MPH

5.12.6 Messenger and Contact Wires

Messenger Wire:

4/0 19-strand copper weld type EK

Contact Wire:

Single AWG 4/0 bronze alloy 80 grooved, and adhering to MBTA Specification No. 16122

Supplemental Feeder Wire:

Minimum of one 1,000 kcmil insulated cable running parallel to track per track

5.12.7 Electrical Clearance

The following clearance shall be maintained between live conductors (including pantograph) and any grounded fixed structures in accordance with AREMA Chapter 33, Part 2, or as shown in the following table:

Clearance	**Static**	**Passing**
Nominal Minimum	9”	7”
Absolute Minimum	8”	6”

Where Static Clearance is defined as the clearance between the catenary system and any grounded structure when not subject to pantograph pressure; and Passing Clearance is the clearance between the catenary system or pantograph and an overhead structure under actual operating conditions during the time it takes the train to pass.

The following Electrical Clearances shall be maintained for the OCS System:

OCS and Closely Adjacent Structure Absolute minimum	9 inches Static 8 inches Static	7 inches Dynamic 6 inches Dynamic
OCS and Vehicles Absolute minimum	9 inches Static 8 inches Static	7 inches Dynamic 6 inches Dynamic
OCS and Overhead Utility	According to NESC	
OCS Clearances at Bridges	If the Bridge Clearance to Rail exceeds 24 ft., 19 ft. contact wire height and 23 ft. messenger height can be installed without any restriction. If the Bridge Clearance is less than 23 ft. the contact wire can be lowered without reducing the span provided minimum OCS to ground clearance can be maintained. If height is less than 23 ft., then span lengths can be reduced allowing for the system height at each end of the span to be reduced. Where possible, provide a three foot minimum clearance between the contact wire and the bridge elements. Otherwise, provide a Protection Board.	

Pantograph Clearance Envelope: A pantograph clearance envelope shall be developed for application of all tracks including superelevation, for worst case track conditions and full vehicle roll with a 6 inch mechanical and electrical clearance. No equipment except OCS steady arms attached to the contact wire, shall intrude into pantograph clearance envelope. See Dwg. No SYS-CT7013 titled OCS Pantograph and Catenary System Clearance Envelope.

Clearance of Catenary Poles and Foundations from Track: Catenary Poles shall be clear of the superelevated track centerline taking into account pole deflection, pole rake and encroachment of assemblies attached to the pole. Pole foundations shall be horizontally and vertically clear of the Clearance Envelope by the applicable foundation construction tolerances.

When the above clearances cannot be maintained due to limited headroom such as underneath an overhead structure, with the approval of MBTA, an insulated shield made of glastic material shall be placed directly above the live catenary wire throughout the underside of the overhead structure. All electrical clearances identified are subject to MBTA review and approval.

5.12.8 Safety Factors

The tensions in the messenger and contact wires shall be designed such that the safety factors indicated below are achieved under the worst climatic and wire wear case conditions:

Messenger wire	2.00
Contact wire - Unworn	2.00
- 30% Worn	1.75
Other wires and support hardware	2.50

The factor of safety is defined as the ratio of the force or stress applied to the object divided into its own mechanical or breaking strength.

Hardware items (i.e., insulators, turnbuckles, clamps, pins, splices, etc.) shall have a greater strength than the wire or wires to which they are attached or occur in-line in the respective assemblies.

Poles and Foundations shall be designed using applicable codes and standards and the factor of safety shall be determined by those codes and standards. See Chapter 2, Structural of this document.

5.12.9 System Heights

System height is defined as the distance between the messenger wire and the contact wire at the catenary support point. This standard height is 30" at support locations. This height may be varied at specific locations. Reduced heights maybe used to achieve a more aesthetically pleasing OCS profile, or for maintaining electrical clearances through overhead structures. Reduced heights maybe used, but span lengths and system heights shall be calculated to keep the mid-span hangers to their minimum length.

5.12.10 Contact Wire Height

The contact wire heights along the right of way will be 15'0" above the top of rail. The contact wire height in the yard will be 16'0" above the top of rail or above the roadway surface because of truck traffic beneath the wires. These heights are consistent with MBTA practice.

5.12.11 Contact Wire Gradients

The contact wire gradient changes shall be in accordance with the Stemman Gradient Method that has traditionally been used on the MBTA system. A transition span shall be required to bring about a change in the directional movement of the pantograph either upward or downward and to change from a different grade/slope. This shall be one-half, of the maximum gradient as calculated above, which is equal to one over ten (10) times the line's operating speed.

A flat or zero grade span shall be required when transitioning from one grade or slope to another.

A single-level, zero-gradient, catenary span shall be inserted in-between two different, plus and minus, gradients sections. No back to back gradient changes will be allowed.

5.12.12 Staggers

For mainline OCS; the contact and messenger wires shall be staggered on both tangent and curved tracks, with the relationship to the centerline of the current collector/pantograph. The stagger shall apply to both the messenger and contact wires so that both wires are on the same vertical plane. A maximum of 6 inches stagger shall be used from the center of the LRV pantograph.

The 6-inch stagger is based on the various classes of track allowances, LRV body and pantograph tilt, sway, movements; and OCS movements and construction criteria. Location of the pantograph over in relation to the LRV truck shall be considered.

This stagger shall apply to the maintenance facilities as well.

5.12.13 Tension Lengths & Span Lengths

Tension Lengths: The OCS shall be divided into individual sections called tension lengths. Each section is an end-to-end run of OCS wires. The approximate middle of an OCS tension length shall be fixed with the use of a midpoint anchor. The maximum distance between the midpoint anchor or fixed termination assembly and the last in-running cantilever before the counter weights shall be approximately 1750 feet.

Span Lengths: The distance between catenary pole locations is called the span length. The span length shall be maximized to reduce the number of structures and components. Conductor tensions will vary due to temperature changes and the effects of ice loading causing the messenger wire and contact wire to sag. The maximum span length design will take into consideration the following factors:

- Maximum structure spacing as a function of track curvature
- Conductor blow-off
- Permissible midspan static offset for contact wire spans over tangent tracks
- Permissible midspan static offset for contact wire spans over curved tracks
- Conductor along-track movement with temperature variation, and resulting stagger variation
- Pantograph security analyses for selected contact wire heights

5.12.14 Jumpers

Jumpers are assemblies used to provide a continuous supply of electricity between individual catenary sections, or they are used to maintain an equalization of voltage between the various wires of the catenary systems.

The following types of jumpers shall be used in the OCS:

1. Full Feeding Jumper – This assembly shall be used at locations where electrical current needs to be conducted between two adjacent catenaries. This shall consist of copper wires connected in a continuous loop from the contact wire to the messenger and to the messenger and to the contact wire of the adjacent catenary.
2. Potential Equalizing Jumper – This assembly shall be used at locations where electrical potential needs to be equalized between two adjacent catenary systems. This shall consist of one continuous copper wire connected from the contact wire to the messenger of the catenary requiring equalization and then to the adjacent catenary messenger wire.
3. In-Span Potential Equalizing Jumper – This assembly shall be used at locations where electrical potential needs to be equalized within a span of a single catenary system. This copper wire jumper is usually placed in each span of catenary, adjacent to the first hanger location, and secured to the hanger. This jumper shall consist of one continuous wire from the contact wire to the messenger wire.

4. Feeder Cable Connection – This assembly shall be used at locations where the feeders are to be attached to the catenary system from a substation, or switching location. This assembly consists of copper cables to be attached to the messenger wire.

Wires shall be clamped together with copper or bronze parallel clamps. Ends of the wires shall be arranged in the direction pointing away from the normal direction of travel.

Assemblies shall consist of various parts such as; parallel messenger clamps, parallel contact clamps, and flexible jumper wire.

5.12.15 Termination Assemblies

Termination assemblies are used to terminate the various catenary wires to a pole or wayside structure. The assemblies are insulated to isolate the electrical energy from the pole or termination structure.

Several types of termination assemblies shall be used in the OCS. They are as follows:

1. Simple Catenary Fixed End Termination Assembly – This assembly is used for the termination of both the messenger and contact wires to a pole termination bracket.
2. Single Contact Wire Fixed Termination Assembly – This assembly is used for the termination of a single contact wire to a pole bracket.
3. Messenger Wire Fixed Termination Assembly – This assembly is used for the termination of a single messenger wire to a pole bracket.

Typical assemblies shall consists of multiple parts, such as strain insulators, preformed wire dead ends, thimbles, ½" diameter steel guy wire extra high strength, turnbuckles, clamps, bull ring, messenger wire and contact wire dead ends, small part steelwork attachments, pole brackets, and other items needed to make a complete assembly.

5.12.16 Balance Weight

The auto-tension system shall be tensioned by the application of a pulley system, mounted on the exterior of the pole, and with a mechanical advantage of 2.0 for a single contact wire system and with a mechanical advantage of 3.0 for a messenger wire and contact wire system. The weight shall consist of a single cast iron unit, galvanized, and painted to match the pole color. A guide tube shall be provided with an attachment around the weight to restrict side movement. Two stops shall be provided to stop the weight from moving beyond the temperatures of zero degrees Fahrenheit and 120 degrees Fahrenheit. Design must also provide for a compensating plate with attachment holes to provide the required tension for the messenger and contact wires.

5.12.17 Mid-Point Anchor Assembly

The mid-point anchor assembly is used to anchor or hold the catenary and allow the catenary to expand and contract from that point. Mid-point anchors will be provided as required by the design and sound and proven engineering practice.

The assembly is comprised of the following basic components: turnbuckles, inline insulators, wire terminations, high strength steel cable, parallel clamps, steel links and pole brackets.

5.12.18 Cantilever Assemblies

The basic support assembly for the OCS is a cantilever assembly. A cantilever assembly is comprised of several steel pipes of varying diameters and lengths, positioned in a triangular arrangement to support the catenary system and to allow the required movement for the auto-tensioning system.

The different cantilever shall be utilized as appropriate, and include the following:

1. Push off – is used to push away the OCS to a staggered amount that is away from the centerline of the pantograph and the supporting structure.
2. Pull off - is used to pull the OCS towards the supporting structure a staggered amount that is inside from the centerline of the pantograph.
3. Simple catenary tangent track.
4. Simple catenary curved track.

Each assembly is sized to the loadings that may be applied by the OCS. The basic loadings shall be defined as light, medium and heavy. Some assemblies will be defined with one basic loading due to their application.

The loadings shall be a combination of the OCS weights applied to the cantilever and the radial loads being applied due to alignment configurations and catenary staggering.

The parts included in a cantilever assembly are as follows: pole clamps, swivel attachments, insulators, pipe connectors, clevis pipe clamps, pipe dead ends, "V" hanger assemblies, messenger saddle clamps, contact wire swivel clamps, and fittings to complete the assembly.

5.12.19 OCS Head-spans or Cross-spans

Head-spans are a single or multi-wire arrangement, placed between two supporting points, for the supporting and/or registering of OCS. Registering is the locating of the catenary over the pantograph, which is also known as stagger.

Head-spans shall be used where poles or supporting structures are not able to be placed directly adjacent to or in-between the tracks to accommodate a cantilever assembly. Any number of OCS elements can be supported or registered from a head-span arrangement. The head-span design shall provide for the double insulation between the individual OCS and the supporting structures.

The various parts included in a head or cross span mainline assembly are as follows: pole clamps, double clevis attachments, strain insulators, wire thimbles, hanger assemblies, messenger support clamps with pulleys, contact wire steady arms, turnbuckles, wire wedge and compression style dead ends, contact wire steady or pull-off arms, and other fittings to complete the assembly.

5.12.20 Portal Structure

A portal structure is a horizontal steel structural member placed between two supporting structural steel columns in order to support and register the OCS. Knee-braces shall be used for strengthening of the structure when necessary, and when clearances allow. See Chapter 2, Structural of this document for other portal design considerations. Portal structures are used for multiple tracks where a head-span arrangement is found to be not practical for registering of the contact wire.

5.12.21 Single Contact Pull-Off Assembly

The single-contact pull-off assembly is used for the pulling off or positioning of the contact wire to the outside of, or to the centerline of a pantograph travelling through a curve.

The various basic parts included in a multiple pull-off assembly are as follows: pole clamps, strain insulators, wire thimbles, messenger suspension clamps, contact wire pull-off arms, Y-clevis, turnbuckles, wire wedge and compression style dead ends, and other fittings necessary to complete the assembly.

5.12.22 Double Catenary Pull-Off Assembly

The double pull-off assembly is used for the pulling off or positioning of the catenary to the outside of, or to the centerline of pantograph travelling through a curve. The term "double" refers to two (2) catenaries being pulled toward a pole or supporting structure.

The various basic parts included in a double pull-off assembly are as follows: pole clamps, strain insulators, wire thimbles, messenger suspension clamps, contact wire pull-off arms, y-clevis, turnbuckles, wire wedge and compression style dead ends, and other fittings necessary to complete the assembly.

5.12.23 Catenary Hangers

Catenary hangers are used to suspend the contact wire from the messenger wire. The length of the hangers shall vary to maintain the contact wire in a level line between the support locations.

The Standard MBTA Hanger defined in MBTA Power Division Specification P-160 will be used in the majority of locations. Adjustable Insulated Hangers will be used in extremely low profile situations.

5.12.24 Insulation

All cantilevers shall maintain double insulation between the catenary wires and the structure or attachments. The simple catenary shall use insulated messenger wire clamping attachments in conjunction with secondary insulators attached to the mast brackets to maintain the necessary double insulation. All cantilevers shall be attached to the support poles with hinged brackets for single or center pole back to back applications.

5.12.25 Switching and Feeding Assemblies

Disconnect switches shall be used to isolate sections of the catenary from one another. The switches are manual or motor-operated as appropriate.

The components for the assembly are a blade style switch, usually mounted in a weather proof box; full feeding jumpers positioned either side of the switch, and insulated cables from the switch to the individual catenaries.

5.12.26 Miscellaneous Assembles

1. Catenary Wire Splices may be required to splice individual wires of the same type together. The messenger splice assembly shall be a compression type splice. Mechanical type splices may be used at dead ends and insulators in accordance with the design and sound and proven engineering practice. The rating of the splice shall be stronger than the messenger wire. The contact wire splice shall be constructed of bar stock and shall have a grooved configuration for insertion of the contact wires. The contact wires will be held in place by mechanical set screws which shall extend through the splice and through the top surface of the wire. The contact wire splice shall have a breaking strength rating greater than the conductor to which they are attached.
2. Switch Heaters are needed to heat the switch rails to eliminate the build-up of ice on the switch points and possible incomplete operation of the track switch. The heater shall be a metal rod placed in direct contact with the rail, and shall be powered by the catenary through a connection to the messenger wire or the supplemental along track feeder. The assembly basic components include the messenger wire or feeder connection clamp, insulated wire, fused disconnects box, switch heater rods, ground connection to the rail, conduit to support and protect the cables, and other attachments and hardware to make a complete assembly.
3. Contact wire bridge assemblies, are required where there is a direct crossing of two contact wires. These assemblies shall be used in overlaps, crossovers, and railroad turnouts. The intent is to control the uplift of the lowest of the trolley wires during the transition from one to another. The assembly is comprised of the

following basic parts: a metal bar and trolley clamps. The distance from the top of the in-running trolley wire to the bottom of the tube or trolley wire used in the assembly shall be approximately the height of the trolley wire, with a small gap for adjustment and floating purposes.

4. Shop Support Assemblies – The contact wire within the maintenance building shall be attached to an elastic hanger which will be mounted on an insulated block. The insulated block will be attached to a rigid support attached to the supporting steel structure of the building. The assembly shall be comprised of the following basic parts; elastic hanger, trolley clamps, and insulated block with appropriate fastening method.
5. Signals Switch Heater Assembly – The signal switch heater assembly shall be a conduit and wire system to bring the electrical power feed from the catenary to the switch heater control box. The basic components of the assembly are as follows: a fused disconnect and weather proof box attached to the catenary pole, conduit with strapping clamps for pole attachment, a messenger wire clamp for attachment to the catenary, and the insulated wire from the messenger wire to the power distribution box.

5.12.27 Down Guy Assemblies

There are two types of down guy assemblies used in the system. These assembly types are as follows:

1. Down Guy Assembly – This assembly attaches between the pole structure and the down guy foundation.
2. Down Guy Assembly – This assembly attaches between the pole structure and to the base of an adjacent pole structure.

Each assembly consists of various parts such as: shackles, preformed wire dead ends, thimbles, ¾" diameter steel guy wire extra high strength, turnbuckles, clamps, and small part steelwork attachments, and where necessary guy guards.

5.12.28 Sectioning of the OCS

Mainline: The OCS shall be electrically sectionalized by means of mechanical section insulators of the non-bridging type located near each substation. The OCS shall include sectionalization at crossovers, the yard, and/or other special track-work locations to provide flexibility for operations and maintenance. Section insulators shall be used at these crossovers, pocket tracks, turnouts, and siding locations.

The section insulator assemblies are comprised of the following basic items; messenger wire insulator, messenger wire dead ends, supporting hangers from the messenger wire insulator. Disconnect switches and jumper assemblies will be provided where appropriate.

Maintenance Building: The maintenance building shall be sectionalized in the following manner: the building shall be sectionalized from the yard; each track in the building shall be individually electrically fed; each track shall have a manually operated switch, and each door way shall have section insulators positioned each side of the door to provide a dead/non-bridging gap between the yard and the building.

For tracks with overhead access by personnel from the mezzanine level access shall be interlocked with the electrical condition of the contact wire.

Maintenance Yard and Storage Yard: The maintenance yard shall be electrically isolated from the mainline catenaries. The yard sectioning shall be arranged into smaller electrical sections/areas that can be energized or de-energized, in the event of an LRV incident.

The storage yard, shall be electrically divided at a minimum in half also to provide flexibility in operation and not to immobilize the LRV trains during an incident.

5.12.29 Lightning/Surge Protection

Lightning/Surge Arrestors shall be provided for the OCS for over-voltage and lightning protection. The arresters shall be rated to withstand the maximum system voltage and external induced voltages from other sources. The arresters shall be capable of discharging the energy resulting from lightning strikes to the ground.

Both sides of disconnect switches between power sections and all feeder riser cables shall be protected by lightning arresters. The design and installation of arresters shall prevent grounding of electrical circuit during catastrophic failure.

A connection from the OCS messenger wire to a lightning/surge arrestor which is connected to a ground rod or mat shall be provided at each feeder cable connection point to the messenger or contact wire (for trolley wire system). Other protection maybe installed because alignment or local conditions warrant.

Arresters shall be provided at the end of the track and all along the OCS on each side with the distance between the arresters not exceeding 1,000 feet.

The ground connection from the lightning arrestor shall be connected directly to a ground rod(s) or mat, with a resistance of not more than 5 ohms. Lightning/surge arrestor connection maybe combined with the pole/structure ground connection.

5.12.30 Warning Signs

Warning signs shall be attached to the OCS or the supporting structures to warn personnel of the proximity of high voltage wires. Signs shall be attached to the OCS to denote the end of the electrified wires over the track(s).

A "high voltage" sign shall be attached to the OCS structures in station areas, and also can be used along the railroad right-of-way.

A "Danger Live Wire" sign with a lightning bolt symbol shall be used in the yard facilities or at crossings along the right of way.

An "Electric Train Stop" sign shall be attached to the OCS to warn an operator the OCS is ending and there is no further electrical service.

Each sign shall be composed of large lettering which is clear to be read. The basic colors to be used on each sign are red, black and white. The white color is the basic background color. Exact sign layouts will be subject to approval by the MBTA.

5.12.31 Pole Number Signs

Each pole shall have a number sign applied to the surface of the pole. The sign shall be a metal tag with raised numbers in black. Where the poles are placed on the outside of the track, preferred installation shall be to locate pole number sign on both side of the OCS Pole and at minimum an OCS Pole number sign should be installed on the side of the pole facing normal direction of travel. For poles placed in the center of the track, the number signs shall be placed on each face facing the direction of travel. Pole numbering signs shall be in accordance with MBTA Power Department specifications.

5.12.32 Poles and Foundations

Poles in general shall be galvanized I-beam, except those requiring a special type other than an I-beam, and installed in direct concrete embedments. At station platforms, the pole embedments shall be built separately from any part of the passenger platform, and other facilities. All poles, except those mounted on selected structures, shall be installed in direct concrete embedments. Poles on the new viaduct section shall be supported by means of anchor bolts cast into concrete supports. (See Chapter 2, Structural for more information.) A bonding cable attached between the pole and a ground plate installed, as part of the foundation installation, shall ground each pole only if a direct ground cannot be obtained. This shall be a welded connection. The ground strap shall be installed in such a manner as to minimize theft of the strap. The pole, foundation bolts, reinforcing bars, and ground rod shall be electrically connected.

Poles on the historic viaduct shall be set into the existing hole in the pier railing in the same manner as the existing poles to be removed. They shall be connected to the pier floor below the walkway inside the pier in a similar fashion to the existing poles. The pole shall have a sleeve encircling it at the pier railing opening in the same manner as the existing pole to secure and seal the pole and opening. Poles shall be three section tubular steel poles of sufficient strength and rigidity to meet deflection and loading but shall be of the same outside diameter as the existing ones. All poles shall be of the same size and height. A decorative pole hood of the same shape, configuration, and size as the existing pole hoods shall be used at the top of the pole to protect the interior of it from the elements.

5.12.33 Pole Sizes

Poles shall be sized in accordance with NESC Rule 260 and limited to no more than five or six types to simplify application.

5.12.34 Anchor Bolts

Anchor bolts shall be sized to resist the maximum design loads imposed on the poles with the corresponding pole overload factors. In order to avoid the problem of having numerous anchor bolt patterns during construction, the design shall standardize the anchor bolt arrangement into two patterns. These patterns can be used on several pole sizes. The bolt pattern for the down-guys shall be placed in such a manner that the anchor base plate shall line up with the direction of pull.

5.12.35 Pole Deflection

Pole deflection plus foundation rotation during train operation shall not exceed 2.0 inches at contact wire height. Pole deflection at the top of the pole under NESC heavy loading condition shall not exceed 3% of the pole length. Overload factors shall not be applied in the calculation of pole deflection.

5.12.36 Foundations

Foundation design shall be coordinated with the track, facilities, and any discipline of design. The design and construction of the pole foundation and guy anchor foundations shall conform to established civil and structural engineering practices, ASTM and ACI standards. The foundations shall be reinforced concrete and shall be capable of withstanding the design load imposed during installation, operation and maintenance.

5.12.37 Down Guys

Catenary terminations at poles or structures shall be accomplished by a double wire down guy. These down guys reduce the bending moment applied to the pole and foundation. The down guy foundation may be of an augured type cast-in-place reinforced concrete similar to pole foundations, a screw anchor type, an attachment to the base of an adjoining pole, an attachment to a wall, or an attachment to a separate foundation type. The selection for the foundation type will be based on the individual situation. Also included is a single down guy for all mid-point anchor assembly locations.

5.12.38 Pole Grounding and Bonding

Poles embedded in concrete foundations will typically be grounded to earth and additional grounding may not be necessary. All poles, including poles on piers, decks, at the top of retaining walls, or embedded in concrete, will be measured for ground resistance.

All OCS support structures shall be grounded to a total ground resistance not exceeding 25 Ohms.

5.12.39 Any Pole or Structure that does not Meet Grounding Requirements shall be Grounded by Two 4/0 AWG Copper Stranded Wires to Separate Ground Rods. Pole Placement or Spacing

Pole spacing shall be maximized as much as possible to reduce the number of structures and components. The typical pole spacing along tangents will be 150 feet with a closer spacing on curves using a spacing of twice the curve radius, and in special areas.

5.12.40 Bridge or Overhead Structure Attachments

Attachment to overhead bridges or overhead structures shall not be used unless other methods are not available. In instances with clearance limitations or where bridge spans are greater than the allowable OCS span, attachments may be required. On overhead bridges, a soft suspension assembly shall be used to minimize pantograph bounce and loss of contact between the pantograph and contact wire.

5.12.41 Overhead Bridge Protection

In order to prevent the possibility of persons or objects coming in contact with a live catenary system and the grounded structure, protective fencing shall be provided. At locations, where the catenary passes under overhead structures, that are equipped with sidewalks or walkways and there is less than 10 feet of clearance to the nearest wire, highway fence is preferred. The exception is when an existing bridge cannot be retrofitted with an anti-climb fence. In that case, a protective barrier or guard shall be placed over the catenary on both tracks on both sides of the overhead bridge.

5.12.42 Over-grade Bridge

Where the catenary and track are supported by over-grade bridge or aerial structure, all metallic materials attached to the bridge shall also be attached to the electrical drainage connections. Where poles are to be mounted, the pole ground shall be attached to the electrical drainage connections.

5.12.43 Construction Tolerances

The following are system-wide allowable construction tolerances:

a.	Contact wire height at all locations	-0” to +1”
b.	Messenger wire height at all locations	+/- 1”
c.	System depth	30”+/- 1½”

5.12.44 Commissioning and Factory Tests

All overhead catenary system equipment mentioned above shall undergo complete factory and onsite inspections and testing as required by the applicable standards and in accordance with the manufacturers’ recommendations. Qualified testing firms shall certify all testing.

5.12.45 Pole Attachment to Walls

Due to right of way width constraints and the potential for pole foundations to conflict with drainage lines and other underground utility lines, it will be necessary to use wall structures to support catenary poles in some areas. The standard wide flange catenary pole will be attached to the wall soldier pile at steel soldier pile locations.

- Where walkway clearance is an issue and wall height allows, the bottom of the catenary pole will be located a minimum distance above the walkway which meets NFPA 130 requirements.

- The soldier pile that the catenary pole will be attached to shall be strengthened to accommodate the additional load as well as loss of cross sectional area over time. A minimum of 1/16 inch of steel thickness corrosion loss on the entire steel section shall be assumed. The soldier pile adjacent to the attachment on each side will also be similarly strengthened so the attachment could be moved if necessary.

- In addition to the specified hot dip galvanizing for all soldier piles, the soldier piles with catenary pole attachments (as well as the adjacent piles as noted above) will be protected from corrosion through the application of coal tar epoxy coating. The pole shall be coated from a minimum length of six inches below the concrete soil interface (six inches into the concrete) to a minimum of twelve inches above the soil/air interface. Specifications shall require that any hot dip galvanized steel damaged during handling or installation shall be repaired.

5.13 Communications

5.13.1 Supervisory Control and Data Acquisition (SCADA) Requirements

The current supervisory control and data acquisition (SCADA) system expansion shall be established to permit monitoring and controlling key elements throughout the facility, including any remotely located equipment or facilities, from the MBTA Operations Control Center (OCC) and hub monitoring facilities. The SCADA system is referred to as the Hub Monitoring and Control System (HMCS).

- The Operations Control Center is located at 45 High Street, Boston, MA, operated by MBTA.

- The HMCS includes local hub monitoring facilities that include security monitoring capabilities. The location of the hub monitoring facilities shall be coordinated with MBTA Operations and Security Personnel.

The architecture of the SCADA system shall employ a fail-safe network topology. Each programmable logic controller (PLC) shall be designed with a redundant "hot-standby" configuration, capable of a seamless transfer of data upon a failure of the main processor. Additionally, the programmable logic controller shall be equipped with redundant power supplies.

The SCADA system shall employ a universal remote input/output network protocol, allowing different networkable devices the ability to communicate with the programmable logic controller. Remote input/output (RIO) cabinets shall be distributed throughout the facilities in order to minimize "hard-wired" cable runs between field devices and the SCADA system. Each remote input/output cabinet shall be designed to accommodate the required number of points for digital input (DI), digital output (DO), analog input (AI), and other data modules as needed, with an additional fifty percent (50%) spare of each point type (DI, DO, AI, etc.). The remote input/output cabinet shall be housed in a NEMA 4X cabinet sized to accommodate the required number of input/output modules (including spares).

The design of major mechanical and electrical equipment shall incorporate provisions for communication, control, and/or indications, via normally-open and normally-closed contacts, transducers, and auxiliary relays.

The SCADA (HMCS) system shall aggregate all station and communications alarms as well as door access inputs secondary to the Access Control System.

The Hub Monitoring and Control System (HMCS) system will monitor and control the following systems at the stations:

- Fire alarm system
- Escalators
- Elevators
- AFC fare vending equipment

Alarm conditions will be transmitted to OCC and other designated locations to dispatch emergency or maintenance staff as appropriate.

An Input/output points list to include all spare points shall be required.

The HMCS system interfaces at the Station through a Programmable Logic Controller (PLC). The type used by MBTA is a General Electric Fanuc 90-30 series or a later generation of equipment as approved by the MBTA. The PLC backplane used shall be the 10 slot frame with the 350 or current equivalent central processing unit (CPU) type. The PLC shall be configured to interface with the monitored station equipment through Contact Closures, Contact Opens or Analog Interfaces (Discrete Inputs, Analog Inputs, PA). Equipment to be controlled shall be interfaced through Contact Closures, Contact Opens and Analog Interfaces (Discrete Outputs, Analog Outputs).

The PLC shall be mounted on an appropriate DIN rail or 19" rack mount as required by the final design. The PLC shall have an emergency power source such as a UPS to supply power for the specified time period during a station emergency power outage. The PLC and termination interfaces shall be located in the Station Communication Room.

The terminal interfaces between the PLC and the monitored and controlled station equipment shall have Phoenix Protection Blocks to direct any input voltages over the specified limit to ground.

The PLC shall be networked to the Station LAN and programmed with an IP address to comply with the MBTA Station Address standard. The network shall be through an IEEE 802.3 RJ-45 port supporting a standard Ethernet interface. The PLC shall also have an RS232 port for local craft access.

Identification, testing and documentation of the PLC I/O points shall be the responsibility of the contractor. Addition of each station's I/O points to the HMCS database shall be the responsibility of the MBTA Communications Section. Addition of the Monitor and Control screens to the HMCS system shall be the responsibility of the MBTA Communications Section. Testing, confirmation and certification (sign off) of the accuracy of the HMCS screen to Field equipment shall be a joint procedure with the Construction Contractor and the MBTA Communications Section.

Interface wiring design drawings shall be submitted to MBTA Project Engineer prior to installation and as-built drawings with test results and operation certifications of each stations PLC shall be submitted prior to final system testing.

The HMCS system is described in detail in the MBTA Specifications for Hub Monitoring and Control System. The Station PLC is described in detail in the MBTA Specification Section 16415, Programmable Logic Controller.

5.13.2 Telephone

This system shall consist of two separate and distinct elements: 1) the Public Switched Network (Verizon Centrex) and 2) the MBTA Voice over IP (VoIP) circuits. Equipment shall be designed to preclude a single point failure from potentially causing loss of all telephone capability. The system design shall utilize VoIP for Customer Information and emergency kiosks and maintenance telephones to meet operational requirements. Wayside blue light emergency telephones shall use Centrex.

RJ-11 Telephone and RJ-45 Ethernet data cabling shall be installed and tested in each Station room, lobby and platform as required by the MBTA Communications Section. All telephone and data cable shall be terminated in the Station Communications Room at industry standard communications blocks. CAT-6 cable shall be used to connect each Telephone port to a standard TIA/EIA punch down block cross connect. CAT-6 cable shall be used to connect each RJ-45 Ethernet port to a standard Ethernet termination and distribution panel before being connected to the Station Ethernet switch with CAT-6 jumpers. All CAT-6 cabling shall be tested to 100Base T standards.

Telephones shall be supplied by the Contractor at points specified by MBTA Communications Section and shall meet MBTA requirements for use suitability (wall mount, table top, hardened, etc.) to include elevator telephones with automatic called capability to the OCC and Transit Police.

The Telephone/Data system is described in detail in the MBTA Specification Sections 16420, Centrex Line Telephone System, 16711, Inside Plant Voice and Data Cabling, 16718, Wayside Telephone System and 16790, Internal Wire and Cable.

5.13.2.1 Wayside Telephones

Wayside telephones will be provided along the Right of Way at crossovers, signal houses, and in accordance with NFPA 130 requirements. These phones will allow operators and other workers to communicate directly with the Operations Control Center (OCC).

The Wayside Telephones shall be configured with the MBTA Station Centrex System. The Wayside Telephone system shall be required to have the same emergency uptime requirements as the station emergency telephones. The design shall consider the local Exchange Carrier, Verizon, to configure no more than 3 telephones per Centrex line and to configure numbers and locations of the phones to be able to provide physical locations of the phones to the Transit Police or any MBTA Emergency Services section.

12 pair CAT-6 cables shall be installed to all phone locations with one pair in each cable supplying voltage for the LED signs at the top of the kiosks. Weather resistant, 2 line telephones shall be supplied for installation in these wayside phone locations. The lights at the top of the kiosk shall be blue with impact resistant covers as noted.

This work is governed by the latest revision of MBTA Specifications Section 16718—Wayside Telephone System and NFPA 130 as applicable.

5.13.2.2 Wide Area Network (WAN)

The MBTA will use a new 10 Gb/s Ethernet network for communications between facilities since their legacy SONET Wide Area Network (WAN) is at capacity limits. The 10 Gb/s network will interconnect computers and equipment at all stations and facilities and connect to the OCC. A Fiber Optic cable design and installation consisting of one 96 strand single mode communications cable and one 96 strand fiber optic single mode signal cable shall interconnect all of the GLX Stations and Vehicle Storage and Maintenance Facility. The Fiber Optic cables shall be run on opposite sides of the Right of Way on messengers along the OCS catenary poles where allowed with the exception of where the cables enter and leave stations where the cables shall be run inside combined station conduits. The new fiber optic cables will primarily be installed aerially on the OCS catenary poles where applicable along the GLX corridor. New Fiber Optic cables shall be installed through existing tunnels complete to the OCC at 45 High Street. The 96 strand communications fiber optic cable will terminate at the new GLX station communications rooms and at the following existing communications rooms/locations: the Science Park Signal Room, the North Station/Garden Communications Room, the North Station Superstation Communications Room, the Haymarket Communications Room, the State Street Communications SWR Room, the DTC Red Line Vault Room, and the Second Floor of 45 High Street, The new 96 strand fiber optic cables shall provide network connections from the field to the new WAN and SWAN systems at 45 High Street. The Fiber Optic cable plant shall support the GLX general purpose network, or “Corporate Network”, the switched Ethernet network for the Secure Stations CCTV project (called the Security WAN or “SWAN”), and connectivity for AFC, Public Address, MCS (PLC) and AVAYA VoIP Network System.

A separate Fiber Optic cable shall be installed to support the Signal System. Refer to Section 6 “Light Rail Signals”. Communications Fiber Optic cables shall demark at stations then separate single mode fiber optic cables and copper cables for communications functions shall be installed to Signals Bungalows and rooms, Sub Stations (TPSS) and other sites not located on station platforms. Telephone and security network connections to signal bungalows and rooms shall be via the local communications fiber and copper cables.

The cables shall be physically isolated, with one cable running on the west side of the light rail infrastructure and the other cable running within the signal cable troughs. The cables will provide fully redundant communications capabilities. Traction power substations and the new Vehicle Storage and Maintenance Facility shall be connected to the fiber network. The Maintenance Facility shall have a direct Fiber Distribution Cabinet on one of the main Fiber Optic Plant but the TPSS stations shall be connected to the Fiber Optic Plan through the nearest station FDC. Cables shall be mounted on catenary poles as reinforced aerial cable, or as ROW space permits, as buried cable or run in conduits along the corridor. In areas where trough is provided, the cable will be installed in trough.

All fiber optic cables along the right of way on messenger, within troughs, and in conduit shall be routed within 1.5 inch innerduct.

Splicing shall not be allowed on the right of way. A minimum of 50 feet of slack fiber shall be provided for each fiber bundle at all bungalows or termination panels. The slack shall be properly coiled in a means or enclosure designed to properly handle the fiber.

The WAN switch installed at each station shall provide the Station Local Area Network with its redundant Wide Area Network connection. The Final Designer will coordinate with the MBTA, the WAN maintenance contractor, and the CM/GC team to ensure all Ethernet nodes are properly configured.

The Station Ethernet switch shall provide an interface for Station Ethernet systems installed under this project to communicate over the WAN. The Station Ethernet switch is critical to the proper operation of the Automated Fare Collection (AFC) Equipment; and the Hub Monitoring and Control System PLC as these systems will utilize the Station Ethernet switch to transport data. The Station Ethernet switch shall support data and voice. AFC connections shall be MultiMode Fiber Optic cable via an additional Ethernet switch, separate from other systems.

The Secure Stations Ethernet switch shall connect to the Fiber Optic plant directly and connect to local Ethernet switches with Power over Ethernet supporting all CCTV video connection and traffic at each station. The Secure Stations Ethernet switch at the station will also connect to the Network Digital Video Recorder servers. The Secure Station Switched Ethernet network shall also provide connectivity and security for the Security Access Control system. The Secure Stations Ethernet switch shall be specified in accordance with current MBTA standard security specifications and guidelines. A secondary switch shall be used as needed to limit cable lengths to no more than 300 feet.

The general purpose Wide Area Network and Secure Stations Ethernet switches shall be located in each Stations Communications Room. All Fiber Optic connections shall be located in separate Fiber Distribution Cabinets in each Stations Communication Room. An auxiliary communications room or cabinet will be used to house secondary Ethernet switches for distribution.

The Union Station Branch shall be equipped with two 96 Strand Fiber Optic cables – one for communications and one for signals - providing redundancy, which will also connect to the main Fiber Optic plant network at the Communications Room at Lechmere.

Software for the WAN and the SWAN shall be specified by MBTA Communications and installed by the Contractor as required to configure complete and integrated networks.

All Communications network elements will be supported by the UPS and Station Emergency power as required to meet eight (8) hours of standby time.

The WAN and SWAN systems are described in detail in the MBTA Specification Section 16400, Basic Communications Requirements, Section 16401, Fiber Optic Cable System and Section 16717, Fiber Optic Communication System.

5.13.2.3 Station Local Area Network (LAN)

The Station Local Area Network (LAN) shall provide the station interface to the Wide Area Network (WAN) via the Station Ethernet switches, to the station Public Address System, Variable Message Signs System, Fare Collection System, Hub Monitor and Control System and Station PLC.

The Station LAN and CCTV "Secure Stations" LAN's shall be designed and installed separately and connected to separate WAN's as required by MBTA.

The Station LAN shall provide IEEE 802.3 RJ-45 port Ethernet connectivity over CAT-6 cable and Single Mode and MultiMode Fiber Optic Cable with media converters as required to meet IEEE standard distance specifications for 100 Base T, 1000 Base T and Fiber Optic Gigabit Ethernet speed capacity as required by the subsystem the LAN connects. The Station LAN switches shall be of standard manufacture to meet MBTA performance specifications and provide SNMP remote monitor and control functions as well as a local RS-232 craft interface.

The Station LAN elements shall be powered by UPS in the event of a station emergency to meet the uptime requirements of the subsystems it supports.

The LAN system is described in detail in the MBTA Specification Section 16400, Basic Communications Requirements, Section 16401, Fiber Optic Cable System and Section 16717, Fiber Optic Communication System.

5.13.2.4 Customer Information Call Box

Information call boxes will be provided at all stations. The equipment will be VoIP and compatible with the existing Passenger Assistance Supervisory System located at Authority's Police Station at 240 Southampton Street and with the Authority's Customer Call Center located at 10 Park Plaza. Separate call buttons shall indicate "Emergency 911" and "Customer Information".

The audio path between the various stations, the Police Station, and the Customer Call Center shall be over the SWAN.

The same Call Box Telephone shall be used for both Emergency calls and Customer Information. Separate call buttons shall be clearly marked for each function. All markings shall also comply with Federal ADA standards for public use as well as meeting local equal access agreements with the Boston Center for Independent Living (BCIL).

Locations of the Telephone Call Boxes (kiosks) as well as Call Box design shall confirm to Federal ADA standards. The telephones shall be powered during Station emergencies

The telephone units shall be of a hardened design with a "Police Assistance" LED sign at the top of the call box.

The Customer Information Call Box system is described in detail in the MBTA Specification Section 16445, Passenger Emergency Telephones (Customer Information Call Box) and Section 16447, Elevator Intercom System.

5.13.2.5 Verizon Demarcation

The Verizon demarcation point shall be a locked cabinet adjacent to the Station Communications room or within the Station Communications room in a separate locked area. All Verizon Centrex and other Voice and Data Circuits shall interface with Station systems at that Point of Presence.

If the use of Voice over Internet Protocol (VoIP) telephone systems is determined for use in the GLX project the Verizon demarcation shall be included in the design at Stations and the Vehicle Storage and Maintenance Facility.

All Verizon equipment shall be powered by an appropriate UPS system to allow full feature operation during station emergencies.

The design shall provide for interface with Verizon during the Design and Specification phase of the project to allow sufficient time for the Local Exchange Carrier to plan their provisioning as well as provide input for the design team for the Demarcation space, including required racks or cabinets and access.

The Telephone system is described in detail in the MBTA Specification Sections 16420, Verizon Centrex Line Telephone System, Section 16520, Communication Room Requirements.

5.13.3 Closed Circuit Television (CCTV)

A Closed Circuit Television (CCTV) system shall be provided as a means of visually monitoring and verifying reported incidents from the MBTA Operations Control Center. Cameras shall be located to provide coverage of the public segments of the paid station areas and selected areas in and around the stations. Additionally, CCTV cameras shall be provided to allow coverage of the maintenance facility and all controlled access areas including the perimeter of the facility and the storage tracks. The CCTV system design shall utilize camera types and all system components which shall interface with the current CCTV Management system provided by VidSys.

Camera locations and views design shall be guided by the Secure Stations initiative and by MBTA Security section personnel. Some camera locations shall include:

- All access controlled doors
- FVM locations
- Fare Gates
- Interior of the Fare Controller location showing the Controller
- Customer Emergency and Information Telephone kiosks
- Elevator doors and interiors
- Escalator and stairs facing the direction of passenger flows
- Platforms including platform ends
- All pedestrian track crossings
- Other locations indicated by Industry Best Practices and MBTA Security and Operations

The CCTV system shall be a real time IP video system working in conjunction with the Hub Center Digital Video System. The system will utilize new IP cameras within the stations and transmit live and recorded video via IP to various monitoring locations.

Station design shall consider the location of CCTV camera monitors at the head end of each platform so that consist operators have camera views of the platform as are located at several Green Line Stations. Coordination with both MBTA Security and Operations sections shall be considered for this feature.

The CCTV system will use the separate MBTA Security WAN as a means of transmitting IP video to locations on the WAN. The system will incorporate the expansion of the MBTA storage network for Networked Video Recorders (NVR's) to accommodate storage for the new cameras and shall include any and all hardware and software that may be required to transmit/receive video over an IP network for a complete and functional system.

CCTV camera location design shall consider views of bus stops, bicycle storage and parking lots associated with the stations.

The current MBTA "'Secure Stations" project is implementing a Security Network which is relocating and increasing the bandwidth available for streaming station camera images to image storage as well as is increasing the number and location of station cameras. The results of the project will indicate the direction of the CCTV system design for the GLX stations and facility. NVR location design shall consider aggregation of several station camera image streams into the central CCTV image management system or into a designated field location. The NVR will have the capability to transmit live and recorded video over the WAN to other users.

Each station will include an uninterruptible Power Supply that meets or exceeds the following specification: 750VA Rack Mount UPS, Input 120V-208V/ Output 120V, Battery Runtime at full load: 7 Minutes.

Sufficient numbers of Ethernet switches providing power over Ethernet ports of adequate wattage to provide IP cameras with power shall be provided, installed and configured as part of the design. Communications closets shall be implemented to house Power over Ethernet (PoE) switches in order not to exceed Cat 6 cable distance limitations. In no case shall Ethernet extenders be used. The station CCTV LAN shall meet the requirements of the Station Security Network. The design shall confirm with MBTA regarding the total number of PoE ports to be installed and provisioned, including ports set aside for maintenance and future capacity.

5.13.3.1 Camera Types

Camera types used in the CCTV system design at each station shall utilize Pan, Tilt, and Zoom (PTZ) as well as fixed view IP cameras to meet the required views of the platform, mezzanine, access controlled doors, Fare Vending Machines and gates, and any areas designated by MBTA Safety and Security personnel.

The CCTV system is governed by the MBTA Secure Stations Initiative specifications.

Cameras shall support dual streaming output and shall utilize IP Ethernet connectivity.

Cameras utilized at above grade and at grade stations shall be equipped to automatically clear their lenses and protective covers from the elements under all types of weather conditions.

Fixed cameras shall utilize Varifocal lenses to enable camera views to be tuned on site. Cameras shall also include optical image stabilization to cancel the effects of shake and vibration.

A rigid mounting of the cameras is essential to provide vibration-free images on the monitors in the control room. Where cameras must be mounted on poles, the poles and enclosures must be designed to withstand a 100 mph wind load and still maintain a usable image.

The exact location of each camera and default PTZ orientation shall be determined through the above criteria tempered by the presence of objects which may obstruct view.

Cameras shall be installed at any vehicle or pedestrian crossing of GLX and Commuter Rail tracks in the station facility vicinity to observe activities. IP Cameras requiring PoE connectivity which are more than 384 cable feet from a PoE switch shall be connected with fiber optic cable with a media converter and a POE injector near the camera or camera cluster. Fiber to Ethernet cable media converters shall be managed and have SNMP status reporting capability.

Many of the cameras will be mounted in locations which will require protection from natural elements. Such locations which require special blowers or heaters which keep camera or enclosure lenses clear shall require additional power. Other Locations and camera view requirements will require Pan, Tilt and Zoom enclosures which also may require additional power in addition to that wattage from a PoE switch. These additional power sources shall be provided by the GLX project and shall have emergency power such as UPS to insure continuous service during station emergencies. Conduit requirements for these separate power sources shall be determined by the level of voltage and wattage delivered and by EMI protection requirements.

Building (access control): Cameras shall generally have heavy duty pan, tilt and zoom (PTZ) capability. NEMA 4X rated, dome type color cameras shall be used throughout facility as a part of the access control system. Cameras shall have the following additional attributes:

- Solid state design
- Vandal resistant dome enclosure
- Automatic focus lenses with auto-iris
- PTZ controllable from the control rooms
- Low light black and white mode
- Digital “flipping” function

5.13.3.2 Camera Operation

The output signal of the camera shall be compatible with the existing video management system. The design will utilize standard Cat-6 cable from the camera to the communications rooms and shall support PoE Plus where the camera design requires.

Video will be saved to a storage area network utilizing a RAID 5 + 1 disk storage configuration as defined by the MBTA Secure Stations Initiative specifications.

5.13.4 Fire Detection and Alarm

The fire detection system (FDS) shall be a distributed intelligence addressable type system. It shall primarily be comprised of microprocessor based; intelligent type local fire alarm control panels (FACPs), and associated peripherals, which are located throughout the project. The FACPs shall connect to the supervisory control and data acquisition (SCADA/HMCS) system, and be supervised in accordance with NFPA72. The FACP shall automatically report alarms to the local fire department. Alarms shall automatically report in parallel to the MBTA OCC via the HMCS. Consideration of the ability of the Fire Alarm system to be able to remotely display the status of all alarm sensor locations shall be included in the design.

Installation and locations of all fire alarm initiating devices shall comply with the requirements of NFPA 72, and the appropriate Fire Departments.

System requirements/functions include:

- All devices, equipment and components relating to the fire detection system shall be listed by Underwriters Laboratories, Inc. (UL) and/or approved by Factory Mutual Research Corporation (FM), for fire detection system signaling purposes.
- The capability of detecting fire by automatically sensing heat, smoke, flame, water flow or by accepting manual fire alarm pull station initiation.
- The system shall be a class a (style D) supervised system. All initiating circuits, control circuits and indicating circuits shall be independently supervised for opens, shorts and grounds that impair the function of the system.
- Battery backup power supply shall be provided at each local FACP. Battery backup power supply for the local FACP shall be a storage battery and charger complying with the requirements of the Fire Departments and NFPA Standard 72.

Fire alarm systems will be provided at each station and at the maintenance facility. The system is a microprocessor-based multiplex control system utilizing distributed processing techniques that gathers and reports data over a network of panels. The network will consist of a FACP and Intelligent Remote Control Transponder Panels, which integrate peripheral devices over the multiplex network. Data communications between panels, if necessary, shall be accomplished through regenerative digital transmission techniques, which enable complete stand alone or sub network operation of remote panels in the event of a primary CPU or network communications failure.

MBTA preference is to transmit alarm signals to SCADA. Station fire alarm shall include direct notification of the host city. (For Ball Square Station, signal shall notify both Medford and Somerville.) The fire alarm system is not intended to be a mass notification system remotely.

The system will have full analog sensing capabilities; will be able to identify the exact location of every sensor and monitored device in the system, and will operate as described elsewhere in the MBTA specifications (MBTA Specification Section 16705—Station Fire Alarm System, rev. 2/2006 or latest revision).

5.13.4.1 Device Requirements

All field mounted devices shall be listed by UL and/or Factory Mutual Research Corporation for fire protective signaling system purposes, and shall comply with the requirements of the NFPA, the Fire Departments, and the following:

- Spot heat detectors shall be of the self-restorable type. Air duct detectors shall operate on a cross sectional air sampling principle.
- Manual fire alarm pull stations shall be of double action type, and shall have the feature of indicating operation physically until reset. The means of resetting the manual pull stations shall be other than a break glass rod. No glass shall be employed in a manual fire alarm pull station.
- All fire alarm pull station locations shall comply with the requirements of the various Fire Departments.
- All field mounted devices shall be commercially available, and shall be suitable for the location of its intended use.
- Rate of rise detectors are not permitted without special permission of the Fire Department involved.
- Annunciation devices will be provided as appropriate for the safe evacuation of all public and MBTA /secure spaces.

5.13.4.2 Buildings

Automatic fire detectors shall be provided for the stations and buildings, including air plenums of the building HVAC systems, except areas protected by automatic sprinkler system or other fire protection system.

Smoke detectors shall be provided for areas, whether protected by fire suppression systems or not, which are used to store high value or critical equipment or supplies. This includes areas such as electrical/utility closets, etc.

Manual fire alarm pull stations shall be provided for some constantly occupied locations, and at each means of egress from the building, to provide manual emergency fire reporting. The location of all manual pull stations shall conform to NFPA 72.

Water flow sensors and tamper switches for all building automatic sprinkler systems shall be provided. Addressable interfaces to the FDS shall be provided for these devices, and outputs, taken from other control panels, such as fire pump control panels, etc., if those other control panels are UL and NFPA approved for fire alarm reporting.

Magnetic door holders and smoke detectors used for triggering door holders shall be addressable.

A graphic type remote annunciator that shows the floor plans of a building or buildings and associated areas covered by the fire detection system, shall be provided near the main entrance of each building, or other locations required by the Fire Departments, The FACP location(s) shall be indicated on the annunciator floor plans, and a "you are here" arrow indicating the annunciator location shall be fully visible on the annunciator.

A red beacon acceptable to the local Fire Department and connected to the building FACP(s) shall be installed outside of each station and building to indicate the location of the annunciator to the Fire Department. The beacon location shall be coordinated with the annunciator location.

A remote detector indicator shall be placed above the door to any locked room or electrical/electronic rooms. Electrical /electronic rooms shall include any electrical rooms or closets, all TSCS related electronic rooms, UPS electronics rooms, etc. Generator and battery rooms do not require remote indicators.

Master boxes shall be located within the buildings, proximate to the FACP's. The final locations for the master boxes shall be approved by the appropriate Fire Department.

5.13.4.3 Special Conditions

For some special areas or conditions, additional design requirements and consideration are to be provided as follows.

- Rooms such as electrical equipment room, communication room etc., shall be a separate fire zone from the other areas in the building. Smoke detectors shall be provided in these areas.
- These devices shall be directed towards the work yard or storage area.

5.13.5 Radio Communication

The current Land Mobile Radio Communication system operates in the 800 MHz band as licensed by the FCC. The legacy 470 MHz band radio system will not be used to support GLX operations. The MBTA shall provide either a propagation study or field test reports or both verifying radio coverage for the 800 MHz radio system along the GLX corridor that will include activation of the planned primary site at the John Hancock building.

The design shall consider propagation needs of the new 800MHz Trunked Radio system along the extended Green Line right-of-way for voice and data as required by the new Radio system. It is anticipated that a Bi-Directional Amplifier (BDA) and UPS will be provided at each station. Radiating coaxial cable and antennas will be provided for the necessary coverage in public and non-public areas of the stations.

The Final Design Team will coordinate with the MBTA to determine the level of effort required by in-house forces should additional radio coverage be required along the GLX ROW. A likely location for the full function Transmitter and Receiver site will be the Vehicle Maintenance Facility. A full 48 rack unit shall be needed for the full function site. Space for the full equipment rack shall be included in the communications room design.

In addition to BDAs to extend coverage into traction power substations and signal bungalows, it is also likely that the Maintenance Facility building will require BDAs to insure proper radio connectivity.

Sites for BDA antennas at each station and the Vehicle Maintenance and Storage Facility (VMSF) shall be coordinated with the station and VMSF design.

The Radio system is described in detail in the MBTA Specification Sections 16500, Basic Radio Requirements, 16505, Radio Subsystem, and 16510, Radio Antenna System.

5.14 Access Control

The access control portion of the access control & intrusion detection (AC & ID) system shall be used to control the movement of persons through site areas, facilities, secure areas, buildings, and vehicle parking facilities. Requirements of the access control portion of the system, at a minimum, are the following:

- Access to any area in which equipment and/or other items are stored, for which the replacement cost is estimated to exceed $10,000.00 shall be controlled by card reader. All access controlled areas shall be confirmed by MBTA Safety and Security personnel.

- Access to any area which is designated as "restricted" by the MBTA shall be controlled by card reader.

- All card readers which are located "outdoors" i.e., perimeter card readers, parking lot card readers, etc. and any other card reader designated as "intercom required" by the MBTA shall be equipped with an intercommunication device, which shall establish bi-directional communication between these card readers and the remote and local operations control rooms. Card Readers shall include protocols utilized currently utilized by MBTA’s proximity cards.

- All MBTA employee parking facilities shall be provided with an entrance gate controlled by a card reader. Use passive proximity type cards with photo identification capability, card readers, electromagnetic locks, and electric door strikes.

- The CCTV System shall provide camera views of all doors which are Access Controlled.

- The Access Control System components utilized at the stations and facilities shall interface with and be controlled by the existing MBTA Lenel OnGuard system. The Access Control System shall utilize the MBTA Security Ethernet SWAN for communications.

- All Lenel controllers, door access equipment, and card readers shall be Lenel compatible and installed by qualified and certified Lenel technicians. Changes to the existing central systems to configure the field equipment shall also be performed by Lenel certified technicians. The Security Access Control system shall be connected to the Station CCTV LAN and to the Secure Stations Wide Area Network. CCTV system cameras shall monitor all doors where card access control is implemented.

5.15 Intrusion Detection

Currently the MBTA implements intrusion detection at tunnel portals. As there are no portals on the GLX project, intrusion detection will be implemented only at door switches as part of the access control system.

5.15.1 Detector Types

No longer applicable.

5.15.2 Intrusion Alarm Annunciation Requirements

Primary annunciation for the intrusion detection portion of the system will be at the Hub Monitoring Center and the MBTA operations control room through the existing HMCS or Lenel systems as required by MBTA Security and Safety.

Alarm annunciation will include the following information, presented in an intuitive, user friendly, graphical interface:

- Location of alarm
- Address of device
- Nature of alarm (i.e. type of detection)
- Time and date
- Panel from which alarm was received
- Priority of alarm

5.16 Public Address and LED Signage System

The Passenger Information System consists of the Public Address System and the Variable Message Sign System both of which utilize a single Station Control Unit (SCU). Each of these is described separately in the following sections. Both are required to meet Federal ADA requirements for Transit Stations as well as the 2006 MBTA/BCIL (Boston Center for Independent Living) accessibility agreement. The Passenger Information System shall meet the requirements of NFPA 130.

The Passenger Information System shall be continuously available and operable during Station power outages and during other emergency conditions so that emergency announcements may be made by remote or local MBTA and Public Safety personnel to insure the safety of all Passengers being powered by appropriately configured UPS and Station Generation systems.

The Passenger Information system must be able to announce audible messages as well as displaying the same messages on the LED signage system so that messages are transmitted both visually and verbally, in accordance with ADA accessibility regulations.

The Station Passenger Information System shall be completely functionally and feature compatible with the existing ARINC AIM© system.

The Public Address (PA) system will include the following components:

- Station Public Address System including
  - Station loudspeakers
  - Local microphone at each station

    - Local microphones on each platform
    - Ambient Noise sensing microphones
    - Station Public Address Computer (running ARINC's AIM© software)
    - Station Digital Signal Processor (DSP)
    - Station Output Amplifiers

- Communications connections to OCC at 45 High Street
- Remote Access Terminals
- Changes to existing Arinc servers will be part of the design effort and coordinated with the MBTA and its PA maintenance contractor
- Changes to the graphical user interface (GUI) at the OCC at 45 High Street will be part of the design effort and coordinated with the MBTA and its PA maintenance contractor

The Public Address system and the Variable Message Signs shall both be interfaced to and driven from the SCU which is a computer with ARINC AIM software.

The PA and VMS components shall have alarm outputs interfaced to the SCADA HMCS system.

The Public Address hardware including amplifiers, input multiplexers, station servers and a local microphone shall be located in the Station Communications Room. Speakers, Ambient Noise Microphones and a remote microphone for local live announcements shall be located as required on the platforms, in the mezzanines and in the bus facilities as required by the project design to provide 12 dB level above ambient noise as messages to meet clarity standards.

The installed PA system shall have the capacity to add 50% more speakers without the addition of output amplifiers as well as shall be expandable for future needs by adding output amplifiers.

The project stations are located at grade in residential areas requiring that the noise levels meet local ordinances and restrictions during required hours. These restrictions shall be met by programmable PA multiplexors which shall have the ability to reduce the dB output according to the time of day as well as ambient noise levels.

The PA system is described in detail in the MBTA Specification Section 16448, Public Address Systems.

The Variable Message System (VMS) will have the capability to interface with the ARINC Announcement Control System (part of the Public Address System) to provide Variable text messages synchronized with audible voice announcements that are in compliance with the provisions of the Americans with Disabilities Act (ADA). LED signage will be provided in each station at the station lobby and the platform. Signs will be installed perpendicular to the platform, per the 2006 agreement between the MBTA and the BCIL.

The Signs shall be installed as required by the Station architectural design to provide passengers with timely scheduling and arrival/departure messages. Signs shall be dual and single sided as required by the Station design. The signs shall be operational and maintenance compatible with the existing Daktronics signs.

The Variable Message Signs shall have LED component lighting to enable maintenance repair of the signs without complete removal of the entire sign. The VMS signs shall be interfaced through serial connection.

The VMS enclosures shall be Intrusion Protected at an IP65 level to prevent dirt and water intrusion during adverse weather and normal maintenance conditions they will be exposed to.

The VMS system is described in detail in the MBTA Specification Section 16449, Variable Message Signs and Section 16745, Next Train Signs.

5.17 Automatic Fare Collection System

This section specified the Fare Collection System which consists of three Station components: 1) Fare Vending Machine (FVM), 2) Fare Gate (FG), and 3) Station AFC Controller, all to be supplied by MBTA AFC section to the project. The FVM and FG systems shall be connected to the separate AFC Ethernet switch with a multimode cable as required by the vendor. The AFC system design likely will be impacted by the selection process of a new Fare Gate system (Fare Gate Generation II) by MBTA as there are not enough Fare Gates in MBTA storage to supply all of the Green Line Extension project stations. This will affect the size of the FG footprint. The FVMs are sourced from Scheidt & Backmann under separate procurement and standardized throughout MBTA facilities to ensure complete compatibility and interchange with the current system.

The AFC Ethernet switch shall interface with the Station SONET switch and is configured with a separate Virtual Local Area Network (VLAN).

The designed locations of the FVMs and FGs shall be coordinated with the MBTA AFC section manager. All FVMs and FGs shall have Closed Circuit Television (CCTV) cameras monitoring their locations.

The Fare Gates shall be compatible with the current Charlie Card and Ticket System. The Fare Gates have an emergency control panel at each station to provide central power control in case of an emergency requiring the gates to be fully opened. The AFC Controller is a computer server located in a secure cabinet at the station. This Controller processes the Tickets and Charlie Cards which are submitted at the Fare Gates by the Passengers then controls the Fare Gates to open or deny entry. Egress through Fare Gates shall meet NFPA 130 standards for passenger throughput.

The Ethernet switch used for the AFC System is layer 3 and utilizes a multimode fiber optic cable to connect to each of the FVMs, Fare Gates, and the Fare Controller server. The AFC switch is connected to the Station switch which provides a VLAN for AFC system use separate from other Station data traffic.

The AFC System shall be ADA compliant and meet the MBTA/BCIL accessibility agreement.

The AFC System Communications is described in detail in the MBTA Specification for a Station Local Area Network.

5.18 Maintenance Facility Communications and Security

The vehicle maintenance facility shall require the design of communications systems to make it operable. Those systems shall include

1. Ethernet switch for WAN connectivity
2. Cable and Fiber determination and termination
3. Ethernet switches
4. Telephone System
5. Access Control System
6. Intrusion Detection System
7. CCTV Camera System monitoring of both the Facility and storage yard
8. Automated Fare Collection System lockbox drop and controller
9. Radio bidirectional repeaters inside the facility and to provide coverage for the storage yard

The design of these systems shall be coordinated with the Facility architecture design, shall be consistent with existing MBTA Maintenance Facility features and functions and shall be interfaced with existing MBTA head end systems.

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Chapter 6

6.1 Green Line Signal System Description

This section describes the proposed project limits of the Green Line Extension project as well as a brief summary of the existing and proposed signal systems.

6.1.1 Signal System Project Limits

The northern/eastern limits of the signal work will coincide with the northern limits of the new track construction at Union Square on the Union Square Branch and College Avenue on the Medford Line. At the southern/western end, the signal work will extend to the existing North Station Turnback beyond the southern limits of track construction on the viaduct. Additionally, fiber for signal data shall be routed through all new and affected signal instrument houses to the Operations Control Center, and will include all necessary interfaces at the OCC and field locations.

6.1.2 Existing Signal System

The existing Green Line operates in two basic modes. The B, C, and E Line surface branches operate under light rail vehicle signals that are an integral part of the motor vehicle traffic signal network. The Central Subway, including Lechmere and the D Line out to Riverside, use an automatic block, color light signal system with no automatic train protection capabilities.

Because of its age and nature of operation, the existing Green Line Signal System uses very diverse technologies, from legacy 25 cycle based power frequency track circuits to vital microprocessor based interlockings using 100 Hz power frequency track circuits and non-vital processor interfaces to Human-Machine user interfaces.

Routing of trains is supported in the field with an Automatic Vehicle Identification (AVI) system. At critical junctions, switches are aligned according to the route requested by onboard equipment. Each route has been assigned a three digit numerical number that is set by the Operator according to the origination and destination locations.

6.1.3 Proposed Signal System

The proposed signal system for the extension will be consistent with the existing automatic block color light signal system, while using the latest underlying technology and products. The signal aspects will comply with the existing MBTA "Rules for Streetcar Motorpersons, Station Personnel, and other Employees of the Light Rail Lines."

The block design and interlocking logic for the new signal system shall be optimized for maximum throughput that is required for transit systems such as the Green Line, while maintaining safe train operation. The operating headways are intended to be five (5) minutes on both the Medford and Union Square branches, and two –and-one-half (2/1/2) minutes on the viaduct between North Station and the new junction Interlocking where the extension splits to the Medford and Union Square branches. A recovery buffer of 25 % will be provided as long as headways are not adversely affected.

The proposed system will be a combination of vital and non-vital processors to control and indicate the wayside signal components. The existing AVI system will be extended to include the additional interlockings and yard movements.

It should be noted that the MBTA has completed a feasibility study for the implementation of a Positive Train Control (PTC) system on the Green Line. The signal design for the GLX project will provide for additional capacity within the wayside signal housings for future PTC equipment.

6.2 General Design Elements

The signal system will ensure the safe operation of trains through functions such as train detection, broken rail detection, signaling for safe train separation, and route security through interlockings on all portions of the track except the yard. The yard will be non-signal territory.

The signal system shall be compatible with the existing Green Line signal system, existing AVI system, existing and proposed Green Line rolling stock, existing and proposed traction power systems, and other work on the GLX project.

The design and implementation will provide a complete, functional, reliable and maintainable vital signal system. The design shall provide the block layout, interlocking logic and circuits, interface logic and circuits, proposed room layout, and equipment placement and mounting. The signal system design shall provide for full and complete integration into existing and known future systems.

The signal system will be designed to utilize a fail-safe approach, ensuring that all vital circuits failing to respond as intended will not result in an unsafe condition.

Signal Design shall develop site specific, detailed logic presented in relay equivalent format for contractor use in developing detailed application logic in their supplier's specific product platform.

6.2.1 Compliance with Standards

The design will conform to the most current version of the following standards to the greatest extent possible:

- American Railway Engineering and Maintenance of Way Association (AREMA) Communications and Signals Manual
- Institute of Electrical and Electronic Engineers (IEEE)
- National Electrical Manufacturer's Association (NEMA)
- Federal Highway Administration (FHWA)
- Manual on Uniform Traffic Control Devices (MUTCD)
- Audio Frequency Track Circuit (AFTC) standards
- American National Standards Institute (ANSI) standards
- American Society for Testing and Material (ASTM) standards
- American Society for Quality Control (ASQC) standards
- Federal Railroad Administration and Code of Federal Regulations Part 49 (CFR 49)
- Insulated Power Cable Engineers Association (IPCEA) standards
- Electronic Industries Association (EIA) standards
- National Electrical Manufacturers Association (NEMA) standards

- Massachusetts Electric Code (MEC)
- National Electric Safety Code (NESC)
- Underwriters Laboratories (UL) standards
- MBTA standards, practices, and recommendations

In case of conflict, the following priority shall prevail:

- Federal, state and local laws and regulations
- Contract Specifications and Contract Drawings
- MBTA standards
- AREMA standards, practices and recommendations
- Other standards as delineated above

6.2.2 Existing MBTA Specifications and Drawings for Basis of Design

Specifications and drawings shall utilize practices from the most recent and relevant MBTA projects. At a minimum, these shall include the Haymarket North, Columbia Junction, Haymarket to Science Park and Blue Line 6-Car Signal System Upgrade. The design shall also accommodate all As-Built documents for the Haymarket to Science Park Project and the existing Science Park to Lechmere Installation.

These specification sections shall include, but not be limited to:

- Basic Contract Requirements and Standard Specifications
- Basic Technical Requirements and Standard Specifications
- Basic Electrical Requirements and Standard Specifications
- Relevant Communication Requirements and Standard Specification
- Relevant Security System Requirements and Standard Specifications
- Signal System Requirements and Specifications
  - Basic Technical Requirements – Signals
  - Abbreviations, Nomenclature and Definitions – Signals
  - Drawings and Tracings
  - External Signal Cable
  - Electromagnetic Compatibility Requirements
  - Cable Raceways and Aerial Cable Support Systems
  - Signal Equipment Housings
  - Wayside Cases
  - Junction Boxes
  - Internal Wire and Cable
  - Cable Trays
  - Plug Connectors
  - Relays
  - Signal Data Network
  - Vital Microprocessor Interlocking Systems
  - Non-Vital Microprocessor Interlocking Systems
  - Local Control and Maintainer Panels
  - Rectifiers, Batteries and Battery Charging Equipment
  - DC Power Supplies
  - Signal Transformers
  - Power Switch-and-Lock Movement Layouts

- Hand-Throw Switch, Electric Lock and Timer, and Detail Layouts
- Signal Layouts
- Wayside Pushbutton Layouts
- Power Frequency AC Track Circuits
- Audio Frequency Digital Track Circuits
- Rail Bonding
- Signal Power and Distribution
- 100 Hz Frequency Converters
- Rail Heating System
- Signal System Event Recorder (Micro-Aide or approved equal)
- Automatic Vehicle Identification System
- Grounding of Equipment
- Miscellaneous Components and Products
- Signal Training
- Signal System Tests

6.2.3 Coordination with Other Work

The proposed GLX signal equipment will be located so that it does not interfere with existing Commuter Rail operations, existing Green Line operations, freight operations, track clearances, retaining walls, bridges, catenary structures, stations, and other work on the GLX project. Signal equipment will be placed in accordance with the dynamic envelop of the Green Line vehicles. Signal equipment will not obscure lines of sight, provide an unsafe environment for MBTA personnel, or present a hazard to the general public in any form.

6.2.4 Signal Operations

The Automatic Block signal System (ABS) will be based upon color light signals and designed for right-hand, single direction running only. Reverse direction running will be in accordance with the Authority's rulebook and relevant special orders. The ABS color light signal system will not be designed to support reverse running.

6.2.5 Vehicles and Safe Braking

There are currently two vehicle types operating on the Green Line, Type 7 vehicles and Type 8 vehicles. The MBTA is in the process of procuring new rolling stock, which will be designated as Type 9 vehicles. Trains may consist of one to four cars. The Type 7 and Type 8 vehicles are operationally compatible in that they can be coupled to each other, while Type 9 vehicles will not be compatible with either Type 7 or Type 8 vehicles. A safe breaking rate of 1.47 mphps shall be used as the criteria for all car types and consists.

6.2.6 Mainline Signaling

Mainline signaling will be accomplished through the use of vital and non-vital microprocessor based systems. Each location will communicate to the adjacent locations and the OCC via a redundant and diversely routed signal data fiber network. Diverse routing shall be maintained by installing separate fiber bundles along either side of the ROW for the entire corridor. The work will include any improvements or additions necessary between the wayside systems and the OCC.

Terminal interlockings will include automatic turn back functionality based on track circuit occupancy. At the Red Bridge Interlocking/junction, route selection from Lechmere to either Union Square or College Ave will be accomplished by AVI with pushbutton backup selection. Routing from the mainline tracks to the yard will be accomplished by AVI with pushbutton backup selection. Routing from the yard to the mainline shall be accomplished through pushbutton route selection.

The new GLX signal system will be made up of vital components commonly found in light rail transit systems present in the United States. The system will provide space for physical expansion of the vital system to support a future PTC system.

6.2.7 Yard Interface Track Signaling

The yard leads will be signaled as part of the Red Bridge (Union Square branch) and Brickbottom (Medford Line) interlockings. The vital signal systems will safely allow for routes to be cleared into and out of the yard via pushbutton selection. All non-signal yard switches will be hand-throw. All train movements in the yard will be made at restricted speed according to MBTA rules.

6.3 Signal System Components

The signal system will consist of components including, but not limited to, track circuits, wayside signals, switches, vital and non-vital microprocessor and circuits, control and indications, communications systems, signal power, equipment housings, signal wires and cables, and snow melters.

6.3.1 Track Circuits

100Hz phase selective track circuits shall be installed from the existing North Station Turnback out to the Union Square and College Avenue Terminals. The 100 Hz phase selective track circuits shall be the Siemens SE-3 or an engineer approved equal. All track circuits shall be designed to be fully adjustable with properly sized components for continuous shunting. The maximum length of any track circuit shall not exceed the manufacturer recommended maximum. All cabling to and from the wayside shall be properly sized as required by the equipment manufacturers and as needed for the application. For future needs and maintenance the number of conductors to be installed for each track circuit shall be as required by the equipment manufacturer with adequate spare conductors consisting of 4 pairs daisy chained through the wayside junction boxes in each direction from the central instrument house (CIH) for future needs and maintenance.

6.3.2 Wayside Color Light Signals

Color light signals will be located at the entrance point to each signal block as required by the block design. All ABS signal layouts will be equipped with a base junction box and LED lighting. All interlocking signal layouts will also be equipped with a split base AAR terminal junction box and LED lighting, except the Red over Red aspects and yellow over yellow for berthing requirements, which shall be single filament bulbs wired in series unless determined by suppliers that adequate light out protection can be provided by the processor for LED signals for these aspects. Terminal boards, wiring, number plates, hoods, padlocks, transformers, ladders and mounting hardware will be supplied as needed. Wall mounted signals shall be supplied with the same features including easily accessible junction boxes and wall mounted ladders.

Signals will be GRS Co. Type FA, US & S Co. Style "N", or Safetran Model CLS-2000 LED, or approved equal. Interlocking units should have a blank cover/unit between working light units to ensure aspect recognition. All units will allow for wires to pass through and have a door to provide easy lamp access.

LED's will be uniform in shade and density for the respective colors in accordance with the AREMA recommendations for LED signals. LED's will be secured to the signal head and will utilize a neoprene gasket to provide water and dust proof seal between the LED and the signal head.

Signals will be designed to be distinct at 1000 feet in advance, where preview permits, from a height of seven feet above the top of the rails.

Start Sign and bell and bus hold logic shall reside in the Non-Vital Programmable Logic Controllers (NVLPC).

Each signal unit will be equipped with a hood and phankill.

6.3.2.1 Home Signals

Each interlocking home signal will be capable of displaying appropriate aspects as listed below, and will be placed at the entrance point to every interlocking for each track. Home signals will be located and designed for normal direction running. However, at the turnback locations a reverse home signal is provided to assist in managing trains that may become inoperable just after leaving the station. Where no reverse direction moves are allowed, permanent Red/Red "Z" signals shall be provided. Blank heads will be applied as needed.

The design and placement of home signals will conform to the latest MBTA standards.

Home Aspect	Indication
Red/Red	Stop
Vertical Arrow	Proceed on through route
Left Arrow	Proceed on diverging route to the left
Right Arrow	Proceed on diverging route to the right

Note – the above aspects are to be confirmed as part of the design process.

6.3.2.2 Automatic Signals

Automatic signals will display the aspects listed below, and will be placed at the entrance point to every intermediate block between interlockings. Automatic signals will be located for normal direction running only. No automatic signals will be located for reverse direction running. Double berthing aspects shall be provided at the entrance to each platform except at turnback locations. The design and placement of automatic signals will conform to MBTA standards.

Automatic Aspect	Indication
Red	Stop and proceed after 1 minute at restricted speed (10 MPH) to the next signal
Yellow	Proceed, prepared to stop at the next signal
Green	Proceed at authorized speed
Yellow/Yellow	Come to a complete stop then proceed at restricted speed to an appropriate berth

Note – the above aspects are to be confirmed as part of the design process.

6.3.2.3 Miscellaneous Signals

Miscellaneous signals generally are not color light signals. They perform important safety and operations functions.

TAK lights, if and as required will be provided along curves and other areas of restricted view to warn maintenance workers on the right of way that a train is approaching. TAK lights will be lunar white signals, sized and placed in conformance with the latest MBTA standards. All TAK light logic shall reside within the Vital Processor. The location of TAK lights shall be determined as part of the block design process in conjunction with the recommendations of the MBTA Safety Department.

Where the combination of steep grades and slippery rail conditions due to adverse weather conditions may affect the operator's ability to restrict the speed of the train, control lines shall be permanently extended in lieu of Wet Signs. This design shall be similar to the current Green Line westbound from Science Park to North Station.

Lighted "START" signs and bell will be provided at the inbound end of all turnback platforms. The Start Sign, Bell, and Bus Hold logic shall reside within the NVLPC. When the "START" sign is lighted with the bell ringing, and in conjunction with the applicable wayside signal being clear, it will indicate to the train operator that they should depart the station on their scheduled trip. The "START" sign and bell work as a function of OCC schedule dispatch system. They shall not activate until a clear route has been established for the train to proceed.

Where required, Bus Hold Lights (BHL) will be used to provide information to bus drivers wherever a transfer from the GLX to a bus route is possible. BHLs will be lunar white signals placed in clear view of the bus driver when the bus is at the station stop, and will be illuminated when a train is approaching the platform. The number and placement of the BHL lights will be determined as part of the design and planning process.

6.3.3 Rail Bonding

Rail bonding shall be in compliance with all current MBTA standards and practices, as well as applicable manufacturer recommendations. Appropriate bonding will be provided at all non-insulated rail joints, frogs, switches, as well as all electrical connections for track circuits and traction return current. All rail bonding plans and materials shall be subject to MBTA department specific approval.

6.3.4 Wayside Pushbutton Layouts

Wayside pushbuttons will work in conjunction with the specific application at each location. Pushbuttons will function as an override where installed in conjunction with AVI routing. Pushbuttons will function as the primary route request where trains enter service from the yard or turnback stations.

Each pushbutton assembly will consist of a pushbutton box, equipped with recessed buttons, illuminated LED indicators, identification plates and all necessary appurtenances and wiring required to install a fully operational device. The Pushbuttons shall be located and installed at a height that is reachable by the operator from the cab of the Green Line trolley. Pushbuttons will be rated for low voltage 12/24 VDC operation. The pushbutton box will be NEMA 4X rated, 14-gauge stainless steel construction. The box will come equipped with an oil resistant neoprene door gasket and padlock hasp, sized to fit standard MBTA size padlocks.

6.3.5 Power Switch-and-Lock Movement Layouts

Mainline power switch-and-lock movement layouts will be Alstom 5F 110 VDC dual control switch-and-lock movements or Engineer approved equal. All complete switch-and-lock movement layouts will include a junction box, throw rod, insulated swivel, front rod, straps, point lug, lock rod, detector rod, shims, identification plates, required screws, nuts, washers, pins, grease fittings, cotter keys, plates, adjusting brackets, and hardware to mechanically couple the switch-and-lock movement to the switch points and to install the switch layout on Azobe timbers. The switch-and-lock movement elements will be designed to the latest MBTA standards and practices.

The switch-and-lock movement layouts to be provided will be gear driven from the motor. The movements will have double adjustable type lock, detector rods, and a throw-rod basket. A manual power/hand" selector lever will be provided. The switch-and-lock movement motors will be designed for continuous normal operation at 90 to 130 VDC and will perform intermittent operation at 130 to 150 VDC without sustaining any damage. All switch-and-lock movements will be factory tested using 150 VDC without damage to any of the components.

All complete hand throw switch-and-lock movements with electric lock layouts will include a junction box, rod, mounting holes, mounting bolts, wiring inlets, contacts, terminal binding posts, screws, nuts, washers, internal circuit controller heater, 600 VDC snow melters and all other necessary appurtenances required for a complete and operational installation. The internal heaters will have sufficient capacity to prevent adverse effects to the circuit controller and the motor compartment from high moisture and winter conditions.

Snow Melters shall be controlled from the MBTA standard heater control cases.

Hand-operated yard switches will include:

- Point detection (normal/reverse indications)

- Mechanical target illuminated Red/Green to indicate point position to operators
- Normal/reverse designation mounted on the switch panels
- Switch number designation will be stenciled on the top of the machine
- Switch Point Snow Melters

The hand throw switch will be approved for use on main line rapid transit operations or as approved by the Engineer. All hand throw switches will come equipped with internal heaters, with sufficient capacity to prevent adverse effects to the circuit controller from high moisture and winter conditions. Snow melters will be controlled from MBTA standard heater control cases.

6.3.6 Vital Signal System Elements

The vital signal system is responsible for the safe movement of all trains and their passengers. The vital system will process and execute all vital functions in accordance with the latest industries standards. The vital system will include, but not be limited to, all applicable electrical circuits and "hard" wiring, redundant vital microprocessors, track circuits, line circuits (double break), vital relays and all life/safety components that make up the signal system.

6.3.6.1 Vital Microprocessor Interlocking System (VMIS)

The work included in this section is for the design and logic development of the vital signaling systems. The design will call for furnishing, installing and testing all components and aspects of the redundant vital microprocessor interlocking systems (VMIS). The VMIS will control and receive indications from wayside signal devices. This will include but not be limited to all control line and vital safety functions at interlockings in accordance with all applicable AREMA recommendations and requirements as per the C&S Manual(s). The VMIS system to be implemented shall be the latest revision of Microlok II, as made by Ansaldo/US&S.

Non-vital functions or logic shall not be performed in the VMIS. Non-vital functions will be allowed for communications purposes only between the vital and non-vital processors. The VMIS shall be designed so that all logic and functions can be acceptance tested without influence from the non-vital logic or functions. The non-vital logic must be disabled or replaced with a test program using the proper I/O and nomenclature to inject requests as needed to initiate the vital logic functions under test.

The vital system will be designed based upon the closed circuit/loop principles, software diversity, use of proven vital hardware design techniques, and the manufacturer's safety model to achieve safety for the vital components and system. The use of multiple processors based on voting to enhance the probability of achieving safety is not acceptable. All vital function inputs and outputs shall use printed circuit boards designed for double-break application, and all vital wiring to the vital processors shall be double broken. All input/output and interface wiring for either VMIS system (normal and standby) shall be designed to be completely isolated so that a failure of any component affecting one of the VMIS units will not impact the other system.

The redundant VMIS units shall execute the exact same logic/application when in their final configuration to support operations. There shall be no difference between the two systems. It will be acceptable to have different logic/applications running during acceptance testing only.

The power feeds to the redundant VMIS systems shall be isolated and separately fused so that a failure in one unit shall not affect the partner unit. The input/output circuits of each VMIS unit shall be separately fused and isolated so that the failure of either system will not impact the other.

The redundant VMIS units shall be designed to function in a "warm-standby" manner as a minimum requirement with functioning in a "hot-standby" manner as a goal. Each unit will be clearly labeled "Normal" and "Standby."

- Transfer to the partner unit shall be automatic and instantaneous without special commands or programs.
- Transfer of control between normal and standby units will not compromise the processor controlled and indication functions. These functions will be designed in a fail-safe mode to prevent the clearing of signals into a protected section of track.
- There will be no preference or default normal state in the transfer logic for normal or standby operation. However, one unit should be designated as "Normal" and the other as "Standby".
- Each unit will provide a "health" status indication to support system failover and transfer from the Status and Control panel.
- In addition to the "Normal" and "Standby" units, a third cold standby unit will be rack installed complete with all (same count) boards specific to the VMIS units installed and running at that installation. The cold standby system will include two processor units with application and executive logic preloaded and matching those running in the normal and standby VMIS units. Additionally, the cold standby will include any boards that have site specific IC chips. The programming of these spare boards will be fully tested during acceptance testing so that field maintenance personnel can replace a failed executive system board without performing extensive field testing to certify application logic.

General Requirements

VMIS systems and equipment will be designed in accordance with this section and all applicable standards. They shall also include, but not be limited to the following:

- Provide a system, which has a proven record (a period of at least five years in revenue service) of implementation and the operation within a 13.8KVAC and 600VDC electrified rail transit environment.
- A system that is proven to be reliable, maintainable, and provides operational flexibility and safety of train movements.
- Each VMIS processor (except the cold standby unit) will perform internal self-diagnostics that will quickly and accurately identify failed boards or vital processes as they occur.
- Application development shall be done by the contractor on a system certified by the VMIS manufacturer using their most recent stable development platform, based upon site specific, detailed relay equivalent logic provided in the design. If available, the application development shall be done using a graphical user interface, programming using standard relay or ladder logic functions.
- An application development and monitoring system suited for field installation shall be provided with each VMIS unit. Use of manufacturer limited retest processes will be acceptable following proof and acceptability of that process to the Engineer.
- Complete system documentation, generic and application specific, in both hardcopy and electronic format shall be provided.
- Site licenses to use all furnished system software for the entire MBTA infrastructure without limitation.
- Other apparatus including, but not limited to, modems, network interfaces, chassis, cables, power supplies, test equipment and all circuit boards.
- Engineering efforts will include, but not limited to, all application, software, hardware and support engineering.
- 100% spare capacity for normal and standby systems for future expansion in application logic.

- 20% spare capacity for all installed I/O for the normal and standby systems for future expansion.
- All timers other than loss of shunt shall be externally settable or settable in such a way that it does not require the reloading of application logic.
- Event recording/data logging of all inputs, outputs, timers, and logic states of variables shall be logged and recorded. The capacity will allow for a minimum of 30 days of data storage before overwriting any data.
- The design shall log all maintenance and diagnostic indications for troubleshooting purposes. Diagnostic data shall be displayed in a supplier provided development tool on the Maintainers Computer to assist in the efficiency of troubleshooting and taking corrective action.
- All apparatus will be rack mounted.

6.3.6.2 Relays

Vital Relays
Vital DC relays, will be of the plug-in type and rack-mounted. They will have a transparent dust cover made of a non-flammable composition that will not support combustion.

Vital relays, with a nominal operating voltage of 10-16 volts, will be capable of operating continuously without resultant damage with a minimum voltage range of 7 to 21 volts inclusive applied to their operating circuits.

Biased neutral vital relays will be designed so that gravity alone will prevent the armature from picking up if they are de-energized or if no current is applied to the coil due to interruption of the normal magnetic circuit. Biased neutral vital relays will be designed so that up to 50 times working energy applied for two seconds at both normal and reverse polarity will not affect their operating characteristics by more than two percent, and will not pick up their armature on reverse polarity.

Each vital relay will have a minimum of four dependent front-back contacts, two independent front contacts and one independent back contact unless approved by the Engineer. All front contacts will be silver-to-metalized carbon, except for heavy duty, extra heavy duty, or special application relays. The design will include two independent spare contacts for future use.

All vital circuits that require multiple relays to meet the design requirements will be wired in series (cascading) unless approved by the Engineer.

Vital relays front or back contacts will be capable of a minimum of five million operations.

Arc suppression for vital relays will be built into the relay.

Contact arrangements will be identical for similar types of relays. Exceptions will be made for special function relays only and require approval of the Engineer.

All plug-in style, rack mounted relays will come equipped with a mechanical keying device preventing an incorrect relay-type installation.

Relay plugboards and all elements necessary for a functioning vital relay shall be of the same manufacturer or as approved by the relay manufacturer.

All relays shall be designed to work in electronic processor environment and shall not generate electromagnetic interference that may disrupt the proper functioning of any electronic systems (snubbers).

Switch Machine Control
Switch machine control shall be done using vital relays specifically designed to interface to the selected switch machine and/or as approved by the equipment manufacturers. The use of solid state switch controllers is prohibited.

Slow Acting Relays
Slow Acting Relays, i.e. slow pickup or slow release, will have their slow acting characteristics provided by the use of copper or aluminum washers or slugs applied to the relay core.

Vital AC Track Relays
Vital AC track relays will not be used. DC relays manufactured as part of the 100 Hz steady energy phase selective track circuits will be used.

Non-vital Relays
All non-vital relays will be equipped with a minimum of six front-back contacts. Stationary contacts will be bifurcated silver, palladium, or approved equal. Movable contacts will be bifurcated silver, palladium with gold overlay, or approved equal.

Non-vital relays will meet or exceed the following requirements:

- Maximum Temperature Rise: 175 degrees F at 30V DC
- Insulation Resistance: 1.5 x 1010 ohms
- Ambient Operating Temp.: minus 60 to 160 (degrees F)
- Dielectric Strength: 500 volts RMS, 60 Hz between all mutually insulated parts
- Mechanical Life: 100 million cycle operations
- Electric Life: 10 million operations (0.5 ampere resistive load at 77 degrees F)
- Contact Resistance:
  1. Before Life 100 milliohms max. at 6V DC, 100 ma
  2. After Life: 200 milliohms max, at 6V DC, 100 ma

All Non-vital relays will be plug-in DC neutral biased or diode-suppressed relays with a nominal operating voltage of 24 volts DC. Where other voltages are required, the relay and application will be submitted to the Engineer for approval. The Non-vital relays will work reliably when the applied voltage is between 18 volts and 42 volts.

Identification
All relays will have an Engineer approved nametag on both the front and back of the relay, as well as on the back (the side the relay does not plug into) of the relay plugboard. All tagging will not interfere with the operation of the relay or prevent visual inspection.

6.3.7 Non-Vital Signal System Elements

The non-vital portion of the signal system shall be comprised of various systems to assist in the efficient operation and monitoring of all signal system equipment and all train movements throughout the Green Line Extension. At a minimum, these systems will include redundant non-vital processors , redundant signal data networks, diversely routed and redundant signal fiber networks, interfaces with the VMIS units, interfaces with the MBTA Operations Control Center, interfaces with the Automatic Vehicle Identification (AVI) route requests, non-vital relays, non-vital event recorders, and support for Local Control and Maintainer Panels.

Redundant non-vital processors shall be responsible for processing all logic functions other than the vital functions that are performed in the VMIS units. The non-vital processors can be microprocessor-based, integrated Vital and Non-Vital Microprocessor Interlocking Systems as long as the vital and non-vital programs can be separately programmed and tested without adversely affecting each other. A fallback position if these requirements cannot be achieved will be use of the GE/Fanue NVPLC systems currently in use by the MBTA. All user control and indications of wayside devices will be through the processor systems.

6.3.7.1 Non-Vital Programmable Logic Controllers

The redundant non-vital systems will be configured to have the same standby capabilities as the vital system.

The NVPLC units will consist of programmable logic controller equipment, an I/O system and power supplies complete with surge protection. The I/O system will be designed so that field equipment does not have to be disconnected for non-vital microprocessor maintenance. As needed normal and standby non-vital microprocessor will be equipped with a central processing unit, memory module, self-diagnostics, Ethernet serial communications link and I/O modules for interface to the inputs and outputs.

All non-vital equipment will be rack mounted.

The NVPLC units will be as manufactured by GE/Fanuc, an MBTA standard product, or an Engineer approved equal. All equipment furnished will be modular, interfacing off-the-shelf components. No failure of, or within either of the VMIS units shall cause the non-vital microprocessor to switchover.

The non-vital system units will be the interface point for communication to the OCC.

The non-vital system shall be designed and programmed to allow the removal of control from the OCC.

The event recorder shall have a capacity to record all non-vital events for a minimum of seven days without overwriting.

The list of recorded events, inputs, and outputs shall be submitted to the MBTA for approval as part of the plan submittal for each CIH location.

The non-vital system will have event recording for all inputs, outputs, and non-vital functions. All event recorder data will be recorded, time/date stamped and accessible on the network or via dialup phone line.

The non-vital application design shall log all maintenance and diagnostic indications for troubleshooting purposes.

Provide Site Licenses to use all furnished system software for the entire MBTA infrastructure without limitation.

Application development shall be done by the contractor on a system certified by the NVPLC manufacturer using their most recent stable development platform, based upon site specific, detailed relay equivalent logic provided in the design. If available, the application development shall be done using a graphical user interface, with programming using standard relay or ladder logic functions.

6.3.7.2 Signal Fiber Network

A redundant and diversely routed fiber network shall be designed consisting of one 96 strand single mode communications cable and one 96 strand fiber optic single mode signal cable to support all signal system data between field locations, as well as between the field locations and the Operations Control Center (OCC). A minimum of twelve strands of the communications cable strands will be designated for signal use only. Refer to Section 5.13.2.2 Wide Area Network (WAN) for communications network design criteria.

The fibers – consisting of one 96 strand single mode communications cable and one 96 strand fiber optic single mode signal cable - for the redundant fiber networks shall be routed on opposite sides of the right of way for the length of the right of way where applicable. Where conduit and trough are available, the fiber optic cables shall be installed in separate conduit and trough dividers. All fiber optic cables shall be installed in 1.5 inch innerduct throughout the route. Orange shall be used for communications cable and blue shall be used for signal cable.

The fiber installed along either side of the right of way shall be terminated in each signal bungalow for inclusion in the network.

From the OCC, the two fiber bundles – consisting of one 96 strand single mode communications cable and one 96 strand fiber optic single mode signals cable -will take diverse routes and will land at all signal bungalow locations in their respective paths. It is expected that the paths for the two fiber bundles will join on the same right of way in the North Station Turnback area of the Green Line.

The 96 strand communications fiber optic cable will terminate at the new GLX Stations CIH bungalows and at the following existing CIH locations: the Science Park Signal Room, the North Station/Garden Signal Room, the Haymarket GL Signal Room, and the Second Floor of 45 High Street.Splicing shall not be allowed on the right of way. A minimum of 50 feet of slack fiber shall be provided for each fiber bundle at all bungalows or termination panels. The slack shall be properly coiled in a means or enclosure designed to properly handle the fiber.

6.3.7.3 Signal Data Network

A redundant signal data network shall be designed to manage all signal data local to the respective bungalows, between the bungalows and between the bungalows and the Operations Control Center (OCC). The network equipment shall be robust and have a track record of functioning successfully on an electrified transit system for no fewer than five years. The equipment shall be OTN Systems OTN-X3M-NC42C, N50/N70 Series, ETS-3GC7F or approved equals.

The design shall partition the network bandwidth through the use of S-Lans. S-Lans are not susceptible to hacking and can guarantee network bandwidth for each functional partition. The design shall identify all data to be transmitted over the network including origination and destination, frequency, and packet size to determine the necessary bandwidth for each type of data. The data shall be functionally isolated so that a failure that disables one functional path will not degrade the overall functionality of the signal system and its support of service. The redundant path with its data will support full system functionality.

Network data traffic shall also be segmented so that data traffic is not propagated beyond where it is useful for system functionality.

All networking equipment diagnostics as well as network system availability shall be made viewable on the Maintainer's panel for ease of troubleshooting and making timely repairs.

The network shall be designed with centralized management and configuration consoles. These consoles shall be diversely located should the other system lose communication with the network.

6.3.7.4 Local Control Panels (LCP)

Local Control Panels shall be capable of controlling all signal system functionality at the applicable interlocking locations. There shall be a Local Control Panel for each CIH that has interlocking functionality.

- Entrance/Exit
- Signal cancel
- Fleet on/off
- Switch normal/reverse/auto
- Switch block/unblock
- Exit block/unblock
- Track display
- Alarm acknowledge
- Transfer control
- Emergency bypass
- Control panel on/off

Local Control Panels will be a hardwired Mosaic tile panel with levers and LED indications as manufactured by Mauell Corporation or other approved panel manufacturer. The hardwired panel shall function based on a serial or remote networked parallel I/O from the non-vital system. The panel shall have levers and indication LEDs to monitor and manage all interlocking functionality. The panel shall be capable of being completely powered down and disabled when not in use. The panel shall have a hinged key-lockable glass cover.

6.3.7.5 Maintainers Panels

The Maintainers Panels shall provide real-time monitoring of subsystems integrated into the signal system and shall be of the Mosaic tile type. HMI panels shall not be considered. The Maintainers Panels shall at a minimum, provide for the monitoring of signal field devices, train locations, communication links, network devices, network connections, VMIS units, NVPLC systems, and power systems.

6.3.7.6 Status and Control Panels

Status and Control Panels shall provide real-time system status indications for all critical subsystems supporting operational functionality. The Status and Control Panel shall also provide control over the online status for the major subsystems, including NVPLC and VMIS. The Status and Control Panel shall be a metallic hardwired panel with LED indications, heavy duty levers and etched labels.

6.3.7.7 Maintenance PC's

Maintenance PC's shall be designed in as an integral part of the processor systems. There shall be a minimum of two maintenance PCs and a monitor associated with each field location to allow for the simultaneous monitoring of redundant systems or the simultaneous monitoring of the online VMIS and NVPLC.

The Maintenance PC's shall have all necessary applications installed for monitoring all processor-based systems. They shall also have all application tools necessary for remote access and management of systems on the same network. Capabilities other than system monitoring shall require authentication.

The Maintenance PC's shall be hardened equipment designed to function in the harsh environment of an electrified transit system.

6.3.7.8 Operations Control Center Interface

The non-vital systems shall interface directly to the OCC over the Signal Data Network. Communications will be serial based, using a local terminal server port for each PLC to route the data to the OCC Network.

Code-Bit Assignment Sheets shall be developed in conjunction with MBTA OCC staff to define all control and indication data bits to be transmitted and received.

6.3.7.9 Automatic Vehicle Identification and Field Routing

An Automatic Vehicle Identification (AVI) system will be provided and integrated into the existing system. Key points will be located as needed for the routing of trains at diverging track locations, at end of line terminals, and at the locations where trains enter and exit from the yard. The AVI system will decode the route number from the vehicle and transmit route requests to the non-vital systems based on the Code Control Box (CCB) settings on the vehicle, and transmit vehicle and route data to the OCC for integration into system data and Dispatcher display.

The AVI selection will be able to be cancelled and re-routed with a field push-button interface. Pushbutton boxes will be provided as needed at the appropriate field locations. The pushbutton boxes will allow the operator to cancel and/or request a route.

The existing OCC display of AVI data shall be modified by the MBTA. Similar to the NVPLC to OCC interface, an AVI interface shall be developed as part of the design in conjunction with the MBTA.

The AVI field equipment shall be supported by an uninterruptable power source and will keep the AVI System online for the same duration that the vital systems within the CIH will remain online.

6.3.8 Equipment Housings

Central Instrument Houses (CIH) will be designed as needed to house all functional signal system elements. CIHs will be of adequate size to accommodate all signal equipment, plus 20% usable spare capacity for future equipment racks. CIHs will be located in the vicinity of each station, at interlockings, and as needed to avoid cable runs of excessive distances. CIHs will be factory wired complete.

Equipment racks will have standard open frame configuration, will be shock mounted and isolated from ground. All racks and equipment chassis shall be discretely grounded to the CIH ground bus using ground cable.

CIHs will include all necessary electrical sources, lighting, HVAC systems, means of cable entry, pre-wired cable racks, and fire suppression systems. The HVAC system shall be a two part system and shall not use air transfer with the outside as means of cooling or heating.

Junction boxes will be used for switch machines, signal layouts, electric locks, auxiliary interlocking locations, at the ends of platforms, and as needed. Junction boxes shall provide adequate space for triple or double post terminals as needed, terminal boards, cable, fiber slack, and all other necessary appurtenances.

6.3.9 Signal Power for CIHs

Signal power shall feed all signal equipment and system loads. Signal power shall be isolated and ungrounded through the use of transformers specifically designed for this function.

Two separate 480 VAC single phase power feeds shall be delivered to each CIH from two different substations. If feeds from two substations are not possible, the separate feeds shall come from the same substation on two different sources.

Power for all signal system elements shall come from the closest station except for the CIHs located at the Red Bridge Junction between Lechmere, Union Square and Washington Street, which will receive power from the Red Bridge Traction Power Substation.

At each station or at the Red Bridge Traction Power Substation, the signal power will come directly from the secondary side of the redundant 13.8 KV to 480 V AC transformers. The 13.8 KV is delivered from the closest traction power substation.

The 480 V AC single-phase signal power shall be delivered to the CIH on separate cables. They will interface at the CIH on redundant tap adjustable transformers to step the voltage down to 120 V AC.

The 120 V AC ungrounded transformer secondary windings shall feed an automatic transfer switch and a network of manual bypass disconnect switches should the automatic transfer switch require heavy maintenance.

The secondary of the automatic transfer switch and bypass network shall feed the signal power bus that provides power to all signal equipment and functions originating from this CIH (BX).

All signal power feeds and system components shall be consistent across all CIHs for ease of maintenance. The design and sizing of the signal power delivery system shall be based on the design and calculated signal loads originating in the respective CIHs. The CIH with the greatest load shall be used as the basis for the other CIHs.

The Design shall include a coordination study to ensure proper protection and coordination of upstream and downstream devices. Electrical ratings and settings of the proposed equipment will be selected to ensure coordinated operation under both normal and worst case conditions.

6.3.10 Utility Power for CIHs

Power for CIH lighting, utility outlets, HVAC and the fire protection system shall come from a separate dedicated 480 V AC three phase power feed from the closest station or Red Bridge Traction Power Substation in the case of the CIHs in that area.

The 480 V AC feed shall originate on the secondary side of the automatic transfer switch that selects the power source for the stations, unlike the signal power feeds that receive their power directly from the secondary of the transformers.

The 480 V AC utility feed with ground, will provide power to the CIH utility loads through the required disconnect switches, transformers, breaker panels, etc. The design and sizing of the utility power delivery system shall be based on the design and calculated utility loads in the CIHs. The CIH with the greatest load shall be used as the basis for the other CIHs.

The Design shall include a coordination study to ensure proper protection and coordination of upstream and downstream devices. Electrical ratings and settings of the proposed equipment will be selected to ensure coordinated operation under both normal and worst case conditions.

6.3.11 Low Voltage Power Sources for Signal System Elements

From the 120 V AC signal power (BX), all other voltages as needed shall be developed. This includes, but is not limited to signal lighting, vital systems power, non-vital systems power, switch machine power and AC power frequency track circuit power. The BX shall feed all manner of power supplies, converters, isolation transformers and battery chargers as needed.

6.3.11.1 Vital Systems and VMIS Units (B12)

All vital systems internal to the CIH shall operate on a 12 V DC battery system (B12). The B12 source shall be ungrounded.

The battery bank shall be of sufficient capacity to support all systems powered by the B12 for a minimum of four hours. The batteries must be lead acid based, and shall be sealed for ease of maintenance. The Design shall be supported by calculations that project the entire load that must be supported by B12 power source, as well as the proper size for all components and cabling.

The batteries shall be charged by redundant battery chargers connected to the batteries in parallel. Each battery charger shall be capable of individually supporting the full system load plus 50% for expansion, in addition to charging a completely discharged battery bank. The chargers, together or individually, shall be capable of supporting the entire load with the batteries disconnected.

The B12 battery chargers shall be powered from the BX120 source. The battery chargers shall be wall mounted.

The batteries and charging system shall be designed so that the batteries and chargers can be isolated through the use of fused disconnect switches for maintenance or replacement.

6.3.11.2 Line Battery (LB12)

12 V DC Line battery voltage (LB12) shall be provided to support low voltage functions external to the CIH. Redundant 12 V DC power supplies, powered from the ungrounded BX120, shall generate the LB12.

The LB12 system shall be sized according to the calculated load plus 100% spare capacity for expansion. Additionally, all cable size and fusing shall be determined.

The power supplies shall be rack mounted. The power supplies shall be as manufactured by Acopian.

6.3.11.3 Signal Lighting

A consistent method across all signals is preferred.

If signal lighting is output directly from the VMIS, the design shall provide for redundant isolated power sources so that a ground in the lighting circuits external to the VMIS will not induce a ground on any other of the power sources in the CIH.

6.3.11.4 Non-Vital Systems and NVPLC Units (B24)

All stand-alone non-vital systems internal to the CIH if utilized shall operate on a 24 V DC battery system (B24). The B24 source shall be ungrounded.

The battery bank shall be of sufficient capacity to support all systems powered by the B24 for a minimum of four hours. The batteries must be lead acid based, and shall be sealed for ease of maintenance. The Design shall be supported by calculations that project the entire load that must be supported by B24 power source, as well as the proper size for all components and cabling.

The batteries shall be charged by redundant battery chargers connected to the batteries in parallel. Each battery charger shall be capable of individually supporting the full system load plus 50% for expansion, in addition to charging a completely discharged battery bank. The chargers, together or individually, shall be capable of supporting the entire load with the batteries disconnected.

The B24 battery chargers shall be powered from the BX120 source. The battery chargers shall be wall mounted.

The batteries and charging system shall be designed so that the batteries and chargers can be isolated through the use of fused disconnect switches for maintenance or replacement.

6.3.11.5 Automatic Vehicle Identification System

The Automatic Vehicle Identification (AVI) system hardware requires 120 V AC, and shall be powered from an uninterruptable power supply (UPS) that is compliant with the existing MBTA AVI requirements.

6.4 Signal System Tests

6.4.1 Acceptance Test and Certification Plan

Develop a test plan that identifies a clear and logical progression for the successful inspection, testing and certification of all signal system elements and the signal system as a whole. Include in the test plan the requirements for configuration control to address documentation management, as well as a process for identification, tracking and resolution of dependencies – what needs to be tested in what order, what needs to be retested, and how.

6.4.1.1 Point of Manufacture Product Factory Inspection and Tests

Develop specification sections that detail the requirements for all product testing and certification requirements for the contractor, including methods for determining quality assurance relevance and compliance at the point of manufacture. Define the quantities requiring inspection and testing based on the application of the component.

All components related to vital or fail-safe circuits and logic shall be tested. Documentation of test performance shall be submitted for each component.

For all other components, an approved number of randomly selected units from the manufacturing process will be tested to ensure the adequacy and acceptability of all component types produced.

6.4.1.2 Factory Acceptance Inspections and Tests

Develop specification sections that require detailed procedures to be developed by the contractor for the following activities at a minimum:

- Visual and Mechanical Inspection
- Simulation Wiring and Functional Verification Test
- Wiring, Cable and Fiber Jumper Verification (Point-to-Point)
- Grounding Verification of all Racks and Equipment Chassis
- Energy Distribution Systems Continuity, Phasing and Isolation Test – Power Off
- Energy Distribution Systems Verification, Phasing and Level Test – Power On
- Vital Relay Test and Certification
- Vital Wiring and Cable Breakdown Test
- Vital Line Circuit and Line Data Test
- Vital Logic (VMIS) Functional Test and Breakdown (Interlocking and Control Line)
- AF Track Circuit Preliminary Setup and Verification Test
- AC Power Frequency Track Circuit Preliminary Setup and Verification Test
- Signal Data Network Configuration Verification
- Non-Vital Wiring and Cable Breakdown Test
- Non-Vital Systems Functional Test and Breakdown (NVPLC, LCP, Status and Control, HMI)
- OCC Interface Verification and Functional Test
- System Failover Tests
- AVI System Functional Test
- Vital and Non-Vital Event Recorder functional Tests

6.4.1.3 Site Acceptance Inspections and Tests

Develop specification sections that require detailed procedures to be developed by the contractor for the following activities at a minimum:

- Visual and Mechanical Inspection
- Cable Routing Inspection
- Signal Power Feed System Wiring and Cable Verification – Power Off
- Signal Power Feed System Test – Power On
- Utility Power Feed System Wiring and Cable Verification – Power Off
- Utility Power Feed System Test – Power On
- Ground Grid and Ground Bus Verification Test
- Field Cable Insulation Resistance Test
- Field Cable Verification Test (Point-to-Point)
- Fiber Verification and Certification Test (OTDR and Power Level)
- Wiring, Cable and Fiber Jumper Verification (Point-to-Point)
- Grounding Verification of all Racks and Equipment Chassis
- Energy Distribution Systems Continuity, Phasing and Isolation Test – Power Off
- Energy Distribution Systems Verification, Phasing and Level Test – Power On
- Vital Wiring and Cable Breakdown Test
- Vital Line Circuit and Line Data Test
- Vital Relay Test and Certification
- Vital Logic (VMIS) Functional Test and Breakdown (Interlocking and Control Line)
- AF Track Circuit Setup and Verification Test
- AC Power Frequency Track Circuit Setup and Verification Test
- Switch and Lock Movement Adjustment, Breakdown and Functional Test
- Signal Layout Adjustment and Lighting Test
- Signal Data Network Configuration Verification
- Non-Vital Wiring and Cable Breakdown Test
- Non-Vital Systems Functional Test and Breakdown (NVPLC, LCP, Status and Control, HMI)
- OCC Interface Verification and Functional Test
- System Failover Tests
- Snow Melter Checkout, Breakdown and Functional Test
- AVI System Functional Test
- Vital and Non-Vital Event Recorder functional Tests
- Battery Systems Tests
- HVAC System Tests
- Fire Protection System Test (simulated)

6.4.1.4 Acceptance Test Equipment and Special Tools

Develop specification sections that require that the Contractor will have all test instruments and equipment necessary to conduct the required tests, including two spare sets of all equipment, available and ready for use not less than one week in advance of inspection or test performance. "Ready for use" will mean properly matched for test parameters, properly calibrated, properly programmed, sufficiently supplied with leads, probes, adapters, stands etc., necessary to conduct the particular test as required by the test procedure.

All temporary or interim test related materials, special tools, connections, jumpers, etc. will be furnished and available not less than one week in advance of the test performance. This will also include all versions of software, programming (PROMs, EPROMs, etc.), hardware, relays, etc., required to accommodate inspection or testing.

6.4.2 Acceptance Test and Certification Plan Quality Assurance

Develop specification sections that require the contractor to identify and develop a quality assurance plan to certify that the test plan, procedures and datasheets shall fully exercise all aspects of the signal system and that they will demonstrate that the system will perform all of its safety and operational functions as intended.

Identify and develop all quality assurance requirements to ensure that all acceptance tests and inspections have been performed and documented in accordance with the Contract Documents and all applicable industry standards, as well as all Federal, State and local codes.

The Engineer will have the right to witness any or all factory and field tests conducted. The Engineer will be notified in writing prior to each inspection or test. No part of the signal system will be placed in service without an authorized representative of the MBTA witnessing and certifying successful completion of the in-service test procedures by signoff on the completed test forms.

Configuration Control/Revision Verification – Prior to performing each test procedure related to the processor subsystems, the Contractor, with MBTA representatives witnessing, shall certify that the hardware and application configuration of each processor based system is as expected and is consistent with the identification and revision noted on the test datasheets.

6.4.3 Acceptance Test and Inspection Precedence and Progression

Develop specification sections that require the contractor to identify the precedence and prerequisites for testing as milestones requiring approval before proceeding to the next level of acceptance testing.

6.4.4 Discrepancy Reporting, Tracking and Resolution

Develop specification sections that require the contractor to develop a process for the reporting, tracking and resolution of all discrepancies identified during inspections and acceptance testing. The process should clearly identify the priority and level of attention that should be provided in resolving discrepancies for the various types of systems and components.

The resolution of a discrepancy is not final until the Engineer has approved it. All discrepancies shall be resolved by the Contractor and at no expense to the MBTA.

If equipment replacement is required to resolve a discrepancy, the replacement shall be new and shall be required to go through the same rigorous tests and quality assurance requirements as equipment of the same function and position.

All design changes found necessary to obtain proper operation will be submitted in writing to the Engineer for approval prior to their permanent implementation.

6.4.5 Acceptance Testing and Inspection Reports and Certification

Develop specification sections that require the contractor to identify and develop the requirements for the reporting of all inspections and tests so that quality assurance and oversight authorities may efficiently and completely review the documentation for accuracy and completeness.

Develop a means of creating a complete and logical paper trail, starting with inspections and testing, then identifying any discrepancies, their resolution, the level of retest and the subsequent completed test data and updated test procedures.

Develop a complete and detailed configuration control process whereby the Signal System shall be certified for operation.

6.5 Training

Both the design consultant and the contractor will have responsibilities for developing Training Plans for the various MBTA departments and employee disciplines. The Training Plan shall provide the MBTA staff with the necessary expertise to operate, maintain, modify and upgrade the newly installed systems and equipment.

Identify and design the necessary training support systems that shall be fully capable of emulating all field installations and simulating a wide range of in service failures as part of training simulations.

At a minimum, the following training shall be provided by the design consultant:

- Management Training – high level operations and maintenance training
- Operations Dispatcher Training and Support
- Operations Train the Trainer and Support

At a minimum, the following training shall be provided by the contractor:

- Signal Maintainer Training and Support
- Signal Engineering Training and Support

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Chapter 7

7.1 Railroad (Commuter Rail) Signal System Description

This section describes the impacts of the proposed Green Line Extension project on the existing Railroad that currently supports Commuter Rail Service as well as freight and maintenance activities. The affected lines are the New Hampshire Mainline and the Fitchburg Main Line, as well as track used for routing trains into yard and maintenance facilities. The track alignment and interlocking reconfiguration upgrades will have to be carefully phased to minimize any impact on railroad activities and service.

7.1.1 Signal System Project Limits

Upgrades to the existing signal system will be required as a result of several factors. These include relocation of the track, modification of interlocking configurations, as well as mitigation of signal sight-line issues and other technical concerns resulting from being in close proximity to an electrified transit system.

Due to its nature, the signal system work will extend beyond the physical construction limits of the Green Line Extension project. The upgrade of the signal system elements must extend beyond the point where mitigation is required, or to the nearest signal system control point. At these locations, an interface between the new and existing systems and technologies will be implemented.

7.1.2 Existing Signal System

The existing railroad signal system employs GE Transportation DC Coded Track Circuits (GETS Electro Code) and processor based interlocking control systems (GETS ElectrologIXS) to support a color light signal system. The existing system is dispatched form the control center located in the Cobble Hill Operations Facility using a computer-based system for right-of-way and train management.

7.1.3 Proposed Signal System

The proposed signal system for the impacted portions of the railroad shall be consistent and fully compatible with the existing systems and interfaces. Systems and equipment will be selected on their ability to minimize the need for specialized, one-of-a-kind interfaces or applications. The new system will use the latest processor and track circuit systems compatible with method of operation on the New Hampshire and Fitchburg main lines.

At a minimum the design will have to successfully address the following issues:

- Replacement of interlocking systems as part of the reconfiguration of affected interlocking tracks.
- Upgrade and replacement of track circuit technology from DC to AC based track circuits.
- Positioning of signals and addition of repeater signals based on new track alignment and line-of-sight obstructions.
- Design and application of a new block design due to the reconfiguration and repositioning of interlockings, as well as the updated track circuit technologies and repositioning of the track.

- System interfaces and integration at adjacent signal control locations.
- Updates to the existing control center systems to allow for proper train management through the newly configured track.

7.2 General Design Elements

The signal system will ensure the safe operation of trains through functions such as train detection, broken rail detection, signaling for safe train separation, and route security through interlockings on all portions of the modified and reconfigured track sections.

The new signal system elements shall be compatible with the existing railroad signal system, and will include all necessary and appropriate technology improvements. The implementation of the signal system upgrades will be phased according to the track work.

The design and implementation will provide a complete, functional, reliable and maintainable vital signal system. The provided criteria are not to be considered complete. They are offered to provide sufficient information to complete the design, installation, testing, commissioning and certification of the signal system. Design shall include the block layout, interlocking logic and circuits, interface logic and circuits, equipment placement and mounting, acceptance test procedures and inspections, acceptance standards, as well as development of all training and construction phasing. The signal system design shall provide for full and complete integration into existing and known future systems.

The signal system will be designed to utilize a fail-safe approach, ensuring that all vital circuits failing to respond as intended will not result in an unsafe condition.

7.2.1 Compliance with Standards

The design will conform to the most current version of the following standards to the greatest extent possible:

- American Railway Engineering and Maintenance of Way Association (AREMA) Communications and Signals Manual
- Institute of Electrical and Electronic Engineers (IEEE)
- National Electrical Manufacturer's Association (NEMA)
- Federal Highway Administration (FHWA)
- Manual on Uniform Traffic Control Devices (MUTCD)
- Audio Frequency Track Circuit (AFTC) standards
- American National Standards Institute (ANSI) standards
- American Society for Testing and Material (ASTM) standards
- American Society for Quality Control (ASQC) standards
- Federal Railroad Administration and Code of Federal Regulations Part 49 (CFR 49)
- Insulated Power Cable Engineers Association (IPCEA) standards
- Electronic Industries Association (EIA) standards
- National Electrical Manufacturers Association (NEMA) standards
- Massachusetts Electric Code (MEC)
- National Electric Safety Code (NESC)
- Underwriters Laboratories (UL) standards
- MBTA standards, practices, and recommendations

In case of conflict, the following priority shall prevail:

- Federal, state and local laws and regulations
- Contract Specifications and Contract Drawings
- MBTA standards
- AREMA standards, practices and recommendations
- Other standards as delineated above

7.2.2 Existing MBTA Specifications and Drawings for Basis of Design

Specifications and drawings shall utilize practices from the most recent and relevant projects.

7.2.3 Coordination with Other Work

The design and implementation of the railroad signal system upgrades shall be fully coordinated and scheduled with all other work and projects. Systems and equipment shall be located so as not to interfere with other activities and to minimize the amount of reinstallation.

Signal equipment will not obscure lines of sight, provide an unsafe environment for work staff, or present a hazard to the general public in any form.

7.2.4 Signal System Upgrades

The upgrades to the railroad signal system shall be based on current MBTA and Commuter Rail Standards and will take into account the current and projected service capacity.

Signal system functionality will be accomplished through the use of vital and non-vital microprocessor based systems as well as the implementation of AC coded track circuits. The work will include any improvements or additions necessary between the wayside systems and the control center.

The upgrades to the signal system will be designed and implemented based on the new track and interlocking layouts, as well as the routing required for supporting operations. The signal system design and implementation shall allow space for future PTC capabilities and potential system expansion.

7.2.5 Vehicles and Safe Braking

The design shall take into account the vehicle characteristics as well as the railroad standards for the layout of the updated block design. There may be multiple block designs based on the phasing of the construction.

7.3 Signal System Components

The signal system will consist of components including, but not limited to, track circuits, wayside signals, switches, vital and non-vital microprocessor and circuits, control and indications, communications systems, signal power, equipment housings, signal wires and cables, and snow melters.

7.3.1 Track Circuits

Track circuits for use on the commuter rail lines shall be based on GETS's ElectroLogIXS platform utilizing AC Coded Track Circuits as provided by GE Transportation. All track circuits shall be configured so that they will function reliably and at levels no greater than twenty percent below their maximum designed working capacity.

All cabling to and from the wayside shall be properly sized as required by the equipment manufacturers and as needed for the application. The number of conductors to be installed for each track circuit shall be as required by the equipment manufacturer.

7.3.2 Signals

Signals will be located as required by the block design, operational requirements and applicable standards. Signals shall be positioned according to required preview sight lines. Where necessary, repeater signals and other means shall be used to address obstructed previews.

Signals, cabling and wiring shall be designed according to the requirements of the railroad, all applicable standards and in accordance to manufacturer's recommendations.

7.3.3 Rail Bonding

Rail bonding shall be in compliance with all current standards and practices, as well as applicable manufacturer recommendations. Appropriate bonding will be provided at all non-insulated rail joints, frogs, switches, as well as all electrical connections for track circuits and traction return current.

7.3.4 Power Switch-and-Lock Movement Layouts

Mainline power switch-and-lock movement layouts will be Alstom 5F in compliance with the existing railroad standards in terms of layout, products, circuiting and logic. Switch-and-lock movement layouts will be complete and shall include internal heaters, snow melters, all necessary junction boxes, throw rods, swivels, front rod, point lug, lock rod, detector rod, shims, identification plates, required screws, nuts, washers, pins, grease fittings, cotter keys, plates, adjusting brackets, and hardware to mechanically couple the switch-and-lock movement to the switch points and to install the switch layout on ties. Special Trackwork Moveable Point Frogs will be M23 type.

All hand throw switch-and-lock movements will be complete with electric lock layouts, and will include a junction box, rod, mounting holes, mounting bolts, wiring inlets, contacts, terminal binding posts, screws, nuts, washers, internal circuit controller heater, and all other necessary appurtenances required for a complete and operational installation.

Internal heaters will have sufficient capacity to prevent adverse effects to the circuit controller and the motor compartment from high moisture and winter conditions.

Snow melters shall have sufficient capacity to keep the switch points and adjacent rail free from snow and ice. The snow melters shall be designed complete with heater control cases to allow management of the snow melters.

7.3.5 Vital Signal System Elements

The vital signal system is responsible for the safe movement of all trains and their passengers. The vital system will process and execute all vital functions in accordance with the latest industry standards. As needed, the vital systems will make use of properly applied vital relays, processor based subsystems, track circuit modules, and all life/safety components that make up a fully functional vital signal system. Where terminated on the processor based subsystems, all wiring will be double broke.

The vital systems will be designed based upon the GETS ElectroLogIXS platform utilizing closed circuit/loop principles, software diversity, use of proven vital hardware design techniques, and the manufacturer's safety model to achieve safety for the vital components and system. The use of multiple processors based on voting to enhance the probability of achieving safety is not acceptable. All vital function inputs/outputs shall connect to printed circuit boards designed for double-break, and all vital wiring to the processors shall be double broken.

Redundant systems with a warm-standby configuration shall be used; all input/output and interface wiring shall be designed to be completely isolated so that a failure of any component affecting one of the subsystems will not impact the partner subsystem. Additionally, all power feeds and fusing shall be designed to support complete isolation of the redundant systems.

The vital portions of the signal system shall be designed using all applicable standards and the latest versions of the products currently employed on the existing railroad to minimize costs associated with interfacing dissimilar products.

The design shall provide for all application circuits and logic in support of the block design and operational requirements. All systems shall be designed so that they can be efficiently and successfully tested according to all applicable testing standards and requirements.

General Requirements

The vital systems and equipment will be based upon the GETS ElectroLogIXS platform designed in accordance with this section and all applicable standards. They shall also include, but not be limited to the following:

- Provide a system, which has a proven record (a period of at least five years in revenue service) of implementation and the operation in close proximity to a 13.8KVAC and 600VDC electrified rail transit environment.
- A system that is proven to be reliable, maintainable, and provides operational flexibility and safety of train movements.
- Each VMIS processor will perform internal self-diagnostics that will quickly and accurately identify failed boards or vital processes as they occur.
- For vital processor based systems, application development shall be done on a system certified by the VMIS manufacturer using their most recent stable development platform.
- Application logic shall be fully simulated against test procedures and datasheets for verification of safety and functionality.
- The application development system shall be capable of full monitoring all executing logic and hardware for the purposes of acceptance testing and maintenance activities.
- An application development and monitoring system suited for field installation shall be provided with each VMIS unit. The application development system shall not be capable of loading new application logic to a VMIS unit without proper authentication of the individual performing the activity.
- Use of manufacturer limited retest processes will be acceptable following proof and acceptability of that process to the Railroad Operator and the Engineer.
- Complete system documentation, generic and application specific, in both hardcopy and electronic format shall be provided.
- Site licenses to use all furnished system software for the entire MBTA infrastructure without limitation.
- Other apparatus including, but not limited to, modems, network interfaces, chassis, cables, power supplies, test equipment and all circuit boards.
- Engineering efforts will include, but not limited to, all application, software, hardware and support engineering.
- 100% spare capacity for future expansion in application logic.
- 20 % spare capacity for all installed I/O for the normal and standby systems for future expansion.
- All timers other than loss of shunt shall be externally settable or settable in such a way that it does not require the reloading of application logic.

- Event recording/data logging shall be provided as an integral part of the system. For relay-based systems, an event recorder designed specifically for this function shall be used and shall be consistent with existing system already in use on the railroad.
- The design shall log all maintenance and diagnostic indications for troubleshooting purposes. Diagnostic data shall be displayed in an HMI developed troubleshooting graphical user interface on the Maintainers Panel to assist in the efficiency of troubleshooting and taking corrective action.
- All apparatus will be rack mounted.

7.3.6 Non-Vital and Control Center Signal System Elements

The non-vital signal systems shall be comprised of various systems to assist in the efficient operation and monitoring of all signal system equipment and all train movements for the reconfigured interlockings and new track alignment. The non-vital subsystems and functions include all non-vital logic, local control screen and functionality, code lines and systems, as well as the control center functionality and user interface.

7.3.6.1 Signal Fiber Network

Not Applicable.

7.3.6.2 Maintenance PC's

Maintenance PC's shall be designed in as an integral part of the installed systems.

The Maintenance PC's shall have all necessary applications installed for monitoring all processor-based systems. They shall also have all application tools necessary for remote access and management of systems on the same network. Capabilities other than system monitoring shall require authentication.

The Maintenance PC's shall be hardened equipment designed to function in the harsh railroad environment.

7.3.7 Equipment Housings

Signal Bungalows will be designed as needed to house all functional signal system elements utilizing PTMW Inc. bungalows designed to the specifications of the railroad operator. Signal Bungalows will be of adequate size to accommodate all signal equipment, plus spare capacity for future equipment. Signal bungalows will be located adjacent to the reconfigured interlockings in accordance with the requirements of the railroad operator.

CIHs will include all necessary electrical sources, lighting, HVAC systems, means of cable entry, pre-wired cable racks, and fire suppression systems. The HVAC system shall be a two part system and shall not use air transfer with the outside as a means of cooling or heating.

Junction boxes and equipment cases will be integrated into the design as needed for remote equipment and cable terminations. Junction boxes shall provide adequate space for triple or double post terminals as needed, terminal boards, cable, fiber slack, and all other necessary appurtenances.

7.3.8 Signal Power

The Signal Bungalows will be powered from the closest local utility feed.

The power feeds shall be sized to support all loads, including spare capacity for future expansion. This will be reflected in the sizing of all components. Calculations will be done to confirm the sizing of all power system components.

As much as possible and for ease of maintenance, all signal power feed components shall be consistent with existing installations and for all new signal bungalows. The bungalow with the greatest load shall be used as the basis for the other bungalows.

The Design shall include a coordination study to ensure proper protection and coordination of upstream and downstream devices. Electrical ratings and settings of the proposed equipment will be selected to ensure coordinated operation under both normal and worst case conditions.

7.4 Signal System Tests

7.4.1 Acceptance Test and Certification Plan

Develop a test plan that identifies a clear and logical progression for the successful inspection, testing and certification of all signal system elements and the signal system as a whole. Include in the test plan the requirements for configuration control to address documentation management, as well as a process for identification, tracking and resolution of dependencies – what needs to be tested in what order, what needs to be retested, and how.

7.4.1.1 Point of Manufacture Product Factory Inspection and Tests

Develop specifications that detail requirements for all product testing and certification requirements of the contractor, including methods for determining quality assurance relevance and compliance at the point of manufacture. Define the quantities requiring inspection and testing based on the application of the component.

All components related to vital or fail-safe circuits and logic shall be tested. Documentation of test performance shall be submitted for each component.

For all other components, an approved number of randomly selected units from the manufacturing process will be tested to ensure the adequacy and acceptability of all component types produced.

7.4.1.2 Factory Acceptance Inspections and Tests

Develop specifications that detail procedures that shall be developed by the contractor for the following, at a minimum:

- Visual and Mechanical Inspection
- Simulation Wiring and Functional Verification Test
- Wiring, Cable and Fiber Jumper Verification (Point-to-Point)
- Grounding Verification of all Racks and Equipment Chassis
- Energy Distribution Systems Continuity, Phasing and Isolation Test – Power Off
- Energy Distribution Systems Verification, Phasing and Level Test – Power On
- Vital Relay Test and Certification
- Vital Wiring and Cable Breakdown Test
- Vital Line Circuit and Line Data Test
- Vital Logic (VMIS) Functional Test and Breakdown (Interlocking and Control Line)
- Track Circuit Preliminary Setup and Verification Test
- Signal Data Network Configuration Verification
- Non-Vital Wiring and Cable Breakdown Test
- Non-Vital Systems Functional Test and Breakdown (NVPLC, LCP, Status and Control, HMI)
- Control Center Interface Verification and Functional Test
- Event Recorder functional Tests

7.4.1.3 Site Acceptance Inspections and Tests

Develop specifications that detail procedures that shall be developed by the contractor for the following at a minimum:

- Visual and Mechanical Inspection
- Cable Routing Inspection
- Power Feed System Wiring and Cable Verification – Power Off
- Power Feed System Test – Power On
- Ground Grid and Ground Bus Verification Test
- Field Cable Insulation Resistance Test
- Field Cable Verification Test (Point-to-Point)
- Fiber Verification and Certification Test (OTDR and Power Level)
- Wiring, Cable and Fiber Jumper Verification (Point-to-Point)
- Grounding Verification of all Racks and Equipment Chassis
- Energy Distribution Systems Continuity, Phasing and Isolation Test – Power Off
- Energy Distribution Systems Verification, Phasing and Level Test – Power On
- Vital Wiring and Cable Breakdown Test
- Vital Line Circuit and Line Data Test
- Vital Relay Test and Certification
- Vital Logic (VMIS) Functional Test and Breakdown (Interlocking and Control Line)
- Track Circuit Setup and Verification Test
- Switch and Lock Movement Adjustment, Breakdown and Functional Test
- Signal Layout Adjustment and Lighting Test
- Non-Vital Wiring and Cable Breakdown Test
- Non-Vital Systems Functional Test and Breakdown (NVPLC, LCP, Status and Control, HMI)
- Control Center Interface Verification and Functional Test
- Snow Melter Checkout, Breakdown and Functional Test
- Event Recorder functional Tests
- Battery Systems Tests
- HVAC System Tests
- Fire Protection System Test (simulated)

7.4.1.4 Acceptance Test Equipment and Special Tools

Develop specifications that require that the Contractor provide all test instruments and equipment necessary to conduct the required tests, including two spare sets of all equipment, available and ready for use not less than one week in advance of inspection or test performance. "Ready for use" will mean properly matched for test parameters, properly calibrated, properly programmed, sufficiently supplied with leads, probes, adapters, stands etc., necessary to conduct the particular test as required by the test procedure.

All temporary or interim test related materials, special tools, connections, jumpers, etc. will be furnished and available not less than one week in advance of the test performance. This will also include all versions of software, programming (PROMs, EPROMs, etc.), hardware, relays, etc., required to accommodate inspection or testing.

7.4.2 Acceptance Test and Certification Plan Quality Assurance

Develop specifications that require that the contractor identify and develop a quality assurance plan to certify that the test plan, procedures and datasheets shall fully exercise all aspects of the signal system and that they will demonstrate that the system will perform all of its safety and operational functions as intended.

Identify and develop all quality assurance requirements to ensure that all acceptance tests and inspections have been performed and documented in accordance with the Contract Documents and all applicable industry standards, as well as all Federal, State and local codes.

The Engineer will have the right to witness any or all factory and field tests conducted. The Engineer will be notified in writing prior to each inspection or test. No part of the signal system will be placed in service without an authorized representative of the MBTA and the operator of the railroad having witnessed successful completion of the in-service test procedures by signoff on the completed test forms.

Configuration Control/Revision Verification – Prior to performing each test procedure related to a processor subsystem, the Contractor, with MBTA/Railroad Operator representatives witnessing, shall certify that the hardware and application configuration of each processor based system is as expected and is consistent with the identification and revision noted on the test datasheets.

7.4.3 Acceptance Test and Inspection Precedence and Progression

Develop specifications that require that the contractor identify and develop the precedence and prerequisites for testing as milestones requiring approval before proceeding to the next level of acceptance testing.

7.4.4 Discrepancy Reporting, Tracking and Resolution

Develop specifications that require the contractor to develop a process for the reporting, tracking and resolution of all discrepancies identified during inspections and acceptance testing. The process should clearly identify the priority and level of attention that should be provided in resolving discrepancies for the various types of systems and components.

The resolution of a discrepancy is not final until the Engineer has approved it. All discrepancies shall be resolved by the Contractor and at no expense to the MBTA.

If equipment replacement is required to resolve a discrepancy, the replacement shall be new and shall be required to go through the same rigorous tests and quality assurance requirements as equipment of the same function and position.

All design changes found necessary to obtain proper operation will be submitted in writing to the Engineer for approval prior to their permanent implementation.

7.4.5 Acceptance Testing and Inspection Reports and Certification

Develop specifications that require the contractor to identify and develop the requirements for the reporting of all inspections and tests so that quality assurance and oversight authorities may efficiently and completely review the documentation for accuracy and completeness.

Develop a means of creating a complete and logical paper trail, starting with inspections and testing, then identifying any discrepancies, their resolution, the level of retest and the subsequent completed test data and updated test procedures.

Develop a complete and detailed configuration control process whereby the Signal System shall be certified for operation.

7.4.6 Training

Develop specifications that require the contractor to develop a Training Plan for the railroad operator's engineering and maintenance department according to discipline. The Training Plan shall provide the railroad staff with the necessary expertise to operate, maintain, modify and upgrade the newly installed systems and equipment.

Identify and design the necessary training support systems that shall be fully capable of emulating all field installations and simulating a wide range of in service failures as part of training simulations.

8 Noise and Vibration

Chapter 8

8.1 Impact Limits and Design Criteria

Specific properties that would be exposed to noise and/or vibration impact prior to mitigation are defined in the noise and vibration sections of the Green Line Extension Project Environmental Assessment (EA). Specific mitigation commitments for potential noise and vibration impact are listed in the EA.

The following are the noise and vibration limits used in assessing potential impact and the design criteria for mitigation. Noise and vibration impact and mitigation are consistent with that defined in the FTA guidance manual "Transit Noise and Vibration Impact Assessment" (Report FTA-VA-90-1003-06, May 2006).

8.2 Noise Impact Limits

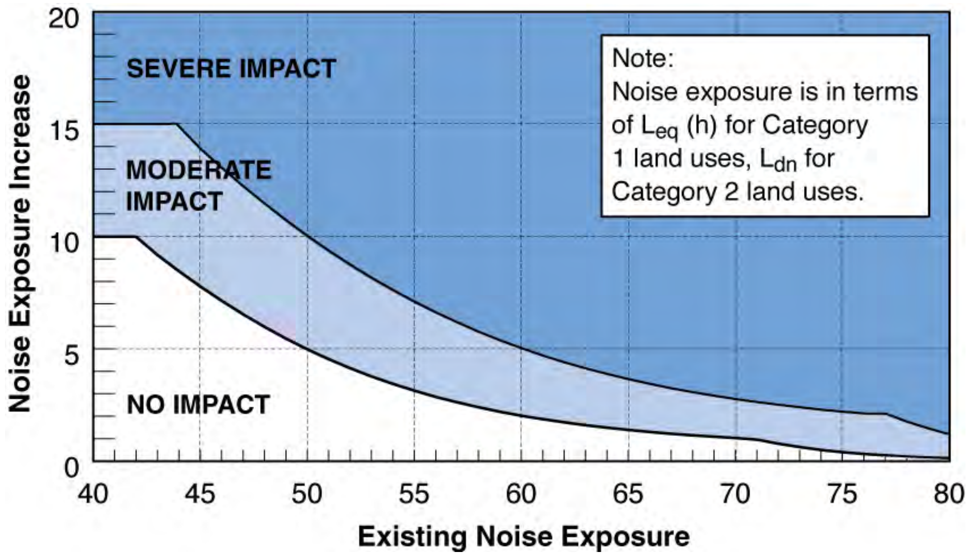
Noise impact criteria are defined on a sliding scale as a comparison of existing noise levels to the noise exposure increase due to the project (see Figure 8-1). The noise exposure increase is calculated as the difference between future noise levels and existing noise levels. Future noise levels are calculated as the sum of existing noise sources taking into account any modifications to these sources (e.g. moving existing commuter tracks or bus routes) and new project-related noise sources.

The following list describes the noise metrics used to assess impact;

- Day-night sound level (L_{dn}) for FTA Category 2 receptors, which are residences and buildings where people normally sleep,
- Existing peak hourly-equivalent sound level (L_{eq}) during hours of sensitivity for FTA Category 1 receptors, which are tracts of land where quiet is essential for buildings and parklands, and
- FTA Category 3 receptors, institutional land uses with primarily daytime and evening use such as schools, libraries, theatres and places of worship.

These noise criteria are applied at exterior locations of frequent human use including outdoor patios, decks, pools and play areas. If no exterior locations are identified, the criteria are applied at the building façade of sensitive interior spaces.

Figure 8-1 Noise Impact Criteria



8.3 Groundborne Noise Impact Limits

Table 8-1 shows the groundborne noise limits that apply to the interior spaces of sensitive buildings that do not have significant airborne paths such as large buildings with no windows or when the rail alignment is in a tunnel.

Table 8-1 Groundborne Noise Limits

	Green Line Trains	Commuter Trains
Vibration-Sensitive Receptor	**Decibels (dBA re: 20µPa)**	**Decibels (dBA re: 20µPa)**
Special Buildings: Concert Halls, TV Studios, Recording Studios	25	25
Special Buildings: Auditoriums	30	38
Special Buildings: Theaters	35	43
FTA Category 2: Residential Buildings	35	38
FTA Category 3: Schools, Churches, Hospitals, Museums, Libraries	40	43

Source: FTA, 2006.

8.4 Construction Noise Impact Limits

The construction noise criteria applicable to this project are based on the Central Artery/Tunnel (CA/T) Noise Control Specification 721.560. This detailed construction noise specification is consistent with the City of Cambridge Noise Ordinance (Ord. 1326, Chapter 8.16.070, adopted May 18, 2009), the City of Somerville Noise Ordinance (No. 2000-11, §§ I—VII, IX, adopted Nov. 22, 2000) and the City of Medford Noise Ordinance (Revised Ordinances Chapter 38, Article II, Sec. 38-34). This specification establishes noise criteria limits according to time of day and type of sensitive land use, defines allowable limits for the maximum noise emissions of specific equipment and defines the components of a noise monitoring plan to be prepared prior to construction, the noise monitoring equipment to be used, noise reduction measures that may be implemented and reporting requirements.

Construction lot-line noise limits depend on the time of day (daytime, evening or nighttime) and the type of sensitive land use (FTA-defined sensitive land use, commercial areas and industrial areas). These criteria are based on the L10 noise descriptor. For daytime construction (7:00 AM to 6:00 PM), the limits are defined as the greater of 75 dBA or the background or ambient level plus 5 dBA for FTA-defined noise sensitive sites, 80 dBA or the background plus 5 dBA for commercial areas and 85 dBA or the background plus 5 dBA for industrial areas. For evening construction (6:00 PM to 10:00 PM), the L10 limit for FTA-defined noise sensitive sites is the background plus 5 dBA. For nighttime construction (10:00 PM to 7:00 AM), the L10 limit for FTA-defined noise sensitive sites is the background plus 5 dBA (if the background is less than 70 dBA) and plus 3 dBA (if the background is greater than 70 dBA). Commercial and industrial areas are not considered to be sensitive to construction noise during the evening or nighttime since they are generally closed during these periods.

Table 8-2 Construction Lot-Line Noise Limits

Land Use (c)	**Time of Day**	**L10 Level (dBA)**	**L_{max} Level (dBA)**
FTA Land Use Categories (1,2,3)	Daytime	75 or Background + 5 (a)	85 (b) / 90 (impact equip.)
Commercial	Daytime	80 or Background + 5 (a)	None
Industrial	Daytime	85 or Background + 5 (a)	None
FTA Land Use Categories (1,2,3)	Evening	Background + 5	85
Commercial	Evening	None	None
Industrial	Evening	None	None
FTA Land Use Categories (1,2,3)	Nighttime	Background + 5 (existing < 70)	80
FTA Land Use Categories (1,2,3)	Nighttime	Background + 3 (existing > 70)	80
Commercial	Nighttime	None	None
Industrial	Nighttime	None	None

Source: CA/T Noise Specification 721.560

a Noise from impact equipment is exempt from this requirement.

b All measurements shall be taken at the affected lot-line. In situations where the work site is within 50 feet of a lot-line, the measurement shall be taken from a point along the lot-line such that a 50 foot distance is maintained between the sound level meter and the construction activity being Monitored.

c Lot-line noise limits shall apply to all points along the receptor's lot-line.

In addition to construction lot-line noise limits, noise limits at 50 feet for specific equipment have been identified. A list of these construction noise limits is provided in Table 8-3.

Table 8-3 Construction Equipment Maximum Noise Limits and Usage Factors

Construction Equipment	Maximum Noise Level at 50 feet (dBA, slow)	Usage Factor
Auger Drill Rig	85	20%
Backhoe	80	40%
Bar Bender	80	20%
Blasting	94	1%
Boring Jack Power Unit	80	50%
Chain Saw	85	20%
Clam Shovel	93	20%
Compactor (ground)	80	20%
Air Compressor	80	40%
Concrete Batch Plant	83	15%
Concrete Mixer Truck	85	40%
Concrete Pump	82	20%
Concrete Saw	90	20%
Crane	85	20%
Dozer	85	40%
Dump Truck	84	40%
Excavator	85	40%
Flat Bed Truck	84	40%
Front End Loader	80	40%
Generator (25 KVA or less)	70	50%
Generator (over 25 KVA)	82	50%
Gradall	85	40%
Grader	85	40%
Horizontal Boring Jack	80	25%
Hydraulic Break Ram	90	10%
Impact Pile Driver	95	20%
Insitu Soil Sampling Rig	84	20%
Jackhammer	85	20%
Mounted Hammer (ram)	90	20%
Paver	85	50%
Pickup Truck	85	40%
Pneumatic Tools	85	50%
Pumps	77	50%
Rock Drill	85	20%
Scraper	85	40%
Slurry Plant	78	100%
Slurry Trenching Machine	82	50%
Soil Mix Drill Rig (Jet Grouting)	80	50%
Tractor	84	40%
Vacuum Excavator	85	40%
Vacuum Street Sweeper	80	10%
Vibratory Concrete Mixer	80	20%
Vibratory Pile Driver	95	20%
Welder	73	40%
All Other Equipment > 5 HP	85	50%

Source: CA/T Noise Specification 721.560

8.5 Groundborne Vibration Impact Limits

Table 8-4 presents the limits for vertical vibration velocity in decibels (VdB, relative to 1 micro-inch per second) and absolute rms (root-mean-square) levels. These limits are for potential human annoyance or disruption to sensitive equipment inside buildings.

Table 8-4 Groundborne Vibration Limits for Annoyance

Vibration-Sensitive Receptor	Green Line Trains		Commuter Trains	
	Decibels (VdB re: 1µin/s)	Absolute (rms, in/s)	Decibels (VdB re: 1µin/s)	Absolute (rms, in/s)
Special Buildings: Sensitive Manufacturing, Vibration-Sensitive Research, Concert Halls, TV Studios, Recording Studios*	65	0.0018	65	0.0018
Special Buildings: Auditoriums, Theatres	72	0.0040	80	0.01
FTA Category 2: Residential Buildings	72	0.0040	75	0.0056
FTA Category 3: Schools, Churches, Hospitals, Museums, Libraries	75	0.0056	78	0.0079

Source: FTA, 2006.

- This criterion is based on levels that are acceptable for most moderately sensitive equipment. Defining limits that are more sensitive require a detailed analysis.

Table 8-5 presents the groundborne vibration limits for potential damage to structures. Since vibration levels from transit operations rarely exceed these values, these criteria typically apply only to construction activities. These limits include peak-particle vertical velocity limits in absolute levels and decibels assuming a crest factor of 4 (representing a peak particle velocity (PPV)-rms difference of 12 VdB).

Table 8-5 Groundborne Vibration Limits for Potential Structural Damage

Building Category	Decibels (VdB re: 1µin/s)	Absolute Peak-Particle Velocity (PPV, in/s)
Reinforced-concrete, steel or timber (no plaster)	102	0.5
Engineered concrete and masonry (no plaster)	98	0.3
Non-engineered timber and masonry buildings	94	0.2
Buildings extremely susceptible to vibration damage	90	0.12

Source: FTA, 2006.

8.6 Noise Mitigation Design Criteria

Noise mitigation is required where feasible, reasonable and effective for all severe noise impacts with exterior locations of frequent human use. For severe noise impacts with no exterior locations of frequent human use, mitigation is required for interior spaces if interior spaces would be exposed to future noise from project sources greater than an interior day-night sound level (L_{dn}) of 45 dBA or single-event maximum noise levels (L_{max}) greater than 65 dBA from train pass bys or 70 dBA from train horns.

Noise mitigation is required where feasible and reasonable for moderate noise impacts based on the following factors:

- If existing noise levels are above 65 L_{dn} from transportation noise sources, then moderate noise impacts should be considered as though they are severe and mitigation provided accordingly.
- Where future noise levels fall within the range of moderate impact affects the need for mitigation. If future noise levels are in the top 50% of the moderate range, then mitigation should be provided.
- Community views are an important factor in determining the need for mitigation. If there is significant opposition to mitigation measures (e.g. noise barriers) for moderate noise impacts, they may not be implemented.
- Other factors such as the density of affected sites, the sensitivity of the property and the effectiveness of mitigation measures should also be considered in determining the need for mitigation of moderate noise impacts.

The noise reduction goal for mitigation is to provide a substantial decrease in future noise levels. Any noise mitigation measure including noise barriers and sound insulation must provide a minimum of 5 decibels of noise reduction to be considered an effective measure.

8.7 Construction Noise Mitigation Design Criteria

The goal for construction noise mitigation is to maintain noise levels below both the lot-line noise limits and the equipment-specific maximum noise levels. Construction noise mitigation should include the preparation of a Noise Control Plan in conjunction with the contractor's specific equipment, schedule and methods of construction, maximum noise limits for each piece of equipment, prohibition on certain types of equipment during the nighttime hours and engineering noise control measures.

An Acoustical Engineer will prepare a Noise Control Plan in conjunction with the contractor's specific equipment and methods of construction. This Plan will be consistent with that specified in the CA/T 721.560 Noise Specification. Key elements of the Plan include:

- Identification of specific sensitive sites where noise monitoring will occur
- Background noise monitoring prior to and during construction
- Construction equipment noise certification testing
- Prohibition of impact pile-drivers during evening and nighttime hours (i.e. 6:00 PM to 10:00 PM and 10:00 PM to 7:00 AM)
- Prohibition of vibratory sheet pile-driving and all impact devices including hoe rams, jackhammers and pavement breakers during nighttime hours
- Requirement for ambient-adjusting or manually adjusted backup alarms set to 5 dBA over background levels
- Truck idling limited to five minutes
- Acoustic shield requirement for jackhammers, chainsaws and pavement breakers
- Methods for projecting construction noise levels
- Detailed engineering noise control measures
- Methods for responding to community complaints
- Reporting of noise monitoring results, noise reduction measures used and responses to the community

8.8 Vibration Mitigation Design Criteria

The goal for mitigating potential vibration impact from the proposed Green Line Extension project is to keep future vibration levels from the proposed project at or below existing vibration levels and, when feasible and reasonable, reduce future vibration below the impact criteria shown in Table 8-4. Vibration mitigation must be feasible, reasonable and effective. Vibration mitigation is considered effective if it can provide 5 VdB or more of vibration reduction.

The goal for mitigating potential structural damage to nearby buildings from construction activities is to maintain vibration levels below the criteria shown in Table 8-5.

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9 Drainage

Chapter 9

9.1 General

This chapter sets forth Stormwater Management Design Criteria (SMDC) to design the stormwater management system for the rail corridor and roadways for the MBTA Green Line Extension project.

9.1.1 Codes, Standards, References, and Guidelines

Unless noted, or directed otherwise, the following standards, codes and guidelines shall be used in the design of all stormwater management systems and facilities for the rail corridor, roadways and intersections, stations, and site design elements, as appropriate, and as set forth in this chapter. Design element-specific references are described in the subsequent sections.

1. The latest edition, including revisions, amendments and supplements, of the following publications:
    - MBTA Railroad Operations Commuter Rail Design Standards Manual
    - MBTA Book of Standard Trackwork Plans
    - MBTA Book of Standard Plans – Track and Roadway
    - MBTA Railroad Operations Commuter Rail Design Standards Manual for Track and Roadway
    - MBTA Commuter Rail Track and Roadway Book of Standard Plan
    - MBTA Railroad Operations Commuter Rail Design Standards Manual for Bridges.
    - MBTA Railroad Operations Directorate Guidelines and Procedures for Construction on MBTA Railroad Property. These specifications provide general safeguards to railroad property owned or controlled by the MBTA and to railroad operations upon that property during the performance of construction and/or related activities on, over, under, within or adjacent to the railroad property.
    - MBTA Manual of Guidelines and Standards
    - MBTA Guidelines for Designing Barrier-Free Transportation Facilities
    - MBTA Commuter Rail Station Access Guidelines
    - MBTA Maintenance of Way Division Green Line – Light Rail Transit Track Maintenance and Safety Standards.
    - Massachusetts Department of Environmental Protection (MassDEP) Stormwater Policy
    - Massachusetts Department of Environmental Protection (MassDEP) Stormwater Management Standards
    - Massachusetts Department of Environmental Protection (MassDEP) Stormwater Handbook
    - MassHighway Project Development and Design Guide

- MassHighway Construction Standard Details
- MassHighway Standard Specifications for Highways and Bridges
- MassHighway Storm Water Handbook for Highways and Bridges
- MassHighway Drainage Manual
- Massachusetts State Building Code

Massachusetts Department of Environmental Protection (MassDEP) standards, guidelines and policies -

- MADEP Erosion and Sediment Control Guidelines for Urban and Suburban Areas
- MADEP Protocol for Stormwater Best Management Practice Demonstrations

2. Current versions of the following relevant policies, procedures and directives:
   - MassHighway Engineering Directives
   - MassHighway Policy Directives
   - MassDOT Highway Division Engineering Directives
   - MassDOT Highway Division Policy Directives

3. MassHighway Project Development and Design Guide MassHighway Design Manual
4. MassDOT Highway Division LRFD Bridge Manual Design Guidelines MassDOT Highway Division Right of Way (ROW) Manual
5. MassHighway Standard Specifications for Highways and Bridges MassDOT Highway Division Supplemental Specifications to the Standard Specifications for Highways and Bridges
6. MassDOT Highway Division Standard Special Provisions
7. MassHighway Construction and Traffic Standard Details

Massachusetts Department of Transportation (MassDOT) policies, procedures and directives -

- MassDOT Highway Division Engineering Directives
  - Guidance and policies regarding the design, construction and maintenance of drainage structures and roadway drainage systems
  - Design Criteria for MassHighway Projects and Bicycle and Pedestrian Accommodation Requirements
- MassDOT Highway Division Policy Directives
  - MassHighway Department Drainage Connection Policy

9.1.2 Existing Permits and Regulatory Requirements

9.1.2.1 National Pollutant Discharge Elimination System (NPDES) Permit Requirements

The drainage and stormwater management design criteria for the Green Line Extension project is guided by the regulatory requirements as authorized by the NPDES permit program that controls water pollution by regulating point sources that discharge pollutants into waters of the United States. The closed drainage system in this project, which includes under drains, manhole structures and trunk lines that intercept runoff from the corridor connect to local drainage systems that ultimately discharge to the Millers River, Mystic River and Charles River. Stormwater discharges from the railroad corridor, roadways and intersections should be in compliance with the effluent limitations, monitoring requirements and other conditions set forth in the most recent NPDES permits related to the aforementioned discharging water bodies. The following NPDES permits are related to stormwater discharges from the project site:

- NPDES Permit No. MA0003590 2007 Reissuance – This permit authorizes MBTA and MBCR to discharge treated stormwater from the facility located at the MBTA Commuter Rail Maintenance Facility (also known as the BET yard) to the Millers River (segment ID MA 72-31). Stormwater discharge from the 54" drain line that the leaves the railroad ROW at Washington Street, follows Cobble Hill Road to Inner Belt Road and ultimately connects to the Old Stone Culvert that outfalls to the Millers River will be regulated by this permit.
- NPDES Permit No. MA0101982 – This permit authorizes the City of Somerville to discharge from two combined sewer overflow (CSO) to Alewife Brook and Upper Mystic River. Stormwater discharge from the 52" drainage trunk line that leaves the railroad corridor south of School Street, at the intersection of Medford Street and Pearl Street, connects to the 66" storm drain in Marshall Street. This storm drain ultimately discharges to the Somerville Marginal CSO screening and chlorination facility, outfalls to the Mystic River, which will be regulated by this permit
- NPDES Permit No. MA0101974 – This permit authorizes the City of Cambridge to discharge from 12 CSOs to Alewife Brook and Charles River. Stormwater discharge from the 48" drainage trunk line that conveys from the Fitchburg line and the BET yard to the Charles River will be regulated by this permit.
- NPDES Stormwater Management Plan for MassHighway Owned and Operated Highways – This plan was developed to comply with EPA's general NPDES permit MAR043025, which authorizes MassHighway to discharge stormwater, specifically Part V – Transportation MS4 Stormwater Management Program. The project site lies in District 4 of MassHighway Districts and the overall drainage criteria shall be in compliance with MassHighway's existing stormwater management program.

9.1.2.2 Clean Water Act and Total Maximum Daily Load (TMDL) Requirements

The two discharging water bodies, Charles River (segment ID MA72-08) and Mystic River (segment ID MA71-02), that receive stormwater runoff from the railroad corridor, roadways and intersections are both listed on the Category 5 303(d) List of Impaired Waters in the Massachusetts Year 2010 Integrated List of Waters. Both these segments do not meet surface water quality standards after implementation of technology-based controls and, as such, require the development of TMDLs. Drainage design criteria for stormwater management for this project shall be guided by minimizing the causes of impairment and complying with existing or future TMDL requirements, where applicable, to the maximum extent practicable.

- Charles River Segment (ID MA72-08) – Causes of impairment include but not limited to metals (other than mercury), nutrients, oil and grease, pathogens, priority organic compounds, turbidity, taste, color and odor. TMDLs have already been completed for nutrients and pathogens in the lower Charles River watershed. Stormwater discharges from the project site to this water body shall meet the wasteload allocations (WLA), respectively for each pollutant set forth in the respective TMDLs without exceeding the water quality standard for that pollutant.
- Mystic River Segment (ID MA71-02) – Causes of impairment include metals (other than mercury), nutrients and pathogens. Stormwater management design criteria shall be in compliance with TMDL requirements for these pollutants as and when they are developed.

9.1.3 Existing Stormwater Bylaws Requirements

The design criteria for the stormwater management system for the railroad corridor, roadways and intersections when in Cambridge, Somerville and Medford shall be in accordance with the stormwater bylaw regulations for Cambridge, Somerville and Medford, respectively.

9.1.3.1 City of Cambridge Wastewater and Stormwater Drainage Use Regulations

This sub-section presents the stormwater management requirements for design and construction of facilities in Cambridge. On-site retainage of stormwater and implementation of other stormwater management measures to control the rate, volume and characteristics of stormwater discharged to the City's combined sewer or stormwater drainage systems shall be required whenever appropriate, as determined by the Department of Public Works (DPW). Every person seeking to establish new connection to the City's combined sewer or stormwater drainage system or to reconstruct, repair or modify an existing connection for a facility undergoing expansion or rehabilitation shall be required to obtain a Stormwater Pollution Prevention Plan (SWPPP) and may be required to prepare and implement a stormwater management plan. Such a plan may include structural and non-structural measures to manage stormwater during and after construction of the new or expanded facility. The design and maintenance of such facilities shall be subject to the approval of the DPW in accordance with the Cambridge Wastewater and Stormwater Guidelines and shall meet all current state and federal regulations. The design, installation and maintenance of such facilities shall be at the Owner's expense. The DPW shall have the right to inspect such facilities in accordance with their Regulations.

9.1.3.2 City of Somerville Stormwater Regulations

According to the Stormwater Management Policy for the City of Somerville (issued February 3, 2011), the Somerville Zoning Ordinance (SZO) forbids adverse development impacts to abutters, city systems and water quality, and encourages diversion, detention, retention and mandates maximum groundwater recharge with no increase in runoff volume or rate at site boundaries. New sanitary sewer connections for flows over 2,000 GPD require a 4:1 removal of infiltration and/or inflow to qualify for a permit. As part of their stormwater regulations, the City also follows MassDEP's Stormwater Management Regulations issued in 2008 for both water quality and quantity, covering standards, applicability, planning and best management practices.

9.1.3.3 City of Medford Stormwater Regulations

The stormwater design guidelines for the City of Medford are based on the NRCS 25-year design storm such that peak discharge under proposed or future conditions flow does not exceed the peak discharge from existing conditions flow. The stormwater management program for the City also addresses the NPDES MS4 requirements for the six minimum control measures related to both stormwater quantity as well as quality.

9.2 Rail Corridor

9.2.1 General

This subchapter sets forth Stormwater Management Design Criteria (SMDC) to design the stormwater management system for the rail corridor, as part of the MBTA Green Line Extension project.

9.2.2 Design Methodology

The stormwater management system for the rail corridor shall be designed in accordance with MBTA and MassDEP standards.

9.2.3 Design Criteria

The design criteria for the stormwater management system for the rail corridor shall be in accordance with the MBTA Railroad Operations Commuter Rail Design Standards Manual, Section I, Chapter 5, and the MassDEP Massachusetts Stormwater Policy.

1. Construction of the Green Line Extension project is classified as a redevelopment project.
2. Drainage calculations and design work shall be signed and sealed by a registered professional engineer.
3. Existing drainage patterns shall be maintained wherever possible.
4. To the maximum extent possible, drainage of the roadbed will be handled by a gravity system.
5. Track drainage system shall be designed to accommodate peak flows produced by the 50-year design storm and maintain a maximum water level 18 inches below top of tie during the 100-year design storm.
6. The track under drain invert shall maintain a minimum depth of 4'-6" from the top of rail.
7. The track under drain centerline shall be at least 6'-6" from the track centerline.
8. Manholes shall be installed at all pipe junctions and grade or alignment change points. Storm drain manholes and/or cleanouts shall be installed at a maximum interval of 300 feet.
9. Track perforated pipe under drains minimum diameter shall be 12".
10. Where perforated pipes are being used to carry water with groundwater control a secondary requirement, the pipe shall be laid with perforations up.
11. Pipes under railroad tracks shall be designed for Cooper E80 loading and shall have a minimum cover of 2 feet from bottom of tie to the top of pipe.
    a. Do not drain areas from beyond the track bed through the track structure. Typically, a ditch or subdrain should lie between the track and the adjacent ground area to intercept fines from an adjacent slope which would foul the ballast.
    b. At locations where there will be a future track, crown the subgrade on the centerline between the tracks. Where practical, keep the ditch or subdrain on the field side of the future track clear of the future track so it does not have to be changed later.
    c. Typical drainage pattern for double track roadbed section is from a crown between the tracks to a ditch or subdrain on the field side of the tracks. When double track is between walls a single subdrain may be located between the tracks. "Walls" may include a retained cut or a retained fill where the walls are too close to the tracks to allow ditches or subdrains.
    d. Typical drainage pattern for single track is a crown line on the centerline of the track to ditches or subdrains on each side. When a single track is between walls, the ditch or subdrain may be located on one side and the subgrade sloped in one direction to the ditch or underdrain. At side platform stations, the platform should drain away from the track. A subdrain should be placed between the track and the platform to drain half of the track bed, and any water from platform canopies or areas behind the platform that are not handled by other site drainage. If there is a wall on the opposite side of the track from the platform, the entire track area should drain to the subdrain lying between the track and platform.

According to the MBTA standards, design considerations related to design flows for local drainage are preferred to be computed by the Rational Equation. The track drainage system including all open track bed areas exposed to direct precipitation shall be designed to accommodate the peak flows produced by the 50 year rainfall event. All runoff shall be fully contained within the drainage system, no surcharge will be allowed for un-depressed catch basins and the capacity of all pipes, ditches, etc. shall equal or exceed the 50 year runoff. In addition, the storm drainage system shall be designed to maintain a maximum water level 18" below top of tie during the 100 year rainfall event.

Other drainage design considerations for the railroad corridor related to design storm, ditches, storm drains, perforated pipe drains, recharge and detention ponds, and sedimentation and erosion control shall be in accordance with the MBTA Railroad Operations Commuter Rail Design Standards Manual, Section I, Chapter 5, sub-section B.3.

Construction of the Green Line Extension project is classified as a redevelopment project, and shall be in accordance with the requirement of Standard 7, as stated above. All redevelopment projects must fully comply with the provisions of the Stormwater Management Standards requiring the development and implementation of a construction period erosion and sedimentation control plan, a pollution prevention plan, an operation and maintenance plan, and the prohibition of illicit discharges. All redevelopment projects are also required to meet the following Standards only to the maximum extent practicable: Standard 2, Standard 3, and the pretreatment and structural stormwater best management practice requirements of Standards 4, 5, and 6 and improve existing conditions. For redevelopment projects, stormwater management system must be designed to remove 80% of TSS from impervious surfaces only to the maximum extent practicable. Existing stormwater discharges are also required to comply with Standard 1 only to the maximum extent practicable. For purpose of Standard 7, "To the maximum extent practicable" means that:

1. Proponents of redevelopment projects have made all reasonable efforts to meet the applicable Standard;
2. They have made a complete evaluation of possible stormwater management measures including environmentally sensitive site design that minimizes land disturbance and impervious surfaces, low impact development techniques, and stormwater best management practices (BMP); and,
3. If not in full compliance with the applicable Standard, they are implementing the highest practicable level of stormwater management.

The MassDEP Stormwater Handbook, Volume 2, Chapter 3 contains a redevelopment checklist that both the issuing authority and the applicant can use to determine whether the stormwater management system for a redevelopment project has been designed in accordance with all the requirements of Standard 7.

Finally, it is proposed that existing drainage patterns shall be maintained wherever possible, and the drainage of the roadbed will be handled by a gravity system to the maximum extent possible. Where feasible, drainage discharge should be directed to stormwater systems and not CSO pipelines.

9.3 Roadways and Intersections

9.3.1 General

This subchapter sets forth Stormwater Management Design Criteria (SMDC) to design the stormwater management systems for roadways and intersections with proposed geometrical improvements, as part of the MBTA Green Line Extension project.

The roadway bridges governed by this section are as follows:

- Medford Street
- School Street
- Lowell Street
- Broadway
- College Ave

9.3.2 Design Methodology

Roadway and intersection stormwater management systems shall be designed in accordance with MassDOT and MassDEP standards.

9.3.3 Design Criteria

The design criteria for roadways shall be in accordance with the MassDOT Project Development and Design Guide, Chapter 8, and the MassDEP Massachusetts Stormwater Policy.

- Construction of the roadway and intersection improvements is classified as a redevelopment project.
- The MassDEP Stormwater Management Standards shall be met to the maximum extent practicable as defined in Stormwater Management Standard 7.
- Existing drainage patterns shall be maintained wherever possible.
- Storm drain systems shall be designed to accommodate peak flows produced by the 10-year design storm.

9.4 Stations

9.4.1 General

This section sets forth SMDC to design the stormwater management system for the stations, as part of the MBTA Green Line Extension project.

9.4.2 Design Methodology

The stormwater management system for the stations shall be designed in accordance with the MBTA guidelines for drainage design as put forth in the MBTA Railroad Operations Commuter Rail Design Standards Manual, Section II, Chapter 6 and the MassDEP Stormwater Policy and Stormwater Management Standards.

9.4.3 Design Criteria

The following are some of the drainage design criteria used for stormwater management according to the MBTA commuter rail design standards for site drainage, which refers to actions required to manage storm water in both paved and unpaved areas of a station site. Please refer to the latest version of the MBTA Commuter Rail Design Standards Manual, Section II Chapter 6 and the MassDEP Stormwater Policy and Stormwater Management Standards for the complete list of criteria:

1. Minimum and maximum slopes in paved areas will vary with the material and location, but should be as prescribed in the Circulation and Parking sections of the MBTA Commuter Rail Design Standards manual.
2. The selection of particular storm frequency will be based upon the need for maximum reliability of operation, consistent with economy and local experience.
3. The following hydraulic factors should be considered to design the storm drain system:
    a. Avoid designs that require pumping
    b. Slopes shall be self-cleaning at minimum flows.
    c. Gravity flows are desired to be self-cleaning at a velocity of 2 feet per second. Where this minimum is impractical to obtain, the design should consider the effects of sedimentation, odors, and operational difficulties at lower velocities.
    d. Minimum pipe size should be 12 inches.

Stormwater management systems for each platform shall be design to collect and contain NRCS 50-year storm according to the design frequency criteria set for mainline trackbed drainage in Section I, Chapter 5 of the MBTA Commuter Rail Design Standards Manual. The stormwater management system will collect and contain runoff from all impervious surfaces created as part of station construction for removal of total suspended solids and controlled discharge. Removal of 80% of total suspended solids is required prior to release of stormwater runoff.

9.5 Site Design

9.5.1 General

This subchapter sets forth SMDC to design the stormwater management systems for site design improvements, as part of the MBTA Green Line Extension project.

The sites governed by this subchapter are as follows:

- Lechmere Station, Cambridge, MA
- Vehicle Maintenance & Storage Facility, Somerville, MA

9.5.2 Design Methodology

Site design including stormwater management systems shall be using methodology in accordance with MBTA, the City of Somerville, MA Department of Public Works – Engineering Division, and the City of Cambridge, MA Department of Public Works.

9.5.3 Design Criteria

The design criteria for site design stormwater management systems shall be in accordance with the following Final Development Plan and the amended NPDES Permit, and any additional permits required by MassDEP.

The design shall include a Stormwater Report to document compliance with the above mentioned stormwater criteria.

Lechmere Station shall be designed according to the North Point Development Drainage Report prepared by Parsons Brinckerhoff Quade & Douglas, Inc. submitted to the City of Cambridge Department of Public Works for the North Point Cambridge Land Company LLC in October of 2007.

Lechmere Station is also subject to the City of Cambridge, MA Planning Board general findings listed in the Notice of Decision on the Final Development Plan Case No PB#179 on April 15, 2003.

The Vehicle Maintenance and Storage Facility will require permits to be filed through an amendment of the existing National Pollutant Discharge Elimination System (NPDES) Permit No. MA0003590 for the MBTA Commuter Railroad Maintenance Facility issued on June 13, 2007.

The design shall include Shallow UIC Class V Injection Wells, and will require permits from the MassDEP. The stormwater discharged into a UIC well must be treated to remove contamination levels to meet the reportable concentration limits for groundwater as specified in the Massachusetts Contingency Plan (MCP).

The sites are under the jurisdiction of the United States Environmental Protection Agency (EPA) and National Pollution Discharge Elimination System (NPDES). Railroad Transportation is categorized under Sector P: Land Transportation and Warehousing and is considered to be an Industrial Activity which has specific requirements for preparing a Stormwater Pollution Prevention Plan.

10 Landscape Architecture

Chapter 10

10.1 General

The landscape architectural design criteria will address three discrete elements of the Green Line project:

- Stations
- Maintenance & Storage Facility
- Transit Corridor

While much of the design criteria will address softscape elements (plant materials), the criteria will also address hardscape elements (pedestrian pavements and site furnishings) for the Green Line project. All softscape and hardscape elements will be selected with sustainability and perpetual maintenance as the primary determining factors in the selection process.

An overarching concern among the three discrete elements identified above will be the protection and maintenance of desirable existing trees/vegetation within the project limits. Appropriate tree protection and maintenance work will be included to protect these valuable natural assets such as fencing around the drip-line of trees, mulch protection for any exposed roots and watering to keep roots moist until soils are back filled.

A non-native invasive plant species removal plan will be prepared by the Contractor and implemented within the project limits. In addition, vegetation shall be introduced where potential soil erosion can be addressed and/or mitigated by soil stabilization using vegetative materials. Landscape plantings shall be installed throughout the project limits; and the Contractor will provide a one-year plant material warranty period that will commence following the initial acceptance of all landscape plantings within the project.

10.2 Stations

Each station will have the following typical elements/amenities:

- Durable and environmentally sustainable pedestrian pavements. Pavers are specifically discouraged by MBTA and are to be considered only for non-pedestrian way areas. Concrete walkway surfaces shall be a minimum of 4,000 PSI 28 day compressive strength with steel reinforcing. Any integral colors shall meet Leadership in Energy and Environmental Design (LEED) heat island reduction requirements.
- Appropriate site furnishings including but not limited to: benches, waste/recycling receptacles; both enclosed and exterior bicycle racks, way finding devices, maintenance devices such as salt boxes, yard hydrants, newspaper dispenser designated areas, etc. Furnishings shall be commercial grade or better with stainless steel tamper proof hardware. Any wood elements shall be Forest Stewardship Council (FSC) certified to potentially meet LEED Gold rating requirements.
- Appropriate landscape plantings to provide a functional and aesthetically pleasing environment. Landscape plantings will be selected to provide valuable green space for transit patrons, relate to the station's

immediate environment, and require minimal maintenance. Plantings shall be native to reinforce the non-native invasive plant species removal plan.

- Fencing, walls, screens, and other protection and edge defining structures. These important structures will meet or exceed Mass DOT and MBTA functional requirements and will provide a logical transition between MBTA property and the neighborhood. The minimum fence requirement is fusion bonded vinyl coated chain link.
- Railings and guardrails shall be durable, require minimal maintenance, and conform to all MAAB and Universal access requirements.
- MBTA guidelines require 10 Foot candles of light on plazas for safety/security. Any plaza lighting design and level of light should be dark sky compliant and not spill light onto neighboring properties. Designed light levels are to be reviewed with the MBTA.

10.3 Maintenance and Storage Facility

The maintenance facility, due to its functions and space requirements, will have a more limited landscape architectural treatment that is generally related to the facility's vehicular entrance and building entrance, and the perimeter of the site. The following elements/amenities will be incorporated where feasible:

- Durable and environmentally sustainable pedestrian pavements.
- Appropriate site furnishings: benches, waste receptacles, bicycle racks, etc.
- Appropriate landscape plantings at the facility's main vehicular entry area and building entry area to provide a functional and aesthetically pleasing environment.
- The landscape and hardscape features should help define a barrier to the non-public spaces at the facility.
- Landscape plantings for visual screening will be provided along the facility's frontage on Inner Belt Road.

10.4 Transit Corridor

The Green Line Extension traverses through areas that are currently vegetated. Desirable existing trees/vegetation shall be protected and maintained during the construction period and supplemented with additional landscape plantings. The following elements will be addressed within the transit corridor:

- Performance of a tree/vegetation inventory early in the design process.
- Establishment and performance of a tree protection and maintenance program in advance of the commencement of construction operations.
- Removal of non-native invasive plant species.
- Installation of landscape plantings for visual screening along the transit corridor where feasible.

In addition to vegetative considerations, the overall aesthetic of the corridor should be cohesive, workmanlike, and thoughtful. The aesthetic design of the retaining walls and noise barriers should be considered from multiple perspectives, including, but not limited to: neighbors, commuter rail/light rail users, and roadway users. Anti-graffiti elements should be inherent in the design of the walls, using the Orange Line corridor retaining walls as a baseline for design. Wall aesthetics and design shall be coordinated with catenary poles, signal equipment, utilities and any other infrastructure required by the MBTA.

Fencing along the corridor should be coordinated with the walls, neighbors, and the community path. The fencing should be a fusion bonded vinyl coated chain link, at a minimum—both man and vehicle gates should be included at regular intervals to aid in future corridor access for railroad workers.

11 Oil and Hazardous Materials

Chapter 11

11.1 General

The Green Line Extension project design criteria for the Oil and Hazardous Material Group consist of several tasks which are summarized below. These tasks will be conducted and/or coordinated with the Licensed Site Professional for the Green Line Extension project (GLX Project LSP).

- Evaluate and identify potential environmental liabilities associated with the potential presence of Oil and/or Hazardous Materials (OHM) prior to property acquisition needed for station construction and associated railway corridors and layover facility. Phase I Environmental Site Assessments (ESAs) were previously performed for each of the proposed station locations in order to determine the likelihood of OHM to be present at each property. Based on the findings of the Phase I ESAs, which were documented in the Draft Environmental Assessment / Environmental Impact Report (DEIR), limited Phase II subsurface investigations were recommended to assess site conditions and evaluate the nature and extent of OHM, if present, at each property prior to acquisition and construction. Should OHM be present, regulatory obligations may need to be fulfilled in accordance with applicable regulations including the Massachusetts Contingency Plan (MCP).
- Screen for the presence of OHM in the project corridor based on Phase I and Phase II ESA and Right-Of-Way (ROW) environmental assessment results targeting proposed areas of construction. Environmental samples are to be selectively collected during the advancement of geotechnical and/or environmental borings and/or test pits to assist in pre-characterizing OHM potentially present in areas where soil disturbance is proposed during construction of the stations and railway corridor.
- Based on the results of the environmental sampling conducted during the geotechnical phase and the Phase II and ROW assessments, develop and Environmental Management Plan to manage contaminated media. The plan will contain site-specific guidance for soil and ground water management that will detail soil pre-characterization requirements needed for off-site disposal, likely soil destinations, and assist in estimating associated costs. Should groundwater also require management during construction, the plan will detail applicable permits and requirements to be followed.

Additional information of these three tasks is described in greater detail below.

11.2 Evaluation of Environmental Liabilities Associated With Property Acquisitions

11.2.1 Preparation of Phase I ESAs

In order to permit a user or purchaser of a property to satisfy one of the requirements to qualify for the "innocent landowner, contiguous property owner, or bona fide prospective purchaser" limitations on the landowner liability protection, customary practice is to conduct a Phase I ESA on the prospective property (ies).

The ESA constitutes "all appropriate inquiry" (AAI) into the previous ownership and uses of the property consistent with good commercial or customary practice. An AAI or ESA is conducted to determine if Recognized Environmental Conditions (RECs) are likely to be present at the prospective property. A Phase I ESA was performed for all the proposed station locations and layover facility which are part of the land acquisition for the proposed Green Line Extension project. Additional Phase I ESA's were conducted on partial property acquisitions along the railroad right-of-way.

The American Society for Testing Materials (ASTM) "Standard Practice for Environmental Site Assessments: Phase I ESA Process" (the ASTM Standard) E 1527-05, was created to develop the methods to determine if an REC is present. The ASTM Standard includes a review of databases, a site reconnaissance, interviews, and a review of historic aerial photographs, topographic maps, and Sanborn maps by an Environmental Professional to determine if RECs are present at the property. The ASTM Standard defines a REC as "the likely presence of any hazardous substance or petroleum products on a property under conditions that indicate an existing release, a past release, or a material threat of a release of any hazardous substances or petroleum products into structures on the property or into the ground, groundwater, or surface water of the property."

The ASTM Standard requires an Opinion regarding the potential for each REC to affect the property. Based on the RECs and their potential impacts, a limited Phase II subsurface investigation may be recommended which would involve the collection of soil and/or groundwater samples to further document the site conditions and evaluate the nature and extent of OHM at each property. Phase II investigations are recommended only when greater certainty is required regarding the identified Recognized Environmental Condition(s).

11.2.2 Potential Possibilities after Property Acquisition

After the Massachusetts Department of Transportation (MassDOT) or the Massachusetts Bay Transportation Authority (MBTA), purchases or acquires interest in a contaminated property, they may have obligations under the MCP for assessment and remediation of OHM, if present. Therefore, efforts should be made to identify OHM prior to acquiring interest in properties since MassDOT/MBTA may qualify as an "eligible person" under the Massachusetts Brownfields Act. An "eligible person" is defined under the Act as an owner or operator who did not own or operate the site at the time of the release and who did not cause or contribute to the contamination at the site. If the MassDOT/MBTA were determined to be an "eligible person", they could re-establish MCP deadlines for the submittal of response actions and related reports, referred to as Comprehensive Response Actions.

In addition, as per Section 5C of the Massachusetts General Laws (MGL), Chapter 21E, also referred to as the Massachusetts Oil and Hazardous Material Release Prevention and Response Act, "an eligible person shall be exempt from liability to the Commonwealth or to any other person for contribution, response action costs or property damage…" However, the exemption would only be applicable if a Permanent Solution, consisting of a Response Action Outcome (RAO) or a Temporary Solution consisting of a Remedy Operation Status (ROS) were achieved and maintained. A ROS is used for sites where an active remedial program is being implemented that would lead to a Permanent Solution.

The eligible person may be required to complete response actions for the entire site which may extend beyond the property boundaries, particularly if the release causes impacts to groundwater and/or surface water. Response actions may need to be continued beyond what is required for station, retaining wall, or other project-related construction, as a Permanent Solution or Temporary Solution must be achieved for site closure under the MCP.

The *Affected Environment section in the DEIR* provides the findings of the Phase I ESAs in the study area relative to hazardous materials. This *Environmental Consequences section in the DEIR* summarizes each alternative and potential OHM impacts and includes a discussion of the relative effects based on the RECs that were identified in the *Affected Environment section* and how contaminated soil would be evaluated, managed, and disposed. RECs include the presence or potential presence of oil, hazardous materials, or hazardous wastes that may constitute a present or potential threat to human health, safety, welfare, or the environment.

11.3 Preliminary Data Collection

The purpose of the preliminary data collection is to obtain existing conditions data for the project corridor, including supplemental field survey as well as limited soil and groundwater data. The assessment activities are intended to screen soil and groundwater conditions prior to construction and are not intended to be a complete environmental assessment of each property acquisition or parcel.

Data acquisition and corridor screening includes collecting representative samples during the Geotechnical and Environmental Programs based on areas of suspected OHM contamination and in areas where soil disturbance will likely occur as a result of construction of the project. Soil samples are collected for field screening and laboratory analysis. A total of ten groundwater monitoring wells will also be installed during this program; groundwater will be submitted for laboratory analysis. Approximately 145 borings and 102 test pits will be used to screen the corridor for OHM concerns prior to construction.

Prior to property acquisition, limited Phase II Site Assessments were recommended to further document the site conditions and evaluate the nature and extent of OHM, if present, at each significant property acquisition prior to acquisition and construction. The total number of property acquisitions requiring assessment prior to acquisition and/or construction, as required by the MBTA has not been determined.

At the end of the program, a summary report will be prepared detailing the soil and groundwater analytical results, field observations, current environmental conditions, and recommendations for waste management.

11.4 Management and Contaminated Media and Regulatory Compliance

For contaminated property owned by the MassDOT/MBTA, response actions will be required pursuant to the deadlines outlined in the MCP. Notification to the Massachusetts Department of Environmental Protection (MassDEP) is required if a reporting condition is identified as per the MCP or if oil and/or hazardous materials (OHM) is detected in soil and/or groundwater above the applicable standards, referred to as the Reportable Concentrations. The GLX project LSP shall verify that notification is required, and direct further assessments, direct response actions, and specify procedures for work performed in the contaminated areas, such as soil excavation, in accordance with the MCP and, if need be, to render appropriate LSP Opinions. The GLX Project LSP will also determine if risk reduction measures are required beyond that required for GLX construction.

Special Project Designation (SPD) for the GLX has been obtained from MassDEP. A separate SPD has been created for each municipality in which the GLX is to be implemented. The effect of the SPD is to extend MCP deadlines for response action and report submittals so that the response actions can be coordinated with the construction of the stations, layovers, retaining walls, and expansion of the rail lines. The SPD also have the effect of combining individual release notification under a new and separate Release Tracking Number (RTN) for each municipality. New notifications, as necessary, will be made under pre-established "daughter" RTNs designated by MassDEP.

At many sites containing impacted soil, it is often not feasible, nor is it a sustainable approach to reach a regulatory endpoint by using soil excavation and off-site disposal as the only type of remediation. Other options such as the re-use of soil in order to minimize the quantity of soil to be excavated and disposed off-site should be evaluated. For low levels of impacted soil where a risk assessment shows an unacceptable risk for current and future unrestricted use, a deed restriction consisting of an Activity and Use Limitation (AUL) may be implemented after construction is completed to meet a regulatory endpoint. As per 310 CMR 40.1012(3)(c) of the MCP, AULs are not required within railroad rights-of-way.

All soil impacted with OHM that is generated (excavated) during the implementation of the Green Line project will require management in accordance with the MassDOT/MBTA Design Construction Standard Specifications, Section 02282, entitled "Handling, Transportation and Disposal of Excavated Material." Preliminary assessment activities should be implemented in coordination with the Project LSP to identify the type and quantity of OHM impacted media that may require management under these protocols and help select the optimal disposal methods and/or destination prior to generation. A summary of the MBTA Specification is summarized in the following sections.

11.4.1 Management of Soil

As contaminated soil or groundwater may be present within the project Limits, limited pre-characterization of soils prior to excavation, as recommended by the GLX Project LSP, would be performed. The pre-characterization would consist of a limited subsurface investigation whereby soil samples would be collected, screened, and submitted for laboratory analysis in order to define the nature and extent of contamination in areas where soil disturbance would occur. Based on the pre-characterization described above, an Environmental Management Plan containing site-specific soil and groundwater management guidance would be prepared for the project that is consistent with MBTA specifications.

The Environmental Management Plan would be implemented as a waste management tool during soil excavation and removal activities that would occur during construction to ensure soil is property characterized, re-used and/or exported. The purpose of the Environmental Management Plan is to expedite construction and avoid unexpected costs by minimizing costly off-site disposal and maximizing the re-use of soil within the boundaries of the project.

If areas of contamination are identified that will require off-site disposal or treatment, the Environmental Management Plan would identify those locations and establish anticipated disposal classification. It would categorize the soil based on its regulatory status from the specific areas to be excavated. Based on the subsurface investigation analytical results, the soil would be anticipated fall into four groups, consisting of 1) non-regulated - background; 2) soil subject to the anti-degradation policy in 310 CMR 40.0032(3); 3) MCP regulated; and 4) RCRA Hazardous Waste. Re-use and disposal options for each category would then be designated.

Based on the anti-degradation policy in the MCP and a pre-risk screening, which would be performed to determine the risk associated with the current and foreseeable use of the property, the re-use of soil may be possible within the project that is above the MCP standards as long as regulatory endpoints could be met.

Should OHM impacted soil be generated (excavated) during project-related excavation that requires export or on-site re-use, this material would also need to be properly characterized and managed in accordance with applicable regulations. Proper management would ensure appropriate re-use on the project site to prevent unacceptable exposure to contaminants or export to appropriate destinations. Characterization would entail the collection of soil samples and analysis for specific parameters specified in the MassDEP policies for re-use and disposal of contaminated soil. Pre-characterization should reduce the need to stockpile excess soil onsite pending characterization. A minimum of ten business days are required for laboratory analysis and approval at a disposal facility or landfill. In-situ pre-characterization may be implemented to minimize the need for stockpiling, with associated analysis and facility acceptance schedules. Pre-characterization can also identify appropriate potential reuse locations in advance of construction.

Although re-use should be the preferred alternative, when characterization of soil after excavation is necessary, the soil shall be segregated into approximately 500 cubic yard sections (or appropriate quantities depending on proposed export destination) and placed on and covered with polyethylene sheeting of 10 mil or greater thickness. Covers shall be placed on each stockpile at the end of each day's operations, and would be secured in place to prevent runoff and erosion. A representative sample would be collected from each of the segments and submitted for laboratory analysis. The specific analysis to be performed and frequency will depend upon the requirements of the receiving facility that was selected to accept the soil. Should alternate soil disposal options be pursued (i.e., asphalt batching), analytical requirements may vary depending on the analytical requirements for that facility.

Based on the results of the characterization, a Bill of Lading or Material Shipping Record would be prepared to facilitate the export of the soil to the selected disposal facility. The Bill of Lading would need to be prepared and/or certified by an LSP. Soil management would be conducted pursuant to the MCP; if analyte concentrations exceed an applicable MCP notification standard these soils would be managed on-site and off-site utilizing either a Release Abatement Measure (RAM) Plan or, in the case of excavation for utilities, a Utility-related Abatement Measure (URAM) Plan, as applicable.

11.4.2 Management of Groundwater

If groundwater is encountered during the project, it will require management in accordance with applicable regulations. If the volume would be limited and subsequent offsite disposal is deemed to be the most cost effective disposal option, the groundwater can be temporarily stored in a fractionation tank or tanker truck, characterized and properly disposed. For managing larger volumes of groundwater, it may be more cost effective to obtain an Environmental Protection Agency (EPA) Construction General Permit or Remediation General Permit for discharge to surface waters/storm drains or a permit from the local sewer authority, if allowed, for discharge to sanitary sewers. Adequate time for receipt of sewer permits would be required. On-site recharge, which requires no permit, shall be the preferred method for groundwater management.

11.4.3 Management of Aboveground and Underground Storage Tanks

Storage tanks may be encountered on properties scheduled for MBTA acquisition. Storage tanks are usually above ground storage tanks (ASTs) and may be used for storage of heating oil, waste oil, or other liquid wastes. Storage tanks may also be installed underground (UST) and used typically for gasoline and/or oil storage. If an AST or UST is identified, the local Fire Department shall be contacted and the appropriate removal permit(s) obtained. Soil screening during UST removal shall be conducted in accordance with MCP requirements by a qualified environmental professional under the supervision of a Licensed Site Professional. Notification in the event that an MCP reporting condition is encountered shall be conducted in consultation with MassDOT/MBTA.

11.4.4 Management of Hazardous Demolition Debris and Used Railroad Ties

Asbestos containing materials, including roof flashing, tiles, and other materials may be present in the building materials of the buildings that would be undergoing demolition, based on their age. In addition, lead-based paint, mercury, and PCBs may also be present in the building materials and/or fixtures. Prior to demolition a licensed asbestos and hazardous materials contractor would sample the building material(s), including roof flashing, tiles, and other materials, as well as the potential lead-based paint, mercury, and PCBs. If these hazardous materials are found to be present in the structures, they must be removed by a licensed contractor in accordance with applicable Federal and state regulations.

Used wooden railroad ties are typically coated with chemical preservatives including creosote which contains SVOCs and would require special handling procedures. The discarded railroad ties must be managed and disposed of in accordance with applicable regulations.

11.4.5 Health and Safety Requirements

Health and safety procedures must be performed under the guidelines of the Occupational Safety and Health Administration (OSHA). All construction workers involved in performing the response actions must be appropriately health and safety trained in accordance with the applicable provisions of OSHA, which mandates specific procedures that must be followed to be protective from exposure to contaminated media. In addition, all geotechnical and environmental investigations must be performed under a site-specific health and safety plan.

11.4.6 MCP Closure

At the completion of response actions at properties acquired by MassDOT/MBTA for which an RTN was obtained from the MassDEP, but where an Response Action Outcome (RAO) Statement has not yet been submitted, a condition of No Significant Risk as defined by the MCP would be the objective. MassDOT/MBTA and the GLX Project LSP would complete MCP activities in accordance with the MCP under the provisions of the SPD.

11.4.7 Temporary Construction-Period Impacts

Recommendations for mitigation measures during construction may include special handling, dust control, and management and disposal of contaminated soil and groundwater in order to minimize the potential for construction delays and to provide adequate protection to workers and any nearby sensitive receptors. All response actions must ensure that any nearby or adjacent receptors are adequately protected.

12 Safety and Security

Chapter 12

12.1 Introduction

The modern Light Rail Transit design shall address system elements according to the requirements of the applicable standards listed. Should any standard or requirement conflict, the most stringent standard shall apply. The purpose of this chapter is to establish the safety and security standards for the design of all elements of the Green Line Extension (GLX) Project. To ensure the safety and security of the system and to resolve hazards and mitigate vulnerabilities on the project, the designer and contractors shall comply with the current version of the GLX Project's Safety and Security Management Plan (SSMP), Safety and Security Certification Plan (SSCP), and after they are developed, with the State Oversight Agency (SOA)-approved System Safety Program Plan (SSPP) and System Security & Emergency Preparedness Plan (SSEPP). These documents describe the process for approving the Design Criteria, and for making changes to, or approving deviations from, the approved Design Criteria.

Once these Design Criteria are approved, all changes and/or deviations must go through a formal review process, as described in the SSMP and detailed in the SSCP or MBTA Administrative Procedures or Standard Operating Procedures. This formal review process is needed to assure that all potential safety or security impacts of the suggested criteria change, or deviation, have been adequately assessed and found acceptable before it is approved. The Project Manager, Project Management Consultant, or Design Engineer shall formally present recommended changes in, or deviations from, the manner described in the GLX SSCP and Procedures manuals.

Some general requirements for the development and use of the safety and security design criteria are as follows:

1. Standards, specifications, regulations, design handbooks, safety design checklists and other sources of design guidance will be reviewed for pertinent safety and security design requirements applicable to the system. The design shall establish criteria derived from all applicable information. Some general system safety and security design requirements are:
   - Identified hazards and vulnerabilities shall be eliminated or associated risk shall be reduced through design, including material selection or substitution. When potentially hazardous materials must be used, such materials selected shall pose the least risk throughout the life cycle of the system.
   - Hazardous substances, components and operations shall be isolated from other activities, areas, personnel and incompatible materials.
   - Equipment shall be located so that access during operations, servicing, maintenance, repair or adjustment minimizes personnel exposure to hazards (e.g. hazardous chemicals, high voltage, electromagnetic radiation, cutting edges or sharp points) and threats.
   - Risk resulting from excessive environmental conditions (e.g. temperature, pressure, noise, toxicity, acceleration and vibration) shall be minimized.
   - Risk resulting from human error in system operation and support shall be minimized as part of the design effort.

- Risk resulting from excessive vulnerability to threats (e.g. theft, vandalism, sabotage, assault) shall be minimized as part of the design effort
- In the case of risk from hazards and vulnerabilities that cannot be eliminated, alternatives that will minimize such risk shall be considered. (e.g. interlocks, redundancy, fail safe design, system protection, fire suppression and other protective measures, such as clothing, equipment, devices and procedures, fencing, lighting, CCTV surveillance, alarm systems, and access control)
- Power sources, controls and critical components of redundant subsystems shall be protected by physical separation or shielding, or by other suitable methods mutually agreeable to the design and the project team.
- When alternate design approaches cannot eliminate the hazard, safety and warning devices and warning and cautionary notes shall be provided in assembly, operations, maintenance and repair instructions, and distinctive markings shall be provided on hazardous components, equipment and facilities to ensure personnel and equipment protection. These shall be standardized in accordance with commonly accepted commercial practice or, if none exists, normal procedures. Where no such common practice exists, the design shall propose the method or methods to be used for review and approval. The design shall provide all warnings, cautions and distinctive markings proposed for review and comment.

2. Qualitative and quantitative analyses shall be performed, documented and furnished as part of the design process to ensure adequate consideration of safety and security. At a minimum, a Preliminary Hazard Analysis (PHA) and initial Threat and Vulnerability Assessment (TVA) shall be conducted for the project, and additional analyses may be conducted as the need arises. If the recommended hazard resolution or vulnerability mitigation conflicts with the approved design criteria, it will be evaluated through the same process as any other deviation from the approved design criteria.

3. The Safety and Security Certifiable Items List (CIL) shall be used as the basis to develop design modifications and operating and maintenance procedures to eliminate or control the hazards and vulnerabilities. Approved resolutions of hazards or mitigations of vulnerabilities will be included on the CIL and/or other documentation as described in the SSCP.

4. Safety and Security information and procedures shall be developed for inclusion in instructions and other publications. These shall include, but not be limited to, testing plans and procedures, operational training, the book of operating rules, maintenance procedures, and SOPs for both normal and emergency operations.

12.1.1 Project Safety and Security Organization

The Project's safety and security organization is described in the GLX SSMP and will be detailed in support plans such as the SSCP. Refer to those plans for information on the Project safety and security organization and individual and committee responsibilities.

12.2 System Safety and Security Criteria

The GLX design shall address system elements according to the requirements of the applicable standards listed. Should any standard or requirement conflict, the most stringent standard shall apply. Standards, specifications, regulations, design handbooks, safety and security design checklists, and other sources of guidance shall be reviewed for pertinent safety or security design requirements applicable to the system. The design shall establish criteria derived from all applicable information. General safety criteria that shall be adopted are described in Section 12.2.1 and general security criteria are described in Section 12.2.2. Project-specific safety and security criteria are described in Section 12.2.3. A listing of applicable codes and standards, as well as reference documents, is found in Section 12.2.4.

12.2.1 General Safety Criteria

These criteria for systems, fixed facilities, structural designs, and subsequent operational procedures shall ensure that the system safety goals are implemented and documented through all aspects of design development, construction, implementation, testing, operations, and maintenance. General system safety criteria include:

1. Minimize exposure of personnel operating, maintaining, or repairing equipment to hazards such as entrapment, chemical burns, electrical shock, cutting edges, sharp points, electromagnetic radiation, or toxic atmospheres.
2. Emergency equipment/devices for public use shall be clearly identified and accessible. Interlocks, cutouts, fittings, etc., shall be accessible through access panels, which shall be secured to prevent tampering and vandalism.
3. Where failures could result in personal injury, major system damage, or inadvertent operation of safety critical equipment, redundancy or fail-safe principles shall be incorporated into the design.
4. Physical and functional interfaces between subsystems shall be analyzed. Those hazards associated with interfaces shall be specifically identified as system integration hazards and tracked for effective resolution.
5. There shall be no single-point failures in the system that can result in an unacceptable or undesirable hazard condition.
6. If an unacceptable or undesirable hazard condition can be caused by combining multiple incident failures, then the first failure shall be detected, and the system shall achieve a known safe state before subsequent failures occur.
7. All safety critical elements in a vital system shall be designed and implemented with fail-safe principles. Fail-safe principles shall be realized by designing the system to have intrinsically safe failure characteristics or by designing the system with verifiable techniques that detect potentially unsafe failures and ensure that the system reverts to a known safe state.

    - The following criteria shall be used, as a minimum, for implementing fail-safe functions and vital circuits:
        - Component failures or loss of input signals shall not cause unsafe consequences and shall not, when added to other failures, cause unsafe consequences.
        - All systems must be designed Failsafe to prevent an unsafe condition from occurring. No latent failure shall result when combined with any other failure.

    - The following criteria shall apply to electrical/electronic circuits:
        - Broken wires, damaged or dirty contacts, relays failing to respond when energized, or loss of power shall not result in an unsafe condition.
        - The relays used in vital circuits shall conform to all applicable parts of the AREMA Communications and Signals Manual of Recommended Practice, Section 6, Relays.
        - Circuitry components shall be considered able to fail in either the open or shorted condition. It shall be assumed that multi-terminal devices can fail with any combination of opens, shorts, or partial shorts between terminals. Protection shall be provided in the event that any amplifier is subject to spurious oscillations at any frequency.

8. Where redundancy is used in a safety critical area, there shall be no single point of failure that would result in the loss of safety protection. Redundant paths shall not contain a common predominant failure mode.

9. Design shall include component interlocks wherever an out-of-sequence operation can cause a hazard.

10. Suitable warning and caution notes in operating, assembly, maintenance and repair instructions, and

distinctive markings on hazardous components, equipment, or facilities for personal protection, shall be provided.

11. Color-coding used for equipment and facilities shall be uniform.
12. Each design shall be evaluated for hazards to identify basic deficiencies, inherent hazards of operation, safety critical malfunctions, maintenance hazards, human factors deficiencies, environmental hazards procedural deficiencies, and for compliance with codes, standards, and regulations. Written documentation of this evaluation shall be provided at the time final design is accepted.
13. The system safety analysis shall include review of fixed facilities and structures for employee access and maintenance safety.
14. Maintenance activities required to preserve or achieve risk levels shall be prescribed to the Director of Light Rail Operations during the design phase. These maintenance activities shall be minimized in both frequency and in complexity of their implementation. The personnel qualifications required to adequately implement these activities shall also be identified.
15. Software faults shall not cause an unacceptable or undesirable hazard condition.
16. Unacceptable hazards shall be eliminated by design.
17. Hazardous substances, components and operations shall be isolated from other activities, areas, personnel and incompatible materials.
18. Risk resulting from excessive environmental conditions (e.g. temperature, pressure, noise, toxicity, acceleration, and vibration) shall be minimized.

12.2.2 General Security Criteria

System security shall be provided by a combination of procedures, subsystems and devices to assure security of passengers, employees, equipment, and facilities. Operating procedures shall be developed to maintain the fullest use of the security systems provided.

The System Security goal is to provide transit system facilities and operations that minimize threats to the employees, patrons, contractors, first responders, and the general public that operate, maintain, construct, use or are in the vicinity of transit operations. To accommodate this goal, engineering designs shall be reviewed to determine if threats and vulnerabilities have been identified and eliminated, and minimized or controlled to an appropriate level throughout the intended service life. Engineering designs must satisfy security design requirements applicable to the individual systems and elements.

More detailed goals of the System Security Program include:

- Design security into the GLX Project by using such concepts as Crime Prevention through Environmental Design (CPTED) and security technology.
- Incorporate security features into the designs to reduce threats and vulnerabilities, such as: fencing, lighting, guard shacks, security office, gates, sensors or motion detectors, burglar/intrusion alarm systems, Closed Circuit TV (CCTV), public address systems, emergency telephones, silent alarm, card or controlled access.
- Employ a continuing Threat and Vulnerability Assessment (TVA) Process.
- Implement identified security countermeasures throughout the design.
- Implement the recommendations included in the FTA's Transit Security Design Considerations, FTA-TRI-MA-26-7085-05, November 2004.
- Comply with any U.S. Department of Homeland Security, Office for Domestic Preparedness directives.

- Use the Transportation Research Board Report Deterrence, Protection, and Preparation as guidance throughout the design.

The security design shall incorporate the following mitigation strategies as an integral part of the design process of new facilities:

- **Defensive Layering**: Defensive layering provides multiple levels of security in order to slow or prevent an adversary's access to a site.

- **Crime Prevention through Environmental Design (CPTED) principles**: One of the primary aims of CPTED is to reduce the opportunity for specific crimes by creating an environment that does not tolerate crime. It focuses on design techniques and use of a particular space to deter crime with four basic elements: natural surveillance, natural access control, territorial reinforcement, and maintenance. CPTED strategies include: maximizing visibility of people, patron flow areas and building/structure areas; providing adequate lighting and minimizing shadows; graffiti guards, mylar shatter guard protection for glass windows; landscape plantings that maximize visibility; gateway treatments; perimeter control; elimination of structural hiding places; and open lines of sight.

- **Target Hardening**: Target hardening employs structural techniques to increase the ability of a building to withstand an explosion while minimizing the loss of life and property damage.

- **Situational Crime Prevention (SCP) principles:** SCP is closely related to CPTED. Its premise is that the physical environment can be managed to produce desired behaviors in those who enter a facility by such factors as assuring cleanliness, the type and amount of staffing, and various operational and physical measures.

- **Physical Security System Elements**: Physical security elements are intended to: 1) delay an intruder to allow time to detect them; and 2) inform responders of a penetration of a facility or protected area.

- **Passenger Security**: Train-borne intercom shall be provided for passengers to notify the operator of any urgent incidents on board the vehicle.

- **Public Security:** In addition to application of CPTED design principles, public street areas where the vehicles will pick up and discharge passengers should be designed to enable them to be maintained clean and secure. Stop areas should be marked and illuminated for maximum assurance of safety and security, and shelters designed to minimize vandalism and graffiti.

- **Facility Security**: CCTV cameras shall be provided at various facilities to-be-determined. A Fire and intrusion alarm systems shall be provided to monitor critical facilities and equipment such as traction power substations and communications equipment. Alarms and CCTV will be monitored at the Operations Control Center.

- **Information and Information System Security**: Sensitive data such as personal identification information, procurement documents, security information and designs of information storage systems shall be fortified against unauthorized access. Additionally, contract specifications will require contractors to establish a formal information protection program and plan that at least meets the following SSI requirements.

    - Compliance with the Code of Federal Regulations regarding the release of transit-related Homeland Security Information.
    - Protected security related information may not be subject to subpoena or discovery and not subject to inspection by the general public, and shall include:

        - Assessments, plans or records that reveal MBTA susceptibility to terrorism.
        - Drawings, maps, or plans showing location and vulnerabilities of infrastructure.
        - Records or other information that detail specific emergency response plans.
        - Written information detailing response agency plans to a terrorist attack.
        - Identification of equipment used for covert, emergency, or tactical operations.
        - Response agency radio frequencies, codes, passwords, or programs.
    - Personal, Financial, and Medical Information shall be protected in accordance with federal regulations (e.g. Freedom of Information Act, Privacy Act, Health Insurance Portability and Accountability Act [HIPAA], and Health and Human Services Standards for Privacy of Individually Identifiable Health Information).
    - Information Technology Systems used to store and process security and personal information shall be protected, as the stored data would warrant.
    - Individuals who require access to sensitive, personal, or proprietary information in order to accomplish their duties shall sign and comply with a non-disclosure agreement. This agreement prohibits an employee from disclosing designated information, even after their employment ceases.

12.2.3 Project Specific Safety and Security Criteria

Safety and security criteria are interspersed in respective sections of the Design Criteria Manual. Detailed safety and security-related criteria for the various subsystems of the GLX Project can be found in the applicable sections of the Design Criteria Manual:

- Civil, Track, Community Paths and utilities: 1.0
- Structural: 2.0
- Stations: 3.0
- Mechanical and Electrical: 4.0
- Systems: 5.0
- Light Rail Signals: 6.0
- Railroad (Commuter Rail) Signals: 7.0
- Noise and Vibration: 8.0
- Drainage: 9.0
- Landscape Architecture: 10
- Oil and Hazardous Material: 11.0

Additional information relating to safety and security criteria and the processes with which they were developed can be found in the following documents, separate from the Design Criteria Manual:

- Safety and Security Management Plan (SSMP)
- Safety and Security Certification Plan (SSCP)

- Preliminary Hazard Analyses (PHA)
- Threat and Vulnerability Assessment (TVA)
- Rail Activation Plan (RAP)
- System Integration Test Plan (SITP)
- Start-Up and Pre-Revenue Operations Plan (PROP)

The Design Engineer shall identify those system elements and design standards to comply with the major steps in the safety and security certification process. These steps are implemented beginning with system design and continue through the start of revenue operation.

- Define and identify those safety-critical system elements to be certified.
- Define and identify those security-related elements to be certified
- Define and develop a Certifiable Elements List (CEL) and Certifiable Items List (CIL).
- Identify safety and security requirements for each certifiable element
- Verify and document design compliance with the safety and security requirements

Each design certifiable item shall have an associated verification form. As detailed in the SSCP, the designers and design supervisors will complete the criteria conformance review checklists, which will then be reviewed and signed by the Safety and Security Working Group (SSWG) and the Safety and Security Executive Review Committee (SSRC). After design for an element is completed and certified, the Construction Manager/General Contractor (CM/GC) team will complete the construction verification checklists. The CM/GC will verify that each identified design item has been constructed, and tested as necessary, and then will be reviewed and signed by the SSWG and SSRC as described in the SSCP.

12.2.4 Codes and Standards

Detailed safety-related and security-related criteria for various systems and subsystems of the project are covered in the applicable section of this Design Criteria Manual. References to these items are provided below to assist the designer.

- AREMA Manual for Railway Engineering
- TCRP Report 57
- APTA Guidelines for Design of Rapid Transit Facilities
- NESC sections 25, 26, rule 261H, Article 225
- MUTCD (part 10)
- Policy on Geometric Design of Highways and Streets
- Roadway Design Guide (AASHTO)
- 49 CFR192; ASME Guide for Gas Transmission and Distribution Piping Systems
- Occupational Safety and Health Administration (OSHA)
- IEC-1287, EN12663-2000, EN15227, EN1993-1-9
- ANSI/UL 1995, Section 33
- ANSI/ASHRAE Standard 15
- ANSI Z26.1
- NFPA 70, 72, 101, 130

- ISO 2204, 3381, 3095
- AREA manual Chapter 33 part 2
- International Building Code (IBC)
- FTA's Transit Security Design Considerations, FTA-TRI-MA-26-7085-05, November 2004.
- Applicable Federal, state, and local codes and standards

The following documents were used as guidance or reference for the design criteria and shall be used as such for all phases of the design process:

- *Compliance Guidelines for States with New Starts Projects, DOT-FTA-MA-5006-00-1*, U.S. Department of Transportation, Federal Transit Administration, June 2000.
- *Manual for the Development of Rail Transit System Safety Program Plans.* American Public Transit Association, September 1991.
- MIL-STD 882D, *System Safety Program Requirements*, U.S. Department of Defense, January 19, 1993.
- FTA Regulations, 49CFR, Part 659, *Rail Fixed Guideway Systems; State Safety Oversight*, U.S. Department of Transportation Federal Transit Administration, April 29, 2005.
- *Handbook for Transit Safety and Security Certification,* DOT-FTA-MA-90-5006-02-01, U.S. Department of Transportation Federal Transit Administration, November 2002.
- *Hazard Analysis Guidelines for Transit Project*, DOT-FTA-MA-26-5005-00-01, U.S. Department of Transportation Federal Transit Administration, January 2000.

In addition to the documents listed above, the design shall be in accordance with the following standards. If the standards requirements conflict, the most stringent requirement shall apply.

- Standards for Rail Fixed Guideway Systems, CCR 723-14.
- National Fire Protection Association (NFPA) – 1, 2, 10, 13, 14, 70, 72, 90A, 101, 130
- Federal Occupational Safety and Health Administration (OSHA) Standards
  - (General Industry), 29 CFR 1910
  - (Construction Industry), 29 CFR 1926
- Massachusetts State Building Code, Uniform Fire Code (UFC) and/or International Fire Code (IFC), supplemented by local municipal code amendments.

The following regulations and guidelines shall be considered in the design of the GLX Project, where applicable:

- Federal Railroad Administration - 49CFR 51, 201, 202, 205, 207, 209, 211, 213, and 241.
- *Integration of Light Rail Transit in To City Streets* – Transit Cooperative Research Program (TCRP) Report 17. American Public Transit Association (APTA) *Guidelines for the Design of Rapid Transit Facilities.*

Chapter

13

13.1 Vehicle Maintenance and Storage Facility

The design requirements for the Vehicle Maintenance and Storage Facility are shown in Attachment 3 "VMSF Design Criteria". Changes have been made during the course of project development that require some revisions to the design criteria.

- **Raised Access Floors:** Raised Access Floors are called for at Module A "Private Office" (page 5.5 in Attachment 3), at Module B "Workstation" (page 5.6), at Module C "Shared Office with Two Workstations" (page 5.7), at Module D "Shared Office with Three Workstations" (page 5.8), at Module E "Shared Office with Four Workstations" (page 5.9), at Module F "Conference Room" (page 5.10), at Module G "Copy/File/Storage Area" (page 5.11), at "Lobby/Operator's Room" (page 5.23), and at "Kitchenette/Vending Area" (page 5.25). The Raised Access Floors were proposed to accommodate under-floor heating ducts. With the in-floor radiant heating system now proposed, the under-floor space that was to be created by the Raised Access Floor is no longer necessary and the requirement for a Raised Access Floor in all these spaces can be removed.

- **The Heating and Cooling of Storage Areas:** Heat to 70° Fahrenheit is called for at the "Storeroom" (page 5.69) and Heat to 70° Fahrenheit and Air Conditioning is called for at the "Tool Storage Area" (page 5.71). These areas will now be open to the adjacent Shop Areas. No separate heating and cooling requirements are necessary for these Storage Areas; they will be subject to the same conditions as the adjacent Shop Areas.

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Attachment 1 - MBTA Design Preferences for Various Building Components and Systems

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Green Line Extension Project

Design Criteria Manual

Attachment 1

MBTA Design Preferences for Various Building Components and Systems

1 Attachment 1

The following list provides a compilation of MBTA Design Preferences for various building components and systems. These listed preferences should be incorporated in the design of the Green Line Extension, unless specifically superseded by information contained in the Chapters of the Design Criteria Manual.

1.1 Building and Station Maintenance

- All walking surfaces to be concrete.
- All stairs to be concrete with aluminum treads with anti-skid.
- All wall surfaces to be concrete masonry painted.
- No hung ceilings, open loft type with exposed utilities.
- Vertical glazing only.
- Passage doors to be Special Lite model SL-15.
- Emergency door panic hardware to be Von Duprin 99EO.
- Door locks to by Schlage LV9080L.
- Key ways to be Yale Y1.
- Door closers to be LCN-4111.
- Lexan to be minimum polycarbonate 0.0236 inch.
- Roofs to be flat slope standing seam metal, otherwise must be an approved FM Global standard.
- No pigeon or gull perches.
- No roof gutters.
- Any proposed retail must be at street level.

1.2 Subway Stations

1.2.1 Platforms

- Drain platforms away from the tracks (Rehab of existing stations – may not be possible).
- Platforms shall be surface slip-proof (coefficient of friction = 0.8 minimum).
- Provide a tactile platform edge.
- The horizontal distance between the platform edge and subway door is a maximum distance of 4 inches (must be field measured).
- The vertical distance between the top of platform and subway doors is a maximum distance of 2 inches (must be field measured).

- Provide working water hose bibs a maximum horizontal distance of 200 feet apart.
- Provide sufficient drains.
- Provide a Janitor's room that contains a slop sink separate from the restroom
- The platform cross-slope shall be between 1% and 2% in slope.
- Provide customer seats a minimum of 200 feet apart.
- All walking surfaces to be concrete.
- All wall surfaces to be CMU.

1.2.2 Headhouse

- Vertical glazing only.
- No pigeon or gull perches inside or outside.
- No glazed vents.
- Exterior wall mounted light fixtures.
- "T" Sign to be externally illuminated.
- Roof to be sloped metal – no gutter.
- Doors should be half –glazed.
- Single three-foot doors with frame both sides.
- Top-mounted pneumatic door closures.
- Styrofoam core/metal plastic laminate door construction.
- Separate emergency double three-foot doors; opened from inside only.
- Roof-mounted vent fans.
- Ladder/hatch to roof.
- No mother –operated dampers.
- Provide storage room for vendors.
- Provide slop sink and room for station cleaners.
- Provide room for electrical panels.
- Provide room for water closets.
- Provide room for ejectors, when necessary.
- Use of custom designed clocks should be avoided.
- 48" overhang for exterior elevators per 3.6.2 of Design Standard.
- All walking surfaces to be concrete other than tile floor areas.

1.2.3 Surface Site Work

- Trapped catch basins in lieu of OCR sand separators
- All electrical splice boxes and pullboxes are to be located above grade or in light pole bases.
- Water gate valves to be located in snowplowed areas.

1.2.4 Canopies

- Provide canopies that are free of ledges, shelves, etc. that would be nesting locations for birds.
- If ledges, shelves, lights, etc. are present, provide appropriate bird screening measures.

1.2.5 Escalators and Elevators

- Provide caved epoxy floors per Design Standard 2008
- Two elevators from street level to platforms
- Sump pumps are not permitted by code.
- Provide 120 volt, 20 amp outlet with waterproof cover dedicated for sump pump in pit
- Provide 115 volt single phase sump pump with float
- Provide sump in pits for groundwater accumulation.
- Provide discharge pipe to oil/water separator then sanitary sewer for pump connection.

1.2.6 Electrical

- All lighting fixtures below 20 feet off floor surfaces, preferably
- At stairways and escalators, all light fixtures to be wall mounted.
- Prefer 4-foot fluorescent, high output, 43 watt.
- Fluorescent fixtures to be vapor proof UL listed wet location with clip hinge lenses, stainless steel metal components.
- Fluorescent fixtures to be 277 Volt, -20 degree ballast.
- One light fixture per ballast: magnetic ballast only.
- All lighting levels to exceed code for safety and security purposes (call Building Division).
- 480 Volt circuit breakers off of switchgear.
- Provide one normal and one standby circuit breaker for each use.
- Automatic transfer switch should be specified without bypass isolation switch.
- Emergency lighting to be 600 Volt DC fluorescent, if no emergency generator backup.
- Avoid indirect lighting or uplighting.
- Exterior lighting should be down directed.

- Unit substations shall be double-ended 13.8 KV AC powered.
- Emergency generator to handle station lighting, tunnel lights, elevators, communications, signals, inspector booths, CSA booths, fare gates and equipment, public announcement system.
- Electrical panels to have a typed index card.
- Electrical panels to have hinged trim and door.
- All conduits penetrating/leaving a floor or ceiling to have brass made labels for ease of tracing.
- All buried conduits shall not have any splice/junction boxes (i.e., straight pull).
- One-third (1/3) of normal lights in station should be on time clock to be turned off from 2:00 a.m. to 4: 30 a.m.
- 480 V circuit breakers on the 13.8/480 switchgear must be ground fault interrupters (GFI).
- All main circuit breakers at the panelboards should be GFIs to avoid the upstream effect of the tripping.
- Provide street level disconnect for portable emergency generator feed.
- Exterior lighting to be controlled by one photocell facing north (n time clocks) mounted in close proximity to light control panel.
- Exterior pole-mounted lighting all splices to be above ground.
- All 480 V power panels (or less) and light panels are to be located separately from communication rooms, traction substations and unit substations.
- Provide 110 V disconnects for elevators and escalators within machine rooms.
- Limit fixture design to 5 lamp types. Prefer fluorescent.
- Emergency generator should be sized to handle entire station load
- Light levels should be double building code requirements.
- Avoid ceiling mounted lighting over stairs and escalators, wall mount.
- Any light fixture lenses should be hinged
- Prefer open ceiling design for access

1.2.7 Mechanical - HVAC

- Heat pumps and AC units to be a split system
- Vent lines between ejector pumps and bathrooms
- Provide fresh air source to all HVAC conditioned rooms.
- National gas or electric heating service.

- Generally double building code requirement for ventilation
- CIR/Electrical Substation rooms to have positive pressure ventilation to control rail dust.
- Six (6) air changes per hour for station ventilation.
- Avoid exhaust ventilation systems using tunnel air as make-up air.
- No internal insulation of ductwork.
- All proposed HVAC equipment must be easily accessible for filter maintenance and servicing
- Prefer open ceiling design for access
- Mechanical ventilation for lobby
- Sprinkler design to be reviewed by FM Global
- Storm drain piping to be minimum 6 inch in diameter
- Lobbies to have floor drains
- See R. McLaughlin for train washing pretreatment before discharge to sewer

1.2.8 Mechanical – Fire Protection

- Two standpipe street connections for each zone.
- Dry standpipe Siamese connections to be aluminum.
- Provide proper dry standpipe signage
- Avoid enclosing piping in structural columns
- Wet/dry sprinkler heads should be located less than 20 feet off horizontal pedestrian surfaces.
- Provide test valve for sprinklers.
- Provide drain valve for sprinklers and standpipes.

1.2.9 Lobbies

- Provide Mechanical Ventilation for Lobbies.
- Provide floor drains for lobbies.
- Prefer open ceiling design for access.
- All walking surfaces to be concrete other than tile floor areas.
- All wall surfaces to be CMU.

1.2.10 Mechanical - Plumbing

- Janitorial/cleaners room should be separate from bathrooms.
- Platform hose bibs to be drained from platform level.
- Two (2) ejectors for sewage.

- Exposed water lines to be heat traced and insulated.
- Exposed drain lines to be heat traced and insulated.
- Exterior water gate valves to be located in snow plowed areas.
- No drain or utilities to be encased in structural concrete columns.
- Gravity drains for escalator and elevator pits/mechanical rooms.
- Ventilate bathroom.
- Ventilate janitor room.
- Backflow prevention with meters on potable lines.
- Ventilate ejector rooms with ten (10) air changes per hour.
- Platform drains should be accessible.
- Drain valves to be accessible without entering confined spaces.
- Exterior water service meters and gate valves should not be located in snow-covered areas or pits.
- Sinks to be cast iron, not china.
- Fixtures should be Chicago or equal
- Water heaters should be Rudd or equal
- Water meters should have remote reading capability
- Avoid landscape sprinkler irrigation systems
- Avoid use of copper for underground water service feeds

1.3 Subway Tunnels

1.3.1 Electrical

- All lighting to be fluorescent at 277 V, magnetic ballast only
- Disconnect switches to be placed at end of platform into the first niche in the tunnel – one disconnect per side.
- All fixtures to be individually fused (in-line fuse)
- All power and light panels to have hinged trim and door
- No remote ballasts

1.3.2 Mechanical – Dewatering Pump Systems

- Suction style pumps (Gorman Rupp or equal)
- Impeller removal with no piping impact

- One (1) AC pump 208 Volt
- One (1) DC pump 600 Volt
- Each pump individually controlled with separate mechanical float systems
- Provide street access to pump room with door/shaft to remove pumps and equipment
- Provide wet well access 3' x 3' square opening with steel plate cover and ladder
- Low/high water alarm tied to OCC and nearest attendance booth (ITCP panel)
- Provide exhaust fan
- Fire hose wye connection on discharge line
- Emergency portable BS2102 Flygt with automatic controller or equal
- Room heat to 65 degrees
- Use Building Division specification for the AC/DC controllers
- Use flashing/beacon lights outside the pump rooms for hi-water alarms
- Install vent shafts, ventilation fans, tied to fire management panels (FMP) where applicable

1.4 Bus Repair Garages

1.4.1 Electrical

- Hinged light and power panel trim and covers

1.4.2 Mechanical

- Rotary style air compressors with refrigerated air dryers and 150 PSIG capability
- Heat and A/C systems to use 100% outside fresh air to avoid reuse of vehicle exhaust fumes.
- Prefer electrical screw type lifts or surface mounted lifts
- Heated air curtains for all exterior overhead doors.
- Natural gas fired heating systems.
- Aluminum telescoping overhead doors.

1.4.3 Environmental

- Use above ground storage tanks
- Use natural gas where possible
- Use trapped catch basins instead of DCR sand separators
- Provide sampling port for all sewer discharge

- Provide sampling port for all storm drain discharges
- All oil and water separators to be located in truck accessible areas

1.5 Storage Garages

1.5.1 Electrical

- All lighting systems to HID (HPS)
- Each fixture to be individually fused
- Ballast try must be removable for replacements
- Heat trace exposed wet fire sprinklers

1.5.2 Mechanical

- No air operated wash stands
- Unheated garage areas to receive six air ventilation changes per hour
- Aluminum telescoping overhead doors.

1.5.3 Environmental

- Use above ground storage tanks
- Use natural gas where possible
- Use trapped catch basins instead of DCR sand separators
- Provide sampling port for all sewer discharges
- Provide sampling port for all storm drain discharges
- All oil and water separators to be located in truck accessible areas.

1.6 Heavy Rail Maintenance Facilities

1.6.1 Mechanical

- Rotary Style air compressors.
- Natural gas heating systems.
- Electric screw type lifts.
- Heated air curtains at exterior overhead doors.

1.6.2 Environmental

- Use above ground storage tanks

- Use natural gas where possible
- Use trapped catch basins instead of DCR san separators
- Provide sampling port for all sewer discharges
- Provide sampling port for all storm drain discharges
- All oil and water separators to be located in truck accessible areas

1.7 Light Rail Maintenance Facilities

1.7.1 Mechanical

- Rotary style air compressors
- Natural gas heating systems
- Electric screw type lifts

1.7.2 Environmental

- Use above ground storage tanks
- Use natural gas where possible
- Use trapped catch basins instead of DCR san separators
- Provide sampling port for all sewer discharges
- Provide sampling port for all storm drain discharges
- All oil and water separators to be located in truck accessible areas

Attachment 2 – Corrosion Control/Stray Current Mitigation Design Criteria

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Green Line Extension Project

Design Criteria Manual

Attachment 2
Corrosion Control/Stray Current Mitigation Design Criteria

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Contents

1 Introduction

The project will extend the existing MBTA Green Line light rail transit system by roughly 17,000 feet north and west of Lechmere Station and includes six new stations servicing parts of Medford and Somerville, Massachusetts. There is an existing locomotive commuter rail in most areas of the proposed alignment. The project will expand the current transit system from two commuter rail tracks by adding two additional light rail tracks for the Green Line.

The Corrosion Control/ Stray Current Mitigation Design Criteria identify the requirements for facilities and systems to mitigate corrosion caused by contact with corrosive environments and the effects of stray current. The corrosion control and stray current mitigation design shall be coordinated, as necessary, with other design disciplines to produce a comprehensive and fully integrated design.

This current document builds on the document "Corrosion Control/Stray Current Mitigation Design Criteria for the Massachusetts Bay Transportation Authority Green Line Extension", HDR/Schiff, September 3, 2011. The HDR/Schiff document discussed similar issues to those discussed in this current document but at a level consistent with an earlier stage of design development. Nothing in the current document is in opposition to the material presented in the HDR/Schiff document.

The design criteria are separated into three areas: stray current mitigation; soil and water corrosion mitigation and; atmospheric corrosion mitigation.

2 Stray Current Mitigation

Stray current mitigation design criteria shall apply to facilities and systems in order to mitigate the corrosive effects of stray current to a reasonably achievable level primarily by providing and maintaining high levels of electrical isolation from ground for the traction power distribution system and maintaining acceptable levels of track-to-earth voltage. Stray current mitigation shall be designed to reduce or limit the emissions of stray earth currents at the source, under normal operating conditions, rather than mitigating corresponding detrimental effects which may otherwise occur.

2.1 Traction Power System

The traction power distribution system shall be designed as a dedicated system, providing traction power solely to the Green Line. Shared use of traction power facilities is not permitted, except for common transit-related systems such as providing a power source and feeders for communications and train control. The traction power system shall be designed to provide electrically isolated, independent subsystems for the main line, yard and vehicle maintenance facility (shop) under normal operating conditions.

2.2 Traction Power Substations

There shall be no permanent direct electrical connections between the traction power negative return system and ground, except as noted below for the vehicle maintenance facility (shop) system. All traction power stray current and corrosion control provisions shall be coordinated with the traction power design discipline.

The negative bus of the shop traction power distribution system is connected to the ground system for personnel safety purposes. The incoming ac supply neutral shall be electrically separate from the dc negative return system. To mitigate excessive stray current the shop traction power distribution system shall be electrically isolated from the yard traction power distribution system under normal operating conditions. This is typically accomplished by installing rail isolation joints in the tracks and section isolators in the OCS at the shop apron.

The yard traction power distribution system shall be electrically isolated from the main line traction power distribution system under normal operating conditions. This is typically accomplished by installing rail isolation joints in the tracks and section isolators in the OCS at the yard lead tracks.

The spacing between traction power substations shall be such that the track-to-earth voltage limits established in the traction power design criteria are not exceeded. A device shall be installed at each traction power substation to automatically connect the negative return system to ground when excessive dc track-to-earth voltage is present. The equipment shall be capable of automatically removing the connection to ground when the excessive dc voltage is no longer present.

The traction power substations shall be designed with provisions for stray current collection and monitoring facilities. At a minimum, each traction power substation shall be provided with equipment to allow the connection of the negative bus to a stray current collection system or earth ground mat through a relay (normally open), diode, adjustable resistor, fuse and current monitoring shunt. Access to the monitoring equipment shall be provided by dedicated wall space within the traction power substation, if available, or mounted outside of the traction power substation in a weather tight enclosure with a conduit between the enclosure and the negative bus.

The traction power substations shall be designed with space available for the future installation of stray current drainage devices from underground utilities or transit structures. Drainage facilities will only be installed if testing is performed that demonstrates no other feasible methods of stray current mitigation exist. Dedicated space may be provided within the traction power substation or a conduit may be provided to route a drainage cable to the negative bus for the future installation, if necessary.

2.3 Traction Power Positive Distribution System

The dc positive distribution system shall be designed in accordance with the provisions established in the overhead contact system (OCS) design criteria. Stray current mitigation criteria related to the OCS system are:

- The OCS shall be double-isolated from supporting structures to limit current leakage to ground. The maximum current leakage to ground from the OCS shall not exceed 2.5 milliamperes per mile of single track OCS with 2,500 dc voltage applied between the OCS and ground.
- For locations other than at bridge structures, electrical grounds for adjacent OCS support poles shall not be interconnected to each other or to a common ground system. Separate ground

rods and copper cable shall be provided for each OCS support pole. The purpose of the separate grounds is to minimize the possible transference of stray current from one portion of the transit system to another through an electrically continuous ground system. Steel reinforcement in concrete foundations should be made electrically continuous.

- For OCS poles located on aerial structures, electrical grounding shall be common either through existing structure grounds or by providing a common electrical grounding cable for interconnection of the pole grounds.
- For OCS bridge soffit supports (embedded and externally attached) under a bridge, provisions shall be made for galvanized catenary support channels, swivel pins and eyebolts. The supports shall be interconnected through an appropriately sized copper ground cable that extends to a grounding electrode. Any embedded portions of the OCS support hardware, concrete inserts, and studs shall be coated with an approved epoxy.

2.4 Traction Power Negative Return System

The negative return system of the main line and yard shall be electrically continuous and isolated from ground through the use of isolating track fasteners, coatings, insulating membranes, separation from ballast and isolation from any grounded track appurtenances. The magnitude of electrical isolation of the negative return system from ground is determined through track-to-earth resistance testing in accordance with ASTM G165. The minimum acceptable uniformly distributed track-to-earth resistance, normalized to 1,000 track-feet (2 rails) is:

- At grade ballasted track with concrete or composite ties, 500 ohms;
- At grade ballasted track with wooden ties, 250 ohms;
- Aerial ballasted track with concrete or composite ties and electrical isolation membrane, 1000 ohms;
- Grade crossings and embedded track, 250 ohms.

Test facilities shall be provided, where necessary, to facilitate track-to-earth resistance testing and monitoring.

Where ballasted track construction is utilized, the minimum separation between the ballast and any part of the rail (base, fasteners, etc.) shall be 1 inch.

For embedded track construction, the minimum volume resistivity of electrical insulating materials shall be 1×10^{14} ohm-cm as measured in accordance with ASTM D257. The surface profile of the final grade shall be sloped away from the rail to allow for proper drainage and reduced accumulation of debris.

Rails at grade crossings shall be coated (except the rail head and gauge face) with an approved epoxy coating. Track drains shall be provided near the ends of each grade crossing to aid in preventing debris build up and moisture retention.

All tracks shall be constructed with proper drainage to prevent water from contacting the rails or connected appurtenances under normal operating conditions.

The negative return system shall be constructed as electrically continuous circuits. Rail electrical continuity shall be accomplished through the use of continuously welded rail (CWR), rail-to-rail bonding (impedance bonds), track-to-track cross bonding, and bonding around all mechanical rail joints (except rail isolation joints) in special trackwork locations.

2.5 Transit Fixed Facilities

Transit fixed facilities include MBTA-owned reinforced concrete and metallic structures constructed as part of the Green Line Extension project.

2.5.1 Retaining Walls

Retaining walls for the Green Line Extension project include precast concrete panel and steel soldier pile walls, soil nail walls, MSE walls, and cast-in-place walls.

The Federal Highway Administration report NHI 09-087 suggests that requirements for stray current control and monitoring should be evaluated for structures within 100-200 feet of the nearest rail of dc transit systems. The MBTA presently does not have guidelines that state a distance limit for the consideration of stray current control of retaining walls or other structures adjacent to the track route.

For the Green Line Extension project retaining walls constructed for the project that are within 200 feet of the nearest rail and parallel to the track route shall be evaluated for the necessity of stray current control requirements. Retaining walls in excess of 100 feet in length and within 30 feet of the nearest track and parallel to the tracks shall require provisions for stray current control.

Stray current control for those structures where it is determined necessary shall consist of provisions for electrical continuity, electrical isolation in sections not exceeding approximately 250 feet and appropriate testing and bonding facilities.

2.5.2 Viaduct

The viaduct for the Green Line Extension project will have a reinforced concrete deck with tie and ballast track construction. A heavy-duty electrical isolation membrane shall be spray applied to the deck within the ballasted area. The membrane will provide electrical isolation of the tracks from the concrete reinforcing steel and ground.

Stray current control for the viaduct shall consist of a stray current collection and drainage system. The stray current collection system shall extend for the full length of the viaduct structure and be placed directly above the electrical isolation membrane. The system shall include the necessary junction boxes, conduits and testing facilities to provide a means to monitor the stray current collection system and to connect the system to the traction power negative return bus in the traction power substations.

Electrical continuity bonding of steel reinforcement in the concrete viaduct deck is not necessary due to the electrical isolation membrane and stray current collection system.

2.5.3 Existing Rail Bridges

The project will include installing tie and ballast new tracks on existing steel girder superstructure rail bridges. Floor beam panels shall be non-metallic unless calculations demonstrate that metallic materials are necessary. The ballast pan shall be coated with a heavy-duty spray-applied electrical isolation membrane.

Stray current control for the existing rail bridges shall consist of a stray current collection and drainage system similar to that described for the viaduct above. The stray current collection system shall extend for the full length of the bridge structure and be placed directly above the electrical isolation membrane and bituminous concrete. The system shall include the necessary junction boxes, conduits and testing facilities to provide a means to monitor the stray current collection system and to connect the system to the traction power negative return bus in the traction power substations. Track drainage shall be constructed of non-metallic materials if practical. If metallic materials are necessary, provision shall be included to electrically insulate (or provide physical gaps) in the drainpipe at 50 foot intervals and to electrically isolate the track drains from the deck reinforcement.

2.5.4 Existing Highway Bridges

The track route crosses under several existing highway bridges with concrete abutments and wing walls parallel to and near the tracks. It is impractical to retrofit existing reinforced concrete structures for stray current control due to the lack of reliable electrical continuity of the reinforcing steel.

All new construction cast-in-place reinforced abutments and wing walls for bridges crossing over the tracks shall be provided with provisions for stray current mitigation. The provisions include electrical continuity bonding of all horizontal reinforcement in both faces of the abutment, wing walls and footing. Vertical collector bars shall be welded to the horizontal reinforcement at a maximum spacing of 250 feet and at each end of the abutment. At each end of the abutment two test cables shall be exothermically welded to the collector bar and routed to a test station embedded in or mounted on the face of the abutment at a height convenient for testing. The two test cables shall be terminated on a non-conductive panel.

In addition to the electrical continuity bonding, the face of the abutment adjacent to the tracks shall be coated with an approved epoxy that extends a minimum of 1 foot above final grade.

2.5.5 Station Structures

The project includes grade level and elevated station structures. Grade level stations consist of a reinforced concrete platform placed on the signals/communications reinforced concrete duct bank and a center foundation. Beneath the station are reinforced concrete water retention boxes. Stray current control requirements for the grade level station structures consists of electrical continuity bonding of the longitudinal reinforcement in the face of the signal/communications duct bank that is adjacent to the tracks. Vertical collector bars are required at a maximum spacing of 250 feet and at each end of the platform. At each end of the platform two test cables shall be exothermically welded to the collector bar and routed to a test station mounted on the platform at a location convenient for testing during revenue service. The two test cables shall be terminated on a non-conductive panel. Electrical continuity bonding is not necessary for the platform, central foundation or the water retention boxes.

In addition to the electrical continuity bonding, the face of the duct bank adjacent to the tracks shall be coated with an approved epoxy that extends a minimum of 1 foot above final grade.

Elevated stations must be evaluated on an individual basis to determine the provisions necessary for stray current mitigation.

2.5.6 Underground Reinforced Concrete and Metallic Utilities

At a minimum, all underground utilities installed under the project shall follow the requirements of the MBTA Railroad Operations Directorate – Pipeline Occupancy Specifications. MBTA-owned underground reinforced concrete and metallic utilities require provisions for stray current mitigation.

Prestressed concrete cylinder pipe shall not be installed in the vicinity of the tracks or traction power substations without a request submitted on a case-by-case basis and approved by the MBTA. The request must demonstrate that the installation of other pipe materials is impractical based on engineering calculations.

The design of prestressed concrete cylinder pipe, if approved, shall include the following minimum provisions:

- Electrical continuity between the prestressed wires and steel cylinder;
- Each pipe joint shall be provided with electrical continuity bonding plates on each end. The number of bonding plates required shall be determined on an individual basis;
- Electrical isolation devices/fittings for electrical isolation of the pipe from interconnecting pipelines, other structures, and for segregation into discreet electrically isolated sections, depending upon the total length of the pipeline;
- Testing facilities to allow for the verification of electrical continuity and effectiveness of electrical isolation devices. Test facilities shall be located at all electrical isolation devices and at intermediate locations determined on an individual basis;
- External coating with an approved coating material.

Reinforced concrete non-pressure piping does not require electrical continuity of the reinforcing steel or bonding of the pipe joints. Reinforced concrete non-pressure pipe and associated manholes shall be coated on the external surface with an approved epoxy.

The minimum stray current mitigation provisions for underground metallic utilities include:

- Electrical continuity through welded or bonded pipe joints;
- Electrical isolation from interconnecting non-MBTA utilities;
- Electrical isolation from grounded piping within structures;
- Installation of testing facilities at all electrical isolation locations and intermediate locations determined on a case-by-case basis;
- Protective coatings and cathodic protection requirements will be determined on a case-by-case basis.

All utilities that cross under the tracks should cross as close to perpendicular to the tracks as practical. Pipelines transporting flammable or hazardous materials must be installed in casings that extend across the entire track right-of-way when crossing the tracks. Cathodic protection shall be applied to all pipelines and casings transporting flammable or hazardous materials.

2.6 Facilities Owned by Others

Stray current and corrosion control requirements for existing utilities and structures or utilities and structures installed and/or relocated or modified by the utility or structure owner as part of this project shall be the responsibility of the utility or structure owner unless otherwise stipulated in an Agreement between the owner and the MBTA. Minimum stray current and corrosion control requirements, when guidance is requested by the utility or structure owner shall be in accordance with this Attachment for MBTA-owned structures and utilities.

3 Baseline Corrosion Control Survey

A baseline corrosion control survey will be performed to evaluate the corrosive tendencies of the soil along the proposed route. The soil sample collection and testing will be coordinated with the Subsurface Exploration program of the Geotechnical design discipline to minimize costs to the project. The locations of the soil borings where corrosivity testing will be performed are shown in the Subsurface Exploration Work Plan. Testing will be performed on samples collected at depths of 5, 10 and 15 feet. The testing will include on-site measurement of soil pH and oxidation-reduction potential. Laboratory testing will include measurement of soil resistivity/conductivity, determination of the presence of sulfides if the oxidation-reduction potential measured was less than 100 millivolts and the measurement of anions and cations if the soil resistivity measured is less than 5000 ohm-cm. Upon completion of the testing, the data will be analyzed and a Baseline Corrosion Control Survey report will be submitted.

The baseline corrosion control survey information will be utilized for determining the appropriate corrosion control measures for underground metallic and reinforced concrete structures.

4 Corrosion Mitigation

Corrosion due to contact with corrosive environments shall be mitigated through material selection, coatings, electrical isolation, electrical continuity, cathodic protection or a combination of these measures as appropriate.

4.1 Soil and Water Corrosion Mitigation

The corrosion mitigation design shall be coordinated with the stray current mitigation design in order to identify proper placement of test facilities so that evaluation of the soil/water and stray current mitigation effectiveness can be achieved, while minimizing the number of test facilities required. Corrosion mitigation designs that include the installation of cathodic protection shall be coordinated with owners of adjacent underground structures through a corrosion coordinating committee to ensure stray current interference is minimized or avoided.

Corrosion mitigation is required for all structures where failure of such structures caused by corrosion may affect safety or interrupt continuity of operations.

Piping (pressure and non-pressure) and conduit shall be non-metallic unless metallic materials are required for specific engineering purposes. Use of metallic materials must be supported by engineering calculations when used in lieu of non-metallic materials.

Aluminum and aluminum alloys shall not be used for direct burial purposes.

4.1.1 Electrical Isolation of Piping

Devices used for electrical isolators for corrosion control shall include nonmetallic inserts, isolating flanges, couplings, unions, and/or concentric support spacers. Devices shall meet the following criteria:

- Following insertion of the isolation into the operating piping system, the isolation shall have sufficient electrical resistance so that no more than 2% of a test current applied across the device shall flow through the isolator and through any conductive fluids, if present;
- Mechanical and temperature ratings equivalent to the structure in which they are installed;
- Where isolating devices are used in metallic pipelines, internal polyamide epoxy coating shall be applied on each side of the isolator for a distance equal to two times the pipe diameter on which they are used. Where conductive fluids with a resistivity of less than 2,000 Ω-cm are present, internal coating requirements shall be based on separate evaluation determining need for additional coating. All internal coatings utilized for pipelines that transport potable water shall satisfy the requirements of NSF-61;
- Non-metallic, concentric support spacers and watertight end seals shall be used where the piping is routed through a metallic casing. An isolated connection shall be provided at all tie-ins to non-protected facilities;
- Isolating devices for metallic pipelines (except non-metallic units) installed in hand hole, vault or chambers or otherwise exposed to partial immersion or high humidity shall have a protective coating applied over all components;
- Design shall specify the need for, and location of, isolating devices. Inaccessible isolating devices, such as buried or elevated isolators, shall be equipped with accessible permanent test facilities. The test facilities shall include, as a minimum, 2 isolated and tagged wire test leads connected to each side of the isolating device and terminated at a test station box;
- A minimum clearance of 12 inches shall be provided between new and existing metallic structures. When conditions do not allow 12 inches of clearance, the design shall include the following special provisions to prevent electrical contact between the existing structure(s):
    - Installation of a non-metallic (PVC or similar material) block or sheet between the structures.
    - Installation of a pre-formed, correctly sized, reinforced fiberglass pipe saddle around the appropriate pipe where it crosses the existing structures.

4.1.2 Electrical Continuity of Piping

Electrical continuity shall be provided for all non-welded metallic pipe joints and shall meet the following criteria:

- Electrical continuity shall be achieved by directly buried, isolated, stranded copper wire with the minimum length necessary to span the joint being bonded. Wires shall be rated at 600 V with HMWPE isolation;
- To minimize current attenuation in cathodic protection installations, wire size shall be based on the electrical characteristics of the structure and resulting electrical network;
- A minimum of two #6 AWG wires shall be used per joint for redundancy. Wire resistance shall be such that the bond resistance is a maximum of 110% of the theoretical calculated pipe resistance for an 18-inch length of pipe. The bonding wires shall be installed using the thermite welding method;
- Exothermic welds and adjacent bare piping shall be coated with a coal tar epoxy coating after the welding.

4.1.3 Cathodic Protection

Cathodic protection systems for buried metallic structures shall be used where soil conditions indicate that soil corrosion may reduce the service life of the facility below the design requirements consistent with the structure life objectives. The presence of stray currents and regulations may also require the design and installation of cathodic protection for underground metallic structures. Design of cathodic protection shall be performed by a registered professional corrosion engineer, a NACE International Corrosion Specialist or a NACE International Cathodic Protection Specialist. Cathodic protection shall be provided by galvanic or impressed current protection systems. Testing of cathodic protection systems shall be performed in accordance with NACE TM0497.

Galvanic cathodic protection shall be used wherever feasible to minimize interference with other underground metallic utilities. When galvanic cathodic protection is used for new facilities, the facilities shall be provided with a compatible coating system. All galvanic anodes shall be connected to the structure via test stations.

Impressed current systems shall be used only when the use of galvanic systems is not technically and/or economically feasible. The MBTA shall approve use of these systems at the conceptual stage prior to detailed design. The systems shall utilize separate and isolated anode beds. Cathodic protection schemes that require connection to the transit system's negative return system, in lieu of using a separate isolated anode bed, shall not be permitted.

The cathodic protection design shall consider the following:

- Presence of anaerobic bacteria;
- Need for mutual protection schemes;
- Limitation of structure-to-electrolyte potential;
- Accessibility after construction is completed;
- Optimum location of anodes for ease of replacement and avoidance of interference with other metallic structures;
- Need for monitoring facilities;
- Power availability, space availability for installation, structure geometry.

The cathodic protection system design shall be based on theoretical calculations that shall include the following parameters:

- Cathodic protection current density (suggested minimum of 1 milliampere per square foot (mA/ft^2) of bare area);
- Total current requirement;
- Estimated/anticipated current output per anode;
- Estimated/assumed percentage bare surface area (minimum 1%);
- Estimated/indicated total number of anodes, size and spacing;
- Estimated/anticipated anode bed resistance;
- Minimum anode life of 30 years (maximum 50% efficiency for magnesium anodes and an 85% utilization factor). The sum of the anticipated anode life and time to failure based on a corrosion rate anticipated at 90% cumulative probability level shall not be less than 50 years.

Impressed current systems shall be designed using constant output voltage rectifiers or automatic potentially controlled rectifier units, with permanent reference electrode facilities. Rectifiers shall be rated at a minimum of 50% above calculated operating levels to overcome a higher-than-anticipated anode bed resistance, lower-than-anticipated coating resistance, or the presence of interference mitigation bonds. Other conditions which may result in increased voltage and current requirements shall be considered.

The design shall include test facilities that permit initial and periodic testing of cathodic protection levels, structure-to-electrolyte potentials, interference currents and system components (such as anodes, isolating devices and continuity bonds). At a minimum, the test facilities shall consist of the following:

- Two structure wire connections for each structure;
- One reference electrode wire;
- Conduits and termination (test) boxes

The design shall specify the locations and types of test facilities for each cathodic protection system and coordinate approval and/or permits as necessary for the facilities to be installed. The number, type and spacing of the test facilities shall be sufficient to determine the adequacy of cathodic protection, electrical continuity and electrical isolation.

4.1.3.1 Ferrous Pressure Piping

All new buried cast iron, ductile iron and steel pressure piping shall be cathodically protected on an individual structure basis. In addition to the cathodic protection, the piping system design shall include the following minimum features:

- Conformance with existing standards and specifications of the MBTA;
- Conformance with federal, state and local codes for regulated piping;
- Application of a protective coating to the external surface of the pipe;

- Electrical isolation of pipe from interconnecting pipe, casings and other structures, and segregation into discrete electrically isolated sections depending upon the total length of piping. Electrical isolation fittings located within 50 feet of a rail shall be provided with zinc grounding cells or other appropriate surge suppression devices;
- For pressure piping entering MBTA facilities below grade, electrically isolate pipe immediately inside of the wall penetration. For pressure piping entering MBTA facilities above grade, electrically isolate pipe immediately outside of the wall penetration. Pipe penetrations through the walls and floors shall be electrically isolated from building structural elements;
- Piping encased in concrete, including thrust blocks, shall be provided with a coating material that extends a minimum of six inches beyond the concrete-to-soil interface.
- Electrical continuity through the installation of insulating copper wires across all mechanical pipe joints or fittings other than intended isolators;
- Permanent test/access facilities shall be installed at all isolated insulated connections to allow for verification of electrical continuity, electrical effectiveness of isolators and coating, and evaluation of cathodic protection levels. Additional test/access facilities shall be installed at intermediate locations, determined on an individual structure basis.

4.1.3.2 Copper Piping
Buried copper pipe shall be electrically isolated from non-buried piping, such as that contained in a station structure, through use of an accessible isolating union installed where the piping enters through a wall or floor. The necessity for cathodic protection of copper piping shall be determined on an individual basis.

Pipe penetrations through the walls and floors shall be electrically isolated from building structural elements. The isolator should be located inside the structure and not buried.

Copper water service lines shall be electrically isolated from ductile iron mains utilizing isolating corporation stops.

4.1.3.3 Gravity Flow Piping (Non-Pressure)
Corrugated steel piping shall be internally and externally coated with a sacrificial metallic coating and a protective organic coating.

Cast or ductile iron piping shall be designed and fabricated to include the following provisions:

- An internal mortar lining with a bituminous coating on ductile iron pipe only and shall not be required for cast iron soil pipes;
- A bituminous mastic coating on the external surfaces of pipe 6 inches on each side of a concrete/soil interface.

Evaluation of the need for electrical continuity, electrical isolation and cathodic protection shall be conducted on an individual basis.

Reinforced concrete non-pressure piping shall include the following provisions:

- Water/cement ratios meeting the minimum provisions of AWWA;
- Chloride concentration shall not exceed 150 ppm in the total concrete mix of mixing water, cement, admixture and aggregates;
- Pipe design shall be in accordance with ASTM C76;
- Concrete used in the manufacture of this pipe shall be in accordance with ACI 201.2R and ASTM C150.

4.1.3.4 Buried Concrete/Reinforced Concrete Structures

The design of cast-in-place concrete structures, precast utility structures or other precast structures shall be based on the following criteria:

- The type of cement utilized shall be based on the anticipated exposure conditions in accordance with ACI 201.2R and ASTM C150. Use of a concrete mix with a cement type not specifically listed in ACI 201.2R shall be reviewed and must be approved by the MBTA. ASTM C452 shall be used as criteria for evaluation of the sulfate resistance of concrete mixes with non-standard cement types;
- Concrete to be in contact with soil or groundwater shall have a water/cement ratio not greater than 0.45. Refer to applicable sections of ACI 201.2R;
- The concrete mix should be such that the water soluble and acid soluble chloride concentrations, at the concrete/reinforcing steel interface, do not exceed the values stated in ACI 222R for reinforced concrete in wet conditions;
- Concrete cover over reinforcing steel shall comply with ACI codes. Provide a minimum of 2 inches of cover on the soil/rock side of reinforcement when pouring within a form and a minimum of 3 inches of cover when pouring directly against soil/rock or excavation support systems;
- Epoxy coated reinforcing steel is approved for use in structures that do not require electrical continuity bonding of the reinforcement for stray current mitigation purposes;
- The need for additional measures, as a result of localized special conditions, shall be determined on an individual basis. Additional measures may include application of sealers, corrosion inhibitors and protective coating to concrete and reinforcing steel.

Precast standardized facilities, such as manholes, vaults and pull boxes shall meet the requirements specified in this section or must be reviewed on an individual basis to determine alternative criteria when they cannot be practically modified to meet some or all of the provisions specified.

Below grade shotcrete used for permanent support shall be in accordance with ACI 506.2 and applicable provisions specified in this section. In the case of conflicting specifications, the more rigid or conservative specification shall be applicable. No special corrosion control measures are required for shotcrete applications, which are not used for permanent support.

4.1.3.5 Reinforced Concrete Retaining Walls

Cast-in-place concrete retaining walls shall be in accordance with the requirements in 4.1.3.4.

Mechanically stabilized earth (MSE) retaining walls that do not require stray current mitigation provisions in accordance with 2.5.1 shall meet the requirements in 4.1.3.4, and the following provisions:

- Steel reinforcement and embedded tie strip anchors shall be constructed without special provisions for establishing electrical continuity;
- Steel reinforcement of adjacent modules shall not be electrically interconnected. The reinforcing strips shall be coated with a fluidized-bed epoxy resin system or liquid 100% epoxy system;
- Tie strips shall be coated with a fluidized-bed epoxy resin system or coal-tar epoxy system prior to module construction;
- Longitudinal reinforcing steel within precast concrete parapets and cast-in-place junction slabs shall not be made electrically continuous.

4.1.3.6 Support Pilings

The following is applicable only to support piling systems which are to provide permanent support. Pilings used for temporary support do not require corrosion control provisions.

Designs based on the use of metallic supports exposed to the environment shall be designed to meet the following minimum criteria. The minimum requirements listed shall be coordinated with the structural design discipline. The minimum corrosion control specification may not be appropriate in all conditions.

- Application of a barrier coating to the pile from 1 foot above the surface to a minimum of 5 feet below the expected low groundwater level. The barrier coating shall be applied to all exposed surfaces including splices;
- Inclusion of additional wall thickness to the structural requirements for the pile. A minimum of 0.125 inch shall be included for each face or surface contacting the soil environment from the surface to a minimum of 5 feet below the expected low groundwater level.
- The interior of open ended pipe piles shall be considered exposed to the soil environment and provided with a corrosion allowance of a minimum 0.125 in. The interior of closed end pipe piles shall be considered as a surface contacting the soils unless filled with a cementitious mortar.
- The need for special measures, such as electrical isolation measures, electrical continuity, monitoring devices and cathodic protection, shall be determined on an individual basis, based on type of structure, analysis of soil borings for corrosive characteristics and the degree of anticipated structural deterioration caused by corrosion.

Reinforced concrete piling, including fabrications with prestressed members, shall be designed to meet the requirements in 4.1.3.4.

Concrete-filled steel cylinder columns, where the steel is an integral part of the load bearing characteristics of the support structure, shall be designed considering the need for special measures, such as increased cylinder wall thickness, external coating system, stray current mitigation and/or cathodic protection. The design shall be determined on an individual basis, based on type of structure, analysis of soil borings for corrosive characteristics and the degree of anticipated structural deterioration caused by corrosion. Chloride restrictions for the concrete fill shall be in accordance with ACI 222R.

4.1.3.7 Electrical Conduits

Galvanized steel conduits shall have the following minimum provisions:

- Direct burial conduit shall be coated with PVC or other accepted coating system regularly in use for direct burial;
- Conduit within duct banks shall have a minimum of 3 inches of concrete cover on soil sides. Coating shall not be required when conduits are installed in concrete;
- Coating shall be provided for conduits installed above grade, in a corrosive atmosphere, and in wet atmospheres. Coating shall be of a type suitable for exposure to wet and corrosive atmospheres;
- All couplings and fittings shall be coated with the identical coating materials used for the conduit lengths.

Electrical continuity shall be established throughout the conduit as follows:

- Use of standard threaded joints;
- Installation of bond wires across non-threaded joints. Bond wires shall be installed using the thermite weld method. Bond wire sizing shall depend on the conduit diameter as follows:
    - 1 to 3-inch diameter conduit - #10 AWG bond wires
    - 4 to 6-inch diameter conduit - #8 AWG bond wires

Buried non-metallic conduits shall be encased in concrete including couplings and fittings except at transitions where metallic materials are required (stub-ups, penetrations, etc.).

4.1.3.8 Casings

Pipeline casings, if required, shall be installed bare, unless coating and cathodic protection is required by the owner. Casing isolators and spacers shall be installed on the carrier pipe to avoid electrical contact between the casing and the carrier pipe. Test facilities shall be provided at each end of the casing to allow testing of the status of electrical isolation between the casing and carrier pipe. The test stations shall contain at a minimum:

- Two test wires connected to the carrier pipe;
- Two test wires connected to the casing;
- A test wire to a reference electrode located adjacent to the carrier pipe near the end of the casing;
- A terminal board for and enclosure to house the test wires located in a location easily accessible for testing.

4.2 Atmospheric Corrosion Control Systems

Designs shall ensure the required service life of a particular facility is not compromised because of corrosion-related problems or failures due to exposure to the atmosphere or ice melting chemicals.

Structures and systems shall be protected against atmospheric conditions, meteorological conditions, air pollutants and ice melting chemicals by proper material selection, the use of coatings and sealants in order to maintain necessary function and appearance of transit system structures exposed to the environment.

The evaluation of the atmosphere shall be conducted by research of the local air quality agency to identify pollutant types and levels.

The evaluation of the past meteorological history of the region shall be conducted through research of the local weather agencies. The data gathered shall be used to evaluate the impact on atmospherically exposed structures.

4.2.1 Steels and Ferrous Alloys

Carbon steel, ductile, and cast iron exposed to the atmosphere, except for track and track fasteners, such as spring clips, spikes and rail plates, shall have a barrier or sacrificial coating applied to all external surfaces. Barrier coatings may be appropriate for track fastening hardware in locations subject to ice melting chemicals. High strength, low alloy steels shall be protected similarly to carbon steels except where used as a weathering steel exposed to the outside environment. The design shall incorporate complete drainage of all surfaces, coating of metal-to-metal contacting surfaces, and sealing of crevices. The potential staining of adjacent structures shall be considered.

Stainless steel surfaces shall be cleaned and passivated after fabrication. Series 200 and 300 stainless steels are suitable for use in most exposed situations without further protection, with Type 316 being preferred for its superior corrosion resistance. Series 400 stainless steel can also be used, but might exhibit staining. A barrier coating should be used on stainless steel exposed to roadway deicing salts and certain marine environments. All hardware used to couple or connect shall be the same stainless series or as approved by the MBTA.

4.2.2 Aluminum Alloys

All aluminum alloys shall receive a sealed, hard anodized finish to provide the best weather-resistant surface. A barrier coating should be used on aluminum exposed to roadway deicing salts or other atmospheric corrosive pollutants.

4.2.3 Copper Alloys

Copper and its alloys can be used where equipment is exposed to weather without additional protection. A coating shall be utilized only where a natural patina is not desired. Bimetallic couplings shall be prohibited.

4.2.4 Magnesium Alloys

Magnesium alloys shall have a barrier coating applied when long-term appearance is critical. Bimetallic coupling shall be prohibited.

4.2.5 Zinc Alloys

Zinc alloys can be used without additional protection. A shop-applied barrier coating may be utilized to extend the design life of components or to enhance component appearance. Bimetallic coupling shall be prohibited unless the intent of the coupling is for sacrificial protection by the zinc alloy.

4.2.6 Coatings

Coatings shall have established performance records for the intended service and be compatible with the base metal to which they are applied. Coatings shall be able to demonstrate satisfactory gloss retention, color retention and resistance to chalking over their minimum life expectancies. Coatings shall have minimum life expectancies, defined as the time prior to major maintenance or reapplication, of 15 to 20 years.

4.2.6.1 Metallic-Sacrificial Coatings

Acceptable coatings for carbon and alloy steels are as follows:

- Zinc (hot-dip galvanizing [2 ounces per square foot (oz/ft^2)] or flame sprayed);
- Aluminum (hot-dip galvanizing [2 mil thickness] or flame sprayed);
- Flame sprayed aluminum-zinc alloy;
- Cadmium and electroplated zinc (for fastening hardware located in sheltered areas only);
- Inorganic zinc (used as a primer).

4.2.6.2 Organic Coatings

Organic coating systems typically consist of a wash primer (for galvanized and aluminum substrates only), a primer, intermediate coat(s) and a finish coat. Acceptable organic coatings, for exposure to the atmosphere, include, but may not be limited to:

- Aliphatic polyurethanes
- Vinyl copolymers
- Fusion-bonded epoxy polyesters, polyethylenes, and nylons
- Acrylics
- Alkyds
- Epoxy
- Organic zinc-rich epoxy (used as a primer)

4.2.6.3 Conversion Coatings

Conversion coatings, such as phosphate and chromate coatings, shall be used as pretreatment only for further application of organic coatings.

4.2.6.4 Ceramic-Metallic Coatings (Cermets)

Ceramic-metallic coatings are acceptable for use on metal panels and fastening hardware.

4.2.6.5 Graffiti-Resistant Coatings

Surfaces which are accessible to graffiti shall be protected with a graffiti-resistant coating. This includes concrete and painted steel surfaces within stations, such as walls, columns and equipment enclosures.

Such areas shall be protected up to a minimum height of 10 ft. The coating shall be a urethane-type coating and shall be applied in accordance with the manufacturer's latest published instructions.

4.2.7 Sealants

All crevices shall be sealed with a polysulfide, polyurethane or silicone sealant.

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Attachment 3 – Vehicle Maintenance and Storage Facility Design Criteria

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DESIGN CRITERIA

Introduction

This chapter presents the Design Criteria for the proposed Vehicle Maintenance and Storage Facility (VMSF) by providing both micro and macro level design requirements. Functional Relationship bubble diagrams for these spaces can be found in *Chapter Two - Basis of Design*. The Design Criteria format found in this chapter consists of Functional Area Modules. The Functional Area Module represents a detailed description of specific design issues for each of the areas listed in the Preliminary Space Needs Program. LRV Administration and Operation Modules represent typical finishes and furniture layouts for the appropriate square footage. LRV Maintenance, Service, Material Handling, Facilities Maintenance, and Engineering and Maintenance Modules list and illustrate appropriate finishes, equipment, and functions required. *All Modules and related equipment are for representation purposes only and do not necessarily depict strict design conformance*

Sustainable Design

There are several sustainable design opportunities which can be approached at the new VMSF. Regardless of whether the MBTA chooses to achieve LEED rating or not, these are good design practices. The Sustainable Design section outlines potential sustainable design opportunities appropriate for this type of facility. These options are broken into Building Design and Materials, Mechanical Systems, Plumbing Systems, and Electrical Systems.

Modules

The Functional Area Modules in this section are general in nature and can be found in each building at VMSF. Reference each area location **office/support area modules sheet** for relationships to other areas and comments specific to each space.

Transportation Modules

The standards previously established in *Chapter Three - Space Needs Program* are defined graphically on the following pages and are applied to each office area within each group. These are only typical modules and can be modified to meet unique circumstances.

Maintenance Facility Modules

Each of the Maintenance Facility modules contains information regarding the function of the space, affinities, critical dimension (if any), equipment, furnishings, and finishes related to this operation. Technical considerations for architectural, structural, mechanical, plumbing, and electrical systems are delineated on the facing page. The space is graphically illustrated. Specific layouts of each area will be developed during detailed design. Note that the equipment and furnishings listed are not intended to be all-inclusive. A detailed equipment list is developed which provides the all-inclusive list of equipment. A listing of the abbreviations utilized in the text is listed below.

Abbreviations

A	=	Amperes
AFF	=	Above Finished Floor
ATF	=	Automatic Transmission Fluid
CA	=	Compressed Air
CG	=	Chassis Grease
CNG	=	Compressed Natural Gas
fc	=	Foot Candles
GFI	=	Ground Fault Interrupter
EC	=	Engine Coolant
EO	=	Engine Oil
GO	=	Gear Oil
HO	=	Hydraulic Oil
NG	=	Natural Gas
SF	=	Square Feet
UC	=	Used Coolant
UO	=	Used Oil
VAC	=	Volts AC
VCT	=	Vinyl composite tile
W	=	Water
WWF	=	Windshield Washer Fluid
K	=	1,000 Pounds
lb	=	Pound
PSI	=	Pounds per Square Inch

SUSTAINABLE DESIGN

SUSTAINABLE DESIGN

Site

- Alternative transportation
  - ♦ Bicycle storage/changing rooms
  - ♦ Minimize parking spaces to less than local zoning requirements
  - ♦ Preferred parking for alternate low emitting and fuel vehicles
- Pollution Prevention
  - ♦ Create and implement an Erosion & Sedimentation Control (ESC) Plan
  - ♦ Oil/water separator to filter storm water run-off
  - ♦ Bio-swale treatment of storm water runoff to remove pollutants
  - ♦ Off-site lighting reduction
  - ♦ Night sky pollution
- Development and Design
  - ♦ Native non-irrigated landscaping
  - ♦ Reduce heat islands (Roof & Non-roof)
  - ♦ Green Roofs
  - ♦ Implement stormwater plan to prevent erosion

Water Conservation

- Drought-resistant native landscaping
- Reduce potable water consumption for irrigation by 50%
- Utilize collected rainwater / recycled water to reduce watering
- Reclaim and reuse 70% of train washer water
- Low flow/dual-option plumbing fixtures and waterless urinals
- Employ strategies that reduce water use by 20% and 30%

Energy Conservation/Carbon Emissions Reductions

- Optimize performance
  - ♦ Metal trellises over glazing reduce heat gain and glare
  - ♦ Heat recovery wheels on makeup air units
  - ♦ Radiant slab heating in maintenance (Hydronic Coils)
  - ♦ Ground source heat pump cooling and heating of offices and operations
  - ♦ Ground Source Geothermal HVAC for Enhanced Efficiency
  - ♦ Displacement Ventilation
  - ♦ Energy Recovery System to Capture Energy from Exhaust Air Stream
  - ♦ 100% Fresh Air System
  - ♦ CO2 Monitoring
  - ♦ Spot Cooling
  - ♦ Building orientation
  - ♦ Occupancy/Photo Sensor Controls Integrated with Daylighting
  - ♦ Daylighting at Work and Circulation Areas
- Green Power
  - ♦ Solar panels or wind turbines - reduce usage by on site production
  - ♦ Double-pane/low-emissive glazing to reduce heat gain
  - ♦ Minimize the use of electric lighting during daylight hours
  - ♦ Super insulated wall and roof systems

Energy Conservation/Carbon Emissions Reductions (Continued)

- Minimum Performance Standards (AHRAE/IESNA 90.1 2004)
  - ♦ Annual energy use index (Energy Star) goal of 35 to 60 kBtu/sf/yr max
  - ♦ Evaluate renewable energy systems potential (2.5% minimum)
  - ♦ Reduce energy costs 28% - 42% as compared to a minimally compliant
  - ♦ Provide a sliding scale cost estimate for purchase of off-site green power
  - ♦ Dedicated HVAC Control for Work Areas
  - ♦ Ventilate Hazardous Works Areas
  - ♦ Horizontal View Panels Service Bay Doors

Materials

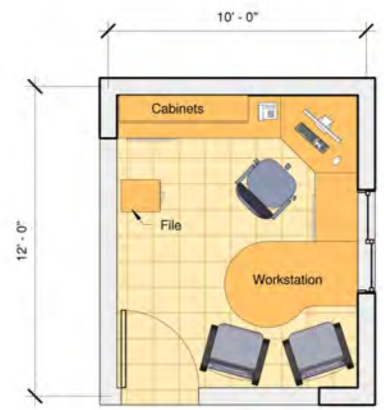
- Building Reuse
  - ♦ Construction waste management, divert 50% and 75% from disposal
- Materials Reuse
  - ♦ Recycled content in all carpet, tile, millwork, and ceiling finishes
  - ♦ Recycled content in all CMU, concrete, and steel structure components
  - ♦ Collected on site including paper, glass, plastic, cardboard, metal and batteries
  - ♦ Low VOC emitting paint for all interiors
  - ♦ High fly ash content of concrete
- Proximity
  - ♦ Locally harvested and manufactured materials
  - ♦ Modular Furniture Systems
  - ♦ Regional Materials
  - ♦ Certified Wood
- Plan for future use
  - ♦ Extensive Material and Equipment Evaluation
  - ♦ Multiple Levels of Benefit from Single Modification
  - ♦ Ensure Programmatic Functionality
  - ♦ Life Cycle Cost Analysis

SUSTAINABLE DESIGN

Efficiency and Quality of Operations

- Minimum Performance
  - ♦ Conform to IAQ and ASHRAE 62.1 2004 standards
  - ♦ Prohibit smoking in the building and located designated area 25 feet from entries
  - ♦ Install permanent ventilation monitoring systems
  - ♦ Commitment to Green Power
- Construction Management
  - ♦ Protect stored on-site or installed absorptive materials from moisture damage.
  - ♦ Replace all filtration media prior to occupancy
  - ♦ Perform a building flush-out prior to occupancy
  - ♦ Occupied building shall be ventilated at a min. 0.30 cfm/sq.ft
- Low emitting materials
  - ♦ Adhesives / sealants, paints, carpet and composite wood
  - ♦ Green seal standard for commercial adhesives
  - ♦ Anti-corrosive and anti-rust paints
  - ♦ No added urea-formaldehyde resins in laminating adhesives on wood
- Building systems
  - ♦ Under floor air distribution
  - ♦ Daylight and Occupancy sensored lighting systems in all areas
  - ♦ Daylighting of all regularly occupied areas
  - ♦ Natural ventilation & light
    - ◊ Daylight 75% of spaces
    - ◊ Views for 90% of spaces
- Plans for flexibility
  - ♦ Bike racks
  - ♦ Flex Shop Space
  - ♦ Appealing Public and Private Spaces
  - ♦ Circulation should be Function Driven and Equipment Driven

MODULE A: 120 SQUARE FOOT PRIVATE OFFICE



FUNCTIONAL CHARACTERISTICS

Function: Enclosed shared office with separate workstations for each occupant.

Relationship to Other Areas

- Case specific. Reference office descriptions.

Critical Dimensions

- 9' -0" vertical clearance

Equipment/Furnishings

- Task chair
- Guest chairs
- 24" deep work surfaces
- 42" x 42" corner work surface
- Under surface vertical files
- File cabinets

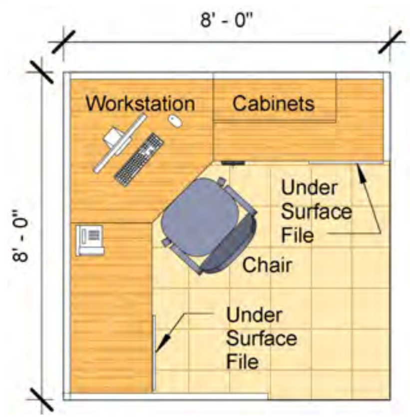
Design Features

- Carpet floor covering (Administration/Operations)
- VCT floor covering (Maintenance)
- Acrylic latex-painted masonry and/or metal stud and gypsum board walls
- Suspended tile ceiling with fluorescent lighting, 30 fc average
- Secured entry: Single 3'-0" door
- Systems furniture
- Data and telephone receptacles
- Exterior window required
- General purpose duplex receptacles, 120 VAC, 20 A

Sustainable Design Criteria

- Lighting design to meet targeted LEED points
- Operable windows/natural ventilation /natural lighting
- Lighting controls: Occupancy sensors
- Raised access floor

MODULE B: 64 SQUARE FOOT WORKSTATION



FUNCTIONAL CHARACTERISTICS

Function: Open office workstation

Relationship to Other Areas

- Case specific. Reference office descriptions.

Critical Dimensions

- 9'- 0" vertical clearance

Equipment/Furnishings

- Task chair
- 24" work surfaces
- 42" x 42" corner work surface
- Under surface vertical files

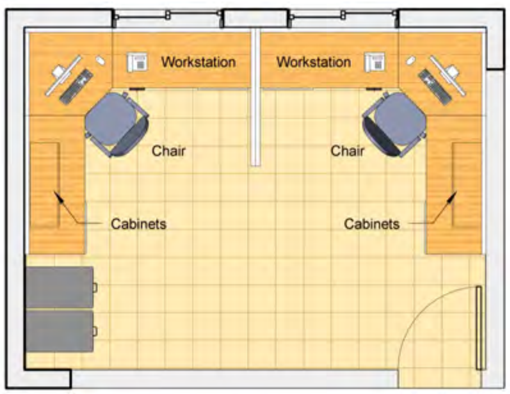
Design Features

- Carpet floor covering (Administration/Operations)
- VCT floor covering (Maintenance)
- Acrylic latex-painted masonry and/or metal stud and gypsum board walls
- Suspended tile ceiling with fluorescent lighting, 30 fc average
- Systems furniture
- Data and telephone receptacles
- General purpose duplex receptacles, 120 VAC, 20 A

Sustainable Design Criteria

- Lighting design to meet targeted LEED points
- Operable windows/natural ventilation/natural lighting
- Lighting controls: Occupancy sensors
- Raised access floor

MODULE C: SHARED OFFICE TWO WORKSTATION



FUNCTIONAL CHARACTERISTICS

Function: Enclosed shared office with separate workstations for each occupant.

Relationship to Other Areas

- Case specific. Reference office descriptions.

Critical Dimensions

- 9' -0" vertical clearance

Equipment/Furnishings

- Task chairs
- 24" deep work surfaces
- 42" x 42" corner work surface
- Under surface vertical files
- File cabinets

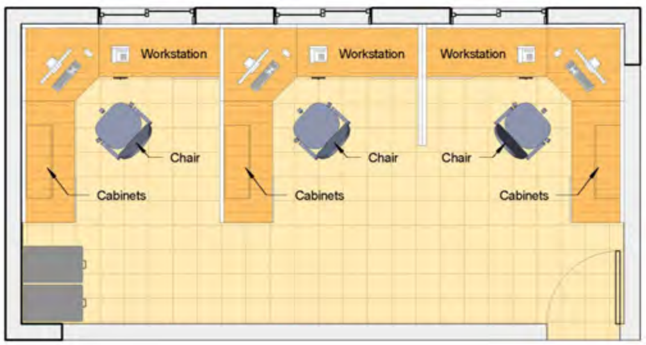
Design Features

- Carpet floor covering (Administration/Operations)
- VCT floor covering (Maintenance)
- Acrylic latex-painted masonry and/or metal stud and gypsum board walls
- Suspended tile ceiling with fluorescent lighting, 30 fc average
- Secured entry; single 3'-0" door
- Systems furniture
- Data and telephone receptacles
- Exterior window required
- General purpose duplex receptacles, 120 VAC, 20 A

Sustainable Design Criteria

- Lighting design to meet targeted LEED points
- Operable windows/natural ventilation /natural lighting
- Lighting controls: Occupancy sensors
- Raised access floor

MODULE D: SHARED OFFICE THREE WORKSTATION



FUNCTIONAL CHARACTERISTICS

Function: Enclosed shared office with separate workstations for each occupant.

Relationship to Other Areas

- Case specific. Reference office descriptions.

Critical Dimensions

- 9' -0" vertical clearance

Equipment/Furnishings

- Task chairs
- 24" deep work surfaces
- 42" x 42" corner work surface
- Under surface vertical files
- File cabinets

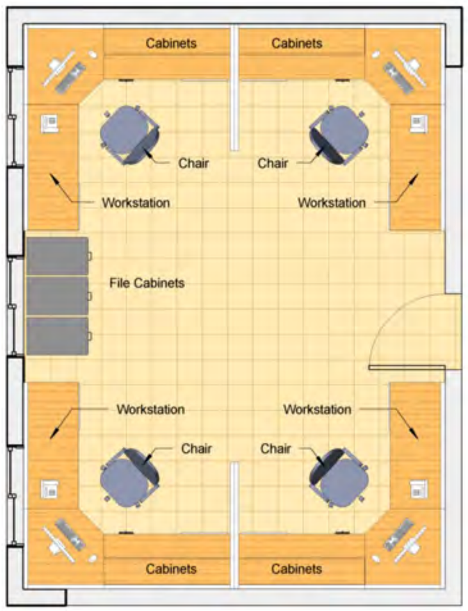
Design Features

- Carpet floor covering (Administration/Operations)
- VCT floor covering (Maintenance)
- Acrylic latex-painted masonry and/or metal stud and gypsum board walls
- Suspended tile ceiling with fluorescent lighting, 30 fc average
- Secured entry: Single 3'-0" door
- Systems furniture
- Data and telephone receptacles
- Exterior window required
- General purpose duplex receptacles, 120 VAC, 20 A

Sustainable Design Criteria

- Lighting design to meet targeted LEED points
- Operable windows/natural ventilation/natural lighting
- Lighting controls: Occupancy sensors
- Raised access floor

MODULE E: SHARED OFFICE FOUR WORKSTATION



FUNCTIONAL CHARACTERISTICS

Function: Enclosed shared office with separate workstations for each occupant.

Relationship to Other Areas

- Case specific. Reference office descriptions.

Critical Dimensions

- 9' -0" vertical clearance

Equipment/Furnishings

- Task chairs
- 24" deep work surfaces
- 42" x 42" corner work surface
- Under surface vertical files
- File cabinets

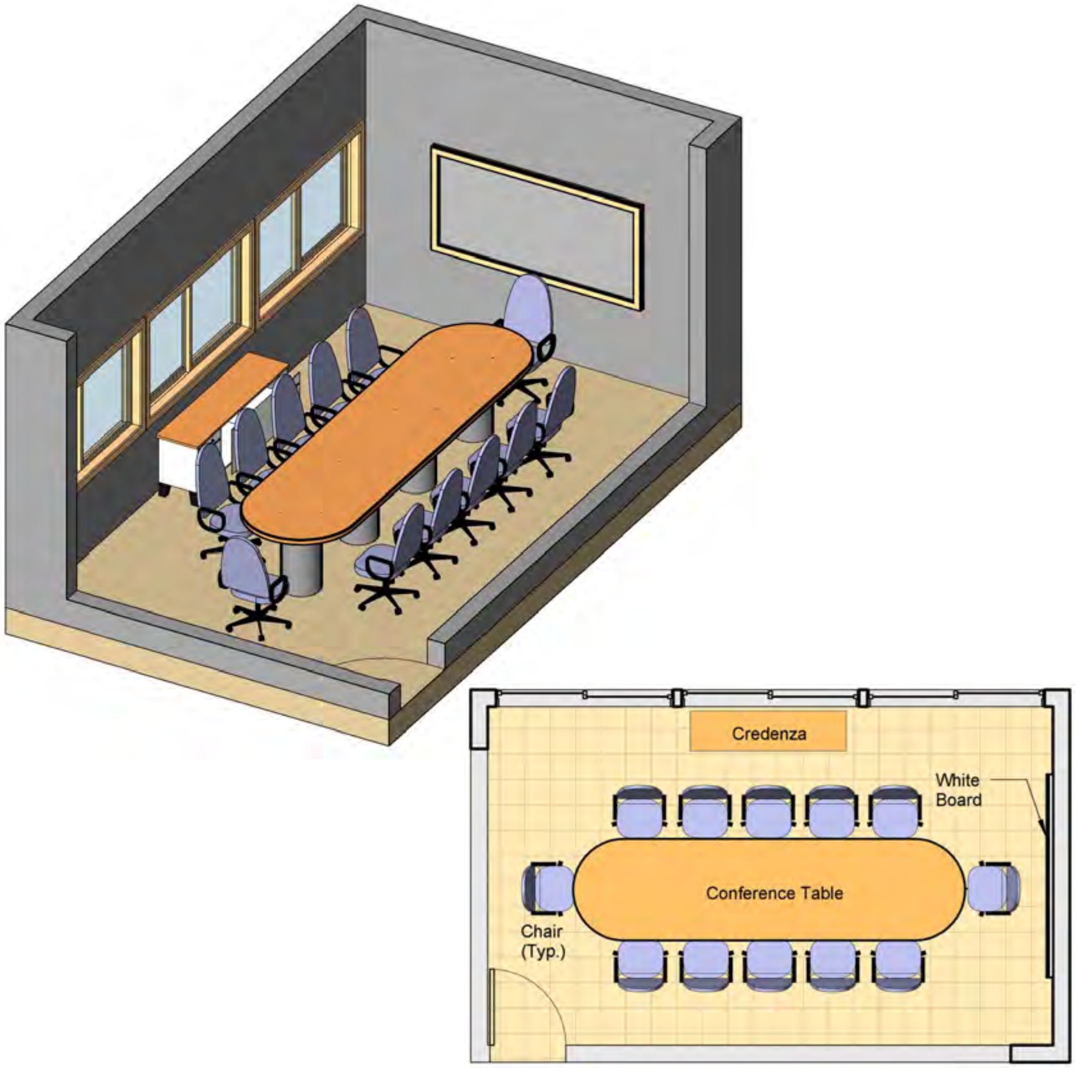
Design Features

- Carpet floor covering (Administration/Operations)
- VCT floor covering (Maintenance)
- Acrylic latex-painted masonry and/or metal stud and gypsum board walls
- Suspended tile ceiling with fluorescent lighting, 30 fc average
- Secured entry; single 3'-0" door
- Systems furniture
- Data and telephone receptacles
- Exterior window required
- General purpose duplex receptacles, 120 VAC, 20 A

Sustainable Design Criteria

- Lighting design to meet targeted LEED points
- Operable windows/natural ventilation/natural lighting
- Lighting controls: Occupancy sensors
- Raised access floor

MODULE F: CONFERENCE ROOM



FUNCTIONAL CHARACTERISTICS

Function: Separate room for meetings.

Relationship to Other Areas

- Case specific, reference office/office support models

Critical Dimensions

- 9'-0" vertical clearance

Equipment/Furnishings

- Conference table
- Conference chairs
- Credenza
- A/V equipment
- Whiteboard

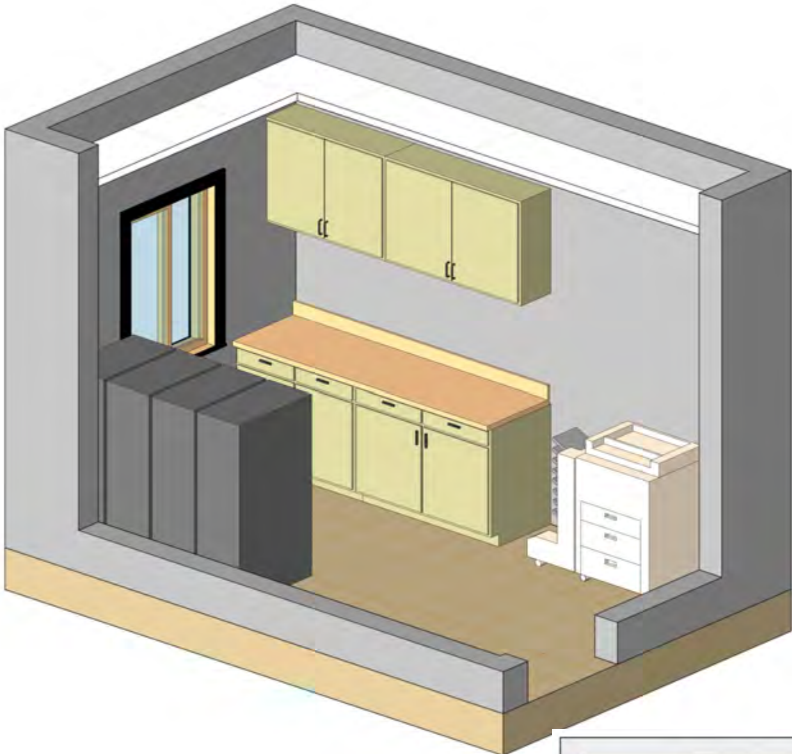
Design Features

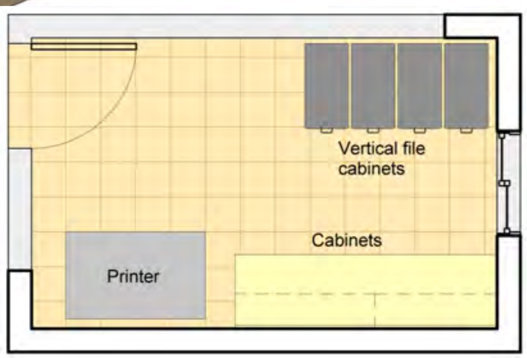
- Carpet floor covering transportation areas or VCT in maintenance areas
- Acrylic latex-painted masonry and/or metal stud/ gypsum board walls
- Suspended tile ceiling with fluorescent lighting, 30 fc average
- Single 3'-0" door
- Computer and telephone receptacles
- Exterior windows required
- General purpose duplex receptacles, 120 VAC, 20 A as required by code

Sustainable Design Criteria

- Lighting designed to meet targeted LEED points
- Operable windows/natural ventilation/natural lighting
- Raised access floor
- Lighting controls: Occupancy sensors

MODULE G: COPY / FILE / STORAGE AREA





FUNCTIONAL CHARACTERISTICS

Function: Dedicated alcove or room for copier/printer/scanner/fax machine and storage for office supplies.

Relationship to Other Areas

- Case specific, reference office/office support modules

Critical Dimensions

- 9'-0" vertical clearance

Equipment/Furnishings

- Copier/printer/scanner/fax machine
- Work surface with cabinets below
- Filing cabinets
- Shelving

Design Features

- Carpet floor covering transportation areas or VCT in maintenance areas
- Acrylic latex-painted masonry and/or metal stud/gypsum board walls
- Suspended tile ceiling
- Electrical
  - ♦ Fluorescent lighting, 30 fc average
  - ♦ Computer and telephone receptacles
  - ♦ General purpose duplex receptacles, 120 VAC, 20 A as required by code
  - ♦ As required by equipment

Sustainable Design Criteria

- Lighting designed to meet targeted LEED points
- Operable windows/natural ventilation/natural lighting
- Raised access floor
- Lighting controls: Occupancy sensors

MODULE H: RESTROOM

FUNCTIONAL CHARACTERISTICS

Function: Restroom for male and female employees, shared by all Administrative staff.

Relationship to Other Areas

- Case specific, reference office/office support modules

Critical Dimensions

- 9'- 0" vertical clearance

Equipment/Furnishings

- Toilet
- Urinal
- Sink
- Mirror
- Hand dryer

Design Features

- Ceramic tile floor covering and wall covering
- Epoxy painted drywall ceiling
- Plumbing: Toilets, urinals, and wash sinks; as required by code
- Electrical:
  - ♦ Fluorescent lighting, bi-level switching, task lighting over counters
  - ♦ General purpose duplex receptacles, 120 VAC, 20 A, GFI protected where required by Electrical Code
  - ♦ As required by equipment

Sustainable Design Criteria

- Lighting designed to meet targeted LEED points
- Lighting controls: Occupancy sensors
- Natural lighting

MODULE I: MEN'S AND WOMEN'S RESTROOMS / SHOWERS

FUNCTIONAL CHARACTERISTICS

Function: Separate restrooms for male and female employees including separate showers.

Relationship to Other Areas

- Case specific, reference office/office support modules

Critical Dimensions

- 9'- 0" vertical clearance

Equipment/Furnishings

- Toilet
- Urinal
- Sink
- Mirror
- Hand dryer
- Shower, lockers, bench, and wall hooks

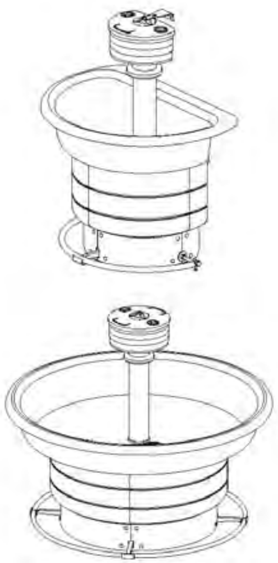
Design Features

- Ceramic tile floor covering and wall covering
- Epoxy painted drywall ceiling
- Plumbing: Toilets, urinals, and wash sinks, as required by code
- Shower to be separate room with changing area
- Electrical:
  - ♦ Fluorescent lighting, bi-level switching, task lighting over counters
  - ♦ General purpose duplex receptacles, 120 VAC, 20 A, GFI protected where required by Electrical Code
  - ♦ As required by equipment

Sustainable Design Criteria

- Lighting designed to meet targeted LEED points
- Lighting controls: Occupancy sensors

MODULE J: MEN'S AND WOMEN'S LOCKERS / SHOWERS / RESTROOM



FUNCTIONAL CHARACTERISTICS

Function: Separate restrooms for male and female employees including a separate shower and lockers for changing.

Relationship to Other Areas

- Case specific, reference office/office support modules

Critical Dimensions

- 9'- 0" vertical clearance

Equipment/Furnishings

- Toilet, Urinal
- Deep hand wash sinks
- Mirror
- Hand dryer
- Enclosed shower with bench and wall hooks
- Full height 18" x 18" lockers

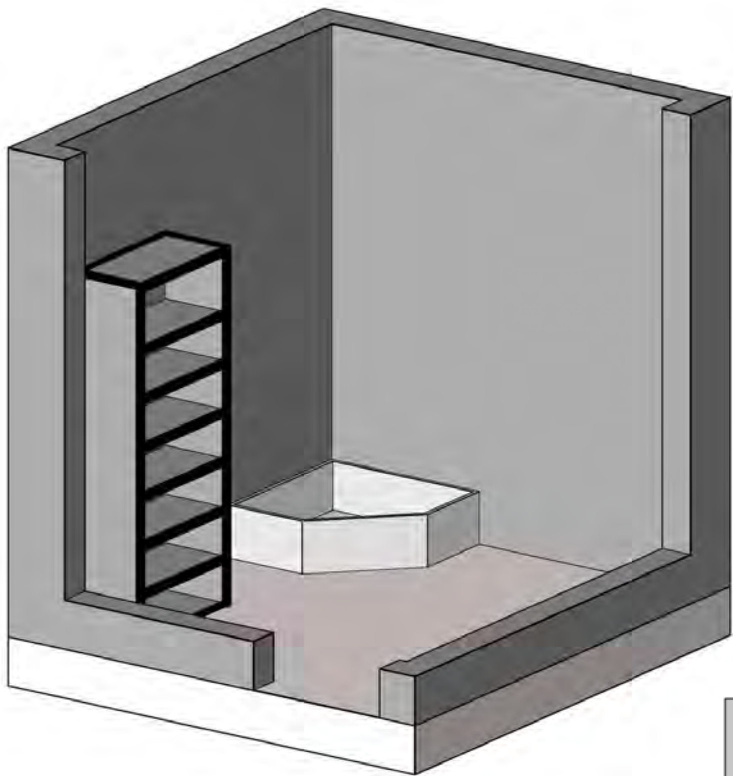
Design Features

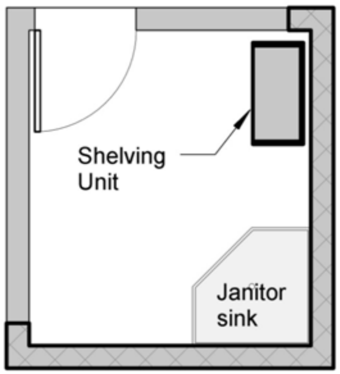
- Ceramic tile floor covering and wall covering
- Epoxy painted drywall ceiling
- Plumbing: Toilets, urinals, and wash sinks; as required by code
- Shower to be separate room with changing area
- Electrical:
  - ♦ Fluorescent lighting, 30 fc average, bi-level switching, task lighting over counters
  - ♦ General purpose duplex receptacles, 120 VAC, 20 A, GFI protected where required by Electrical Code
  - ♦ As required by equipment

Sustainable Design Criteria

- Lighting designed to meet targeted LEED points
- Lighting controls: Occupancy sensors

MODULE K: PORTER'S ROOM





FUNCTIONAL CHARACTERISTICS

Function: Enclosed area for janitorial supplies and mop sink.

Relationship to Other Areas

- Case specific, reference office/office support modules

Critical Dimensions

- 9'-0" vertical clearance

Equipment/Furnishings

- Mop sink and metal shelving

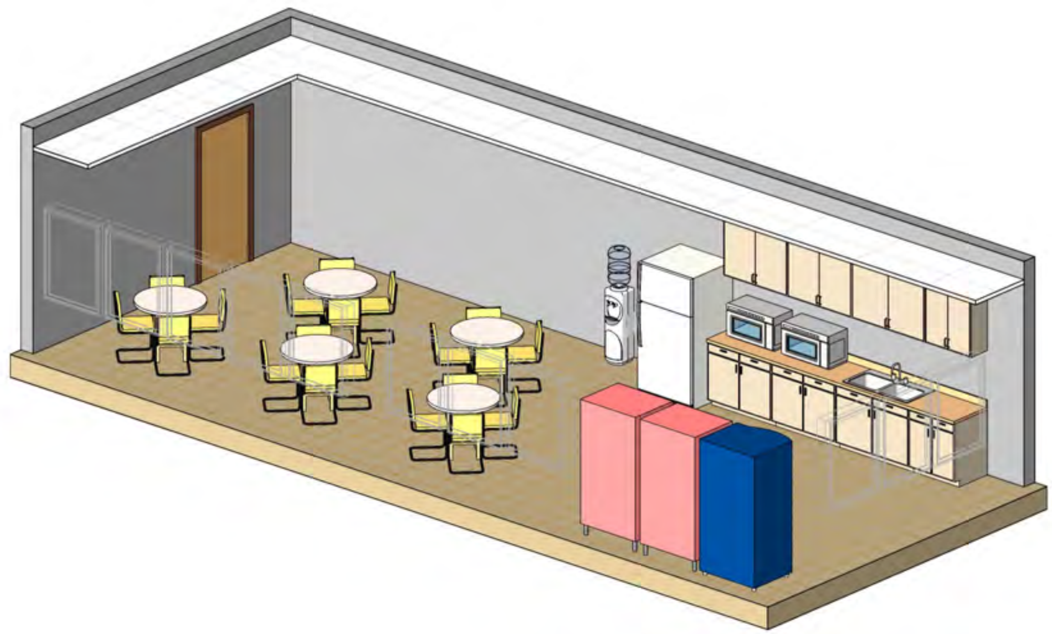
Design Features

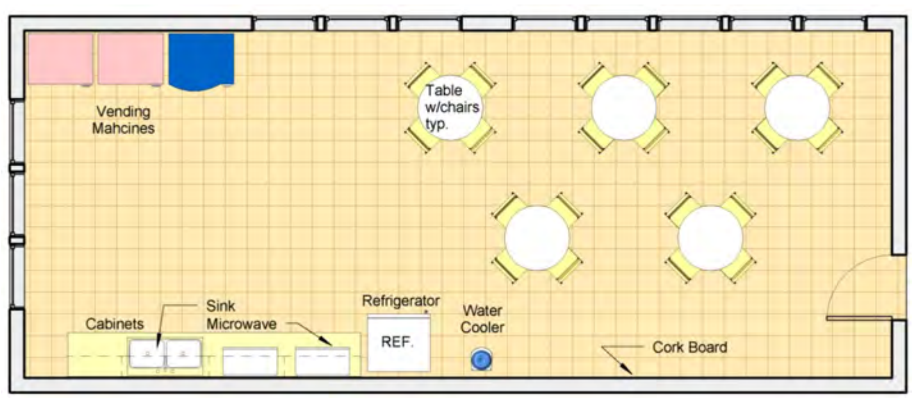
- Floor: Exposed concrete slab
- Walls: Soil and grease resistant
- Ceiling: Painted exposed structure
- Secure area
- Plumbing: Water supply to mop sink
- Electrical:
  - ♦ Fluorescent lighting, 30 fc average
  - ♦ General purpose duplex receptacles, 120 VAC, 20 A, GFI protected as required by Electrical Code

Sustainable Design Criteria

- Lighting designed to meet targeted LEED points
- Lighting controls: occupancy sensor

MODULE L: CREW / BREAK ROOM





FUNCTIONAL CHARACTERISTICS

Function: Enclosed room used as a break area for staff assigned to the building.

Relationship to Other Areas

- Case specific, reference office/office support modules

Critical Dimensions

- 9'-0" vertical clearance

Equipment/Furnishings

- Counter space, upper and lower cabinets, sink with disposal, microwaves, refrigerators, vending machines, water cooler, and tables and chairs

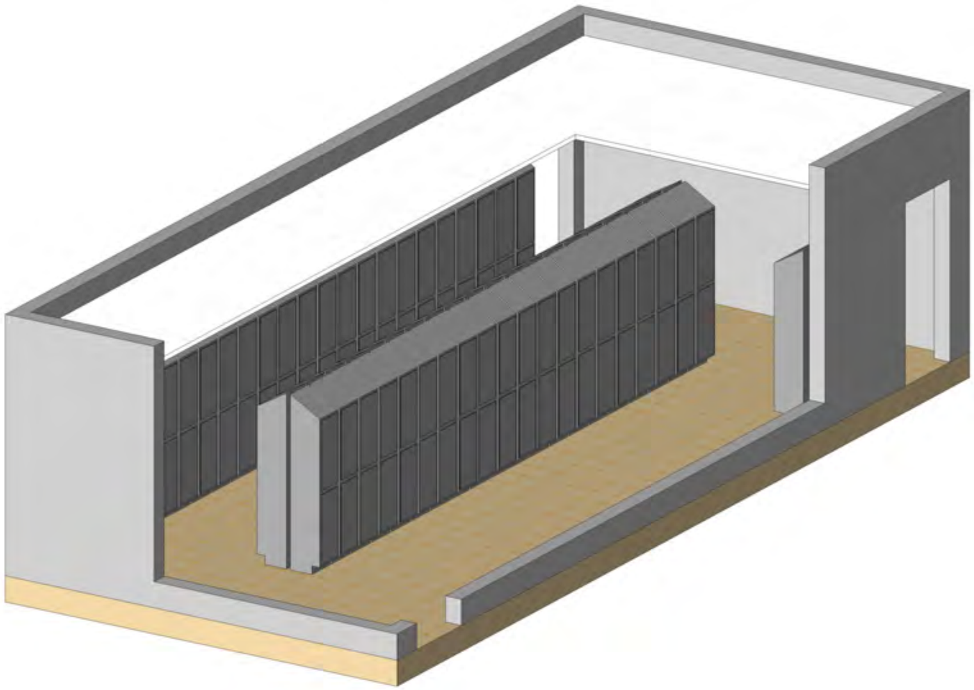
Design Features

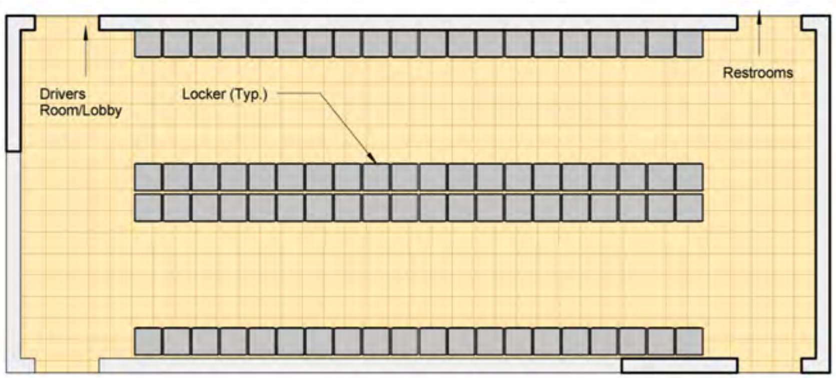
- VCT floor covering or exposed concrete
- Acrylic latex-painted masonry and/or metal stud and gypsum board walls
- Suspended tile ceiling
- Mechanical: As required by equipment
- Plumbing: Water for sink and refrigerator
- Electrical:
  - ♦ General purpose duplex receptacles, 120 VAC, 20 A, as required by code
  - ♦ Computer and telephone receptacles
  - ♦ Fluorescent lighting, bi-level switching, 30 fc average
  - ♦ As required for equipment

Sustainable Design Criteria

- Lighting design to meet targeted LEED points
- Operable windows/natural ventilation/natural lighting
- Raised access floor (Administration/Operations only)
- Lighting controls: Occupancy sensors

MODULE M: LOCKER ALCOVE





FUNCTIONAL CHARACTERISTICS

Function: Alcove for the Operators to store personal gear and clothing in half height lockers.

Relationship to Other Areas

- Case specific, reference office/office support modules

Critical Dimensions

- 9'-0" vertical clearance

Equipment/Furnishings

- Half-height 15" x 15" x 36" inch lockers. One each per Operator assigned to the facility

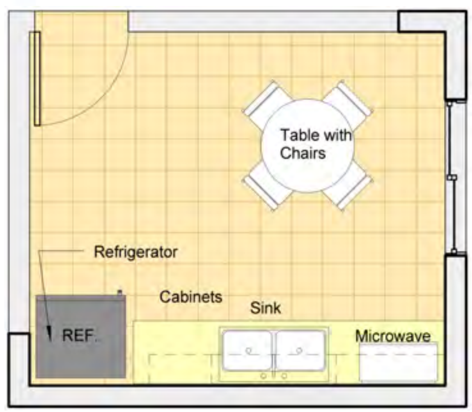
Design Features

- VCT floor covering or colored concrete
- Acrylic latex-painted masonry and/or metal stud/ gypsum board walls
- Suspended tile ceiling with fluorescent lighting , 30 fc average
- General purpose duplex receptacles, 120 VAC, 20 A locate as required by code.

Sustainable Design Criteria

- Lighting designed to meet targeted LEED points
- Raised access floor (Administration/Operations only)
- Lighting controls: occupancy sensor

MODULE N: KITCHENETTE



FUNCTIONAL CHARACTERISTICS

Function: Enclosed area for a refrigerator, microwave, sink, and storage.

Relationship to Other Areas

- Case specific, reference office/office support modules

Critical Dimensions

- 9'-0" vertical clearance

Equipment/Furnishings

- Refrigerator, microwave, water cooler
- Sink, counters, and storage cabinets
- Table with chairs
- Trash/recycle bins

Design Features

- VCT floor covering
- Acrylic latex-painted masonry and/or metal stud and gypsum board walls
- Suspended tile ceiling
- Mechanical : As required by equipment
- Plumbing: Water for sink and refrigerator
- Electrical:
  - ♦ General purpose duplex receptacles, 120 VAC, 20 A, as required by code
  - ♦ Computer and telephone receptacles
  - ♦ Fluorescent lighting, 30 fc average
  - ♦ As required for equipment

Sustainable Design Criteria

- Lighting design to meet targeted LEED points
- Operable windows/natural ventilation/natural lighting
- Raised access floor
- Lighting controls: Occupancy sensors

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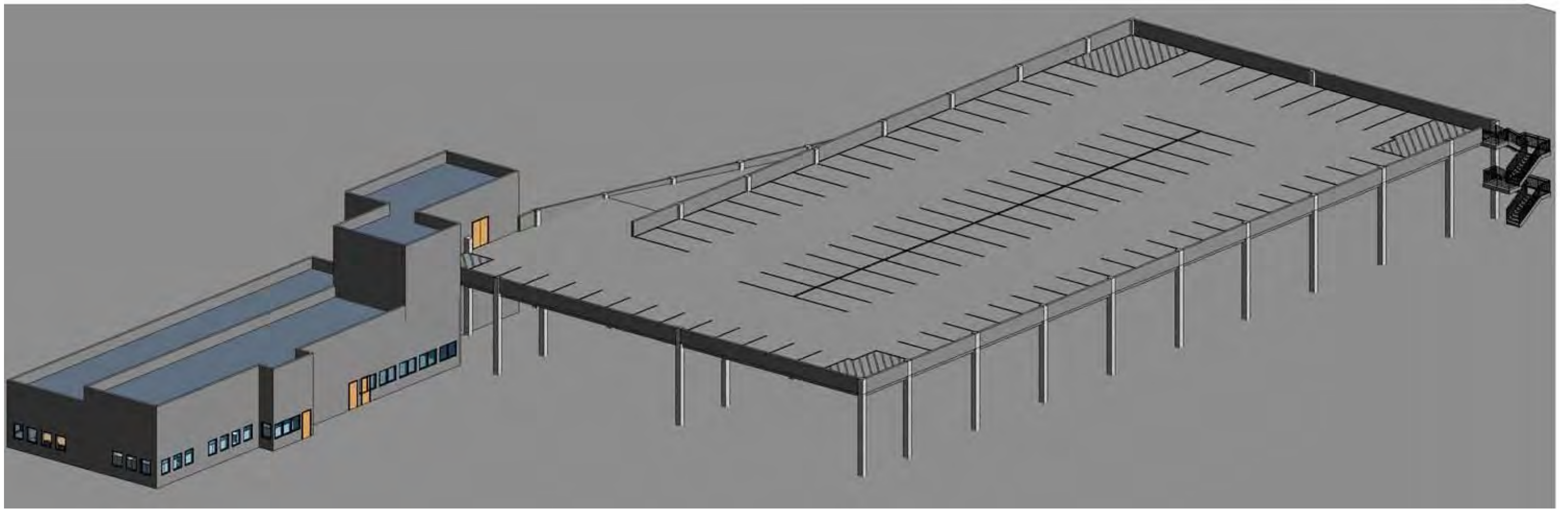
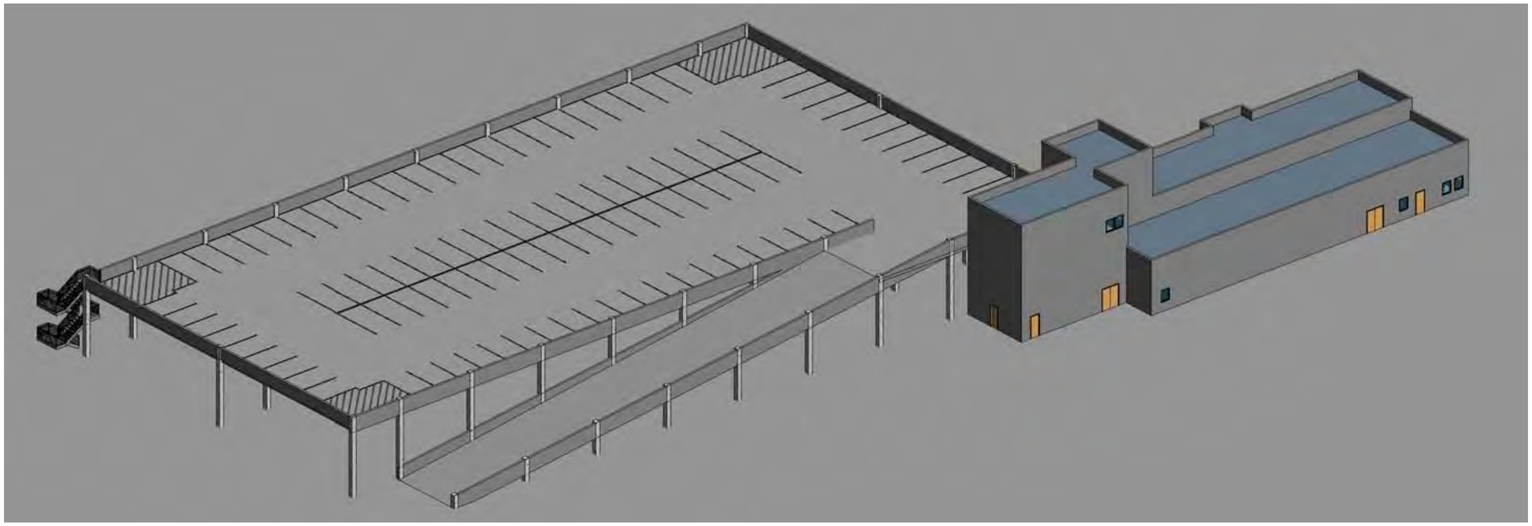
TRANSPORTATION





TRANSPORTATION OFFICE AREAS / OFFICE SUPPORT MODULES

DIRECTOR/DEPUTY DIRECTOR/ SUPERINTENDENT - Module D (Shared Satellite Office)

Relationship to Other Areas

- Access to the public entrance
- Access to support areas

Comments

- Satellite workspace
- Separate workstation for each person located in a shared secure office

SUPERVISOR - Module E

Relationship to Other Areas

- Adjacent to Official/Inspector's office and Yard Master Office
- Access to Operator's Areas
- Access to the public entrance
- Access to support areas

Comments

- Four workstations located in a shared secure office

CLERK - Module B

Relationship to Other Areas

- Access to the public entrance
- Access to support areas
- Access to all office areas

Comments

- Custom millwork with chair

YARD MASTER - Module C

Relationship to Other Areas

- Direct Access to a view of the LRV storage yard
- Access to Operator's Areas
- Access to the public entrance
- Access to support areas

Comments

- Two workstations located in a shared secure office
- Adjacent to Official/Inspector's office and Supervisor Office
- Direct Access to the LRV storage yard
- Provide1/2 height lockers - one for each Official/ Inspector

CONFERENCE ROOM - Module F

Relationship to Other Areas

- Access to all office areas
- Access to Kitchenette
- Access to Restroom

Comments

- Sized for all administrative staff, 10-12 people

COPY/FILE/STORAGE AREA - Module G

Relationship to Other Areas

- Access to all office areas

Comments

- Separate room to meet LEED requirements

RESTROOM - Module H

Relationship to Other Areas

- Adjacent to Official/Inspector's office and Yard Master Office
- Access to office areas, Kitchenette, Conference Room

Comments

- Restroom for office staff only

MEN'S AND WOMEN'S RESTROOMS/ SHOWERS - Module I

Relationship to Other Areas

- Adjacent to Lobby/Operators" Room and Locker Room

Comments

- Restroom mainly used by Drivers/Operators
- Sized for shift changes

PORTER'S ROOM - Module K

Relationship to Other Areas

- Access to entire building
- Adjacent to Restroom

Comments

- Allow for storage of janitorial cart

OFFICE AREAS / OFFICE SUPPORT MODULES

LOCKER ALCOVE - Module M

Relationship to Other Areas

- Adjacent to Lobby/Operator's Room and Restrooms

Comments

- Provide one half-height locker per Driver/Operator assigned to the facility
- Open area (no changing)

KITCHENETTE - Module N

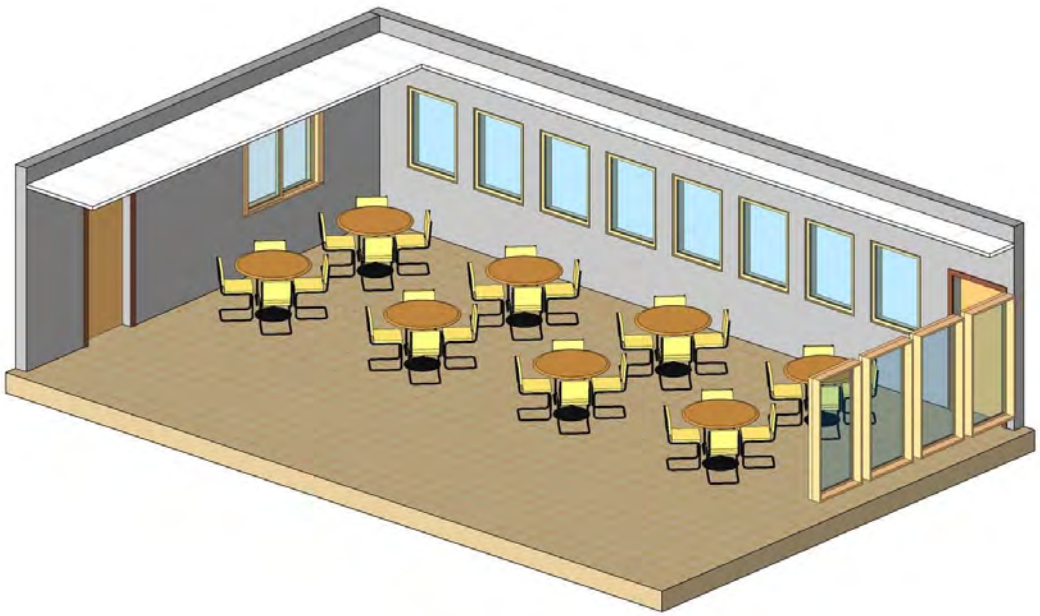
Relationship to Other Areas

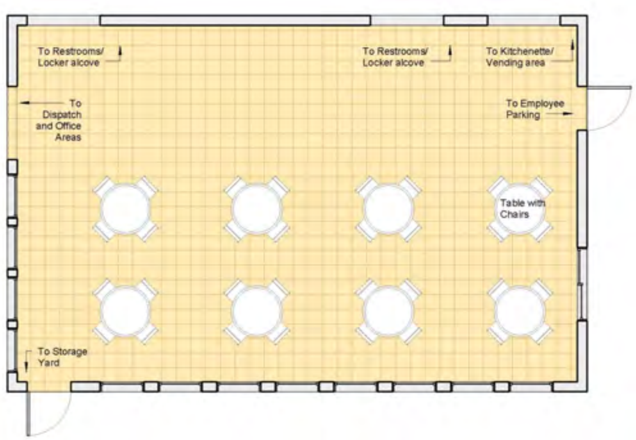
- Access to all office areas
- Access to Conference Room
- Access to Restroom

Comments

- Break area for Administrative staff

LOBBY / OPERATOR'S ROOM





FUNCTIONAL CHARACTERISTICS

Function: Area for drivers to report, receive information, and write reports. Space shall accommodate up to 40 Operators.

Relationship to Other Areas

- Adjacent to Dispatch, Kitchenette/Vending Area, Restrooms, and Lockers
- Access to office areas, LRV Storage

Critical Dimensions

- 10' - 0" vertical clearance

Equipment/Furnishings

- Computer kiosks
- Tables and chairs
- Message and Information boards and kiosks
- Wall mounted TV

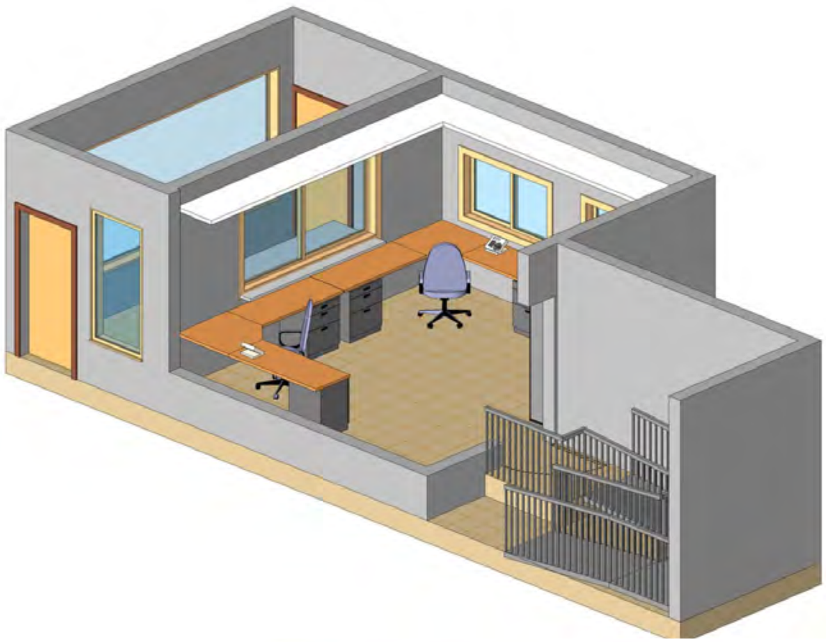
Design Features

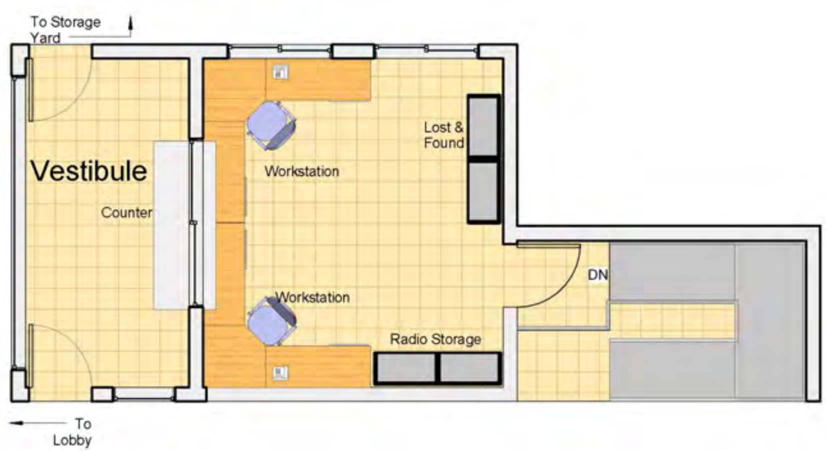
- VCT floor covering or colored concrete
- Acrylic latex-painted masonry and/or metal stud/ gypsum board walls
- Windows to exterior and Dispatch
- Electrical
  - ♦ Fluorescent lighting, 30 fc average
  - ♦ Computer and telephone receptacles
  - ♦ General purpose duplex receptacles, 120 VAC, 20 A as required by code

Sustainable Design Criteria

- Lighting designed to meet targeted LEED points
- Operable windows/natural ventilation/natural lighting
- Raised access floor
- Lighting controls: Occupancy sensors

OFFICIAL / INSPECTOR





FUNCTIONAL CHARACTERISTICS

Function: **Dispatch:** Secure enclosed area for radio and window dispatchers responsible for communication with train Operators. **Vestibule:** Enclosed space at window for Operator check-in, receive work assignments, and communicate with Officials.

Relationship to Other Areas

- Adjacent to Operator's Room, and Restrooms
- View of train storage
- Access to other office areas

Critical Dimensions

- 9'-0" vertical clearance

Equipment/Furnishings

- Dispatch: Custom millwork counter/systems furniture for 2 workstations with task chairs
- Shelving for radio consoles and lost and found
- Under surface vertical files
- Stainless steel counter top (walk-up height)
- Half-height lockers (1per dispatcher)

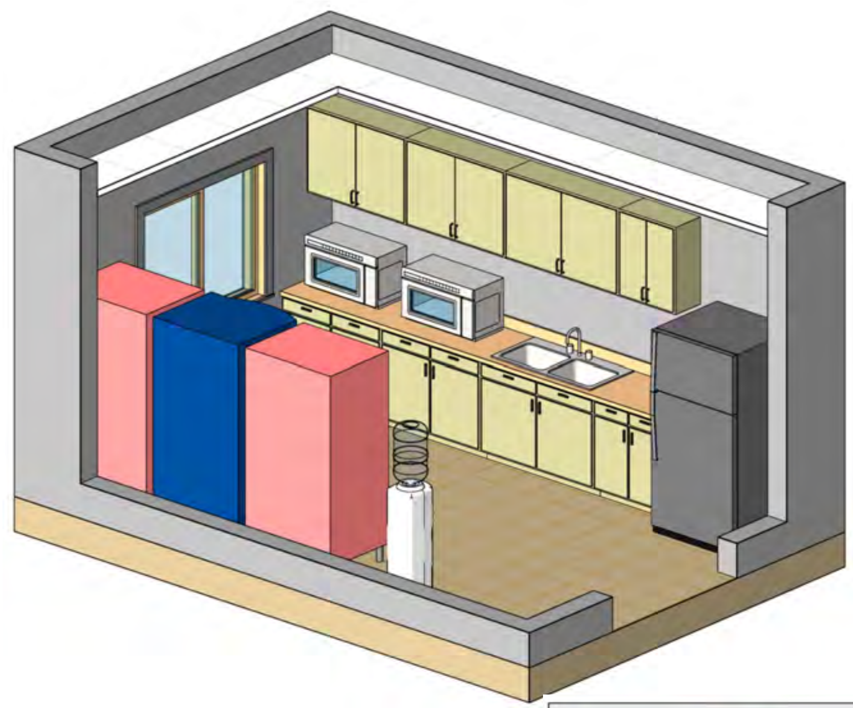
Design Features

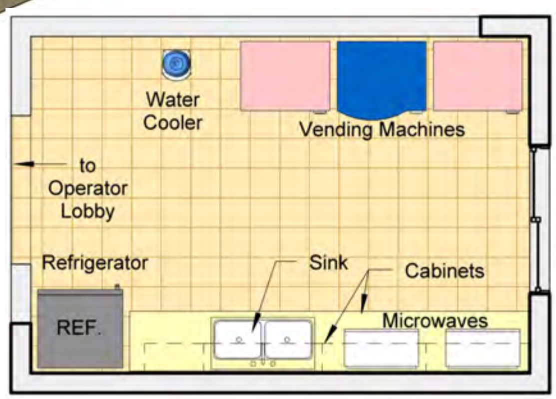
- Acrylic latex-painted metal stud/gypsum board walls or enamel painted masonry walls
- Suspended tile ceiling
- Computer and telephone receptacles
- Fluorescent lighting, 30 fc average
- General purpose duplex receptacles, 120 VAC, 20 A
- Secure/closable window at counter
- Vestibule: Enclosed with windows to Drivers Room, VCT flooring or exposed concrete
- Dispatch: secured entry, raised floors, VCT floor covering

Sustainable Design Criteria

- Lighting design too meet targeted LEED points
- Lighting controls: Occupancy sensors
- Dispatch: Operable windows/natural ventilation

KITCHENETTE / VENDING AREA





FUNCTIONAL CHARACTERISTICS

Function: Area for a refrigerator, microwave, sink, and storage.

Relationship to Other Areas

- Adjacent to the Operator areas

Critical Dimensions

- 9'-0" vertical clearance

Equipment/Furnishings

- Refrigerator, microwave, water cooler, vending machines
- Sink, counters, and storage cabinets
- Trash and recycle bins

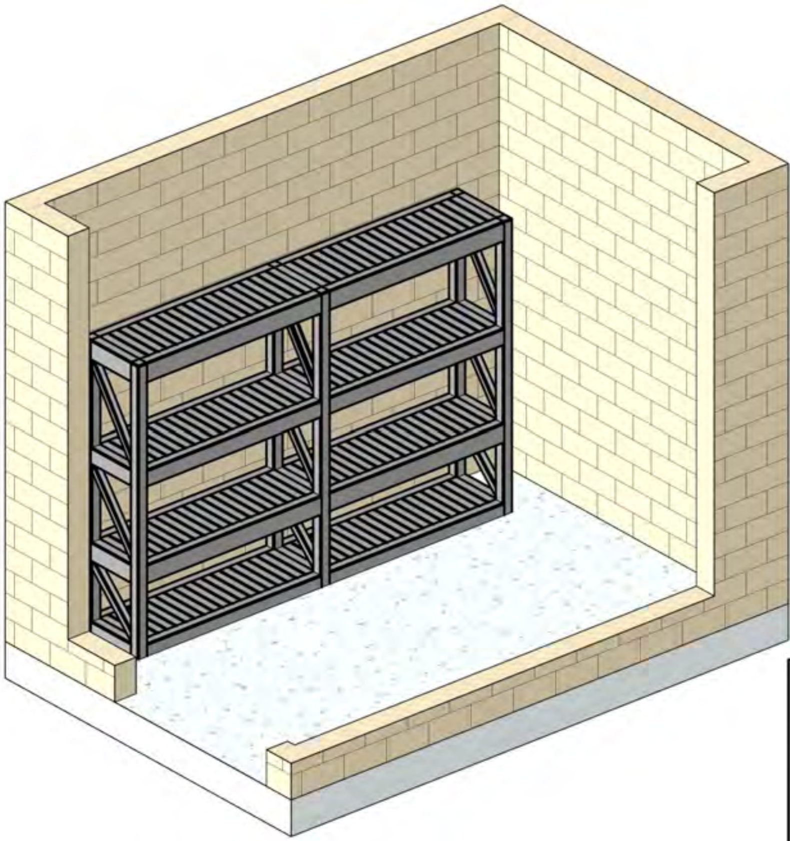
Design Features

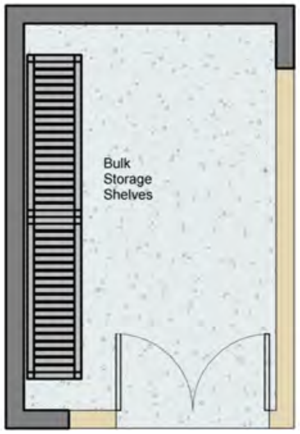
- VCT floor covering
- Acrylic latex-painted masonry and/or metal stud and gypsum board walls
- Suspended tile ceiling
- Mechanical: As required by equipment
- Plumbing: Water for sink and refrigerator
- Electrical:
  - ♦ General purpose duplex receptacles, 120 VAC, 20 A, as required by code
  - ♦ Computer and telephone receptacles
  - ♦ Fluorescent lighting, 30 fc average
  - ♦ As required for equipment

Sustainable Design Criteria

- Lighting design to meet targeted LEED points
- Operable windows/natural ventilation
- Raised access floor
- Lighting controls: Occupancy sensors

STORAGE





FUNCTIONAL CHARACTERISTICS

Function: Secure area for the storage of signs, shovels, message boards, and salt.

Relationship to Other Areas

- Access to all administration areas

Critical Dimensions

- 9'-0" vertical clearance

Equipment/Furnishings

- Steel shelving and racks

Design Features

- Exposed concrete floor
- Enamel painted masonry
- Painted exposed structure ceiling
- Electrical
  - Fluorescent lighting, 30 fc average
  - General purpose duplex receptacles, 120 VAC, 20 A as required by code
  - As required by equipment
- Secured entry

Sustainable Design Criteria

- Lighting designed to meet targeted LEED points
- Lighting controls: Occupancy sensors

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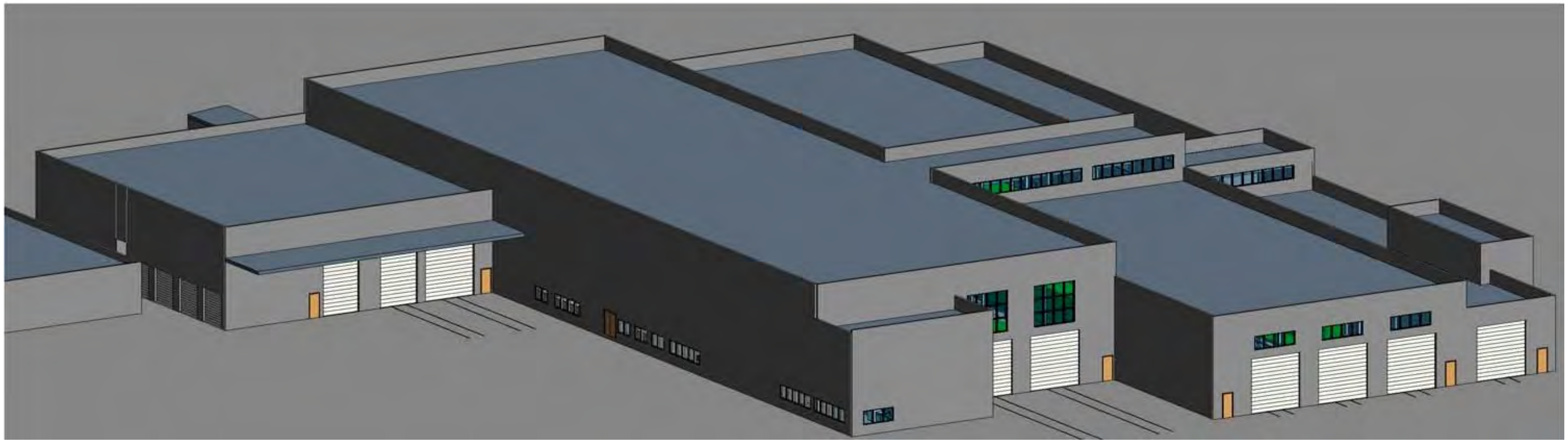
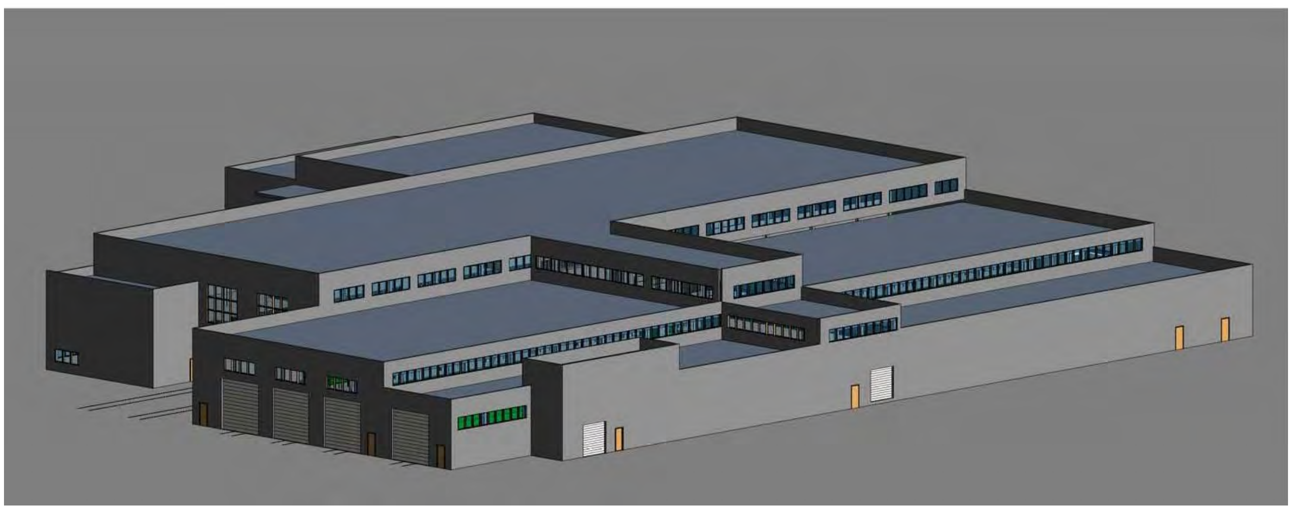
MAINTENANCE





LRV MAINTENANCE OFFICE AREAS / SUPPORT AREAS

DIRECTOR/DEPUTY DIRECTOR/ SUPERINTENDENT (SHARED SATELLITE OFFICE) - Module D

Relationship to Other Areas

- Access to public entrance for LRV Maintenance
- Access to office and support areas for LRV Maintenance

Comments

- Satellite workspace
- Separate workstation for each person located in a shared secure office

SUPERVISOR - Module A

Relationship to Other Areas

- Access to public entrance for LRV Maintenance
- Access to office and support areas for LRV Maintenance
- Adjacent to Carhouse Foreperson and Foreman Shared office

Comments

- Office to open directly into Foreperson Work Area

CREW/BREAK ROOM - Module L

Relationship to Other Areas

- Access to Restroom/Locker/Showers
- Access from Repair/Shop area

Comments

- Access to exterior patio area

CARHOUSE FOREPERSON/FOREMAN (FOREPERSON WORK AREA) - Module E

Relationship to Other Areas

- Access to public entrance for LRV Maintenance
- Access to office and support areas for LRV Maintenance
- Adjacent to Supervisor's Office

Comments

- Glass wall with view of LRV Maintenance Shop
- Four workstations located in a shared secure office

STOREROOM SUPERVISOR - Module A

Relationship to Other Areas

- Access to Part's Storage

Comments

- Satellite office space for Store Room staff

CONFERENCE ROOM - Module F

Relationship to Other Areas

- Access to all office areas
- Access to Foreman's Break Room

Comments

- Size for 6 to 8 people

LOCKER ALCOVE - Module M

Relationship to Other Areas

- Access to Restroom
- Access to Service Bay

Comments

- Provide one full-height locker per Service and Clean

COPY/FILE/STORAGE AREA - Module G

Relationship to Other Areas

- Access to all office areas

Comments

- Open to Foreperson Work Area

FOREMAN'S BREAK ROOM - Module N

Relationship to Other Areas

- Adjacent to Foreperson Work Area
- Access to all office areas
- Access to Conference Room

Comments

- Access from within Foreperson Work Area
- Supervisor staff use only.

RESTROOM - Module H

Relationship to Other Areas

- Adjacent to Men's and Women's Restroom

Comments

- Unisex restroom
- Provide shower and lockers

MEN'S AND WOMEN'S LOCKERS/ SHOWERS/RESTROOM - Module J

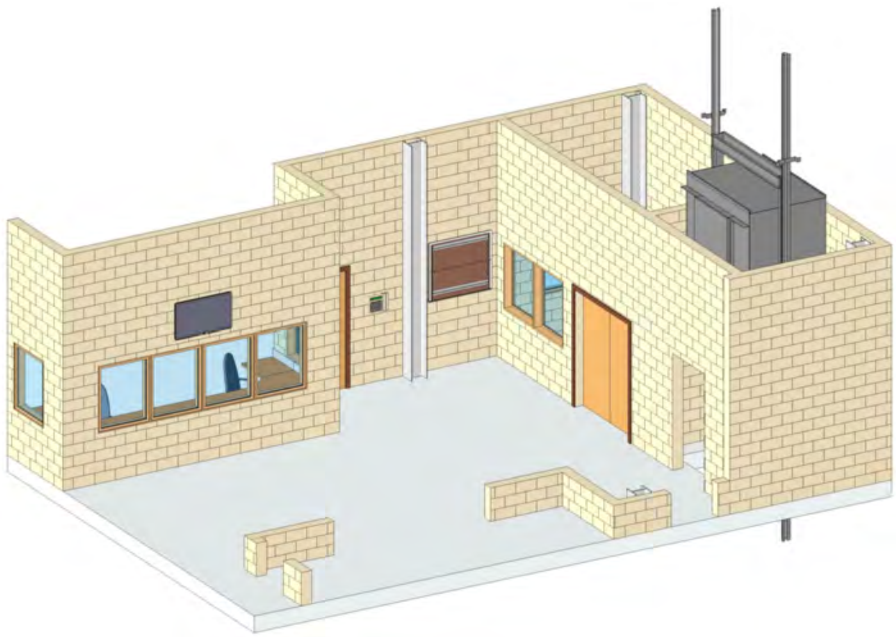
Relationship to Other Areas

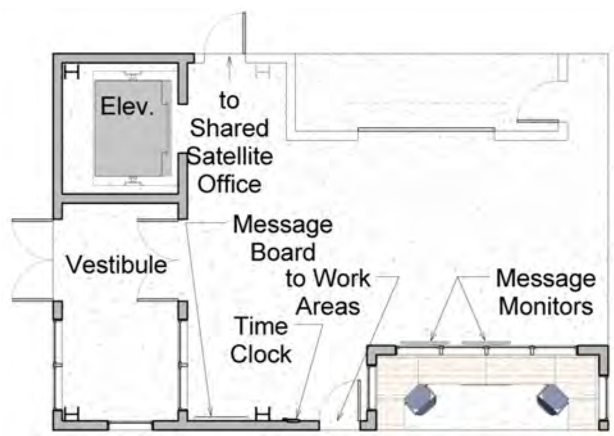
- Access to all Shop/Repair areas

Comments

- Provide one full size locker per Repairer
- Changing area at lockers
- Restroom provides equally to male/female employees

MAINTENANCE LOBBY





FUNCTIONAL CHARACTERISTICS

Function: Central entrance for LRV maintenance staff and customers to the facility.

Relationship to Other Areas

- Limited customer access to the facility
- Access to Office Areas
- Access to all LRV maintenance areas

Critical Dimensions

- 9'-0" vertical clearance

Equipment/Furnishings

- Flat screen TV for announcements
- Time clock
- Cork board

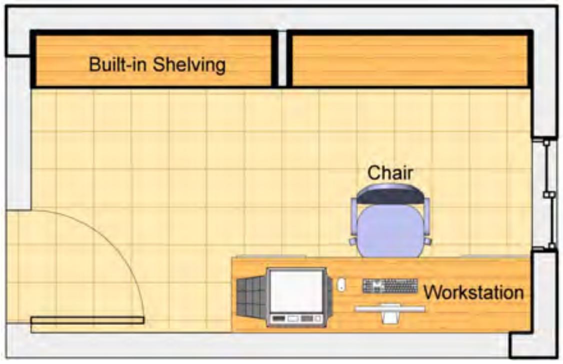
Design Features

- Exposed concrete
- Can be a combination of enamel painted masonry and acrylic latex-painted metal stud/gypsum board walls
- Suspended tile ceiling
- Data outlets
- Fluorescent lighting, 30 fc average
- General purpose receptacles, 120 VAC, 20 A, as required by code

Sustainable Design Criteria

- Lighting designed to meet targeted LEED points
- Operable windows/natural ventilation

MANUALS LIBRARY



FUNCTIONAL CHARACTERISTICS

Function: Enclosed area for storage and reference of vehicle maintenance reference manuals.

Relationship to Other Areas

- Access to the Storeroom
- Adjacent to the Foreperson Work Area
- Access to all repair areas

Critical Dimensions

- 9'-0" vertical clearance

Equipment/Furnishings

- Workstation with computer and copier/printer
- Built-in shelving for reference manuals

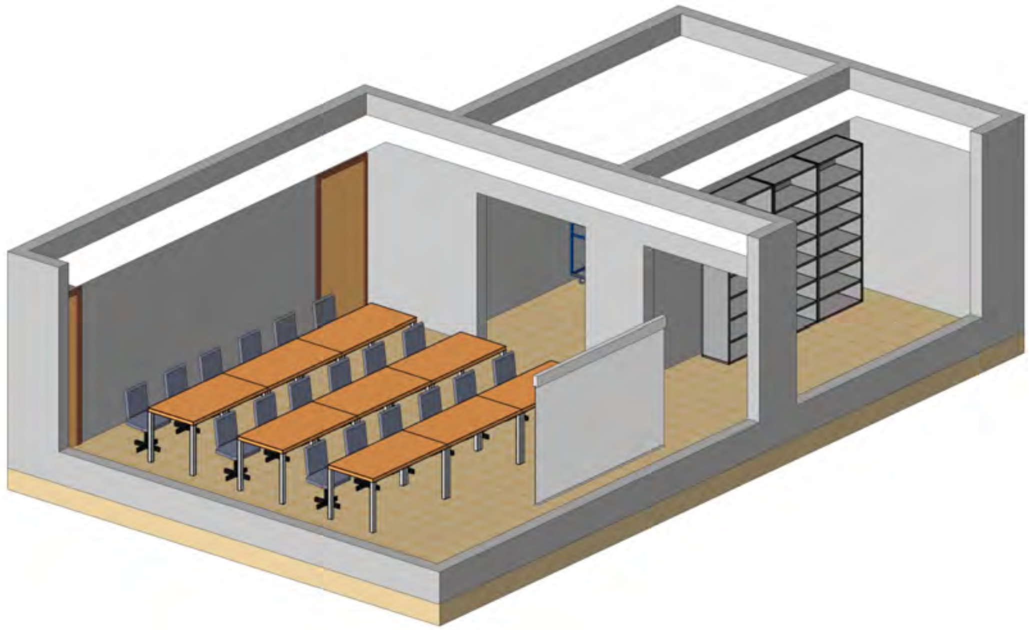
Design Features

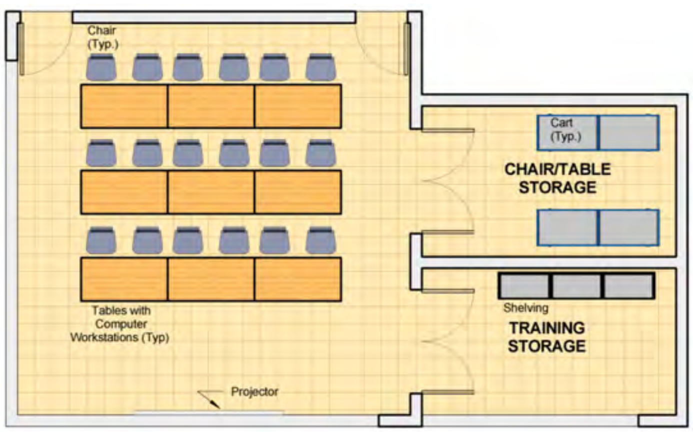
- VCT floor covering or colored concrete
- Acrylic latex-painted masonry and/or metal stud/ gypsum board walls
- Suspended tile ceiling
- Fluorescent lighting, 30 fc average
- Computer and telephone receptacles
- General purpose duplex receptacles, 120 VAC, 20 A to meet code requirements

Sustainable Design Criteria

- Lighting designed to meet targeted LEED points
- Lighting controls: Occupancy sensors

MAINTENANCE TRAINING ROOM





FUNCTIONAL CHARACTERISTICS

Function: Large room for maintenance training activities.

Relationship to Other Areas

- Access to the Repair Bays
- Access to Men's and Women's Restrooms

Critical Dimensions

- 9'-0" vertical clearance

Equipment/Furnishings

- Chairs, tables, computer workstations
- Including but not limited to: Projector, DVD player, and a television
- Training supply storage: metal shelving
- Chair and table Storage: Chair storage carts

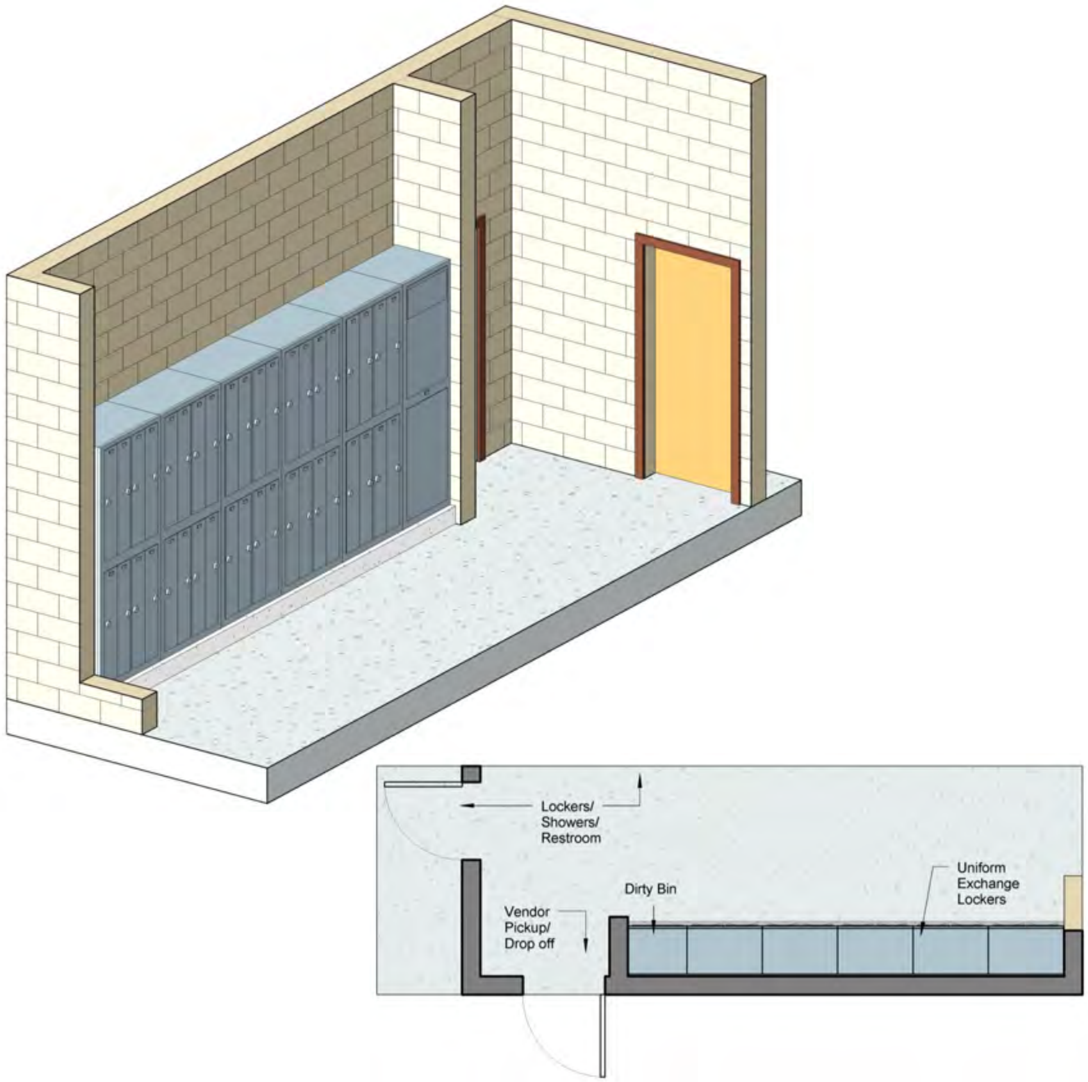
Design Features

- Doors: 3'-0", as required to meet code
- Training supply storage: Secure entry double 3'-0 wide doors, access from inside Training Room
- Chair and table storage: double 3'0" wide doors; access from inside Training Room.
- VCT floor covering or exposed colored concrete
- Acrylic latex-painted masonry and/or metal stud/ gypsum board walls
- Electrical
  - ♦ Fluorescent lighting, 30 fc average
  - ♦ Computer and telephone receptacles
  - ♦ General purpose duplex receptacles, 120 VAC, 20 A as required by code

Sustainable Design Criteria

- Lighting designed to meet targeted LEED points
- Lighting controls: Occupancy sensors

UNIFORM LOCKER AREA



FUNCTIONAL CHARACTERISTICS

Function: Alcove area for venders to drop off clean uniforms and pick up dirty uniforms.

Relationship to Other Areas

- Accessible from Men's and Women's Lockers/ Showers/ Restroom for LRV Maintenance
- Adjacent to an exterior door for vendor pickup/drop off

Critical Dimensions

- 9'-0" vertical clearance

Equipment/Furnishings

- Vender provided uniform lockers
- Bin for dirty uniforms

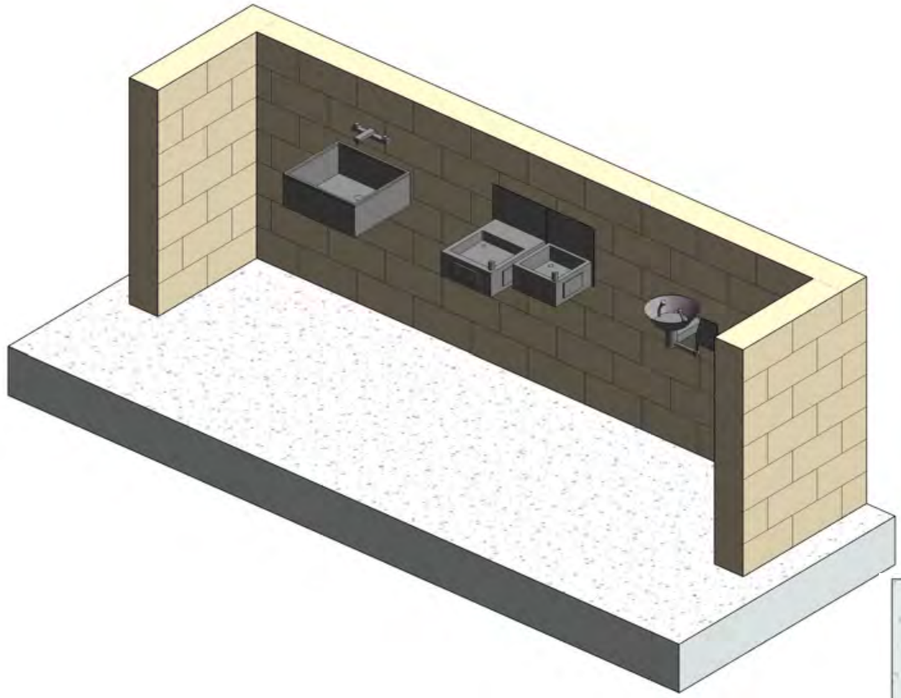
Design Features

- Exposed concrete floor
- Housekeeping pad for lockers
- Painted exposed structure
- Fluorescent lighting, 30 fc average
- General purpose duplex receptacles, 120 VAC, 20 A; as required by code

Sustainable Design Criteria

- Lighting designed to meet targeted LEED points
- Lighting controls: Occupancy sensors

HAND WASH / EYE WASH / DRINKING FOUNTAIN



FUNCTIONAL CHARACTERISTICS

Function: Dedicated area for hand wash sink, eye wash station, and a drinking fountain

Relationship to Other Areas

- Accessible from all repair and shop areas

Critical Dimensions

- 12'-0" vertical clearance

Equipment/Furnishings

- Deep stainless steel sink
- Eye wash station
- Drinking foundation

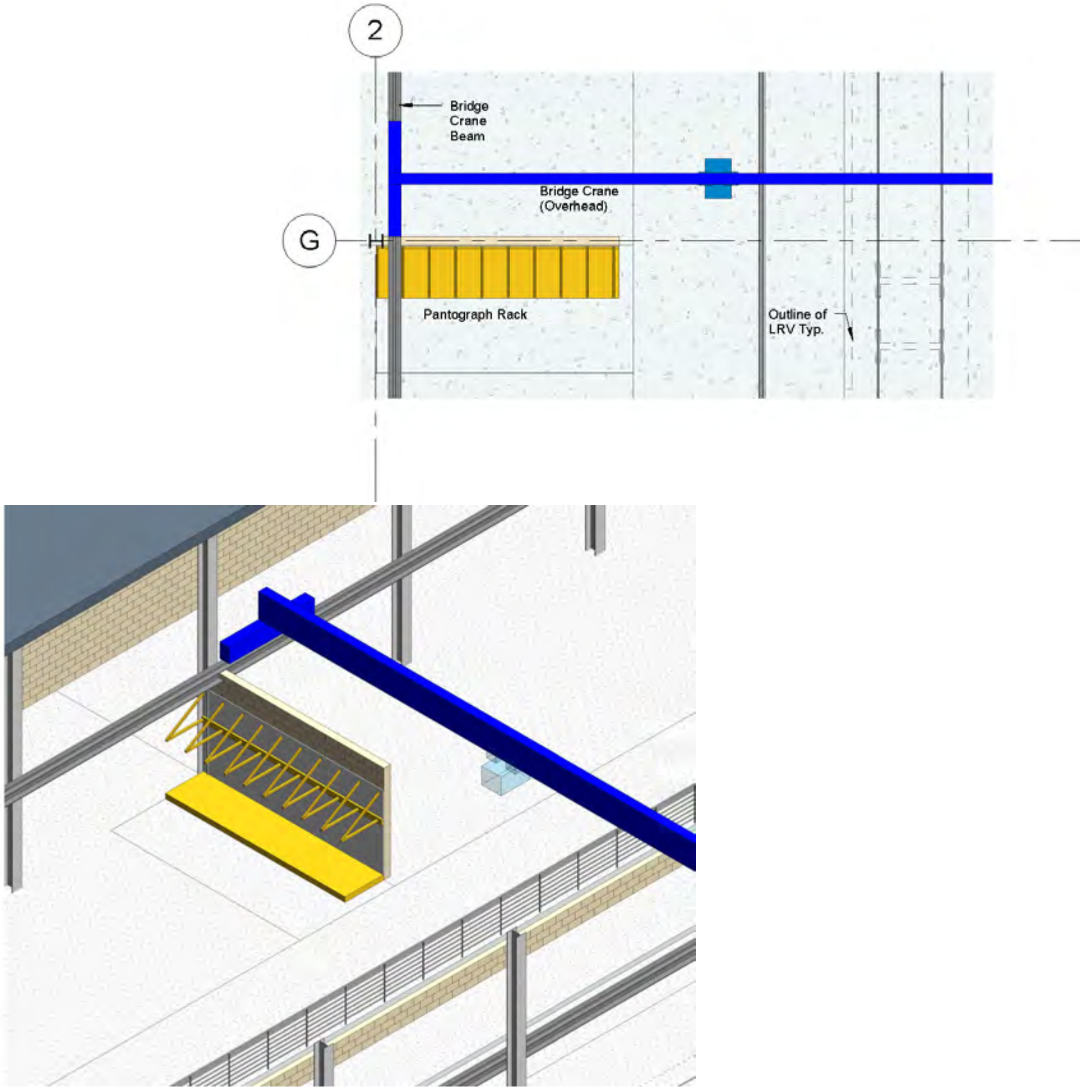
Design Features

- Exposed concrete floor, enamel painted masonry, painted exposed structure ceiling
- Plumbing
  - ♦ Floor drain
  - ♦ As required by equipment
- Electrical
  - ♦ Outlets mounted at 3'-6" AFF
  - ♦ Route conduit from above
  - ♦ General purpose duplex receptacles, 120 VAC, 20 A, GFI protected, on walls
  - ♦ As required by equipment, receptacles/disconnects on walls

Sustainable Design Criteria

- Utilize natural lighting strategies
- Provide user-adjustable comfort and lighting controls
- Lighting Design to meet targeted LEED points
- Radiant in-floor heating

PANTOGRAPH STORAGE



FUNCTIONAL CHARACTERISTICS

Function: Dedicated area for storing LRV pantographs

Relationship to Other Areas

- Access to Component Change Out (CCO) Bays
- Accessible from all repair and shop areas

Critical Dimensions

- 12'-0" vertical clearance

Equipment/Furnishings

- Wall mounted storage rack

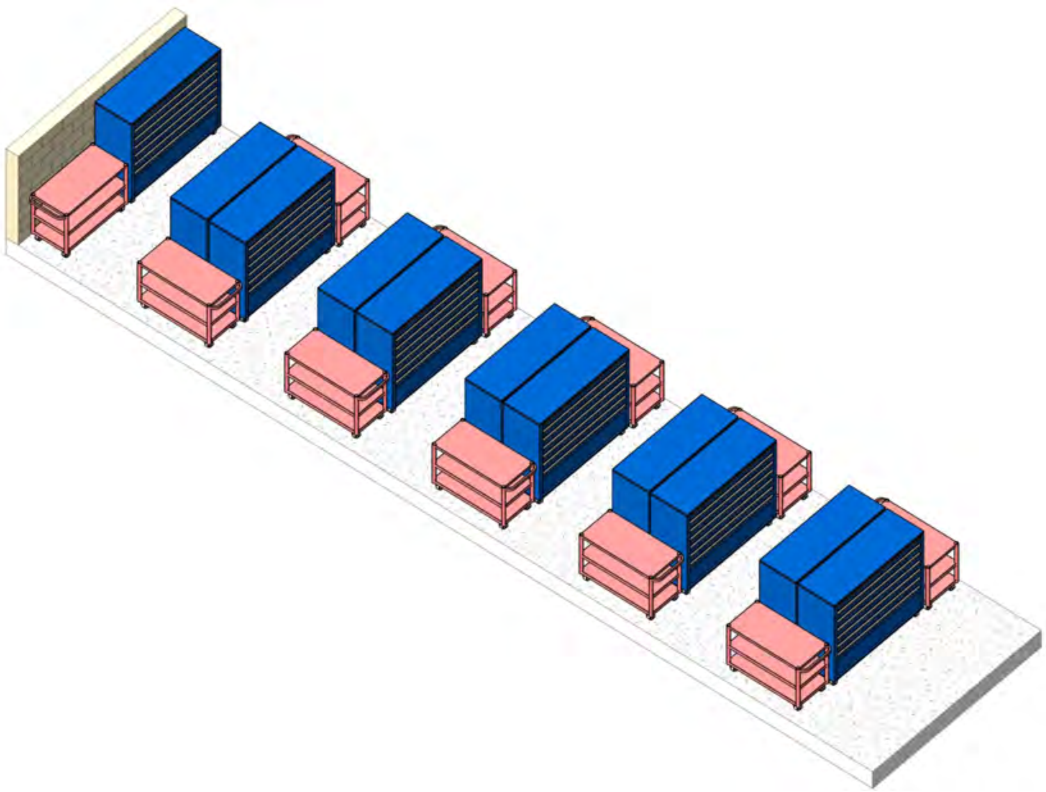
Design Features

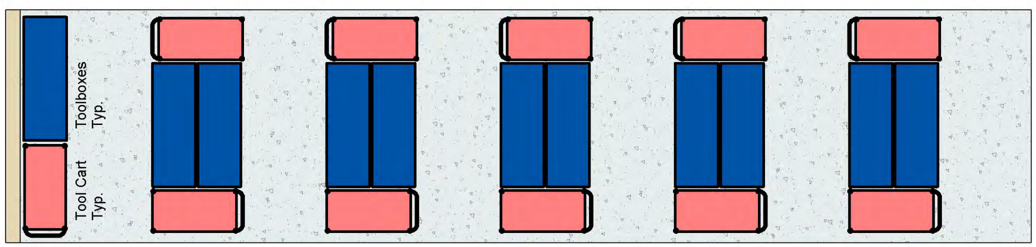
- Exposed concrete floor, enamel painted masonry, painted exposed structure ceiling
- Electrical
  - ♦ Mounted at 3'-6" AFF
  - ♦ Route conduit from above
  - ♦ General purpose duplex receptacles, 120 VAC, 20 A, GFI protected, on walls
- Access to the bridge crane
- CMU wall to mount and support storage rack
- Fluorescent lighting, 30 fc average

Sustainable Design Criteria

- Utilize natural lighting strategies
- Provide user-adjustable comfort and lighting controls
- Lighting design to meet targeted LEED points

TOOL BOX STORAGE





FUNCTIONAL CHARACTERISTICS

Function: Dedicated area for the storage of each Mechanic's personal tool boxes

Relationship to Other Areas

- Access to Component Change Out (CCO) Bays
- Accessible from all repair and shop areas
- Access to all shop areas

Critical Dimensions

- 12'-0" vertical clearance

Equipment/Furnishings

- Mechanic furnished tool box
- Mobile cart

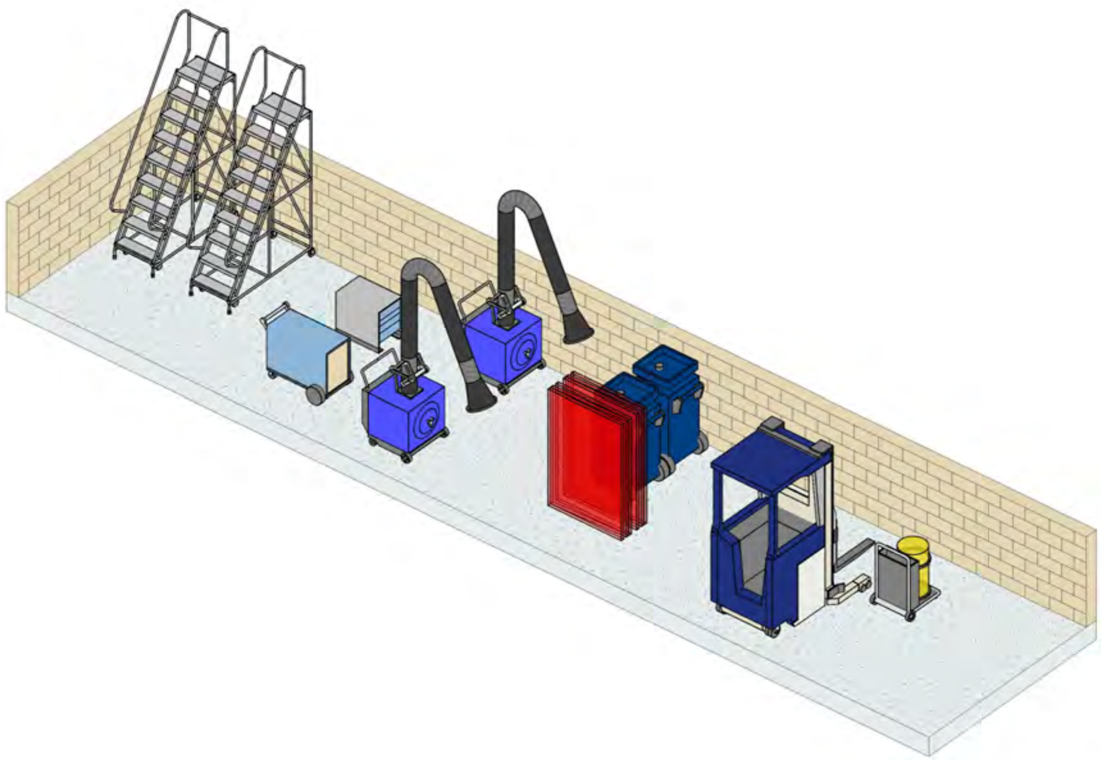
Design Features

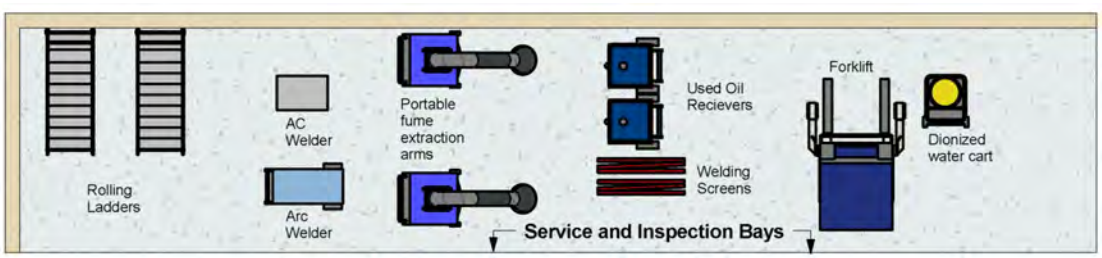
- Exposed concrete floor, enamel painted masonry, painted exposed structure ceiling
- Electrical
  - ♦ Mounted at 3'-6" AFF
  - ♦ Route conduit from above
  - ♦ General purpose duplex receptacles, 120 VAC, 20 A, GFI protected, on walls
  - ♦ Fluorescent lighting, 30 fc average
- Limited-height 54" walls

Sustainable Design Criteria

- Utilize natural lighting strategies
- Provide user-adjustable comfort and lighting controls
- Lighting Design to meet targeted LEED points
- In-floor radiant heat

PORTABLE EQUIPMENT STORAGE





FUNCTIONAL CHARACTERISTICS

Function: A dedicated area for storage of portable shop equipment.

Relationship to Other Areas

- Access to Component Change Out (CCO) Bays
- Adjacent to Service and Inspection (S&I) Bays
- Access to all shop areas

Critical Dimensions

- 12’-0” vertical clearance

Equipment/Furnishings

- Portable equipment including but no limited to: Ladders, diagnostic equipment , used fluid drain pans, battery chargers, work platforms, welders, portable fume extraction, portable welding screens, portable water de-ionization cart

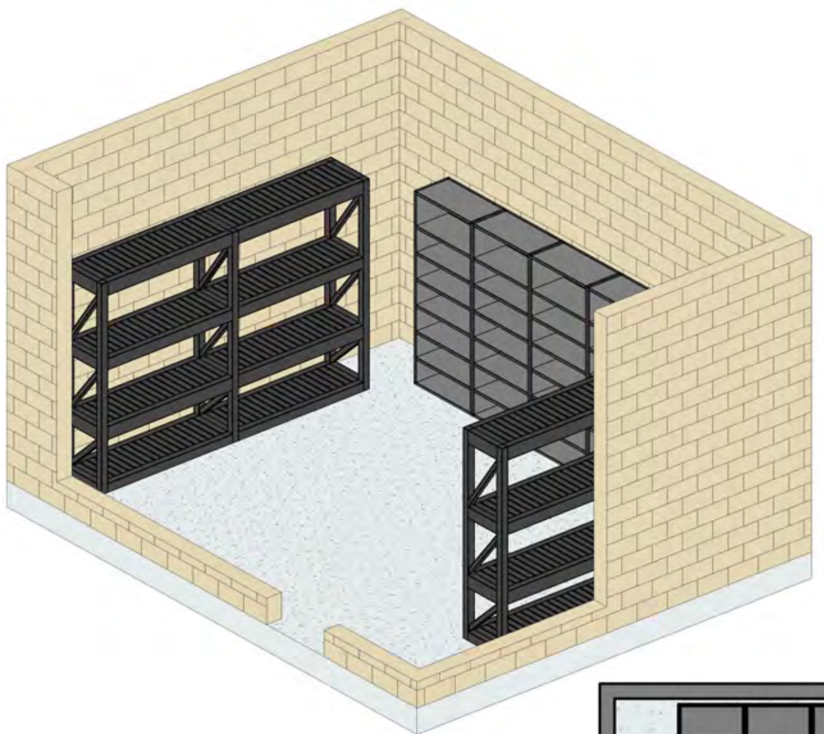
Design Features

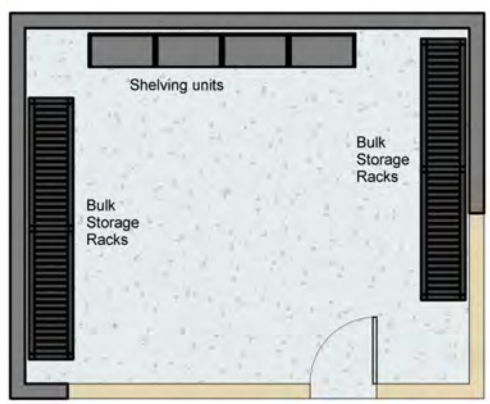
- Exposed concrete floor, enamel painted masonry, painted exposed structure ceiling
- Electrical
  - ♦ Outlets mounted at 3’-6” AFF
  - ♦ Route conduit from above
  - ♦ General purpose duplex receptacles, 120 VAC, 20 A, GFI protected, on walls
- Fluorescent lighting, 30 fc average
- Limited-height 54” walls

Sustainable Design Criteria

- Utilize natural lighting strategies
- Provide user-adjustable comfort and lighting controls
- Lighting design to meet targeted LEED points
- In-floor radiant heat

CLEANING SUPPLY STORAGE





FUNCTIONAL CHARACTERISTICS

Function: Enclosed area for interior cleaning supplies, carts, and equipment.

Relationship to Other Areas

- Adjacent to Service and Clean Bay

Critical Dimensions

- 12'-0" vertical clearance

Equipment/Furnishings

- Metal shelving and racks

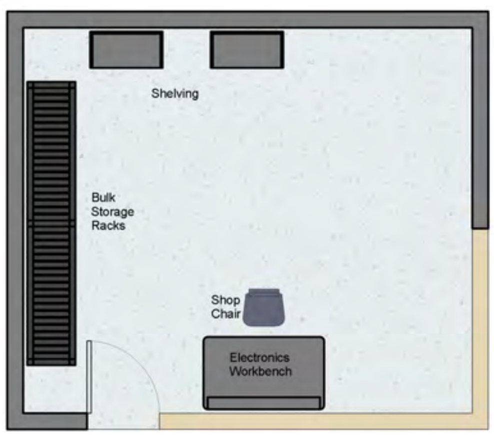
Design Features

- Floor: Exposed concrete slab
- Walls: Soil and grease resistant
- Ceiling: Painted exposed structure
- Secure area
- Electrical:
  - ♦ Fluorescent lighting, 30 fc average
  - ♦ General purpose duplex receptacles, 120 VAC, 20 A, GFI protected as required by Electrical Code and required for charging equipment
  - ♦ Mount outlet(s) at 3'-6" AFF

Sustainable Design Criteria

- Lighting design to meet targeted LEED points
- Lighting controls: Occupancy sensors

AUTOMATED FARE COLLECTION (AFC) SHOP / STORAGE



FUNCTIONAL CHARACTERISTICS

Function: Secure room for fare collection system network, storage, supplies, and minor repair work.

Relationship to Other Areas

- Access to Restrooms

Critical Dimensions

- 9'-0" vertical clearance

Equipment/Furnishings

- Steel shelving and racks

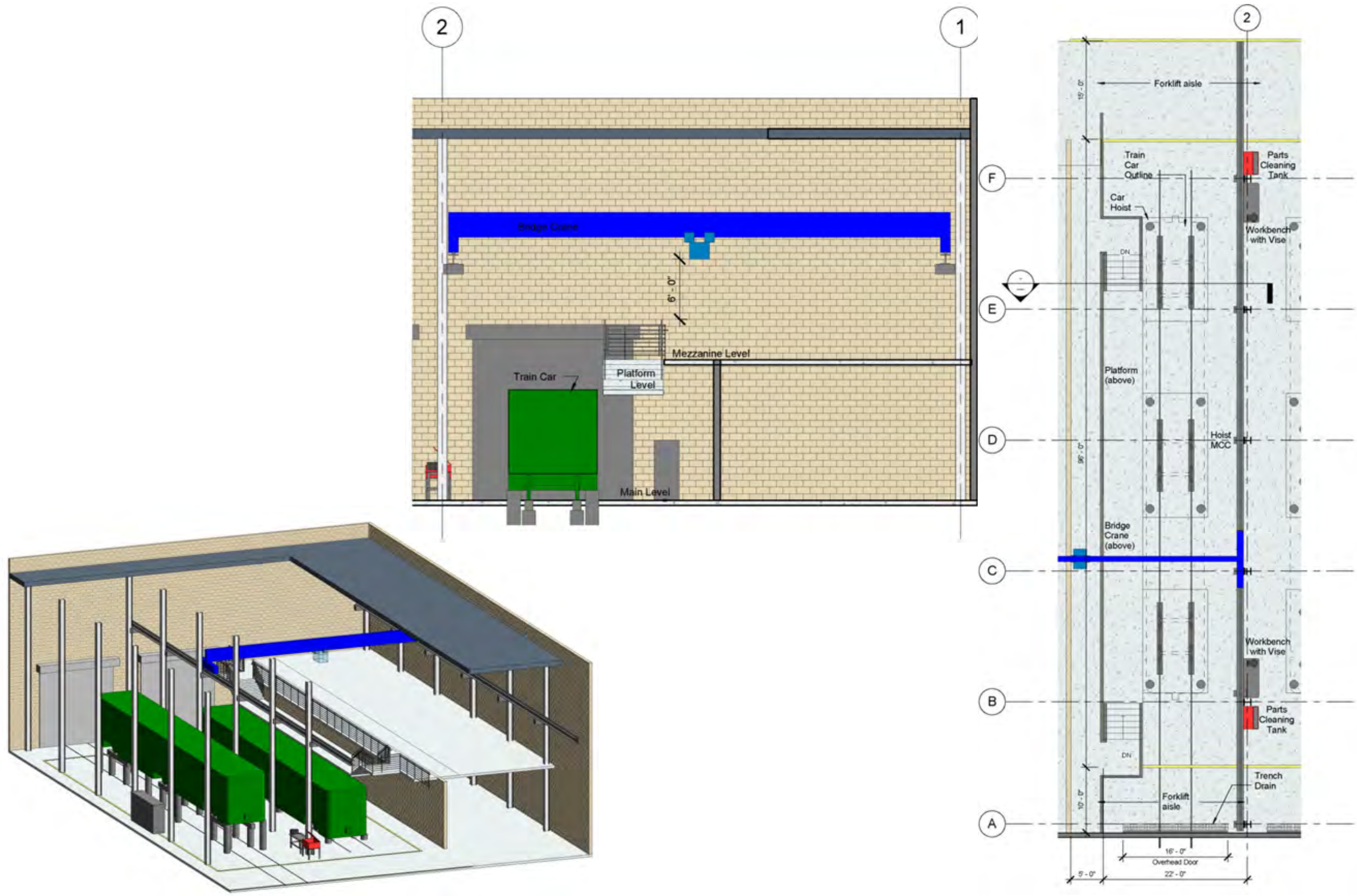
Design Features

- Exposed concrete floor
- Enamel painted masonry
- Painted exposed structure ceiling
- Electrical
  - ♦ Fluorescent lighting, 30 fc average
  - ♦ General purpose duplex receptacles, 120 VAC, 20 A as required by code
  - ♦ As required by equipment
- Secured entry

Sustainable Design Criteria

- Lighting designed to meet targeted LEED points
- Lighting controls: Occupancy sensors

COMPONENT CHANGE OUT (CCO) BAY



COMPONENT CHANGE OUT (CCO) BAY

FUNCTIONAL CHARACTERISTICS

Function: A repair bay for component change out of trucks, pantographs, and HVAC units. Other uses include emergency heavy repair of LRVs.

Relationship to Other Areas

- Adjacent to Common Work Area and Portable Equipment Storage
- Access to Part Room and Manuals Library
- Accessible from Maintenance Offices

Critical Dimensions

- 24'-0" vertical clearance to hook of bridge crane above
- 22'-0" wide by 95'-0" long

Equipment/Furnishings

- Severe use workbench with vise (1 per bay)
- Parts Cleaning Tank (1 per bay)
- Bridge crane(s)
- Car hoist with body supports
- Mobile scaffolding (1 set total)

Design Features

- One car position per bay
- Allows forklift access to all sides of LRV

Sustainable Design Criteria

- Utilize natural lighting strategies
- Provide user-adjustable comfort and lighting controls
- Lighting Design to meet targeted LEED points
- In-floor radiant heat

TECHNICAL CONSIDERATIONS

Architectural

- Finishes
  - ♦ Floor: Soil, grease, water, slip resistant concrete with integral non-metallic light reflective hardener, and chemical bonded concrete sealer
  - ♦ Walls: Soil and grease resistant, light colored finish
  - ♦ Ceiling: Painted exposed structure, light colored finish
- Doors
  - ♦ Personnel door with view panel to meet applicable code exit requirements.
  - ♦ Exterior overhead doors: high speed roll up, 16' x 16', automatic operator, interior and exterior push button controls with lockout on exterior. Sensors on exterior and interior for automatic roll up and roll down
- CCO Bay adjacent to platform: Provide platform mounted off column on opposite side of Bay

Structural

- Control joints in floor slab at adequate spacing
- Structure as needed to support equipment
- Structure for bridge crane

Mechanical

- As required by equipment
- Destratification fans
- In-floor radiant heat

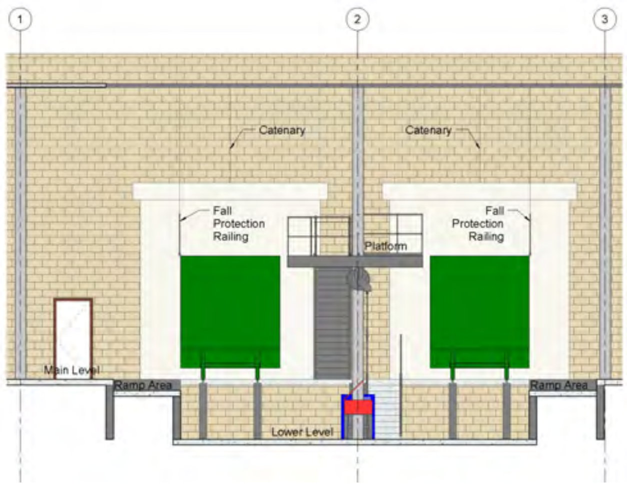
Plumbing

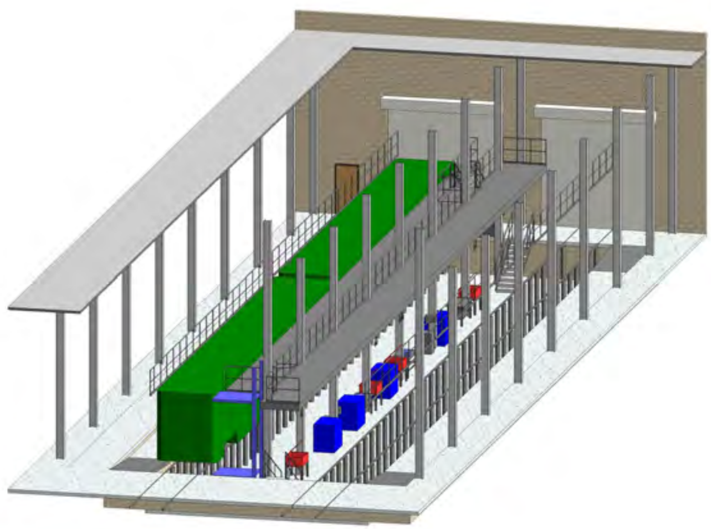
- Trench drains
  - ♦ Run to sediment and oil interceptor
  - ♦ At overhead door with removable covers
- 3/4" water hose bib with standard faucet on main and LLWA level, 2'-0" AFF (1 per bay)
- Compressed air
  - ♦ Main line looped
  - ♦ Compressed air drops, cut off valve, union, separator, regulator with gauge and quick disconnect, 4'-0" AFF
  - ♦ Provide disconnect for 1/2" and 1" impact tools

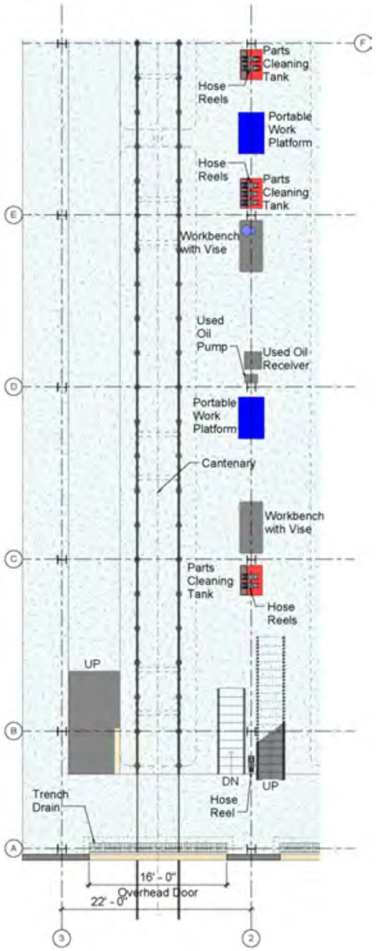
Electrical

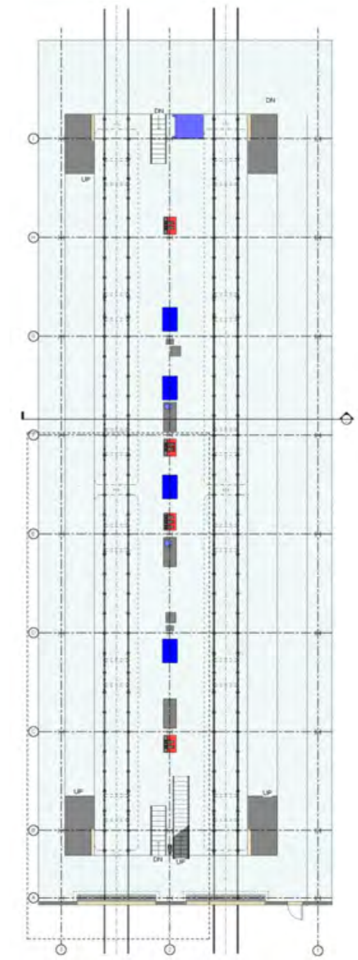
- Lighting
  - ♦ Fluorescent lighting, 50 fc average, fixtures located to illuminate work spaces and around LRV's.
- Power
  - ♦ All receptacles and outlets at 3'-6" AFF
  - ♦ General-purpose duplex receptacles, 120 VAC, 20A, GFI protected, on walls, columns, and bet. OH doors
  - ♦ Welding outlets, centrally located, 208 VAC, 1 phase, 50 A and 480 VAC, 3 phase, 30 A (shared 1 per 2 bays)
  - ♦ Dedicated computer receptacle, 120 VAC, 20 A adjacent to computer conduit
  - ♦ As required by equipment
- Communications
  - ♦ Paging/intercom system speakers
  - ♦ Computer conduit for data line (1 per bay)
- No catenary

SERVICE AND INSPECTION POSITION BAY WITH LOWER LEVEL WORK AREA (LLWA) AND PLATFORM









SERVICE AND INSPECTION POSITION BAY WITH LOWER LEVEL WORK AREA (LLWA) AND PLATFORM

FUNCTIONAL CHARACTERISTICS

Function: Designated bay for performing inspections on LRV's. The interior and exterior of the vehicle will be inspected and critical operating, control, safety, and communications systems checked for proper functioning.

Relationship to Other Areas

- Adjacent to Common Work Area and Portable Equipment Storage
- Access to Part Room and Manuals Library
- Accessible from Maintenance offices

Critical Dimensions

- 20'-0" vertical clearance to structure
- 22'-0" wide by 150'-0" long (for two cars)

Equipment/Furnishings

- Parts lift access to platform and LLWA levels
- Lube reel banks with (CG, GO, HO, and WWF) shared (1 per 2 bays)
- Severe use workbench with vise (2 per bay)

Design Features

- LLWA open full width of bay between the cars
- Ramp down 15" below main floor level on outside of cars
- Stairs from LLWA to finish floor and up to mezzanine
- LLWA depth: 66 inches, under LRV's tracks and between S&I bays
- Used oil extraction pump, rolling drain pan
- Mobile work platform
- Parts cleaning tank
- Platform: Railing with gate top of stairs and parts lift

Sustainable Design Criteria

- Utilize natural lighting strategies
- Provide user-adjustable comfort and lighting controls
- Lighting design to meet targeted LEED points
- In-floor radiant heat

TECHNICAL CONSIDERATIONS

Architectural

- Finishes
  - ♦ Floor: Soil, grease, water, slip resistant concrete with integral non-metallic light reflective hardener, and chemical bonded concrete sealer
  - ♦ Walls: Soil and grease resistant, light colored finish
  - ♦ Ceiling: Painted exposed structure, light colored finish
- Doors
  - ♦ Personnel door with view panel to meet applicable code exit requirements
  - ♦ Exterior overhead doors: high speed roll up, 16'-0" x 16'-0" , automatic operator, interior and exterior push button controls with lockout on exterior; Sensors on exterior and interior for automatic roll up and roll down
- Platform: Railing at center of platform and fall protection railing on opposite side of car

Structural

- Control joints in floor slab at adequate spacing
- Structure as needed to support equipment
- Structure to support elevated tracks over LLWA and testing LRV propulsion systems
- LLWA 66" deep under LRV's tracks and between S&I bays
- Structure to support platform

Mechanical

- As required by equipment
- Destratification fans
- In-floor radiant heat for main level and LLWA floor slabs

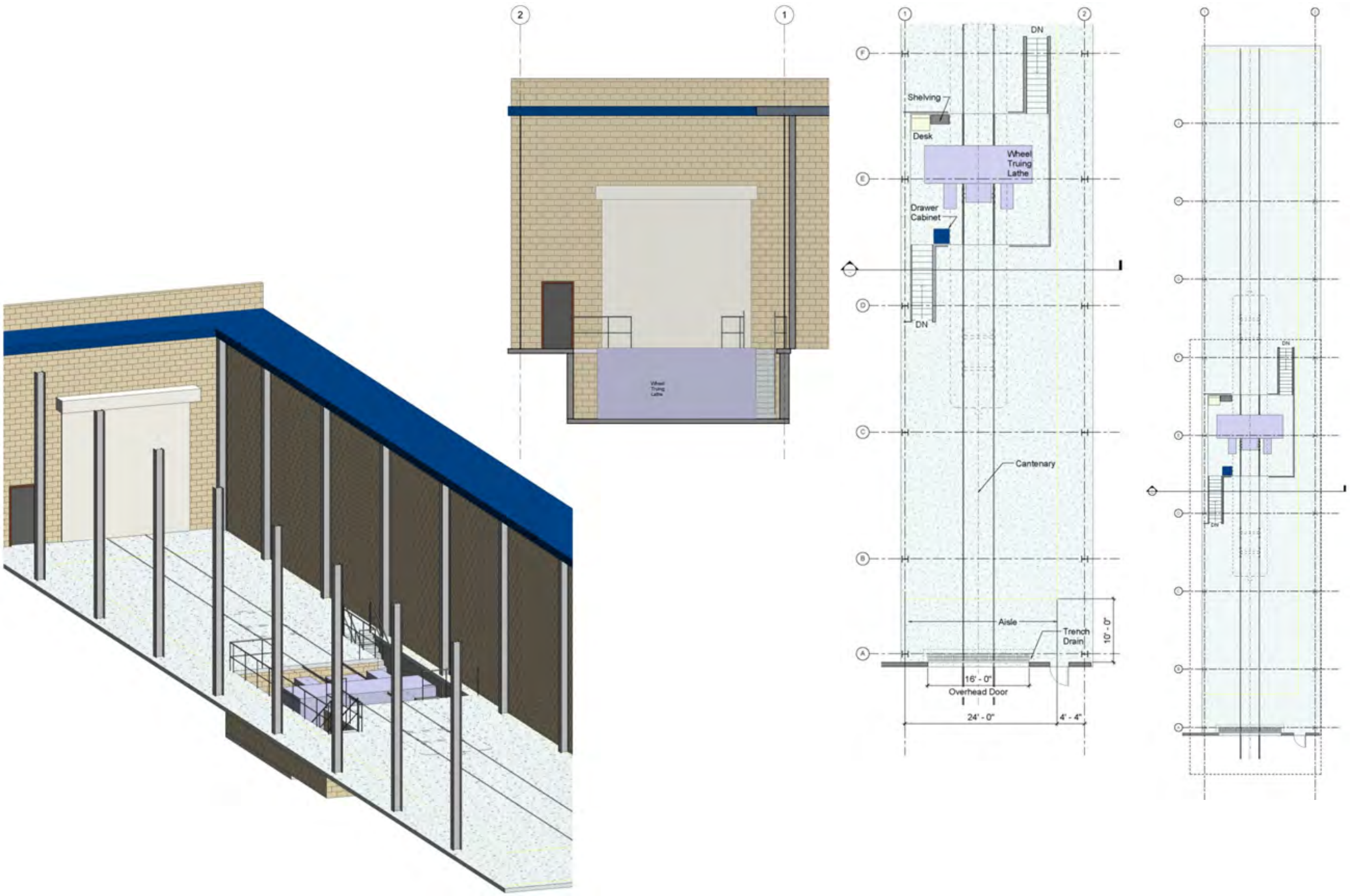
Plumbing

- Trench drains
  - ♦ Run to sediment and oil interceptor
  - ♦ At overhead door with removable covers
  - ♦ At drip lines of the LRV in LLWA. Slope floor between rails to trench drains only. Space between LRV's in LLWA to remain flat/level
- 3/4" water hose bib with standard faucet on main and LLWA level, 2'-0" AFF (1 per bay)
- Lube reel banks with CG, GO, HO and WWF (shared per 2 bays)
- Compressed air
  - ♦ Main line looped
  - ♦ Compressed air drops; cut off valve, union, separator, regulator with gauge and quick disconnect, 4'-0" AFF
  - ♦ Provide disconnect for 1/2" and 1" impact tools

Electrical

- Lighting
  - ♦ Fluorescent lighting, 50 fc average, fixtures located to illuminate work spaces and around LRV's
- Power
  - ♦ 3'-6" AFF
  - ♦ General-purpose duplex receptacles, 120 VAC, 20 A, GFI protected, on walls, columns, and bet. OH doors
  - ♦ Welding outlets, centrally located, 208 VAC, 1 phase, 50 A (shared 1 per 2 bays)
  - ♦ Dedicated computer receptacle, 120 VAC, 20 A adj. to computer conduit
  - ♦ As required by equipment
  - ♦ Bug plug: Outlet for lighting and basic power for LRV (1 per 2 LRV positions)
- Communications
  - ♦ Paging/intercom system speakers
  - ♦ Computer conduit, main level (1 per bay)
- Catenary: Above bays with lockout for accessories working from the platform level
- Lighting system: 2 lights (1 as backup) to verify when catenary is energized and not energized

WHEEL TRUING LATHE BAY



WHEEL TRUING LATHE BAY

FUNCTIONAL CHARACTERISTICS

Function: A bay dedicated to truing wheels on vehicles without removing truck assembly.

Relationship to Other Areas

- Access to Parts Room and Manuals Library
- Accessible from Maintenance offices

Critical Dimensions

- 20'-0" vertical clearance
- 24'-0" wide by 150'-0" long

Equipment/Furnishings

- Severe use workbench with vise (2 per bay)
- Desk with stool, drawer storage unit, and shelving unit in pit area
- Wheel truing lathe and associated equipment

Design Features

- Stairs down to pit level
- Pit level designed with area for maintenance tools and supplies
- Length of the bay is determined by ability to run all wheels of LRV on wheel truing machine without blocking critical functions and the LRV will be inside the building at all times during the process

Sustainable Design Criteria

- Utilize natural lighting strategies
- Provide user-adjustable comfort and lighting controls
- Lighting design to meet targeted LEED points
- In-floor radiant heat

TECHNICAL CONSIDERATIONS

Architectural

- Finishes
  - ♦ Floor: Soil, grease, water, slip resistant concrete with integral non-metallic light reflective hardener, and chemical bonded concrete sealer
  - ♦ Walls: Soil and grease resistant, light colored finish
  - ♦ Ceiling: Painted exposed structure, light colored finish
- Doors
  - ♦ Personnel door with view panel to meet applicable code exit requirements
  - ♦ Exterior overhead doors: High speed roll up, 16'-0" x 16'-0", automatic operator, interior and exterior push button controls with lockout on exterior; Sensors on exterior and interior for automatic roll up and roll down

Structural

- Floor slab designed to accommodate in-floor radiant heat
- Structure as needed to support equipment
- Pit design customized for wheel truing machine

Mechanical

- As required by equipment
- De-stratification fans
- Raised access floor
- In-floor radiant heat

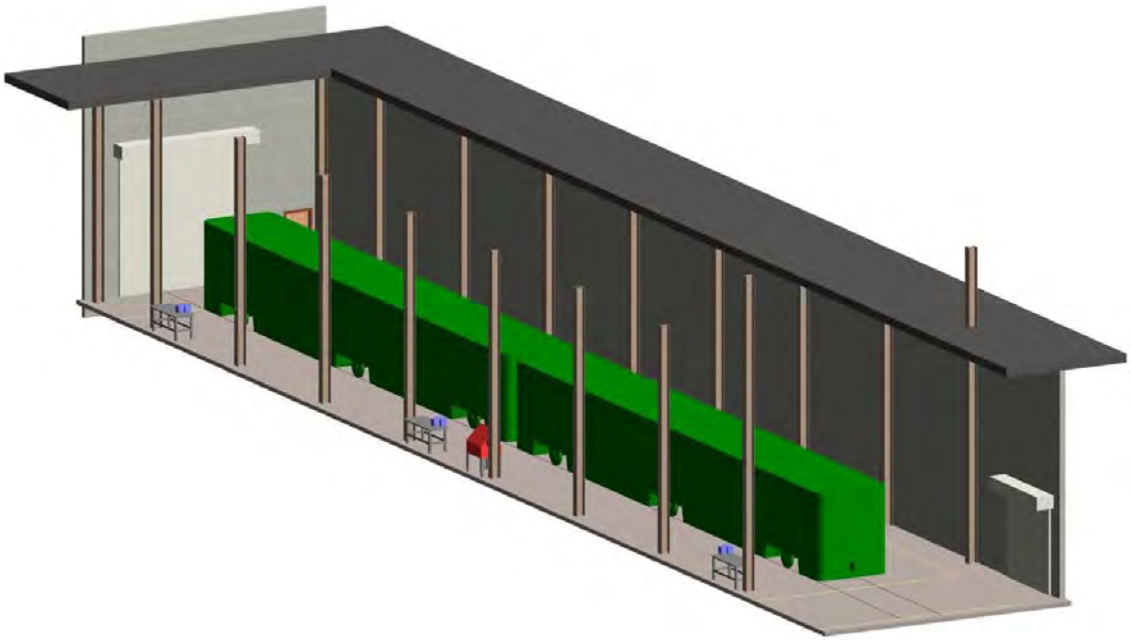
Plumbing

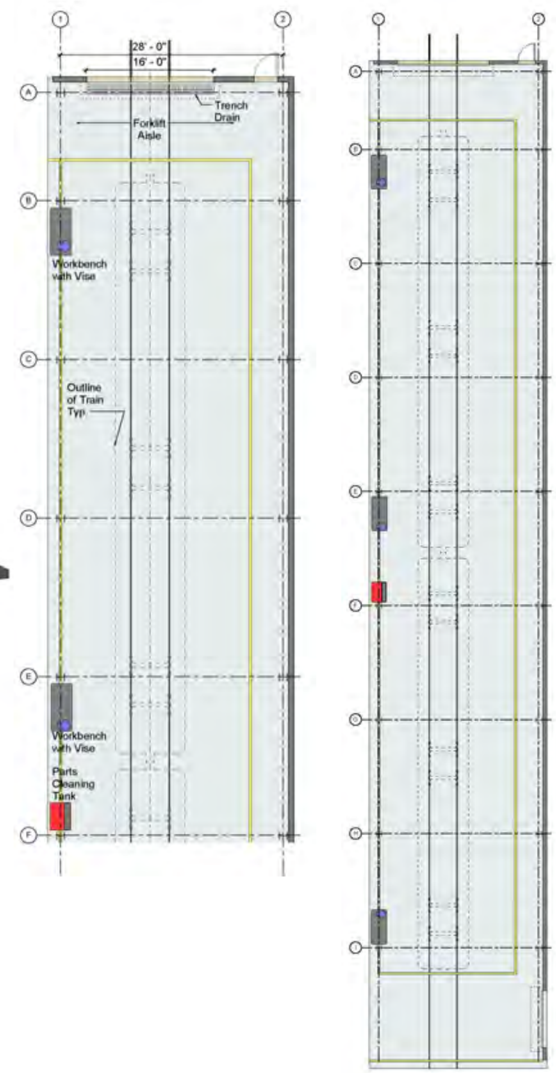
- Trench drains
  - ♦ Run to sediment and oil interceptor
  - ♦ At overhead door with removable covers
- 3/4" water hose bib with standard faucet 2'-0" AFF (1 per bay)
- Lube reel banks with CG, GO, HO and WWF (shared) Compressed air
  - ♦ Main line looped
  - ♦ Compressed air drops, cut off valve, union, separator, regulator with gauge and quick disconnect, 4'-0" AFF
  - ♦ Provide disconnect for 1/2" and 1" impact tools

Electrical

- Lighting
  - ♦ Fluorescent lighting, 50 fc average, fixtures located to illuminate work spaces and around LRV's.
- Power
  - ♦ All receptacles and outlets at 3'-6" AFF
  - ♦ General-purpose duplex receptacles, 120 VAC, 20 A, GFI protected, on walls, columns, and bet. OH doors
  - ♦ Welding outlets, centrally located, 208 VAC, 1 phase, 50 A and 480 VAC, 3 phase, 30 A (shared 1 per 2 bays)
  - ♦ Dedicated computer receptacle, 120 VAC, 20 A adjacent to computer conduit
  - ♦ As required by equipment
- Communications
  - ♦ Paging/intercom system speakers
  - ♦ Computer conduit for data (1 per bay)
- Catenary: Above bay

FLAT FLOOR BAY





FLAT FLOOR BAY

FUNCTIONAL CHARACTERISTICS

Function: Designated bay for performing inspections on LRV's. The interior and exterior of the vehicle will be inspected and critical operating, control, safety and communications systems checked for proper functioning.

Relationship to Other Areas

- Adjacent to Common Work Area and Portable Equipment Storage
- Access to Part Room and Manuals Library
- Accessible from Maintenance offices

Critical Dimensions

- 20'-0" vertical clearance to structure
- 22'-0" wide by 150'-0" (for two cars)

Equipment/Furnishings

- Severe use workbench with vise (1.5 per bay, shared)
- Parts Cleaning Tank
- Lube reel banks with (CG, GO, HO, and WWF) shared (1 per 2 bays)

Design Features

- Flat floor

Sustainable Design Criteria

- Utilize natural lighting strategies
- Provide user-adjustable comfort and lighting controls
- Lighting design to meet targeted LEED points
- In-floor radiant heat

TECHNICAL CONSIDERATIONS

Architectural

- Finishes
  - ♦ Floor: Soil, grease, water, slip resistant concrete with integral non-metallic light reflective hardener, and chemical bonded concrete sealer
  - ♦ Walls: Soil and grease resistant, light colored finish
  - ♦ Ceiling: Painted exposed structure, light colored finish
- Doors
  - ♦ Personnel door with view panel to meet applicable code exit requirements
  - ♦ Exterior overhead doors: High speed roll up, 16'-0" x 16'-0" feet, automatic operator, interior and exterior push button controls with lockout on exterior. Sensors on exterior and interior for automatic roll up and roll down

Structural

- Control joints in floor slab at adequate spacing
- Structure as needed to support equipment

Mechanical

- As required by equipment
- Destratification fans
- In-floor radiant heat

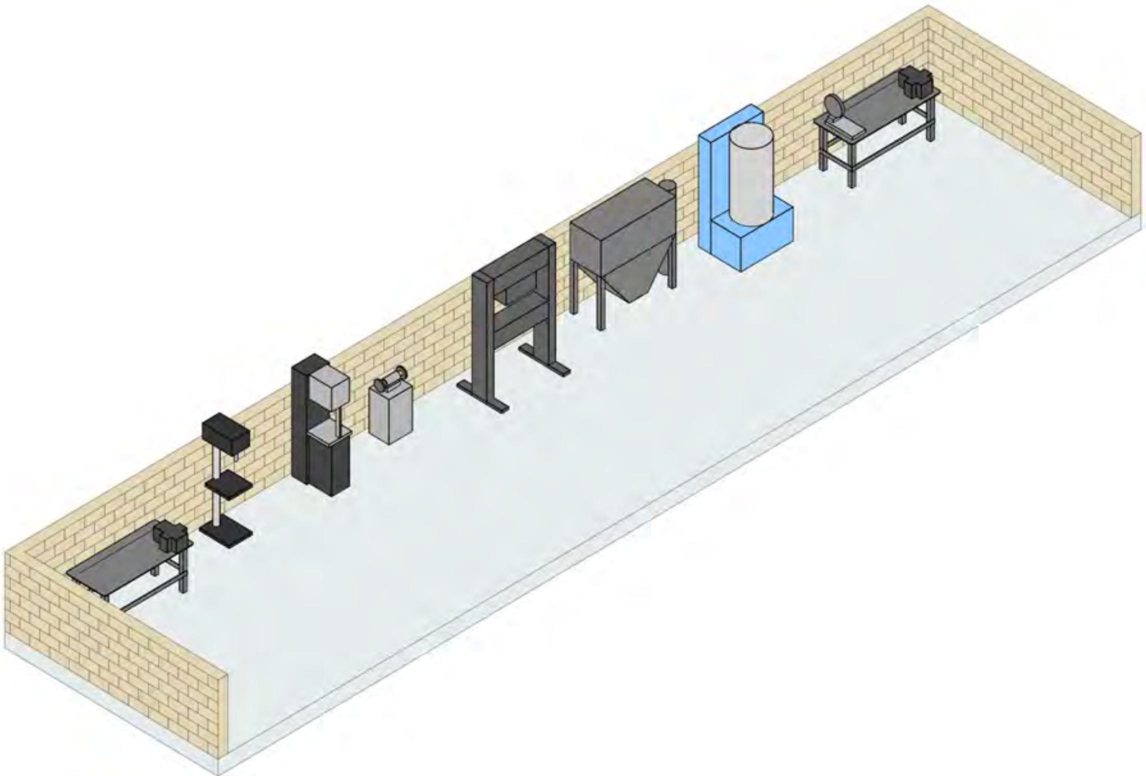
Plumbing

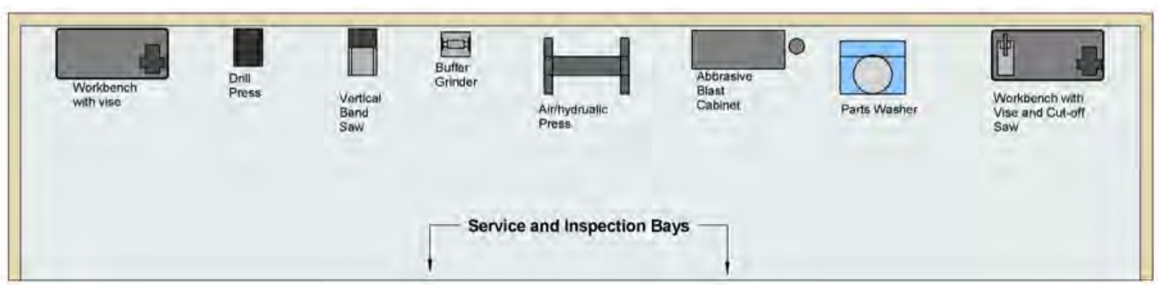
- Trench drains
- Run to sediment and oil interceptor
- At overhead door with removable covers
- 3/4" water hose bib with standard faucet on main and LLWA level, 2'-0" AFF (1 per bay)
- Lube reel banks with CG, GO, HO and WWF (shared per 2 bays)
- Compressed air
- Main line looped
- Compressed air drops, cut off valve, union, separator, regulator with gauge and quick disconnect, 4'-0" AFF
- Provide disconnect for 1/2" and 1" impact tools

Electrical

- Lighting
  - ♦ Fluorescent lighting, 50 fc average, fixtures located to illuminate work spaces and around LRV's.
- Power
  - ♦ 3'-6" AFF
  - ♦ General-purpose duplex receptacles, 120 VAC, 20 A, GFI protected, on walls, columns, and bet. OH doors.
  - ♦ Welding outlets, centrally located, 208 VAC, 1 phase, 50 A (shared 1 per 2 bays)
  - ♦ Dedicated computer receptacle, 120 VAC, 20 A adjacent to computer conduit
  - ♦ As required by equipment
- Communications
  - ♦ Paging/intercom system speakers
  - ♦ Computer conduit, main level (1 per bay)
- Catenary: Above bay
- Bug plug: Outlet for lighting and basic power for LRV (1 per 2 LRV positions)

COMMON WORK AREA





FUNCTIONAL CHARACTERISTICS

Function: Designated area for common fixed shop equipment which supports all repair bays and associated shop areas.

Relationship to Other Areas

- Adjacent to S&I Bays and CCO Bays
- Access to Parts Storeroom, Welding Shop/Storage, and Portable Equipment Storage
- Access from Maintenance office areas

Critical Dimensions

- 14'-0" vertical clearance to any obstruction

Equipment/Furnishings

- Severe use workbench(s) with vise and parts washer
- Buffer grinder with dust collector
- Hydraulic press
- Drill press
- Abrasive blast cabinet
- Horizontal band saw
- Cut-off saw

Design Features

- Limited-height 54 inch walls on three sides for utilities and to prevent blocking vision of shop from office areas
- Forklift access
- Open to LRV Repair Bays

Sustainable Design Criteria

- Natural lighting
- Natural ventilation
- In-floor radiant heat

TECHNICAL CONSIDERATIONS

Architectural

- Finishes
  - ♦ Floor: Soil, grease, water, slip resistant concrete with integral non-metallic, light reflective hardener, and chemical bonded sealer
  - ♦ Walls: Soil and grease resistant, light colored finish
  - ♦ Ceiling: Painted exposed structure, light colored finish
- Doors: None, alcove open to Repair Bays

Structural

- Control joints in floor slab at adequate spacing
- Structure as needed to support equipment

Mechanical

- Destratification fans
- In-floor radiant heat
- As required by equipment

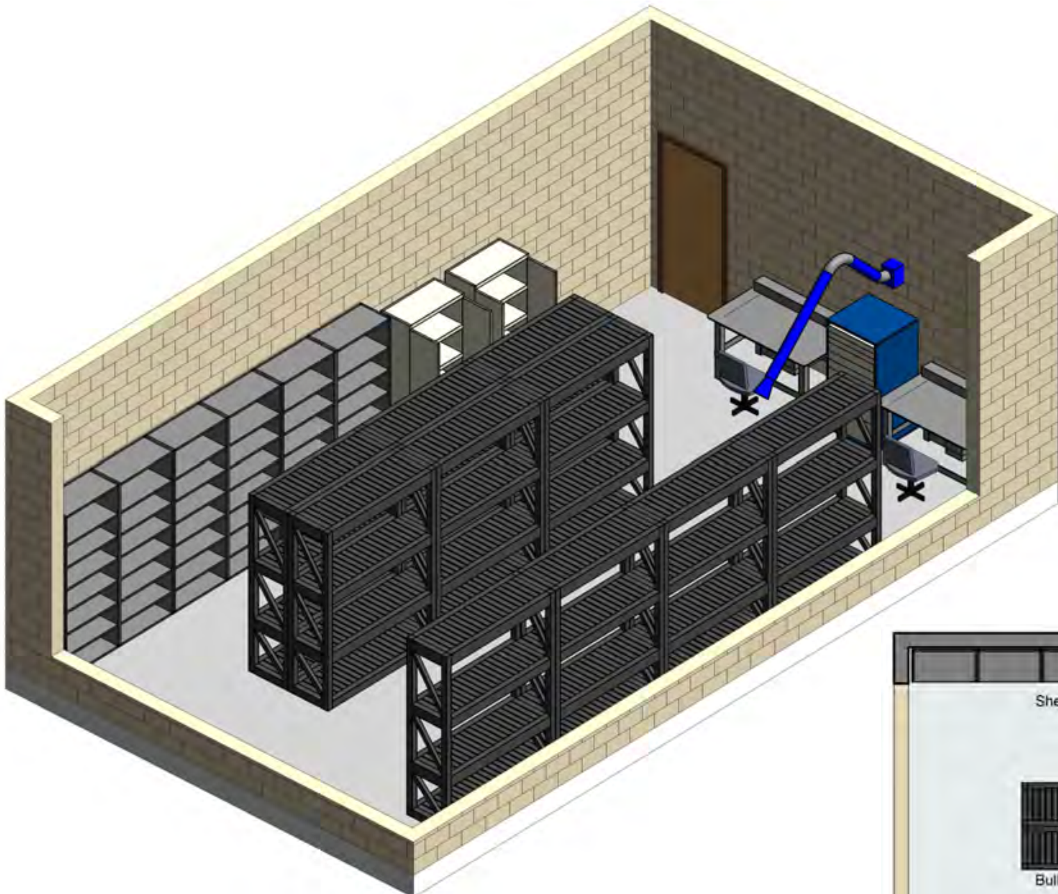
Plumbing

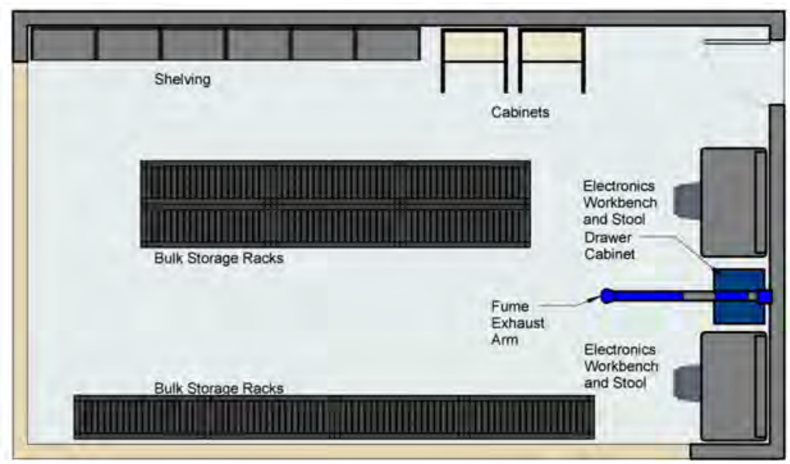
- Compressed air drop
  - ♦ Cut-off valve, union, filter, regulator with gauge, lubricator, and quick disconnect at 4'-0" AFF
  - ♦ Provide disconnects for 1/2" and 1" impact tools
- Water 3/4" water hose bib with standard hose bibb at 24" AFF
- As required by equipment

Electrical

- Lighting
  - ♦ Fluorescent lighting, 50 fc average, local switching, fixture located to illuminate work spaces
- Power
  - ♦ General-purpose duplex receptacles, 120 VAC, 20 A, GFI protected, on walls at 3'-6" AFF,
  - ♦ As required by equipment
- Communications
  - ♦ Paging/intercom system speakers

ELECTRONICS REPAIR SHOP AND STORAGE





ELECTRONICS REPAIR SHOP AND STORAGE

FUNCTIONAL CHARACTERISTICS

Function: Build, repair, and modify vehicle electronic and computer control systems. Install and maintain radio equipment, electrical signage, fare boxes and other electrical equipment for LRV's.

Relationship to Other Areas

- Access to all Restroom/Showers
- Access to Break/Crew Room
- Access to Storeroom
- Adjacent to Repair Bays

Critical Dimensions

- 10'-0" vertical clearance

Equipment/Furnishings

- Static dissipating workbench with shelf and task light
- Storage cabinets
- Drawer cabinets
- Layout table
- Desk
- Bulk storage racks
- Shelving
- Soldering equipment with fume extraction

Design Features

- Includes storage for manuals
- Secure entry
- Dustproof storage required for electrical components

Sustainable Design Criteria

- Utilize natural lighting strategies
- Provide user-adjustable comfort and lighting controls
- Lighting design to meet targeted LEED points
- Lighting controls: Occupancy Sensors

TECHNICAL CONSIDERATIONS

Architectural

- Finishes
  - ♦ Floor: Soil, grease, water, slip resistant concrete with integral non-metallic light reflective hardener, and chemical bonded concrete sealer
  - ♦ Walls: Soil and grease resistant, light colored finish
  - ♦ Ceiling: Painted exposed structure, light colored finish
- Doors
  - ♦ Personnel door with view panel to meet applicable code exit requirements
  - ♦ Secure 3'-0" door

Structural

- Control joints in floor slab at adequate spacing
- Structure as needed to support equipment

Mechanical

- As required by equipment
- Fume extraction arm
- In-floor radiant heat

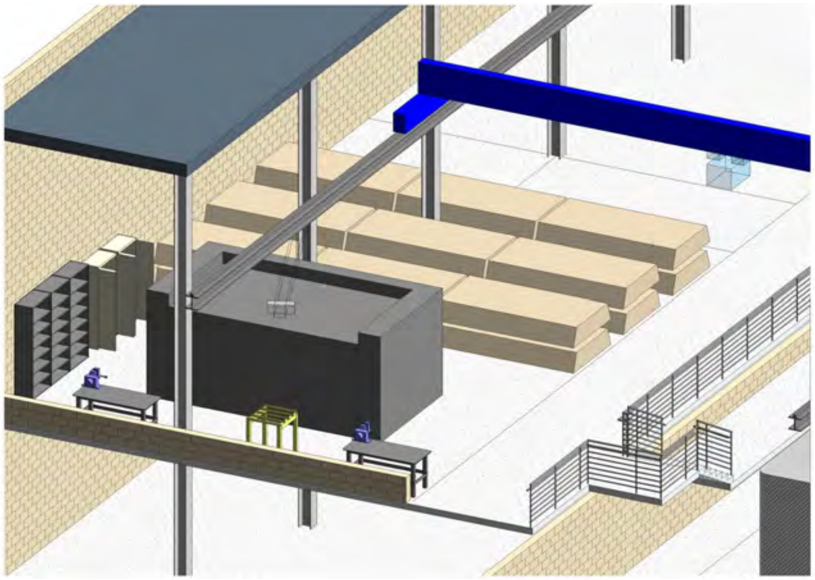
Plumbing

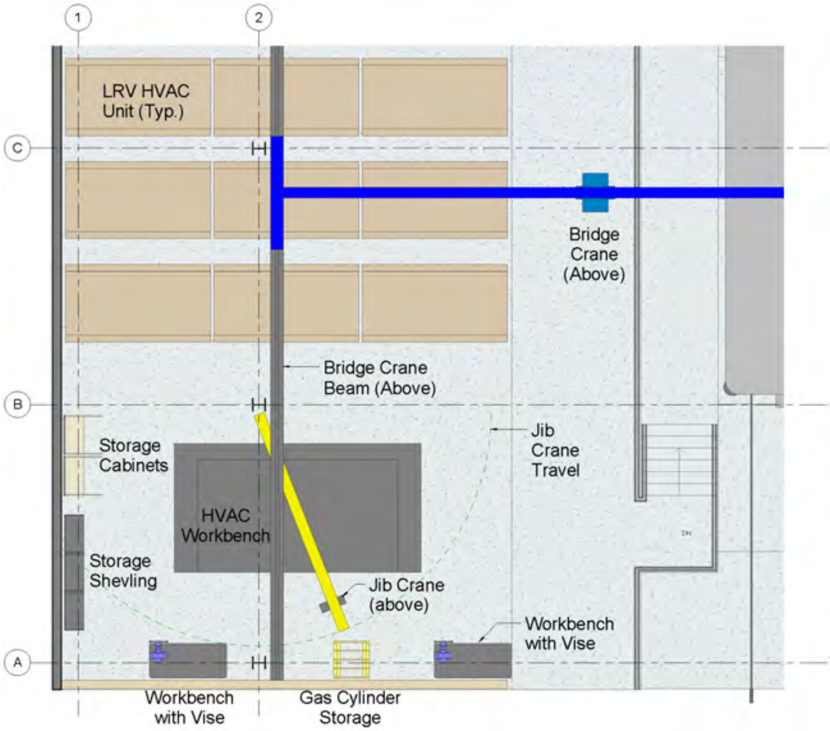
- Compressed air
  - ♦ Main line looped
  - ♦ Compressed air drops; cut off valve, union, separator, and regulator with gauge, 4'-0" AFF

Electrical

- Lighting
  - ♦ Fluorescent lighting, 50 fc average, local switching, fixture located to illuminate work spaces
- Power
  - ♦ All receptacles and outlets mounted at 3'-6" AFF
  - ♦ General-purpose duplex receptacles, 120 VAC, 20 A, GFI protected, on walls, columns, and bet. OH doors.
  - ♦ Dedicated computer receptacle, 120 VAC, 20 A adjacent to data conduit
  - ♦ As required by equipment
- Communications
  - ♦ Paging/intercom system speakers
  - ♦ Conduit for data line

HVAC SHOP AND STORAGE





HVAC SHOP AND STORAGE

FUNCTIONAL CHARACTERISTICS

Function: Storage and repair area for heating ventilating and air-conditioning (HVAC) units. Space will be used mainly for minor testing and repair.

Relationship to Other Areas

- Access to Component Change Out (CCO) Bays
- Access to Parts Storeroom
- Access from Maintenance Office areas

Critical Dimensions

- 12'-0" to any obstruction, bridge crane

Equipment/Furnishings

Shop

- Severe use workbench(s) with vise
- Jib crane with hoist
- HVAC workbench with lift
- Mobile gas cylinder rack, storage cabinets, and shelving units

Storage

- Access to bridge crane for lifting HVAC units onto mezzanine or in place on LRV

Design Features

- Bridge Crane access
- Locate on second floor mezzanine
- Includes manual storage
- HVAC units on rail vehicles may have compressor/ condenser unit split from evaporators, or consolidated into one assembly

Sustainable Design Criteria

- Natural lighting
- Natural ventilation
- In-floor radiant heat

TECHNICAL CONSIDERATIONS

Architectural

- Finishes
  - ♦ Floor: Soil, grease, water, slip resistant concrete with integral non-metallic, light reflective hardener, and chemical bonded sealer
  - ♦ Walls: Soil and grease resistant, light colored finish
  - ♦ Ceiling: Painted exposed structure, light colored finish
- Doors: None, open to maintenance bays and top of vehicle

Structural

- Control joints in floor slab at adequate spacing
- Shop: Structure as needed to support equipment including bridge crane, columned mounted jib crane and HVAC Lift
- Storage: Structure as need to support HVAC units

Mechanical

- General ventilation
- Destratification fans
- As required by equipment

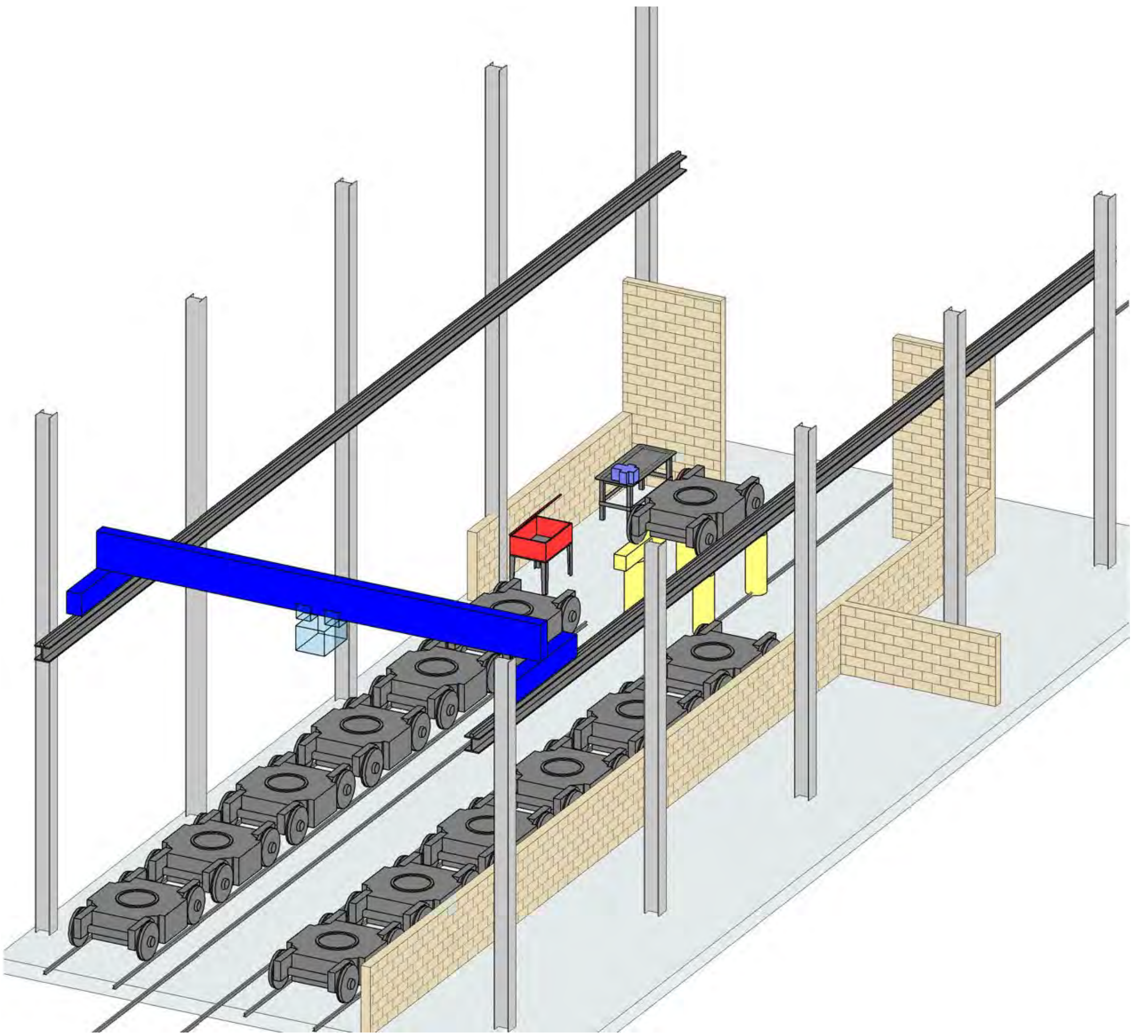
Plumbing

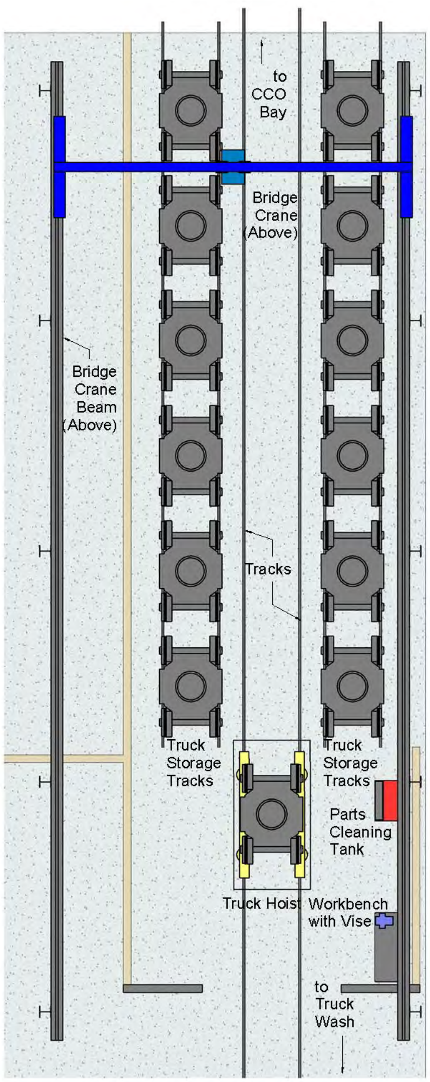
- Compressed air drop
  - ♦ Cut-off valve, union, filter, regulator with gauge, lubricator, and quick disconnect at 4'-0" AFF
  - ♦ Provide disconnects for 1/2" and 1" impact tools
- As required by equipment

Electrical

- Lighting
  - ♦ Fluorescent lighting, 50 fc average, local switching, fixture located to illuminate work spaces
- Power
  - ♦ General-purpose duplex receptacles, 120 VAC, 20 A, GFI protected, on walls at 3'-6" AFF
  - ♦ Dedicated computer receptacle, 120 VAC, 20 A adjacent to data conduit
  - ♦ As required by equipment
- Communications
  - ♦ Paging/intercom system speakers
  - ♦ Computer conduit

TRUCK SHOP AND STORAGE





TRUCK SHOP AND STORAGE

FUNCTIONAL CHARACTERISTICS

Function: Storage and repair area for LRV trucks. Minor repair only.

Relationship to Other Areas

- Access to Component Change Out Bays
- Access to Parts Storeroom and Manuals Library
- Access from Maintenance Office areas
- Adjacent to Truck Wash and Common Work Area
- Accessible form Maintenance office areas

Critical Dimensions

- 20'-0" vertical clearance to hook of the bridge crane above

Equipment/Furnishings

Shop

- Severe use workbench(s) with vise
- Bridge crane
- LRV truck hoist

Design Features

- Bridge crane access
- Forklift access
- Storage: Embedded rail for storage of LRV trucks
- Shop: Embedded rail from CCO Bays and Truck Wash to LRV truck hoist

Sustainable Design Criteria

- Natural lighting
- Natural ventilation
- In-floor radiant heat

TECHNICAL CONSIDERATIONS

Architectural

- Finishes
  - ♦ Floor: Soil, grease, water, slip resistant concrete with integral non-metallic, light reflective hardener, and chemical bonded sealer
  - ♦ Walls: Soil and grease resistant, light colored finish
  - ♦ Ceiling: Painted exposed structure, light colored finish
- Doors: None; open to maintenance bays and top of vehicle

Structural

- Control joints in floor slab at adequate spacing
- Embedded rail
- Shop: Structure as needed to support equipment including bridge crane and LRV truck hoist

Mechanical

- Destratification fans.
- In-floor radiant heat
- As required by equipment

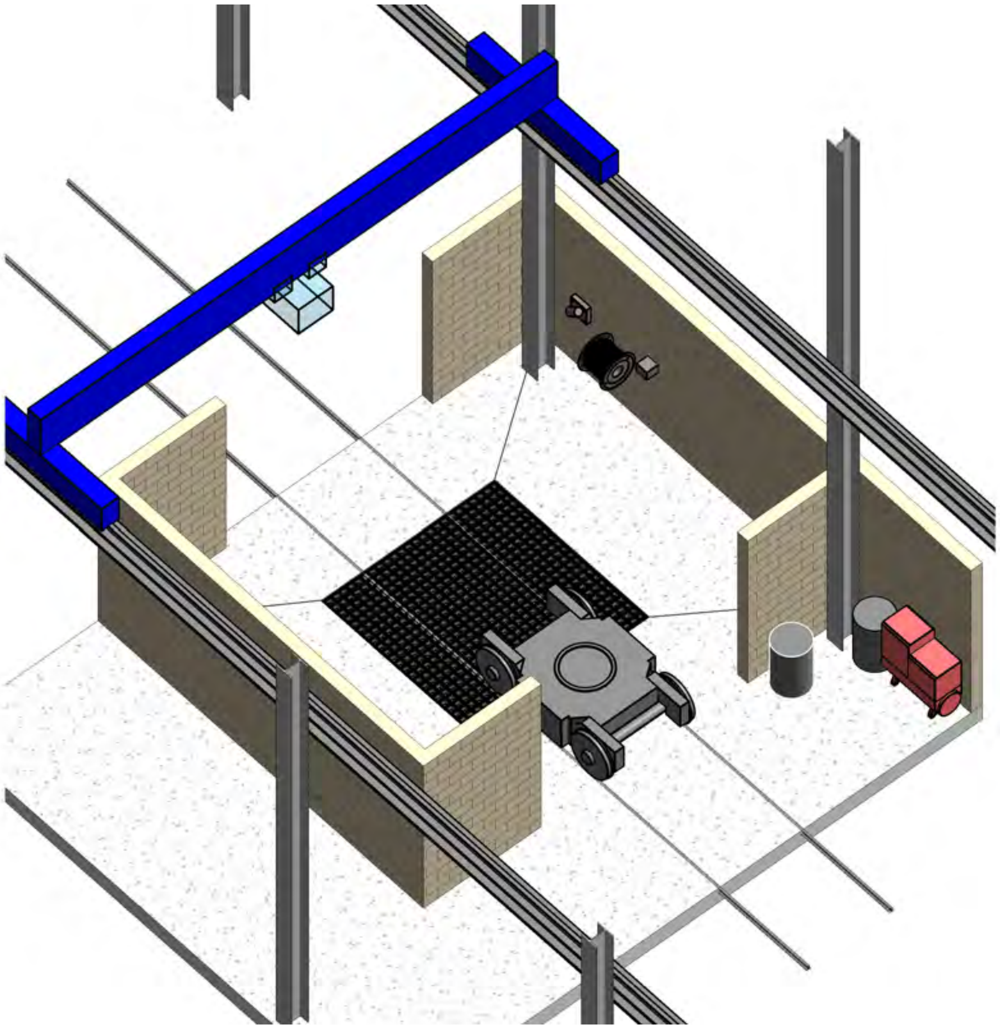
Plumbing

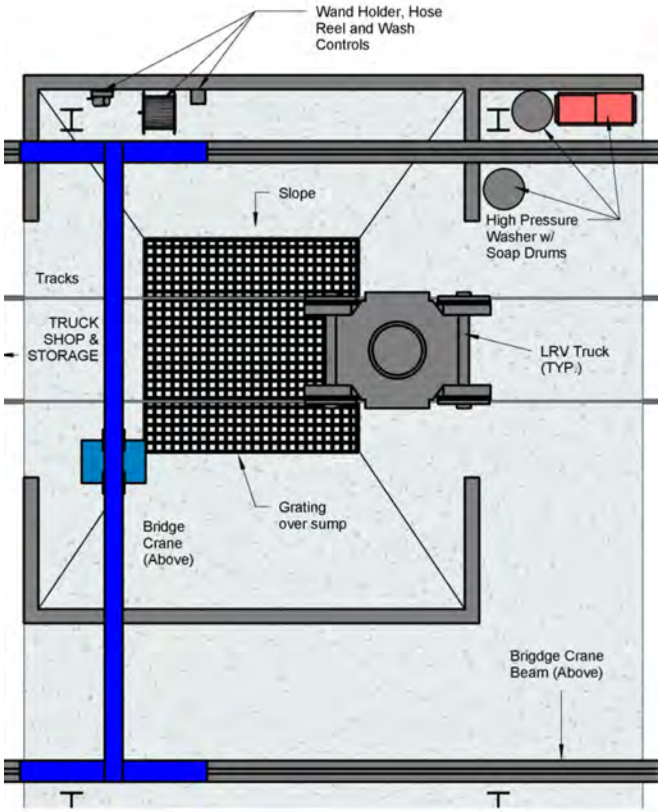
- Compressed air drop
  - ♦ Cut-off valve, union, filter, regulator with gauge, lubricator, and quick disconnect at 4'-0" AFF
  - ♦ Provide disconnects for 1/2" and 1" impact tools
- Water 3/4" water hose bib with standard hose bibb at 24" AFF

Electrical

- Lighting
  - ♦ Fluorescent lighting, 50 fc average, local switching, fixture located to illuminate work spaces
- Power
  - ♦ General-purpose duplex receptacles, 120 VAC, 20 A, GFI protected, on walls at 3'-6" AFF
  - ♦ Dedicated computer receptacle, 120 VAC, 20A adjacent to data conduit
  - ♦ As required by equipment
- Communications
  - ♦ Paging/intercom system speakers
  - ♦ Computer conduit

TRUCK WASH ALCOVE





TRUCK WASH ALCOVE

FUNCTIONAL CHARACTERISTICS

Function: Alcove area for washing LRV trucks with a high pressure washer.

Relationship to Other Areas

- Adjacent to Truck Shop and Storage

Critical Dimensions

- 20’ - 0” vertical clearance to hook of the bridge crane above

Equipment/Furnishings

- High pressure washer with remote wash wands with scabbard, push button controls, and hose reels
- Soap drum(s)
- Access to bridge crane

Design Features

- Includes a large containment sump with grated area
- 10 foot high walls to minimize overspray and allow bridge crane to pass over the space

Sustainable Design Criteria

- Utilize natural lighting strategies
- Provide user-adjustable comfort and lighting controls
- Lighting Design to meet targeted LEED points
- In-floor radiant heat

TECHNICAL CONSIDERATIONS

Architectural

- Finishes
  - ♦ Floor: Soil, grease, water, slip resistant concrete with integral non-metallic light reflective hardener, and chemical bonded concrete sealer
  - ♦ Walls: Soil and grease resistant, light colored finish, smooth finish or glazed block with expoxy grout
  - ♦ Ceiling: Painted exposed structure, light colored finish
- Doors
  - ♦ Personnel door with view panel to meet applicable code exit requirements.

Structural

- Cast-in-place below grade containment sump with structural grating
- Structure as needed to support equipment and bridge crane

Mechanical

- Special ventilation to remove moisture; low air supply to eliminate steam
- Water resistant heating system
- As required by equipment

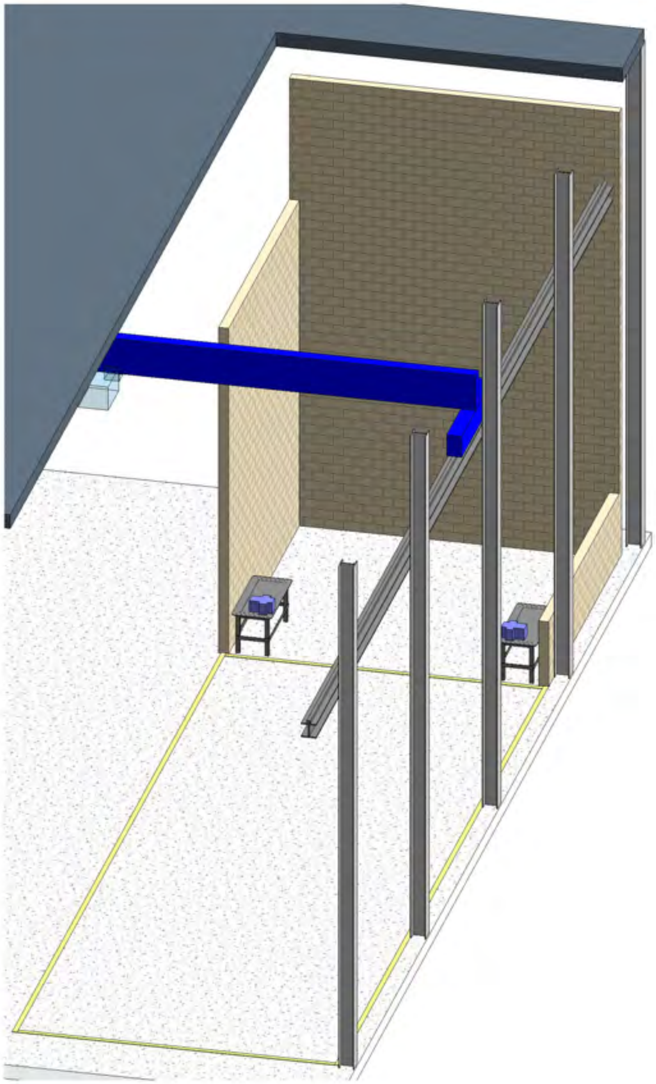
Plumbing

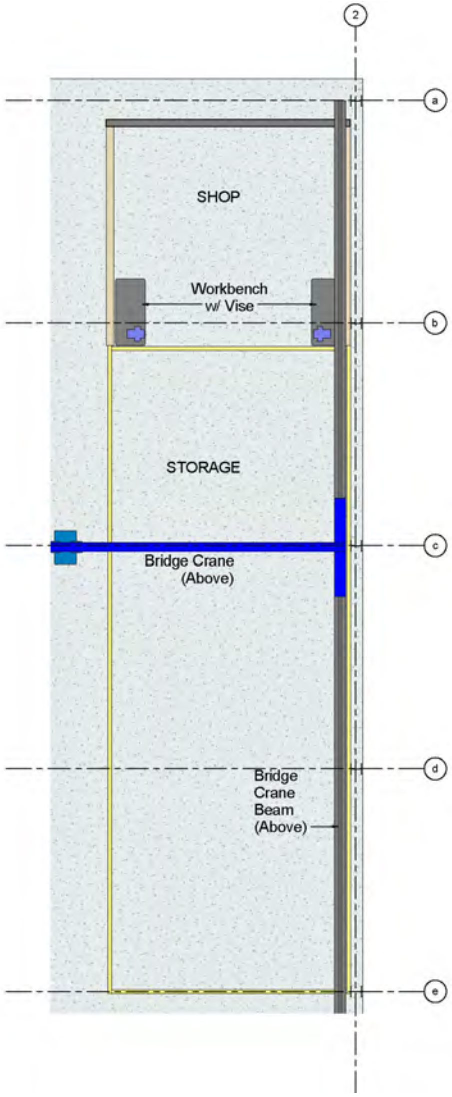
- Containment Sump
  - 6 to 8 inch overflow to sediment and oil interceptor
- 3/4” water hose bib with standard faucet, 2’-0” AFF (1 per bay)
- As required by equipment

Electrical

- Lighting
  - ♦ Water tight fluorescent light fixtures, 50 fc average, located to illuminate workspace
- Power
  - ♦ All conduit and electrical boxes sealed for a wet environment
  - ♦ All receptacles and outlets at 3’-6” AFF
  - ♦ As required by equipment
- Communications
  - ♦ Paging/intercom system speaker

FLEX SHOP / STORAGE





FLEX SHOP / STORAGE

FUNCTIONAL CHARACTERISTICS

Function: Flexible shop and storage space to be converted to any shop space that is required.

Relationship to Other Areas

- Access to all Restroom/Showers
- Access to Break/Crew Room
- Access to Administrative Office areas

Critical Dimensions

- 24'-0" vertical clearance

Equipment/Furnishings

- Severe use workbench with vise
- Overhead bridge crane

Design Features

- Forklift access

Sustainable Design Criteria

- Utilize natural lighting strategies
- Provide user-adjustable comfort and lighting controls
- Lighting design to meet targeted LEED points
- In-floor radiant heat

TECHNICAL CONSIDERATIONS

Architectural

- Finishes
  - ♦ Floor: Soil, grease, water, slip resistant concrete with integral non-metallic light reflective hardener, and chemical bonded concrete sealer
  - ♦ Walls: Soil and grease resistant, light colored finish
  - ♦ Ceiling: Painted exposed structure, light colored finish
- Doors
  - ♦ Personnel door with view panel to meet applicable code exit requirements

Structural

- Control joints in floor slab at adequate spacing
- Structure as needed to support equipment

Mechanical

- As required by equipment
- In-floor radiant heat
- Destratification fan

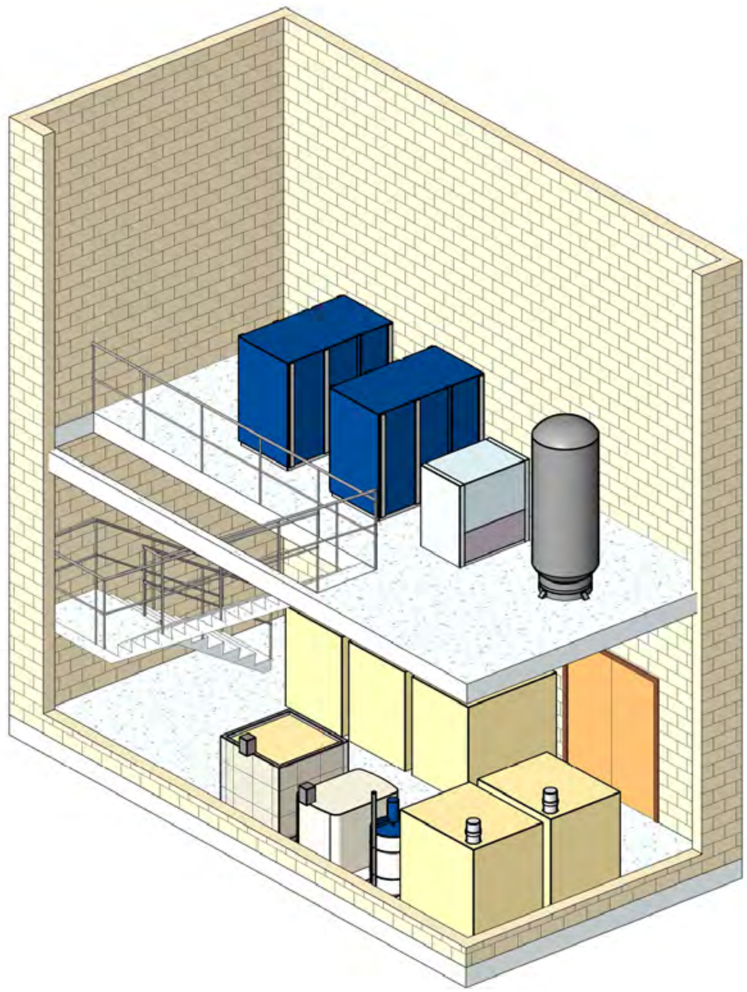
Plumbing

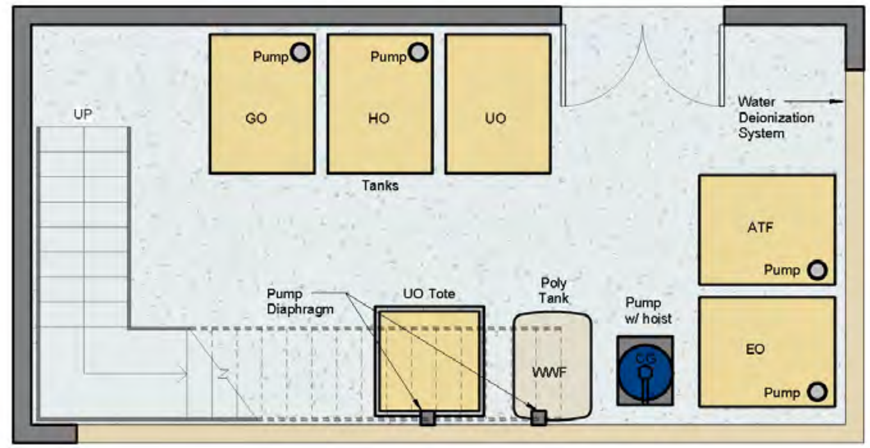
- Water hose bib, 3/4" with standard faucet, 2'-0" AFF
- Compressed air
  - ♦ Main line looped
  - ♦ Compressed air drops; cut off valve, union, separator, and regulator with gauge, 4'-0" AFF

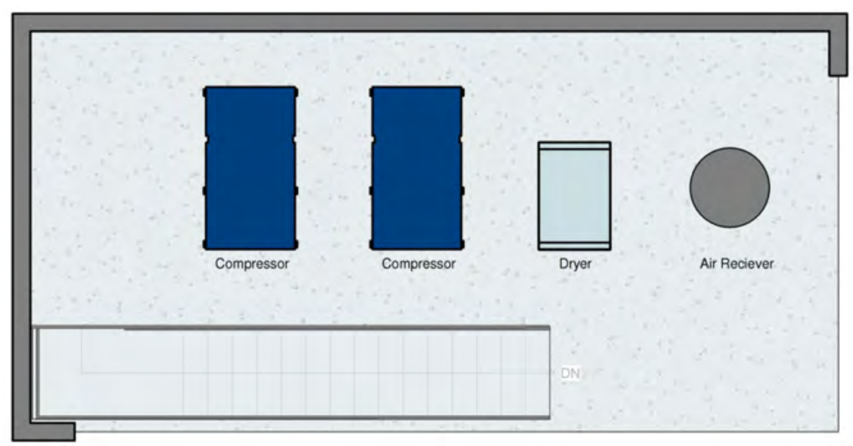
Electrical

- Lighting
  - ♦ Fluorescent lighting, 30 fc average, fixtures located to illuminate work spaces and storage area.
- Power
  - ♦ All receptacles and outlets at 3'-6" AFF
  - ♦ General-purpose duplex receptacles, 120 VAC, 20 A, GFI protected, on walls, columns, and bet. OH doors.
  - ♦ As required by equipment
- Communications
  - ♦ Paging/intercom system speakers

LUBE / COMPRESSOR ROOM







LUBE / COMPRESSOR ROOM

FUNCTIONAL CHARACTERISTICS

Function: Enclosed room for storage and central distribution of lubricants, including, automatic transmission fluid (ATF), chassis grease (CG), diesel exhaust fluid (DEF), engine oil (EO), gear oil (GO), hydraulic oil (HO), used oil (UC), used oil (UO) sand Windshield Washer Fluid (WWF). Space shall include a compressor(s) and refrigerated air dryer(s), and an area for a water deionization equipment.

Relationship to Other Areas

- Access to exterior for deliveries
- Acoustically and physically separated from other areas to prevent migration of noise, dirt, and fumes

Critical Dimensions

- 14'-0" to any obstruction

Equipment/Furnishings

- Above grade fluid storage tanks, air piston and diaphragm pumps. ATF, DEF, EO, GO, HO, and UO stored in above grade double wall ground tanks, CG stored in drums, and WWF stored in a poly tank
- Duplex air compressor
- Refrigerated air dryer
- Water deionization station

Design Features

- Exterior access for deliveries

Sustainable Design Criteria

- Provide user-adjustable lighting controls
- Lighting design to meet targeted LEED points
- Lighting controls: Occupancy sensors

TECHNICAL CONSIDERATIONS

Architectural

- Finishes
  - Floor: Soil, grease, water, slip resistant concrete with integral non-metallic light reflective hardener, and chemical bonded concrete sealer
  - Walls: Soil and grease resistant, light colored finish
  - Ceiling: Painted exposed structure, light colored finish
- Doors
  - ♦ Personnel door to meet applicable code exit requirements
  - ♦ Double 3'-0" wide hollow metal door with interior exit device
  - ♦ No thresholds

Structural

- Control joints in floor slab at adequate spacing
- Housekeeping pad for both the air compressor and refrigerated air dryer
- Structure as needed to support equipment

Mechanical

- Maintain temperature range at 60 to 80 degrees, Fahrenheit
- As required by equipment

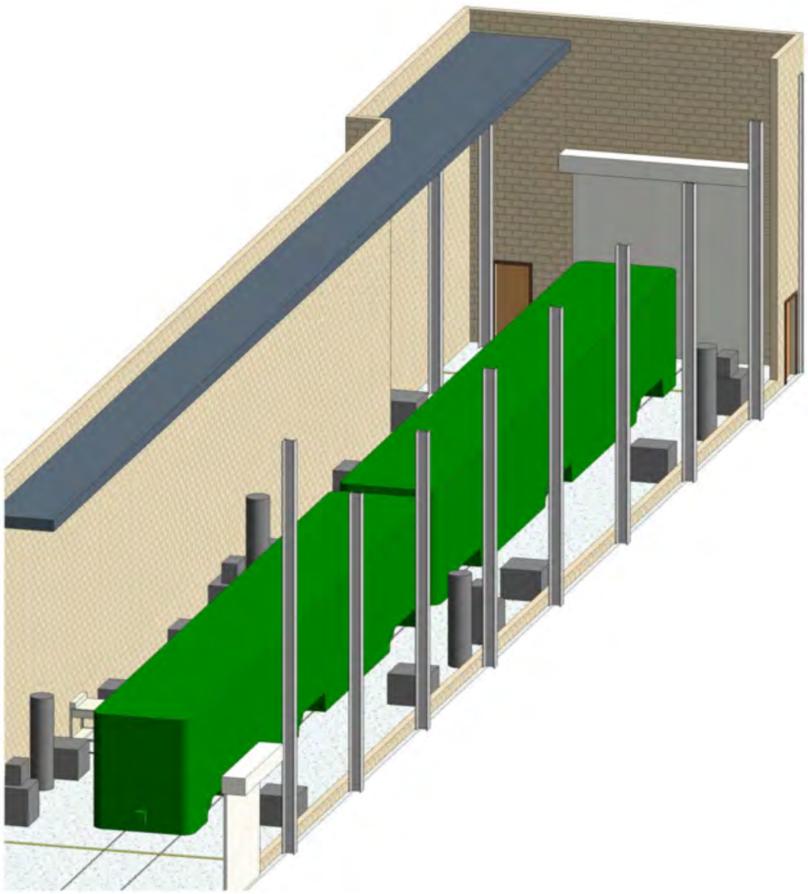
Plumbing

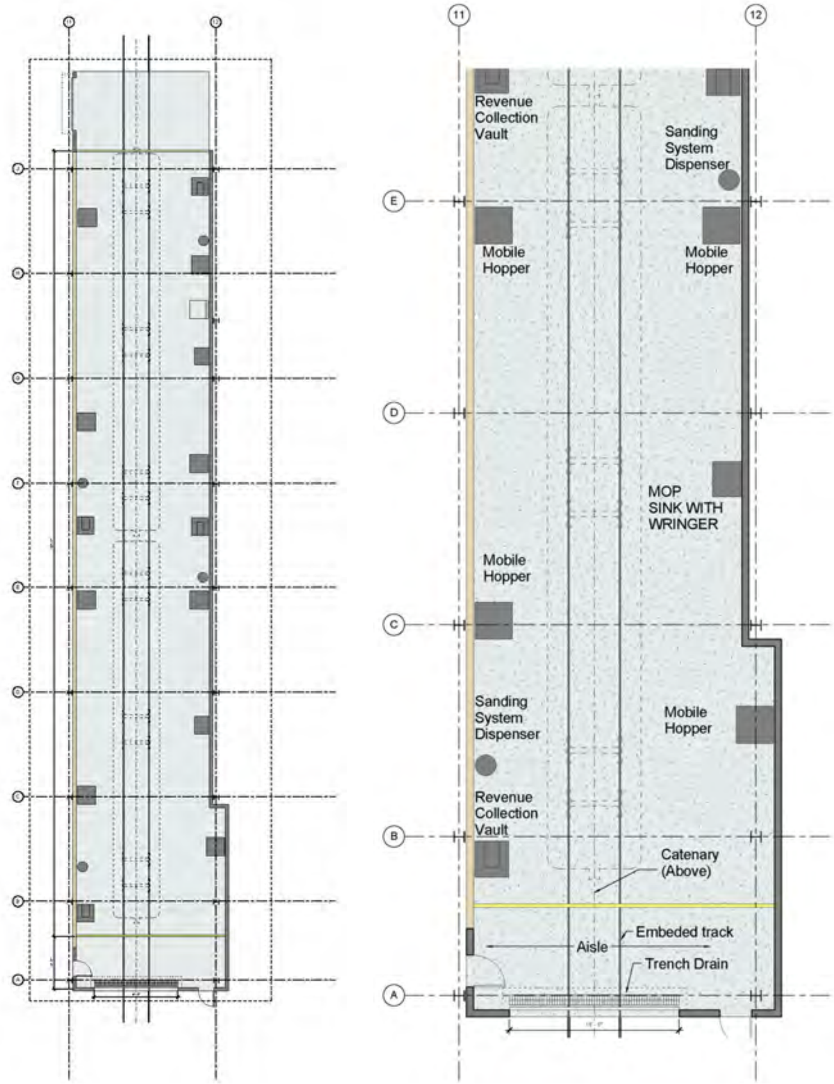
- 3/4" water hose bib with standard faucet 2'-0" AFF
- Compressed air line with cut-off valve, separator, regulator with gauge, lubricator, and quick disconnect on wall at 4'-0" AFF for each lubricant pump
- Tank mount all piston lubricant pump
- Wall mount all diaphragm pumps
- Chassis grease pump mounted to an air operated hoist
- Plumb ATF, CG, DEF, EC, EO, GO, HO, and WWF tanks to corresponding lube reel banks located in the Repair Bays. Size for 2 reels to be used at the same time.
- Plumb UO and UC tanks to corresponding pumps located in the Repair Bays
- Fill ports on the exterior of the building plumbed to each tank
- Fluid monitoring system for ATF, EO, GO, HO, UC, and UO fluids
- Floor drain for condensate from compressor and refrigerated air dryer

Electrical

- Lighting
  - ♦ Fluorescent lighting, 50 fc average, local switching
- Power
  - ♦ General purpose duplex receptacles, 120 VAC, 20 A, GFI protected, on walls at 3'-6" AFF
  - ♦ As required by equipment

SERVICE AND CLEAN BAY





SERVICE AND CLEAN BAY

FUNCTIONAL CHARACTERISTICS

Function: Dedicated bay used for sanding, interior cleaning, vaulting, and exterior hand washing of LRVs.

Relationship to Other Areas

- Adjacent to Sanding Storage
- Access to Cleaning Supply Storage
- Adjacent to the Automated Wash Bay

Critical Dimensions

- 20'-0" vertical clearance
- 25'-0" wide by 150'-0" long

Equipment/Furnishings

- Revenue collection vaults
- Stand up desk with stool
- Mop sinks
- Remote sanding stations

Design Features

- Enclosed area to prevent migration of noise from sanding system

Sustainable Design Criteria

- Utilize natural lighting strategies
- Provide user-adjustable comfort and lighting controls
- Lighting design to meet targeted LEED points
- In-floor radiant heat

TECHNICAL CONSIDERATIONS

Architectural

- Finishes
  - ♦ Floor: Soil, grease, water, slip resistant concrete with integral non-metallic light reflective hardener, and chemical bonded concrete sealer
  - ♦ Walls: Soil and grease resistant, light colored finish
  - ♦ Ceiling: Painted exposed structure, light colored finish
- Doors
  - ♦ Personnel door with view panel to meet applicable code exit requirements
  - ♦ Wash Bay: Exterior overhead doors - highspeed fabric, 16'-0"x 16'-0", automatic operator, interior and exterior push button controls with lockout on exterior. Sensors on exterior and interior for automatic roll up and roll down

Structural

- Control joints in floor slab at adequate spacing
- Control joints to have metal water stops
- Structure as needed to support equipment
- Trench drain with removable cover at overhead door(s)

Mechanical

- Special ventilation to remove moisture
- Low air supply to eliminate mist and steam
- Water resistant equipment
- As required by equipment

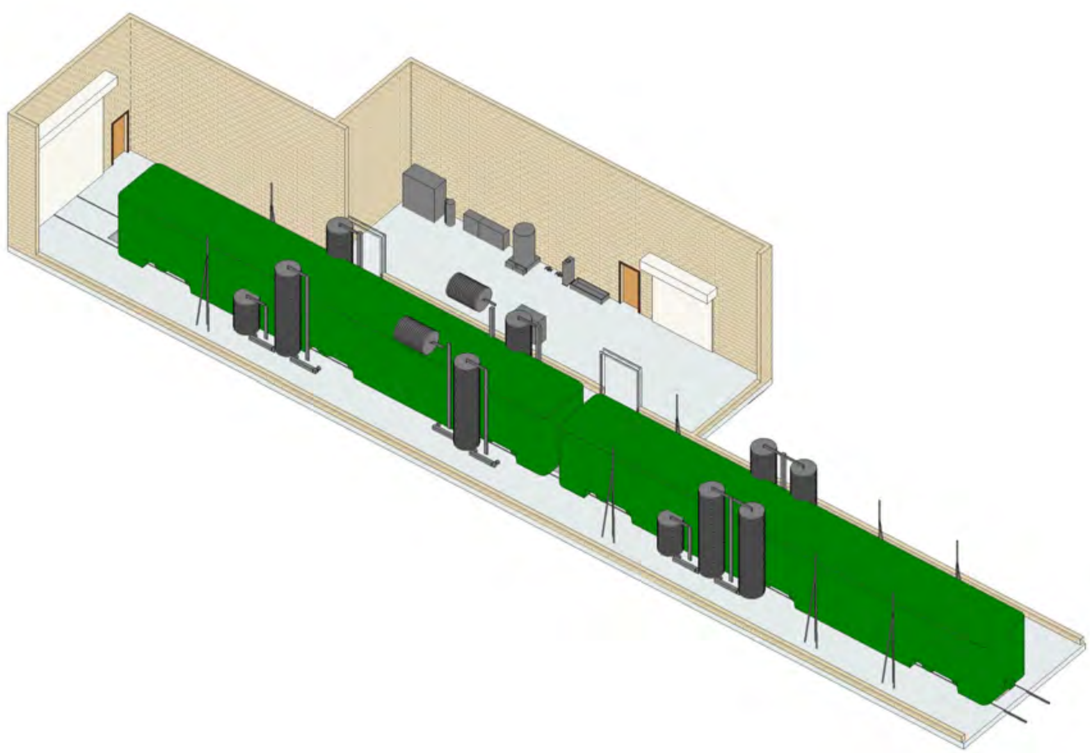
Plumbing

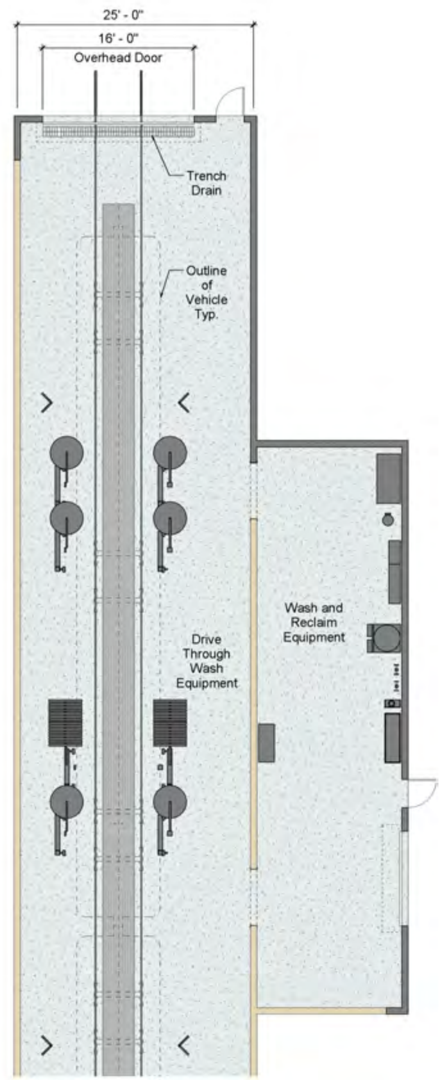
- Trench drains with removable cover at overhead door s)
- 3/4" water hose bib with standard faucet, 2'-0" AFF (1 per mop sink)
- As required by equipment

Electrical

- Lighting
  - ♦ Water tight fluorescent light fixtures, 50 fc average, located to illuminate workspace
- Power
  - ♦ All conduit and electrical boxes sealed for a wet environment
  - ♦ All receptacles and outlets at 3'-6" AFF
  - ♦ As required by equipment
- Communications
  - ♦ Paging/intercom system speaker
- Catenary: Overhead

AUTOMATIC WASH BAY AND WASH / RECLAIM EQUIPMENT ROOM





AUTOMATIC WASH BAY AND WASH / RECLAIM EQUIPMENT ROOM

FUNCTIONAL CHARACTERISTICS

Function: Designated bay for automatic washing of sides, top, front, back, and undercarriage of light rail vehicles.

Relationship to Other Areas

- Adjacent Wash Equipment Room
- Adjacent to Service and Clean Bay

Critical Dimensions

- 20'-0" vertical clearance
- Wash bay 25'-0" by 150'-0" (sized for all wash equipment and to allow adequate dwell time for detergent after application by the detergent arc, and prior to arriving at the brush assembly)
- Length may depend on speed that vehicle can reliably be operated through the wash

Equipment/Furnishings

- Vehicle automatic wash equipment
- Equipment should recycle as much water as possible
- High volume air blow off is optional, but aids in reducing water spots on windows

Design Features

- Includes room for wash equipment controls, pumps, and reclaim equipment
- Bay should be physically isolated from other repair positions and maintenance areas

Sustainable Design Criteria

- Utilize natural lighting strategies
- Lighting Design to meet targeted LEED points
- In-floor radiant heat
- Water reclamation system
- Use of rain water for vehicle washing

TECHNICAL CONSIDERATIONS

Architectural

- Finishes
  - ♦ Floor: Soil, grease, water, slip resistant concrete, epoxy finish, and chemical bonded concrete sealer
  - ♦ Walls: Soil and grease resistant, light colored finish or glazed block with epoxy grout
  - ♦ Ceiling: Painted exposed structure, light colored finish
- Doors
  - ♦ Personnel door with view panel to meet applicable code exit requirements
  - ♦ Wash Bay: Exterior overhead doors - high speed fabric, 16'-0"x 16'-0", automatic operator, interior and exterior push button controls with lockout on exterior. Sensors on exterior and interior for automatic roll up and roll down
  - ♦ Wash Equipment Room: Exterior high lift overhead door: 12'-0"x 12'-0", automatic operator, interior and exterior push button controls with lockout on exterior

Structural

- Control joints in floor slab at adequate spacing
- Control joints to have metal water stops
- Structure as needed to support equipment
- Wash bay:
  - ♦ Integrated trench drain and sump pit with removable covers
  - ♦ Trench drain with removable cover at overhead door(s)
- Wash equipment room - sump pits with removable covers

Mechanical

- Special ventilation to remove moisture
- Low air supply to eliminate mist and steam
- Water resistant equipment
- As required by equipment

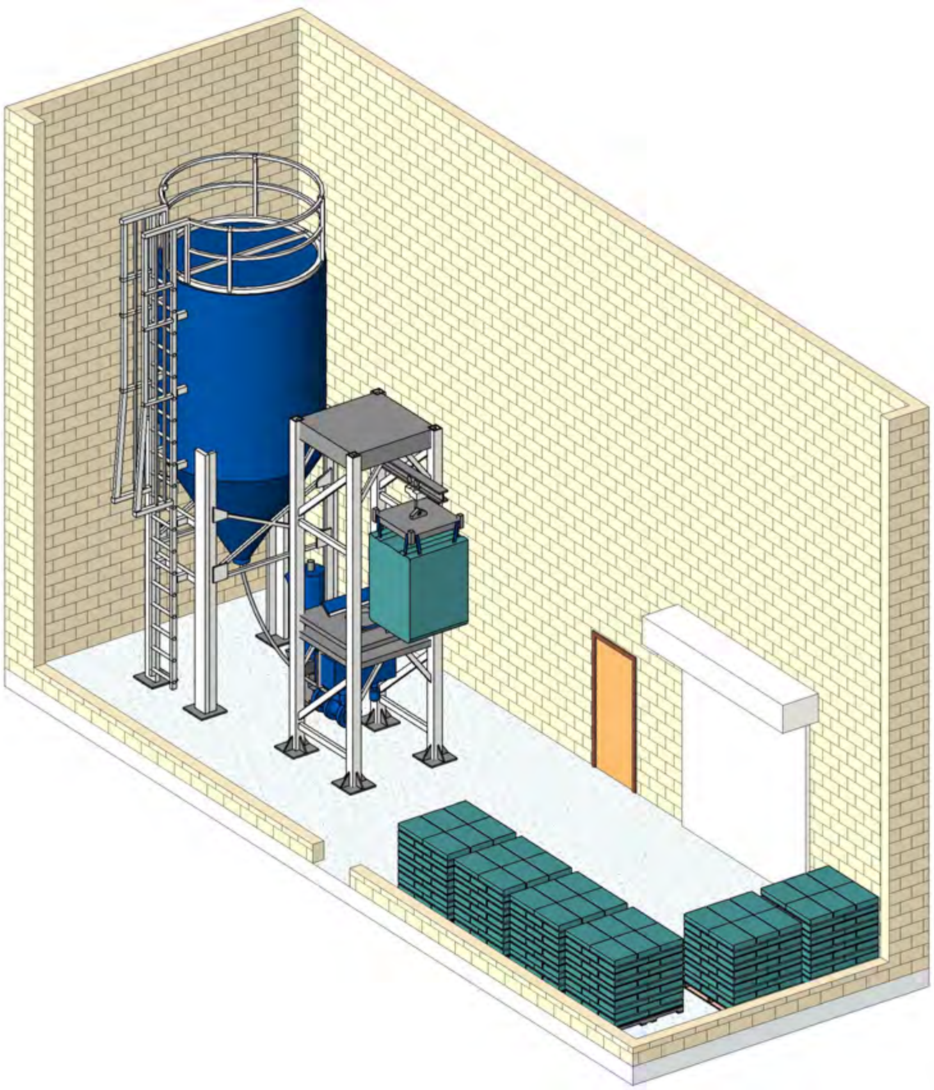
Plumbing

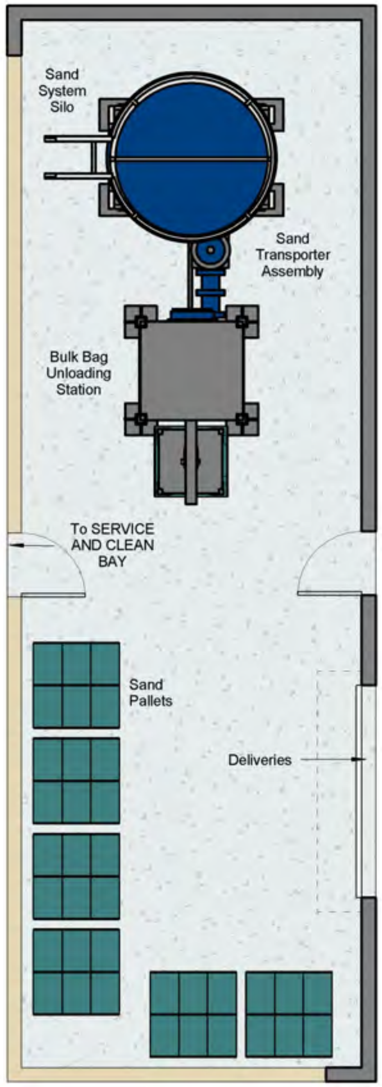
- Trench drains
  - ♦ Integrated trench drain and sump pit with removable covers. Sump pit overflow to sump pits in Wash and Reclaim Equipment Room
  - ♦ Trench with removable cover at overhead door
- Wash equipment room: sump with removable covers and an overflow to sediment and oil interceptor
- Water and compressed air connections to wash and reclamation equipment
- As required by equipment

Electrical

- Lighting
  - ♦ Water tight fluorescent light fixtures, 50 fc average, located to illuminate workspace
- Power
  - ♦ All conduit and electrical boxes sealed for a wet environment
  - ♦ All receptacles and outlets at 3'-6" AFF
  - ♦ As required by equipment

SAND STORAGE





SAND STORAGE

FUNCTIONAL CHARACTERISTICS

Function: Room for storage and distribution of sand to LRVs in the Service and Clean Bay.

Relationship to Other Areas

- Access to Service and Clean Bay
- Access to the exterior for deliveries

Critical Dimensions

- 27'-0" vertical clearance

Equipment/Furnishings

- Sanding silo and pneumatic sanding system to remote sanding stations located in Service and Clean Bay, hoist

Design Features

- Enclosed and heated to keep sand in silo from freezing

Sustainable Design Criteria

- Utilize natural lighting strategies
- Lighting Design to meet targeted LEED points

TECHNICAL CONSIDERATIONS

Architectural

- Finishes
  - ♦ Floor: Soil, grease, water, slip resistant concrete, and chemical bonded concrete sealer
  - ♦ Walls: Soil and grease resistant, light colored finish
  - ♦ Ceiling: Painted exposed structure, light colored finish
- Doors
  - ♦ Personnel door with view panel to meet applicable code exit requirements
  - ♦ Exterior overhead door: High-lifting sectional, steel, insulated, 12' x 12', with view panels, automatic operator, interior and exterior push button controls, and lockout on exterior

Structural

- Control joints in floor slab at adequate spacing
- Structure as needed to support equipment

Mechanical

- As required by equipment
- Temperature to keep sand from freezing
- Humidity control

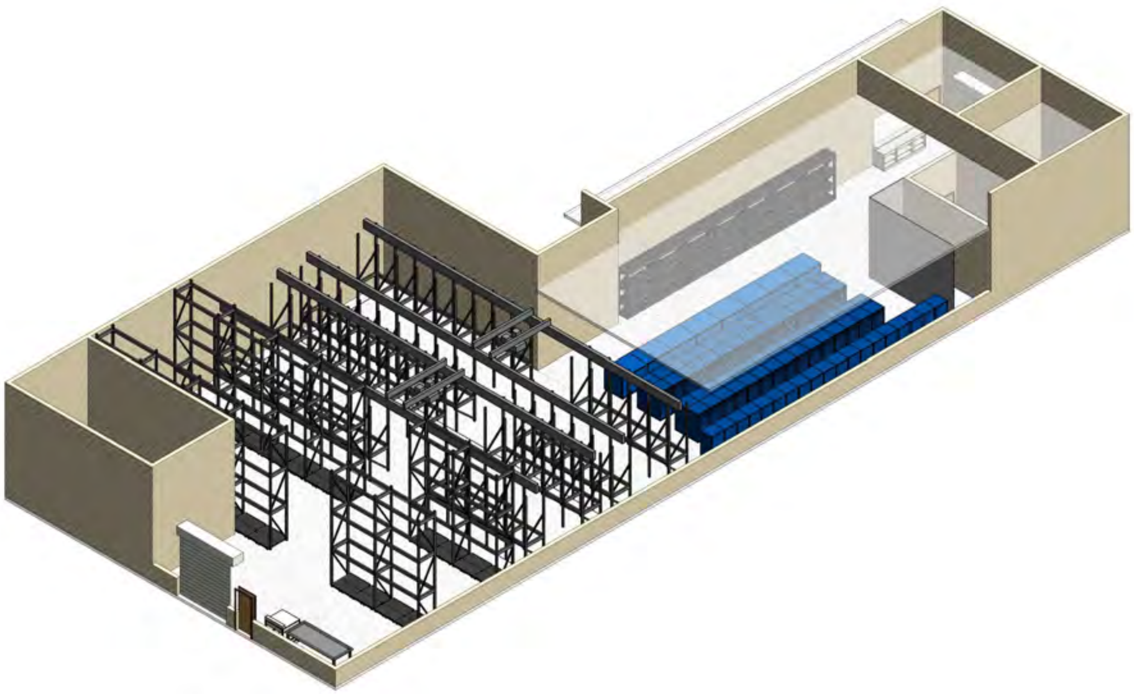
Plumbing

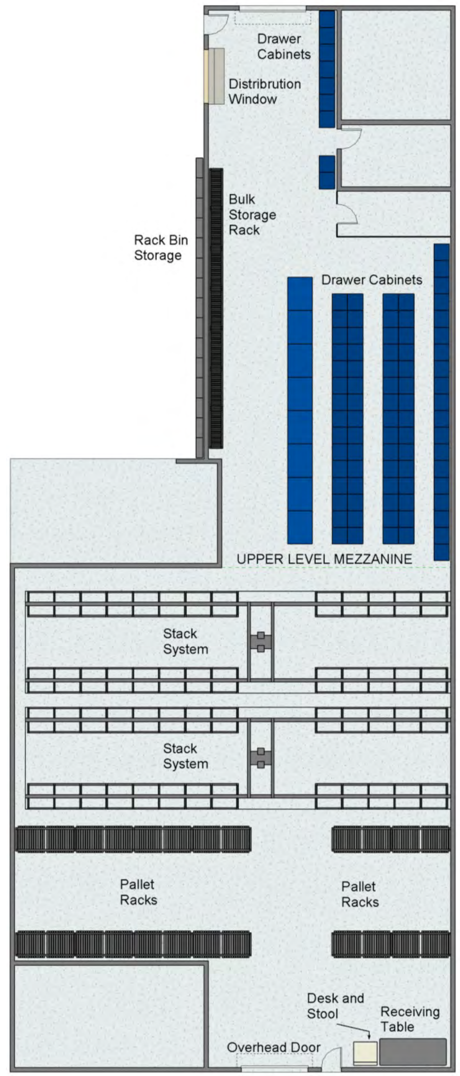
- Compressed air line with cut off valve, regulator with gauge, and quick disconnect at each column at 4'-0" AFF

Electrical

- Lighting
  - ♦ Fluorescent lighting, 50 fc average, local switching, fixture located to illuminate work spaces
- Power
  - ♦ General-purpose duplex receptacles, 120 VAC, 20 A, GFI protected, on walls at 3'-6" AFF
  - ♦ As required by equipment
- Communications
  - ♦ Paging/intercom system speakers

STOREROOM




Drawer
Cabinets
Distribrution
Window
Bulk
Storage
Rack
Rack Bin
Storage
Drawer Cabinets
UPPER LEVEL MEZZANINE
Stack
System
Stack
System
Pallet
Racks
Pallet
Racks
Desk and
Stool
Receiving
Table
Overhead Door

STOREROOM

FUNCTIONAL CHARACTERISTICS

Function: Dedicated secure area for receiving, storage, and issuing of parts, materials, and specialized tools.

Relationship to Other Areas

- Adjacent to the repair bays and shops
- Access to the exterior for deliveries/distribution

Critical Dimensions

- 12'-0" vertical clearance below mezzanine
- 10'-0" vertical clearance on mezzanine
- 16' -0" - 24'-0" clear for high bay (pallet storage)

Equipment/Furnishings

- Layout table and desk at receiving
- Storage shelving, racks, and cabinets
- Storage cabinets
- Marker board (at parts issue counter)
- Parts Lift, 3,000 lb. capacity

Design Features

- Provide issue counter with stainless steel top and locking slide window or overhead cooling door
- Provide staging area for shipping/receiving with an overhead door to the exterior of the building
- Forklift access
- Oxygen and acetylene tank storage and battery storage to be provided

Sustainable Design Criteria

- Utilize natural lighting strategies
- Provide user-adjustable comfort and lighting controls
- Lighting Design to meet targeted LEED points

TECHNICAL CONSIDERATIONS

Architectural

- Finishes
  - ♦ Floor: Soil, grease, water, slip resistant concrete and chemical bonded concrete sealer
  - ♦ Walls: Soil and grease resistant, light colored finish
  - ♦ Ceiling: Painted exposed structure, light colored finish
- Doors
  - ♦ Personnel door with view panel to meet applicable code exit requirements
  - ♦ Exterior overhead door: High-lifting sectional, steel, insulated, 12' x 12', with view panels, automatic operator, interior and exterior push button controls, and lockout on exterior
  - ♦ Interior overhead door: Coiling steel, 10' x 12' door, automatic operator, push button controls

Structural

- Control joints in floor slab at adequate spacing
- Structure as needed to support equipment

Mechanical

- Heat 70 degree F
- As required by equipment

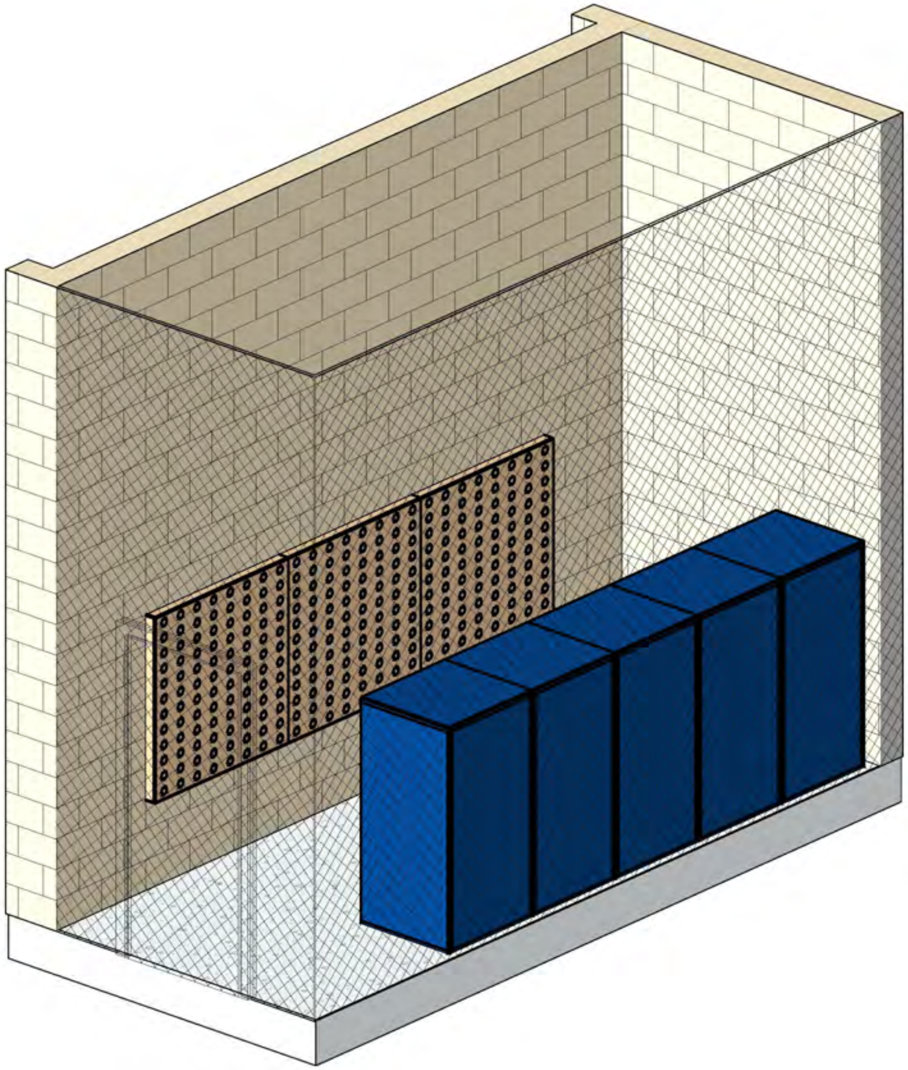
Plumbing

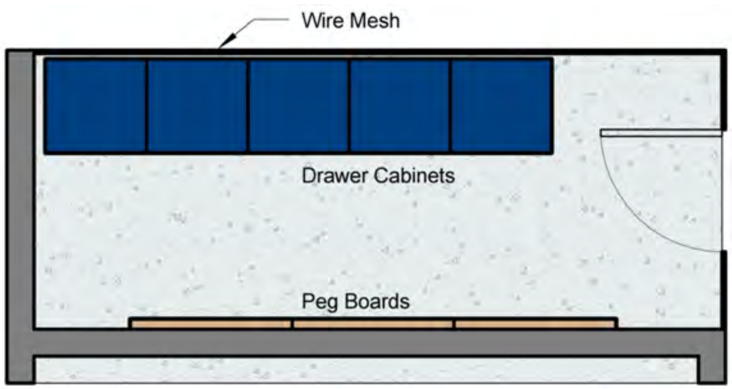
- None

Electrical

- Lighting
  - ♦ Fluorescent lighting, 50 fc average, local switching, fixture located to illuminate work spaces
- Power
  - ♦ General-purpose duplex receptacles, 120 VAC, 20 A, GFI protected, on walls at 3'-6" AFF
  - ♦ Dedicated computer receptacle, 120 VAC, 20 A, adjacent to computer cable conduit at parts window and receiving door
  - ♦ As required by equipment
- Communications
  - ♦ Paging/intercom system speakers
  - ♦ Data outlet and conduit for computer at parts window and receiving door
  - ♦ Buzzer at Parts Window and shipping/receiving door

TOOL STORAGE





TOOL STORAGE

FUNCTIONAL CHARACTERISTICS

Function: Secure area for storing specialized tools and equipment owned by the agency.

Relationship to Other Areas

- Adjacent to the Parts Room
- Adjacent to Maintenance Supervisor's Office
- Access to the Repair Bays and Shops

Critical Dimensions

- 12'-0" vertical clearance

Equipment/Furnishings

- Peg board
- Storage shelving
- Storage cabinets

Design Features

- Provide access from the Supervisor's Office
- Limited personnel access
- Secured access

Sustainable Design Criteria

- Utilize natural lighting strategies
- Provide user-adjustable comfort and lighting controls
- Lighting design to meet targeted LEED points

TECHNICAL CONSIDERATIONS

Architectural

- Finishes
  - ♦ Floor: Soil, grease, water, slip resistant concrete and chemical bonded concrete sealer
  - ♦ Walls: Soil and grease resistant, light colored finish or wire mesh partitions
  - ♦ Ceiling: Painted exposed structure, light colored finish

Structural

- Control joints in floor slab at adequate spacing
- Structure as needed to support equipment

Mechanical

- Heat 70 degree F and air conditioned
- As required by equipment

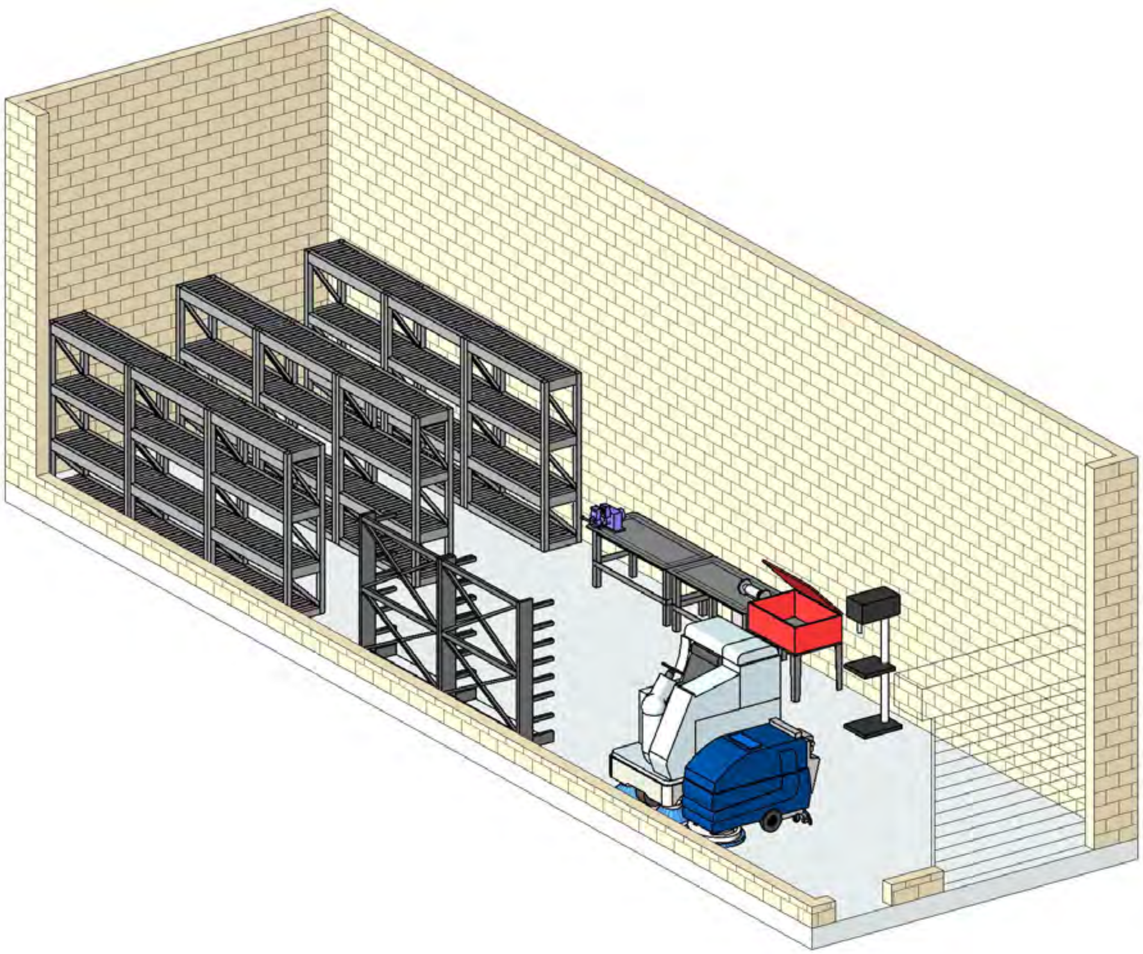
Plumbing

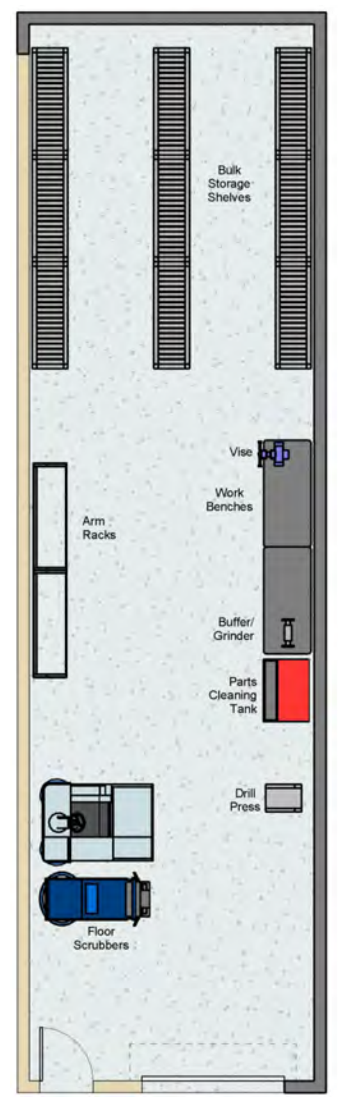
- None

Electrical

- Lighting
  - ♦ Fluorescent lighting, 50 fc average, local switching, fixture located to illuminate work spaces
- Power
  - ♦ General-purpose duplex receptacles, 120 VAC, 20 A, GFI protected, on walls at 3'-6" AFF
  - ♦ As required by equipment
- Communications
  - ♦ Paging/intercom system speakers

FACILITY MAINTENANCE SHOP AND STORAGE





FACILITY MAINTENANCE SHOP AND STORAGE

FUNCTIONAL CHARACTERISTICS

Function: Enclosed, secure shop and materials storage area for maintenance of buildings and grounds on the site.

Relationship to Other Areas

- Access to all Restroom/Showers
- Access to Break/Crew Room

Critical Dimensions

- 14'-0" vertical clearance

Equipment/Furnishings

- Severe use workbench with vise
- Buffer/grinder
- Drill press
- Parts cleaning tank
- Shelving units
- Arm racks
- Floor scrubbers

Design Features

- Forklift access
- Secure entry
- Access to exterior for deliveries

Sustainable Design Criteria

- Utilize natural lighting strategies
- Provide user-adjustable comfort and lighting controls
- Lighting design to meet targeted LEED points

TECHNICAL CONSIDERATIONS

Architectural

- Finishes
  - ♦ Floor: Soil, grease, water, slip resistant concrete with integral non-metallic light reflective hardener, and chemical bonded concrete sealer
  - ♦ Walls: Soil and grease resistant, light colored finish
  - ♦ Ceiling: Painted exposed structure, light colored finish
- Doors
  - ♦ Personnel door with view panel to meet applicable code exit requirements
  - ♦ Overhead doors access: High lift roll up, 10'-0" x 10'-0", automatic operator, interior and exterior push button controls with lockout on exterior
- Bollards on exterior at jambs of overhead door (2 each)

Structural

- Control joints in floor slab at adequate spacing
- Structure as needed to support equipment

Mechanical

- As required by equipment
- In-floor radiant heat

Plumbing

- Water hose bib, 3/4" with standard faucet, 2'-0" AFF
- Compressed air
  - ♦ Main line looped
  - ♦ Compressed air drops; cut off valve, union, separator, and regulator with gauge, 4'-0" AFF

Electrical

- Lighting
  - ♦ Fluorescent lighting, 50 fc average, local switching, fixture located to illuminate work spaces
- Power
  - ♦ All receptacles and outlets at 3'-6" AFF
  - ♦ General-purpose duplex receptacles, 120 VAC, 20 A, GFI protected, on walls, columns, and between OH doors.
  - ♦ Dedicated computer receptacle, 120 VAC, 20 A adj. to data conduit
  - ♦ As required by equipment
- Communications
  - ♦ Paging/intercom system speakers
  - ♦ Conduit for data line

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ENGINEERING AND MAINTENANCE OFFICE/OFFICE SUPPORT MODULES

SIGNALS/TRACK/POWER SUPERVISORS - Module D (Shared Satellite Office)

Relationship to Other Areas

- Access to all office areas
- Access to support areas

Comments

- Satellite work space
- Separate work station for each person located in the shared secure office

SIGNALS INSPECTOR - Module A

Relationship to Other Areas

- Access to all office areas
- Access to support areas

Comments

- Office shall be secure

TRACK GENERAL FOREPERSON - Module D

Relationship to Other Areas

- Access to all office areas
- Access to support areas
- Access to shop areas

Comments

- 3 workstations shall be located in this area

POWER OCS HEAD LINE REPAIRER - Module D

Relationship to Other Areas

- Access to all office areas
- Access to all support areas
- Access to all shop areas

Comments

- 3 workstations shall be located in this area

SUBSTATION - POWER EQUIPMENT TECHNICIAN - Module C

Relationship to Other Areas

- Access to all office areas
- Access to all support areas
- Access to power substation

Comments

- 2 workstations shall be located in this area

COPY/FILE/STORAGE AREA - Module G

Relationship to Other Areas

- Access from all office areas
- Access from Crew/Break Room

Comments

- Open to hallway

PORTER'S ROOM - Module K

Relationship to Other Areas

- Adjacent to restroom

Comments

- Storage for cleaning carts

CONFERENCE ROOM - Module F

Relationship to Other Areas

- Access from all office areas
- Access from all support areas

Comments

- Size for 8 to 10 people

MEN'S AND WOMEN'S LOCKERS/ SHOWERS/RESTROOMS - Module I

Relationship to Other Areas

- Access from all shop/crew areas

Comments

- Include lockers in Restroom
- Size men's and women's equally
- Provide 1 full-height locker per Maintainer

CREW/BREAK ROOM - Module L

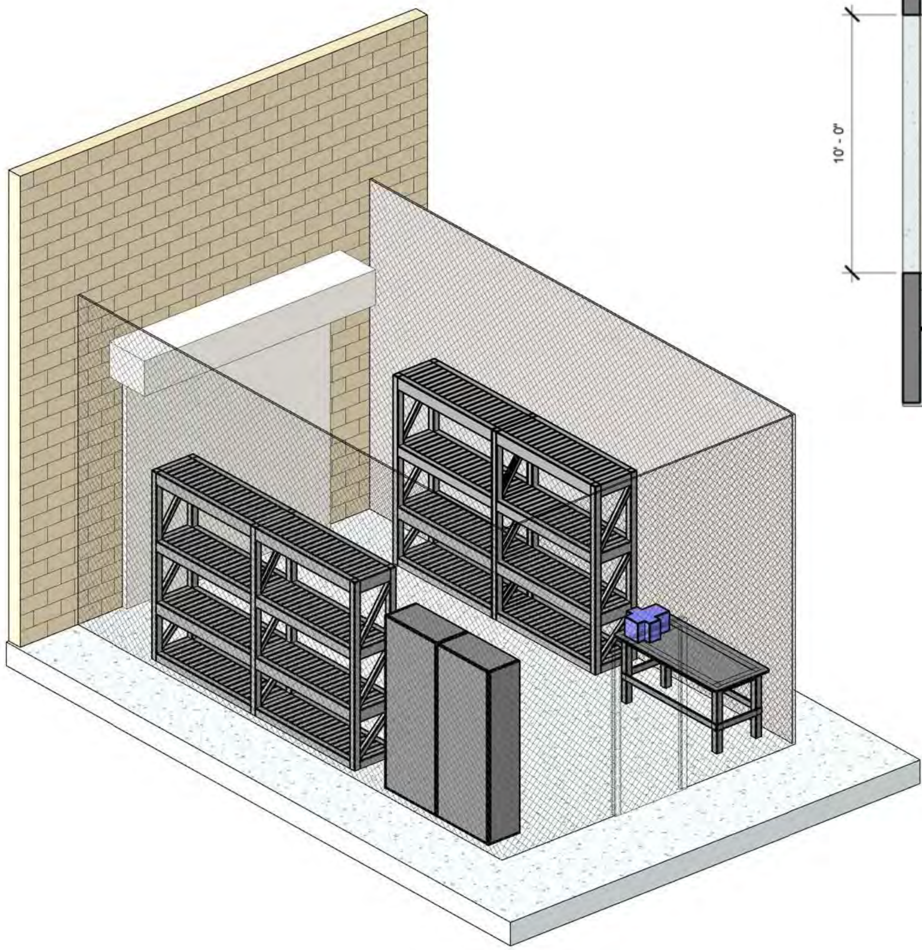
Relationship to Other Areas

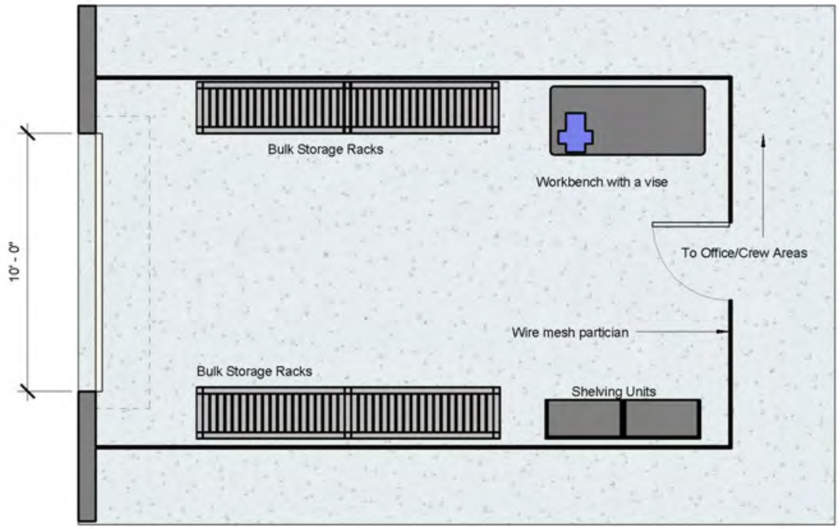
- Access from all shop/storage areas
- Access from all office/support areas

Comments

- Size kitchenette/vending with 3 vending machines, refrigerator, 2 microwaves, and 1 shower

SIGNALS - TOOLS AND LUBRICANTS





SIGNALS - TOOLS AND LUBRICANTS

FUNCTIONAL CHARACTERISTICS

Function: Enclosed, secure shop and materials storage area.

Relationship to Other Areas

- Access to all Restroom/Showers
- Access to Break/Crew Room
- Access to Administrative office areas

Critical Dimensions

- 14'-0" vertical clearance

Equipment/Furnishings

- Severe use workbench with vise
- Storage shelving and racks

Design Features

- Forklift access
- Secure entry
- Access to exterior for deliveries

Sustainable Design Criteria

- Utilize natural lighting strategies
- Provide user-adjustable comfort and lighting controls
- Lighting design to meet targeted LEED points

TECHNICAL CONSIDERATIONS

Architectural

- Finses
  - ♦ Floor: Soil, grease, water, slip resistant concrete and chemical bonded concrete sealer
  - ♦ Walls: Soil and grease resistant, light colored finish, or wire mesh
  - ♦ Ceiling: Painted exposed structure, light colored finish
- Doors
  - ♦ Personnel door with view panel to meet applicable code exit requirements.
  - ♦ Exterior overhead doors: 10'-0" x 10'-0", automatic operator, interior and exterior push button controls with lockout on exterior.
- Bollards on exterior at jambs of overhead door (2 each)

Structural

- Control joints in floor slab at adequate spacing
- Structure as needed to support equipment

Mechanical

- As required by equipment
- Heated to 40 degrees F

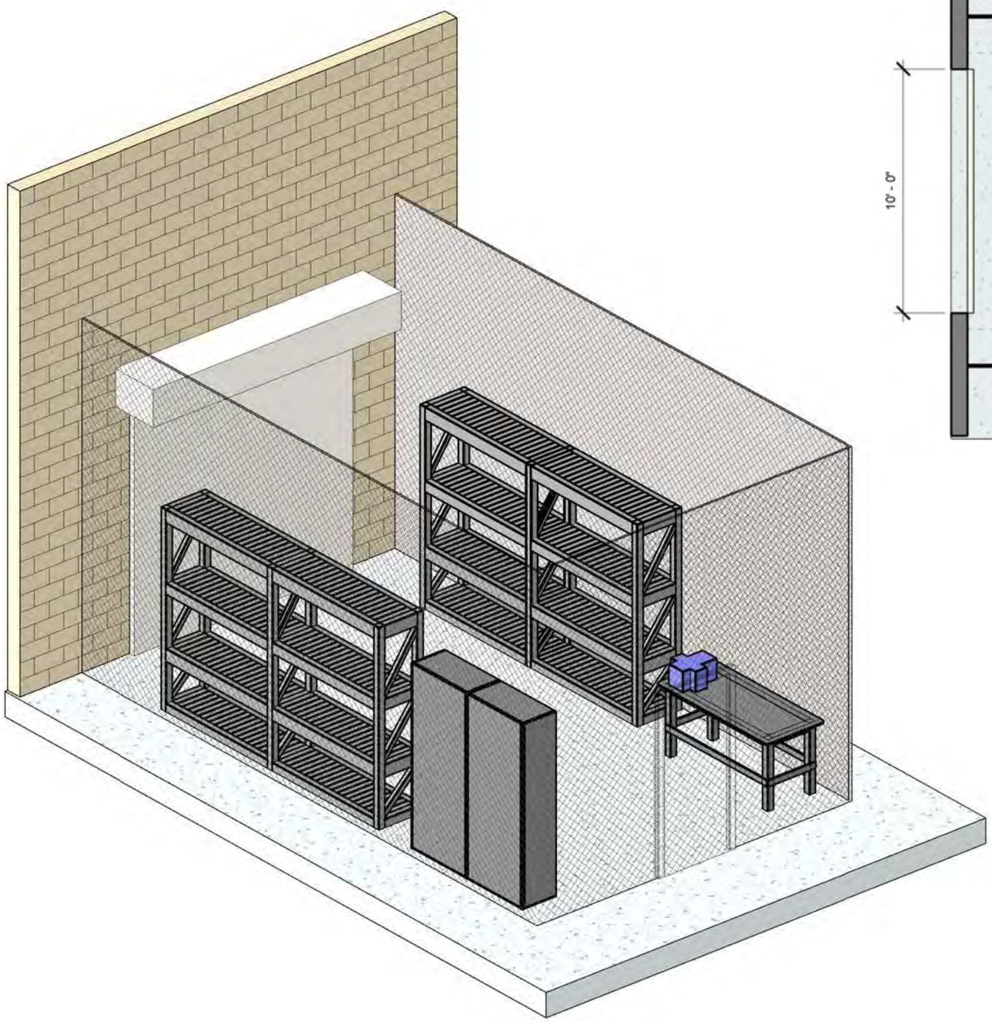
Plumbing

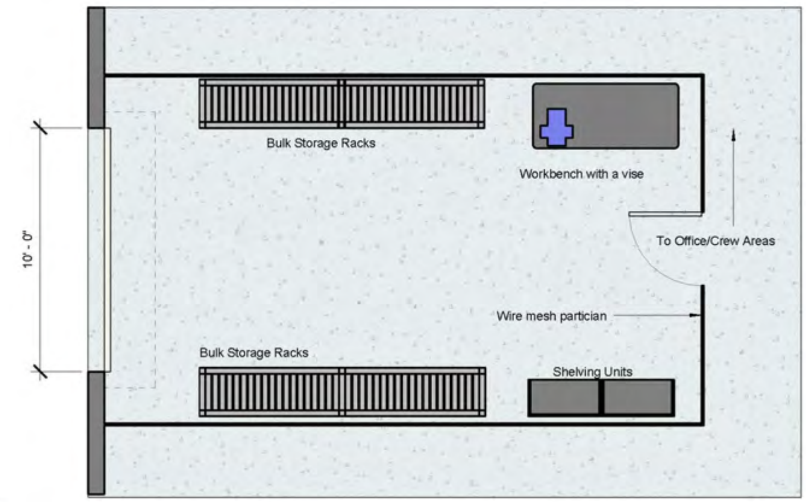
- Water hose bib, 3/4" with standard faucet, 2'-0" AFF
- Compressed air
  - ♦ Main line looped
  - ♦ Compressed air drops, cut off valve, union, separator, and regulator with gauge, 4'-0" AFF

Electrical

- Lighting
  - ♦ Fluorescent lighting, 30 fc average, fixtures located to illuminate work spaces and storage area.
- Power
  - ♦ All receptacles and outlets at 3'-6" AFF
  - ♦ General-purpose duplex receptacles, 120 VAC, 20A, GFI protected, on walls, columns, and between OH doors
  - ♦ As required by equipment
- Communications
  - ♦ Paging/intercom system speakers

TRACK - TOOL ROOM





TRACK - TOOL ROOM

FUNCTIONAL CHARACTERISTICS

Function: Enclosed, secure shop and materials storage area.

Relationship to Other Areas

- Access to all Restroom/Showers
- Access to Break/Crew Room
- Access to Administrative office areas

Critical Dimensions

- 14'-0" vertical clearance

Equipment/Furnishings

- Severe use workbench with vise
- Storage shelving and racks

Design Features

- Forklift access
- Secure entry
- Access to exterior for deliveries

Sustainable Design Criteria

- Utilize natural lighting strategies
- Provide user-adjustable comfort and lighting controls
- Lighting design to meet targeted LEED points

TECHNICAL CONSIDERATIONS

Architectural

- Finishes
  - ♦ Floor: Soil, grease, water, slip resistant concrete and chemical bonded concrete sealer
  - ♦ Walls: Soil and grease resistant, light colored finish, or wire mesh
  - ♦ Ceiling: Painted exposed structure, light colored finish
- Doors
  - ♦ Personnel door with view panel to meet applicable code exit requirements.
  - ♦ Exterior overhead doors: 10'-0"x 10'-0", automatic operator, interior and exterior push button controls with lockout on exterior.
- Bollards on exterior at jambs of overhead door (2 each)

Structural

- Control joints in floor slab at adequate spacing
- Structure as needed to support equipment

Mechanical

- As required by equipment
- Heated to 40 degrees F

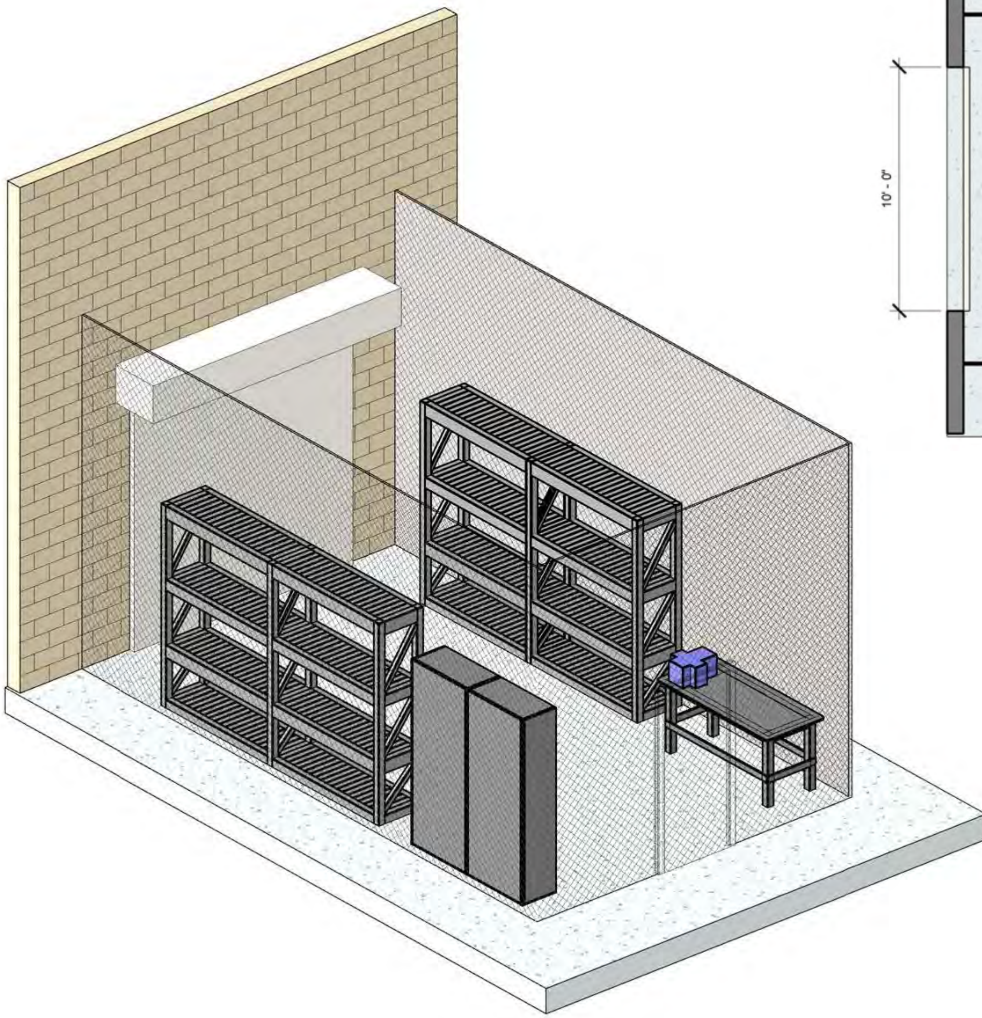
Plumbing

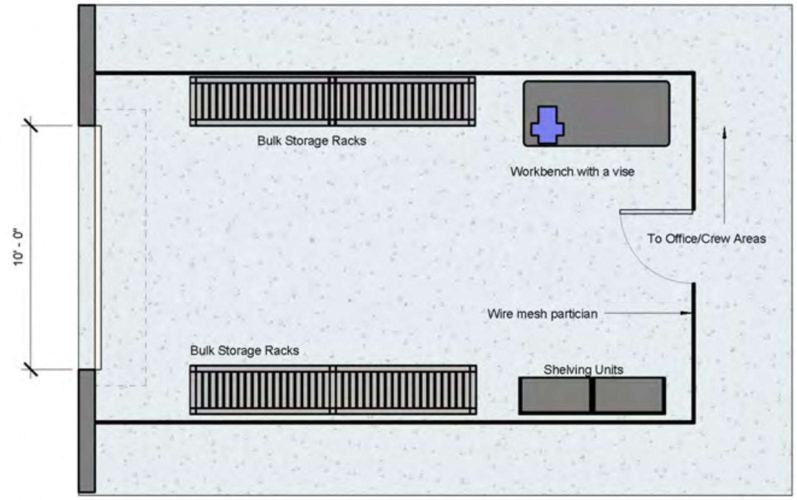
- Water hose bib, 3/4" with standard faucet, 2'-0" AFF
- Compressed air
  - ♦ Main line looped
  - ♦ Compressed air drops; cut off valve, union, separator, and regulator with gauge, 4'-0" AFF

Electrical

- Lighting
  - ♦ Fluorescent lighting, 30 fc average, fixtures located to illuminate work spaces and storage area.
- Power
  - ♦ All receptacles and outlets at 3'-6" AFF
  - ♦ General-purpose duplex receptacles, 120 VAC, 20A, GFI protected, on walls, columns, and between OH doors
  - ♦ As required by equipment
- Communications
  - ♦ Paging/intercom system speakers

TRACK - STOCK ROOM





TRACK - STOCK ROOM

FUNCTIONAL CHARACTERISTICS

Function: Enclosed, secure shop and materials storage area.

Relationship to Other Areas

- Access to all Restroom/Showers
- Access to Break/Crew Room
- Access to Administrative office areas

Critical Dimensions

- 14'-0" vertical clearance

Equipment/Furnishings

- Severe use workbench with vise
- Storage shelving and racks

Design Features

- Forklift access
- Secure entry
- Access to exterior for deliveries

Sustainable Design Criteria

- Utilize natural lighting strategies
- Provide user-adjustable comfort and lighting controls
- Lighting Design to meet targeted LEED points

TECHNICAL CONSIDERATIONS

Architectural

- Finishes
  - ♦ Floor: Soil, grease, water, slip resistant concrete and chemical bonded concrete sealer
  - ♦ Walls: Soil and grease resistant, light colored finish or wire mesh
  - ♦ Ceiling: Painted exposed structure, light colored finish
- Doors
  - ♦ Personnel door with view panel to meet applicable code exit requirements.
  - ♦ Exterior overhead doors: 10'-0"x 10'-0", automatic operator, interior and exterior push button controls with lockout on exterior.
- Bollards on exterior at jambs of overhead door (2 each)

Structural

- Control joints in floor slab at adequate spacing
- Structure as needed to support equipment

Mechanical

- As required by equipment
- Heated to 40 degrees F

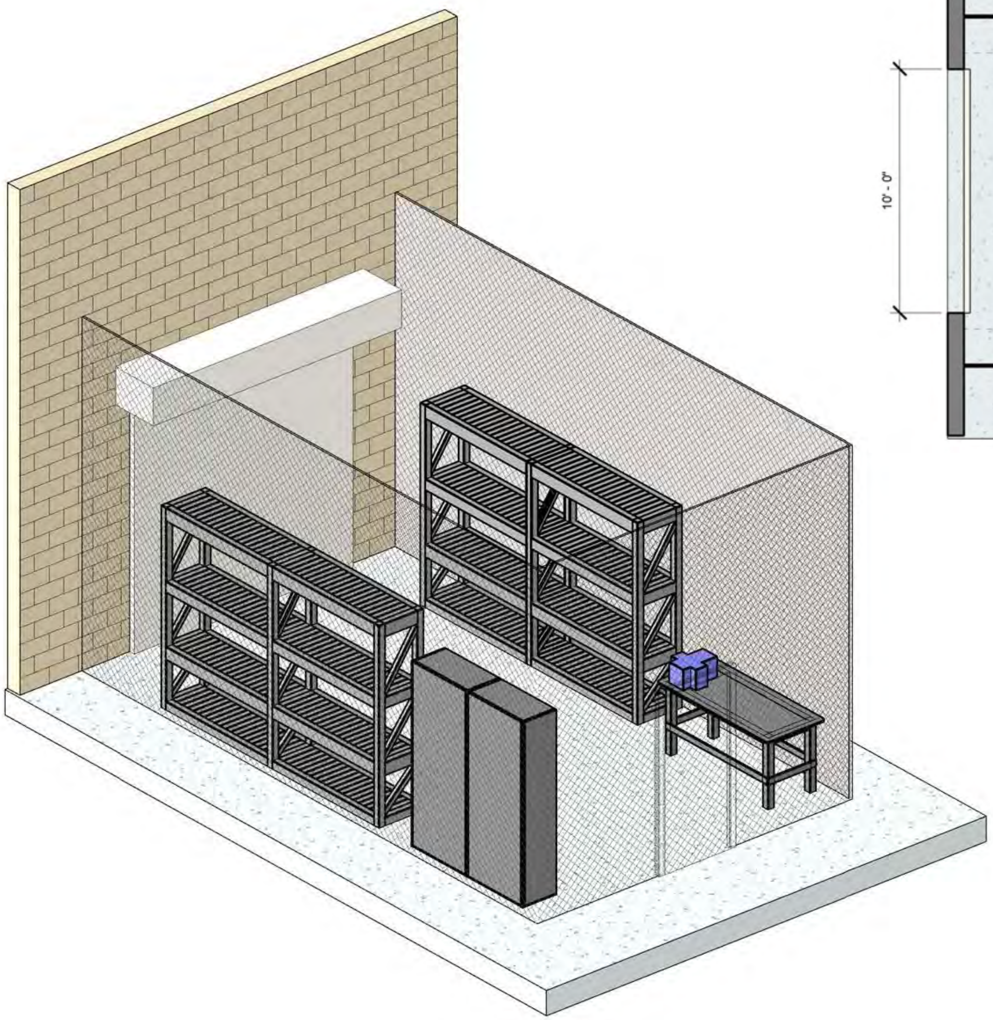
Plumbing

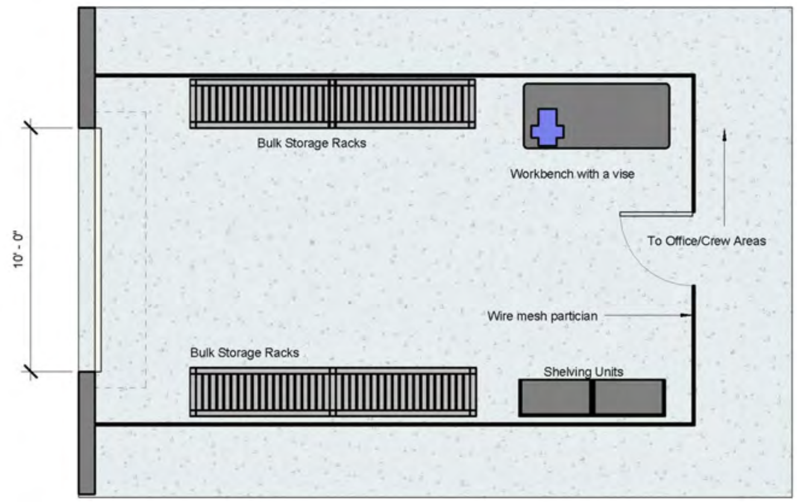
- Water hose bib, 3/4" with standard faucet, 2'-0" AFF
- Compressed air
  - ♦ Main line looped
  - ♦ Compressed air drops; cut off valve, union, separator, and regulator with gauge, 4'-0" AFF

Electrical

- Lighting
  - ♦ Fluorescent lighting, 30 fc average, fixtures located to illuminate work spaces and storage area.
- Power
  - ♦ All receptacles and outlets at 3'-6" AFF
  - ♦ General-purpose duplex receptacles, 120 VAC, 20A, GFI protected, on walls, columns, and between OH doors
  - ♦ As required by equipment
- Communications
  - ♦ Paging/intercom system speakers

POWER - OCS TOOL ROOM





POWER - OCS TOOL ROOM

FUNCTIONAL CHARACTERISTICS

Function: Enclosed, secure shop and materials storage area.

Relationship to Other Areas

- Access to all Restroom/Showers
- Access to Break/Crew Room
- Access to Administrative office areas

Critical Dimensions

- 14'-0" vertical clearance

Equipment/Furnishings

- Severe use workbench with vise
- Storage shelving and racks

Design Features

- Forklift access
- Secure entry
- Access to exterior for deliveries

Sustainable Design Criteria

- Utilize natural lighting strategies
- Provide user-adjustable comfort and lighting controls
- Lighting Design to meet targeted LEED points

TECHNICAL CONSIDERATIONS

Architectural

- Finishes
  - ♦ Floor: Soil, grease, water, slip resistant concrete and chemical bonded concrete sealer
  - ♦ Walls: Soil and grease resistant, light colored finish, or wire mesh
  - ♦ Ceiling: Painted exposed structure, light colored finish
- Doors
  - ♦ Personnel door with view panel to meet applicable code exit requirements.
  - ♦ Exterior overhead doors: 10'-0"x 10'-0", automatic operator, interior and exterior push button controls with lockout on exterior.
- Bollards on exterior at jambs of overhead door (2 each)

Structural

- Control joints in floor slab at adequate spacing
- Structure as needed to support equipment

Mechanical

- As required by equipment
- Heated to 40 degrees F

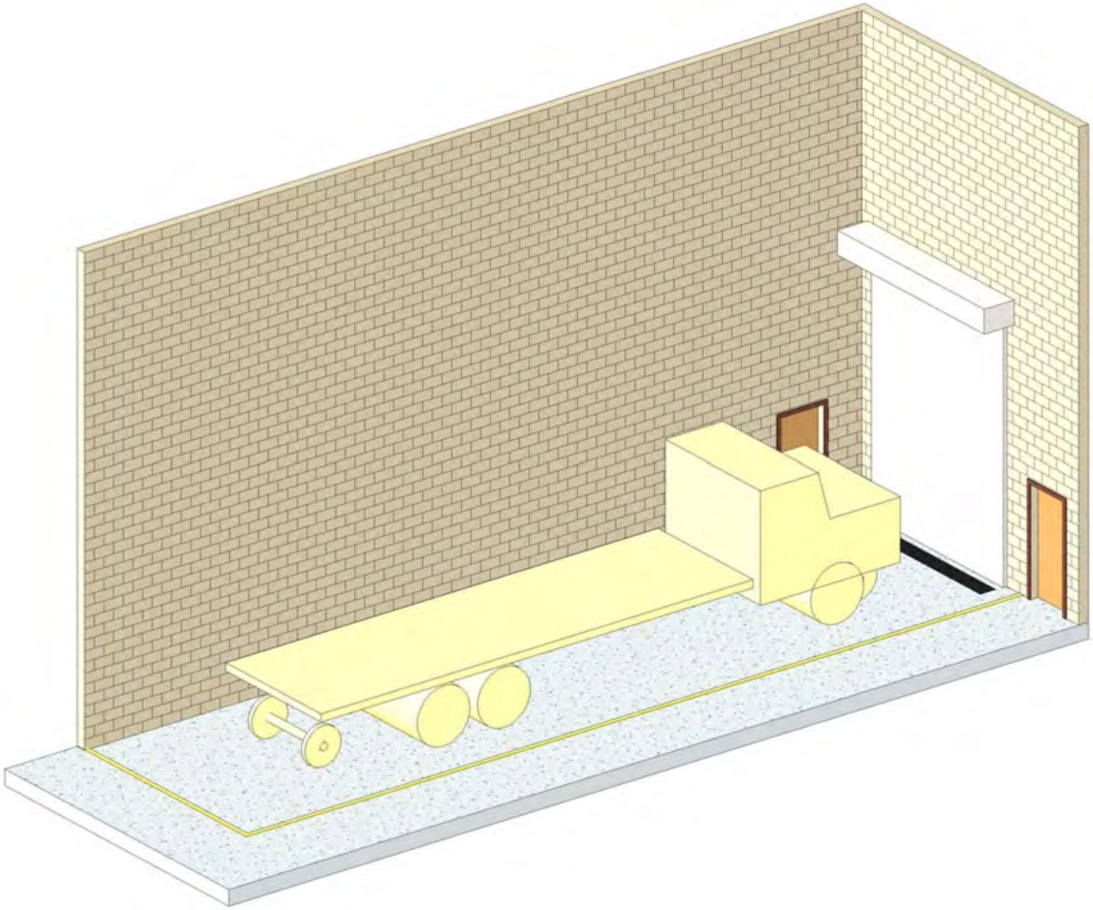
Plumbing

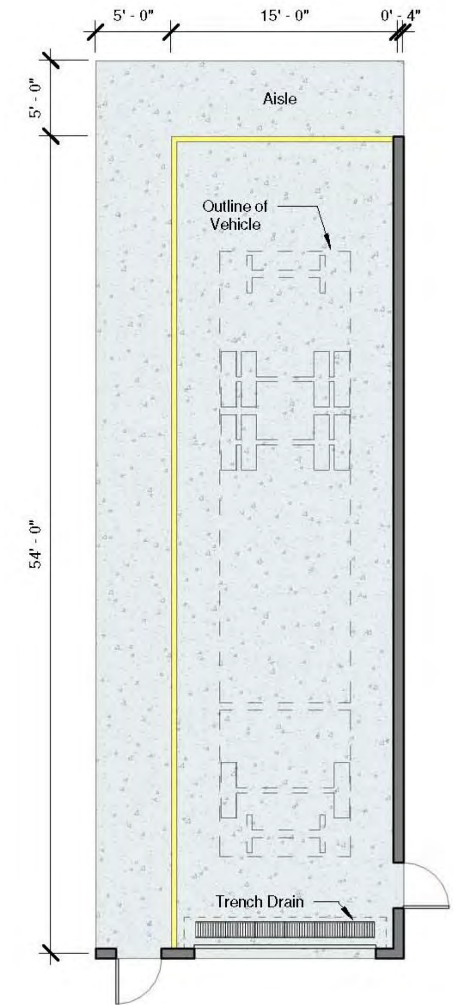
- Water hose bib, 3/4" with standard faucet, 2'-0" AFF
- Compressed air
  - ♦ Main line looped
  - ♦ Compressed air drops; cut off valve, union, separator, and regulator with gauge, 4'-0" AFF

Electrical

- Lighting
  - ♦ Fluorescent lighting, 30 fc average, fixtures located to illuminate work spaces and storage area.
- Power
  - ♦ All receptacles and outlets at 3'-6" AFF
  - ♦ General-purpose duplex receptacles, 120 VAC, 20A, GFI protected, on walls, columns, and between OH doors
  - ♦ As required by equipment
- Communications
  - ♦ Paging/intercom system speakers

POWER - OCS - WORK TRAIN / WIRE TRUCK





POWER - OCS - WORK TRAIN / WIRE TRUCK

FUNCTIONAL CHARACTERISTICS

Function: Enclosed secure vehicle storage area for Engineering and Maintenance

Relationship to Other Areas

- Adjacent to Engineering and Maintenance
- Access to exterior
- Access to Break/Crew Room

Critical Dimensions

- 20'-0" vertical clearance

Equipment/Furnishings

- None

Design Features

- Access to exterior

Sustainable Design Criteria

- Utilize natural lighting strategies
- Provide user-adjustable comfort and lighting controls
- Lighting Design to meet targeted LEED points
- In-floor radiant heat

TECHNICAL CONSIDERATIONS

Architectural

- Finishes
  - ♦ Floor: Soil, grease, water, slip resistant concrete with integral non-metallic light reflective hardener, and chemical bonded concrete sealer
  - ♦ Walls: Soil and grease resistant, light colored finish
  - ♦ Ceiling: Painted exposed structure, light colored finish
- Doors
  - ♦ Personnel door with view panel to meet applicable code exit requirements
  - ♦ Exterior overhead doors: 14'-0" x 14'-0", automatic operator, interior and exterior push button controls with lockout on exterior
- Bollards on exterior at jambs of overhead door (2 each).

Structural

- Control joints in floor slab at adequate spacing
- Floor sloped to trench drain at OH door
- Structure as needed to support equipment

Mechanical

- As required by equipment
- In-floor radiant heat

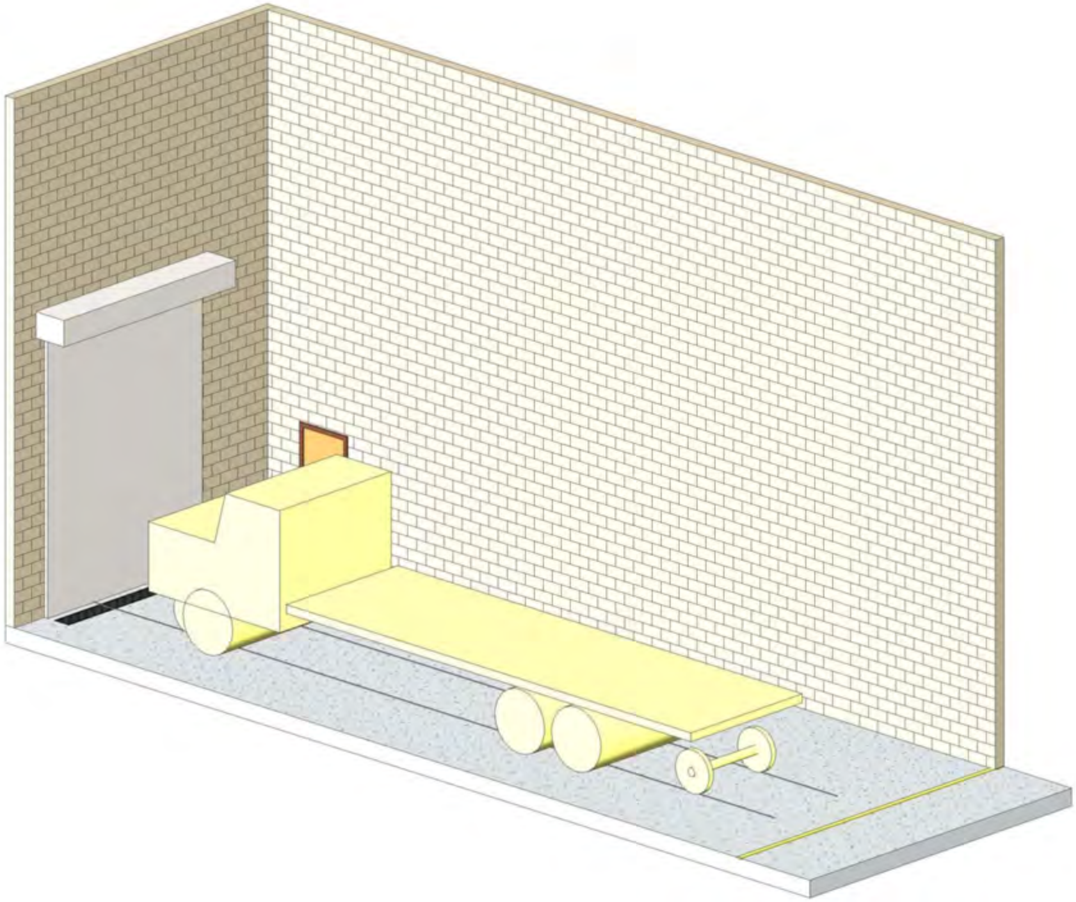
Plumbing

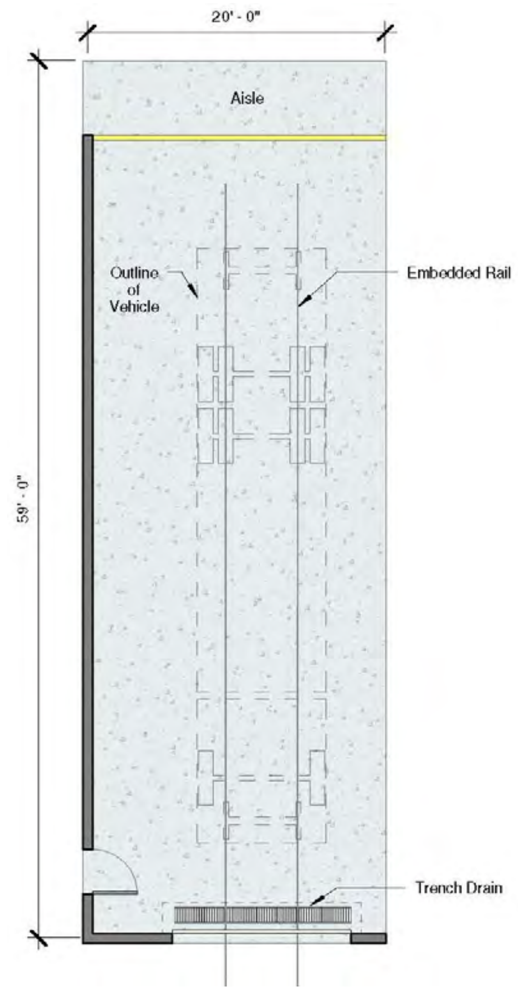
- Trench drains
  - ♦ Run to sediment and oil interceptor
  - ♦ Parallel with vehicle parking with removable covers
- Water hose bib, 3/4" with standard faucet, 2'-0" AFF
- Compressed air
  - ♦ Main line looped
  - ♦ Compressed air drops; cut off valve, union, separator, and regulator with gauge, 4'-0" AFF

Electrical

- Lighting
  - ♦ Fluorescent lighting, 30 fc average, fixtures located to illuminate work spaces and storage area.
- Power
  - ♦ All receptacles and outlets at 3'-6" AFF
  - ♦ General-purpose duplex receptacles, 120 VAC, 20A, GFI protected, on walls, columns, and between OH doors
  - ♦ As required by equipment
- Communications
  - ♦ Paging/intercom system speakers

HI-RAIL TOWER TRUCK





HI-RAIL TOWER TRUCK

FUNCTIONAL CHARACTERISTICS

Function: Enclosed secure vehicle storage area for Engineering and Maintenance group/department. Also used as a Repair Bay.

Relationship to Other Areas

- Adjacent to Engineering and Maintenance Repair Bay
- Access to exterior
- Access to Break/Crew Room

Critical Dimensions

- 20'-0" vertical clearance

Equipment/Furnishings

- None

Design Features

- Access to exterior

Sustainable Design Criteria

- Utilize natural lighting strategies
- Provide user-adjustable comfort and lighting controls
- Lighting Design to meet targeted LEED points

TECHNICAL CONSIDERATIONS

Architectural

- Finishes
  - ♦ Floor: Soil, grease, water, slip resistant concrete and chemical bonded concrete sealer
  - ♦ Walls: Soil and grease resistant, light colored finish
  - ♦ Ceiling: Painted exposed structure, light colored finish
- Doors
  - ♦ Personnel door with view panel to meet applicable code exit requirements
  - ♦ Exterior overhead doors: 14'-0" x 14'-0", automatic operator, interior and exterior push button controls with lockout on exterior
- Bollards on exterior at jambs of overhead door (2 each)

Structural

- Control joints in floor slab at adequate spacing
- Floor sloped to trench drain
- Structure as needed to support equipment
- Embedded rail

Mechanical

- As required by equipment

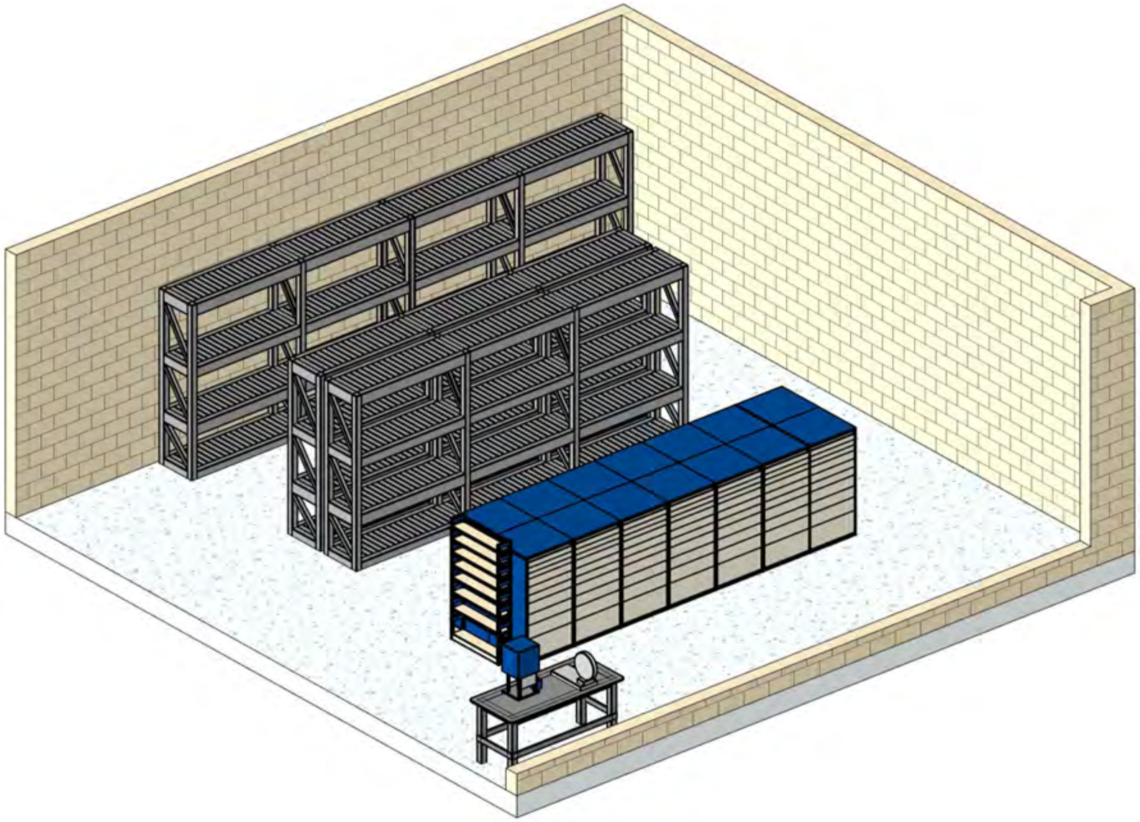
Plumbing

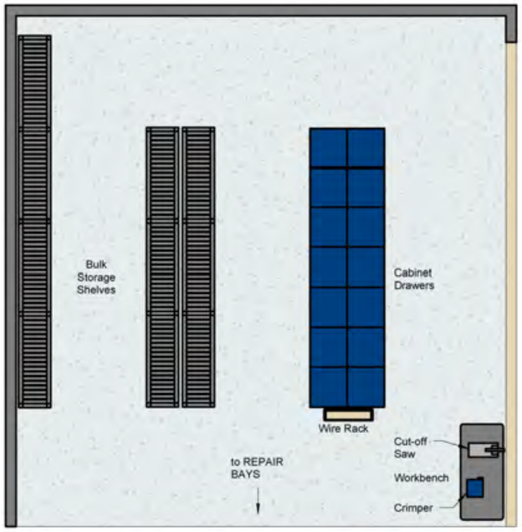
- Trench drains
  - ♦ Run to sediment and oil interceptor
  - ♦ Parallel with vehicle parking with removable covers
- Water hose bib, 3/4" with standard faucet, 2'-0" AFF
- Compressed air
  - ♦ Main line looped
  - ♦ Compressed air drops; cut off valve, union, separator, and regulator with gauge, 4'-0" AFF

Electrical

- Lighting
  - ♦ Fluorescent lighting, 30 fc average, fixtures located to illuminate work spaces and storage area.
- Power
  - ♦ All receptacles and outlets at 3'-6" AFF
  - ♦ General-purpose duplex receptacles, 120 VAC, 20 A, GFI protected, on walls, columns, and between OH doors.
  - ♦ As required by equipment
- Communications
  - ♦ Paging/intercom system speakers

STORAGE




Bulk Storage Shelves
Cabinet Drawers
Wire Rack
Cut-off Saw
to REPAIR BAYS
Workbench
Crimper

STORAGE

FUNCTIONAL CHARACTERISTICS

Function: Dedicated secure area for receiving, storage, and issuing of parts, materials, and specialized tools.

Relationship to Other Areas

- Adjacent to the Engineering and Maintenance Repair Bays and shops
- Access to the exterior for deliveries/distribution

Critical Dimensions

- 12'-0" vertical clearance

Equipment/Furnishings

- Layout table and desk at receiving
- Storage shelving, racks, and cabinets
- Storage cabinets

Design Features

- Provide staging area for shipping/receiving with an overhead door to the exterior of the building
- Overhead bridge crane
- Located on mezzanine

Sustainable Design Criteria

- Utilize natural lighting strategies
- Provide user-adjustable comfort and lighting controls
- Lighting Design to meet targeted LEED points

TECHNICAL CONSIDERATIONS

Architectural

- Finishes
  - ♦ Floor: Soil, grease, water, slip resistant concrete and chemical bonded concrete sealer
  - ♦ Walls: Soil and grease resistant, light colored finish
  - ♦ Ceiling: Painted exposed structure, light colored finish
- Doors
  - ♦ Personnel door with view panel to meet applicable code exit requirements

Structural

- Control joints in floor slab at adequate spacing
- Structure as needed to support equipment

Mechanical

- Heat 70 degree F and air conditioned
- As required by equipment

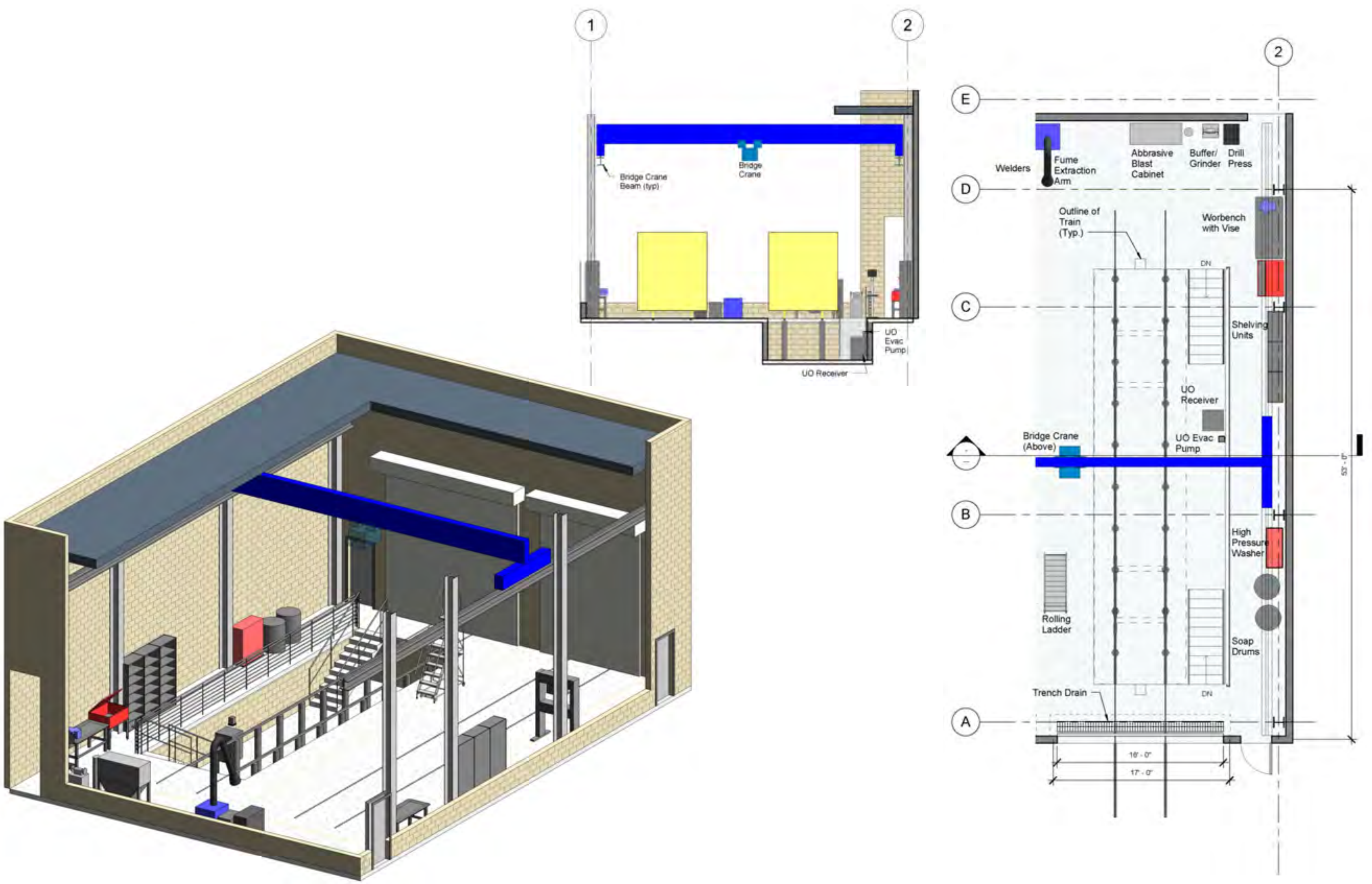
Plumbing

- None

Electrical

- Lighting
  - ♦ Fluorescent lighting, 50 fc average, local switching, fixture located to illuminate work spaces
- Power
  - ♦ General-purpose duplex receptacles, 120 VAC, 20 A, GFI protected, on walls at 3'-6" AFF
  - ♦ Dedicated computer receptacle, 120 VAC, 20 A, adjacent to computer cable conduit at parts window and receiving door
  - ♦ As required by equipment
- Communications
  - ♦ Paging/intercom system speakers
  - ♦ Data outlet and conduit for computer at parts window and receiving door

RAIL BOUND EQUIPMENT MAINTENANCE AND SHOP



RAIL BOUND EQUIPMENT MAINTENANCE AND SHOP

FUNCTIONAL CHARACTERISTICS

Function: Designed bay for performing inspections and PMs on Engineering and Maintenance highrail equipment.

Relationship to Other Areas

- Access to Storage and Manuals Library
- Accessible from office areas

Critical Dimensions

- 20'-0" vertical clearance to bridge crane
- 22'-0" wide by 55'-0" long

Equipment/Furnishings

- Lube reel banks with (CG, GO, HO, and WWF) shared (1 per 2 bays)
- Severe use workbench with vise (2 per bay)
- Buffer/grinder
- Shelving
- Parts clearing tank
- Welders
- Mobile fume extraction
- Vehicle exhaust reel
- Bridge crane
- UO extraction pump and portable receiver
- Hydraulic press
- Abrasive blast cabinet
- Drill press
- High pressure washer

Design Features

- LLWA open full width of bay
- Stairs from LLWA to finish floor
- LLWA depth - 66 inches, under LRVs tracks

Sustainable Design Criteria

- Utilize natural lighting strategies
- Provide user-adjustable comfort and lighting controls
- Lighting Design to meet targeted LEED points

TECHNICAL CONSIDERATIONS

Architectural

- Finishes
  - ♦ Floor: Soil, grease, water, slip resistant concrete with integral non-metallic light reflective hardener, and chemical bonded concrete sealer
  - ♦ Walls: Soil and grease resistant, light colored finish
  - ♦ Ceiling: Painted exposed structure, light colored finish
- Doors
  - ♦ Personnel door with view panel to meet applicable code exit requirements
  - ♦ Exterior overhead doors: 16'-0" x 16'-0" , automatic operator, interior and exterior push button controls with lockout on exterior.

Structural

- Control joints in floor slab at adequate spacing
- Structure as needed to support equipment
- Structure to support elevated tracks over LLWA.
- LLWA 66" deep under LRV's tracks and between S&I bays

Mechanical

- Vehicle exhaust
- As required by equipment
- Destratification fans

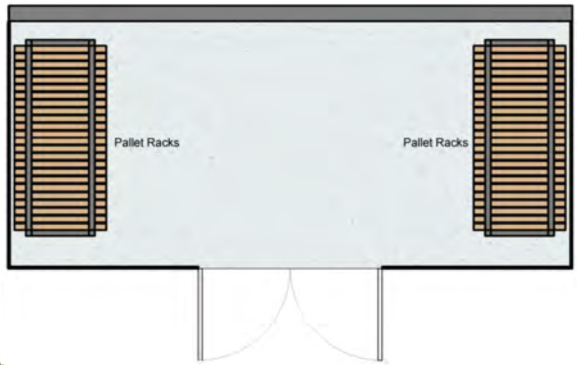
Plumbing

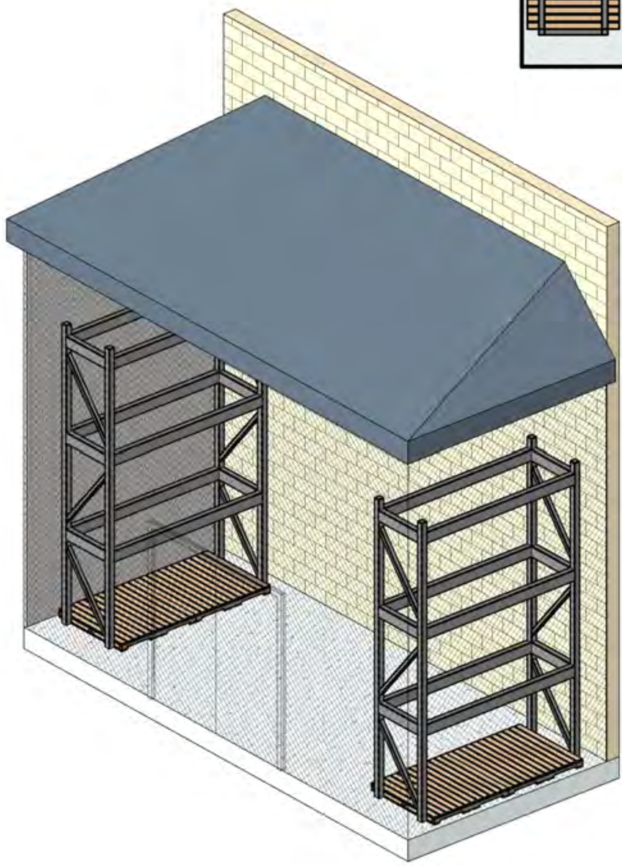
- Trench drains
  - ♦ Run to sediment and oil interceptor
  - ♦ At overhead door with removable covers
  - ♦ At drip lines of the LRV in LLWA. Slope floor between rails to trench drains only. Space between LRV's in LLWA to remain flat/level
- 3/4" water hose bib with standard faucet on main and LLWA level, 2'-0" AFF (1 per bay)
- Lube reel banks with CG, GO, HO and WWF (shared per 2 bays)
- Compressed air
  - ♦ Main line looped
  - ♦ Compressed air drops; cut off valve, union, separator, regulator with gauge and quick disconnect, 4'-0" AFF
  - ♦ Provide disconnect for 1/2" and 1" impact tools

Electrical

- Lighting
  - ♦ Fluorescent lighting, 50 fc average, fixtures located to illuminate work spaces and around LRV's
- Power
  - ♦ 3'-6" AFF
  - ♦ General-purpose duplex receptacles, 120 VAC, 20 A, GFI protected, on walls, columns, and bet. OH doors
  - ♦ Welding outlets, centrally located, 208 VAC, 1 phase, 50 A (shared 1 per 2 bays)
  - ♦ Dedicated computer receptacle, 120 VAC, 20 A adj. to computer conduit
  - ♦ As required by equipment
- Communications
  - ♦ Paging/intercom system speakers
  - ♦ Computer conduit, main Level (1 per bay)

SIGNALS - SWITCH COVERS - COVERED STORAGE





FUNCTIONAL CHARACTERISTICS

Function: Covered secure are for storage of equipment and supplies.

Relationship to Other Areas

- Access shop areas and storage

Critical Dimensions

- 16'-0" vertical clearance

Equipment/Furnishings

- Metal pallet racks

Design Features

- Floor: Exposed concrete slab
- Walls: Wire mesh, or chain link.
- Ceiling: Painted exposed structure
- Doors: 10 feet wide lockable gate
- Secure area
- Electrical:
    - ♦ Fluorescent lighting, 30 fc average
    - ♦ General purpose duplex receptacles, 120 VAC, 20 A, GFI protected as required by Electrical Code and required for charging equipment.

Sustainable Design Criteria

- None

Attachment 3A – Vehicle Maintenance Facility Complex Structural Design Criteria

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GLX Green Line Extension Project

Vehicle Maintenance Facility Complex

Structural Design Criteria

Supplemental Details and Requirements

Prepared for:

Massachusetts Bay Transportation Authority

Revision C

June 2014

Prepared by:

Shaw Environmental & Infrastructure of Massachusetts, Inc

A CB&I Company

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Table of Contents

Acronyms

AASHTO	American Association of State Highway and Transportation Officials
ACI	American Concrete Institute
AISI	American Iron and Steel Institute
AISC	American Institute of Steel Construction
AREMA	American Railway Engineering and Maintenance-of-Way Association
ASCE	American Society of Civil Engineers
ASD	Allowable Stress Design
ASTM	American Society for Testing and Materials
AWS	American Welding Society
CMR	Code of Massachusetts Regulations
CMU	Concrete Masonry Units
EPD	Employee Parking Deck
HSS	Hollow Structural Tubing
IBC	International Building Code
LB	Pound
LFD	Load Factor Design
LRFD	Load Factor Resistance Design
LRV	Light Rail Vehicle
MassDOT	Massachusetts Department of Transportation
MBG	Metal Bar Grating
MBTA	Massachusetts Bay Transit Authority
NFPA	National Fire Prevention Association
PCF	Pounds per Cubic Foot

PLF	Pounds per Linear Foot
PSF	Pounds per Square Foot
RT	Grade Separation Retaining Walls
TB	Transportation Building
VMF	Vehicle Maintenance Facility
VMFC	Vehicle Maintenance Facility Complex

1.0 Objective

This document sets forth the minimum structural design requirements for the Green Line Extension Project Vehicle Maintenance Facility Complex main force resisting systems (i.e., the structural skeleton). The Vehicle Maintenance Facility Complex is located in the city of Somerville and consists of the Vehicle Maintenance Facility (VMF), Transportation Building (TB), Employee Parking Deck (EPD) and grade separation retaining walls.

Additional details and requirements specific to this project follow. The additional requirements are minimum requirements and do not supersede a more stringent requirement of the basic code.

Vehicle Maintenance Facility (VMF)

The Vehicle Maintenance Facility is generally a four-story open structure that will accommodate Light Rail Vehicles for maintenance and cleaning and provides office space. The main floor, where the majority of the maintenance and cleaning activities takes place, has maintenance pits to access the underside of the vehicles. There are raised platforms to service the top portion of the vehicle. There is a mezzanine level primarily used as a storage and lay down area. There are four under hung material handling cranes servicing three bays of this facility. There is an adjacent two-story building separated by CMU fire wall used to handle all truck associated repairs. The first level will accommodate truck cleaning and repair and the mezzanine level accommodates office space. The mezzanine level of this area is common to both structures.

The facility will be designed as a rigid frame structure with the roof deck designed as a horizontal diaphragm transferring lateral loads to the braced rigid frame system. Open web bar joists and wide flange sections used as spandrel beams support the roof for gravity loads. Bracing, perpendicular to the rigid frame, is employed to transfer the lateral building loads to the foundation system. The facility is supported by deep foundation elements consisting of one drilled shaft at each building column. A perimeter grade beam spans between drilled shafts supporting the building exterior facade. The main floor slab is thickened locally to accommodate block walls, embedded RR tracks, and other equipment. The roof is designed to accommodate a blue roof.

Transportation Building (TB)

The Transportation Building includes a single level primary office space with an adjacent 3-level elevator/stair entry tower area on shallow foundations. The office area is constructed of structural steel moment frames supporting open-web steel bar joist with in-fill light gauge metal stud wall framing. A wide-rib steel roof deck acts as a horizontal diaphragm to transfer lateral loading to the moment frame system. The adjacent elevator/stair entry tower is constructed of reinforced 12-inch concrete masonry unity (CMU) exterior bearing/shear walls with 8-inch reinforced CMU interior partition walls. The roof is designed to accommodate a hybrid Blue/Green roof.

Employee Parking Deck (EPD)

The Employee Parking Deck is restricted to passenger vehicles accommodating no more than nine (9) passengers and consists of an elevated cast-in-place concrete beam supported parking deck. Green Line Light Railcars will be stored beneath the EPD. Catenary is attached to the underside of the beams. The substructure of the EPD consists of column/drilled shafts. A two lane ramp, supported by single column/drilled shaft hammer heads, provides vehicular access/egress to the deck.

Grade Separation Retaining Walls (RT)

{Later}

2.0 General

Refer to Section 2.9.1.

3.0 Codes, Specifications and References

Refer to Section 2.9.2. The basic code establishing the minimum structural design requirements is the International Building Code 2009 (IBC 2009) as amended by the Massachusetts Building Code 8th Edition.

4.0 Design Methodology

Refer to Section 2.9.3.

5.0 Loads and Forces

5.1. General

Structures or parts of structures shall be designed considering the loads and forces defined herein. Loads from adjacent buildings or structures shall be included in the design loadings where applicable. In the absence of specific information, provision in the applicable codes for the actual weight and heaviest loadings that the structure is suitable for shall be used. Horizontal and vertical distribution of loads from foundations of existing structures shall be determined in consultation with the geotechnical design engineer.

The following design load criteria are applicable to buildings/structures in general. Design loads for systems and equipment are developed as the system layout progresses and as equipment are procured. The structural engineer shall consider where such conservative loads are important to the structural design and shall document the basis for the loads assumed in the initial design. As equipment loads are finalized, the structural engineer shall reconcile them against the initial design.

5.2. Dead Load (D)

Dead loads shall consist of the actual weight of all components of the structure and all elements that are permanently supported by the structure. For unit dead load of materials, refer to the IBC as amended by the Massachusetts Building Code. The unit weight of materials comprising the dead load, except in special cases involving unusual conditions and/or materials, shall be as follows:

- Light-weight concrete 115 pcf
- Concrete 150 pcf
- Steel 490 pcf
- Sand, gravel and earth filling material 130 pcf
- Utilities (pipes, drains, etc) 200 plf
- Rainwater 62.4 pcf
- Catenary (to be supplied later)

Consideration shall be given to any system or facility such as piping, conduit, manholes, cables, pulling irons, catenary and other services that will apply a load or force or cause a force to be transmitted to the structure. The deadweight of equipment shall be based on its bounding operating condition including the weight of fluids. In addition, permanently attached non-structural elements such as siding, partitions and insulation shall be included. Dead load of cranes and elevators shall not include the rated capacity or impact.

5.2.1. Green Roof

The green roof consists of 8-in thick layer of saturated engineered soil. The dead load shall be taken as 65 psf.

5.3. Live Loads (L)

5.3.1. Construction Loads

Metal decking and elevated concrete floors shall be designed for the wet weight of the concrete plus a construction live load of 20 psf uniform or 300 lb concentrated. For these items used as a form, the deflection shall be limited to the smaller of the span length in inches divided by 180, or 0.75 inch. Construction shall be designed for “unshored” conditions.

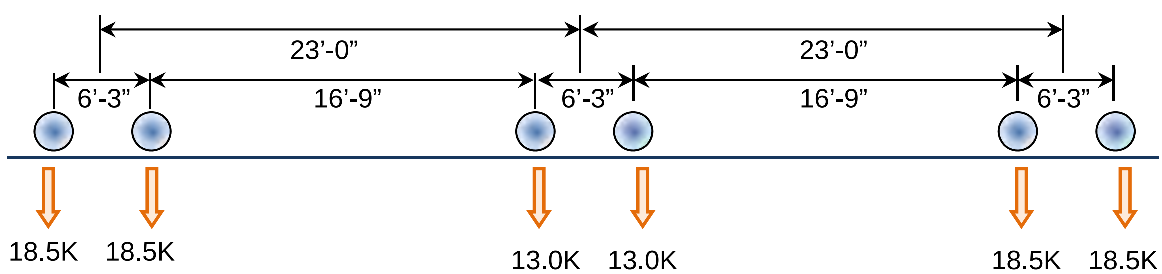
5.3.2. Minimum Area Loads

The minimum live loads for the identified areas shall be applied as given below. Where concentrated loads are specified, they shall be distributed over a 2½ ft by 2½ ft area (6¼ SF) and located to produce the maximum load effects on the member. The area shall be designed for the more severe effects of the uniform and concentrated loads listed.

Corridor	100 psf (first floor); 80 psf, 2000 lb (elsewhere)
Office	50 psf, 2000 lb
VMF Main Floor	250 psf, 3000 lb
VMF Work Platform	60 psf
VMF Mezzanine	125 psf, 2000 lb
Mechanical Room	100 psf
Roof	20 psf (in addition to green and/or blue roof loadings)

5.3.3. Green Line Rail Vehicle

The Vehicle Maintenance Facility Complex shall be designed to accommodate the Type 7, 8 & 9 Light Rail Vehicles. The loads associated with the design vehicle (one that accounts for all three types) are based on the heaviest empty LRV and a 20 psf loading for maintenance personnel and equipment. The resulting axle loads (individual wheel loads are ½ the specified axle load) shall be distributed in accordance with the diagram below:



5.3.4. Crane Loads

Crane and equipment supplier's information shall be used for wheel loads, equipment loads, weights of moving parts and reactions of clamps (if any). Construction loads shall be considered where applicable.

Impact allowance for traveling crane supports, connections and runway beams shall be in accordance with Section 1607.12 of the IBC, unless the crane manufacturer's design specifies higher impact loads. The maximum vertical wheel loads (DL + LL) of the crane shall be increased by the percentage shown below to determine the induced vertical impact:

1. Monorail cranes: 25%
2. Remote operated bridge cranes: 25%
3. Pendant Operated bridge cranes: 10%
4. Hand-geared monorail or bridge crane trolley/hoist: 0%

Runway beams shall be designed for a lateral force equivalent to 20% of the rated capacity, plus weight of hoist and trolley. This force shall be applied horizontally to the traction surface of a runway beam and in either direction perpendicular to the runway beams. The lateral force shall be distributed according to the lateral stiffness of the runway beams and supporting structure.

The longitudinal force on crane runway beams, except for bridge cranes with hand-geared bridges, shall be calculated as 10% of the maximum wheel loads of the crane. The longitudinal force shall be assumed to act horizontally at the traction surface of a runway beam, in either direction parallel to the beam.

Impact and seismic forces shall not be applied simultaneously. Vertical, transverse, and longitudinal impact shall not be considered to act concurrently.

5.3.5. Blue Roof

The blue roof shall be capable of storing 4½ inches of rainwater. The live load shall be taken as 25 psf. Consideration shall be taken with respect to the blue roof drainage system for that portion that can become blocked causing the water to rise above the storage amount.

5.3.6. Railings

Railings and barriers around stairways, and stairwells shall be designed for a horizontal load of 150 plf and a vertical load of 100 plf applied simultaneously along the top rail. Horizontal members other than the top rail shall be designed for a horizontal load of 50 plf and a vertical load of 50 plf applied simultaneously along the member. Posts shall be designed for a transverse load (perpendicular to the run of the railing) equal to 150 plf times the spacing between posts applied at the top rail but no more than 5 ft above the walkway.

5.3.7. Stairways

Stairways shall be designed for a uniform load of 150 psf or a uniform load of 100 psf with a concentrated load of 300 lbs on the center of stair treads. The loading that has the more severe effect on the structure shall be the loading used.

5.3.8. EPD

The Employee Parking Deck shall be designed for a uniform load of 40 psf and a concentrated load of 3 kips applied over a 4.5-in by 4.5-in area. The ramp of the EPD shall be designed for a HS-15 loading in accordance with AASHTO criteria. In addition, the lane areas of the EPD deck shall be locally (bending) designed for the HS-15 loading.

Due consideration shall be given to snow removal activities and the equipment required to remove the snow. A reduced live load during snow removal is permitted.

5.3.9. EPD Vehicle Barrier

The EPD barrier shall be designed for the more severe case of a 6 kip horizontal load applied over one square foot at either 1’-6” or 2’-3” above the deck. The ramp vehicle barrier shall be designed in accordance with the requirements of section 3.1.6 of the MassDOT LRFD 2009 Bridge Manual Parts 1 and 2.

5.4. Wind (W)

Facilities and equipment shall be designed for wind loading effects in accordance with the IBC as amended by the Massachusetts Building Code. The following design parameters are applicable:

Operating Wind Speed (V): 105 mph (3-second gust at 33 feet above ground)

Exposure Category: Category C, unless otherwise noted

Transportation Building Exposure Category: Category B

The design wind pressure for the main force resisting system or components and cladding shall not be less than 10 pounds per square foot multiplied by the area of the building/structure projected on a vertical plane normal to the wind direction, both leeward and windward. For components and cladding, the algebraic sum of the pressures acting on opposite faces shall be taken into account.

The overturning moment due to wind shall not exceed two thirds of the resisting moment of the structure and foundation during the lightest possible condition after construction is complete.

The EPD shall be designed to withstand wind loads of uniform pressure acting on the superstructure and substructure as specified herein. Winds on various system elements, such as communication equipment, catenary supports and all other fixtures on the structure shall be considered in the design of both the superstructure and the substructure. As a minimum, the wind load on the EPD shall be 50 psf applied to the vertical projection of the structure.

5.5. Rain (R)

Each portion of the roof shall be designed to sustain the load of rainwater that will accumulate if the primary drainage system for that portion of the roof is blocked, plus the uniform load caused by water that rises above the inlet of the secondary drainage system at its design flow. The rain loads are based on a 100 year hourly storm in accordance with Figure 1611.1 of the IBC equal to 2.25 inches. The rain loads described herein are those that are in addition to that associated with the dead/live loads of a specified green/blue roof. Structures and components shall be designed for the accumulation of rain water in accordance with the IBC.

5.6. Earth Pressure (H)

Substructure elements shall be proportioned to withstand lateral earth pressure in accordance with the provisions provided in the geotechnical information and as stipulated by the geotechnical engineer. In general, the following guidelines apply:

- The design weight of earth above the water table shall not be less than 130 pcf. The submerged unit weight shall not be less than 68 pcf for earth below the ground water table.
- Structures that retain earth shall be designed for earth pressure, any abutting surcharges and shall consider hydrostatic pressure along with dry and submerged earth pressures based on the groundwater table elevation.
- Structures that retain earth shall be designed to resist an earthquake force, $F_{w,}$ for horizontal backfill equal to $F_w = 0.100(S_s)(F_a)(\gamma_T)H^2$, where S_s and F_a are given in 5.11 below, γ_T is the total unit weight of the soil and H is the height of the wall measured as the difference of finished ground elevation in front of and behind the wall. The earthquake force shall be applied as an inverted triangle over the height of the wall.
- Permanent horizontal loads on structures shall be computed using the at-rest earth pressure coefficient K_o.
- Live loads and dead loads from adjacent buildings shall be considered in computing the design horizontal pressure.
- Transit or railroad surcharge shall follow AREMA criteria. Vehicle surcharge shall be accounted for by using a surcharge load equivalent to 2 ft of soil.
- The factors of safety against sliding shall be 1.5 and against overturning shall be 2.0.
- Resistance from passive earth pressure acting against the wall shall be neglected when computing the factors of safety against sliding and overturning.
- Unbalanced earth pressure on either side of the wall shall be considered to account for construction and/or excavation/backfilling conditions.
- The allowable soil bearing pressures to be used in the design shall be established in consultation with the geotechnical engineer. The maximum design soil bearing

pressure and allowable soil bearing pressure for each foundation elevation shall be noted on the plans.

5.7. Hydrostatic Pressure and Buoyancy (B)

The effects of hydrostatic pressure and buoyancy shall be considered whenever the presence of groundwater is indicated to be at or above the lowest foundation elevation. Hydrostatic pressures for groundwater shall be computed at 62.4 pcf per foot of depth below the water table.

For buoyancy computations, backfill shall be considered as the volume within the vertical planes defined by the outer limits of the structure. The unit weight of backfill atop the footing shall not be taken as more than 130 pcf. The submerged unit weight of backfill shall not be taken as more than 68 pcf. The factor of safety against buoyancy shall be 1.5.

5.8. Snow (S)

The ground snow load shall be taken as 45 psf. Roofs and decks shall be designed for snow loads, drifting, blue roof storage and ponding in accordance with the IBC as amended by the Massachusetts Building Code.

5.9. Ice (I)

Ice sensitive structures, such as open truss-like structures, overhead lines and open platforms, shall be designed in accordance with Chapter 10 of ASCE 7, for the effects of ice accretion formed by freezing rain, sleet and snow.

5.10. Thermal (T)

Provisions shall be made for the deformations and stresses resulting from temperature variations about the base temperature. The expected temperature rise and fall shall be assumed as follows:

Concrete:

Temperature rise:	35ºF	Temperature fall:	45ºF
Coefficient of expansion:	0.6E05 in/in/ºF		

Steel:

Temperature rise:	70ºF	Temperature fall:	100ºF
Coefficient of expansion:	0.65E05 in/in/ºF		

The base temperature for structures shall be taken as 68ºF.

5.11. Earthquake (E)

The seismic design of the structures shall be in accordance with the IBC as amended by the Massachusetts Building Code. The IBC invokes ASCE 7 as the parent code for earthquake design. The following parameters shall be used:

Spectral Response Acceleration Parameter $S_s = 0.28$

Spectral Response Acceleration Parameter $S_1 = 0.069$

Occupancy Category – II

Seismic Importance Factor – 1.0

Site Class - D

Seismic Design Category – B

Site Coefficients: F_a – 1.58; F_v – 2.4; S_{MS} – 0.44; S_{M1} – 0.17; S_{DS} – 0.294; S_{D1} – 0.110

6.0 Loading Combinations

6.1. Load Factor Design

The minimum strength required for structural members and their connections shall be computed from the most critical load combination listed below:

Eq 16-1	1.4 D
Eq 16-2_a	1.2 (D + T) + 1.6 (L + H) + 0.5 L_r
Eq 16-2_b	1.2 (D + T) + 1.6 (L + H) + 0.5 S
Eq 16-2_c	1.2 (D + T) + 1.6 (L + H) + 0.5 R
Eq 16-3_a	1.2 D + 1.6 L_r + f_1 (0.8 W)
Eq 16-3_b	1.2 D + 1.6 S + f_1 (0.8 W)
Eq 16-3_c	1.2 D + 1.6 R + f_1 (0.8 W)
Eq 16-3_d	1.2 D + 1.6 L_r + f_1 L
Eq 16-3_e	1.2 D + 1.6 S + f_1 L
Eq 16-3_f	1.2 D + 1.6 R + f_1 L
Eq 16-4_a	1.2 D + 1.6 W + f_1 L + 0.5 L_r

Eq 16-4$_b$ 1.2 D + 1.6 W + f_1 L + 0.5 S

Eq 16-4$_c$ 1.2 D + 1.6 W + f_1 L + 0.5 R

Eq 16-5[1] 1.2 D + 1.0 E + f_1 L + f_2 S

Eq 16-6 0.9 D + 1.6 W + 1.6 H

Eq 16-7[1] 0.9 D + 1.0 E + 1.6 H

where:

f_1 = 1.0 for platforms and live loads greater than 100 psf; 0.5 for other live loads.

f_2 = 0.7 for roof configurations (e.g., saw tooth) that do not shed snow off the structure; 0.2 for other roof configurations.

1 For structures that retain earth, the seismic (E) load factor shall be 1.43 in lieu of 1.0

L_r – Roof Live Load,

6.2. Allowable Stress Design and Serviceability

For allowable stress design, serviceability and durability checks, the following load combinations shall be investigated:

Eq 16-8 D

Eq 16-9 D + H + L + T

Eq 16-10$_a$ D + H + L_r

Eq 16-10$_b$ D + H + S

Eq 16-10$_c$ D + H + R

Eq 16-11$_a$ D + H + 0.75 (L + T + L_r)

Eq 16-11$_b$ D + H + 0.75 (L + T + S)

Eq 16-11$_c$ D + H + 0.75 (L + T + R)

Eq 16-12$_a$ D + H + W

Eq 16-12$_b$ D + H + 0.7 E

Eq 16-13$_a$ 0.8 D + 1.07 (H + W) + 0.67 f_1 L + 0.33 L_r

Eq 16-13$_b$ 0.8 D + 1.07 (H + W) + 0.67 f_1 L + 0.33 S

Eq 16-13$_c$ 0.8 D + 1.07 (H + W) + 0.67 f_1 L + 0.33 R

Eq 16-13$_d$ 0.8 D + 0.67 (E + f_1 L) + 0.33 L_r + 1.07 H

Eq 16-13$_e$ 0.8 D + 0.67 (E + f_1 L) + 0.33 S + 1.07 H

Eq 16-13$_f$ 0.8 D + 0.67 (E + f_1 L) + 0.33 R + 1.07 H

Eq 16-14 0.6 D + W + H

Eq 16-15 0.6 D + 0.7 E + H

where:

f_1 = 1.0 for platforms, EPD and live loads greater than 100 psf; 0.5 for other live loads.

L_r – Roof Live Load,

7.0 Materials

The principal construction materials for structures are concrete, reinforcing steel, structural steel, stainless steel, bolts, anchor bolts, weld electrodes and formed metal deck. These materials are discussed below.

7.1. Concrete

Refer to Section 2.9.4.

7.2. Masonry

Refer to Section 2.9.4.

7.3. Structural Grout

Refer to Section 2.9.4.

7.4. Reinforcing Steel

Refer to Section 2.9.4.

7.5. Structural Steel

Refer to Section 2.9.4.

7.6. Bolts and Anchor Bolts

Bolts

Structural connections shall be bearing-type connections except where slip critical connections are essential. Sizes for structural bolting material should be limited to 7/8-inch diameter for all ASTM A325, Type 1 bolts or 1-1/8-inch diameter for ASTM A490, Type 1 bolts.

Nuts shall conform to ASTM A563, Grade DH.

Washers shall conform to ASTM F436, Type 1.

Anchor Bolts

Anchor bolts shall not be less than 7/8-inch diameter conforming to ASTM F1554, Grade 55. All anchor bolt assemblies shall be galvanized.

7.7. Welding

Unless specifically noted otherwise on the design drawings, welding of carbon steel shall be in accordance with AWS D 1.1 with a nominal tensile strength of 70 ksi.

7.8. Grating

Grating shall be welded, galvanized steel conforming to MBG 531. All grating shall be banded.

8.0 Other Design Considerations

8.1. Stray Current

Protection of the structure against the stray current shall be incorporated in the structure documents including life expectancy of any isolating and/or sacrificial materials used. Details are to be coordinated with the project engineer responsible to cathodic protection.

8.2. Platform Kickplates

Kickplate consisting of 1/4-inch thick steel plate projecting 4-inches above the platform surface, shall be applied to all platform areas, as required, to satisfy the requirements of the IBC for protection of personnel.

9.0 Foundations

9.1. Soil Data

All geotechnical design perimeters shall be established and provide by the Project's Geotechnical Consultant, Nobis. The subsurface investigation, in general, shall provide information such as: groundwater level(s), soil and rock unit weights, bearing capacity under normal and seismic conditions, angle of internal friction, coefficient of active, passive and at-rest pressures, swelling potential, modulus of elasticity, Poisson's Ratio, compressive and tensile strengths, shear strengths, consolidation, liquefaction potential, PH, resistivity and chemical properties (especially those that might be aggressive to usual structural materials, e.g., chlorides, sulfides, etc.).

The resulting Geotechnical Report shall define the soil properties to be used in design, including densities, strengths, deformity and permeability. The report shall also include recommendations for earth pressure coefficients, allowable bearing capacities, allowable skin friction values, recommended foundation types, settlement estimates, seismic characteristics and construction methods where applicable.

9.2. Shallow Foundations

Foundation design shall take into account the presence of potentially detrimental substances in the soils, if any, such as chlorides and sulfates. This may be accomplished by providing appropriate protection for reinforcement, concrete and metal embedments.

The design bearing pressure shall be provided in the geotechnical report and on the abutment/retaining wall elevation drawings. All footings shall be designed to keep maximum soil pressures within safe bearing values. To protect against undesirable settlement, footings shall be designed to keep the pressures under long term sustained loads as nearly uniform as practicable. The eccentricity of the resultant force shall not exceed ¼ B (footing width). When checking serviceability, uplift of edges and/or corners is not permitted.

9.3. Deep Foundations

The geotechnical report shall provide information relative to foundation materials and recommendations of the length of pile or drilled shaft most suitable for these conditions. Static and dynamic analysis of drilled shafts shall comply with the requirements of AASHTO Standard Specification for Highway Bridges.

9.4. Deformation and Settlement

Deformations of the structure, including foundation settlement, shall be kept to a minimum. Loads induced on structures by a tolerable differential settlement shall be considered in the design. The settlement of a structure shall not exceed 1¼-in and the differential settlement shall not exceed ¾-in between any two adjacent structures.

10.0 Design

10.1. Concrete Design

Design shall follow the methodologies and meet the requirements of ACI 318.

The concrete mix design shall be approved by the project's Engineer prior to use.

Calcium nitrate corrosion inhibitor shall be added to the concrete.

Contraction joints and expansion joints shall be provided in concrete walls and slabs. Spacing of contraction joints shall not exceed 20 ft. Spacing of expansion joints shall not exceed 80 ft. All exterior element joints in contact with soil shall have non-metallic water stops.

10.2. Steel Design

Design shall follow the ASD methodologies and meet the requirements of AISC 360.

Working points of bracing systems on columns, beams and trusses shall be concentric, wherever practical. Working points at column bases shall typically be at the bottom of base plates, except where base plate design is adversely impacted.

The horizontal component of large bracing forces shall typically be transferred to the foundation through the use of shear keys.

Gusset plates shall be 3/8 inch minimum thickness.

Structural steel columns shall have their base plates designed to accept, as a minimum, four 7/8-inch diameter anchor bolts.

Care should be taken to insure that dissimilar materials will not cause accelerated deterioration to the structure. Provisions to avoid contact between dissimilar materials shall be established.

10.2.1. Steel Joists

{later}

10.3. Masonry Design

Design shall follow the methodologies and meet the requirements of ACI 530.

10.4. Deflection Limits

Deflections for steel and concrete floor members shall be less than the limits outlined in Table 1604.3 of the IBC.

In addition, deflections and minimum thickness of concrete beams and slabs shall be governed by Section 9.5 of ACI 318.

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Attachment 4 – The Protection of Station Supports

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AECOM | HNTB

66 Long Wharf
Boston, MA 02110

MEMORANDUM

Date: April 11, 2014

To: Greg Yates
From: Sam Tinsley
Subject: *Green Line Extension Project (GLX)*
Station Column Base Plate Detail / Structural Protection
Cc: Randy Henke, Caroline Downing

Summary

The purpose of this memorandum is to provide the basis for the typical station column base plate and anchor bolt detail currently proposed for the GLX project. The proposed design under consideration was shown in the Advanced Preliminary Engineering (APE) drawing set and in the 60% design drawings for Interim Guaranteed Maximum Price package #4, but is different than what was originally shown in the Advanced Conceptual Design (ACD) drawings.

Advanced Conceptual Design

After we had completed the APE designs, we were advised that the column base detail shown in the ACD drawings from May 2012 was based on direction from the MBTA to allow access for future inspection of the baseplates; unfortunately, that direction does not appear anywhere in the Design Criteria Manual that was issued in conjunction with the ACD drawings. We acknowledge, however, that an addendum to the Design Criteria Manual created Section 2.10.3, which, in part, states the following: *"The columns will be founded on continuous reinforced concrete foundation walls. The foundation walls will extend far enough above the top of rail to elevate the column bases above the point where a derailment impact would occur so that the derailment impact will occur at the continuous foundation wall rather than at individual columns."*

The column baseplates for ACD were designed to sit on top of the foundation walls. The resulting analytical model for the ACD structure assumed a "pinned" base condition for the columns. This assumption allows the column to rotate; therefore, there is no bending moment transfer to the pier, only lateral shear forces. The ability for these columns to rotate results in large column and beam sizes in order to control lateral drift caused by wind and seismic load conditions. For example, in most of the stations each bay in the transverse direction is a moment frame, which is part of the lateral resisting system. The typical column sizes are W14 sections with weights ranging from 283 lb/ft to 398 lb/ft. Similarly, the first floor beams in these moment frames are typically W24X162 sections and the second floor and roof level moment frame beams are W24x76 sections. (The remaining infill beams, which are part of the gravity system, are W16 sections.)

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Advanced Preliminary Design

After reviewing the details and the framing used in the ACD, we studied and adopted an alternative design approach for the column base in the APE design. Instead of assuming a "pinned" condition, the APE design developed a reduction in structural steel framing by designing "fixed" supports at the base of moment frame columns and by reducing the number of moment frames.

With this design approach (the fixed base plate detail) the base of the column is restrained and there is bending moment transfer into the foundations. Consequently, tension forces in anchor bolts are generated in order to transfer moment at the column base. This condition requires more concrete mass in piers in order to satisfy the provisions of ACI 318-08 Appendix D – specifically concrete "breakout" at the sides of the pier. Due to the vicinity of the tracks, there are horizontal clearance limitations that preclude thickening the wall to provide more concrete cover at the anchors and thus, the GLX team proposes encasing the structural steel columns for the full depth of the safety wall and locating the base plates at the base of the wall on the top of the footing, as depicted in Figure 1. With this detail we will be able to provide column base fixity and satisfy base anchorage code requirements.

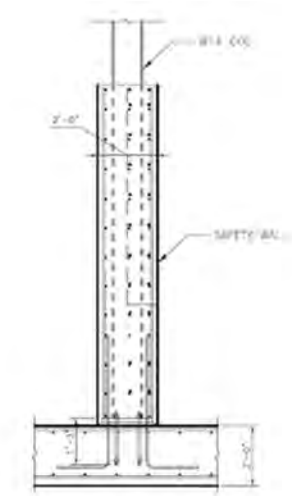


Figure 1. *Proposed Structural Steel Column Base Plate and Anchor Bolt Location*

Structural Steel Material Savings

In order to understand the potential cost savings resulting from this alternative approach, we calculated structural steel tonnage for the ACD and APE Design Submissions, based on quantity takeoffs for each set of design drawings. In our comparison, we excluded plaza areas, canopies, platform roof structures, elevator framing and roof structures of stations detailed with wood framed systems. Furthermore, the structural steel tabulated below separately quantifies the gravity system and the lateral resisting system of each station as "Gravity" steel tonnage and "Frame" steel tonnage, respectively. Lechmere station and Ball Square Station are not included in this comparison because of significant design development modifications between the ACD and APE submissions. Please refer to Table 1 on the next page for the comparison of the five remaining stations.

As shown in Table 1, the APE design has increased the gravity steel weight by 63 tons, and reduced the lateral frame steel weight by 330 tons resulting in a savings of 267 tons. These totals do not include connections and the savings should be a little larger due to the fact that lateral resisting system connections are heavier than basic gravity connections.

Table 1 GLX- Comparison between ACD and APE Steel Weights

Station	Footage (ft^2)		Gravity Tonnage		Frame Tonnage		Total Tonnage	
	ACD	APE	ACD	APE	ACD	APE	ACD	APE
College	7957	13877	27.8	54.0	212.3	101.3	240.1	155.2
Gilman	14847	13374	54	53.7	173.9	100.9	228.1	154.6
Washington	9428	7950	15	23.6	88.6	33.9	103.1	57.5
Lowell	10526	10303	20	44.9	135.2	90.5	154.9	135.4
Union	15043	13382	49	52.2	135.6	88.6	184.6	140.8
Total	57801	58886	165.2	228.3	745.6	415.2	910.8	643.5
Difference		1085		63		-330		-267

At an assumed cost of $5000 dollars per ton for fabricated steel in place, this would mean a $1.3 million savings for these five (5) stations overall. Additional strengthening of the foundation structure to accept bending loads from the “fixed” columns would be marginal.

Protective Measures

In order to protect the structural steel, anchor bolts and pier reinforcement from the influence of surface water that may penetrate grade, the proposed design requires waterproofing to be applied to the below grade pier/wall surfaces and the anchor bolts will be galvanized. We suggest this detail as an added level of protection; however, it does not appear that there is a high water table at any of the station locations. Based on geotechnical information (reports and correspondence with Nobis), a summary of water table issues by station is outlined below:

- The design water table elevation at Washington Station will be in the range of 10.0’ with a series of under slab drains at the lowest floor elevation to drain the station area. Column base plates are detailed at an elevation of approximately 27’ and thus, it is only surface water that may possibly come into contact with the encased base plate at this station.
- The maximum groundwater elevation at Union Square Station has been measured at 5.5’ and for the 100 year storm, groundwater is estimated to be at a maximum of 7.0’. The bottom of

base plate is currently detailed at 6’-1”, which is above groundwater at all but the most severe conditions.

- Boring data indicate groundwater at an elevation of approximately 10’ below grade at Gilman Station. Base plate elevations will be detailed at approximately 4.0’ below finished grade. The groundwater elevation has not yet been finalized for the 100 year storm at this station and will be provided as more data is obtained for this site in the next design.
- Additional boring data, beyond ACD, for College Station and Lowell Station are not available yet and will be provided in the next design phase.

Also, corrosion inhibitors will be added to the concrete mix as a further protective measure.

Therefore, we believe that, since the base plate elevation is higher than the design groundwater elevation at Washington Station and since the base plate at Union Square Station will only be susceptible to the 100 year storm event, the proposed concrete encased, “fixed” base plate detail is a robust, economical solution and one that does not compromise the integrity of the structure. Please refer to Figure 2 for the detail.

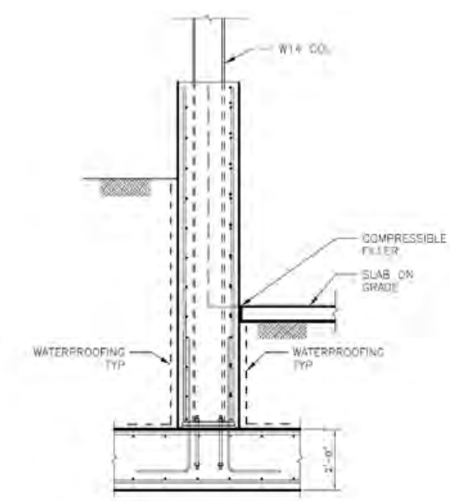


Figure 2. *Proposed Protection from Underground Water*

With respect to the issue of structural protection, continuity of horizontal safety wall reinforcement will be achieved by welding reinforcing bars to each side of the column web and splicing the reinforcing as shown in Figure 3.

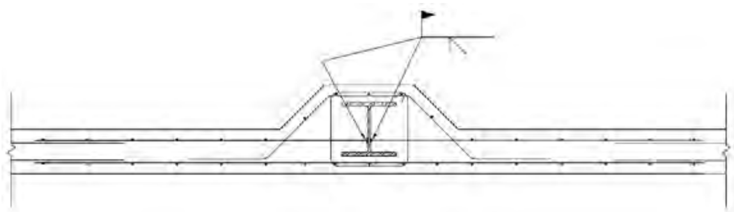
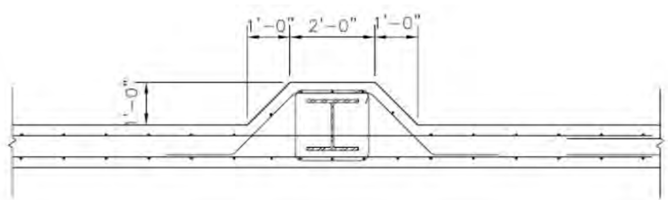
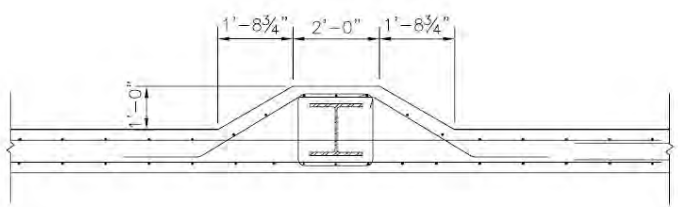


Figure 3. *Plan View Showing Continuity of Horizontal Safety Wall Reinforcement*

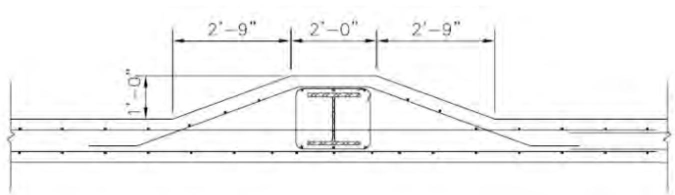
An increase in the pier length as well as the pier angle has also been discussed which will provide additional column protection from train impact and may be incorporated into the structural protection detail. Refer to Options 1, 2 and 3 in Figure 4.



Option 1



Option 2



Option 3

Figure 4. *Plan View Showing Typical Pier Geometry*

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Recommendations for Final Design

The embedded column design approach differs from the ACD submission, which showed base plates on the top of the safety wall. In order to achieve structural cost savings described above, the GLX team proposes encasing the structural steel columns for the full depth of the safety wall and locating the base plates at the base of the column/safety wall on the top of the footing. The proposed detail satisfies the connection requirements and provides a reduction in cost of the steel structure as well as providing a well-protected column base connection.

We understand that steel savings may be achieved with the progress of design and that this is the natural progression of design development. In point of fact, throughout the APE design phase we studied ways to save structural steel to add value to the project and ensure that the structural cost stays within the budget. “Fixing” the column bases of the moment frame columns helped us to achieve this goal.

We respectfully request that the MBTA review and approve this design approach in order for our team to move forward and continue to develop and provide an economical design that satisfies the serviceability and long-term performance requirements for each facility.

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Boston, MA 02110

MEMORANDUM

Date: August 23, 2013
To: Randy Henke
From: Sam Tinsley
Subject: Green Line Extension Project (GLX)
Protection of Structural Supports in the Station/Plaza Areas
Proposed Design Criteria Edits
Cc: Greg Yates, Caroline Downing

Summary

This memorandum is written to summarize the reasoning behind proposed edits to the Green Line Extension Project (GLX) Design Criteria Manual (DCM) regarding protection of station and plaza structural supports in case of a light rail vehicle (LRV) derailment. It is intended that the proposed DCM edits will be reviewed and accepted by the MBTA for use in designing the GLX stations. Proposed DCM edits are attached this memorandum as Attachment A.

Background

There is no industry-wide consensus regarding a design methodology for protecting station structures and other overhead elements from damage and possible collapse due to LRV derailment loads.

GLX stations are typically configured such that the concourse structures will be located between the inbound and outbound tracks for the Green Line light rail vehicles. The light rail platform level is generally lower than the surrounding site. Vertical circulation (elevators, stairs and escalators) will provide access from the street level to the platform. Columns and walls originate at the platform level and support the station entry lobby and plaza at street level above.

The GLX right of way includes both light rail tracks and commuter rail tracks running adjacent to each other. At each station, the light rail tracks are immediately adjacent to each side of a central platform, and the commuter rail tracks are offset from each side of the station platform by the light rail track. The derailment of a light rail vehicle is the only issue of concern related to the protection of station structural supports. The derailment of a commuter rail train at a significant distance away from the station supports is an unlikely scenario and beyond the scope of this memorandum.

In order to proceed with Advanced Conceptual Design (ACD), the GLX PM/CM team conducted a review of current industry practice and developed a methodology for use in developing the project to the ACD level. The review and methodology used for ACD was summarized in a memorandum titled “Review of Structural Protection for Stations and Plazas”, which was provided to the AECOM|HNTB team as

Appendix C of the GLX Design Definition Document (dated January 2012), and which is attached to this memorandum as Attachment B. The "Review of Structural Protection for Stations and Plazas" memorandum discusses practices in use at other transit agencies, and notes that some agencies do not consider light train derailment as a hazard; however, most agencies do consider the impact of light rail derailment and provide "guard rails" and/or "safety walls".

"Review of Structural Protection for Stations and Plazas" suggested two means of structural protection for use in developing the ACD. One method is an additional rail, a "guard rail", which is provided along the section of track adjacent to the station structure. This "guard rail" runs parallel to, inside of, and slightly offset from each of the running rails. Thus, if a derailment occurs, the guard rail contains the wheels of the derailed vehicle, reducing the impact and subsequent damage. The second means of protection for the station structural elements is a "safety wall", which is also parallel to the track and is a reinforced concrete wall integral with the platform columns and supporting the station/plaza above. This wall would be designed to resist the deflected load from a derailed vehicle, thereby increasing the strength and redundancy of the structural system. The "guard rail" and the "safety wall" would be incorporated into the design of all at grade stations.

Subsequent to issuance PM/CM team's "Review of Structural Protection for Stations and Plazas" memorandum, it was discovered that other rail transportation agencies have developed similar design methodologies to those used during ACD by the PM/CM team. Examples include the Valley Metro Light Rail Transit project in Phoenix, AZ. The Design Criteria Manual for Valley Metro includes a methodology for addressing derailment loads that is very similar to that used during ACD. "Chapter 5 – Structural" of the Valley Metro Design Criteria Manual is provided as Attachment C to this memorandum. Section 5.3.4 of the Valley Metro manual provides the methodology used for that project to develop derailment load cases. Other agencies, including the California High Speed Rail Authority, have developed similar guidelines for protection of passenger facilities.

Recommendations for Final Design

Based on review of the research and precedents noted above, and based on our own structural engineering judgment, we are proposing that the MBTA accepts use of concrete "safety walls" to provide structural protection for the columns and walls supporting stations originating at the platform level, and that the design load used for these walls shall be a horizontal load equal to 40% of the weight of one fully loaded (137,000 pounds) Green Line Type 7 car.

Utilizing this approach, for all at grade stations, the design criteria shall be a horizontal load of 54.8 kips (0.40 x 137 kips) applied to the "safety wall" parallel to the GLX tracks at a height of 2'-0" above track level. This load will be distributed over a distance of 10'-0" along the length of the "safety wall". Concurrently, the vertical load from the train's center axles, 48 kips, will be included as two single wheel loads 6'-3" apart, as a vehicular surcharge uniform lateral load equivalent to 3'-3" of at-rest soil. This approach is depicted graphically in Figure 1 below.

While the recommendations for structure protection developed by the PM/CM team for use during ACD specifically addressed conditions at the six at-grade stations, they did not for the aerial station at Lechmere. We believe that these derailment criteria and safety considerations should apply to the elevated station at Lechmere. Therefore, we propose to interconnect and encase the structural steel beams and columns of the Headhouses that are parallel and adjacent to the viaduct with a concrete "safety wall". The load path for this derailment loading is as follows: the load will be applied to the safety wall using the above mentioned parameters and then be transferred thru the Headhouse diaphragm such that it will be resisted by the structure's Lateral Resisting System. The magnitude and application of the derailment loading will be the same as the at grade stations, and would be applied as depicted in Figure 2 below.

As a point of reference, the magnitude of the design impact load is roughly the same as the magnitude of the wind and seismic loads on the lateral resisting system at Lechmere Station. Thus, the structure will be sized as required to support the local effects of the impact loads; however, overall building stability should not be impacted appreciably by these local effects.

Finally, we would note it is our intention to continue the practice identified during ACD that walls or piers supporting entry lobby and plaza areas are considered heavy construction and shall be protected by AREMA 'crash' walls. These walls shall be constructed of reinforced concrete, at least 2'-6" thick and at least 12'-0" long, and have a minimum height of 12'-0" for plaza structures within 25'-0" of the centerline of the tracks in accordance with AREMA Chapter 8, as outlined above. The walls shall be anchored to footings and columns and extend at least 4'-0" below surrounding grade.

We request that the MBTA review and accept these recommendations for use in Final Design of the GLX stations.

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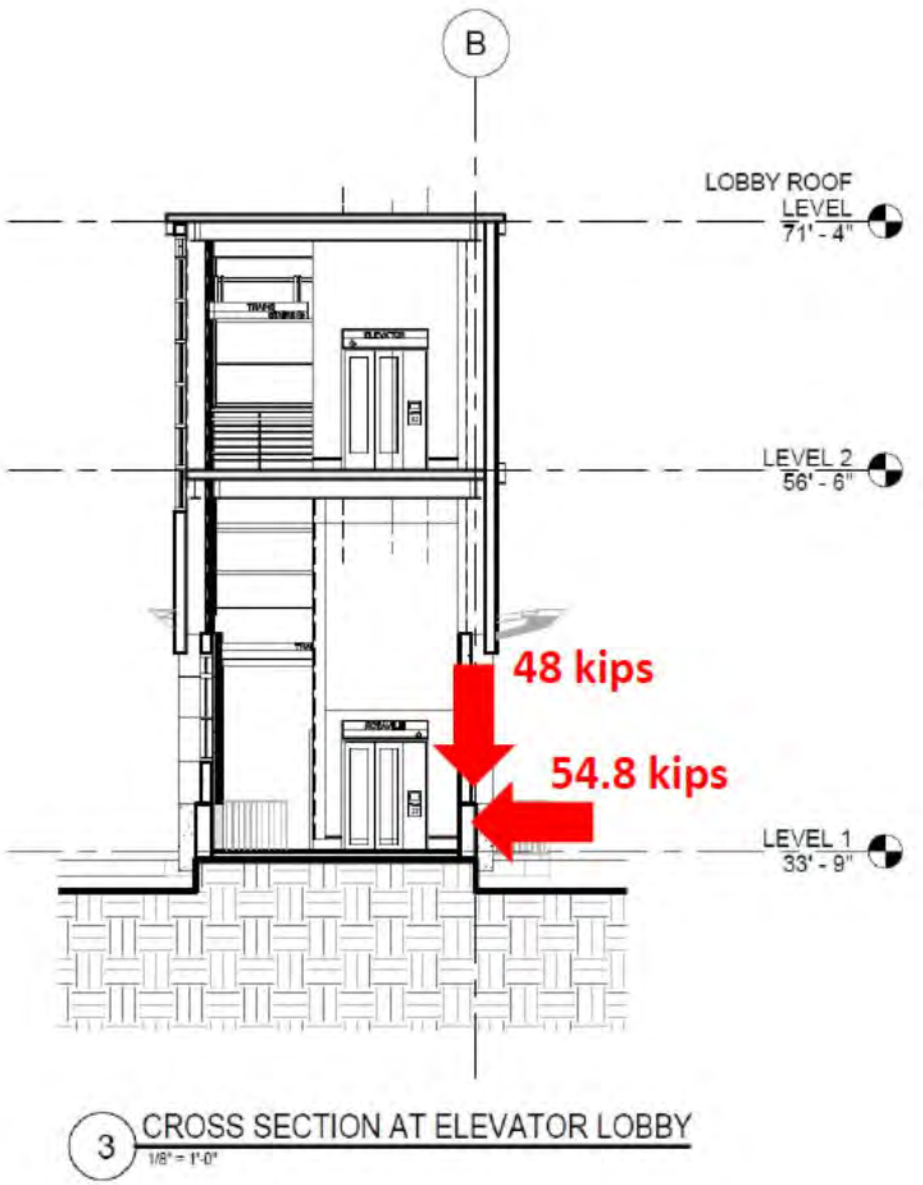

Figure 1.
Derailment Load at At-Grade Station

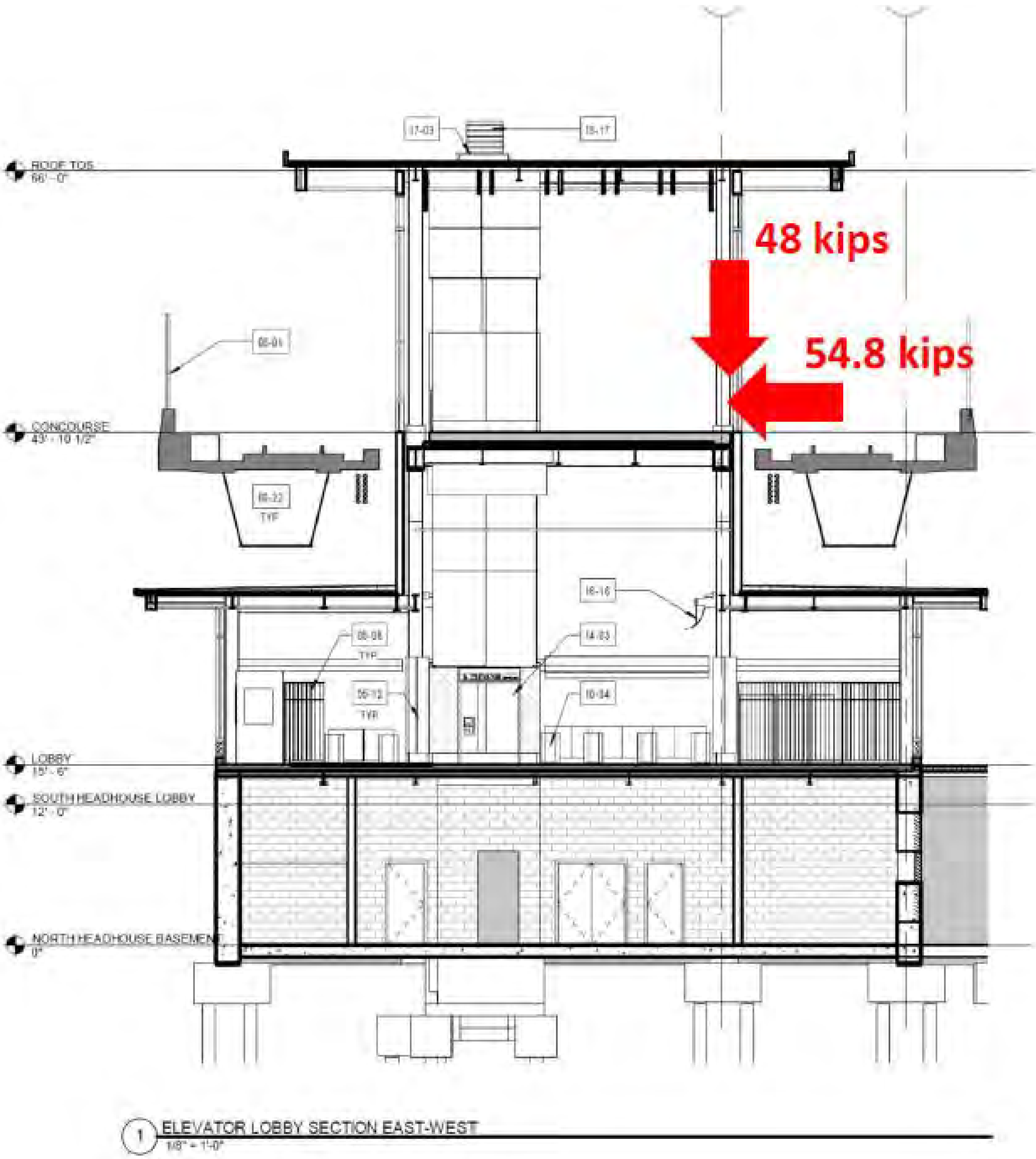

Figure 2.
Derailment Loads at Lechmere Station

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Attachments

Attachment A – Excerpt from the Proposed Revision 1 to the Design Criteria Manual - New Section to be added to Chapter 2 "Structural".

Attachment B – Memorandum "Review of Structural Protection for Stations and Plazas", dated November 1, 2011 prepared by Kleinfelder/SEA as part of the HDR/Gilbane PM/CM team.

Attachment C – Chapter 5 – Structural of the Design Criteria Manual (dated January 2007) for the Valley Metro Light Rail Transit Projects.

TECHNICAL MEMORANDUM

DATE: November 1, 2011

TO: Bob Cone, HDR

FROM: Douglas Peterson, P.E., K/SEA

CC: Michael McBride, HDR; Art Spruch, K/SEA; Carol Dennison, K/SEA; Michael Epp, K/SEA

SUBJECT: Review of Structure Protection for Stations and Plazas

Introduction

The intent of this study is to review the warrants and requirements for structure protection of proposed station and plaza structural supports from damage due to trains in the event of a derailment. The proposed Right of Way (ROW) configuration will operate with two tracks for MBTA Commuter Rail and Amtrak passenger trains and two tracks for MBTA Greenline Light Rail vehicles. All four tracks are within a narrow ROW corridor (see Figures 1 & 2). There is a possibility of derailment in the narrow corridor with the potential to impact station and plaza supports. MBTA Guide Specifications for Light Rail do not include any provisions for the protection of building elements within the track ROW due to train derailment. The purpose of this memo is to review the code requirements and the Standard of Care in the industry for protecting structural elements within the Right of Way of a rail corridor which services a light rail transit system and a commuter rail / passenger train (Amtrak) system.

The proposed stations are to be located between the proposed Green Line tracks. The outbound tracks are on one side of the station and the inbound tracks are on the opposite side. Between the tracks the proposed stations are 17'-6" wide, with columns supporting three stories of framing (see Figure 1). The centerlines of the proposed Green Line tracks are 6'-0" from the face of the station walls. Furthermore, the plaza areas, which will be designed to support both vehicular and pedestrian traffic, will have structural piers between the proposed Green Line tracks.

As currently proposed the station structures lack redundancy and the loss of structural capacity at the base of the structure would result in instabilities in the building frame causing significant damage to multiple levels of the stations. While designing for the loss of any one column at the track level (i.e. progressive collapse design) is theoretically possible the resulting increase in section modulus would be roughly 5 times for columns and 10 times for beams. The difficulty in designing for redundancy is due to the narrow 17'-6" corridor in which the stations are proposed. Furthermore, there are some stations where a portion of the station structural supports would cantilever out over the track and designing for redundancy at these areas may not be possible. In addition, a review of recent similar light rail projects by other transit agencies found that although platforms are located between tracks, stations are not usually located between tracks.

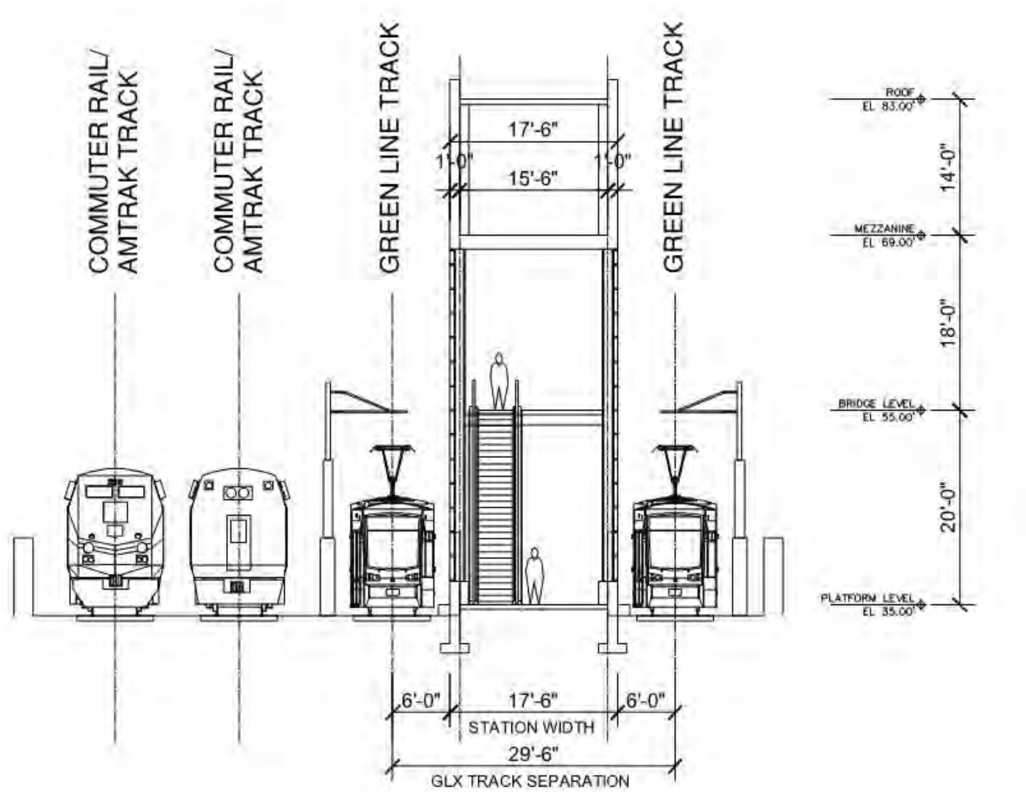


Figure 1: Typical Station Section

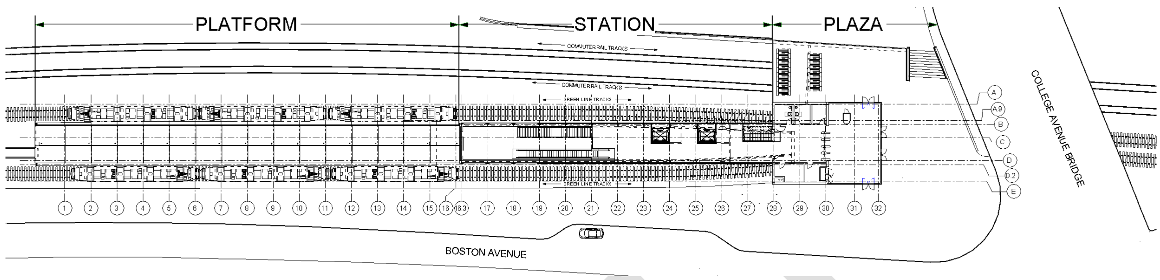


Figure 2: Typical Station Plan View

Protection of the Station Structure

The design of light rail, heavy rail, and street car stations is governed by the following:

- AREMA, Chapter 12: Rail Transit.
- AREMA, Chapter 11: Commuter and Intercity Rail Systems - Applies to the stations because the corridor also has tracks which service commuter rail and Amtrak trains.
- MBTA Guide Specifications for Structural Design - Applies to structures within the track ROW.
- MBTA Railroad Operations: Commuter Rail Design

AREMA Recommendations

Chapter 12, Part 4 Facilities, Section 4.6 Crash Walls is still under development and therefore does not provide any guidance at the time. However, Chapter 11, Section 4.6.1 states, "*The derailment of a passenger or freight train has the potential to damage adjacent structures. Considerations in the design of the stations or other facilities may warrant the inclusion of crash walls. The intent of crash walls is not to resist the full impact of a direct collision but rather to deflect or redirect the force of the moving train*."

MBTA Guide Specifications for Structural Design

Section 4.3.9 states, "*Derailment load is defined as a vertical load that is produced by the train live loading placed with its longitudinal axis parallel to the track*." There are no provisions for horizontal derailment loads.

MBTA Railroad Operations: Commuter Rail Design

Section I Chapter 4 Part N.2 states, "*Single rail guard rails and/or crash walls may be used at such other locations where a derailment would cause significant structural damage to adjacent, vulnerable structures or to the railroad's equipment… (Part c.) Adjacent to any supporting column of an overhead bridge or structure which if stuck by a train would very likely cause catastrophic failure of the structure. A crash wall may be appropriate in such cases…*" Furthermore Part O. Crash Walls states, "*When tracks are immediately adjacent to supports for bridges, buildings and air rights development over the right-of-way, consideration must be given to protecting supporting structure from impact of a train in event of derailment*." At the end of the section it refers to AREMA for more information on crash walls.

The majority of the commuter rail tracks are approximately 25' from the stations. According to this standard, they are not affected by the commuter rail trains. However, although the Green Line train weights are much lower than the commuter rail trains, Green Line trains would still cause significant structural damage to unprotected columns which are immediately adjacent to the tracks.

AMTRAK Standard Design Criteria

Due to Amtrak security restrictions, the relevant portions of Amtrak design criteria related to structure protection of passenger stations were not available for inclusion in this memo.

Standard of Care for Structure Protection

AREMA gives a reasonable indication of the Standard of Care for structure protection of stations in Chapter 12 with a recent questionnaire sent to 13 transit authorities in the United States, Canada, and Mexico. Two of the questions asked are pertinent to structure protection, they are documented in "*Table 12-4-11: Design Loading Questionnaire Responses – VIII: Other Miscellaneous Loads*". The questions and a summary of the responses are listed below.

Question 1: What provisions, if any, do you consider for possible derailment loads sustained by the aerial structure?

Four of the thirteen agencies responded to Question 1 by saying that they provide a barrier wall to resist a horizontal load from a train impact. The height of the applied force of the train ranges from two feet to three feet above top of rail. The magnitude of the load is 40% of the single car weight. Four agencies require only a vertical concentrated load on the structure around the track. Two agencies said that they do not consider any derailment loads and the other three agencies did not respond to the question.

The majority of the agencies (eight of thirteen) take derailment loads into account. Although only Lechmere Station is an aerial "rail viaduct" structure the horizontal loads indicated in this question could be applied to any of the stations within the ROW. The design load of 40% appears to be reasonable because trains reduce their speeds entering and existing stations and if there were a derailment the angle of impact would be highly obtuse.

Question 3: If the columns of the aerial structure are located between active railroad tracks, what provisions, if any, do you consider for possible collision with trains?

Six of the thirteen agencies require that the columns are protected by a crash wall, collision barrier, or guard rail. Two agencies do not allow columns within the Right of Way. The remaining five agencies either responded that they provide no protection or did not respond to the question.

The majority of the agencies (eight of thirteen) take derailment loads into account when structures are located within the Right of Way.

The remaining six stations (other than Lechmere) can be considered aerial structures located within the Right of Way and the stations have pedestrian traffic as well as program space above the platform level.

Protection of the Plaza Structure

Three chapters of AREMA govern the design of the Plaza structural support:

- Chapter 12: Rail Transit
- Chapter 11: Commuter and Intercity Rail Systems
- Chapter 8: Concrete Structures and Foundations.

AREMA Recommendations

The code requirements of Chapters 11 and 12 are detailed above in the Protection of the

Station Structure section.

For piers adjacent to railroad tracks Chapter 8, Section 2.1.5 Pier Protection states:

> "*To limit damage by the redirection and deflection of railroad equipment, piers supporting bridges over railways and with a clear distance of 25 feet or less from the centerline of a railroad track shall be of heavy construction … or shall be protected by a reinforced concrete crash wall. Crash walls for piers from 12 to 25 feet clear from the centerline of track shall have a minimum height of 6 feet above the top of rail. Piers less than 12 feet clear from the centerline of track shall have a minimum crash wall height of 12 feet above the top of rail.*
>
> *The crash wall shall be at least 2'-6" thick and at least 12 feet long. When two or more columns compose a pier, the crash wall shall connect the columns and extend at least 1 foot beyond the outermost columns parallel to the track. The crash wall shall be anchored to the footings and columns, if applicable, with adequate reinforcing steel and shall extend to at least 4 feet below the lowest surrounding grade.*
>
> *Piers shall be considered of heavy construction if they have a cross-sectional area equal to or greater that that required for the crash wall and the larger of its dimensions is parallel to the track."*

Based on the requirements of Chapter 8, Section 2.1.5, it is our opinion that design of the structures supporting the plazas is governed by this section. Where the station plazas require structural support within the track corridor the supports will be within 25 feet of track centerline of at least one of the commuter rail or Green Line rails. In addition to pedestrian traffic the plazas will also support emergency vehicles and potentially a drop-off lane at some locations, which provides an area for cars to turn into to drop off passengers entering the stations. Under these loading conditions it is our recommendation that the plazas be protected that same as bridges.

MBTA Railroad Operations: Commuter Rail Design

See the *Protection of the Station Structure* section for commuter rail design requirements.

Conclusions

The proposed stations and plazas within the Right of Way (ROW) will be composed of two elements serving two different structural functions. The station structural elements support program space and pedestrian traffic, while the plaza structural elements support vehicular and pedestrian traffic.

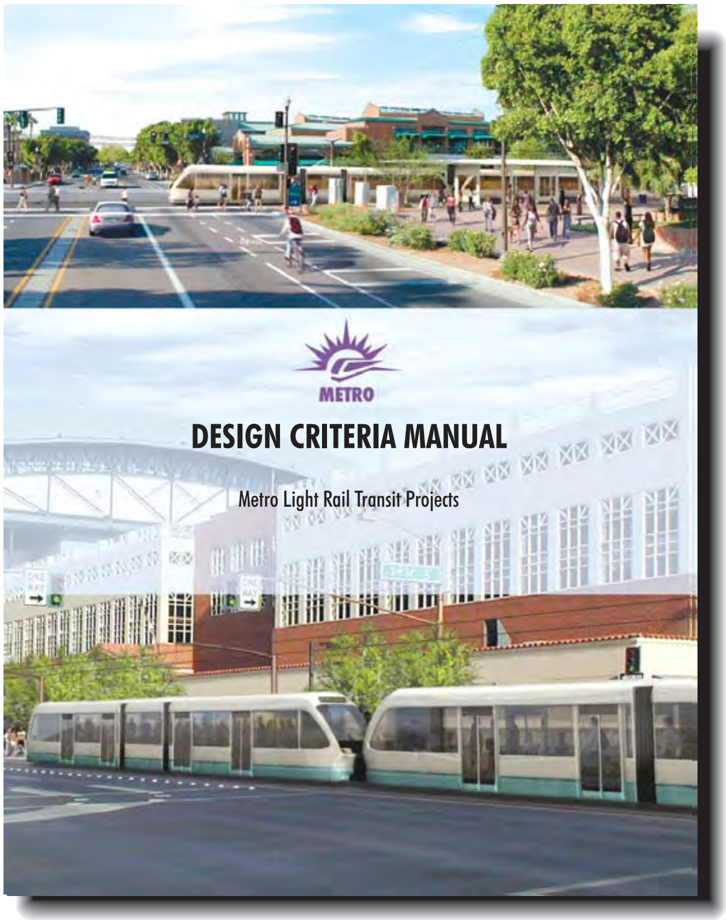
Regarding the protection of station structures, the applicable design standard, AREMA, does not specifically address the structure protection requirements for a station structure within the ROW of light rail, heavy rail, or street cars. However, it does state that crash protection should be considered. Furthermore, it does establish a reasonable Standard of Care for the structure protection of stations by providing the results of a survey of the practices of thirteen metro transit agencies in the US, Canada, and Mexico. The majority of metro agencies surveyed consider crash loads due to train derailment in the design of their stations by providing varying levels of protection of structural elements within the ROW. Based on our review of the relevant code resources and the use of structure protection by majority of transit agencies, it is our professional judgment that structure protection of the proposed stations is warranted. Unless directed otherwise, we propose to protect the primary station supports by use of a concrete curb wall that will extend 4'-0" above the top of rail and also by providing guardrail on the tracks in the area of the stations. The concrete curb wall will be integral with the face of the station wall and support steel columns above. The intent of the curb wall will be to deflect 40% of the live load of one fully loaded Green Line (137,000 lbs, Type 7) car away from the station. For the basis of structure protection, we are using the design speed of 50 mph for the Green Line cars in the corridor. Furthermore, we feel the concrete curb wall could offer a more efficient method to protect the station framing than designing for redundancy.

Regarding the protection of plaza structures, since the plazas will be designed to support vehicular loads, it is our professional judgment that the plaza structural supports be protected similar to bridge piers. Bridge piers adjacent to railroad tracks, within 25 feet of the centerline of the tracks, shall be of heavy construction or protected by pier type "crash" walls per AREMA. Unless directed otherwise, based on our review of the project conditions, we propose to protect the plaza structural supports with pier type "crash" walls per AREMA. Generally, the crash walls needed for the plazas will be at least 2'-6" thick and at least 12 feet long and 12 feet in height.

Applicable Design Standards

- American Railway Engineering and Maintenance-of-Way Association (AREMA), Manual for Railway Engineering, 2011
  - Chapter 8: Concrete Structures and Foundations
  - Chapter 11: Commuter and Intercity Rail Systems
  - Chapter 12: Rail Transit

- MBTA Guide Specifications for Structural Design of Rapid Transit and Light Rail Structures, October 2005
- MBTA Railroad Operations: Commuter Rail Design Standards Manual, Volume 1, Section 1, Track and Roadway, April 19, 1996.
- Amtrak Standard Design Criteria (Not Available)



Chapter 5.0

Structural

5.0 STRUCTURAL

5.1 Introduction

The purpose of this chapter is to establish the standards and design policies for the basic structural design on the METRO LRT project. Structures include bridges, underground structures (cut-and-cover tunnel sections), retaining walls, U-sections, transit stations (at-grade and aerial) and appurtenances, buildings, construction structures, and other miscellaneous structures.

5.2 Design Codes, Manuals and Specifications

The following codes, manuals, and specifications shall be applicable to the design of structures (all publications listed shall be the latest edition unless noted otherwise):

American Association of State Highway and Transportation Officials (AASHTO) Standard Specifications for Highway Bridges hereinafter referred to the AASHTO Standards. American Railway Engineering and Maintenance–of-Way Association for railways design and maintenance standards hereinafter referred to as the AREMA Manual.

AASHTO LRFD Bridge Design Specifications.

AASHTO Guide Specifications for Design and Construction of Segmental Concrete Bridges.

AASHTO Guide Specifications for Structural Design of Sound Barriers.

Arizona Department of Transportation Structural Design Guidelines.

Arizona Department of Transportation Detailing Manual.

Arizona Department of Transportation Standard Specifications for Road and Bridge Construction.

AREMA Manual for Railway Engineering hereinafter referred to as the AREMA Manual.

International Conference of Building Officials (ICBO), Uniform Building Code (UBC), and or International Building Code (IBC).

American Concrete Institute (ACI) ACI 318 Building Code Requirements for Reinforced Concrete hereinafter referred to as ACI 318.

American Institute of Steel Construction (AISC) Manual for Steel Construction hereinafter referred to as the AISC Specifications.

AASHTO Manual for Condition Evaluation of Bridges

AASHTO Guide Specifications for Horizontally Curved Highway Bridges

AASHTO Guide Specifications for Strength Evaluation of Existing Steel and Concrete Bridges

AASHTO Guide Specifications – Thermal Effects in Concrete Bridge Structures

Transit Cooperative Research Program (TCRP) Report 57 Track Design Handbook for Light Rail Transit

Post-Tensioning Institute (PTI) Recommendations for Prestressed Rock and Soil Anchors

Maricopa Association of Governments Uniform Standard Specifications and Details for Public Work Construction

In the event of conflict between these sources, provisions of ADOT govern over AASHTO; AASHTO and ADOT govern over Precast/Prestressed Concrete Institute (PCI), American Concrete Institute (ACI) and AISC; and the rail transit provisions govern over all other references.

The most recent edition of Uniform Building Code, Structural Specialty Code and Fire and Life Safety Code shall be used.

5.3 Loads and Forces

The actual live loads and forces shall be determined based upon the following loads and forces.

5.3.1 Dead Load

The dead load shall consist of the estimated weight of the basic structure and the weight of all elements permanently supported by the structure such as: trackwork, electrification, railings, barriers, utilities, walkways, canopies, walls, and partitions.

5.3.2 Live Loads

Structures subject to light rail vehicle (LRV) train loading shall be designed for the maximum vehicle loading shown in Figure 5-1. The loading of selected rail maintenance equipment shall be assumed to have an axle load/configuration that does not exceed the standard fully loaded LRV. Structural calculations shall be required to confirm the adequacy of the design after the LRV characteristics are confirmed.

Transit passenger stations and other structures not subject to LRV loading shall be designed for live loads prescribed in the Uniform Building Code (UBC)/International Building Code (IBC). Minimum live loads for the transit passenger stations shall be:

Public spaces including passenger platforms, stairways, escalators, mezzanines, corridors, and public restrooms:	150 psf
Office areas:	125 psf
Storage areas:	light storage - 125 psf heavy storage - 250 psf

Equipment spaces (rooms in transit stations or in separate buildings) shall be designed for 250 psf, or the actual weight of equipment, whichever is greater.

5.3.3 Impact

Vertical impact on structures subject to LRV train loads (See Figure 5-1) shall be as follows:

- continuous multi-span structures = 30%
- simple span structures less than 100 feet = 30%
- simple span structures between 100 to 160 feet = 40%

Vertical impact does not apply to abutments, foundations, wall type piers, underground structures with 3 feet or more of cover and base slabs supported by earth (either at-grade or in subways).

Impact on structures subject to LRV loading shall be in accordance with these requirements and in accordance with the AREMA manual. Impact on structures subject to highway loading shall be in accordance with the requirements in the AASHTO Standard Specifications and ADOT Structural Design Guidelines.

5.3.4 Derailment Loads

Derailment loads shall be those produced by the LRT vehicle placed with its longitudinal axis parallel to the track.

5.3.4.1 Application of Derailment Loads

Derailment loads shall be applied to all superstructure and substructure elements subjected to LRT loadings.

5.3.4.2 Vertical Derailment Loads

Lateral vehicle excursion shall be assumed as follows:

1. For track constructed with an emergency guardrail placed 10-inches from each running rail, the lateral vehicle excursion shall vary from 4 inches minimum to 10 inches maximum. Restraining rails, which are placed adjacent to the running rails for reducing wheel wear, shall not be considered as emergency guardrails.

2. For tangent track and curved track with radii greater than 5,000 feet and lacking emergency guardrails, the lateral vehicle excursion shall very from 4 inches minimum to 3 feet-0 inches maximum.

3. For track with smaller radii, and where the distance from the rail to the edge of the deck slab is less than 3 feet-8 inches the maximum excursion shall be adjusted so that the derailed wheel flange is located 8 inches from the rail traffic face of the nearest barrier, if any, or the edge of the deck.

When checking any component of superstructure or substructure that supports two or more tracks, only one train on one track shall be considered to have derailed, the other track being either unloaded or loaded with a stationary train as the situation dictates.

All elements of the structure shall be checked assuming simultaneous application of all derailed wheel loads. However, the reduction of positive moment in continuous slabs due to derailed wheel loads in adjacent spans shall not be allowed.

The vertical derailment load shall be as follows:

$$DR = L + ID$$

Where: L = LRT vehicle live load.

ID = Derailment impact at 100 percent of the axle load to be applied to any two adjacent axles at a time and normal impact factor for all other axles, which produces critical loading condition for the structures.

5.3.4.3 Horizontal Derailment Loads

A. At all sections lacking emergency guardrails, with maximum vehicle speeds between 45 miles per hour and 65 miles per hour, horizontal force due to derailment loads shall be taken as 30 percent of the weight of a single vehicle acting 2 feet above top of rail and normal to the structure centerline for a distance of 10 feet.

B. At all sections lacking emergency guardrails, with maximum vehicle speeds less than 45 miles per hour, horizontal force due to derailment loads shall be taken as 10 percent of the weight of a single vehicle acting 2 feet above top of rail and normal to the structure centerline for a distance of 10 feet.

C. At all sections which include emergency guardrails, with maximum vehicle speeds of 65 miles per hour or less, horizontal force due to derailment loads shall be taken as 10 percent of the weight of a single vehicle acting 2 feet above top of rail and normal to the structure centerline for a distance of 10 feet.

5.3.5 Other Loads and Forces

Other loads and forces (i.e., wind, flowing water, thermal, longitudinal, centrifugal, shrinkage, etc.) on structures shall be as follows:

- structures subject to LRV or highway loading: AASHTO Standards;
- structures subject to railroad loading: AREMA Manual;
- other structures: Uniform Building Code/International Building Code; and
- bridges subject to river flows and scour: AASHTO Standards.

5.4 Seismic Design

Seismic design for all structures subjected to LRT loads shall be in accordance with the ADOT Structural Design Guidelines. Seismic design of buildings and other structures for the forces and displacements produced by ground shaking shall be in accordance with the Uniform Building Code/International Building Code.

5.5 Soils and Geologic Data

The soils in the Phoenix and Tempe area vary. Soil and geologic data/and or reports for the preliminary design of structures shall be site-specific data. Preliminary recommendations shall be provided in the project structural reports prepared during the Preliminary Engineering phase. On Final Design, site-specific soil and geological data shall be obtained to develop the design parameters.

Commonly used foundations for bridges, retaining structures, and buildings in the Phoenix and Tempe area include: spread footings; driven precast concrete piles; and drilled shafts. Foundation recommendations shall be made in a site-specific project geotechnical report(s). Foundations shall be designed according to AASHTO, ADOT Standards, or local jurisdiction standards. River scour where applicable shall also be considered in the report.

5.6 Reinforced and Prestressed Concrete

Reinforced and prestressed concrete structures shall be designed in accordance with the requirements of the following:

- structures subject to LRT train loading: AASHTO and ACI 318
- structures subject to railroad loading: AREMA Manual
- structures subject to highway loading: AASHTO and ADOT Standards
- buildings and other structures: ACI 318

5.7 Structural Steel

Structural Steel structures shall be designed in accordance with the requirements of the following:

- structures subject to LRV loading: AASHTO and AISC
- structures subject to railroad loading: AREMA Manual
- structures subject to highway loading: AASHTO and ADOT Standards
- buildings and other structures: AISC Specifications

5.8 Earth Retaining Structures

Cut and fill earth-retaining structures will vary in different geologic settings along the LRT rail alignments. The selection of the types of retaining structures and their design shall be based on the recommendations in the site-specific project geotechnical report(s). Commonly used earth retaining structures in the Phoenix and Metropolitan area include reinforced concrete cantilever walls and mechanically stabilized earth (MSE) walls. Other wall types may be utilized where site conditions dictate. Consideration should be given to “top-down” construction techniques in cut situations, where right-of-way permits.

5.9 Underground Structures

All underground structures shall be classified in one of the categories listed below. For each category, the following assumptions shall be made:

5.9.1 Reinforced Concrete Box Line and Station Section

A. These structures retain earth but are not free to yield significantly. As a minimum, four basic loading cases shall be investigated. Load values shall be developed from geotechnical information. Additional permanent, temporary, and construction loading cases shall be investigated as required.

Case 1: Full vertical and long-term horizontal load.

Case II: Full vertical load, long-term horizontal load on one side and short-term horizontal load on the other side.

In underground concrete box structures that could be subject to unequal lateral pressures, the structural analysis shall consider the top slab as both restrained and unrestrained against horizontal translation in arriving at maximum shears, thrusts, and moments. However, the ratio of horizontal displacement to height of the wall need not exceed 0.0005.

Case III: Full vertical load with short-term horizontal load neglecting groundwater pressure on both sides.

Case IV: Only dead vertical load with long-term horizontal load including hydrostatic pressure.

B. Foundation Pressures

Vertical pressure on foundation slabs may be divided into hydrostatic and earth pressure components. The hydrostatic component shall be distributed across the width of the foundation in proportion to the depth of each portion of the basic slab below the design groundwater table.

Distribution of the earth pressure distribution shall be based on specified construction procedures if they affect the distribution, and may include elastic foundation effects if significant changes in frame or slab stress are introduced thereby. Where a box structure rests on soil subgrade, a uniform distribution of subgrade soil reaction shall be assumed as one possible condition.

C. For design, the horizontal earth pressure distribution diagram shall be trapezoidal. Compression forces shall not be considered in shear design of the top and bottom slab in box sections.

D. In evaluating the design for temporary loadings produced by construction conditions such as the removal of horizontal struts, consideration shall be given to:

1. Allowable increase in stresses due to the temporary nature of the loading.
2. Creep in the concrete.
3. Effect of soil arching.
4. Wall and slab flexibility.

E. Where it is anticipated that restrutting will be proposed by the contractor, due to the limitations inherent in the design of the permanent structure, the construction specifications are to stipulate that the working drawings, supporting computations, and order of procedure submitted for approval by the contractor must reflect proper consideration of such aspects as magnitude of preload in replacement struts, crushing of packing, and thermal-induced stress and deflection of the permanent structure. The contractor's proposal shall also detail the proposed instrumentation and monitoring thereof to ensure that the permanent structure shall not be overstressed or otherwise damaged.

F. In all cases, the specifications for support of excavation must reflect any limitations inherent in the design of the permanent structure.

G. Allowance must be made for corrosion control in accordance with Chapter 19, Corrosion Control.

5.9.2 Reinforced Concrete Retaining Walls

These structures are free to yield to earth pressure. In retaining walls up to 20 feet-0 inches in height, the design earth pressure shall be computed in accordance with recommendations of the geotechnical report. Retaining walls above 20 feet-0 inches in height shall be designed on the basis of specific soils information relating to the backfill material using an acceptable method as identified in the Geotechnical Report.

5.9.3 Shafts

Permanent shaft walls shall be reinforced concrete. Loadings imposed on the shafts by the surrounding medium shall be determined by the designer in accordance with the Geotechnical Report and shall be consistent with the shaft configuration.

5.9.4 Sound Walls

Ensure sound wall design provides through access to adjacent neighborhoods and appropriate land uses. Sound walls shall comply with the *Urban Design Guidelines for Bridges and Walls*, page 24.

5.10 Portals and U-Sections

A. In locating portals and determining the ends of U-sections and walls, consideration shall be given to providing protection against flooding resulting from local storm runoff.

B. Adequate provision shall be made for resistance to hydrostatic uplift with the immediate and effective removal of water from rainfall, drainage, groundwater seepage, or any other source.

C. U-sections, with both walls continuous with a full-width base slab, shall be used for open-cut sections where the top of rail is less than 4' above the maximum groundwater table. Above that level, independent reinforced concrete cantilever retaining walls may be considered for design.

D. U-sections may be analyzed as continuous structures on elastic foundations. If at any station the two walls are of unequal heights, then the factor of safety against sliding shall be a minimum of:

   1. 1.5 with no passive resistance of the soil.
   2. 2.0 with passive resistance of the soil.

E. Wall thickness for U-sections shall be designed by using:

   1. The geotechnical soils report recommendations for coefficient of lateral earth pressure, at-rest case.
   2. Hydrostatic pressure.
   3. Surcharge effects.

F. U-section grade slab design thickness shall be 6 inches greater than the wall thickness, with a minimum thickness of 24 inches. If the weight of the grade slab (in psf) is less than 40 percent of the hydrostatic head (in psf) as measured from the bottom of the grade slab, then the grade slab shall be designed for uplift pressure.

G. If, at the last U-section segment away from the portals, the abutting at-grade trackway does not consist of a track slab, then a depressed approach slab shall be provided to permit the construction of tie-and-ballast trackbed up to the end of the typical base slab without a sharp break in support at that point.

5.11 Aerial Structures

The criteria set forth in this section shall pertain specifically to the design of bridges carrying light rail transit loadings.

5.11.1 Design Specifications

A. AASHTO current Standard Specifications for Highway Bridges shall govern the design and construction of aerial structures supporting LRV loadings.

B. The Strength Design Method (Load Factor Design Method as per AASHTO) shall be used for the design of all structural components and connections. To ensure serviceability and durability, permanent deformations under overloads, live load deflections, and fatigue characteristics under service loadings shall be investigated.

5.11.2 Application of Loadings

Light Rail Vehicle Loading is defined in Figure 5-1. Unless otherwise directed by METRO, use this loading diagram for structure design on the LRT system. For structures carrying LRV loads, one train per track shall be applied for both strength and serviceability considerations in all materials. When all or a portion of deck width is dedicated exclusively to LRT, only the LRV loads are to be applied to that width.

5.11.3 Reduction in Load Intensity

For structures carrying LRV loads, a track shall be treated as a traffic lane in applying the provisions of AASHTO, current standard specifications for highway construction.

5.11.4 Special Design Considerations

5.11.4.1 Vibration and Deflection Control

To limit vibration amplification due to the dynamic interaction between the superstructure and the LRV, the first-mode natural frequency of flexural vibration of each guideway span should generally be not less than 2.5 cycles per second and no more than one span in a series of three consecutive spans should have a first-mode natural frequencies less than 2.5 cycles per second provided that due consideration is given to possible vibration interactions between the structure and the LRV, and their effect on vertical impact loading.

To ensure rider comfort, the deflection of longitudinal girders under normal live load should not exceed 1/1000 of the span length. For main cantilever girders, the deflection under normal live load should not exceed 1/350 of the cantilever span.

A special analysis shall be conducted for any bridge or superstructures having a first mode of vibration, which is less than 2.5 hertz, or for the condition when more than one span in a series of three consecutive spans has the first mode of vibration, which is less than 3.0 hertz.

This analysis shall model the proposed structure and the proposed LRV. The analysis shall contain a sufficient number of degrees of freedom to allow modeling of the structure, vehicle truck spacing, vehicle primary suspension, vehicle secondary suspension, and the car body. It shall make provision for the placement of the vehicle on the structure in various locations in order to model the passage of the LRV. When the exact configuration of either the vehicle or the structure is not known, the study shall assume a reasonable range of parameters and shall model combinations of those parameters as deemed appropriate.

The analysis shall determine whether impact loads in excess of 30 percent of LRV are required for the design of the structure. The analysis shall also determine whether certain operational considerations such as speed restriction or other provisions are required in order to ensure the safe operation of the LRV over the structure.

5.11.4.2 Trackwork

Consideration shall be given to the thermal force interaction between the structural components and the trackwork system. Thermal force calculations shall start with the Rail Installation Temperature as the base temperature for the trackwork.

5.11.4.3 Fatigue

Consideration shall be given to the effect of change of stress levels caused by passage of light rail trains over structures. Over the life of the structure, 3 million cycles of maximum stress shall be used in estimating the number of repetitive maximum stress cycles.

5.11.4.4 Uplift

Provision shall be made for adequate attachment of the superstructure to the substructure should any combination of loading produce uplift at any support. Where DL, E, or any other loadings tend to reduce the uplift effect, the corresponding load factors shall be taken as 0.9 for DL, 0.75 for E, and zero for other loadings.

5.11.4.5 Friction

Where applicable, friction shall be considered in the design. Friction forces shall include acceleration and braking forces from the LRT vehicle.

5.11.4.6 LRT Stray Current Provisions

Stray current provisions are detailed in Chapter 19, Corrosion Control.

5.11.4.7 Rail Break

Consideration shall be given to the impact loading from a rail break. The design shall limit the rail gap due to a rail break.

5.12 Support and Underpinning of Existing Structures

Support and underpinning of existing structures shall be determined on a site-specific basis considering the following:

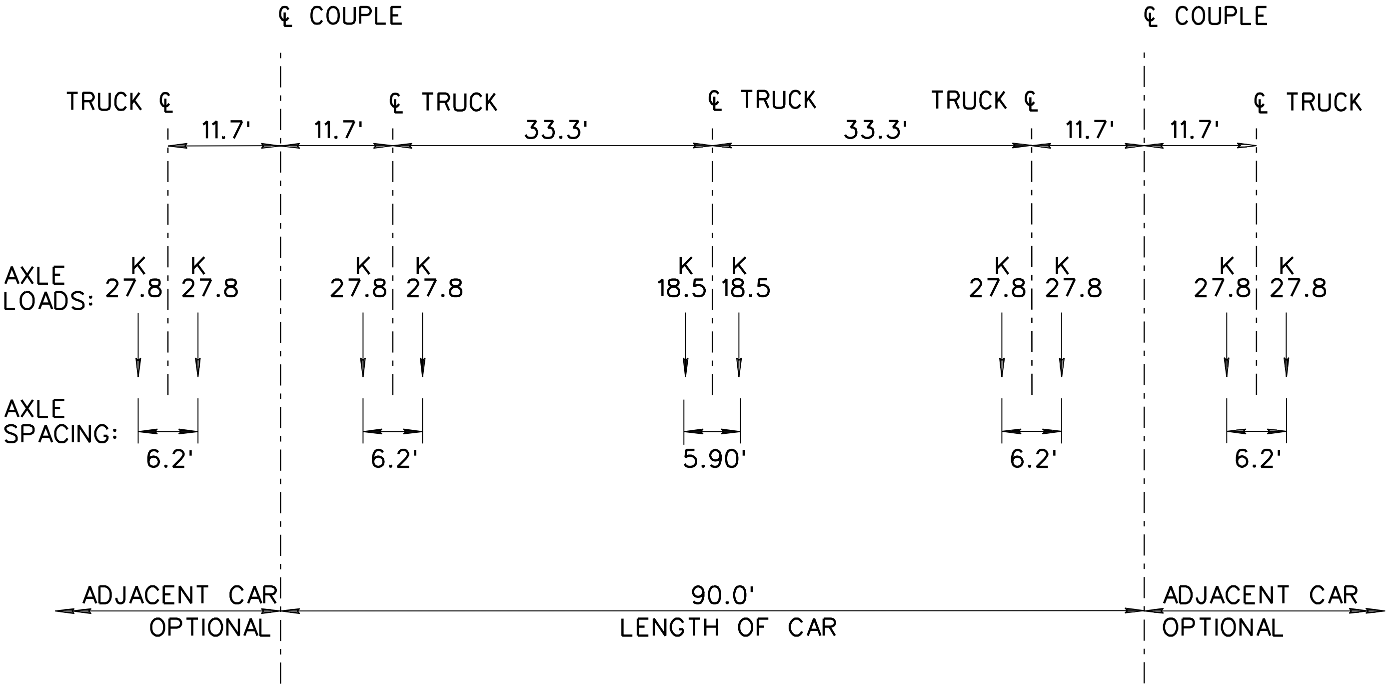
Considerations:

- Type of structure to be underpinned
- Proximity and type of adjacent construction
- Soil properties and tolerable structural deformations
- Methods:
  - Underpinning methods include jacked-down piles, slant-drilled piles, mini-piles, augured shafts, and hand-mined shafts.
  - Rigid protection wall support systems include diaphragm (slurry) walls, contiguous pile (tangent or secant) walls and closely spaced soldier pile walls.

Other methods of controlling ground movement and minimizing settlements include compaction grouting, chemical grouting and ground freezing.

5.13 Support of Excavation Structures

Support of excavation structures shall generally be the responsibility of the Contractor. The Geotechnical Report information will be made available for the Contractor's use. When planning for structures requiring excavation support, spatial and physical constraints (adjacent structures, utilities, etc.) shall be considered.



LIGHT RAIL VEHICLE STATIC LOADING

NOTES:

1. AXLE LOAD IN KIPS.
2. TOTAL LOAD 148,200 LBS/CAR
3. THE LRT TRAIN SHALL CONSIST OF EITHER ONE, TWO, OR THREE CARS, WHICHEVER PRODUCES THE MAXIMUM LOAD FOR THE ELEMENT UNDER CONSIDERATION, APPLIES TO BOTH DIRECTIONS.
4. THE LOADS AND DISTANCES DEPICTED ARE WORST CASE SCENARIO.
5. THE VEHICLE IS ASSUMED TO HAVE AN AXLE LOAD/CONFIGURATION THAT DOES NOT EXCEED THE STANDARD LOAD

METRO	VALLEY METRO RAIL, INC.	DESIGN CRITERIA	DATE January, 2007
		LIGHT RAIL VEHICLE LOADING	FIGURE NO. 5–1

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Attachment 5 – Typical Cross Sections for the At Grade Community Path

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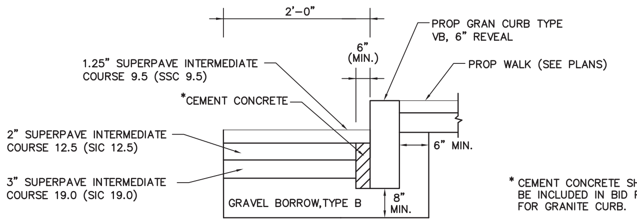
SOMERVILLE COMMUNITY BIKEPATH			
STATE	FED. AID PROJ. NO.	SHEET NO.	TOTAL SHEETS
MASS.	CM/HP-002S (408) X	4	53
	PROJECT FILE NO. 604331		

TYPICAL SECTIONS AND PAVEMENT NOTES



CURB INSTALLATION @ CEDAR STREET

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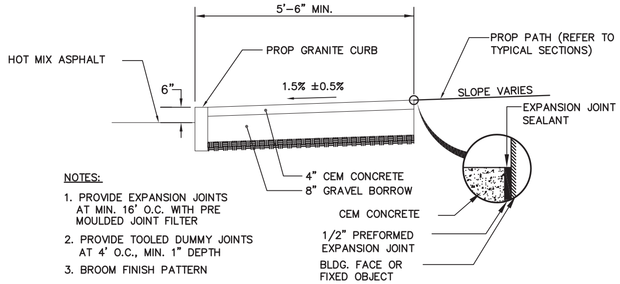
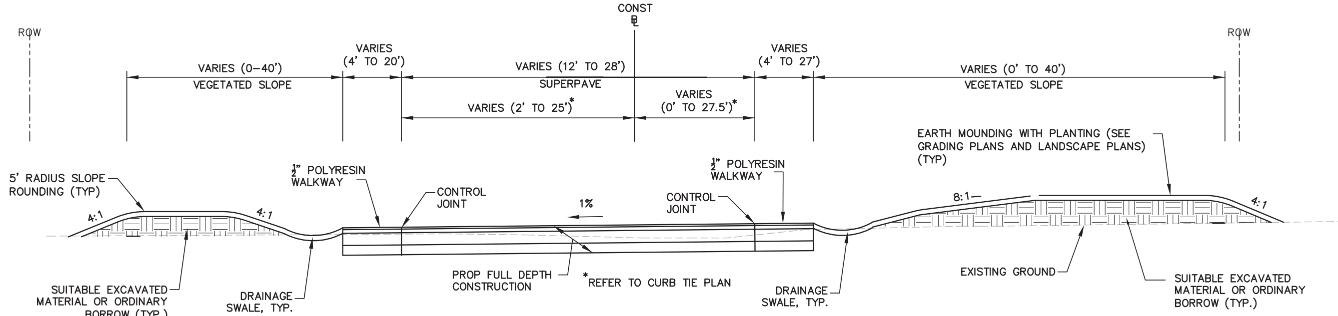


NOTES:

1. PROVIDE EXPANSION JOINTS AT MIN. 16' O.C. WITH PRE MOULDED JOINT FILTER
2. PROVIDE TOOLED DUMMY JOINTS AT 4' O.C., MIN. 1" DEPTH
3. BROOM FINISH PATTERN

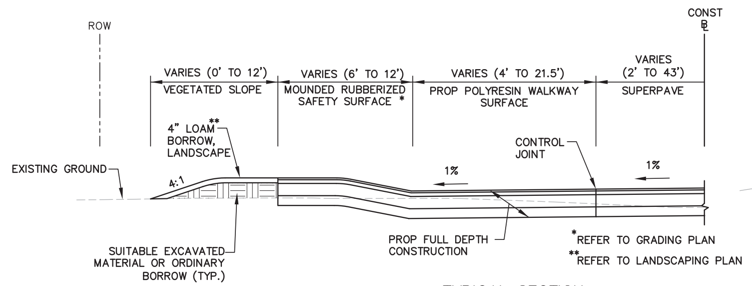
CEMENT CONCRETE WALK ALONG CEDAR STREET

N.T.S.



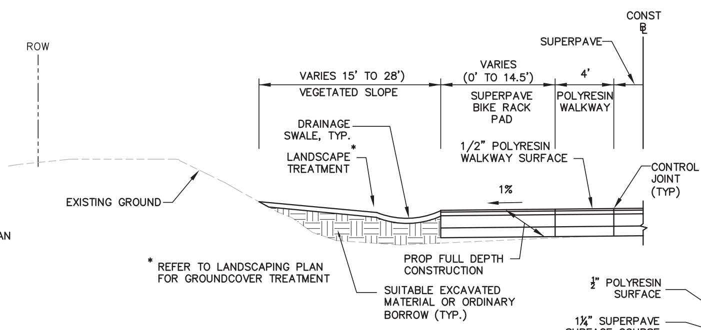
PATH TYPICAL SECTION

N.T.S.



TYPICAL SECTION
STATION 11+00 TO 11+60 LT

N.T.S.



TYPICAL SECTION
STATION 12+50 TO 13+10 LT

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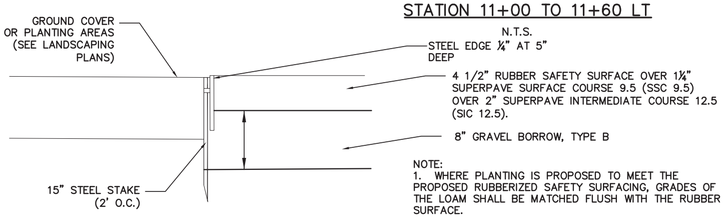


NOTE:
1. WHERE PLANTING IS PROPOSED TO MEET THE PROPOSED RUBBERIZED SAFETY SURFACING, GRADES OF THE LOAM SHALL BE MATCHED FLUSH WITH THE RUBBER SURFACE.

STEEL EDGE AT RUBBERIZED SAFETY SURFACING DETAIL

N.T.S.

PAVEMENT NOTES

PROPOSED FULL DEPTH CONSTRUCTION (PATH):

SURFACE: ½" MICROSURFACING SURFACE TREATMENT OVER 1¼" SUPERPAVE SURFACE COURSE 9.5 (SSC 9.5) OVER 2" SUPERPAVE INTERMEDIATE COURSE 12.5 (SIC 12.5) OVER

SUBBASE: 8" GRAVEL BORROW, TYPE B FOR SUBBASE

PROPOSED RAISED CROSSWALK AT CEDAR STREET:

SURFACE: 3" INTERLOCKING CONCRETE PAVER OVER 1¼" SUPERPAVE SURFACE COURSE 9.5 (SSC 9.5) OVER 2" SUPERPAVE INTERMEDIATE COURSE 12.5 (SIC 12.5) OVER 3" SUPERPAVE INTERMEDIATE COURSE 19.0 (SIC 19.0) OVER

SUBBASE: 8" GRAVEL BORROW, TYPE B FOR SUBBASE

PROPOSED POLYRESIN WALKWAY SURFACE:

SURFACE: ½" RUBBERIZED SURFACE TREATMENT OVER 1¼" SUPERPAVE SURFACE COURSE 2" SUPERPAVE INTERMEDIATE COURSE 12.5 (SIC 12.5) OVER

SUBBASE: 8" GRAVEL BORROW, TYPE B FOR SUBBASE

PROPOSED CEDAR STREET INTERSECTION RAMP CONSTRUCTION:

SURFACE: 1¼" SUPERPAVE SURFACE COURSE 9.5 (SSC 9.5) OVER 2" SUPERPAVE INTERMEDIATE COURSE 12.5 (SIC 12.5) OVER 3" SUPERPAVE INTERMEDIATE COURSE 19.0 (SIC 19.0) OVER

SUBBASE: 8" GRAVEL BORROW, TYPE B FOR SUBBASE

PROPOSED CEMENT CONCRETE WALK:

SURFACE: 4" CEMENT CONCRETE

SUBBASE: 8" GRAVEL BORROW, TYPE B

NOTE: ASHPALT EMULSION FOR TACK COAST SHALL BE APPLIED AT A RATE OF 0.05 GAL/SY.

PROPOSED CEMENT CONCRETE WALK AT DRIVEWAYS:

SURFACE: 6" CEMENT CONCRETE

SUBBASE: 8" GRAVEL BORROW, TYPE B

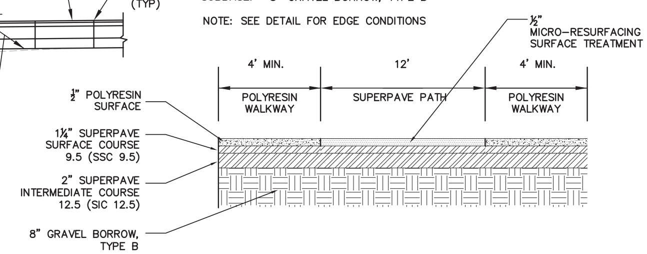
NOTE: ASHPALT EMULSION FOR TACK COAST SHALL BE APPLIED AT A RATE OF 0.05 GAL/SY.

PROPOSED RUBBERIZED SAFETY SURFACING

SURFACE: 4 ½" RUBBER SAFETY SURFACE OVER 1¼" SUPERPAVE SURFACE COURSE 9.5 (SSC 9.5) OVER 2" SUPERPAVE INTERMEDIATE COURSE 12.5 (SIC 12.5).

SUBBASE: 8" GRAVEL BORROW, TYPE B

NOTE: SEE DETAIL FOR EDGE CONDITIONS



PATH AND POLYRESIN WALKWAY SECTION

N.T.S.

WESTON & SAMPSON

IN CHARGE: L. KEEGAN DATE: 9/01/2012
DRAWN BY: A. PECK DATE: 9/01/2012
CHECKED BY: G. SWAN DATE: 9/01/2012
FILE PATH: Z:\MA-Foxboro-Projects\Somerville MA\2110087 - Community Bikepath\CADART\DESIGN\Community Bikepath\dwg\75% Design\ DWG NAME: 04_TypSect.dwg DATE: 03/14/2012 TIME: 10:48 AM