

MBTA GREEN LINE EXTENSION DESIGN-BUILD PROJECT

CONTRACT #E22CN07

TECHNICAL PROPOSAL PART 4: TECHNICAL SOLUTIONS

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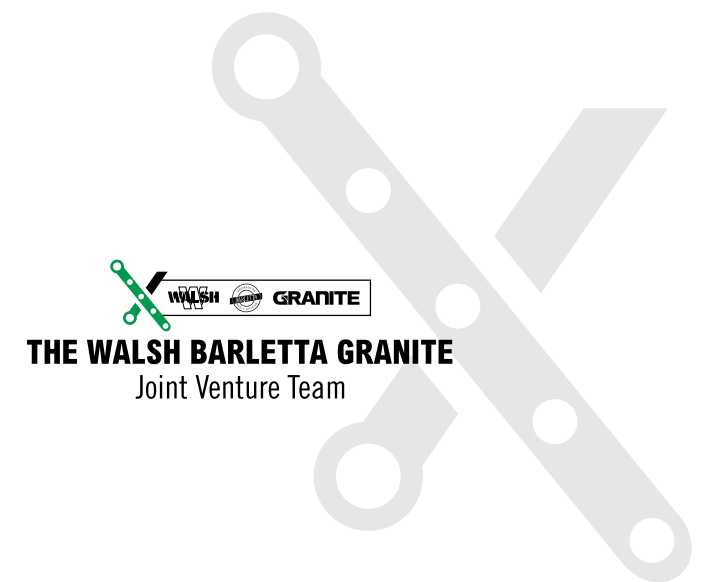


THE WALSH BARLETTA GRANITE
Joint Venture Team



ELECTRONIC

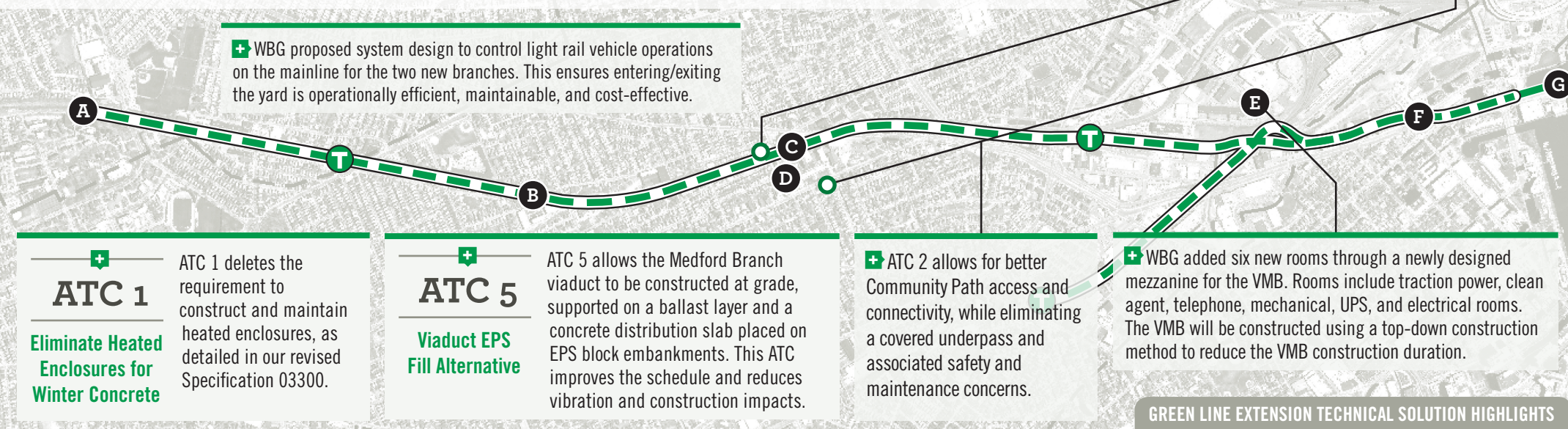
TECHNICAL PROPOSAL: PART 4 TECHNICAL SOLUTIONS



Part 4

TECHNICAL SOLUTIONS

The Green Line Extension will be a vital link for the neighborhoods of Somerville, Medford, Cambridge, and the greater Boston area. WBG's conceptual design provides for the full Project scope as determined by a thorough review of the contract documents, knowledge from designing and constructing various projects for the MBTA, and familiarization with the Project site. We developed our design using all governing regulations and best practices, optimized with innovative concepts to deliver effective Project solutions.



ATC 3

Replacement of School Street Bridge

ATC 3 replaces the existing School Street bridge with a new, single-span structure over the Green Line and NH commuter rail tracks.

ATC 2

Walnut Community Path At Grade

ATC 2 eliminates the Community Path underpass at Walnut Street by placing the path at street level.

+ ATC 1

Eliminate Heated Enclosures for Winter Concrete

ATC 1 deletes the requirement to construct and maintain heated enclosures, as detailed in our revised Specification 03300.

+ ATC 5

Viaduct EPS Fill Alternative

ATC 5 allows the Medford Branch viaduct to be constructed at grade, supported on a ballast layer and a concrete distribution slab placed on EPS block embankments. This ATC improves the schedule and reduces vibration and construction impacts.

+ ATC 2

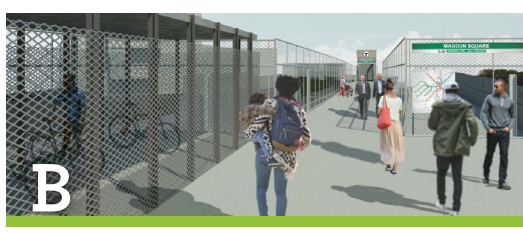
ATC 2 allows for better Community Path access and connectivity, while eliminating a covered underpass and associated safety and maintenance concerns.

+ WBG added six new rooms through a newly designed mezzanine for the VMB. Rooms include traction power, clean agent, telephone, mechanical, UPS, and electrical rooms. The VMB will be constructed using a top-down construction method to reduce the VMB construction duration.

GREEN LINE EXTENSION TECHNICAL SOLUTION HIGHLIGHTS



A College Avenue Station. Improvements, including secure walkways, will benefit both the community of Medford and the students and staff of Tufts University.



B Magoun Square Station. The new station will serve the communities of Somerville for the Green Line "D" Branch and will include accessible accommodation areas.



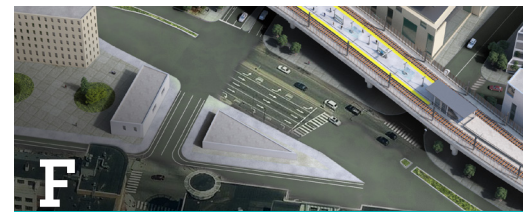
C Gilman Square Station. Located at Medford Street and Pearl Street in Somerville, this station will include historical interpretive displays.



D Walnut Street Community Path. WBG optimizes the Walnut Street Community Path underpass by placing the path at street level.



E Vehicle Maintenance Facility. WBG will design and construct a durable facility to store, operate, and maintain the existing fleet and newly procured light rail vehicles for the MBTA. WBG enhanced the overall building design to include six new rooms for mechanical and electrical equipment and several new doors for emergency egress and equipment room access.



F Lechmere Station. The new station in East Cambridge will reduce train overcrowding found in Boston's downtown stations and will include various ADA compliant accessible walkways.



G Lechmere Viaduct. Located in East Cambridge, the double track structure will support eastbound and westbound tracks of the Medford Branch alignment.

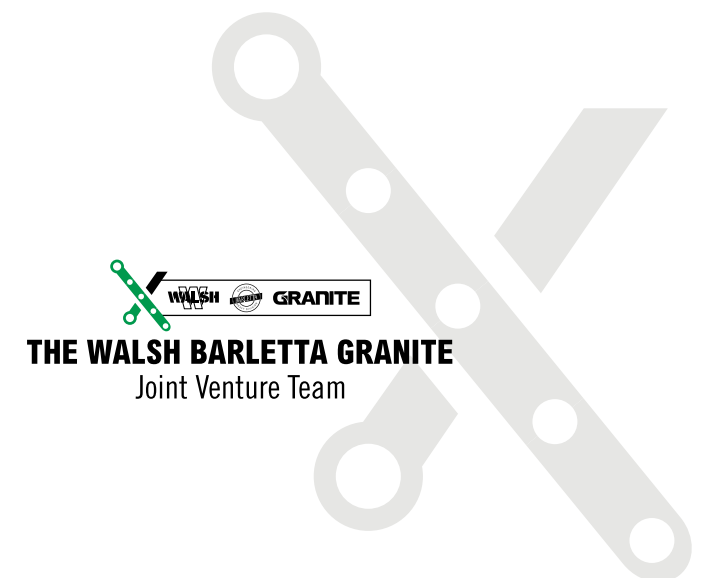
ACRONYM DEFINITIONS

To assist in providing comprehensive technical solutions, WBG lists definitions for all acronyms found within Technical Proposal Part 4.

- ABS:** Automatic Block Signaling
- AC:** Access Control System
- ASD:** Allowable Stress Design
- AVI:** Automatic Vehicle Identification
- BCIL:** Boston Center for Independent Living
- BMS:** Building Mgmt. System
- CCB:** Code Control Box
- CCTV:** Closed-Circuit Television
- CDWM:** Construction and Demolition Waste Mgmt. Plan
- CEPP:** Comprehensive Environmental Protection Program
- CIH:** Central Instrument Houses
- CIL:** Certifiable Items List
- CMP:** Configuration Mgmt. Plan
- CPLC:** Communications Programmable Logic Controllers
- CPT:** Core Penetration Testing
- CPTED:** Crime Prevention Through Environmental Design
- CWR:** Continuously Welded Rail
- DMP:** Deformation Monitor Point
- EACS:** Electronic Access Control System
- ECB:** Emergency Call Box
- EDR:** Electrical Distribution Room
- EMMP:** Excavated Materials Mgmt. Plan
- EMP:** Environmental Mitigation and Monitoring Plan
- FONSI:** Finding of No Significant Impact
- FTA:** Federal Transit Administration
- GMP:** Groundwater Mgmt. Plan
- HMCS:** Hub Monitoring and Control System
- HT:** Heat Treated
- HV:** Heating and Ventilating
- IAQ:** Indoor Air Quality
- IECC:** International Energy Conservation Code
- IESNA:** Illuminating Engineering Society of North America
- ISTP:** Integrated System Test Plan
- IW:** Industrial Waste
- LRFD:** Load and Resistance Factor Design
- LRTMSS:** Light Rail Transit Track Maintenance and Safety Standards
- LRV:** Light Rail Vehicle
- MCP:** Massachusetts Contingency Plan
- MEC:** Massachusetts Electrical Code
- MEP:** Mechanical/Electrical/Plumbing
- MSBC:** Massachusetts State Building Code
- NRCS:** Natural Resources Conservation Service
- NVMP:** Noise and Vibration Mitigation Plan
- NVPCL:** Non-Vital PLC
- OC:** On Center
- OCC:** Operations Control Center
- OCS:** Overhead Contact System
- PA:** Public Address
- PA/TPIS:** Public Address/Transit Passenger Information System
- PoE:** Power Over Ethernet
- PSIM:** Physical Security Information System
- QMP:** Quality Mgmt. Plan
- RC:** Running Clearance
- RFC:** Release for Construction
- RMP:** Requirements Mgmt. Plan
- PTC:** Positive Train Control
- RTN:** Release Tracking Numbers
- RVTM:** Requirements Verification Traceability Matrix
- SCADA:** Supervisory Control and Data Acquisition
- SCU:** Station Control Unit
- SEMP:** Systems Engineering Mgmt. Plan
- SIMP:** System Integration Mgmt. Plan
- STCS:** Signaling and Train Control System
- SWAN:** Security Wide Area Network
- SWPPP:** Storm Water Pollution Prevention Plan
- TMDL:** Total Maximum Daily Load
- TOM:** Train Operations Model
- TP:** Traction Power System
- TPIS:** Transit Passenger Information System
- TPSS:** Traction Power Substations
- TWC:** Train-to-Wayside Communications
- UPS:** Uninterruptible Power Supply
- VAV:** Variable Air Volume
- V&V:** Verification and Validation
- VMB:** Vehicle Maintenance Building
- VMF:** Vehicle Maintenance Facility
- VMS:** Variable Message Signs
- VMIS:** Vital Microprocessor interlocking Systems
- VoIP:** Voice Over Internet Protocol
- VPN:** Virtual Private Networks
- WAN:** Wide Area Network

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SYSTEMS AND SYSTEM INTEGRATION



4.1 Systems and System Integration

WBG brings a systems design and construction team to the GLX Project with nationwide experience in design-build light rail transit, and long-standing relationships with the top systems suppliers. Our approach to safety and systems assurance will use the same processes and plans described in Section 3.3 and will be managed by Systems Integration/Testing & Commissioning Manager, Ed McDonald. Using this systems engineering approach and a series of plans to execute it, we will verify all project requirements have been properly identified, integrated, and incorporated into the final GLX Project turned over to the MBTA.

A. LIGHT RAIL TRANSIT SYSTEMS

Design Methodology and Approach

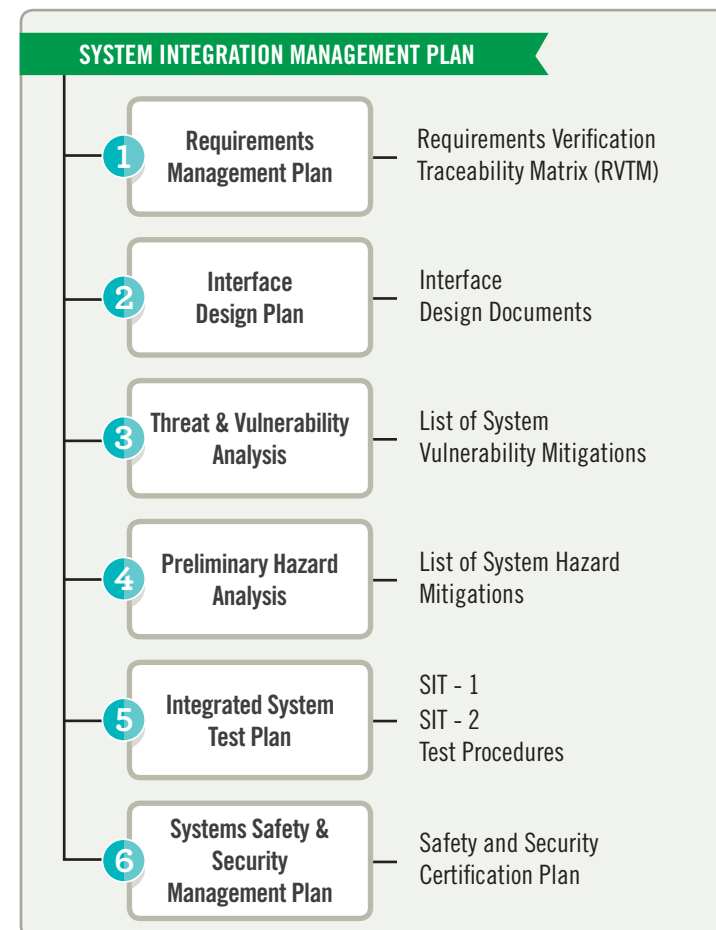
WBG's design team, under the guidance of Design Manager Michael Kennedy, will develop a systems engineering approach to manage requirements, ensure compliance, and attain safety and security goals for the GLX Project. This approach will be based on the guidelines established in the INCOSE Systems Handbook v3.2.2 and/or ISO/IEC 15288 "Systems Engineering – Systems Life Cycle Processes," and uses a series of plans shown in Figure 4.1-1. We will incorporate these recommended practices into the management, design, construction, and testing phases of the Project. We will also rely on industry best practice, proven methodologies, and the experience of our team.

System Engineering Management Plan

The Systems Engineering Management Plan (SEMP) will be the responsibility of Systems Integration/Testing & Commissioning Manager, Ed McDonald. It is the top-level systems document that will describe our entire process, the organization, and the rules for our team, and layout the roadmap to meeting the MBTA's requirements. The SEM has several key components, the most important of which is the System Integration Management Plan (SIMP). The SIMP is described in more detail in Section 3.3 of our Technical Proposal and is our core guide for requirements, design, analyses, and testing, showing the MBTA that our team performed the job correctly. All the plans contained in the SIMP are integrally linked and have critical steps for us to complete and track throughout the project.

Beyond this, the SEM provides guidelines for the project management team to support the process, describes the tools (generally software) that will be used to manage the amount of data that must be collected and linked, and provides the team the configuration control guidelines and rules required to manage contract

Figure 4.1-1 Relationship of Systems Management Plans.



requirements through the life cycle of the Project. The SEM is written and implemented under the direction of the Systems Integration Manager and is configured to the traditional and special requirements generated by the GLX Project.

The SEM will set out a program that will guide the entire WBG team in a unified direction by:

- » Providing a structured and auditable approach to attaining requirements, managing interfaces, and controlling risks throughout the project life cycle
- » Formalizing the processes in all stages of the Project
- » Eliciting agreement between design disciplines to mitigate change and rework
- » Providing a solid basis to generate test plans and commissioning procedures
- » Driving development for required system manuals and training

Requirements Management Plan

Requirements are the basis from which the overall system is designed and constructed and provides the designer with the basis for determining when designs are complete and in compliance with MBTA contract requirements. Clear identification, definition, and management of requirements is essential to ensure the delivery of a functioning and compliant system. The Requirements Management Plan (RMP) will be one of the six subplans described in the SIMP.

The MBTA has established prescriptive and operational requirements, managed throughout the project from origination until completion, rather than by project activity. Failure to adhere to requirements can negatively impact the Project schedule. Therefore, WBG will manage this process to objectively prove that all work complies with the contract requirements. WBG's quality

organization will be a valuable partner in this process. Inspection and verification activities provide evidence of this compliance.

We have divided the project requirements into three groups for tracking purposes. Figure 4.1-2 summarizes each group and the method for tracking the requirements to completion. The RMP process manages all requirements to compliance, whether the requirement is a "will" or "shall" in the contract documents, derived from an interface design, or an environmental restriction.

System Integration Management Plan

The SIMP links all the systems plans that are integrated or depend on each other into one overall plan. The SIMP is described in our Technical Proposal Section 3.3 in detail. The text below focuses on the testing and commissioning process.

Creation of test documentation comes from multiple sources. The major sources of input to those plans and procedures will be drawn from the following sources:

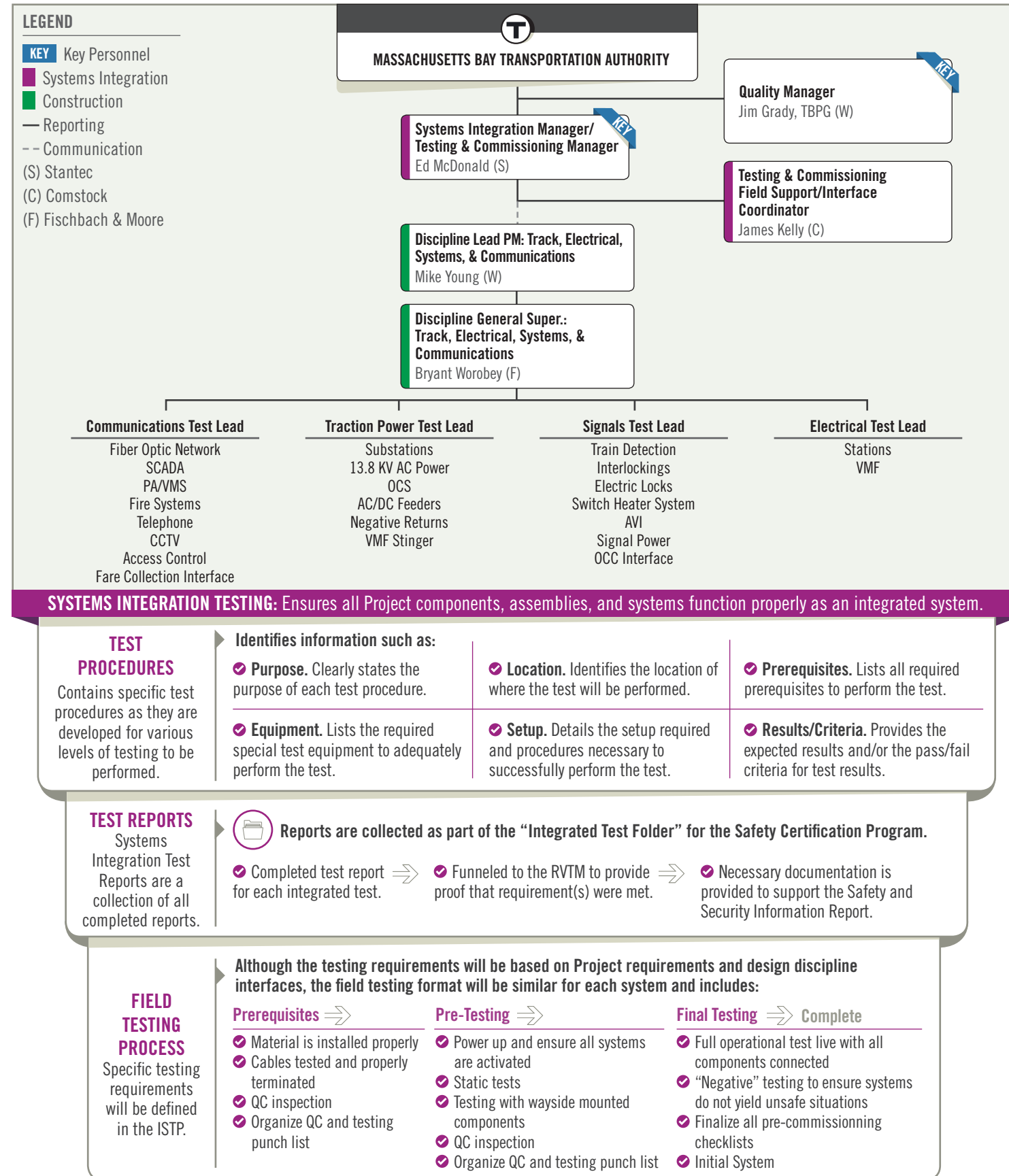
- » Contract requirements
- » Design interface requirements
- » Construction installation verification test documentation
- » Approved design drawings and specifications relating to the procurement, installation or construction of systems equipment, and facilities
- » Relevant test reports for all constructed civil and systems elements (static testing)
- » MBTA regulations
- » FTA Guidelines for Safety and Security

Maintaining the Requirements Verification Tracking Matrix (RVTM) using the requirements management software tool ensures the necessary items for testing are compiled for each design element.

Figure 4.1-2 Project Requirements Grouped by Type.

REQUIREMENT	TRACKING METHOD
Traditional transit systems of signals and train control, communications, security, networks, traction power, and overhead contact systems	Requirements Verification Traceability Matrix (RVTM) using a requirements management software tool such as IBM DOORS. These requirements will follow the complete verification and validation process described in this section.
Safety, hazards, environmental, and system-to-system interfaces	A subset of the RVTM called the Certifiable Items List. These requirements are met when WBG provides a certificate of compliance (or completion) to the MBTA.
Remaining contract technical requirements such as track, stations, bridges, VMF, embankments, etc.	A tracking matrix using spreadsheet software. The engineer of record will establish the requirements for compliance to be satisfied at the time of Release for Construction (RFC) drawings.

Figure 4.1-3 Systems Testing Process Organization Chart



This continuous management of requirements simplifies creation of the testing, inspection, or simulation processes that validates the final product against the MBTA contract requirements.

Testing Organization

WBG's systems testing organization and an outline of the process it will follow are presented in Figure 4.1-3. Project requirements incorporated into the design will be verified from factory through field, and integrated testing and the results will be properly documented for the purposes of safety certification. The complete design process, inclusive of systems integration, will be coordinated with construction and testing and commissioning within the Project Schedule, based on the order the two branches will be opened to revenue service. WBG's current plan is for the Medford Branch to open first.

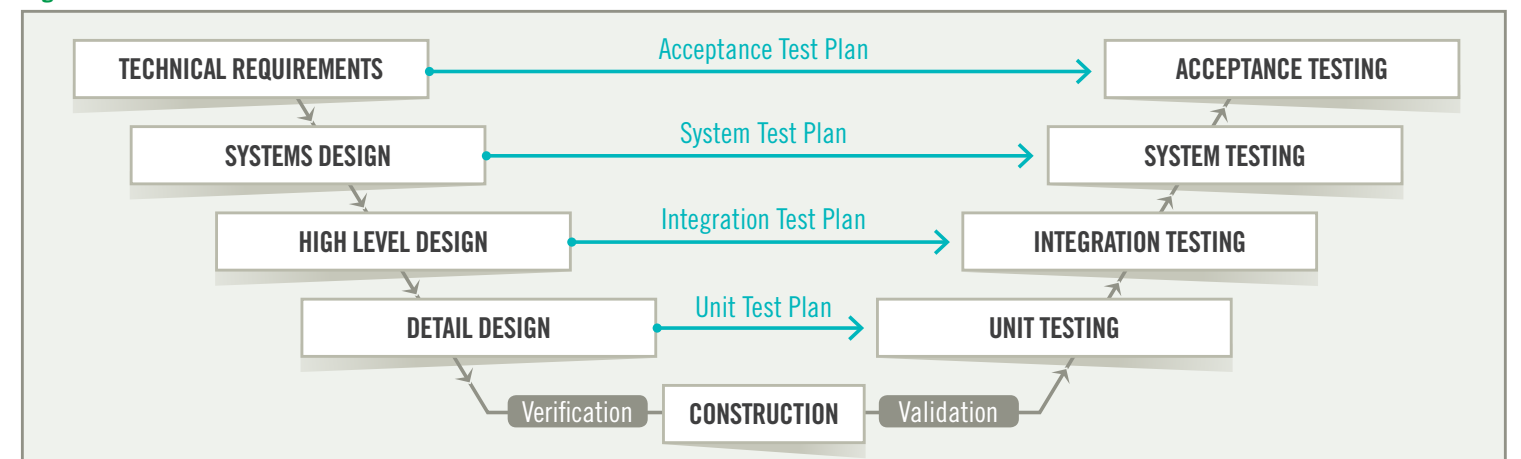
We note the MBTA's requirement to establish a temporary Project Test Center for conducting some SIT-I and all SIT-II integration tests, including dynamic testing with Green Line Light Rail Vehicles (LRVs). The Project Test Center provides the WBG testing organization the opportunity to fully verify the functionality of the newly constructed GLX without adversely affecting existing Green Line operations. Our intended full and successful use of the Project Test Center will ensure that final configuration testing of the GLX at the MBTA Operations Control Center (OCC) will go as smoothly as possible and meet our goal of safely integrating the GLX into existing MBTA operations with minimal impacts.

Verification and Validation

The Verification and Validation (V&V) process is the mechanism whereby the requirements are managed in a traceable manner that follows the development of the requirements into verifiable designs through the construction and installation process and into the inspection and testing process. All the requirements mentioned in the requirements management section will be managed through the V&V process. The process deals only with technical contract requirements. The V&V process will not involve project management, scheduling, items dealing with contract terms and conditions, or other non-technical issues. Following the systems approach, we will use a "V" model to construct our V&V program, similar what is presented in Figure 4.1-4.

The V&V process is a comprehensive documenting and tracking process, which monitors all technical requirements throughout the Project's life cycle including those that change or are deleted. Furthermore, the V&V process provides an auditable method for tracking the technical requirements to their completion. This is achieved when the contractor provides objective evidence, which verifies the design or validates the construction cycle to prove the technical requirements have been completed. The RVTM is contained within the V&V process, linking the design, test, and inspection documentation electronically to each requirement. It facilitates process requirements validation; if a requirement is applicable to multiple designs, it must be verified and validated for each of the design elements.

Figure 4.1-4 V-Model



Key Systems Suppliers and Overall Systems Integrator

Key System Suppliers

While GLX is a large project, the 4.3-mile light rail extension with a Vehicle Maintenance Facility (VMF) and a non-signaled yard falls comfortably within the capabilities of WBG's proven and available systems suppliers. Figure 4.1-5 has a summary of the WBG systems supplier experience.

Signal System: A key component of the systems, especially when it comes to the final operational testing, is the signal system. Alstom and Ansaldo STS have experience and expertise in providing LRT signal systems for projects of similar or larger size and complexity throughout North America and the world. They can design, manufacture, and test the signal system and ensure it is integrated with the remainder of the light rail system.

Communications: Communications ties the Project's systems together and has become one of the largest systems components as its capabilities and use are expanded. Several communications integrators with the necessary transit experience for the GLX Project include: HSQ Technology, Rockwell Collins (formerly ARINC), and Modern Communications Systems (formerly Rail Services Corporation). All have been involved in design-build rail transit projects and understand the high level of design integration required for a successful project and how much of that integration burden relies on their scope.

Traction Power: The traction power scope for GLX is large and diverse, including three substations, 13.8 KV AC primary power, 13.8 KV ring feeders, 13.8 KV distribution to station, and 600V DC distribution for LRT operations with 1,000 KCMIL parallel feeders and a 2,000 KCMIL supplemental negative. Powell Electrical Systems, ABB Inc., and Myers Controlled Power, LLC all have an installed footprint in North America and experience in design-build rail transit.

Overhead Contact System (OCS): WBG will use two experienced suppliers with the requisite capacity for the OCS system: Impulse NC LLC and MAC Products. Both are regularly engaged in supplying the North American market and have long experience with the WBG system design and installation team.

Overall Systems Integrator

Jacobs, as a part of the WBG team, will provide the overall systems integration for the GLX Project using their experience in LRT systems and major integration efforts. Jacobs will design all the rail systems, including track, signals, communications, traction power, catenary and facilities. Ed McDonald of Stantec is the Systems Integration Manager/Testing & Commissioning Manager. He will oversee the systems integration during design and construction to confirm the systems are designed and integrated correctly.

Jacobs and Ed both have experience on the California High Speed Rail (CHSR) system. Jacobs is the engineer of record for the design-build team for this \$1.6 billion project. The CHSR is the first major civil project in the U.S. to incorporate the systems approach to design, construction and testing. Ed has served as the client representative for the largest in-process segment of the CHSR system, leading the systems integration and requirements management for the civil design. Together, Ed and Jacobs have

constructed a workable requirements management system, a design integration plan with the future track and systems design, an interface design system, and a logical approach to developing test plans to validate the system. Ed's current obligations on CHSR will be completed in time for his role on GLX.

On the Staten Island Railroad Project, Ed performed as the lead signals construction manager, integrating the new signal system into a reconstruction of an existing terminal interlocking. This interlocking was under several feet of water during Hurricane Sandy. The design and construction of the entire plant incorporated features to mitigate damage in case of another storm. This project had to be performed while maintaining railroad operation and coordination with a shopping mall being installed over a portion of the track.

Design and construction interfaces can make a system extension complex. As systems integrator on the Metro Dade (Miami) heavy rail project, Ed faced the integration challenge of tying into an existing 1980s system thirty-five years after it was placed in service. This included injecting new track cut into the middle of an operating system interlocking, interfacing analog and digital track circuits, server-based office addition into a mechanical control panel based OCC and two different generations of traction power design. All systems for this \$900 million project were commissioned on schedule.

B. TRAIN CONTROL SYSTEM DESIGN

Signaling and Train Control System Approach and Technical Details

The Green Line Signaling and Train Control System (S&TCS) must be extended to interface with the existing Green Line south of Lechmere Station on the East Cambridge Viaduct, north along the new Medford Branch to College Avenue Station, and west from the new Red Bridge Interlocking along the new Union Square Branch to Union Square Station. The three new yard leads also provide access to the new VMF from the two new branches. Normally, the S&TCS extends from an end-of-line station with no interlocking. For this project, the current end-of-line Lechmere Station is being replaced with a new Lechmere Station located on the new Lechmere Viaduct. The existing S&TCS will need to be modified so that Science Park Station is temporarily the end-of-the line while the new viaduct and station are built. At the conclusion of construction and testing, the new Green Line S&TCS will be cutover into the existing Green Line S&TCS.

Figure 4.1-5 Summary of WBG Systems Supplier Experience

		SUPPLIER NAME	PROJECT HIGHLIGHTS	OWNER	LOCATION
Signals	ALSTOM	Alstom Signaling, Inc.	Hiawatha LRT	Metro Transit	Minneapolis, MN
			St. Clair and Cross County Extensions	MetroLink	St. Louis, MO
			Green, Orange, Blue Line Expansions	DART	Dallas, TX
	ANSALDO STS	Ansaldo STS	Green Line Expansion	DART	Dallas, TX
			North Shore Connector	PAAC	Pittsburgh, PA
			Crenshaw/LAX	LAMTA	Los Angeles, CA
Communications	HSQ TECHNOLOGY	HSQ Technology	Silicon Valley Berryessa Extension	VTA/BART	San Jose, CA
			U830 University Link	Sound Transit	Seattle, WA
	ROCKWELL COLLINS	Rockwell Collins	eBart	BART	Pittsburg/Antioch, CA
			AIM CTC Passenger Information System	MBTA	Boston, MA
			Central Corridor AIM CTC/SCADA/LRT Communications	Metro Transit	Minneapolis/St. Paul, MN
	MODERN COMMUNICATIONS SYSTEMS	Modern Communications Systems	AIM CTC/SCADA/LRT Communications	Metro	Houston, TX
BART Warm Springs Extension			BART	Fremont, CA	
Eagle P3 Airport Commuter Rail			RTD	Denver, CO	
Traction Power	POWELL	Powell Electrical Systems	Blue Line Extension	CATS	Charlotte, NC
			Hiawatha LRT	Metro Transit	Minneapolis, MN
	ABB	ABB Inc.	Silicon Valley Berryessa Extension	VTA/BART	San Jose, CA
			TPSS Improvement Project	STM	Montreal, QC
			Eglinton Crosstown LRT Project	Metrolinx	Toronto, ON
	MYERS CONTROLLED POWER, LLC	Myers Controlled Power, LLC	Evergreen Rapid Transit Line	TransLink	Vancouver, BC
			Hillside/Kew Gardens TPSS Replacement	LIRR	New York, NY
Overhead Contact System	IMPULSE NC LLC	Impulse NC LLC	Traction Power System Upgrades	CTA	Chicago, IL
			BART Warm Springs Extension	BART	Fremont, CA
			South Oak Cliff Corridor SOC3	DART	Dallas, TX
	MAC PRODUCTS INC.	MAC Products	Denver I-225 Project	RTD	Denver, CO
			DART Orange Line I-3	DART	Dallas, TX
			Central Mesa LRT	Valley Metro	Phoenix, AZ
			EXPO II Line	LAMTA	Los Angeles, CA
			Draper Line	UTA	Salt Lake City, UT

WBG'S EXPERIENCED SYSTEMS SUPPLIERS

WBG engaged capable and competitive systems supply firms to assemble the best team to achieve optimal Project systems.

Each firm brings nationwide expertise, including Boston experience, to successfully supply system components to the GLX Project and to the MBTA.



S&TCS Architecture

Proposed System

The proposed S&TCS will be consistent with the existing Green Line S&TCS using the latest underlying technology and products, with a combination of vital and non-vital processors to control and indicate the wayside signal components, as shown in Figure 4.1-6. The control equipment will be contained inside central instrument houses (CIH) located in close proximity to the stations to provide easy access for maintenance and not in wayside enclosures distributed along the right-of-way (ROW). The existing automatic vehicle identification (AVI) system will be extended to include the new interlockings and movements to the yard. Route requests will be available via the AVI system with a pushbutton backup, local control panels within the CIHs, and via remote control from the OCC. The MBTA will perform modifications to the OCC necessary to add the Green Line extension with WBG’s support for testing and activation.

WBG designed the proposed system to control LRV operations on the mainline for the two new branches and entering and exiting the yard. The system is designed in a vital, fail-safe manner, with provisions for making the system operationally efficient, maintainable, cost effective, and upgradeable. The system will be configured with the following major subsystems.

Vital Control System: Based on redundant vital microprocessor interlocking systems (VMIS), the vital signal system will provide for the safe and efficient movement of all trains. The vital system will process and execute all vital functions in accordance with the latest industry standards. The vital system will include, but not be limited to, all applicable electrical circuits and “hard” wiring redundant microprocessors, track circuits, line circuits, vital relays, and all life/safety components that make up the signal system.

The redundant VMIS units will be designed to function in a seamless “hot-standby” manner, with the offline unit taking immediate control without delay and without having to run approach times when required by a failure of the online unit. Each unit will be clearly labeled “Normal” and “Standby.” 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.

All inputs, outputs, timers, and logic states of variables will be logged and recorded. The capacity will allow for a minimum of 30 days of data storage before overwriting any data. The design will log all maintenance and diagnostic indications for troubleshooting purposes. Diagnostic data will be displayed in a supplier-provided development tool on the maintainer’s computer to assist in the

efficiency of troubleshooting and taking corrective action. All VMIS and associated apparatus will be rack-mounted inside each CIH.

Non-Vital Control System: Redundant non-vital processors will be responsible for processing all logic functions other than the vital functions 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. Alternatively, a non-vital programmable logic controller (NVPLC) system similar to those the MBTA currently employs will be used in place of the integrated vital and non-vital system, if it is determined to be the optimum solution. All user control and indications of wayside devices will be through the non-vital processor systems.

The redundant non-vital systems will be configured to have the same standby capabilities as the vital system. Each non-vital processor will be able to be online and working with either vital processor, and vice versa.

Automatic Block Signaling (ABS): The S&TCS provided for GLX will be a wayside ABS system using wayside color light signals. An LRV occupying any section of track will be detected at all times by use of double rail 100 Hz AC steady-energy, phase-selective track circuits powered by redundant frequency converters located inside each CIH.

The signal block layout will interface with the existing Green Line S&TCS. The operating headways will be 5 minutes on the Medford and Union Square Branches, and 2.5 minutes on the viaduct between North Station and the new Red Bridge Interlocking, where the extension splits to the Medford and Union Square Branches. A minimum recovery buffer of 25% headway time will be provided in the design. The maximum authorized speed will be 50 mph, except where civil or block design speed restrictions are imposed.

Interlockings: To provide operational flexibility, terminal turn-back, maintenance facility access and egress, and mid-line storage and turn-back capability, six new interlockings will be constructed on the GLX Project. Interlockings will be controlled remotely from the OCC and locally from the CIH. Route requests will be manual and field automatic. Non-vital switch and exit blocking will be provided for all switches and signals to prevent establishment of routes into occupied and/or designated out-of-service zones. Field automatic

will not be available with any blocks applied. When in turn-back mode, all crossovers will automatically restore to the normal position after the train has accepted the route and cleared the interlocking. Sectional release will be provided on all routes except those where operational analysis demonstrates no operational value.

The OCC will provide constant communication and receipt of indications from the field non-vital processors. In the event communication to OCC from both non-vital processors is lost for more than two minutes, the system will switch to field automatic for route requests and will stay in field automatic until communication to OCC is re-established. Once communication is restored, the system will revert to whichever route requests state it was in before the communication failure occurred.

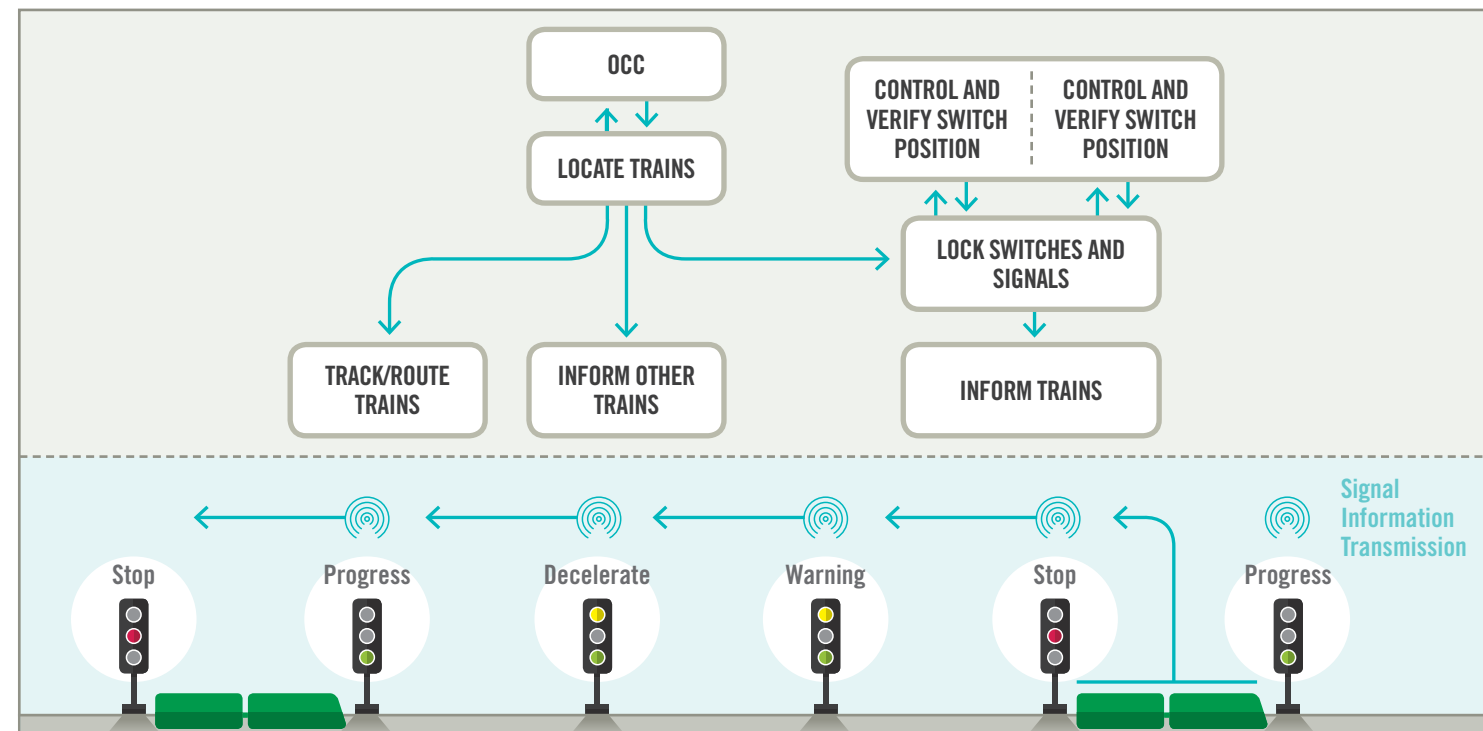
Switch and Lock Movements: All interlocking power switch-and-lock movement layouts will be equipped with mainline dual control 110 VDC switch machines with a manual power/hand selector lever. Solid-state type switch controllers will control interlocking power switches. They will have a discrete indication of when the switch has been placed in hand operation and, while in this state, all signals with routes over the switch will display their most restrictive aspect.

Hand Throw Switch-And-Lock Movements: The hand throw switch-and-lock movements within signaled territory at Red Bridge Interlocking and just east of Magoun Square Station shall have circuit controllers to indicate switch position and be equipped with electric lock layouts.

Switch Snow Melter Heating System: Every track switch within the Project limits will be equipped with rail heating elements powered from 600 VDC traction power to provide unobstructed operation of switch points under all weather conditions. The snow melting system will consist of remotely controlled snowmelter cases, external cable, conduit, rail connections, and other miscellaneous hardware.

Automatic Vehicle Identification System: An AVI system will be integrated into the existing Green Line AVI system and will be compatible with the on board AVI equipment. AVI 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 lead tracks. The AVI system will decode the route number from the vehicle and transmit route requests to the systems based on the Code Control Box (CCB)

Figure 4.1-6 S&TCS Architecture.



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 canceled and re-routed with a field pushbutton 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.

Operations Control Center Interface

The non-vital systems will interface directly with the OCC over the OCC field network. Communications will be serial based, using a local terminal server port for each non-vital system to route the data to the OCC network. Communication protocol between the OCC and non-vital processors will be Modbus protocol with a direct communication link between the two.

Signal Data And OCC Field Networks

A redundant signal data network will be provided to manage all vital and non-vital communication between the CIHs. A separate OCC field network will be provided to manage communication between the respective CIH and OCC. Network data traffic will be segmented so that data traffic is not propagated beyond where it is useful for system functionality. All network equipment diagnostics will be available at a single designated port on the network. In addition, an indication for signal data network availability will be provided for display on the maintainer's panel.

The network will be designed with centralized management and configuration consoles. These consoles will be diversely located should the other system lose communication with the network. For the OCC field network, we will use terminal servers at all field locations to interface between the processor and the data network switch. The signal data network and OCC field network will operate on the fiber optic system.

Revenue Vehicles, Maintenance Vehicles, and VMF Yard Control

The VMF is a manually controlled facility with the mainline signaling system ending on Yard Leads 2, 3, and 4 prior to entering the yard proper. All yard switches are hand throw type, similar to [Figure 4.1-7](#), without point detection or locking requiring routes within the yard to be manually aligned with switches visually verified as being in the correct position prior to train movement over

them. While routes to and from the yard leads and the mainline are controlled by the mainline signaling system at East Somerville and McGrath Interlockings, all movement within the VMF yard and shop facilities are controlled by the yardmaster.

Using voice radio, communication among the yardmaster, the train operator, and the MBTA personnel assigned to the VMF, the train will be guided as required to storage tracks, maintenance tracks, or back to the yard leads. If routed to Shop Tracks 1 or 2, the train can move into the facility powered by the overhead contact system. If routed to Shop Tracks 3 or 4, the train will need to stop on the shop apron and lower its pantograph to allow a stinger bug stick to be attached to the pantograph to provide power to move the train into the shop, the maintenance personnel use manual block derails with a position indicator to establish protection.

Hi-rail maintenance vehicles within the yard present a hazard, since there are no track circuits to detect their presence. They are similar to the trains in this way and must be treated the same. The yardmaster will likewise control their movement into, within, and out of the yard will using voice radio communications.

Additionally, the yardmaster will need to manage a train's release into revenue service by a predetermined schedule or work in conjunction with the OCC to know when to release new trains into service. The yardmaster knows the consist of trains that are parked, which trains require maintenance, and which are available for dispatch.

Fall Back Operation

The proposed fall back operation of S&TCS for failure management, including degraded mode of operations and train detection and protection, includes the following:

- » **Loss of controls and indications with the OCC**
 - Dedicated signal communication system is based on 96-strand fiber optic cable and backed up by a second 96-strand fiber optic cable.
- » **Failure of ABS track circuits and wayside signals**
 - A train operator's communication with OCC mitigates track circuits failure or wayside signal failure.
 - Hot standby and cold standby units back up ABS equipment centralized in CIHs.

- The automatic transfer switch inside CIH switches to a signal power supply, backed up by a standby unit substation.
- » **Failure of interlocking control equipment**
 - Hot standby and cold standby units back up interlocking control equipment.
 - A local control from the local (emergency) control panel inside CIH backs up a loss of OCC control and indication system. The local interlocking operator acts on the dispatcher's orders using the communication system.
- » **Failure of interlocking wayside equipment**
 - Temporarily re-routing trains over functioning switches and manual operation of critical switches using dual control feature mitigates switch machine failure.
 - The train operator's communication with OCC can mitigate wayside signal failure.
 - The automatic transfer switch inside the CIH switches to a standby unit substation that mitigates interlocking power supply failure.

Yard Control Strategy and Interface

A train can enter the VMF by either requesting the route or having OCC establish the route. Trains can enter the facility from either the Union Square or Medford Branches. VMF access from the Medford Branch is only via the inbound track, due to single direction running limitations, and is accessed using AVI with a wayside pushbutton backup at the East Somerville Interlocking. This allows the train to approach Brick Bottom Interlocking, where a pushbutton will give the incoming train access to Yard Lead 2 (YL2) or Yard Lead 3 (YL3). Exiting the VMF to the Medford Branch, the train can approach the Brick Bottom Interlocking on either YL2 or YL3 and request a route via a pushbutton. Again, due to single direction running, the only available exits will be on the outbound Medford track. The request to exit will be granted based on a first-in first-out basis, with trains already on the outbound Medford Line track. AVI will announce the incoming train to the OCC.

A train departing Union Square destined for the VMF will request entry via a pushbutton at McGrath Interlocking onto Yard Lead 4 (YL4). Once the route is cleared, the train can proceed. Exiting the VMF on YL4, the train must stop and make a request by pushbutton to depart. The exit will again be established on a first-in first-out basis, with outbound trains on the Union Square Line. Once cleared,

Figure 4.1-7 Hand throw switch. WBG incorporated hand throw switches with an easy-throw handle and cube direction indicator for optimal safety.



the train can move and the new train will be announced to the OCC using the AVI system.

Pushbuttons are only usable when the system is in automatic mode and all pushbuttons will have a 50-foot track circuit that the train must occupy to make the request.

Signaling and Train Control System Integration with Vehicle

The existing Green Line incorporates an AVI system as S&TCS integration with the vehicle. WBG intends to extend the existing AVI system over the new Green Line extension territory. The AVI system is a non-vital system that performs two tasks:

- » Reports vehicle location to the OCC
- » Request the wayside S&TCS to operate automatic switches and clear route signals at the power interlockings

The AVI system consists of two parts: car-borne equipment and wayside equipment. Every route in normal operation is represented by a unique three-digit code. At AVI key points, this code is transmitted by the car-borne equipment to the wayside equipment via an inductance loop located within the gauge of the track. The wayside equipment reports the vehicle location to the OCC and makes requests to the S&TCS as appropriate.

WBG partner Granite and key systems subcontractor LKCNT built the design-build Hiawatha Light Rail Transit System in Minneapolis, MN. The project required the design-build contract to purchase the wayside and car-borne train-to-wayside communications equipment and provide the portion to the LRV manufacturer supplying them under a separate contract. This required significant communica-

tion and coordination required to ensure the car-borne equipment provided could be integrated into the manufacture of the LRV.

Extending the existing AVI system to the GLX Project and maintaining its compatibility with multiple vehicle types will require early communications among the systems designers, system suppliers, and either the LRV manufacturer (if the LRV is a new build) or the LRT operator (if the LRVs are part of an in-service fleet). WBG will lead the AVI integration process, prioritizing early communications between all necessary and affected parties.

C. COMMUNICATION SYSTEM DESIGN

Overall Systems Topology/ Systems Connection Diagram

See Figure 4.1-9 on the following page.

Communications System Design and Functionality

The Project's communications and security systems designs are based on MBTA and industry standards and best practices, and summarized in Figure 4.1-8. These systems will interface with the existing communications and security systems at the MBTA. Using the project criteria, information from projects such as the B Line Station Consolidation, Green Line ADA, and E&M and Security Departments Task Order Contracts, and our in-depth knowledge of these MBTA systems, WBG will design communications and security systems that meet project requirements, interface to existing systems, and serve the MBTA's operational needs.

Fiber Optic Network

The GLX network will include a fiber optic, cable-based communications cable plant to support the following networks:

- » **The Wide Area Network (WAN):** Provides connectivity to the OCC for the station public address/transit passenger information system (PA/TPIS), the supervisory control and data acquisition (SCADA)/hub monitoring and control system (HMCS), the Avaya telephone system, the Power SCADA system, fare collection (AFC2.0), and corporate IT systems.

- » **The Security Wide Area Network (SWAN):** The communications medium for the closed-circuit television (CCTV) system, the electronic access control system (EACS), and the emergency call box system.

- » **The GLX Signal System:** Uses the dedicated signal network to connect the new equipment located in the CIHs with the existing Green Line signal network. The OCC network and Green Line AVI systems are subscribers to the signal network.

New core (10Gbps) and LAN (1Gbps) data switches will be provided at node locations to expand the WAN (Cisco) and SWAN (extreme) networks. MOXA data switches will be provided for the signal network expansion. IP address schemes and virtual private networks (VPN) will be developed in coordination with the MBTA current IP network plan to integrate these new switches, and their data traffic.

The three communications networks will use two new, diversely routed, 96-strand fiber optic cables extended from the GLX stations, CIHs, Transportation Building, and the Vehicle Maintenance Building (VMB) to the existing fiber optic termination locations at North Station, North Station Garden, and Science Park Station. Additional fiber optic cables will be installed to support ancillary locations, such as traction power substations (TPSS) and pump stations. All fiber optic patch panels and port assignments will be provided to the MBTA for inclusion into its communication department's fiber optic database.

To support data and telecommunications services within GLX locations, category 6 data cable will be provided from the closest communications distribution location to jack locations as shown on the project drawings. At locations where Ethernet limits are exceeded, communications cabinets will be installed. These cabinets will house hardened data switches, patch panels, power supplies, and uninterruptible power supply (UPS) units. This wiring approach is currently deployed as an MBTA standard design developed to meet current requirements, while providing infrastructure to accommodate future needs.

Voice over Internet Protocol (VoIP) Telephone System

Currently, the MBTA has an Avaya telephone switch located at the OCC to provide telephone service to various locations throughout the MBTA via the WAN. This Project will provide an IP gateway at

the VMB to provide telephone service (VoIP, digital, and analog) for the offices and support rooms at the VMB and the Transportation Building. An analog audio module will be provided so staff can make in-building public address announcements through their telephone. An ancillary component of the telephone system will be an audio logging recorder. This unit will be configured to record the telephones within the VMB and Transportation Building.

In addition to telephone service provided through the Avaya telephone switch, the Project will provide Verizon points-of-demarkation at the GLX stations, the Red Bridge TPSS, and the VMB. These new facilities will provide leased communications services to the GLX. Centrex telephone circuits will be deployed to the wayside telephones (up to three telephones per circuit). Wayside telephones will be located every 500 feet along the ROW and at interlockings, truck pads, and emergency egress gates. Each location will have surge protection terminals, be labeled with their location, and be equipped with a blue marker light.

Public Address and Transit Passenger Information System

Each new station's PA/TPIS will provide ADA-compliant audio and visual broadcasts. Each station system will be configured for mezzanine, eastbound, and westbound zones (additional zones will be provided as required). The PA/TPIS's major components include: two-line amber LED variable message signs (text size to be ADA

compliant), loudspeakers, ambient noise sensing microphones (to automatically adjust audio levels per ambient noise levels), digital signal processor, power amplifiers, mixer, microphones, router, VoIP gateway, and station control unit (SCU). The SCU will be provided with Rockwell Collins' (formerly ARINC) Advanced Information Management (AIM) software that will interface, via the WAN, to the existing PA/TPIS headend at the OCC. The GLX station PA/TPIS will be added to the existing headend databases, and the graphical user interface screens for the OCC will be updated to include the new stations. The announcement schedules will also be updated to include the new stations. Updated announcements will be recorded to add the new stations to the PA headend.













In-building PA systems will be provided for the VMB and Transportation Building. These systems will be local to each building, and not interface to the OCC. Each system will consist of loudspeakers, digital signal processor, power amplifiers, mixer, and microphones. Users will access these systems via analog outputs from the new Avaya telephone system gateway.

Loudspeaker placement and tap settings, and amplifier configurations, will be optimized to provide uniform sound coverage throughout areas where passengers and employees will be located. Additionally, 90% of Speech Transmission Index measurements for the PA systems will exceed 0.45 within these areas.

Figure 4.1-8 Communication System Chart.

Communication System Design and System Functionality by Location

WBG team members worked directly with the design of each of these systems and integration to active systems, including developing acceptance test plans.

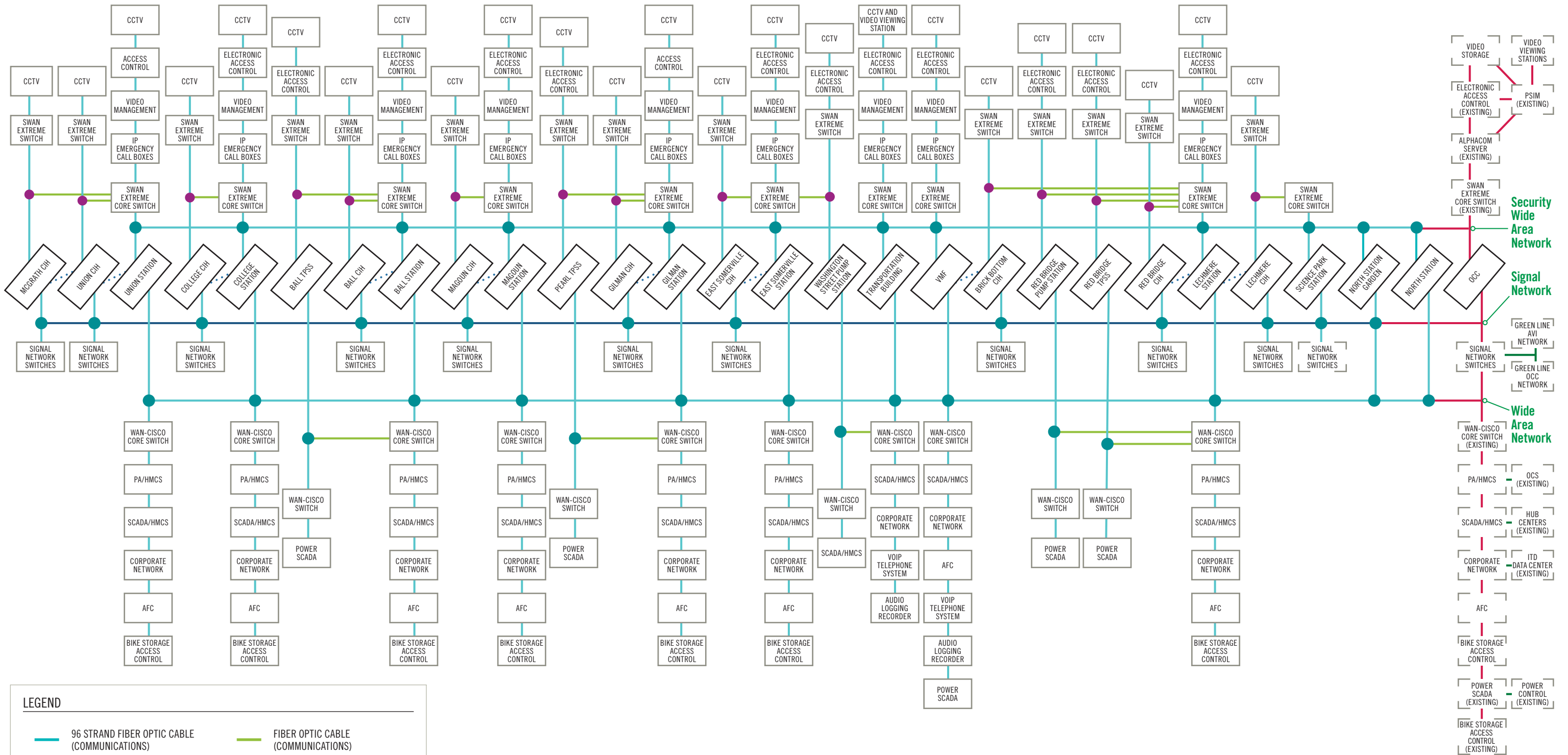
	Typical New GLX Station	VMB	Transportation Building	Traction Power Substations	Pump Stations	Central Instr. Houses
 Fiber Optic Networks	●	●	●	●	●	●
 Fiber Optic Networks (Signals)						●
 VoIP Telephone System		●	●			
 Public Address to 45 High Street	●					
 Public Address Local		●	●			
 Transit Passenger Information System	●					
 Closed Circuit Television	●	●	●	●	●	●
 SCADA with Hub Monitoring and Control System	●	●	●	●	●	
 Access Control System	●	●	●	●	●	
 Fare System Interface	●					
 Uninterruptible Power Supply	●	●	●	●	●	●
 Emergency Call Box	●	●	●			

Interface each communication and security system to corresponding system.

Use Ethernet over fiber optic/copper cable for data transport.

Coordinate with respective system and MBTA for configuration files and IP addressing.

Figure 4.1-9 Systems Topology Diagram.



LEGEND

- 96 STRAND FIBER OPTIC CABLE (COMMUNICATIONS)
- 96 STRAND FIBER OPTIC CABLE (SIGNALS)
- ⋯ 96 STRAND FIBER OPTIC CABLE (SIGNAL-COMM)
- EXISTING EQUIPMENT
- FIBER OPTIC CABLE (COMMUNICATIONS) TERMINATION LOCATION
- 96 STRAND FIBER OPTIC CABLE (SIGNALS) TERMINATION LOCATION
- EXISTING CONNECTIONS
- FIBER OPTIC CABLE TERMINATION LOCATION

NOTES

1. Networks are to be provisioned in ring configurations.
2. Communications fiber optic cable to be installed on the west side OCS catenary poles. Signal fiber optic cable to be installed in the trough. All fiber optic cables to be installed in 1.5" inner duct. Additional fiber optic cables to be installed from the communication rooms to: central instrument houses, pump stations, and TPSS. All fiber optic cables to be single mode.
3. Slack fiber optic cable to be located at each termination site.
4. Each network will utilize two optical strands from both the communications and signals fiber optic cables.
5. Optical fiber strands to be terminated and configured per Technical Provisions Section 11.7.
6. SWAN and WAN will be configured at 10 gb/s. Station and facility LANs will be configured at 1 gb/s.
7. IP addresses, VPNs, and port assignments to be coordinated with appropriate MBTA departments.
8. 5-year Cisco SmartNet contract to be provided for Cisco equipment.
9. AFC interface will be coordinated with the AFC2.0 project office.
10. The HMCS SCADA system will be used by the hub centers to monitor pumps stations, emergency generators, elevators, and fire alarm panels.
11. All communications network elements shall be supported by the UPS and station emergency power.

**Closed Circuit Television**

The CCTV system is used to provide remote surveillance and video recording of areas throughout the GLX project limits for the operations and security departments and transit police. All video cameras will be incorporated into the MBTA's physical security information management (PSIM) system. Live and recorded video can be viewed at a number of client workstations throughout the MBTA. A client workstation will be provided for the yardmaster's office at the Transportation Building. Single person train operator weatherproof monitors and video decoders with dedicated feeds of CCTV cameras viewing the platforms will be provided at the first car marker of each eastbound and westbound platform to assist the motormen in LRV door operations.

Power over Ethernet (PoE) IP-based cameras will be placed within stations at critical locations to view platforms, fare vending machines, walkways, bike storage areas, elevators, and secure rooms. Cameras are also proposed at the interlockings and ROW access pads. Exterior cameras will be located at the VMF, TPSSs, and pump stations.

To support single person train operations, we will provide video decoders and outdoor-rated monitors at the end of each platform. Each monitor will display four video streams from cameras mounted on the corresponding platform so the motorman can verify that passengers are clear of the trolley before door closing.

The Project will provide video management and storage solutions for the proposed video cameras. Video servers will be added at the MBTA's data center at 45 High Street to store video.

**Supervisory Control and Data Acquisition System with Hub Monitoring and Control Systems**

Remote monitoring of pump stations, generators, fire alarm panels, and elevators will be accomplished through the HMCS. Input and output points for the various devices will be connected to new communications programmable logic controllers (CPLC) to be located at GLX stations, the VMF, and pump stations. The CPLCs will interface to the redundant HMCS servers at the OCC via the WAN. The servers will be updated with the new field CPLCs. New HMI menus and graphical user interface screens will be developed for use by the hub center operators.

The HMCS is separate from the Power SCADA system. The Power SCADA is dedicated to the remote monitoring and control of traction and unit power substations, and is used solely by the MBTA Power Department. Each Power SCADA system will connect to the MBTA data center at 45 High Street via the WAN. The power dispatcher graphical user interface screens will include the new substations.

**Access Control System**

The EACS is based on the existing MBTA Lenel On-Guard security platform and will provide access through secure portals to users with authorized credentials. Card readers, door contacts, and electric locks will be provided at doors that lead to critical infrastructure such as communications, electrical, and elevator machine rooms. Double card readers and stanchions will be provided at the entrance to each motorized lift gate. Each card reader will interface to a local access control panel that will then interface to the MBTA PSIM via the SWAN. The PSIM will be updated to include alarm rules such as door propped or forced open. Some portals require monitoring only (such as TPSS roll up doors), and will be equipped with just magnetic door contacts.

Separate from the EACS is the access control system for the bike storage areas. This Access Control System (ACS) will use the WAN to transmit ACS database information to the existing Honeywell Central Access Control Server located at 10 Park Plaza. The ACS will be configured to read iClass and MIFARE cards, and the system will be updated to include the new GLX locations.

**Fare System Interface**

The next generation of the MBTA fare collection system is in the early development stage to upgrade from the initial system installed a decade ago to AFC2.0. This project will coordinate with the AFC2.0 project as the design progresses. Although the stations will not include fare gate arrays, each station will be provided with fare vending machines. Data cabling will be installed to each fare vending machine location to provide WAN connectivity.

**Uninterruptible Power Supply**

All of the communications and security systems require back-up power. These requirements vary amongst the systems. Each communications and security system will have a rack, panel, or DIN rail-mounted UPS that will provide back-up power.

**Emergency Call Boxes**

The proposed Emergency Call Boxes (ECB) are IP-based, ADA compliant, and compatible with the existing Stentofon AlphaCom server located at the OCC. ECBs will be located per ADA regulations on platforms, walkways, at elevator landings, in elevator cabs, and at bike storage areas; and will be equipped with LED-based blue marker lights. These units will have two call buttons, one for emergency and one for information. Emergency calls will be routed directly to the MBTA Transit Police, while information calls will be routed to the hub centers. Non-emergency units (no emergency button) will be placed at the two motorized gates that lead into the VMF. The Project will coordinate call sequences with the MBTA.

Separate from the MBTA security system ECBs will be solar powered, wireless ECBs that meet City of Somerville specifications. These units will be located at 1,000-foot intervals along the Community Path.

Additional Equipment

In addition to all of the system requirements listed above, we will supply two-way portable radios for each piece of hi-rail equipment and various splintered work parties during work in, or adjacent to, a location that could affect Green Line operations. The Project will also provide three 800 MHz portable radios (and their maintenance) for the MBTA's exclusive use for the duration of the Project. These radios will be in accordance with the latest revision of MBTA Specification C6.

Open-Data Link Methods

The existing communications from the head end systems/servers at 45 High Street to the GLX field locations and edge devices will be transmitted via layer 2/3 Ethernet switching systems. As these are existing systems, each proposed individual GLX system device interface, protocol, and IP plan will need to be coordinated directly with the current application configuration files. This specific coordination will allow the respective head end applications to recognize the new field devices. Once the new devices are added to the system, they will be allowed to be controlled and monitored within the functionality of the individual application. Vehicle information and location will be trackable from the current OCC systems, and can be coordinated and continuous with the existing Green Line network of devices.

Proposed and Existing Communication Systems Interface

Each element of the GLX communications and security systems will need to be interfaced to their corresponding existing systems. The data transport of these systems will be via Ethernet over fiber optic/copper cable for each of the subsystems. Each interface will need to be specifically coordinated with each respective system to ensure seamless integration.

Early in the Project, WBG will meet with stakeholders to develop a Configuration Management Plan (CMP) to define roles and responsibilities, verify software versions and IP plans, and define configuration changes required and how they will be made. Without a comprehensive CMP, it is likely that required changes may be missed, incomplete, or unnecessary work performed because of lack of version and document control. The CMP will be a living document that evolves throughout the GLX project life cycle to provide current configuration status, change requests, version control, and hardware status on any of the affected systems, and coordinate work between codependent systems.

D. TRACK WORK SYSTEM DESIGN**Overall Approach and Technical Details**

Construction of the proposed trackwork systems for the light rail and commuter rail within the limits of GLX will involve a systematic and integrated methodology where the requirements of the Project Technical Provisions are fully met. WBG understands the importance of providing the MBTA with an operationally efficient and expandable track system consistent with current MBTA best practices and industry standards.

Track Bed Structure Design

Conformance to the noise and vibration provisions will require that the team design and incorporate vibration isolation within the track bed structure to mitigate noise and vibration at highly-sensitive locations, including closely abutting residential dwellings and institutional facilities. At a minimum, such vibration isolation will include ballast mats and/or resilient rail fasteners to provide a cushion for the dynamic wheel loads imparted through the track structure, specifically via the train wheel/running rail interface, by the moving trains. In addition, specially-engineered trackwork

(such as flange-bearing, spring-rail, or moveable-point frogs) will be included where necessary to minimize the increase in noise and vibration from special trackwork (turnouts and crossovers).

Special Track Work Configurations

Typical special trackwork configurations and details are located at the end of Section 4.1. These conform to the RFP documents and to the subsections below.

Noise and Vibration Approach

To meet the Technical Provisions, WBG worked with Scott Edwards of DBE firm Cross-Spectrum Acoustics. Scott is familiar with the commitments outlined in the Project FONSI (Finding of No Significant Impact) and the Federal Transit Administration (FTA) Transit Noise and Vibration Impact Assessment guidance manual. In accordance with FTA criteria and procedures, a detailed noise assessment and detailed vibration analysis will be carried out to update the recommendations for noise barrier walls and vibration mitigation treatments from the preliminary design study. The analysis will serve to inform the design of noise and vibration mitigation treatments necessary to meet the Project requirements.

Rail Corrugation Approach

The GLX Project includes specific design elements to combat rail corrugation such as using head-hardened premium rail, restraining rail lubricators (Figure 4.1-10), and tight tolerances for the track gauge and horizontal alignment during construction and testing. Past studies indicate that common causes of rail corrugation include fastener stiffness, vehicle suspension, rail metallurgy, track geometry, and operating conditions. Regular maintenance of the track alignment, especially gauge and curvature, in combination with proper train wheel alignment and truing, has been shown to prolong the rail head life cycle and to limit excess noise associated with wheel/rail contact. Conversely, poor or limited wheel set (bogie) steering, as is common with the middle bogie of Green Line Type 8 LRVs, can contribute to irregular rail head wear. Proven measures to limit or prevent rail corrugation also depend on rail lubrication and regular monitoring/measurement of the rail heads using automated sensors mounted on push carts or hi-rail equipment. Early-stage rail corrugation left unchecked will manifest into a more pronounced and difficult corrugation pattern to mitigate. WBG will adhere to

track construction tolerances, as defined in the RFP documents, to minimize the rail and track factors in the corrugation equation.

Proposed End of Track Device

WBG will install hydraulic bumping posts, shown in Figure 4.1-11, at all stub-end track sections in accordance with the Technical Provisions, Section 10.2 (I) (i) and to the dimensions shown on MBTA Maintenance of Way Division Book of Standard Trackwork Plans, Plan Number 925, Bumping Post for LRT Cars. The hydraulic bumpers are designed specifically for use with transit rail vehicles with a center of contact 25 inches above the top of rail and capable of stopping two fully loaded LRVs traveling at 6 mph. The hydraulic design will safely stop the train while minimizing train and coupler damage during accidental anti-climber contact. The bumping post will be installed using 1-inch heat-treated track bolts, bolted directly to the web of the 115 RE rail. There will be four connection points, with three bolts at each point for a total of 12 bolts. Insulated plug rail joints will be installed on both rails in front of the hydraulic bumping posts to isolate the track from signal system and negative power return currents.

Figure 4.1-10 Rail corrugation preventions. A solar-powered wayside rail lubrication system (left) helps to combat rail corrugation (right).



Figure 4.1-11 LRT hydraulic bumping posts located at stub-end tracks.



Special Track Work

Design Methods, Standards, and Criteria

See Figure 4.1-12 for special track work design methods, standards, and criteria that WBG will use to provide the special track work for the GLX Project.

Track Work Components

WBG is aware of the unique characteristics associated with the three LRVs that will operate on the GLX. The vehicle designs of the Kinki-Sharyo 7, Ansaldo Breda Type 8 and the proposed CAF Type 9 LRVs (Figure 4.1-13) each impose different requirements on the track structure and trackwork components. The Green Line trackwork infrastructure will be designed to accommodate the intricacies of these LRVs, with safety and ride quality at the forefront.

Figure 4.1-12 Special Track Work.

ITEM	THE WBG DESIGN METHOD	CRITERIA AND STANDARDS	
Summary	Special Track Work (Overall)	<ul style="list-style-type: none"> » Manufactured from, and compatible with, 115RE rail section with 132# restraining rail section » Design and install on tangent track (horizontally and vertically) » Install on grades less than 2% » Fabricate and install in ballasted track on 7-in. by 9-in. treated wood ties using "Pandrol" type "e" clip and plate assemblies » Install all plates using .9375-in. screw spikes » Design, manufacture, and install bonded insulation joints (when applicable) 	<ul style="list-style-type: none"> ✓ American Railway Engineering and Maintenance-of-Way Association (AREMA) Manual for Railway Engineering Volume 1 ✓ AREMA Portfolio of Trackwork Plans (current editions) ✓ MBTA MOW Division Book of Standard Trackwork Plans ✓ MBTA Green Line Light Rail Transit - Track Maintenance and Safety Standards ✓ MBTA Railroad Operations Book of Standard Plans ✓ Pertinent MBTA specifications
	Mainline Switch Points	<ul style="list-style-type: none"> » Minimum of 30 feet of tangent track will precede switch points on mainline turnouts » Use Azobe tropical hardwood for timber switch ties 	<ul style="list-style-type: none"> ✓ AREMA Portfolio of Trackwork Plans Detail 5100 ✓ MBTA MOW Division Book of Standard Trackwork Plans - Plan No. 411 Standard Switch Point Detail 5100 and Heel Block Assembly
Special Trackwork Components	VMF Switch Points	<ul style="list-style-type: none"> » 150-foot-radius turnouts 	<ul style="list-style-type: none"> ✓ MBTA Book of Standard Plans - Plan No. 615 Trackwork Plan for 150-Foot C.R. Turnout Fully Guarded Design LRT
	Mainline Turnouts	<ul style="list-style-type: none"> » Include guarded double switch point » Install with an asphalt underlayment » Power operated with exception of emergency crossovers located north of Cedar Street at approximately NB 320+00 and at crossover north of Lechmere Station at approximately MB 201+00 along the Medford Branch » Install emergency crossovers using an electrically locked T20 style hand throw switch and UBM or "jump" frogs 	<ul style="list-style-type: none"> ✓ Green Line Design-Build Project Contract Plans ✓ MBTA Railroad Operations Book of Standard Plans - Drawing No. 1030, Asphalt Underlayment
	VMF Turnouts	<ul style="list-style-type: none"> » Install with an asphalt underlayment » Use Racor 22 Switch Stands (or approved equal) for hand-thrown yard turnouts with back saver thrown arm and Aldron Company's low-profile switch cube direction indicator 	<ul style="list-style-type: none"> ✓ MBTA Railroad Operations Book of Standard Plans - Drawing No. 1030, Asphalt Underlayment
	Stock Rails	<ul style="list-style-type: none"> » Sampson undercut style » .125-inch tread depression point of switch to facilitate wheel flange transition to the turnout point » Graduated riser design » Stock rail brace plates at switch points machined to accept point heater elements 	<ul style="list-style-type: none"> ✓ MBTA Book of Standard Plans P- Plan No. 410 ✓ MBTA Specifications
	Frog Flangeways	<ul style="list-style-type: none"> » Design to accommodate LRV wheel profile and be flange bearing, solid manganese » Harden flange bearing surface to a minimum Brinell Hardness of 450HB » Where the crossover move is infrequent, use UBM frogs to mitigate noise, wear, and maintenance; provide a continuous wheel tread and flangeway; and safely transition the LRV wheel over the mainline by using a series of wheel tread and flange ramps 	<ul style="list-style-type: none"> ✓ AREMA Plan No. 671 ✓ MBTA MOW Division Book of Standard Trackwork Plans - Plan No. 850, Solid Manganese Frog Details

The track structure and components will be designed, manufactured and installed using higher than standard specifications for the allowable transit tolerances defined by the MBTA Maintenance of Way Green Line – Light Rail Transit Track Maintenance and Safety Standards. This higher standard will ensure the reliability of the components and their interface with the current and future LRV fleet. The Green Line wheel set and flanges are atypical, so diligence and attention to detail is paramount when designing and installing the track components and structure. The design of the trucks/wheelsets for the new Type 9 LRV will integrate improved braking capacity and thicker wheels to reduce maintenance and increase reliability.

Specifically-designed trackwork components will be incorporated into the rail system for the MBTA Green Line LRV, such as manganese cover guards at all turnouts, flange bearing and unbroken mainline frogs, adjustable restraining rail section using the Pandrol Adjustable Restraining Rail Plate or approved equal, LRV bumping posts, sliding block derails, guarded double switch points, and hook flange frog guards with specified guard-check-gauge tolerances.

Per MBTA standards, all LRT curves under a 1,000-foot-radius will be restrained using 132# restraining rail adjacent to the 115RE running rail. In these situations, WBG will join all restraining rail to the running rail using spacer block assemblies every 23 inches on center, in accordance with MBTA standards. The team has designed the alignment to minimize curves with a radius less than 1,000 feet, thus reducing the need for restraining rail, a known source of rail-borne noise and vibration. However, when the track geometry dictates that a curve must be restrained, we will install wayside back-of-wheel lubricators. These wayside lubricators will be Lincoln type, or approved equal, solar powered, fully programmable units with an electronic wheel sensor and multi-port delivery system. The wayside lubricators will be positioned to lubricate the contact surface of the restraining rail prior to the train entering the curve in the normal direction of traffic. The lubricators will be sized and adjusted in the field to maximize the effective distance of the lubricant.

Special Track Work Design

All Green Line special trackwork will be fully guarded through the turnout move with adjustable manganese cover guards to protect the switch point from wear and to minimize the potential for wheel

climb derailments in the turnout move often associated with LRVs on sharper radius turnouts. A cover guard will be installed to accommodate the LRV wheel profile and back-to-back wheel tolerances. No portion of the cover guard or its assembly will be more than 2 inches above the top of rail. The flangeways through the turnout will be 1.625 inches with 56.5-inch gage, unless otherwise required by MBTA Standards. A 132# guard rail will precede the cover guard for a smooth transition in and out of the switch point area.

Restraining rail block assemblies will be installed in accordance with the approved drawings to provide full guarding from the toe of frog into the tangent track beyond. Special trackwork will have a minimum of 30 feet of tangent track preceding the switch point, allowing ample distance for the LRV to properly align prior to entering the switch on mainline turnouts. Similarly, and where feasible, a short section of tangent will be designed ahead of the switch points within the VMF yard. Restraining rail assemblies will be used to control and align the LRVs along the track where switches abut each other or are placed back to back, as is the case at the yard's ladder track.

Special Track Work Drawings

The following special track work drawings can be found at the end of [Section 4.1](#):

- » Special track work geometry, guardrails, and restraining rails
- » All proposed track structure/rail fastening systems and their associated assemblies
- » Signals and communications infrastructure

E. TRACTION POWER SYSTEM DESIGN

The traction power scope of work for the GLX Project includes a new traction power system (TPS) for the extension. The traction power will be supplied by TPSSs located along the corridor and shall supply the main line tracks and the VMF.

Traction Power Supply Design Process

The design process for the traction power system will build upon existing MBTA design documents, load flow study, and standards. The traction power design will concentrate on providing a reliable

system that is safe and easy to maintain. Furthermore, we understand GLX is not a new start and must seamlessly integrate with an existing passenger rail line. WBG will produce a design that can be constructed with minimal disruption to existing service.

Developing the system requirements is an integral part of the traction power system design. The traction power design team greatly benefits from the previous design efforts. The directive drawings, RIDS, MBTA standards, and load flow study will form the basis of our design and allow us to quickly develop a solid traction power design package. All of these elements will be scrutinized and applied to develop the traction power system.

The traction power load flow simulation will be performed using a software tool that has been nationally validated on many other passenger railroad projects. WBG will use either Train Operations Model (TOM) or Mott McDonald's TRAIN package. The results will be validated by manual calculation and provided in report format with the accompanying input data. This step is a crucial independent check against modeling errors.

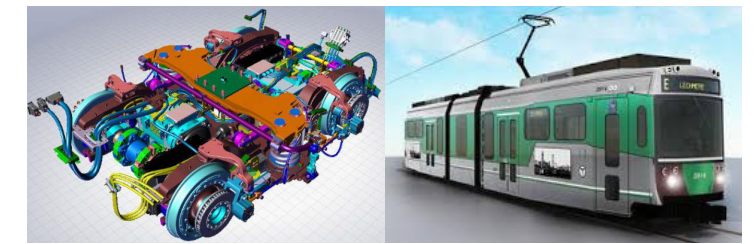
Additional system simulations and studies will include short circuit and relay coordination studies using internationally recognized software packages, such as SKM products. Each set of results will be checked against manual calculations as with the load flow.

The traction power design schedule has been organized for early completion of design elements with long lead times to allow adequate time for procurement and testing.

The traction power system for GLX consists of three new TPSSs. The first TPSS is Red Bridge, which provides power to the Medford and Union Square Branches, as well as the VMF. The Red Bridge TPSS provides a DC feeder to the VMB where a local distribution set of switchgear will be utilized to provide stinger power for maintenance. The second TPSS is Pearl Street, which provides traction power to the Medford Branch as well as loop AC feeders along the ROW to the third TPSS, Ball Square. Ball Square TPSS provides power to the Medford Branch.

The TPSSs receive power from third party utility services (Red Bridge and Pearl Street) and from loop feeders (Ball Square) from the adjacent Pearl Street TPSS. The TPSS design will meet the utility requirements for service. The utility services are recognized

Figure 4.1-13 Proposed type 9 LRV rendering (left) and wheelset isometric view (right).



as key risk items, therefore special early effort will be applied to these items to ensure they are available when necessary. Traction power from the TPSSs will be distributed for use via a distribution network consisting of the OCS and parallel positive and negative feeders that are bonded together at appropriate intervals.

The TPS is intended to work as an integrated system. Nominal conditions for the TPS allow each substation to provide DC power for the trains to use. Under first contingency operations, where one rectifier at a single substation is out of service, the substation may be configured to allow normal operations. A second contingency situation, where an entire substation has failed, is accommodated by operating the wayside switches at the failed substation to “eliminate” the substation from the TPS and allow the adjacent TPSS to provide power to accommodate the load in the section served by the failed TPSS. The train service would not be degraded under these conditions. WBG intends to provide a TPS that is robust enough to sustain a second contingency failure with no degradation of service, per industry standards.

Additionally, the headways, authorized speeds, and travel times included in the basis of design documents, particularly the requirement for 25% greater headways (more frequent service) to assist in service recovery after a disruption, will be incorporated in the project design requirements, and the TPS will be able to support these requirements. TPS behavior will be tested under nominal and contingency modes of operation in the traction power simulation. WBG and Comstock/Fischbach & Moore JV will confirm with MBTA to make certain the TPS operation is understood and acceptable.

The traction power substations provide DC power for the rail traction and three-phase AC power for the passenger stations. These feeders will run along the ROW and provide one of the two redundant power feeders for each station.

The traction power design will, to the extent possible, use the pre-purchased materials indicated in the RFP.

Traction Power Supply Design, Failure Modes, and Mitigations

The traction power distribution system is designed to be robust and reliable under normal and contingency (failure) modes of operation. The basis of the design will be the operating plan, and the system performance will be software validated including post-construction power flow measurement. The previous load flow simulation report has been reviewed and its results will be considered, compared with the study WBG will perform, and incorporated in the design as relevant. The power system design will allow normal operation with any one TPSS out of operation. The power system will allow the distribution system to be sectionalized to “cut out” the faulted TPSS at both the line side disconnect switches or the TPSS DC bus depending upon the failure mode. If a fault in the DC substation equipment is the cause, the line side switches are the logical sectionalizing location. If the fault is the AC section of the TPSS, then the DC bus may be used to “feed through” the traction power. The OCS will be designed to be fault tolerant and allow sections of the OCS to be taken out of service and traffic maintained within the limitations of the track switches.

Each TPSS will include all conversion equipment, control, relaying, controls, and associated components to operate the Project. They will include DC positive feeder cables, negative return cables, supplementary positive and negative cables, and DC disconnect switches as required to provide power to the OCS. The system will be capable of operating AW3-loaded project and existing system vehicles at five minute headways under normal and single contingency outage scenarios without any detriment to operating service.

The DC power system will be separated into electrical sections with section breaks near each TPSS. OCS feeder switches and TPSS bypass switches will be provided to enable a substation to be removed from service while allowing two electrical sections to be joined together. Provisions for an OCS tie switch will be provided at each end-of-line location (Union Square and Ball Square) to connect the OCS of each track together.

The traction power return system will include the running rails and supplemental return cables. The traction power return system

will interface the impedance bonds at the track with the negative return busbar within each TPSS. Each track will be provided with 2-2,000 KCMIL returns per track to the TPSS negative busbar. Midway between substations, the running rails of each track will be interconnected via impedance bonds to share the rail return current equally. The tracks at the end of the line will be connected together via impedance bonds. A single 2,000 KCMIL supplemental negative cable will be provided throughout the project corridor. This cable will be shared between the two tracks and interconnected at each TPSS return connection and at each mid-point between substations. The supplemental return cable will be installed directly on the ballast between the tracks.

A full and complete traction power system commissioning plan will be developed. The commissioning plan will feature product qualification testing, manufacturers testing, and field testing for each element of the traction power system, as well as for the traction power system as a whole.

Conceptual Traction Power System Single-Line Diagram

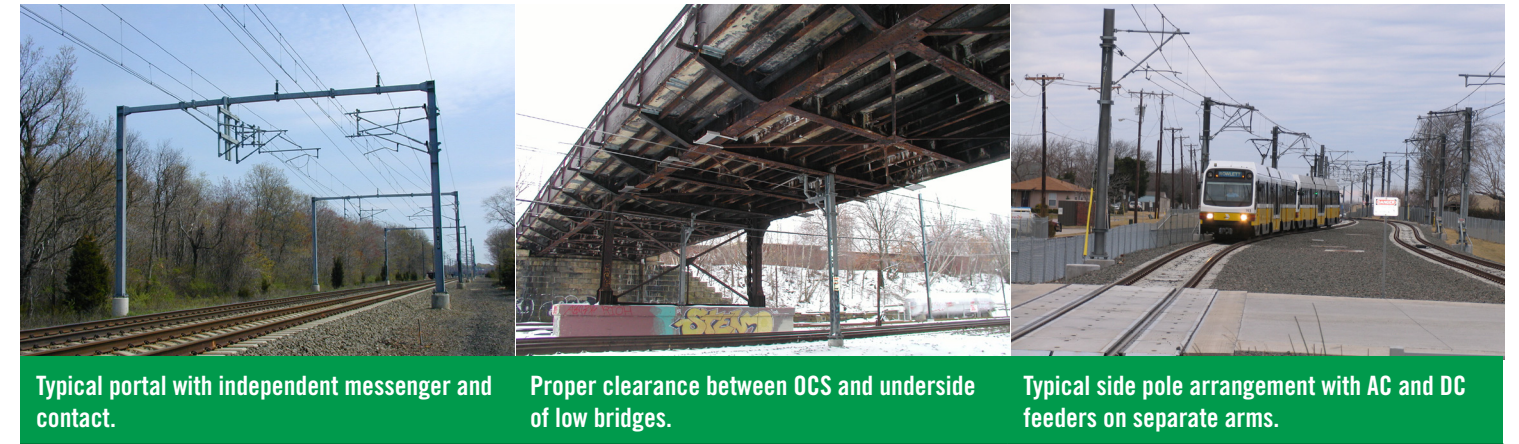
This diagram is provided at the end of [Section 4.1](#).

F. OVERHEAD CONTACT SYSTEM DESIGN

The OCS will be designed to be compatible with the MBTA LRV electrical and dynamic performance requirements to ensure that the vehicle pantograph maintains contact with the contact wire under local climatic, environmental, and operating conditions. The OCS consists of a two-wire auto tension system on the Medford Branch and Union Square Branch, and a single variable tension contact wire in the VMF with double insulation.

Pantograph security will be established by maintaining a minimum contact wire edge distance from the horn of the pantograph under the worst operating condition. A pantograph security analysis will be performed in accordance with UIC 606-1. A safe zone of 6 inches will be used from the centerline of the pantograph for stager and offset. Based on the analysis, a structure spacing chart will be developed to maximize the pole spacing and minimize the overall structure count.

GLX typical OCS arrangements.



Typical portal with independent messenger and contact.

Proper clearance between OCS and underside of low bridges.

Typical side pole arrangement with AC and DC feeders on separate arms.

The OCS components in tension used for the messenger and contact wires and down guys will be forged, formed, machined, or drawn to prevent any casting defects. The OCS will be supported from cantilever pipes or spans wires (with pulley) insulated from the supporting structure with double insulation. The messenger wires will be supported under the top pipe to prevent binding as the cantilever swings along the track due to temperature changes.

The OCS will be electrically supplemented with parallel feeder cables, in underground conduits or aerial on poles as required by the traction power system design. Feeder taps to the OCS will be located per the load flow analysis.

Typical OCS Arrangements

The at-grade section along the alignment will use side poles and portal structures. WBG proposes using independent messenger and contact registration to register the contact wire. This will minimize the effect of an OCS wire tear down on adjacent wires. The areas along the ROW with height constraints (existing overhead bridges) will be handled individually to ensure proper electrical clearances between the OCS and the underside of the bridge. The DC and AC feeders will be lowered to pass under bridges. The electrical clearances will follow NESC and MBTA requirements.

OCS Sectionalization

The OCS will be sectionalized to maximize train operations and flexibility in regard to maintenance and emergency operations. Sectionalizing will be provided at interlockings and substations to provide train movement along the alignment during diverted train operations (non-normal operations).

Typical OCS Pole Arrangements

WBG will use portal structures at the interface point between the existing Lechmere viaduct and the new Lechmere viaduct at existing Pier 13 at Charlestown Avenue. The portal structures will transition to side poles and remain side poles for the remaining lengths of the two track Lechmere and Medford Branch viaducts. The Union Square eastbound and westbound viaducts support single tracks and will use side poles positioned on the outside of curves. Where noise walls are required, the OCS poles will be integral to their construction. The new poles will accommodate the AC and DC aerial feeders on separate arms and be vertically spaced to provide required electrical clearances. The OCS supports for each track will be single track support brackets where possible, as this will minimize the effect of a wire tear down on the adjacent track. This approach allows the adjacent track to be operational during an emergency.

G. AC VOLTAGE DISTRIBUTION

Typical AC Voltage Services

Utility services for the traction power substations will be medium voltage services and make use of the services previously negotiated with Eversource. All service equipment will meet Eversource requirements.

Medium voltage feeders for passenger station backup power will be provided from the TPSS medium voltage switchgear and be routed along the ROW, either on OCS poles or in ductbanks along the viaducts. Medium voltage ring feeders will be provided between Pearl Street TPSS and Ball Square TPSS. These will be routed in

a similar fashion to the passenger station feeders. The medium voltage system will be controlled and monitored locally and via SCADA as described in Section 16311.

Redundant Supply

A TPSS will provide one of the two redundant electric feeds for each station and the other electric feed will be provided from another independent utility feed. A UPS system will be provided in each station and building to provide back-up power to life safety loads, as defined in Section 14.5.3.5 of the Technical Provisions. A standby gas generator will be provided at the VMB and Lechmere Station to provide back-up power to all emergency and optional standby loads.

H. CORROSION CONTROL

GLX installation presents several corrosion control concerns, including stray current corrosion on the system components and foreign structures, soil and water corrosion on underground or submerged utilities, and atmospheric corrosion of system structures. These concerns will be addressed as described in this section.

Corrosion Control Strategy

CorrPro is a leader in the cathodic protection field providing corrosion engineering services across multiple industries, including transit. They have a nationwide transit footprint providing design and testing services for the protection of track, utilities and structures from the corrosive effects of the stray currents generated by an operating DC-powered transit system. Key systems and track subcontractors Comstock and RailWorks have had success working with CorrPro on multiple transit projects. The installation of the GLX Project presents several corrosion control concerns. The major areas of concern and mitigation are shown in Figure 4.1-14.

Corrosion Control Methodology and Design

Piping systems installed along the system route will be supplied with cathodic protection systems to reduce stray current corrosion and soil or water corrosion. The piping cathodic protection systems will include electrical continuity of the piping included in the system, and electrical isolation of the piping from foreign structures. The piping will be supplied with protective coating and sacrificial anodes to provide protection current. Test stations will

be provided on the piping systems for the evaluation of cathodic protection levels, as well as stray current effects. We will address atmospheric corrosion of system components through the use of

Figure 4.1-14 Corrosion risks and mitigation strategies.

RISK	MITIGATION
Stray current corrosion of transit system components	Electrical isolation of track and negative return system components to reduce or eliminate stray currents
Stray current corrosion from foreign structures	Cathodic protection of underground piping systems as well as stray current drainage facilities for utilities, support structures and services
Soil and water corrosion on underground or submerged structures	Cathodic protection for piping systems
Atmospheric corrosion of system components	Properly selected materials and coatings and sealants

properly selected materials and coatings or sealants, as required.

Track to earth resistance levels are generally high when the system is first installed, therefore stray current levels will be low. Track to earth resistance testing performed on short sections of track while they are being installed will assure that the electrical isolation of the track is maintained to its highest achievable levels. Over time, the insulating components of the tracks will degrade, and moisture and debris will accumulate around the rails. This will lead to reduced track-to-earth resistances and increased stray currents. Therefore, all utilities and system structures, such as retaining walls and reinforcing steel in concrete, will be installed with stray current mitigation controls.

Stray currents from the tracks tend to find alternate paths back to the traction power substations. The stray current flows along foreign metallic structures and then discharges to the ground when it encounters electrical discontinuities or flows back to the rails to return to the substation. Corrosion will occur where the current discharges from the metallic surface to the ground. To prevent corrosion on metallic structures, they will be installed with measures to ensure electrical continuity. These measures will include bond wires across pipe joints, welding reinforcing steel in concrete, and continuity bond wires or bars along sheet pile or soldier piles. These electrically continuous structures will then be supplied with stray

current drainage facilities to allow the stray current to flow back to the negative return system without detrimental effects, should the need arise. Test stations will be installed along the structures for the evaluation of stray current effects.

Reducing Stray Current

The operation of a DC-powered transit system will produce stray currents. The goals of WBG’s corrosion design include keeping the magnitude of stray currents to minimal levels and mitigating their effects on the metallic structures located along the GLX route. The potential sensitive receptors of this stray current include utilities, bridge structures, and other metallic infrastructure, as well as the new transit system components including track, structural supports, and retaining walls. Traction power substations will be spaced to keep track-to-earth voltages at acceptable levels. High track-to-earth resistance values will be achieved in ballasted track by separating any portion of the rail from the ballast by a minimum of one inch and providing proper track bed drainage. If the track-to-earth voltages are kept to minimal levels and the track-to-earth resistances are kept to the highest achievable levels, then stray currents should be minimized.

After the transit system is installed, but before it is operational, WBG will conduct a stray current survey to measure stray current levels along the system route. This survey will involve monitoring structure-to-ground potentials on system components, as well as foreign structures. Monitoring will be performed for short terms (15 to 20 minutes) if no stray currents are detected, and for longer term (24 hours) if effects are noted. After the system is operational, the stray current survey will be repeated with testing performed at the locations tested prior to operation, at a minimum. A comparison of the test results will indicate if the new system is producing stray current effects. If stray currents effects are detected, then WBG will determine if additional actions, such as activating stray current bonds, are necessary.

Monitoring and Metering Stray Current During Construction

During construction, the track-to-earth resistance will be tested on short sections of track (approximately 1,000 feet) to ensure that the track resistance is kept to the highest attainable levels. This will keep stray currents to a minimum. Stray current survey will

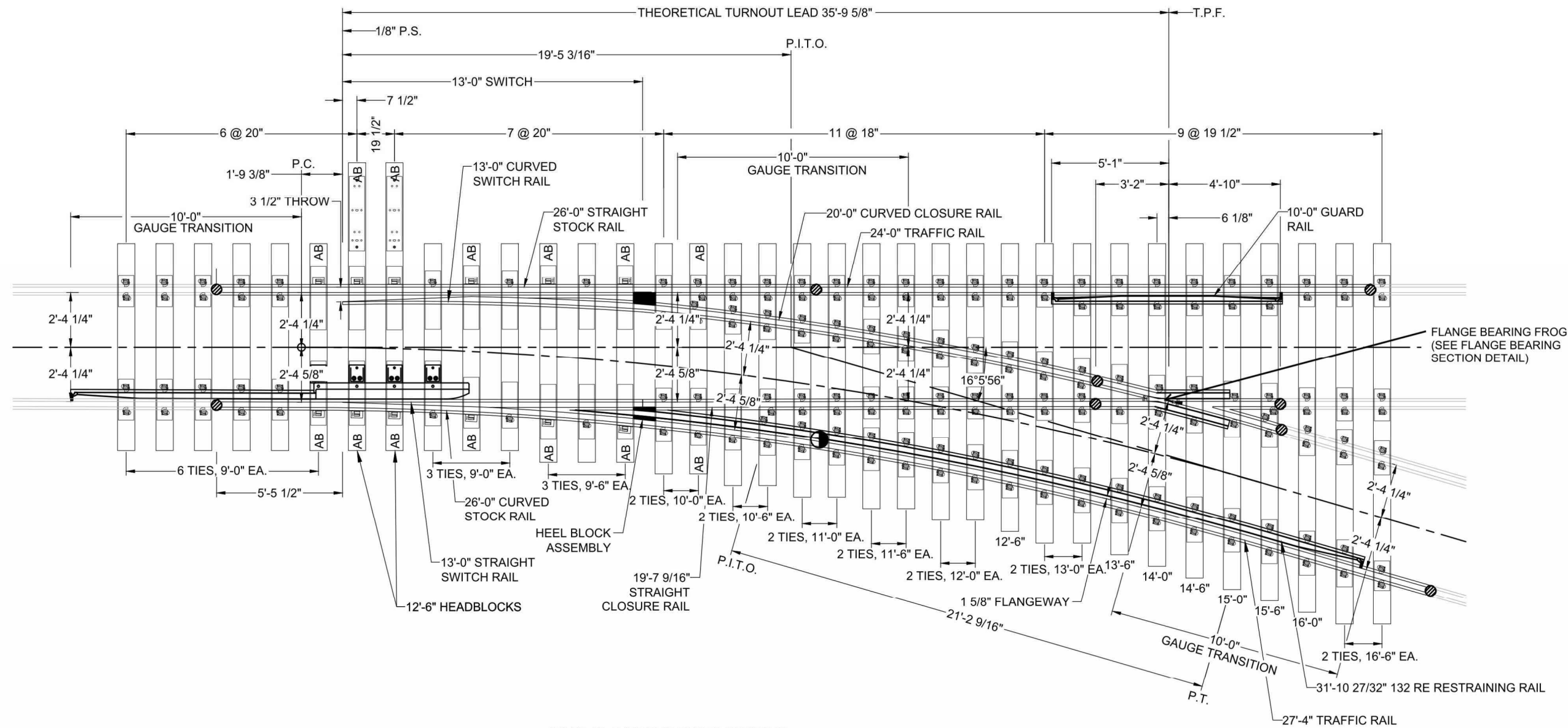
determine if stray current effects are present on existing or newly installed structures. This will be done by monitoring structure-to-earth potentials to determine if stray current effects are present. These effects will be compared to measurements repeated after the system is operational to determine the impact of the new transit system.

Stray Current Best Practices

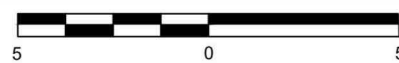
The stray current best practices CorrPro has used on numerous other transit systems, such as Niagara Frontier Transportation Authority, Long Island Railroad, Baltimore MTA, WMATA, DART, and MBTA, include the measures described above. Effective track isolation to minimize stray currents, cathodic protection, and stray current drainage facilities for piping systems, support structures, and system services, are the most effective methods to minimize and mitigate stray current effects. Stray current surveys conducted on existing and newly installed utilities and structures will also indicate the magnitude of existing stray current effects and any stray current effects generated by the newly installed system. Additional mitigation actions, such as activating stray current drains, will be performed based on the results of the stray current surveys.

Figure 4.1-15 Typical 1-inch ballast-to-rail separation WBG will use to reduce stray current on the GLX Project.

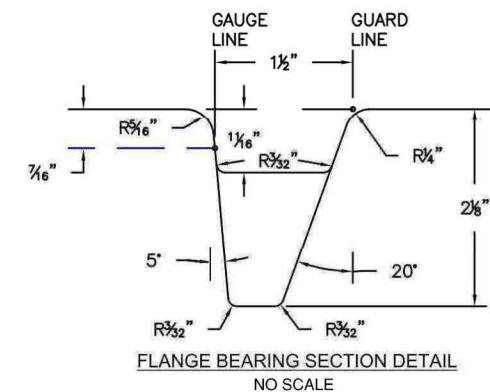




150 FT. CL RADIUS GUARDED TURNOUT



1" = 5'-0"
SCALE IN FEET



LEGEND

- INDICATES RAILS FURNISHED BY THE MANUFACTURER
- INDICATES RAIL FURNISHED BY THE INSTALLER
- ⊙ INDICATES INSULATED JOINTS WITH 3/16" OPENING
- INDICATES JOINTS TO BE FIELD WELDED
- ⊗ INDICATES JOINTS TO BE BOLTED
- AB INDICATES RAIL BRACE LOCATIONS
- ⊖ INDICATES SPECIAL RUNNING RAIL AND RESTRAINING RAIL JOINT

NOTES:

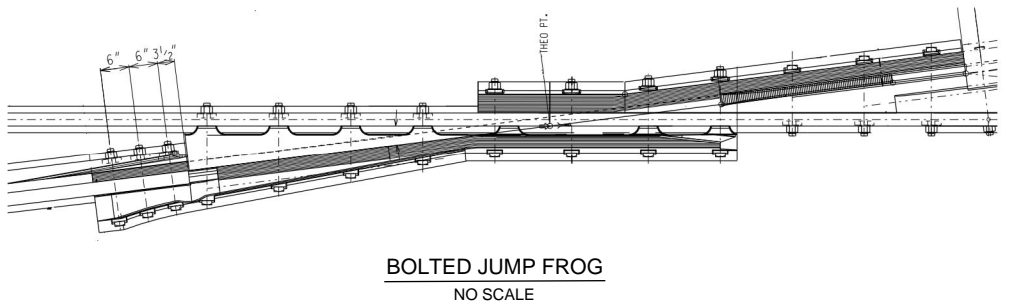
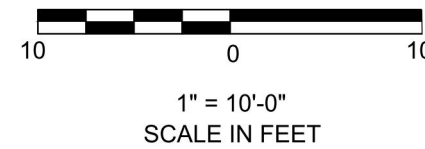
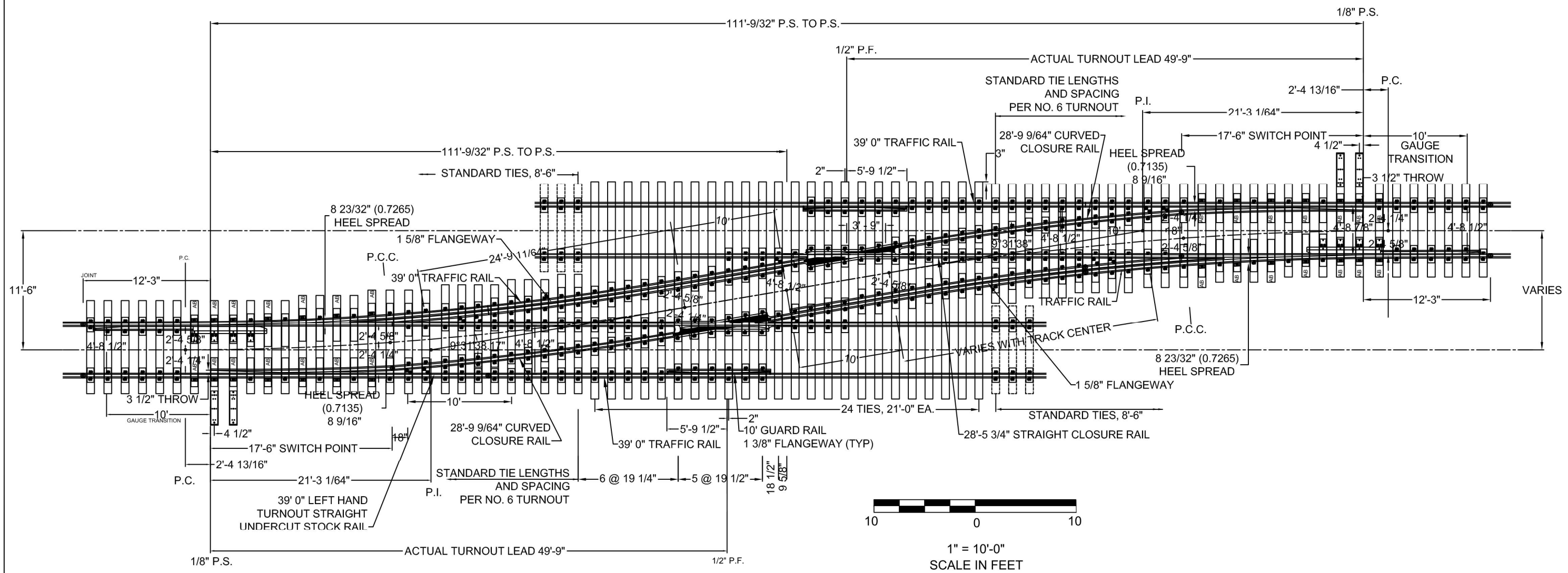
1. GAUGE TRANSITIONS SHALL BE MADE ON INSIDE RAIL OF CURVE AND CONTINUE ON THROUGH SIDE ON INSIDE RAIL OF CURVE, IN TEN FOOT LENGTHS AS SHOWN.
2. MANUFACTURER SHALL SUPPLY FLANGE BEARING FROGS.
3. PROVIDE HMA UNDERLAYMENT IN ACCORDANCE WITH MBTA RAILROAD OPERATIONS STANDARD DWG NO. 1030.
4. ALL SPECIAL TRACKWORK WITHIN THE YARD IS TO BE BOLTED.
5. RAIL BRACES (AB) SHALL BE MACHINED FOR SWITCH HEATER ELEMENT INSTALLATION.

	MASSACHUSETTS BAY TRANSPORTATION AUTHORITY
	GREEN LINE EXTENSION PROJECT
	DESIGN BUILD - MBTA CONTRACT NO. E22CN07 CAMBRIDGE/SOMERVILLE/MEDFORD, MASSACHUSETTS

THE WALSH BARLETTA GRANITE
Joint Venture Team

**FULLY GUARDED 150' RADIUS TURNOUT
WITH FLANGE BEARING FROG**

DATE: SEPT. 28, 2017	SCALE: AS NOTED	SHEET: 000-K-0101
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LEGEND

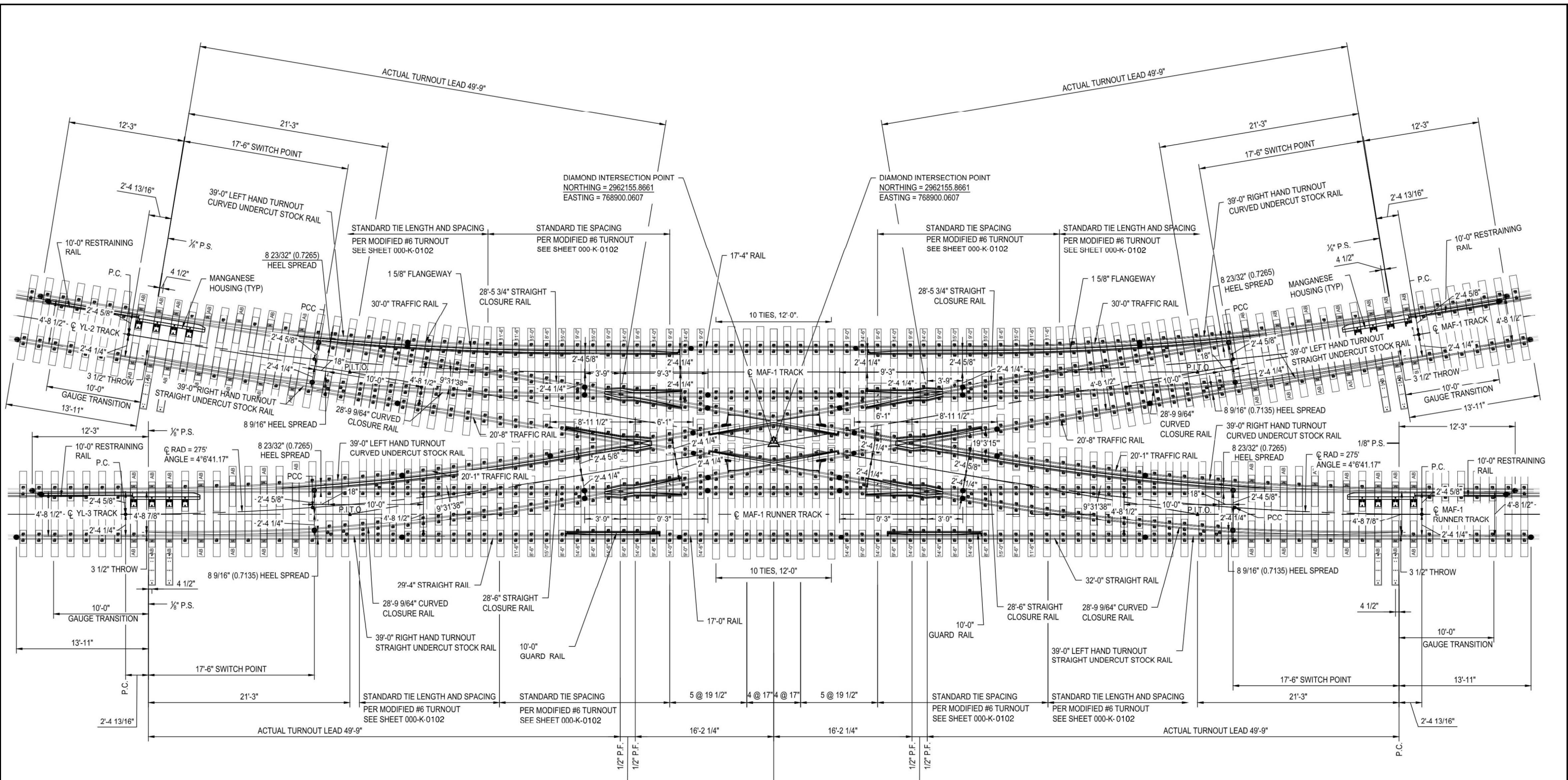
- INDICATES RAILS FURNISHED BY THE MANUFACTURER
- INDICATES RAIL FURNISHED BY THE INSTALLER
- ⊕ INDICATES INSULATED JOINTS WITH 3/16" OPENING
- INDICATES JOINTS TO BE FIELD WELDED
- ⊗ INDICATES JOINTS TO BE BOLTED
- AB INDICATES RAIL BRACE LOCATIONS
- ◐ INDICATES SPECIAL RUNNING RAIL AND RESTRAINING RAIL JOINT

NOTES:

1. GAUGE TRANSITIONS SHALL BE MADE ON INSIDE RAIL OF CURVE AND CONTINUE ON THROUGH SIDE ON INSIDE RAIL OF CURVE, IN TEN FOOT LENGTHS AS SHOWN.
2. MANUFACTURER SHALL SUPPLY JUMP FROGS.
3. JUMP (UNBROKEN MAINLINE) FROGS SHALL BE DESIGNED TO TRANSITION THE TREAD/FLANGE/TREAD MBTA LRV WHEEL PROFILE OVER THE UNBROKEN STRAIGHT FROG RAIL.
4. PROVIDE HMA UNDERLAYMENT IN ACCORDANCE WITH MBTA RAILROAD OPERATIONS STANDARD DWG NO. 1030.
5. ALL SPECIAL TRACKWORK JOINTS SHALL BE WELDED WITH THE EXCEPTION OF INSULATION JOINTS.
6. INSULATION JOINTS SHALL BE LOCATED AS REQUIRED BY SIGNALS SPECIFICATIONS.



	MASSACHUSETTS BAY TRANSPORTATION AUTHORITY GREEN LINE EXTENSION PROJECT DESIGN BUILD - MBTA CONTRACT NO. E22CN07 CAMBRIDGE/SOMERVILLE/MEDFORD, MASSACHUSETTS
MODIFIED NO. 6 - FULLY GUARDED CROSSOVER WITH LRV JUMP FROGS	
DATE: SEPT. 28, 2017	SCALE: AS NOTED
SHEET 000-K-0102	



DIAMOND INTERSECTION POINT
NORTHING = 2962155.8661
EASTING = 768900.0607

DIAMOND INTERSECTION POINT
NORTHING = 2962155.8661
EASTING = 768900.0607

- LEGEND**
- AB INDICATES RAIL BRACE LOCATIONS
 - INDICATES RAILS FURNISHED BY THE MANUFACTURER
 - INDICATES RAIL FURNISHED BY THE INSTALLER
 - INDICATES RESTRAINING RAIL FURNISHED BY THE MANUFACTURER
 - INDICATES RESTRAINING RAIL FURNISHED BY THE INSTALLER
 - ⓪ INDICATES INSULATED JOINTS WITH 3/16" OPENING
 - INDICATES JOINTS TO BE FIELD WELDED
 - ⊗ INDICATES JOINTS TO BE BOLTED

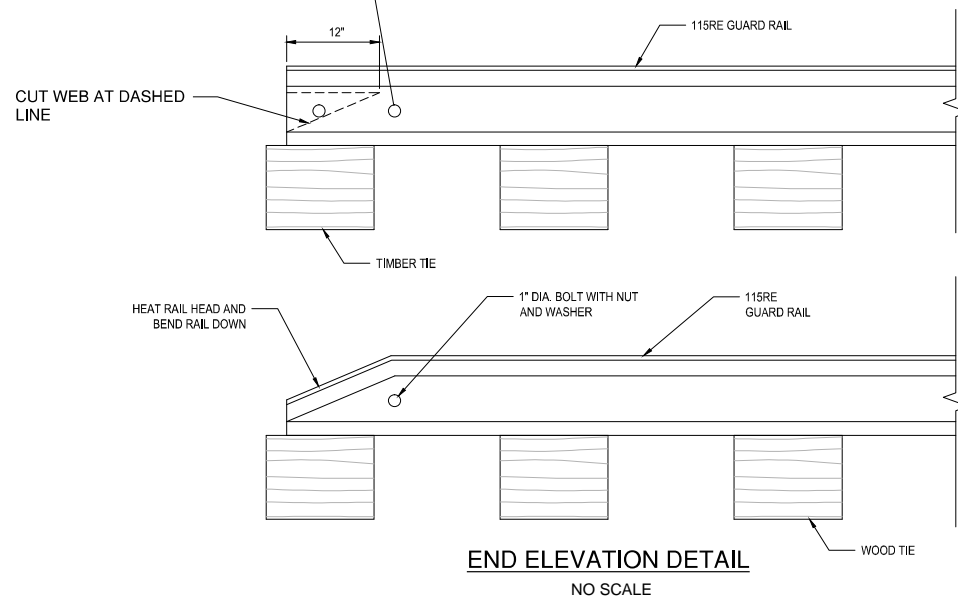
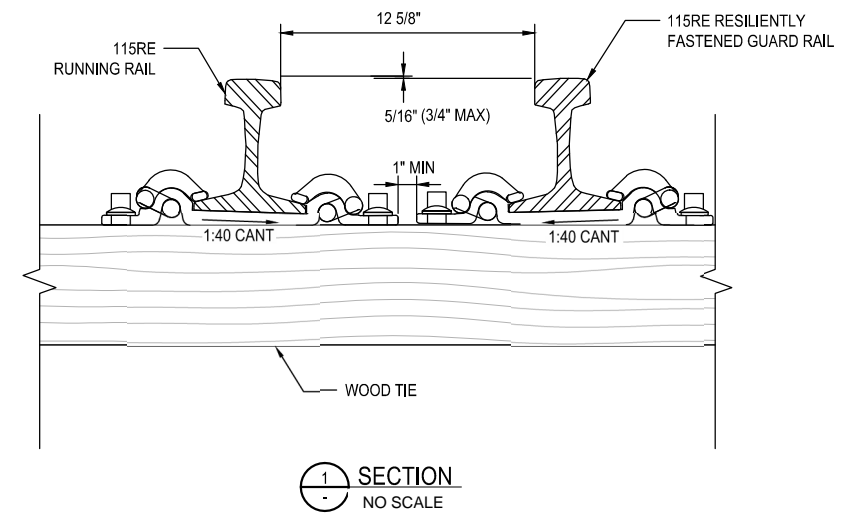
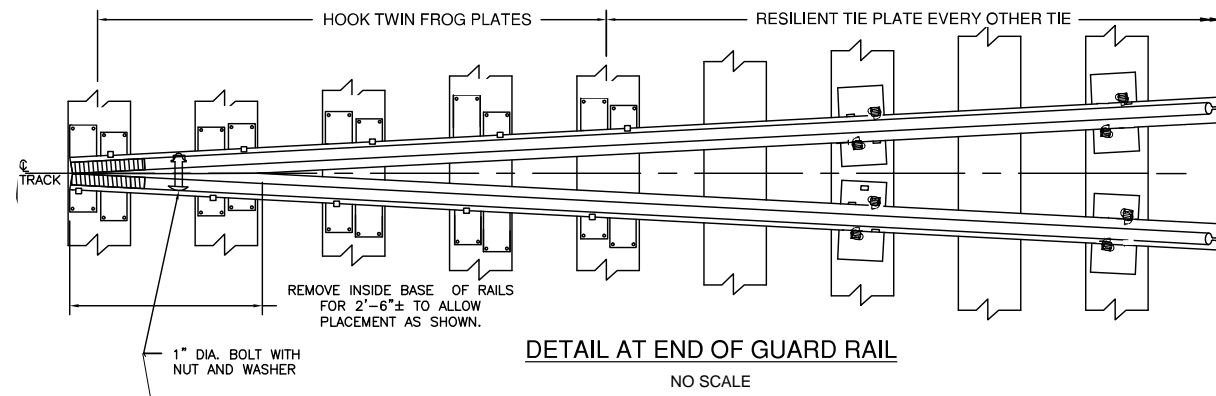
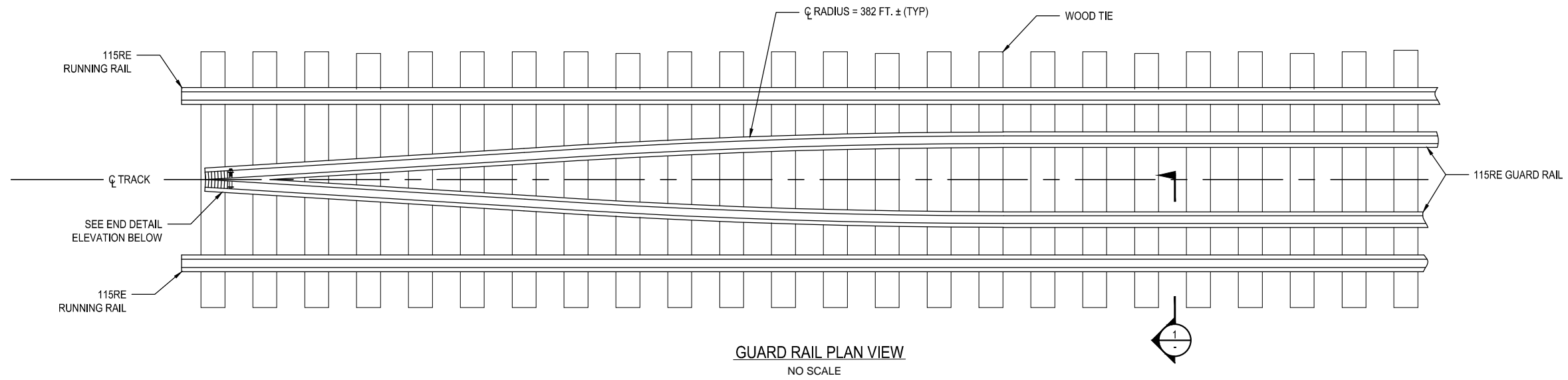
- NOTES:**
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 2. MANUFACTURER SHALL SUPPLY FLANGE BEARING FROGS.
 3. GAUGE TRANSITION SHALL BE MADE ON INSIDE RAIL OF CURVE AND ON THROUGH SIDE ON STRAIGHT CLOSURE RAIL.
 4. GUARD RAIL GAPS ARE REQUIRED AT SPECIAL TRACKWORK. SEE TRACK DETAIL SHEETS FOR FURTHER INFORMATION.
 5. CROSSOVER SHALL BE FULLY GUARDED.

MASSACHUSETTS BAY TRANSPORTATION AUTHORITY
GREEN LINE EXTENSION PROJECT
DESIGN BUILD - MBTA CONTRACT NO. E22CN07
CAMBRIDGE/SOMERVILLE/MEDFORD, MASSACHUSETTS

THE WALSH BARLETTA GRANITE
Joint Venture Team

**MODIFIED NO. 6 - FULLY GUARDED
SPECIAL DIAMOND CROSSOVER**

DATE: SEPT. 28, 2017 SCALE: AS NOTED SHEET **000-K-0103**

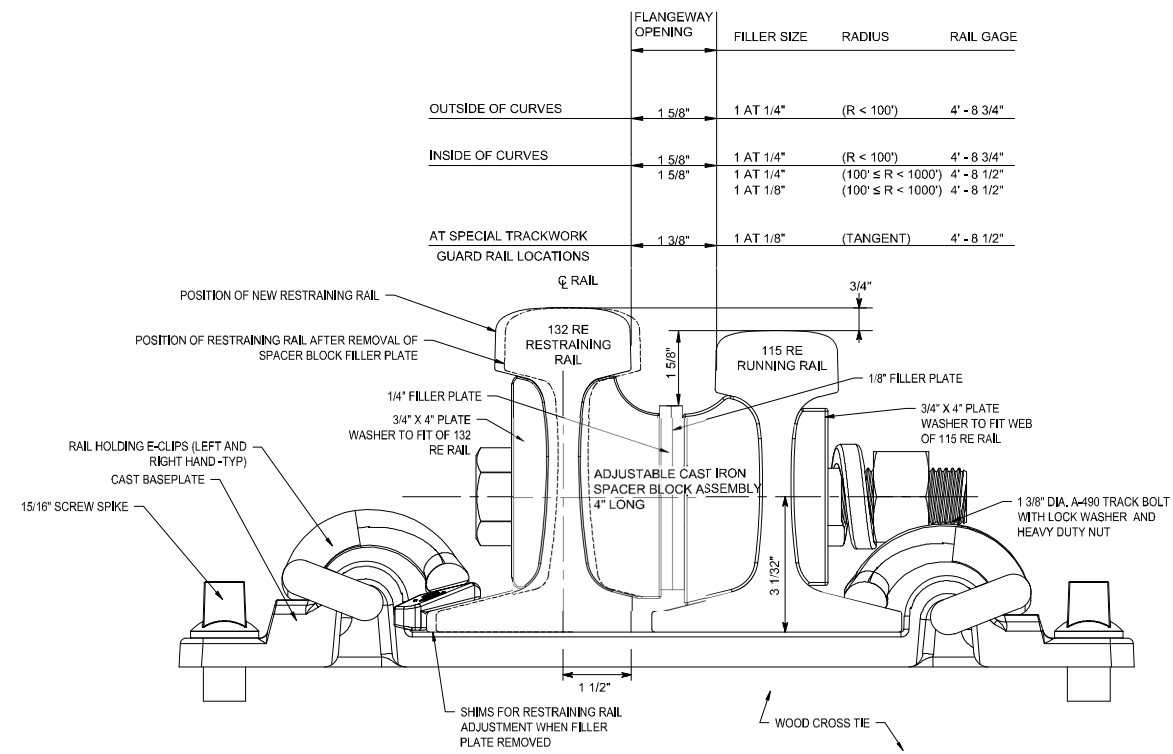


- NOTES:
1. REFER TO MBTA STANDARD DWG NO.'S 900 AND 905 FOR FURTHER DETAILS.
 2. GUARD RAIL SHALL BE RESILIENTLY FASTENED TO EVERY SECOND TIE.
 3. IN LOCATIONS WHERE GUARD RAIL AND RESTRAINING RAIL ARE BOTH REQUIRED, GUARDRAIL SHALL BE INSTALLED ADJACENT TO UNRESTRAINED RAIL ONLY.

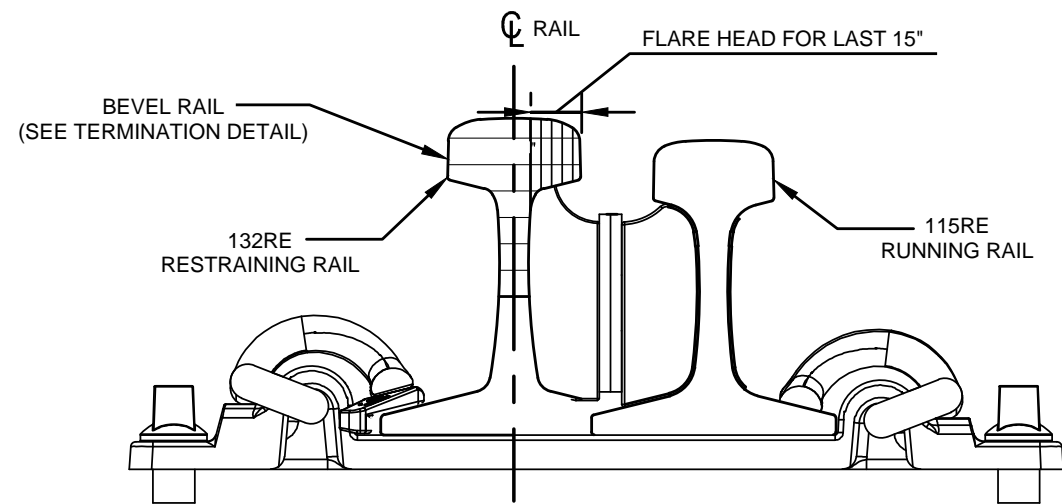
	MASSACHUSETTS BAY TRANSPORTATION AUTHORITY
	GREEN LINE EXTENSION PROJECT DESIGN BUILD - MBTA CONTRACT NO. E22CN07 CAMBRIDGE/SOMERVILLE/MEDFORD, MASSACHUSETTS

THE WALSH BARLETTA GRANITE
Joint Venture Team

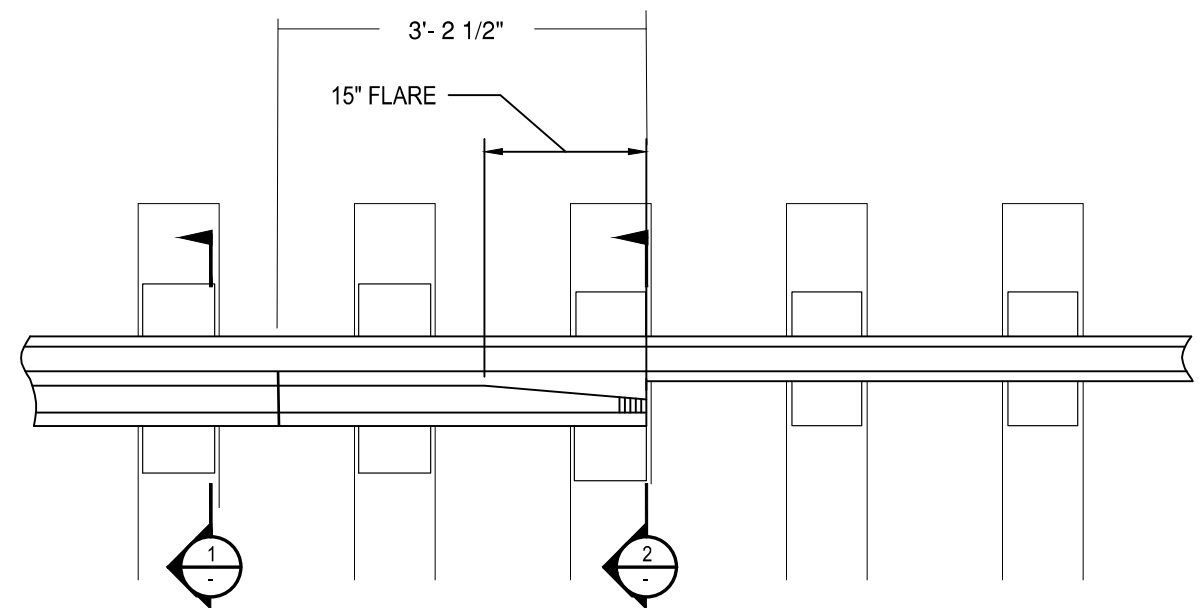
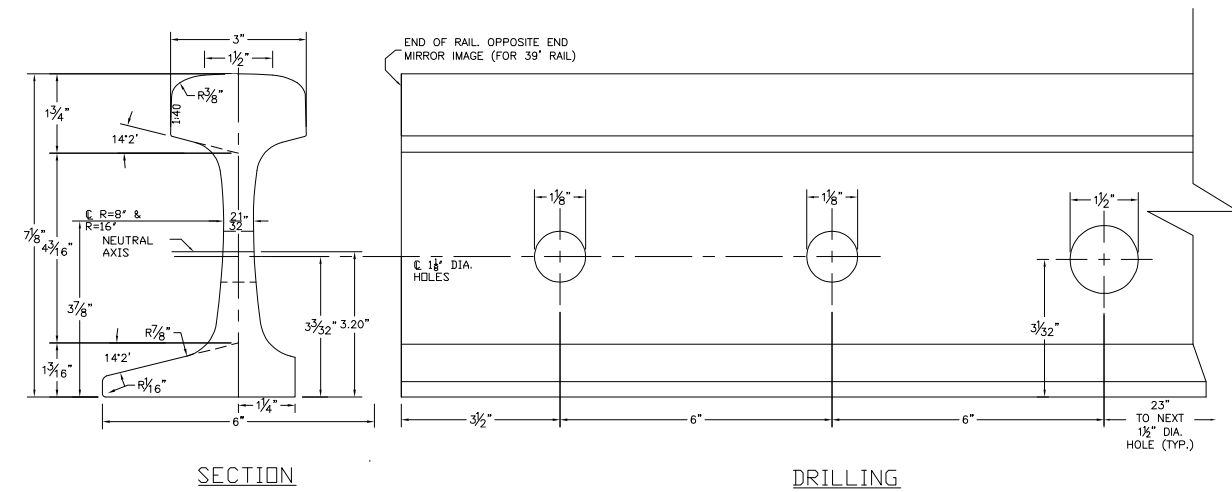
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DATE: SEPT. 28, 2017	SCALE: NO SCALE	SHEET: 000-K-0104



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SECTION
NO SCALE

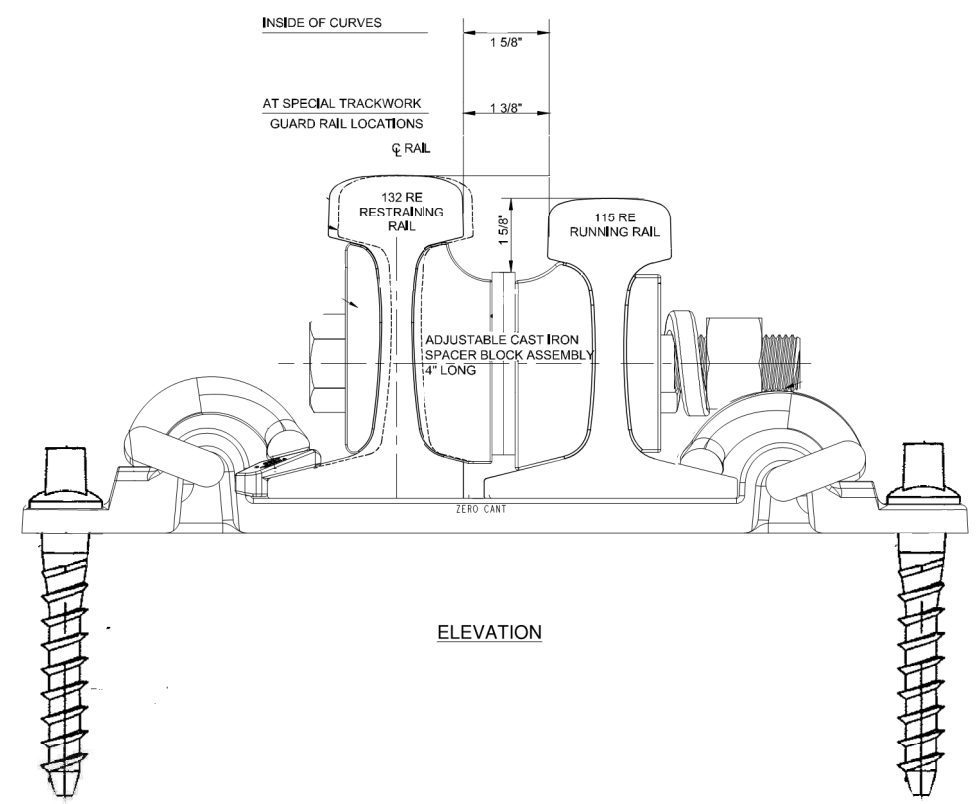
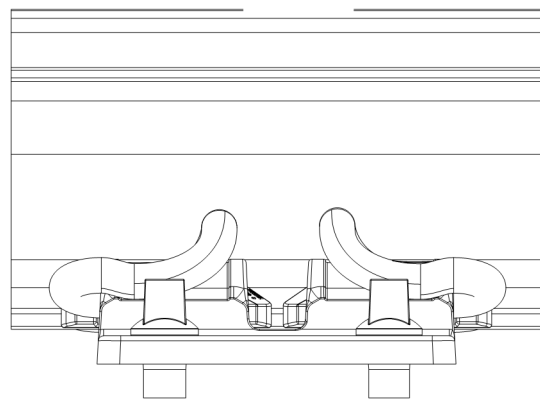
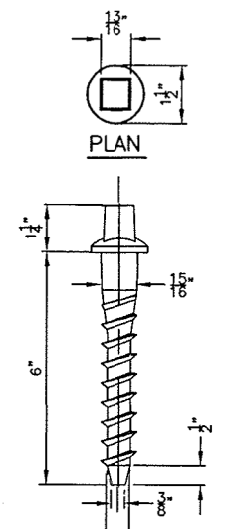
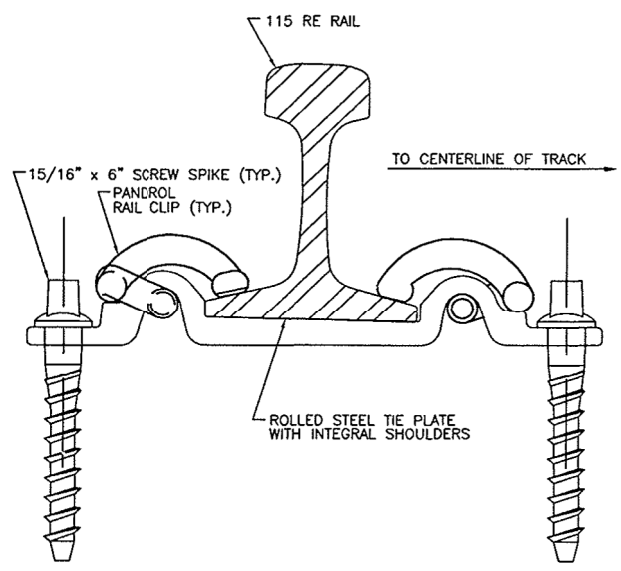
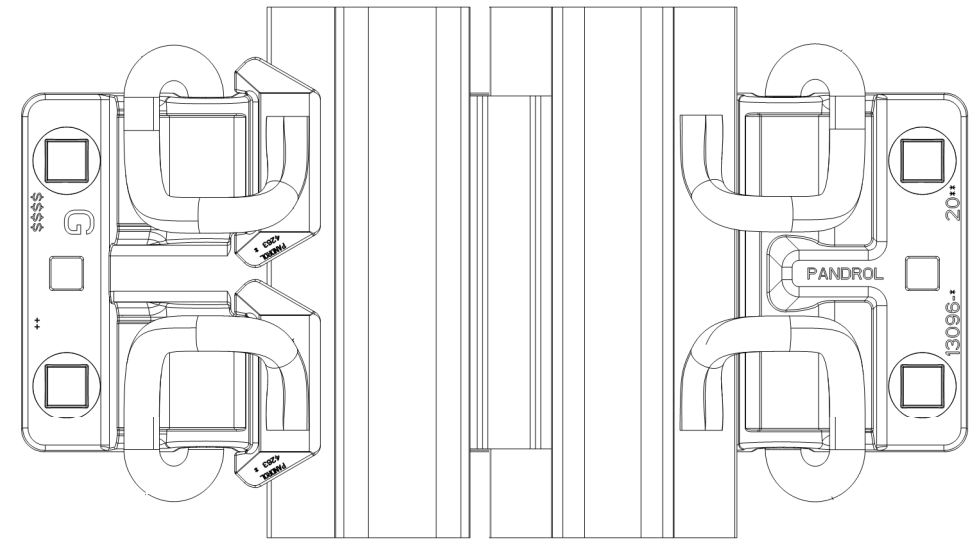
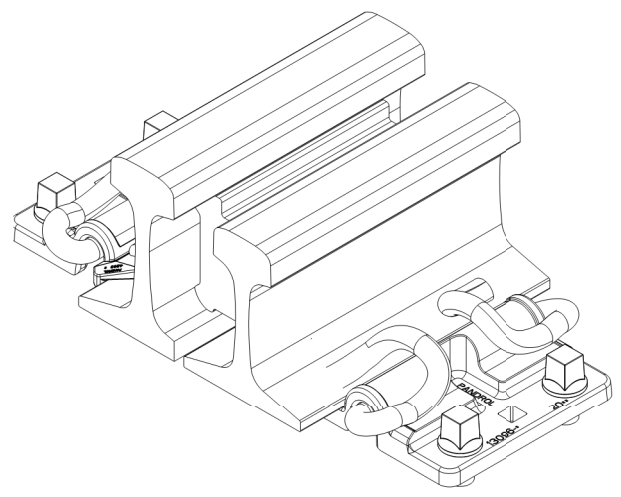
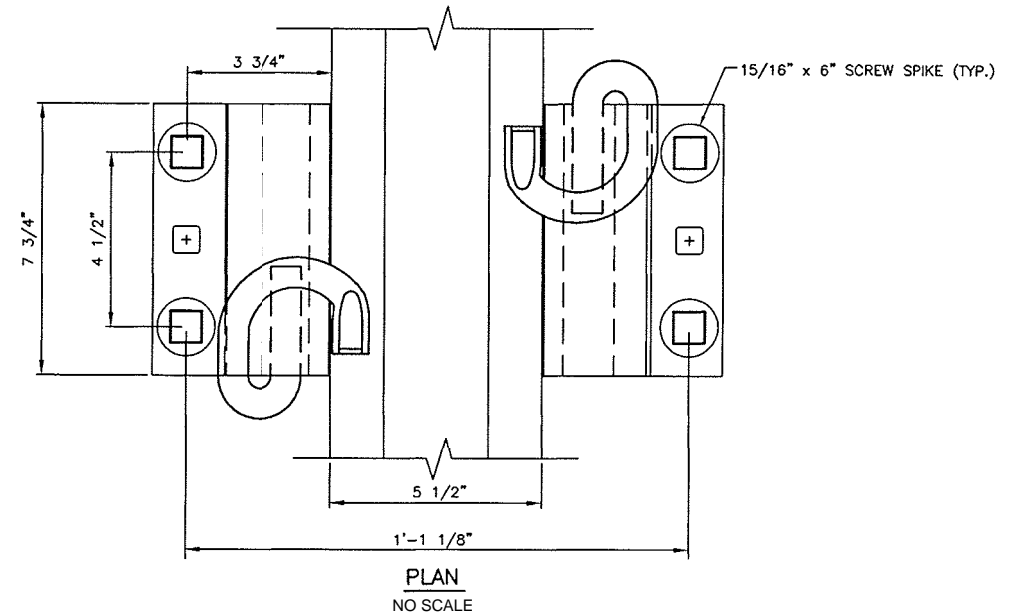


2
SECTION
NO SCALE

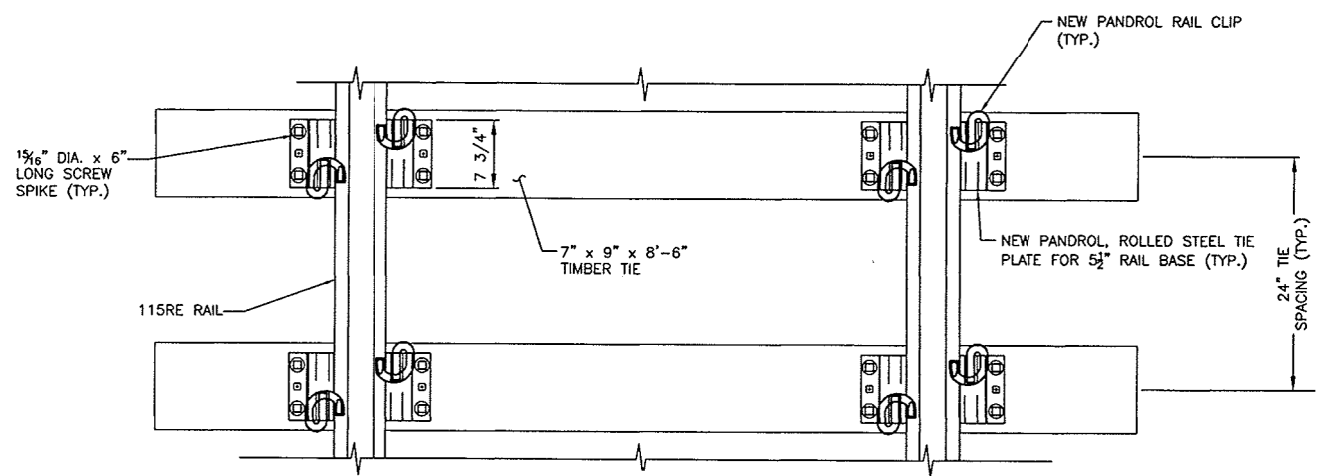


RESTRAINING RAIL TERMINATION DETAIL
NO SCALE

	FLANGEWAY OPENING	FILLER SIZE	RADIUS	RAIL GAGE
OUTSIDE OF CURVES	1 5/8"	1 AT 1/4"	(R < 100')	4' - 8 3/4"
INSIDE OF CURVES	1 5/8"	1 AT 1/4"	(R < 100')	4' - 8 3/4"
		1 AT 1/4"	(100' ≤ R < 1000')	4' - 8 1/2"
		1 AT 1/8"	(100' ≤ R < 1000')	4' - 8 1/2"
AT SPECIAL TRACKWORK GUARD RAIL LOCATIONS	1 3/8"	1 AT 1/8"	(TANGENT)	4' - 8 1/2"



PANDROL ADJUSTABLE RESTRAINING RAIL PLATE
NO SCALE

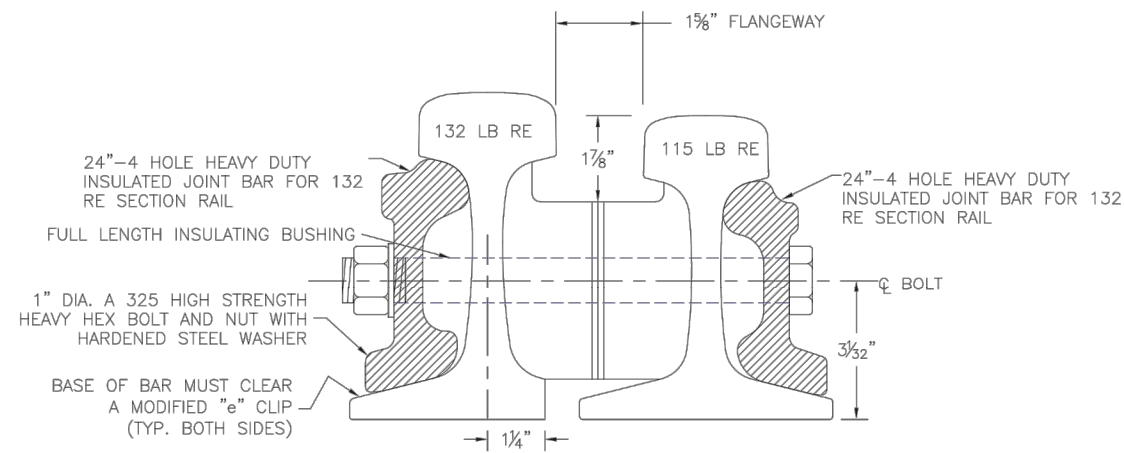
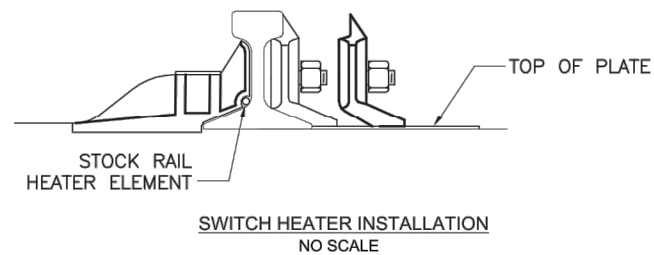
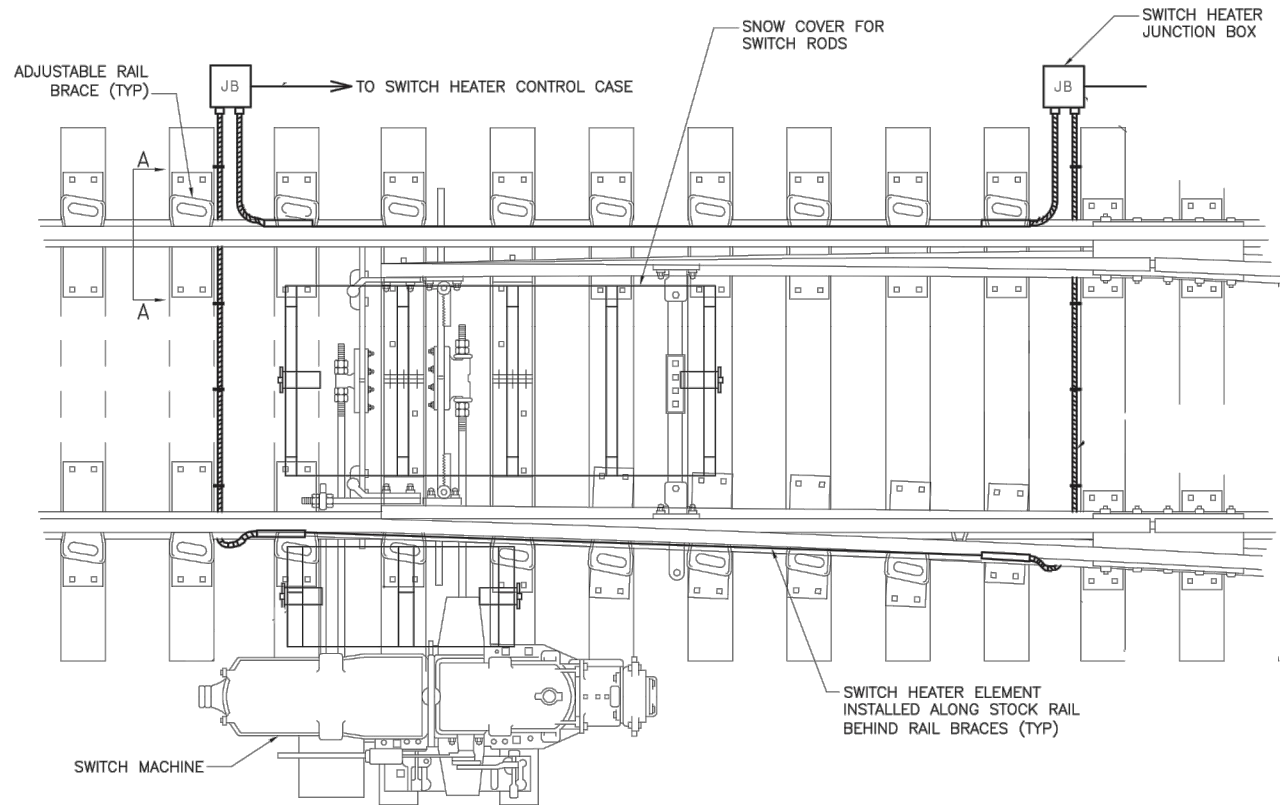


	MASSACHUSETTS BAY TRANSPORTATION AUTHORITY
	GREEN LINE EXTENSION PROJECT
	DESIGN BUILD - MBTA CONTRACT NO. E22CN07 CAMBRIDGE/SOMERVILLE/MEDFORD, MASSACHUSETTS

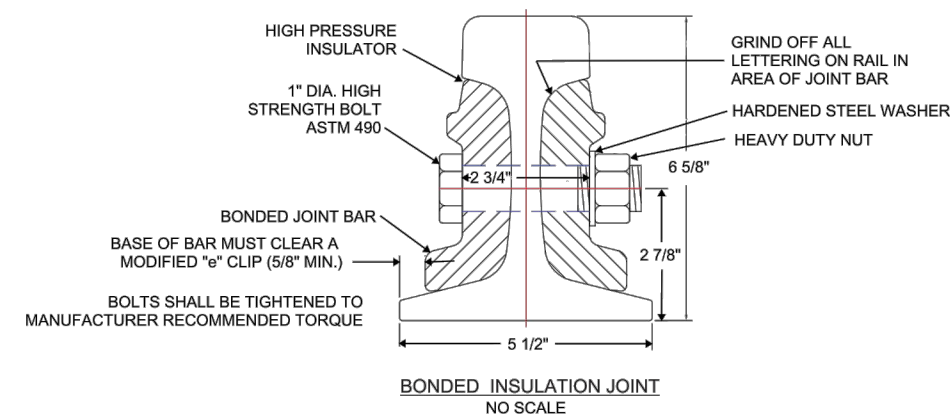
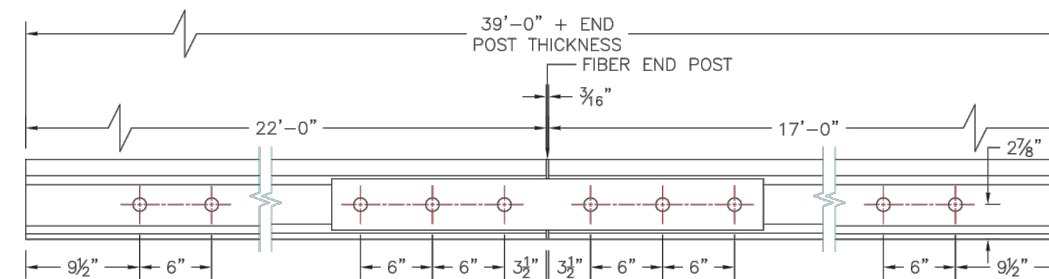
THE WALSH BARLETTA GRANITE
Joint Venture Team

TRACK FASTENING SYSTEM DETAILS

DATE: SEPT. 28, 2017	SCALE: NO SCALE	SHEET: 000-K-0106
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DOUBLE INSULATION JOINT
NO SCALE



BONDED INSULATION JOINT
NO SCALE

NOTES:

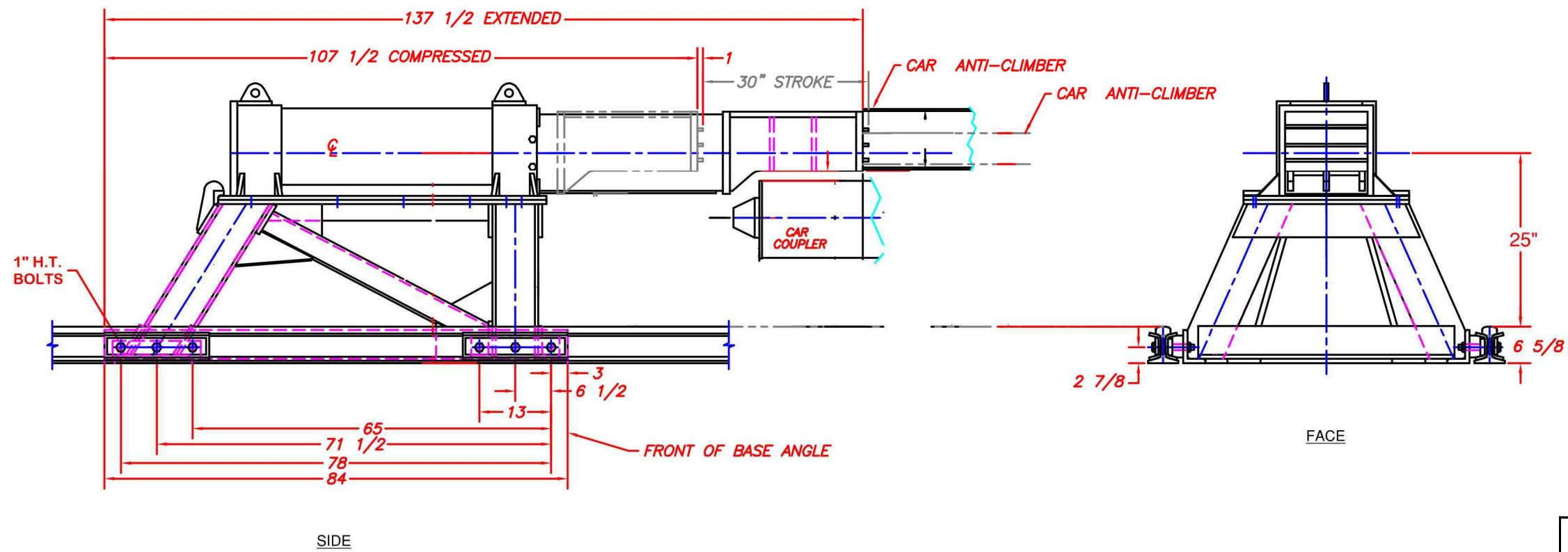
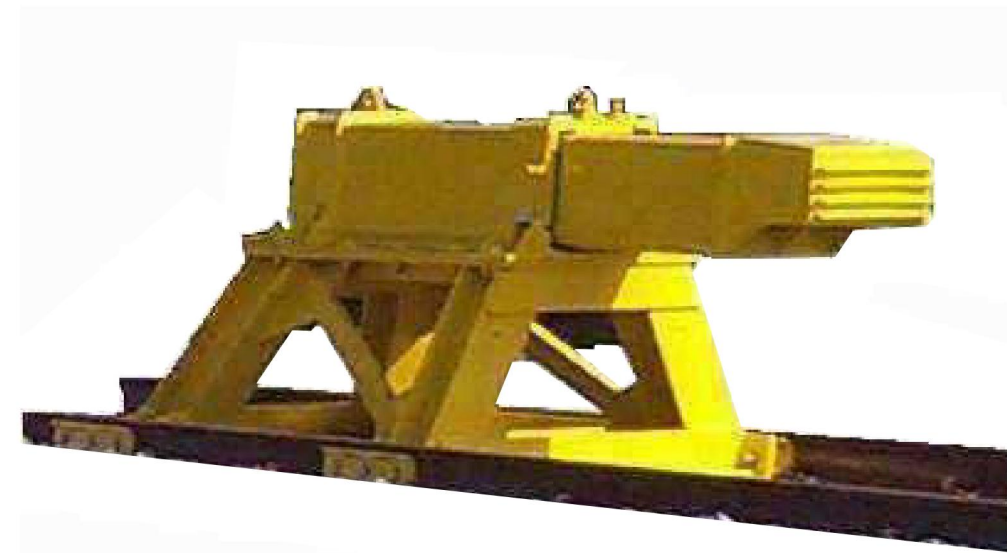
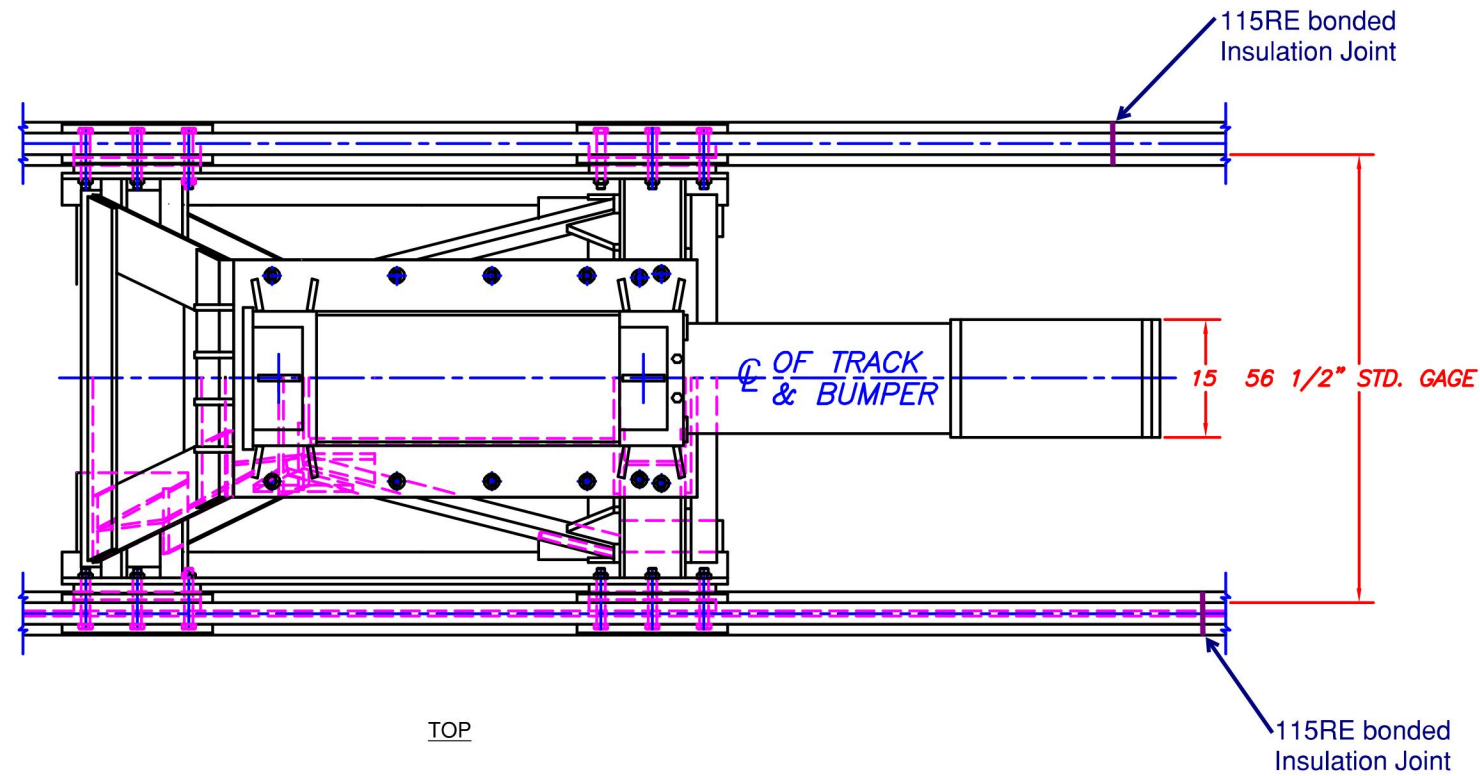
- SWITCH HEATERS TO BE INSTALLED ON ALL SWITCHES, ELECTRIC AND HAND THROWN

	MASSACHUSETTS BAY TRANSPORTATION AUTHORITY
	GREEN LINE EXTENSION PROJECT DESIGN BUILD - MBTA CONTRACT NO. E22CN07 CAMBRIDGE/SOMERVILLE/MEDFORD, MASSACHUSETTS

THE WALSH BARLETTA GRANITE
Joint Venture Team

TRACK AND SIGNAL INTERFACE DETAILS

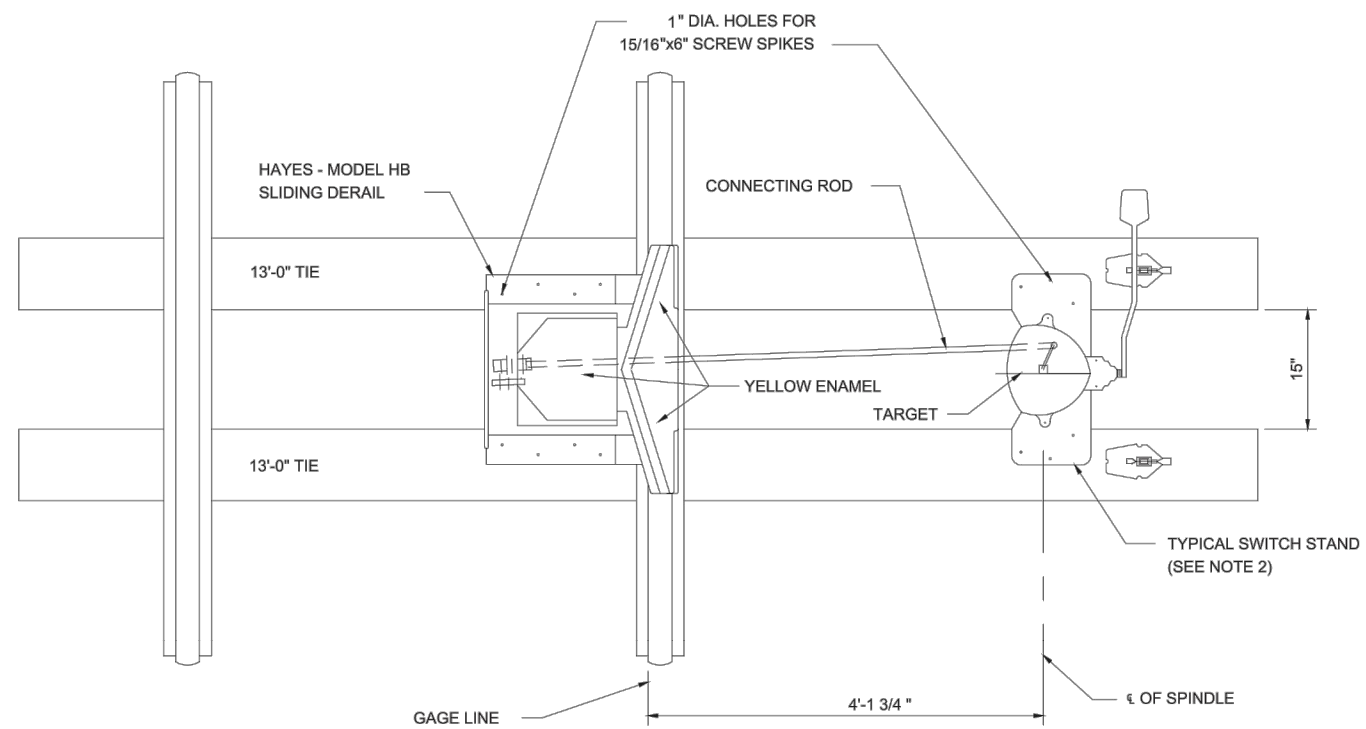
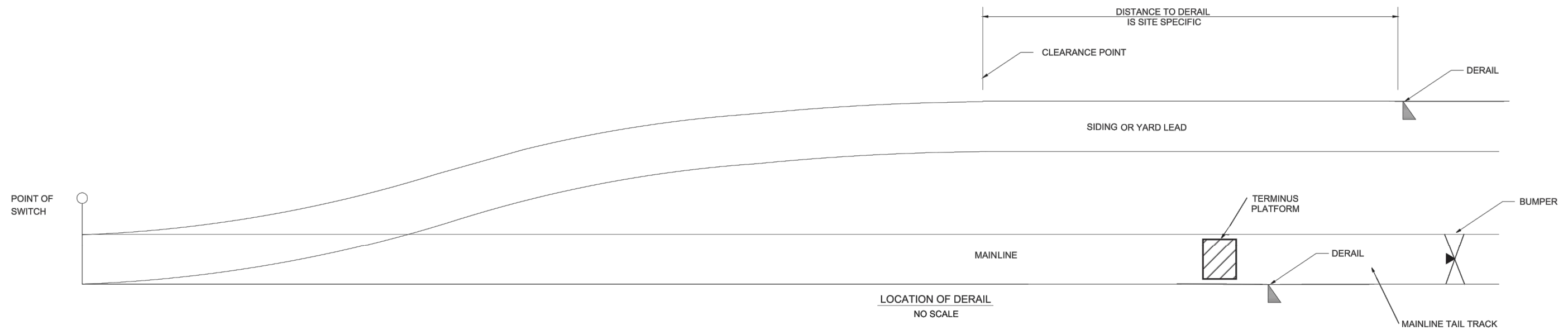
DATE: SEPT. 28, 2017 SCALE: NO SCALE SHEET: **000-K-0107**



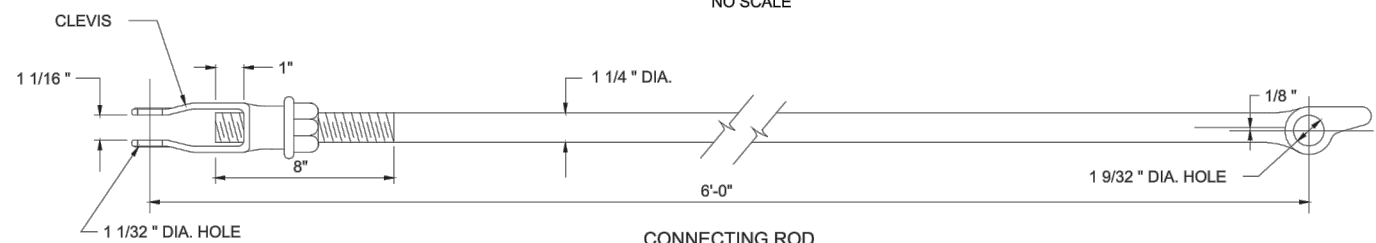
T	MASSACHUSETTS BAY TRANSPORTATION AUTHORITY
	GREEN LINE EXTENSION PROJECT
	DESIGN BUILD - MBTA CONTRACT NO. E22CN07 CAMBRIDGE/SOMERVILLE/MEDFORD, MASSACHUSETTS

THE WALSH BARLETTA GRANITE
Joint Venture Team

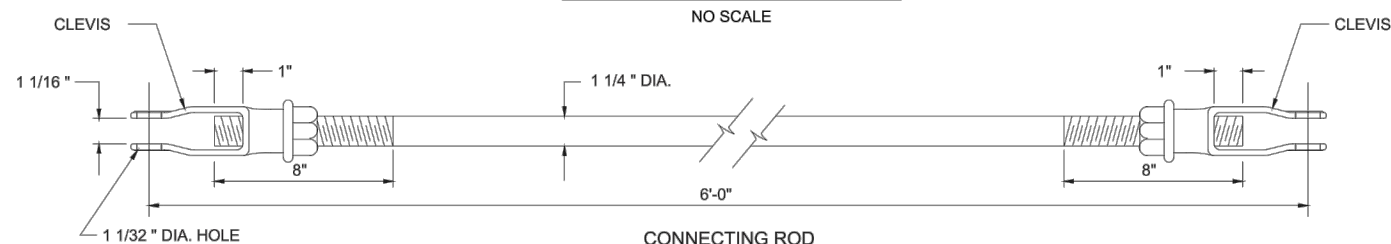
LRV HYDRAULIC BUMPER DETAILS		
DATE: SEPT. 28, 2017	SCALE: NO SCALE	SHEET: 000-K-0108



SWITCH STAND AND DERAIL INSTALLATION
NO SCALE



CONNECTING ROD
FOR NEW CENTURY SWITCH STAND
NO SCALE



CONNECTING ROD
FOR OTHER SWITCH STANDS
NO SCALE

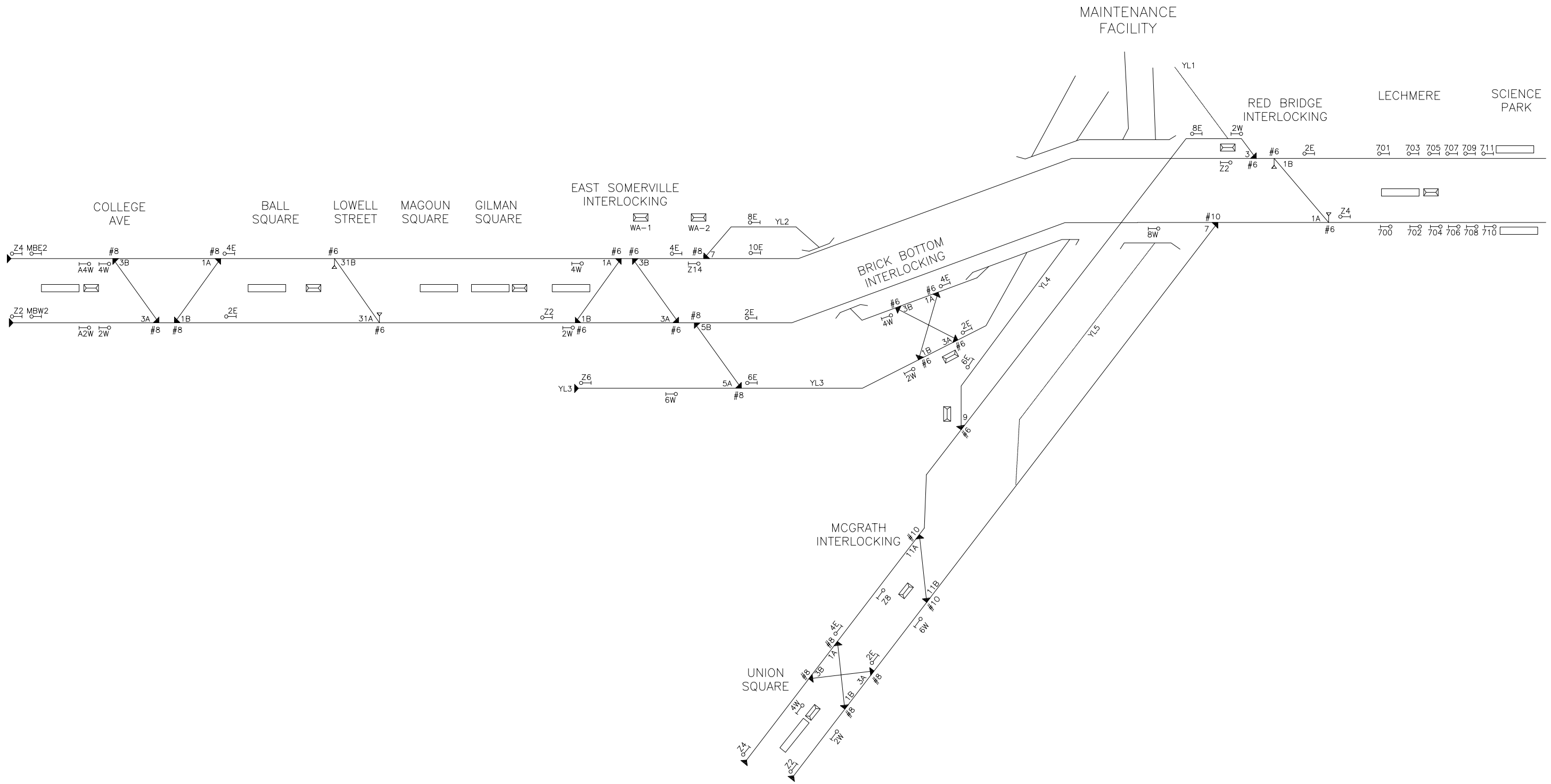
NOTES:

1. THE FOLLOWING SWITCH STAND IS TO BE USED TO OPERATE DERAIL- NEW CENTURY SWITCH STAND, MODEL 50-A AS MANUFACTURED BY BETHLEHEM STEEL OR APPROVED EQUAL.
2. OPERATING ROD TO BE IN TENSION, WITH RED TARGET PERPENDICULAR TO THE RAIL, WHEN THE DERAIL IS IN THE NORMAL POSITION.
3. DERAILS SHALL BE DOUBLE ENDED DERAILING FLANGES WHICH WILL OPERATE AS EITHER LEFT OR RIGHT HAND DERAILS.
4. ALL DERAILS TO ACCOMMODATE PADLOCKS ON BOTH ENDS, ONE A SWITCH LOCK; THE OTHER A PRIVATE LOCK.
5. REFLECTORIZED DERAIL BANNERS SHALL BE USED
6. REFLECTORIZED SHEETING MATERIAL SHALL CONFORM AND BE APPLIED IN ACCORDANCE WITH CURRENT AND APPLICABLE MHD STANDARDS.
7. BANNERS SHALL BE FABRICATED FROM 7 GAGE GALVANIZED STEEL SHEET AS ONE CONTIGUOUS PIECE (NO JOINTS OR SEAMS ALLOWED).
8. SHADE OF COLORATION SHALL BE APPROVED BY THE MBTA



T	MASSACHUSETTS BAY TRANSPORTATION AUTHORITY
	GREEN LINE EXTENSION PROJECT
	DESIGN BUILD - MBTA CONTRACT NO. E22CN07 CAMBRIDGE/SOMERVILLE/MEDFORD, MASSACHUSETTS

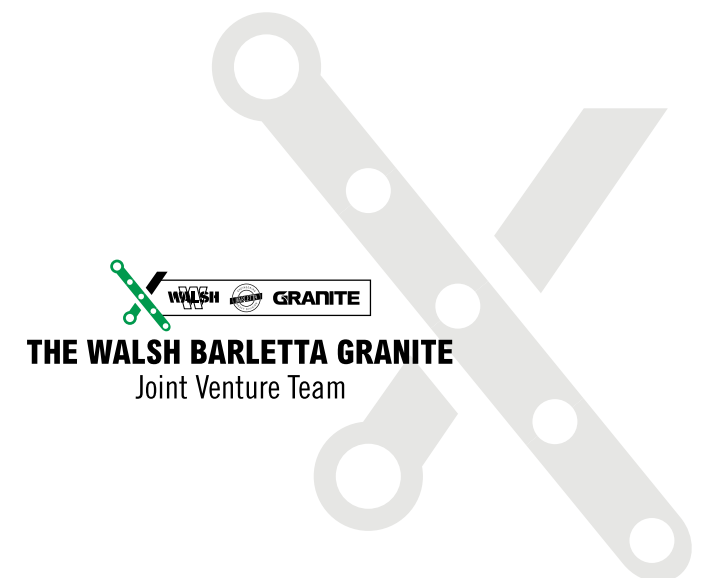
SLIDING BLOCK DERAIL DETAILS		
DATE: SEPT. 28, 2017	SCALE: AS NOTED	SHEET: 000-K-0109



MASSACHUSETTS BAY TRANSPORTATION AUTHORITY
GREEN LINE EXTENSION PROJECT
 DESIGN BUILD - MBTA CONTRACT NO. E22CN07
 CAMBRIDGE/SOMERVILLE/MEDFORD, MASSACHUSETTS

OVERALL SIGNAL SYSTEM SCHEMATIC
 DATE: SEPT. 28, 2017 SCALE: NO SCALE SHEET **000-SC-1001**

ELEVATED GUIDEWAY AND STRUCTURES ALONG THE GUIDEWAY



THE WALSH BARLETTA GRANITE
Joint Venture Team

4.2 Elevated Guideway and Structures along the Guideway

WBG evaluated all proposed guideways, bridges, retaining walls, and noise walls. Each structure was first reviewed for function, layout, and compliance, and then modified or redesigned to provide an optimized solution. Material selection, available steel, constructability, traffic control, and agency requirements were just some of the design considerations. The knowledge gained from this effort will be coupled with design and construction expertise to provide structures that can be built while minimizing impacts to the surrounding community.

A. STRUCTURES ALONG GUIDEWAY

Conformance to Structural Requirements

Section 8 of the Technical Provisions details the design criteria, standards, methodology, and other structural requirements for the various structural elements within the project limits including

viaducts, railroad bridges, roadway and pedestrian bridges, underpasses, retaining walls, and noise walls. We will comply with the requirements for each of these elements. The applicable criteria and standards vary by element but are typically a combination of the latest additions to the following:

- » MBTA Guide Specifications for Structural Design of Rapid Transit and Light Rail Structures (Light Rail Code)
- » MBTA MOW Green Line – Light Rail Transit, Track Maintenance and Safety Standards
- » MBTA Standard Specifications, Construction
- » MBTA Railroad Operations Commuter Rail Design Standards Manual, Volumes I and II
- » MBTA Railroad Operations Book of Standard Plans, Track and Roadway
- » AREMA Manual for the Railway Engineering
- » Load and Resistance Factor Design (LRFD) Bridge Manual, Parts I, II, and III of MassDOT
- » AASHTO – various specifications and guidelines
- » Massachusetts Building Code

Our approach to conforming to various structural requirements is detailed in the following sections.

Design Criteria and Applicable Standards

Elevated Guideway (Viaducts): The elevated guideway (viaducts) elements were designed using the Load Factor Design (LFD) method specified in the Light Rail Code, with detailing for structural elements complying with MassDOT's LRFD Bridge Manual. The Lechmere and Medford Branch viaducts were designed to support eastbound and westbound tracks, while the Union Square eastbound and westbound viaducts were designed to hold single tracks. Loads were determined in accordance with the Light Rail Code, such as revenue vehicles and non-revenue vehicles, noise barriers and wind screens, handrails, guardrails, and other protective railings, as well as earthquake forces. Seismic analysis will be performed following AASHTO Division 1A, Article 4.2 Procedure 3.

Railroad Bridge: The structural steel elements of the Washington Street bridge were designed using the Allowable Stress Design (ASD) method per the AREMA manual. The LRFD method was used for the concrete elements.

GLX structures. Evaluating proposed all structures allowed WBG to gain a full understanding of the details for each to plan and sequence the work.



Roadway and Pedestrian Bridges/Underpasses: Roadway and pedestrian bridges, as well as the underpass at Medford Street, were designed using the LRFD method in accordance with the AASHTO specifications and guidelines specified in Sections 8.4.3.1 and 8.6.3.1. Two new pedestrian bridges will be constructed, one at the College Avenue Station and the second supporting the Community Path at the intersection with School Street. Details of the various components will comply with LRFD Bridge Manual.

Retaining Walls: Retaining walls were designed using the LRFD Bridge Manual. We determined loads according to AREMA, the Light Rail Code, the AASHTO Standard Specifications, and the Massachusetts State Building Code, where each apply, according to Section 8.1.3.3 of the Technical Provisions. Wall components were designed in accordance with AISC and ACI codes where applicable; otherwise, according to FHWA standards. Design (including corrosion protection) will be completed using wall type specific procedures from the FHWA, except where superseded by a reference from the Technical Provisions.

Noise Walls: The design methodology for noise barriers varies by component. WBG designed the structural steel elements using the ASD method, the concrete elements using LFD, and the foundation elements using LRFD.

Serviceability Criteria

The viaduct elements were designed so that the maximum deflection due to live loads, plus impact of revenue trains, does not exceed 1/1000 of the respective span length. Similarly, the maximum deflection due to live loads, plus impact of non-revenue trains, were designed to not exceed 1/800 of the respective span length. Additionally, the Lechmere viaduct was designed in accordance with the level boarding requirements of the Lechmere Station platform. Structures typically were designed through a limiting equilibrium analysis to determine geometry to meet the required safety factor. Using this geometry, geotechnical analyses will be performed to ensure global stability of the overall slope during final design and to evaluate if expected settlement is within acceptable serviceability limits. In the case of flexible retaining walls, a p-y spring type analysis will be conducted to evaluate expected deflections and to develop an economical design of the wall elements.

Where there are adjacent structures, WBG will use specific deflection criteria. Otherwise, movements will be limited to superficial damage according to FHWA guidelines, as required per Technical Provisions Section 15.1.3.1.

Where possible, an anchored wall system will be used, which provides better deflection control than cantilever walls. For soldier pile and lagging walls, which tend to have higher deflections due to the possibility of soil loss, WBG will include provisions for backpacking the lagging. Louvers, hay placement, or cement-mixed packing soil can be included as conditions dictate.

Drainage and Waterproofing System

WBG designed all retaining wall systems to prevent pore pressure build-up behind the wall and to allow water to flow to a drainage system on the excavated side of the wall. See Figure 4.2-1 for a description of our proposed drainage and waterproofing systems.

Right-of-Way

All viaduct structures can be constructed within the right-of-way, including temporary easements provided through third party agreements, except for the replacement of the existing Lechmere viaduct sections which will require City of Cambridge and MassDOT cooperation on necessary lane closures to dismantle the old and erect the new viaduct to Lechmere Station. The viaduct erection across the train yard with the two-track restriction will be strategically challenging, but will be performed without adverse impact to rail traffic. All work involving abutters and third party agreement holders, such as the restrictive environs of the viaduct coming from Lechmere, will be closely coordinated with those parties so they will be aware of all temporary works to ensure all potential impacts to either party are mitigated through proper planning and scheduling.

Frost Heave

We will locate the base of all structures below the depth of frost penetration or remove susceptible materials to below the depth of frost penetration and replace them with non susceptible materials to mitigate frost heave. WBG will never commence construction of works upon frozen subgrades.

Structural Drawings

Structural drawings are provided at the end of Section 4.2.

B. BRIDGE AND UNDERPASS STRUCTURES

General Approach to Meeting Requirements

WBG’s general approach to bridge and underpass design and construction focuses on innovative approaches that will mitigate the impact to the community using surface road pedestrian, bicycling and vehicular travel paths, while producing sensitive, accommodating, and durable final connectivity features to the GLX system expansion. We will comply with Volume 2 Technical Provisions, Sections 8.0 and 15.0, as modified by approved ATCs.

Through our design efforts thus far, WBG has eliminated the need for an underpass at Walnut Street by designing a retaining wall system that will allow the Community Path to rise to street level at this intersection. At Broadway, our full-height drilled shaft,

concrete-faced abutment wall will minimize the time necessary to construct the new bridge while reducing work at track level. These design improvements shorten the overall construction impact to the local community while providing a cleaner, aesthetically pleasing end user product.

Coordinating with the Cities of Somerville and Medford for the necessary traffic detours, lane closures, and intersection improvements is paramount to our work on these structures. WBG has already designated the sequencing and priority of these works in our design deliverables and construction schedule to fully comply with the essential contract requirements, ensuring that adjacent bridges are not simultaneously closed. We intend to maximize the construction operations performed at, under, and near the bridge/underpass work zones, so that minimal construction operations linger behind the major work components, allowing full return of areas to everyday community use.

Figure 4.2-1 Drainage and waterproofing systems, application, and benefit.

TYPE	THE WBG APPLICATION	BENEFIT TO THE PROJECT
Retaining Wall Systems	<ul style="list-style-type: none"> » Design to allow water to flow to a drainage system on the wall’s excavated side » Avoid uncertainties of long-term performance by limiting design of seepage cutoffs 	<ul style="list-style-type: none"> + Prevents build-up of pore pressures behind the wall + Ensures long-term performance
Permanent Drainage Systems	<ul style="list-style-type: none"> » Use drainage fabric or free draining aggregate on the back face of the permanent wall » Use drainage fabric that is either nonwoven fabric when in contact with soil or drainage board when finer materials are likely within the existing embankment being closed » Use pea gravel for free drainage aggregate 	<ul style="list-style-type: none"> + Prevents build-up of pore pressures behind the wall + Ensures long-term performance
Bottom-Up Constructed Walls <i>(cast-in-place, precast block types, mechanically stabilized earth, etc.)</i>	<ul style="list-style-type: none"> » Use drainage fabric in conjunction with free draining aggregate for the construction sequence 	<ul style="list-style-type: none"> + Allows the aggregate to be installed with backfill lifts + Prevents build-up of pore pressures behind the wall + Ensures long-term performance
Top-Down Constructed Walls <i>(soldier pile and lagging, soil nail, secant pile, etc.)</i>	<ul style="list-style-type: none"> » Use pervious wall systems and non-woven textiles 	<ul style="list-style-type: none"> + Eliminates deformations behind the wall caused by installation of free draining aggregates between the wall elements and the retained soil + Eliminates impacts to the construction sequence
Continuous Drilled Shaft Walls <i>(secant pile, tangent pile)</i>	<ul style="list-style-type: none"> » Incorporate drain hole features through the concrete elements » Cover the face of the wall with drainage fabric behind the permanent facing » For secant pile walls, incorporate shorter length unreinforced elements (where structural requirements allow) that extend slightly below the bottom of the excavation 	<ul style="list-style-type: none"> + Directs underseepage to the drainage system + Prevents build-up of pore pressures behind the wall + Ensures long-term performance

Figure 4.2-2 Lechmere Viaduct. A section of the historic Lechmere Viaduct will be salvaged and restored to retain a direct link to the past.



The renderings in [Figure 4.2-2](#) and [Figure 4.2-3](#) are representative views of new viaducts. At Lechmere, a section of the historic viaduct will be retained to provide continuity with the past. The section to be retained will be protected, stored, refurbished, and re-used so that it seamlessly fits with the final built condition.

The rendering in [Figure 4.2-3](#) shows one of the elevated guideways in the foreground and the Vehicle Maintenance Facility (VMF) yard in the background. The three yard leads will provide connections to the Green Line branches, and the VMB in the background will be the focal point of the new site.

ATC 5 replaces portions of the overhead viaducts with at-grade guideway. The revised guideway will be constructed on a subgrade consisting of EPS blocks wrapped in gasoline-resistant geomembrane, within cast-in-place concrete walls. The EPS blocks will bear on a 6-inch sand leveling layer and will be covered with 3 feet of ballast and an 8-inch concrete distribution slab. This ATC eliminates foundations and reduces overall construction impacts at affected locations.

Modifying Bridges & Constructing Underpasses

WBG's design ensures that necessary geotechnical information is accumulated, reviewed, and applied to the final design elements for the work. Once designs are prepared in full accord with the design requirements of Volume 2, Section 8 and submitted for approval, our engineers will be ready for "face-to-face" comment review sessions that will include over-the shoulder reviews with MBTA and MassDOT staff to expedite the approval process. ATC 2 eliminates one pedestrian overpass to bring the Walnut Street Community Path from track level to street grade. In the field, WBG will follow strict guidelines, as outlined in Volume 2, Section 15 of the Technical Provisions, establishing geotechnical monitoring protocols and Section 6 requirements for pre-construction surveys. Additionally, all bridge area work will be planned with stakeholder input and performed accordingly so that adverse effects to street level circulation and revenue train service are minimized.

Proposed Track Structure/Rail Fastening Systems

All proposed track work within the limits of new underpass structures at Medford and School Streets will be constructed independently as

Figure 4.2-3 Viaduct over yard. View of the Union Square westbound elevated guideway (viaduct), VMF yard, and Vehicle Maintenance Building.



a standard wood tie and ballasted track type system conforming to MBTA standards and relevant GLX technical provisions. The continuity provided by a standard ballasted track and resilient fastener system throughout an underpass structure allows for unobstructed ground level, non-specialized maintenance activities of all support systems including track, catenary, signal, and communications lines. Additionally, the track's thermal expansion capability, attained through proper rail distressing, allows the track to move throughout typical day-night and seasonal thermal cycles without the risk of heat-induced rail kinking or cold weather related rail breaks or pull-aparts. While the new underpass structures will typically be constructed with a concrete floor below the frost line, the ballasted track system does not fasten to the structure, and is the right choice to ensure that any expansion is controlled and that the MBTA receives a safe, regulatory compliant rail system.

Waterproofing System Approach

The proposed bridge deck waterproofing system will conform to the current MassDOT Specification Section 965 Special Provision for Membrane Waterproofing (Spray Applied). The system will

be as currently approved by MassDOT and applied by qualified/certified personnel. The spray applied membrane waterproofing for the viaduct bridge decks will be a similar system and conform to MBTA Specifications and approvals.

The work associated with the underpass construction will provide some of the most challenging locations for membrane waterproofing systems. As such, to ensure the highest quality installation, WBG will be using an integrated membrane system that includes pre-applied applications, where the membrane is placed on substrate and then the concrete slab or wall is poured against it. This method will be used for base slabs and existing abutments or drilled shaft walls where concrete facing will be placed as the finished wall of the underpass. Accessible areas, such as underpass roofs, will have the membrane applied post-concrete placement and be properly overlapped and joined to the wall membranes.

At the Washington Street bridge, a ballasted deck structure, spray-applied continuous membrane waterproofing will be applied to provide an impenetrable barrier to water ([Figure 4.2-4](#)).

Site-Specific Approach to Meeting Requirements

In this section, we describe the overall design and construction approach for bridges along the right-of-way. The descriptions for Walnut Street bridge and College Avenue bridge can be found on [page 4-28](#).

Washington Street Bridge

The existing rail bridge over Washington Street consists of four three-span steel through-girder superstructure units with ballasted track. The proposed replacement bridge consists of a single span at 110 feet, supported by drilled shafts with concrete caps at the abutments. The existing granite abutment top courses will be removed, with the lower portions remaining in place to act as abutment retaining walls. The proposed superstructure units are composed of steel through-girders, with steel plates supporting track ballast.

The proposed superstructure also supports the Community Path at the track level. U-back wingwalls are proposed, with the southwest

Figure 4.2-4 Bridge deck waterproofing. Waterproofing application on Barletta's Neponset River Bridge Replacement project for the MBTA.



Figure 4.2-5 Soil nail walls. Soil nail walls at Jacobs' Winter Street project are similar to those that will be used at the Lowell Street Bridge.



wingwall also supporting a cantilevered slab for the Community Path. The steel superstructure through-girders have already been fabricated, and are stockpiled nearby for assembly and erection.

Proposed staging takes advantage of existing bridge structures for temporarily shifting train traffic during demolition and construction of the proposed bridges. The design team performed an initial evaluation to determine that the existing structure is suitable for use in this way.

In addition to reducing construction work along the guideway, using full-height drilled shafts as the bridge pier supports minimizes the amount of temporary support of excavation and the corresponding duration of work and impacts to the Washington Street roadway and pedestrian paths in this area.

Medford Street Bridge

At the Medford Street bridge, an underpass behind the existing southern abutment must be constructed to accommodate the inbound trackway of the GLX and the Community Path.

WBG will commence the construction of the underpass with the installation of drilled shafts south of the existing bridge that will serve as earth retention and as the southern wall of the underpass. Simultaneously, work will be performed on modifying the supports of the existing utility bridge onto the Medford bridge, so that excavation for the underpass can commence.

The road will be closed during underpass construction. Once the excavation is completed behind the existing southern abutment, shear dowels and micropiles will be installed and a full-width floor slab will be placed, essentially bridging from the new, drilled shaft wall to the existing abutment. WBG will construct a CIP facing wall at the drilled shafts and a structural support wall at the existing abutment, followed by the CIP underpass roof. Throughout the concrete construction, we will take care to encapsulate the underpass CIP structure with a uniform waterproofing system that will ensure the integrity of the completed structure.

To bring the excavation back to grade and restore the roadway, edge walls will be installed to provide retainage of the earth and paving, and to support the bridge railing.

School Street Bridge

WBG will implement our approved ATC 3 at School Street. With this method, we are constructing a single span that crosses all four tracks, rather than adding to the existing superstructure. The west bridge abutment will be removed, and a new west bridge abutment will be constructed, providing a longer bridge span of 93.7 feet, compared to the existing 73.5-foot bridge span. This will increase the bridge opening to accommodate the new track. The proposed bridge is composed of composite steel plate girders supporting sidewalks, parking, vehicular traffic, and relocated utilities. The proposed west abutment will be a high cantilever type. The existing east abutment cap will be modified to support the new superstructure. The School Street railway crossing will be fully closed to vehicular traffic during construction and closed to rail traffic during key construction operations, such as girder erection.

The work at the School Street and Medford Street bridges will be sequential to avoid closing adjacent surface routes, and to mitigate vehicle and pedestrian access impacts to the community. Similar to the work at Medford Street, the southern retaining wall for the underpass will be a drilled shaft, concrete-faced wall. Construction will begin with the installation of the new southern retaining wall concurrent with the construction of a temporary support beneath the School Street bridge. This will allow removal and replacement of the existing southern abutment. Work will then continue with removing the existing south abutment and excavating the earth behind it. Concurrent with the CIP facing of the drilled shaft retaining wall, a new pier and spread footing will be constructed to replace the south abutment. A reinforced concrete base slab and roof will complete the underpass.

Cedar Street Bridge

To support the embankment and adjacent property at this location during demolition of the existing southeast wingwall, WBG will install a new cantilevered pile retaining wall with a setback to provide sufficient clearance for the new GLX trackway. Additionally, since the Cedar Street bridge's existing south abutment wall is close to the rail track, a refuge niche will be cut into the wall to provide the necessary safe haven for track walkers to safely conduct their work activities.

Lowell Street Bridge

Beneath the Lowell Street bridge, the previous bridge's granite block wall remains that served as the south abutment. The current bridge is supported on the south side by a drilled shaft abutment that is located to the south of the granite wall. As part of the widening of the right-of-way to accommodate the GLX track alignment, the old granite abutment will be removed in a top down fashion, with excavation and the installation of soil nails to reinforce the drilled shaft abutment proceeding in lifts until final grade is reached ([Figure 4.2-5](#)).

Upon completion of the work to prescribed subgrade, WBG will install a reinforced concrete facing wall at the soil nail-reinforced, drilled shaft abutment. Similarly, the existing wingwalls will be removed and replaced with new soil nail wingwalls with permanent concrete facing.

Broadway Bridge

The existing Broadway bridge is a single span bridge that can only accommodate the existing NHML alignment. To improve the drainage system and allow the addition of the GLX tracks and at-grade Community Path, the bridge must be removed, including currently buried granite abutments from the previous bridge at this location. The new bridge will be a two-span bridge with an overall span of 150 feet and a width of 53 feet. The single bridge pier will be located between the GLX east and westbound tracks.

To minimize the overall construction timeframe and impact to ongoing commuter rail operations, WBG will use full-height drilled shafts for both abutments on this bridge. Upon completion of the installation of the drilled shafts, WBG will demolish the existing Broadway bridge and the buried previous bridge structures in their entirety, with special care taken to ensure that the medical building foundation wall is not impacted (currently a portion of the northeast wingwall is connected to this building).

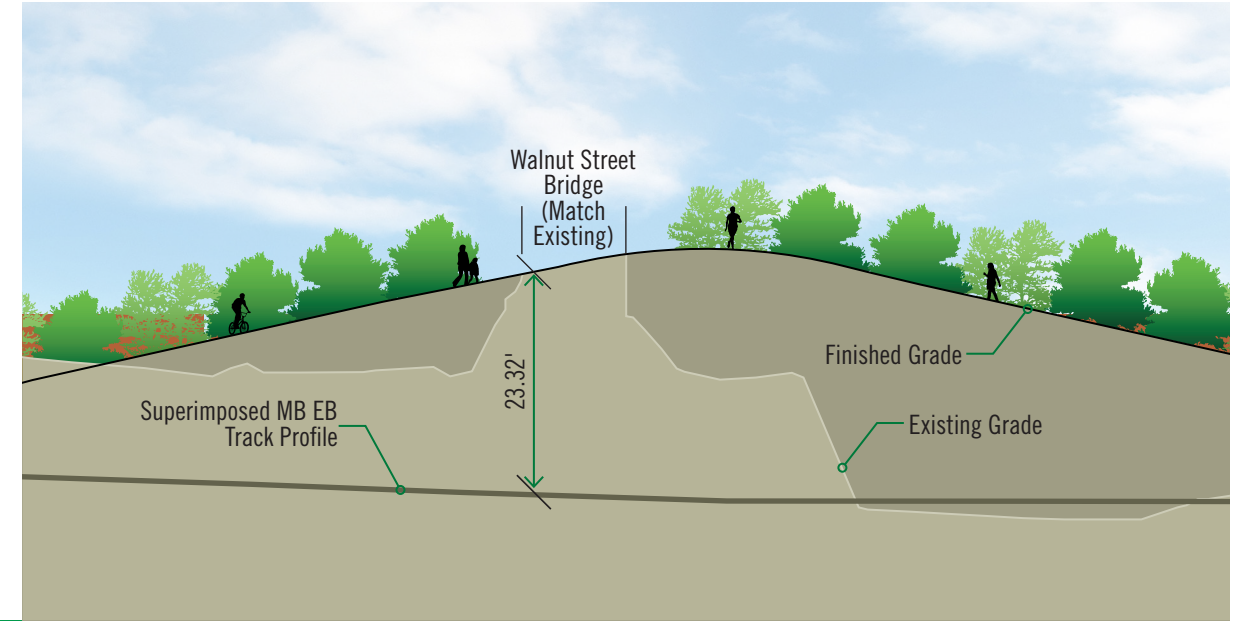
Once demolition is complete, WBG will shift the existing commuter rail away from the northern abutment to allow the deep drainage installation. All adjacent retaining and noise wall foundations will then be completed, allowing the commuter rail to be repositioned to its final alignment in this area. Work on the southern abutment and center pier will follow, with the erection of the superstructure occurring once all substructure work is complete.

Walnut Street Bridge

Through ATC 2, WBG eliminated the need for a pedestrian underpass at Walnut Street through the incorporation of additional sections of retaining wall that will allow the community path to come to street level at Walnut Street along with minor track realignment beneath the existing bridge.

This design revision will eliminate the need to close Walnut Street Bridge for the work associated with the underpass construction and will also eliminate the need to disrupt the major water supply through a 48-inch MWRA water main at this location.

To install the revised retaining wall system, WBG will use temporary earthen ramps within the ROW to create work platforms for the drilling rigs to access the designed top of shaft elevation during installation operations.

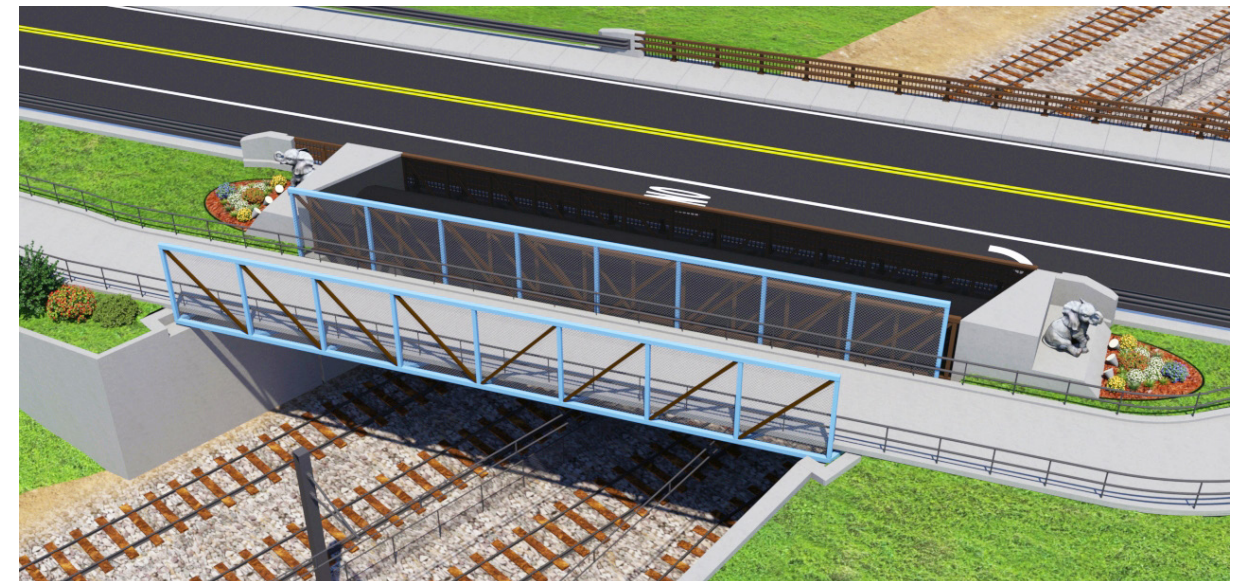


Proposed Walnut Street Bridge. WBG's ATC 2 eliminates the pedestrian underpass, improving track sight lines and increasing pedestrian safety.

College Avenue Bridge

The work at the College Avenue bridge consists of two separate and distinct work elements, the first is a new pedestrian bridge located west of the existing MWRA utility bridge and the second is the creation of a traffic turning lane on the west side of the bridge in the area currently occupied by a raised sidewalk.

WBG will be working on the major retaining walls north of the College Avenue bridge, on both sides of the alignment, during the early phases of our work on the Project. Once the major work on the Boston Avenue side is completed, which consists of the installation of a substantial soil nail, shotcrete, and formed face concrete retaining wall, we will commence work in earnest on the College Avenue Pedestrian bridge. First, WBG will trim the MWRA utility bridge wingwalls, and then perform the necessary SOE to allow the construction of the CIP spread footing and abutment walls. The planned pedestrian bridge is a prefabricated truss bridge, which will be set in place as a single piece.



Proposed College Avenue Pedestrian Bridge. The above graphics show one possible prefabricated truss suitable for this location.

The turning lane work on the existing bridge consists of sidewalk removal, bridge deck reconstruction, and perimeter railing curbing and reinstallation. WBG intends to perform this work after the pedestrian bridge is fully operational and all the traffic signal revisions are in place at the College Avenue/Boston Avenue intersection.

Bridge Drawings

Drawings are located at the end of [Section 4.2](#).

WBG BENEFIT HIGHLIGHTS FOR STRUCTURES ALONG THE GUIDEWAY

+ Benefits of WBG's overall design and construction approach for bridges along the right-of-way including the Walnut Street and College Avenue bridges, include:



Pedestrian Safety. WBG ensures local pedestrians will experience an environment that enhances safety.



Access. WBG improves access to the Community Path by allowing the path to rise to street level.



Track Sight Lines. WBG improves track sight lines through minor track realignment.



Long-Term Maintenance. WBG's structures approach reduces long-term bridge maintenance.

C. GEOTECHNICAL ENGINEERING

The geotechnical engineering for the Project includes subsurface investigations and interpretations, geotechnical analyses, and preparation of design and construction recommendations for the foundation design of train stations, Transportation Building, Vehicle Maintenance Building (VMB), traction power substations, bridges, viaducts, retaining walls, slopes, embankments, and other minor structures (i.e., catenary poles). The geotechnical design and recommendations will also include support of excavations and groundwater control during construction.

Geotechnical Conditions, Constraints, Concerns, and Issues

The borings have identified the following subsurface strata: existing fill, organic soils, fine-grained soils, granular soils, and weathered bedrock. Bedrock is the only layer present at all locations. The depth of the existing fill varies across the project site and is more than 20 feet thick at some proposed structure locations. The existing fill is generally considered unsuitable as foundation bearing material for spread footings. It typically requires undercut and replacement by structural fill beneath the footings.

The organic soils are generally very soft with typical depths 10 to 20 feet below grade. The organic soils generally need to be removed and replaced below proposed spread footings. Most ground improvement techniques such as stone columns do not work well with soft organics; in such cases deep foundations may be required. The fine-grained soils consist of very soft to stiff silt and clay. For a shallow foundation option, the settlement estimate in the fine-grained soils is critical as the serviceability is likely to control the foundation design. Most granular soils encountered are medium dense to very dense in nature and are generally considered suitable materials for foundation bearing, especially the dense glacial tills. The bedrock generally consists of gray, weak to strong, severely to slightly weathered, extremely fractured to sound, fine-grained Argillite. Very shallow weathered bedrock was encountered near College Avenue. Some of the excavations may involve hard rock excavations that require robust excavation techniques such as rock rippers or splitters.

The groundwater condition varies across the project locations, but shallow groundwater table (average 5 feet below grade) is typical. Many soils or groundwater at the project site may be

contaminated with oil and/or hazardous materials. Therefore, the construction activities (earthwork, dewatering, etc.) will follow the oil and/or hazardous materials work plan. In addition, corrosivity tests indicated that many soils have a high corrosion potential. As a result, appropriate corrosion measures are needed to protect the buried concrete and steel structures including any tie-back systems. This is described in further detail in Section 4.1. Most of the construction will occur in urban areas with existing structures and utilities nearby.

Heavy construction equipment may create construction noise and vibrations. Among them, pile driving may create the most noise and ground vibrations. Therefore, a construction noise and vibration control plan is needed to minimize construction impacts.

A geotechnical instrumentation and monitoring plan is needed to monitor ground vibrations and deformation levels at adjacent structure and utility locations. Due to the space limitations such as right-of-way requirements, some of the earthwork may require temporary excavation support that may also need instrumentation/monitoring during excavations. In addition to the existing structures and utilities, future construction may also affect the stability of adjacent slopes. For instance, surface sloughing has occurred at slopes above the existing crib walls between Sycamore and Central Streets. The instrumentation and monitoring plan needs to address such areas with slope instability concerns.

Geotechnical and Hydrogeological Conditions used in Design Development

Numerous borings have been drilled along the proposed Medford and Union Square corridors and were used to summarize the overall geotechnical conditions in the following text.

Fill: Fill is present in most boring locations, primarily as a result of previous grading activities. The thickness varies from 0 to 30 feet at some locations. The fill consists mainly of granular materials such as sand and gravel; cobbles and boulders were noted at a few locations. Most fill areas were likely placed in an uncontrolled manner; SPT blow counts vary and indicate very loose to very dense consistency. Due to this irregularity, we do not recommend placing spread footings directly on the fill, but instead on newly installed select, compacted material after fill removal.

Organic Silt/Clay: Organic materials appear in the area along the Union Square Branch and south of Cross Street on the Medford Branch. Typically, it is 2 to 3 feet in thickness, but up to 10 feet in some locations. Typical depth is between 10 to 20 feet below grade. Due to the unsuitable nature of the material, very soft (weight-of-hammer) material will be removed and replaced below new footings or deep foundations will be used.

Silt/Clay: This cohesive layer appears to be continuous along the Union Square Branch with a typical thickness of 30 feet below the organics. The thickness tapers from 30 feet at Lechmere Station to 5 feet at Washington Street. Further north of Washington Street, this layer is only encountered in some locations. The N-value varies from weight-of-hammer to over 20. Generally, the soils are softer towards the south and stiffer further north along the corridor. For a spread footing option, the settlement evaluation of the clay layer is important. In some locations the clay/silt may need to be undercut, depending on depth, thickness, and preconsolidation stress.

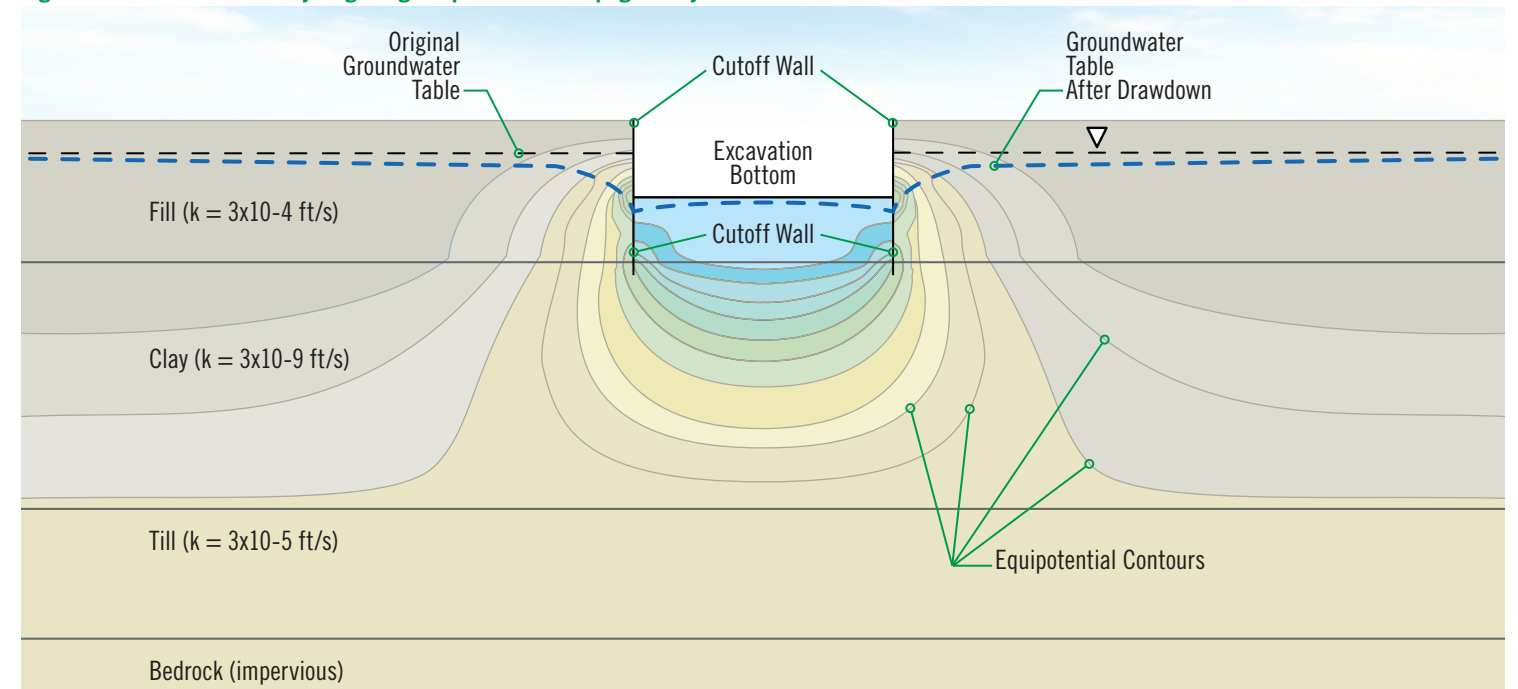
Glacial Till/Sand: This layer is ordinarily located between bedrock and overlying soils and consists of dense to very dense sand and gravel. The depth is typically shallow toward the north and deeper toward the south. The depth of till is about 40 feet at Lechmere and Union Square Stations, and as shallow as 1-foot below grade at College Avenue. Thickness is between 10 to 20 feet, but may vary at different

locations. Natural sand is encountered at some locations above the till or even above the silt/clay layer, and is typically medium dense to dense in consistency. This layer is generally competent as bearing materials for shallow foundations, or glacial till may be used as end bearing materials for deep foundations.

Weathered Bedrock: Below the glacial deposits, the bedrock consists of slightly to highly weathered Argillite with typical rock-quality designation ranging from 0 to 90%. The surface level of the rock varies significantly; generally deeper toward the south and shallower toward the north. The rock surface is about 80 to 100 feet below grade at Lechmere, 60 to 80 feet at Union Square Station, 20 to 40 feet at Gilman and 3 to 19 feet at College Avenue. The bedrock can be used for either shallow or deep foundation bearing materials. If the load demand is high, a rock socket may be used to increase foundation capacity.

The hydrogeological conditions also vary along the corridors, and the groundwater table is typically shallow with an average depth about 5 feet below grade. We will review the previously developed geotechnical and hydrogeological profiles at all major structure locations and develop site-specific recommendations for each structure based on our interpretation of the subsurface conditions. Figure 4.2-6 shows an example of a hydrogeological profile for a typical support of excavation. The soils are divided into layers with

Figure 4.2-6 Illustration of hydrogeological profile and seepage analysis.



assigned hydraulic conductivities. The initial groundwater table is based on the specific hydrogeological conditions encountered near the excavation. Such hydrogeological profiles are then used to design the groundwater control measures, such as cutoff walls, and well points and compute the groundwater inflows.

Soils at the VMF consist of medium dense existing fill over soft to stiff clay underlain by dense glacial till and weathered bedrock. We propose driven piles instead of drilled shafts to eliminate collection and disposal of contaminated soils. Groups of 10-inch square prestressed precast concrete piles are anticipated to provide the capacity required to support the building columns. Concrete piles are generally preferred over steel piles in a corrosive soil condition such as those encountered at the site. Based on the available borings, the dense glacial till is about 30 to 35 feet below grade, at which depth the piles are expected to terminate. If later the additional proposed soil borings at the site suggest the dense glacial till or bedrock depth is shallow, we will consider other alternatives such as micropiles, which could be drilled into the glacial till and bedrock to develop the required capacity.

The viaduct structures typically have high load demands in vertical and horizontal directions. As a result, drilled shafts are usually the preferred foundation type to limit the overall foundation footprint. We have proposed drilled shafts socketed into bedrock to support the viaducts. At Lechmere Branch, many shafts are 100 feet deep due to the relatively deep bedrock. Once we have a better understanding of the structural loads during the final design phase, we will explore other deep foundation options such as driven piles.

The existing three-span Washington Street bridge will be replaced with a single span bridge. With the significant load demand, we propose 7-foot-diameter drilled shafts with 6.5-foot-diameter, 15-foot-long rock sockets to support both abutments. For the bridges at Broadway and Medford Street, the abutments will be supported by 3.5-foot-diameter drilled shafts with 3-foot-diameter, 10-foot-long rock sockets. The bedrock surface is typically about 30 to 40 feet below grade at these bridge locations, based on the boring logs. At the Medford Street bridge, the spread footing of the existing south abutment will be enlarged and strengthened with micropiles. This is due to the additional loads of the new span to accommodate the underpass behind the bridge. The micropile is

anticipated to be 9.625 inches in diameter with 8.5-inch-diameter, 10-foot-long rock sockets.

Based on the anticipated loads and encountered soil conditions, spread footings are proposed at all stations except at Lechmere Station, which is to be elevated on the viaduct. The soils at Lechmere Station consist of medium dense existing fill over very soft organic soils and soft to stiff clays underlain by dense glacial till and weathered bedrock. We proposed 12-inch-diameter steel pipe piles at this preliminary design stage. Anticipated pile lengths range between approximately 80 to 115 feet at the north headhouse and between approximately 45 to 60 feet at the south headhouse. We anticipate the piles will stop in the very dense glacial tills or at the weathered bedrock. We will perform a pile drivability study at the final design phase, particularly when penetrating a thick glacial deposit. We will also explore other deep foundation options such as precast concrete piles.

Geotechnical and Hydrogeological Design Properties

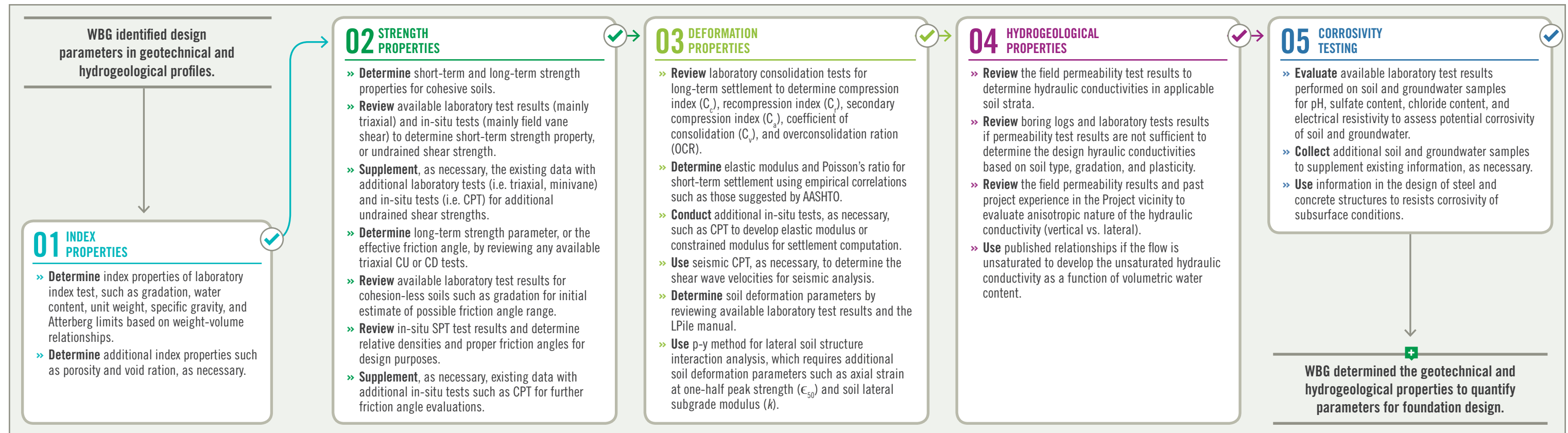
After identifying the necessary design parameters in the geotechnical and hydrogeological profiles, WBG will quantify those parameters for foundation design. We will use existing and future subsurface exploration data to determine the geotechnical and hydrogeological properties shown in Figure 4.2-7.

In addition to these design parameters, we will determine other soil properties as needed for particular design cases. Those parameters may include in-situ lateral stress ratio, soil sensitivities, residual friction angle, etc. For rock properties, laboratory test results on rock cores will be used to determine the index, strength, and deformation properties.

Additional Geotechnical Investigations, Testing, and Analysis

Numerous soil borings for the proposed structures have been drilled at the project site. However, project scope has been modified since the subsurface explorations and some changes, such as structure location, and size have been made to the proposed

Figure 4.2-7 Steps to develop geotechnical and hydrological design properties and parameters.



structures. We will review the completeness of the existing boring data against the proposed structure locations and possible foundation types. The existing in-situ and laboratory test results do not address all necessary soil design parameters; we anticipate that approximately 50 additional are needed to sufficiently define the soil design parameters for relevant analyses during final design phase. Figure 4.2-8 describes the steps WBG will take to identify additional soil borings and tests at locations where subsurface conditions are missing or insufficient (i.e., boring depths not adequate).

Preliminary Hydrogeological Impact Assessment and Risk Assessment

Construction Period

Groundwater Control: The GLX Project footprint has a relatively high water table. In order to ensure a quality subgrade in our construction excavations, WBG will create a Groundwater Management Plan (GMP) to establish the criteria for our soil groundwater control systems. As part of our GMP, we will procure and follow the necessary discharge and disposal permits from local, state, and federal government entities.

We anticipate using a combination of sump pits, collector drains, wells, well points, flow control devices, pumps, and piping to control the water in our subsurface excavations. These excavations include substructure footings, storm sewer and drainage trenches, utility trenches, and drilled shafts. In order to meet water quality requirements prior to discharge, we expect to use settlement tanks that will separate solids and oil from the pumped inflow. The water in the tanks may be treated before discharge.

Our GMP will address our approach to the treatment and disposal of contaminated water. The Reference Information Documents for the RFP show potential for contaminated water near Tufts Street, Ball Square Station, Broadway, and Water Street. Other contaminated soil areas within the right-of-way of the project may also contain contaminated water. We anticipate testing the groundwater for contamination, and those liquids containing oil and hazardous materials will be containerized, hauled off by a licensed hazardous waste hauler, and properly disposed according to the requirements of the 2017 Remediation General Permit. In conjunction with our GMP, we will create a Health and Safety Plan that protects the workforce, the public, and the environment when handling and disposing the contaminated liquids.

Support of excavation will be used to protect railroads, structures, utilities, and other facilities where groundwater intrusion may affect slope stability, ground loss, or settlement. Sheet pile or soldier beam and lagging will be used for cutoff walls. In addition to supporting the existing facilities, these walls will help exclude groundwater from entering the excavation and minimize the exposure to migration and disposal of contaminated groundwater. We will minimize the size and duration of our excavations and grade the slopes around excavations to minimize the inflow of surface runoff.

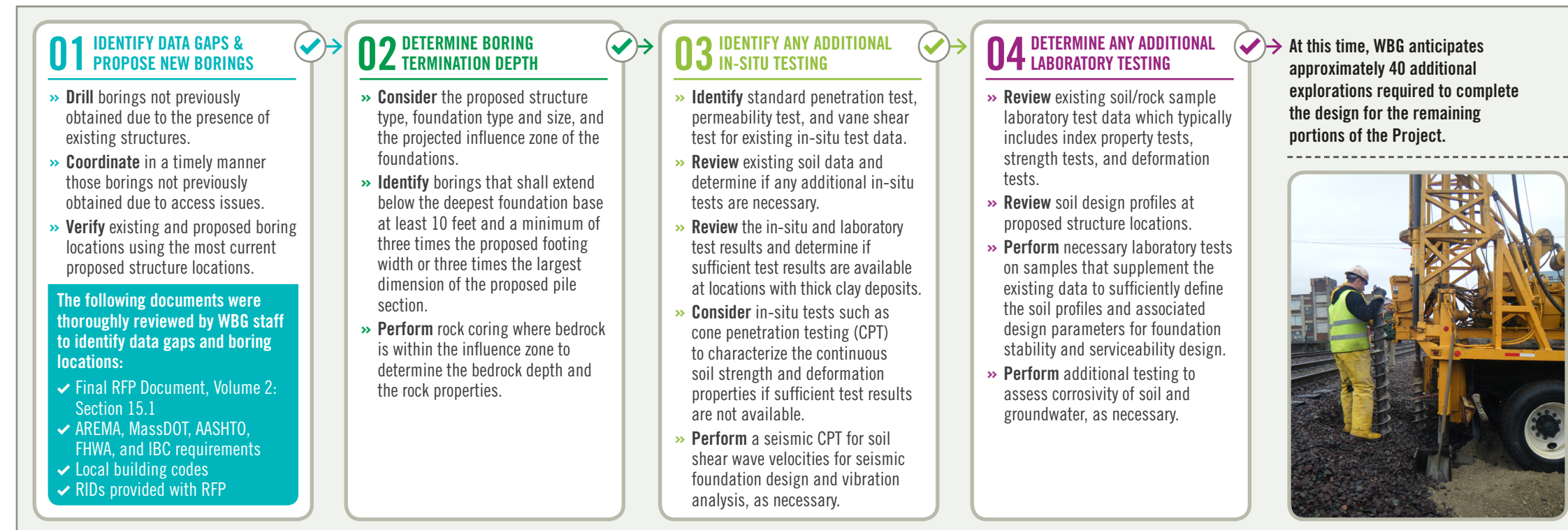
Groundwater Drawdown: The anticipated inflows depend on the geotechnical and hydrogeological profiles at the excavation locations, the hydraulic conductivities of the soils, the type of excavation support system used, and the groundwater conditions near the excavations. Given the subsurface conditions indicated in the borings, the majority of the site consists of granular materials such that the inflow will not be negligible. The flow rate and quantities of the inflow will be analyzed by performing 2D seepage analysis (i.e., axisymmetric) with appropriate hydraulic boundary conditions. Most excavations will require essentially “dry” working conditions for construction purposes. As a result, dewatering design usually coupled with cutoff walls is required to lower the groundwater table to about 2 to 3 feet below the excavation bottom.

We will evaluate the dewatering drawdown effect at the boundary conditions in seepage analysis. Since the subsurface strata may be complex, we will use finite element methods to define the geometries in terms of elements and nodal points. We will then use Darcy’s law to correlate the total head and flow rate on the geometric domain to calculate the flow paths, equipotential lines, and the inflow quantities.

Figure 4.2-6 shows an example of a seepage analysis at an excavation location, where a cutoff wall is assumed on the perimeter of the excavation extending into the clay layer. Groundwater control measures (e.g., dewatering wells inside the excavation support system) are assumed to be in operation continuously so that it represents a steady-state seepage condition. With appropriate boundary conditions, the seepage analysis will compute the anticipated inflows into the excavation to be pumped. The dewatering system will be designed based on the anticipated quantity of inflows using Dupuit-Thiem method.

We will design the dewatering system with minimal groundwater drawdown outside of the excavation zone. If our dewatering design identifies structures that will be located within the groundwater drawdown zone, we will perform a settlement assessment prior to actual dewatering operations. We will use conventional settlement analysis methods (i.e., consolidation theory) to estimate the settlement based on the anticipated groundwater drawdown.

Figure 4.2-8 Geotechnical investigation and analysis steps.



Permanent Condition

The groundwater control strategy will be based on either dewatering techniques or cutoff wall techniques, or a combination of both. When the excavation is to accommodate permanent structures, such as retaining walls or hoist pit, it is critical to design those structures with proper hydrogeological conditions. If the structure will be designed undrained, no groundwater control is to be provided. Correspondingly, the structure has to be designed to withstand the hydrostatic pressures, considering the possible groundwater fluctuations. The hydrostatic condition similar to pre-construction may be assumed and no groundwater inflow is anticipated in permanent condition. For instance, the hoist pit of the VMB may need to be designed for full buoyancy. The waterproofing system of the undrained structure will require a layer of waterproof materials to prevent water infiltration into the structure.

If the structure is to be designed drained, groundwater controls will be needed to satisfy the drained condition. The waterproofing system will consist of either a footing drain (such as a perforated pipe surrounded by gravel or crushed stone or a sump pump, or a combination of both. Due to the permanent design of the system, we anticipate the waterproofing system is in continuous operation. A similar seepage analysis as described for the construction period will be used to estimate the anticipated groundwater inflow: the footing drain or the sump pump will be converted to appropriate hydraulic boundary conditions, and thus a steady-state groundwater flow is expected to occur. Similar to the construction period discussion, we will evaluate the possible ground settlement due to groundwater drawdown and implement mitigation measures as necessary to minimize the drawdown effect outside of the project structures. Figure 4.2-9 shows an example of waterproofing design for a perimeter foundation wall with a groundwater drawdown in the structure vicinity.

Preliminary Geotechnical Impact Assessment and Risk Assessment

The proposed construction corridors are located in densely populated urban areas with numerous buildings, utilities, and infrastructure nearby. The proposed foundation installation activ-

ities and methodologies, such as footing excavations, temporary retaining structures, use of heavy equipment for pile driving, and drilled shaft installations, must be performed using methods that will limit impacts to those structures or utilities. WBG will conduct a pre-construction condition survey to identify possible structures within the zone of influence, to determine the nature (i.e., historic, sensitive, etc.) of the structure, and to document the existing condition of the structures. We will develop an instrumentation and monitoring plan, accompanied by working drawings, as illustrated in Figure 4.2-10 to monitor groundwater levels, vibrations, vertical settlement, and lateral movement of temporary support structures and adjacent ground, existing utilities and structures during construction.

Based on our current design approach, and assessment of existing subsurface conditions, we anticipate that lateral and vertical deformations of temporary and permanent earth support structures will generally be limited to approximately 1 to 2 inches, and 0.5 to 1 inches, respectively. Where construction is located in close proximity to existing structures, the excavation support system and instrumentation monitoring program will be designed to limit impacts to those structures, as described in Figure 4.2-10.

Figure 4.2-9 Illustration of permanent waterproofing at a drained structure.

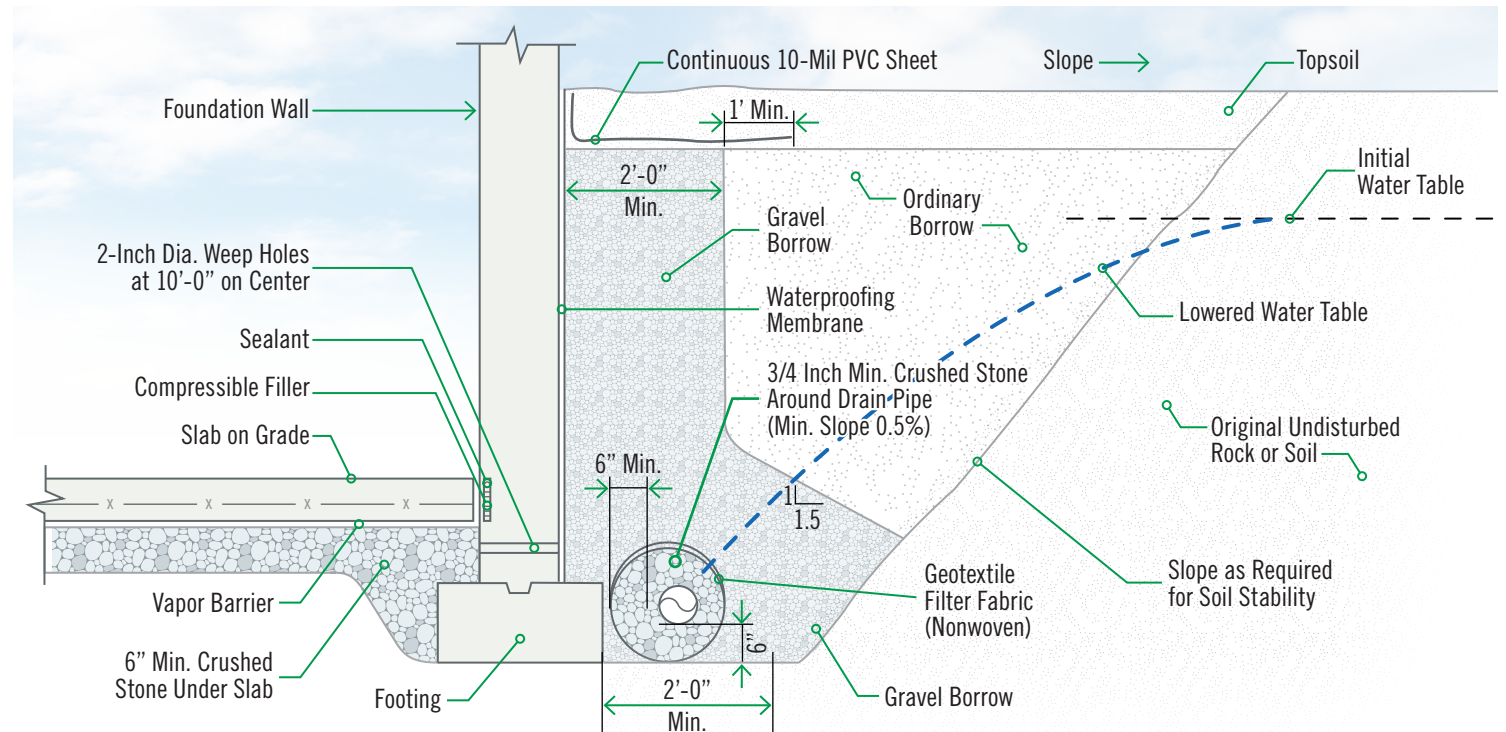


Figure 4.2-10 Preliminary geotechnical impact assessment and risk assessment plan.

01 MONITOR TEMPORARY SUPPORT STRUCTURES

- » **Instrument and monitor** to verify design assumptions and ensure work safety.
- » **Plan** locations of instrumentation around the perimeter of excavations so the overall change of pore pressures and configuration of support systems are monitored and recorded.
- » **Read** each instrument before and after each stage of construction and once daily, at minimum.

Instrumentations include:

- ✓ Observation wells and/or vibrating wire piezometers: *power water pressures*
- ✓ Inclometers: *lateral wall deflection and tilting*
- ✓ Deformation monitor points (DMPs): *lateral/vertical movements*

02 MONITOR ADJACENT GROUND, UTILITIES, AND STRUCTURES

- » **Perform** site inspection, at least once per month prior to construction, to identify all ground/utilities/structures in the construction zone to be monitored.
- » **Document** the initial conditions and determine the nature of all adjacent structures within the zone influence.
- » **Plan and install** instrumentation on adjacent ground/utilities/structures within the influence zone.
- » **Read** each instrument, at minimum, once daily if construction is within 140 feet of structure.
- » **Conduct** inspections during construction to identify any visual adverse effects, particularly on vibration-sensitive structures.
- » **Perform** final post-construction inspection of structure/utility conditions and document any differences.
- » **Abandon** instrumentation in accordance with standard procedures.

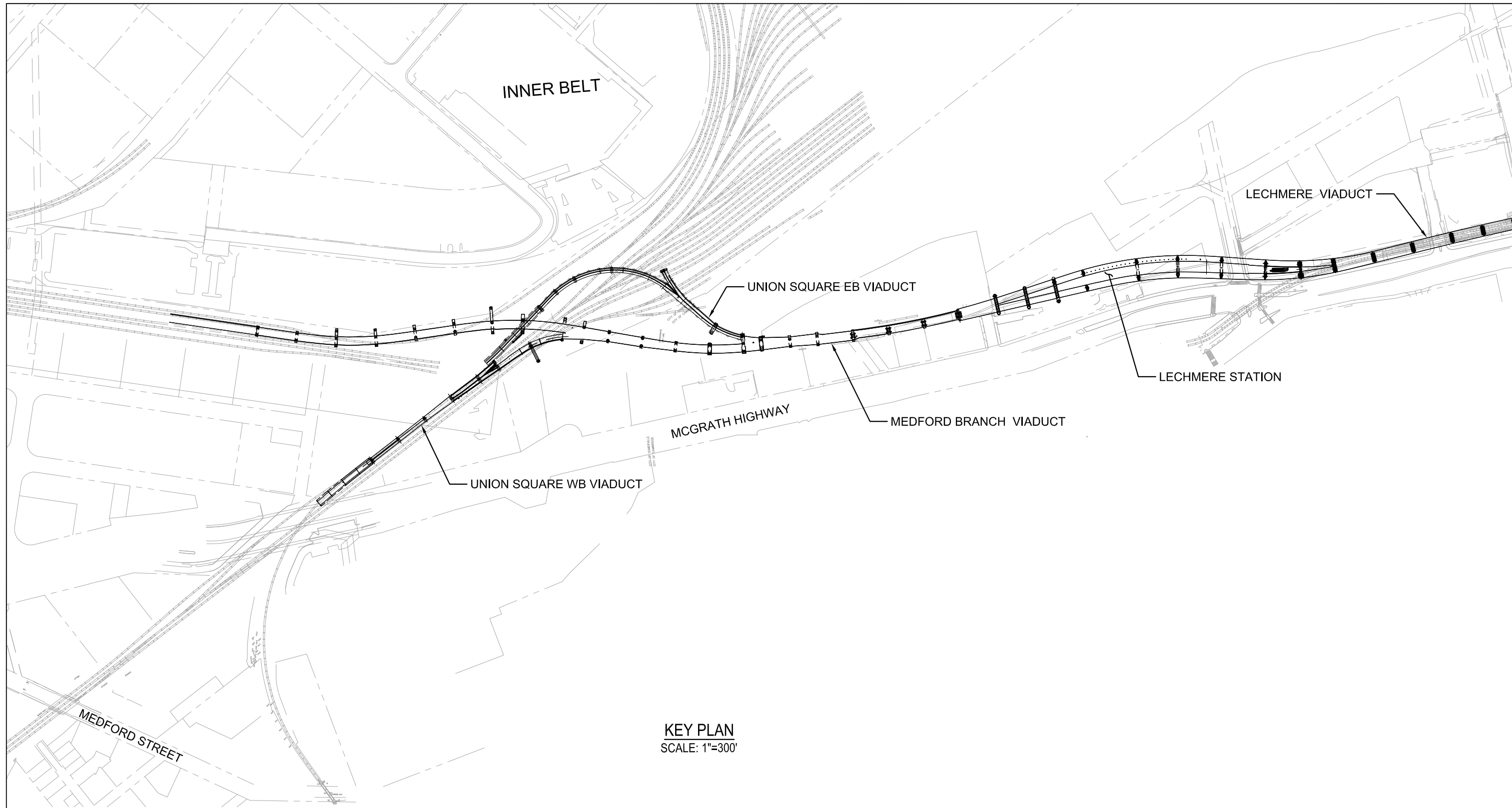
Instrumentations include:

- ✓ DMPs: *vertical/lateral movements*
- ✓ Utility monitoring points: *utility movement*
- ✓ Tiltmeters: *tilting of structures*
- ✓ Inclometers: *lateral wall deflection and tilting*
- ✓ Multi-point probe extensometers: *vertical ground deformations*
- ✓ Piezometers and observation wells: *ground-water levels*
- ✓ Seismographs: *ground vibrations and noise levels*

03 MITIGATION PLAN

- » **Establish** a threshold value and limiting value for each instrument monitoring type depending on the structure/utility type, sensitivity to movement, applicable industrial guidance, and the owner's input.
- » **Develop** a Response Action Plan that anticipates actions to implement on measured deformation/vibration levels.
- » **Execute** the actions defined in the Response Action Plan, upon reaching measurements, to ensure limiting values are not met.
- » **Evaluate** construction methods immediately if threshold values are apparent.
- » **Change** construction method to manage and avoid adverse effects on adjacent structures/utilities.
- » **Stop** work assumed to be contributing to excessive vibration/deformation in the area of concern if the measurement equals or exceeds limiting values.
- » **Implement** mitigation actions to investigate and correct damage to adjacent structures/utilities (may include temporarily restoring site conditions such as excavation backfill for ground stabilization.)
- » **Resume** work only after identifying operations that created or substantially contributed to excessive deformation/vibration values and we have revised or managed the construction method or equipment.

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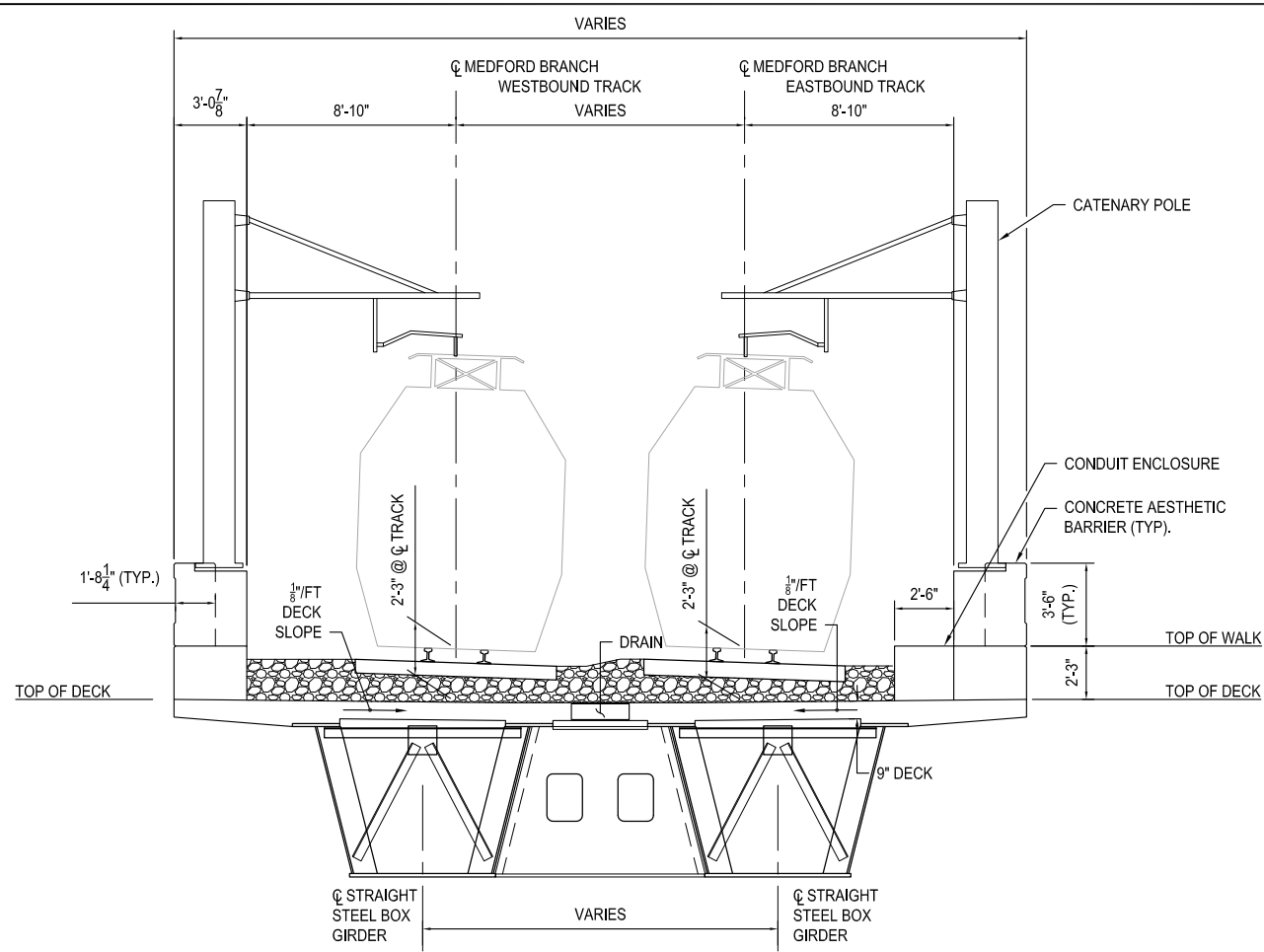
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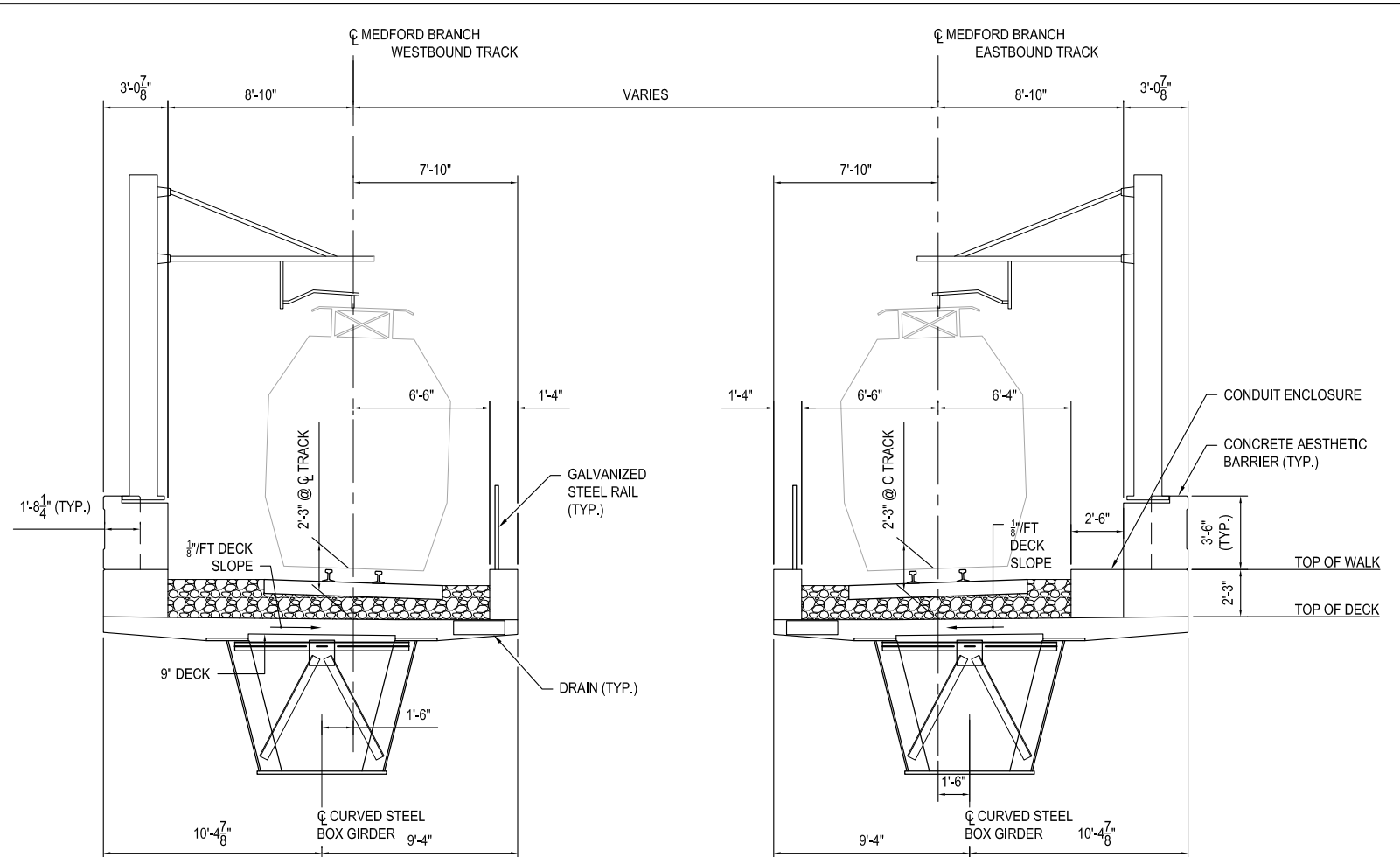
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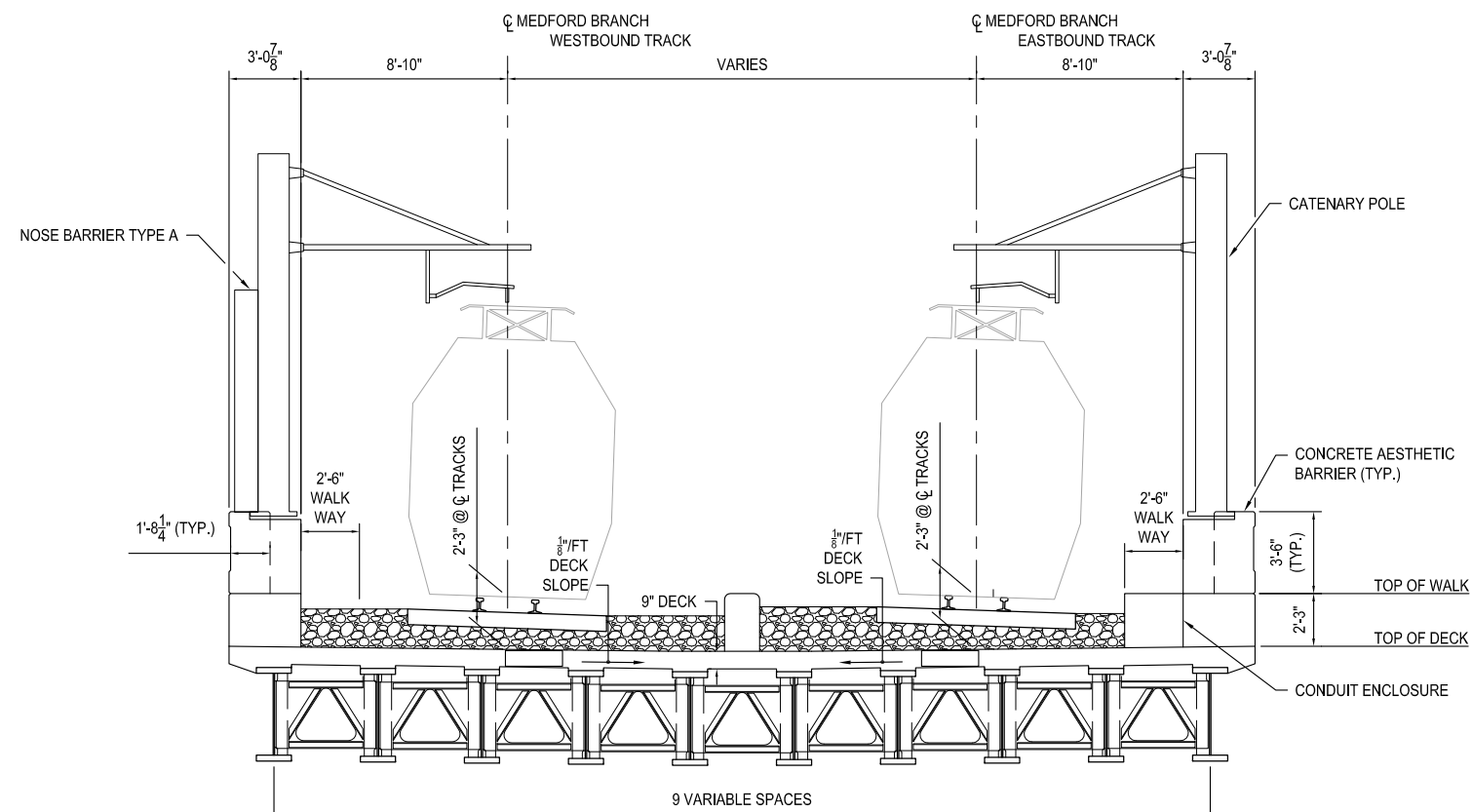
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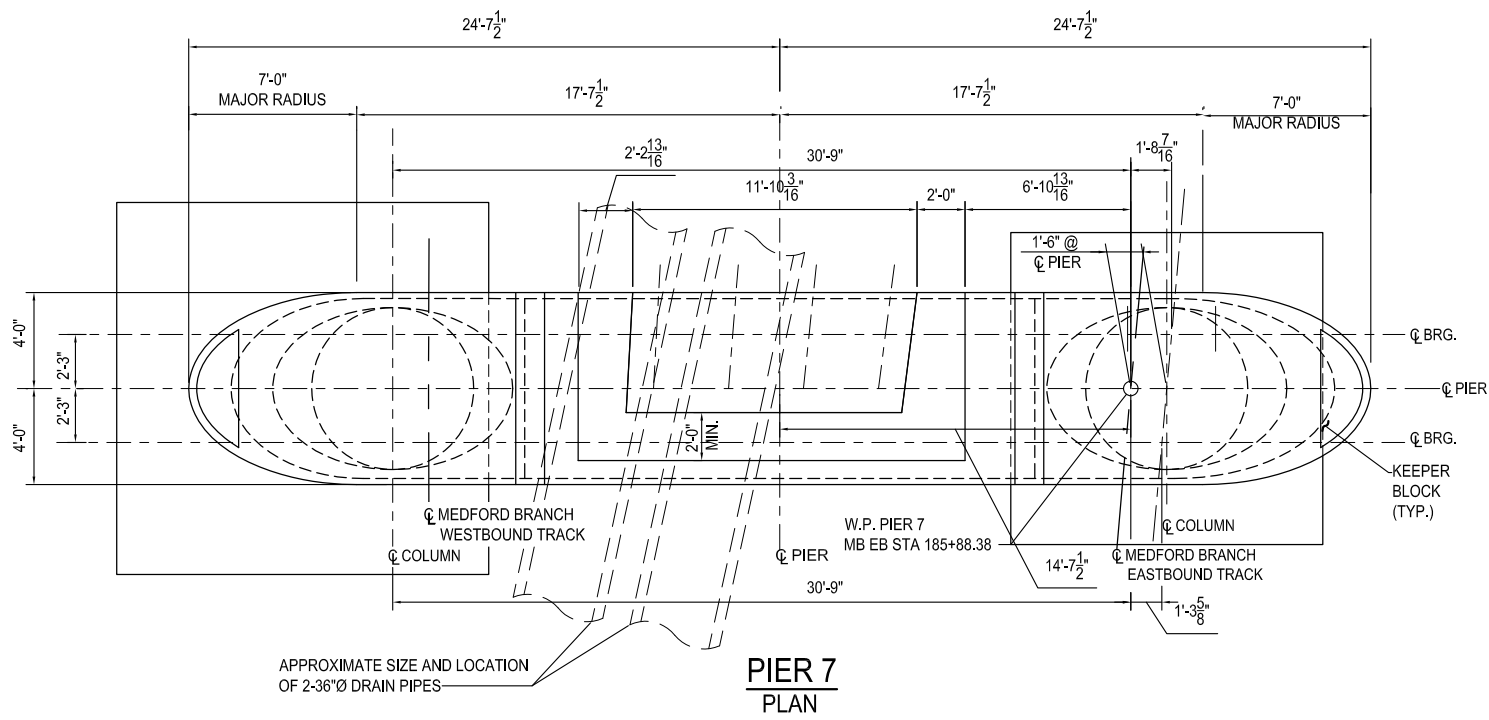
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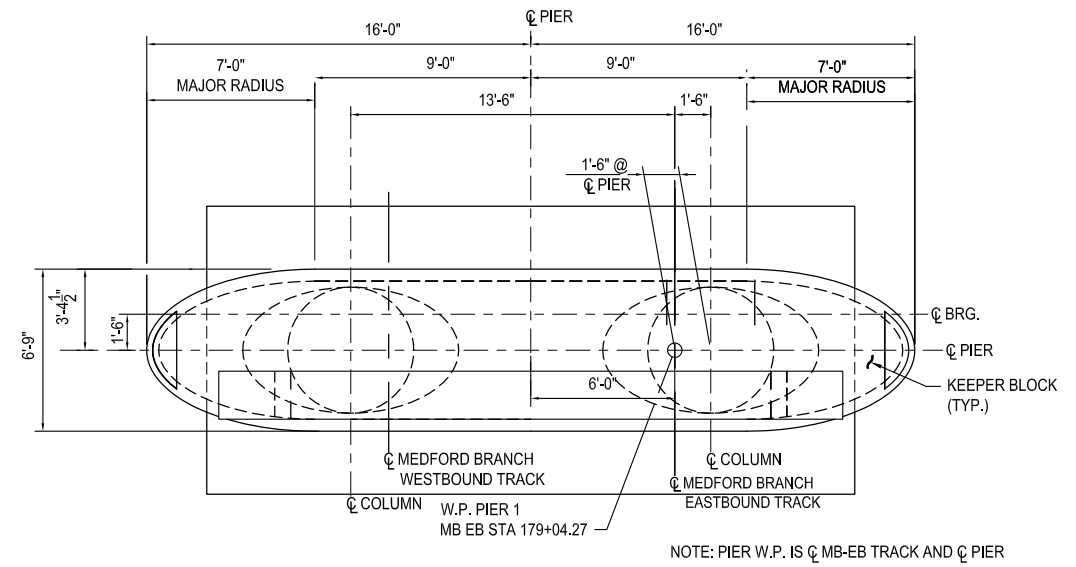
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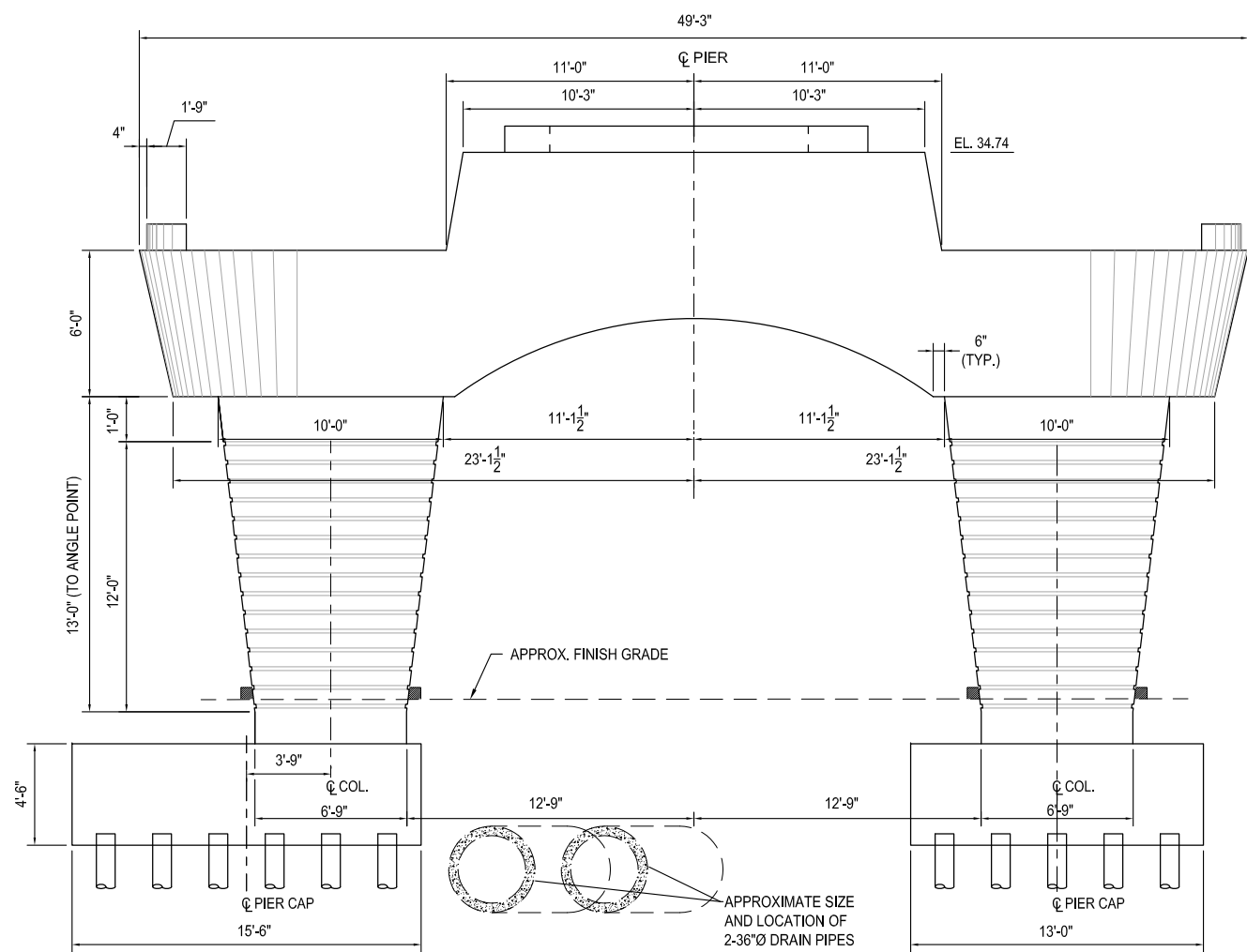
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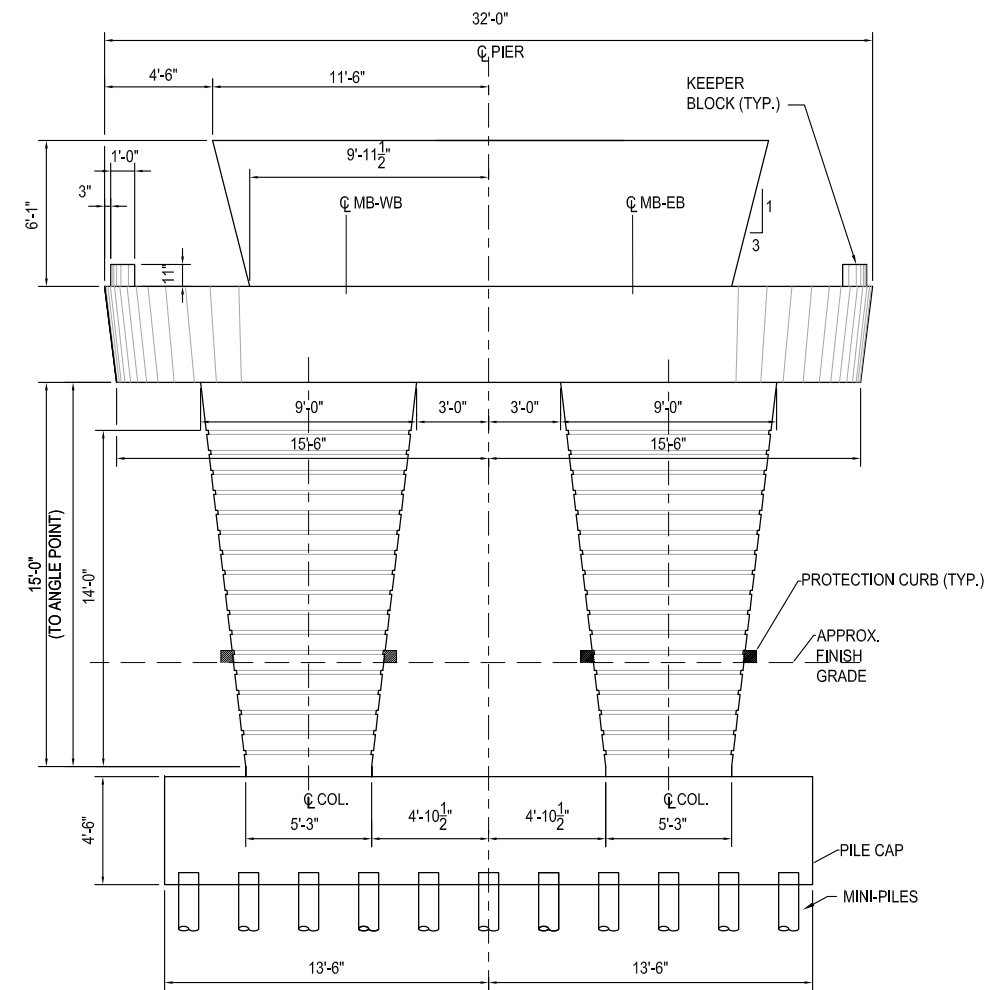
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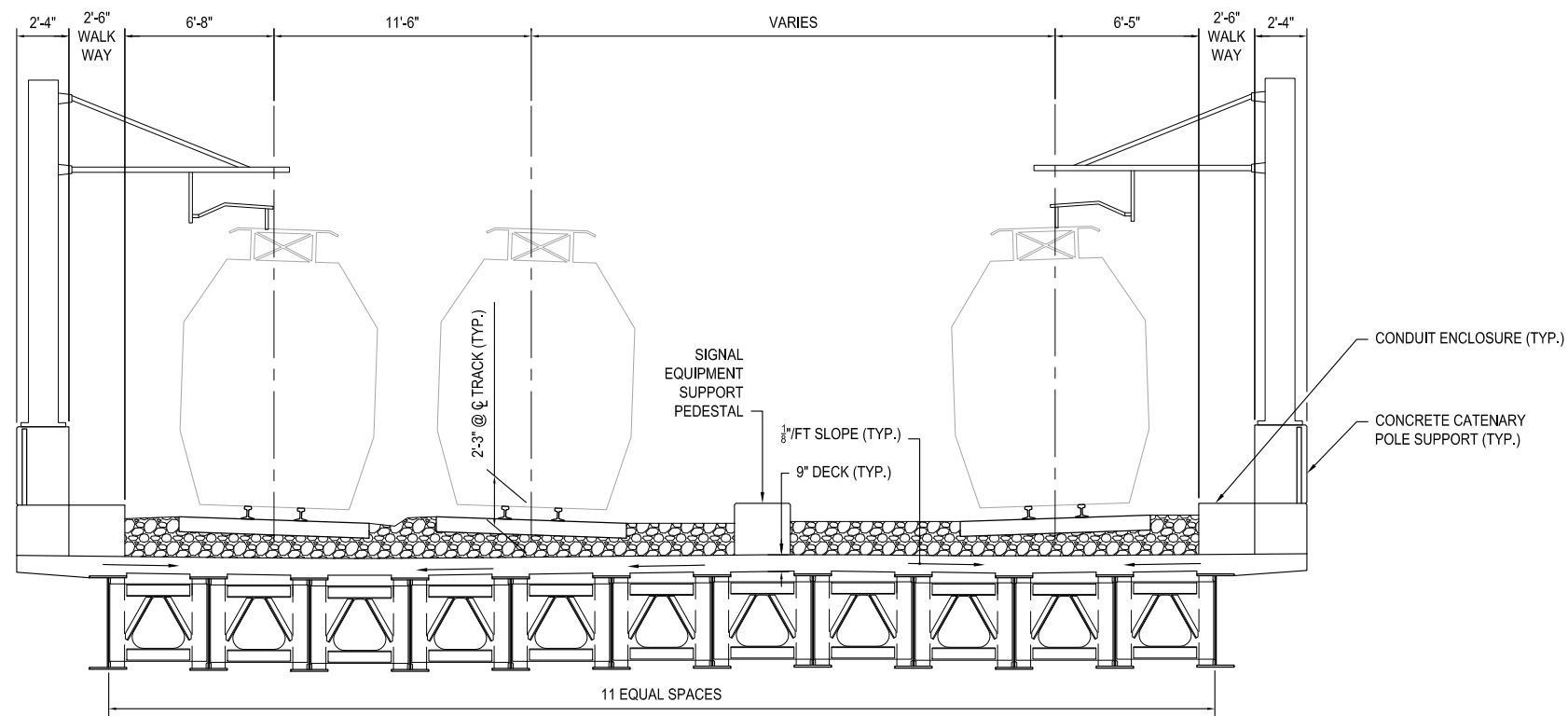
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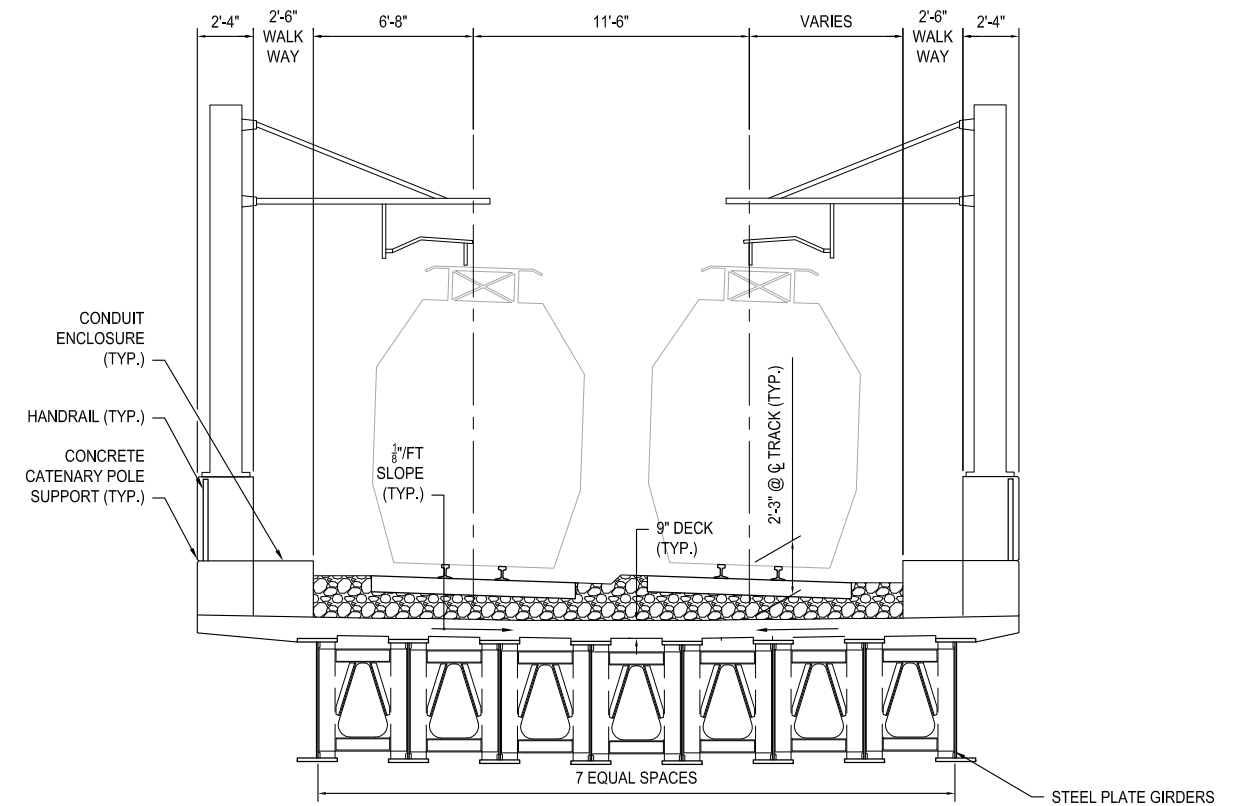
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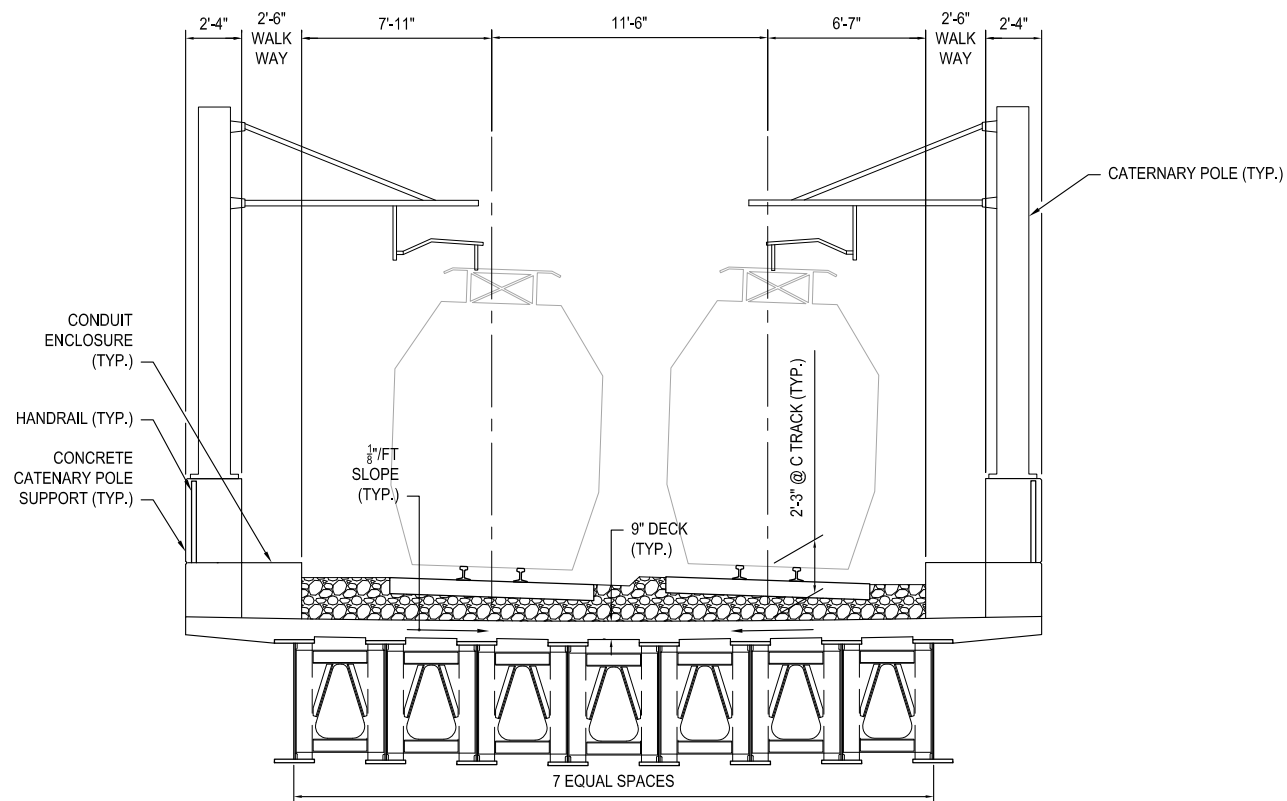
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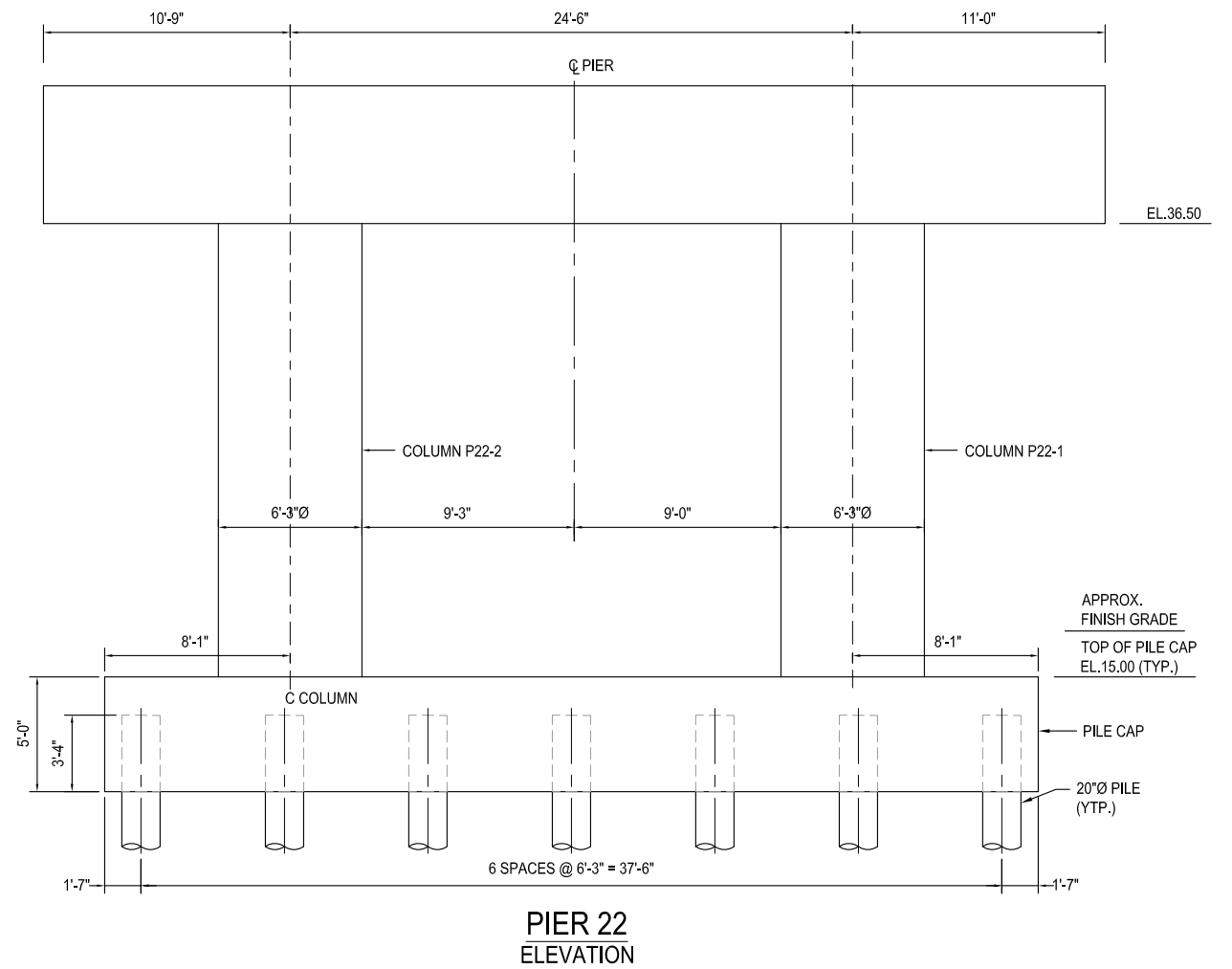
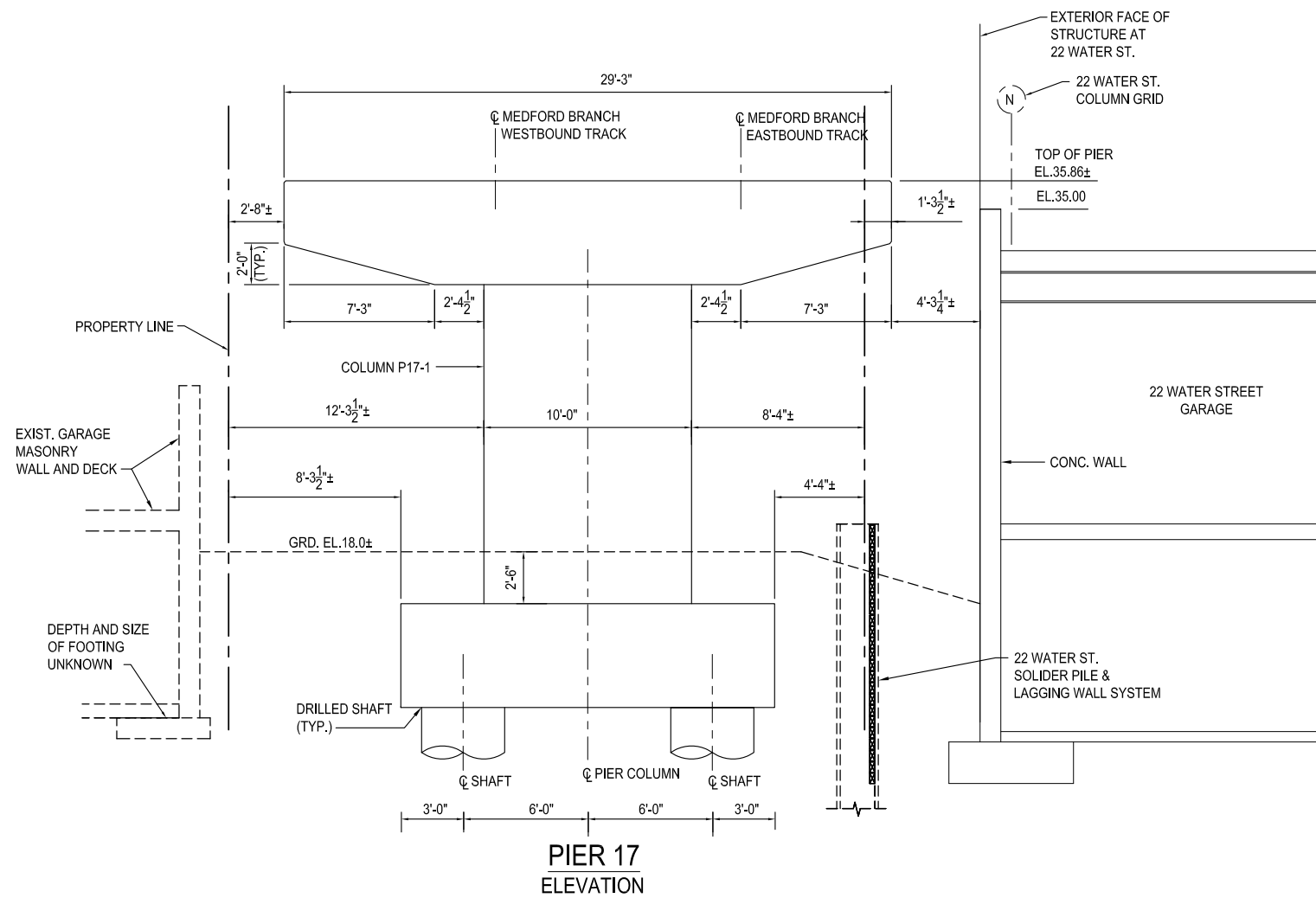
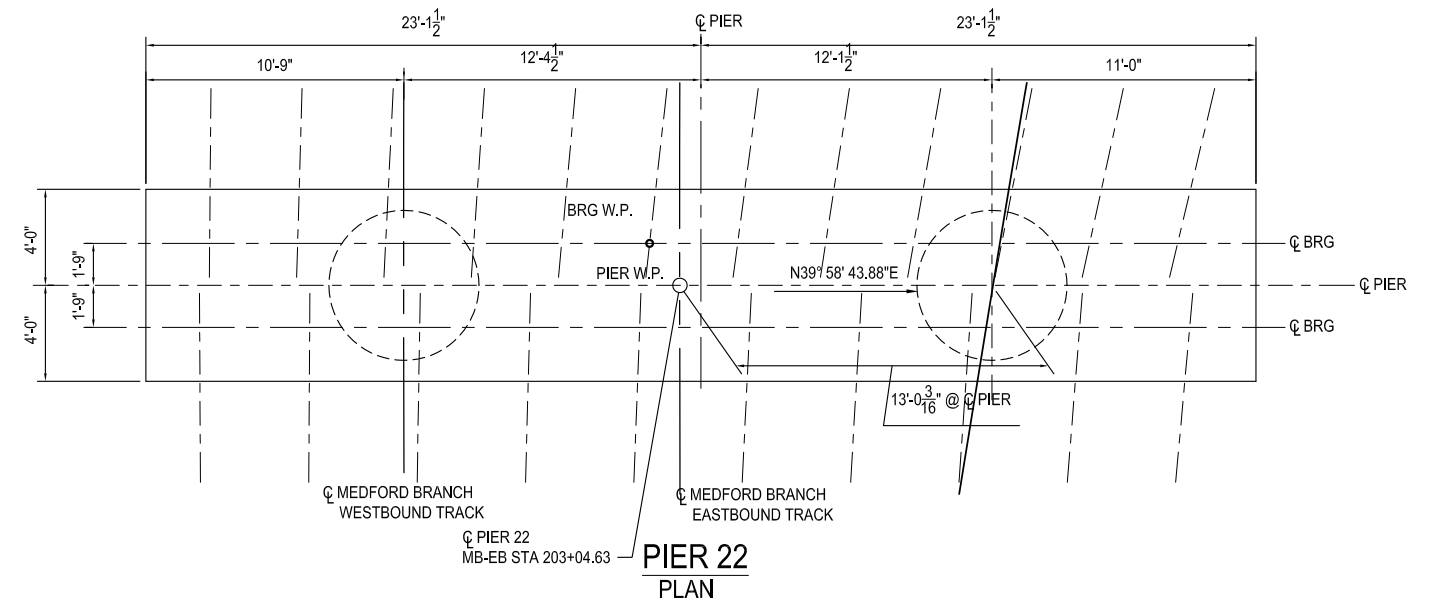
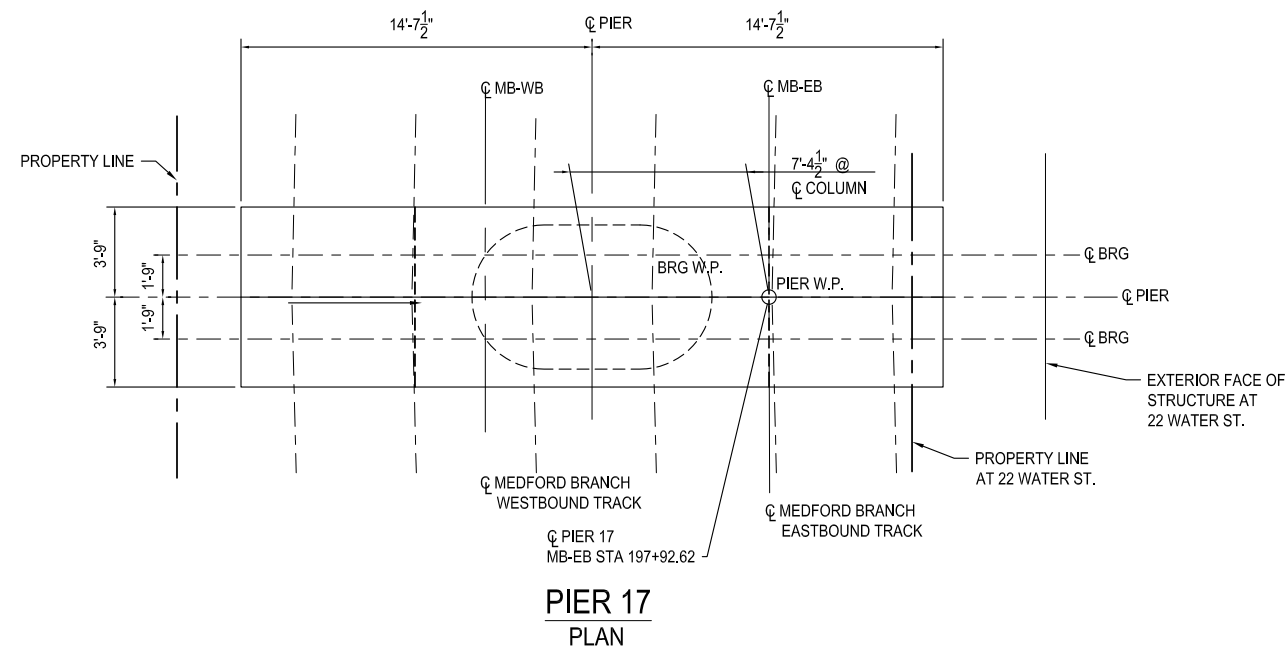


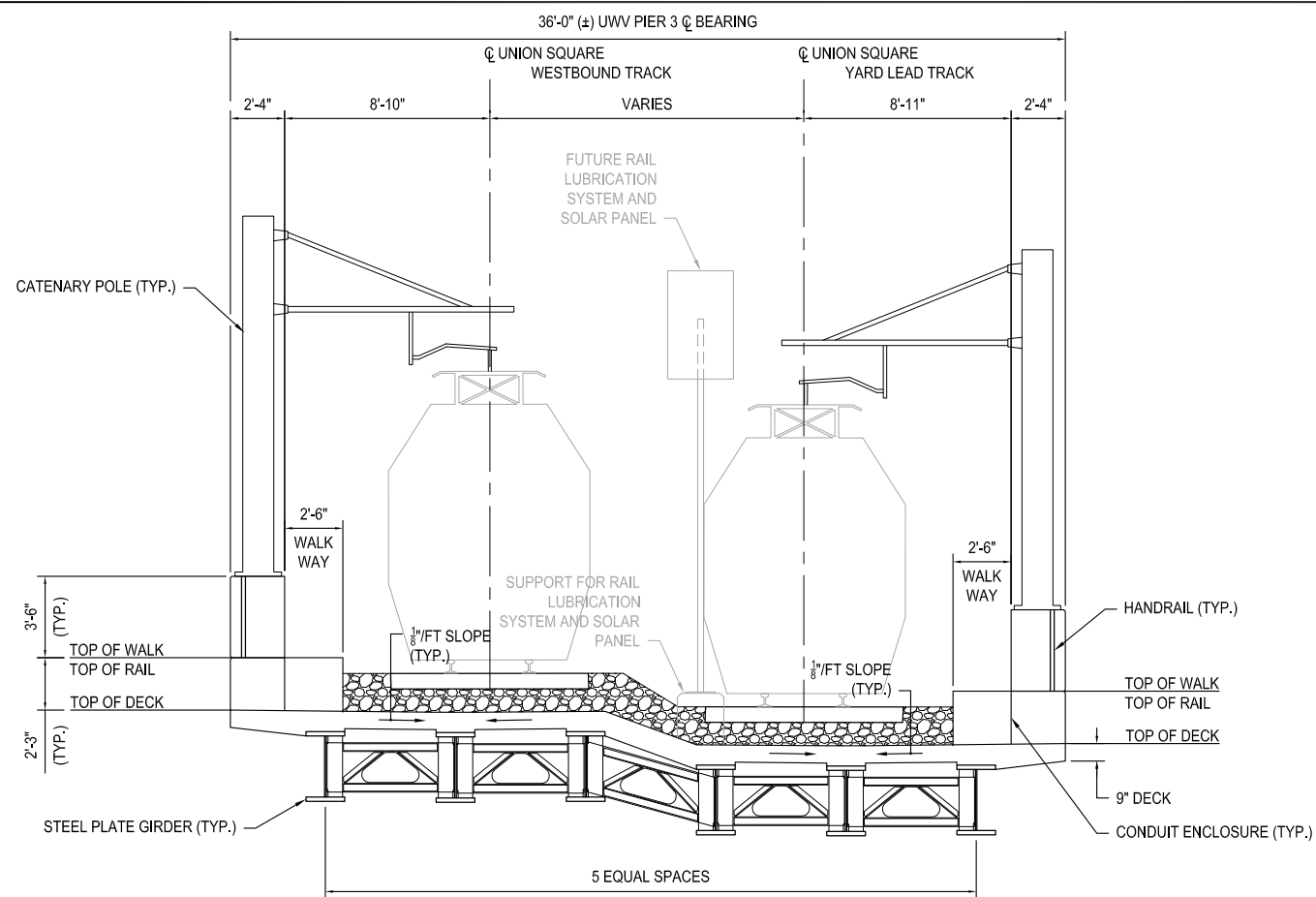
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	MASSACHUSETTS BAY TRANSPORTATION AUTHORITY
	GREEN LINE EXTENSION PROJECT DESIGN BUILD - MBTA CONTRACT NO. E22CN07 CAMBRIDGE/SOMERVILLE/MEDFORD, MASSACHUSETTS

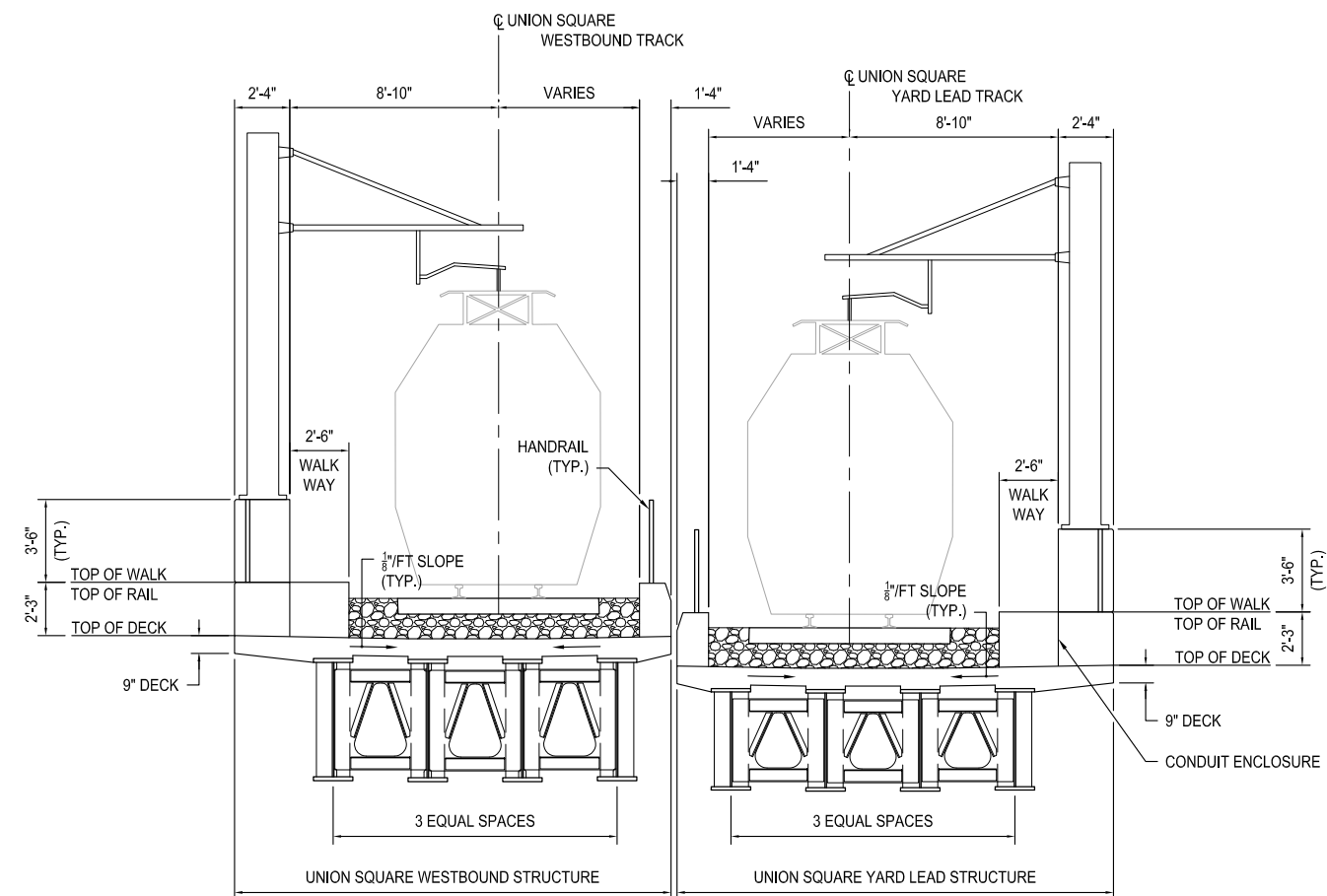
THE WALSH BARLETTA GRANITE
Joint Venture Team

MEDFORD BRANCH VIADUCT TYPICAL SECTIONS		
DATE: SEPT. 28, 2017	SCALE: 1/8" = 1'-0"	SHEET MLV-S-8001

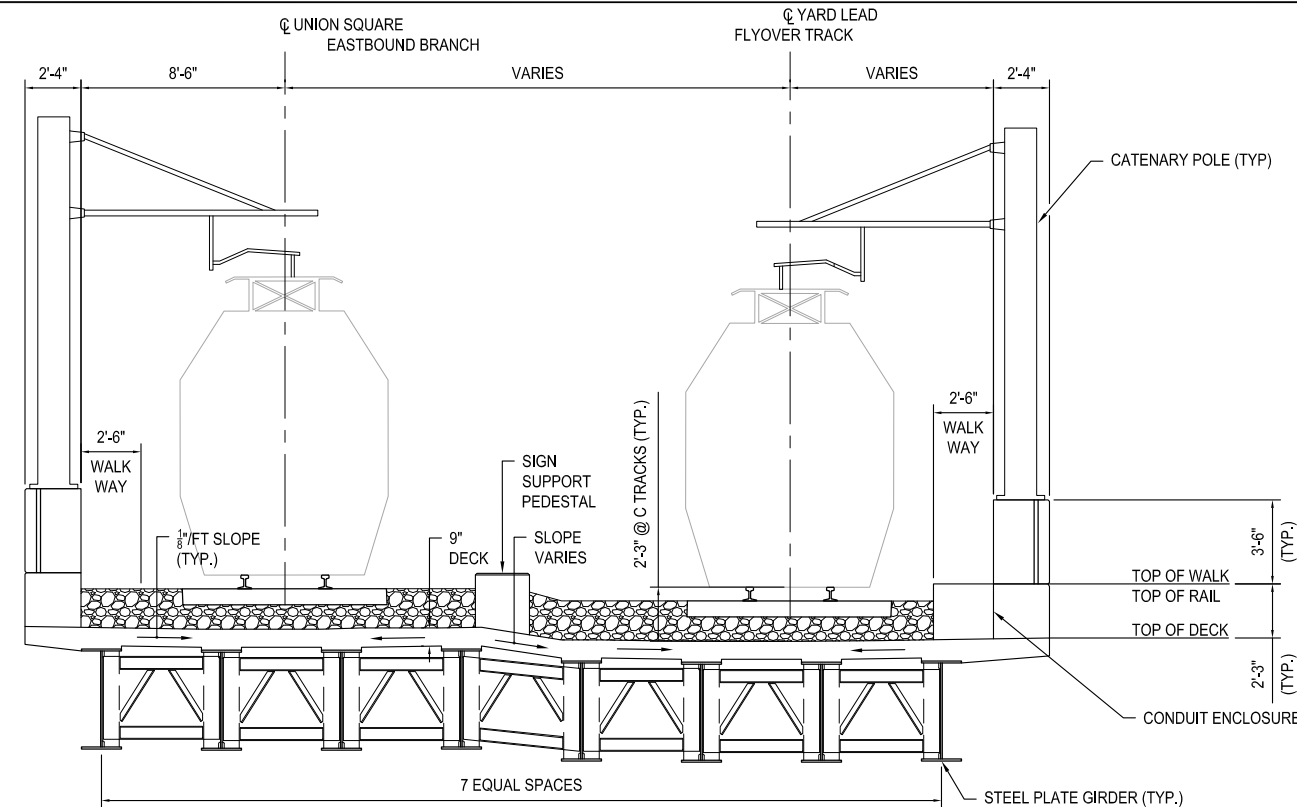




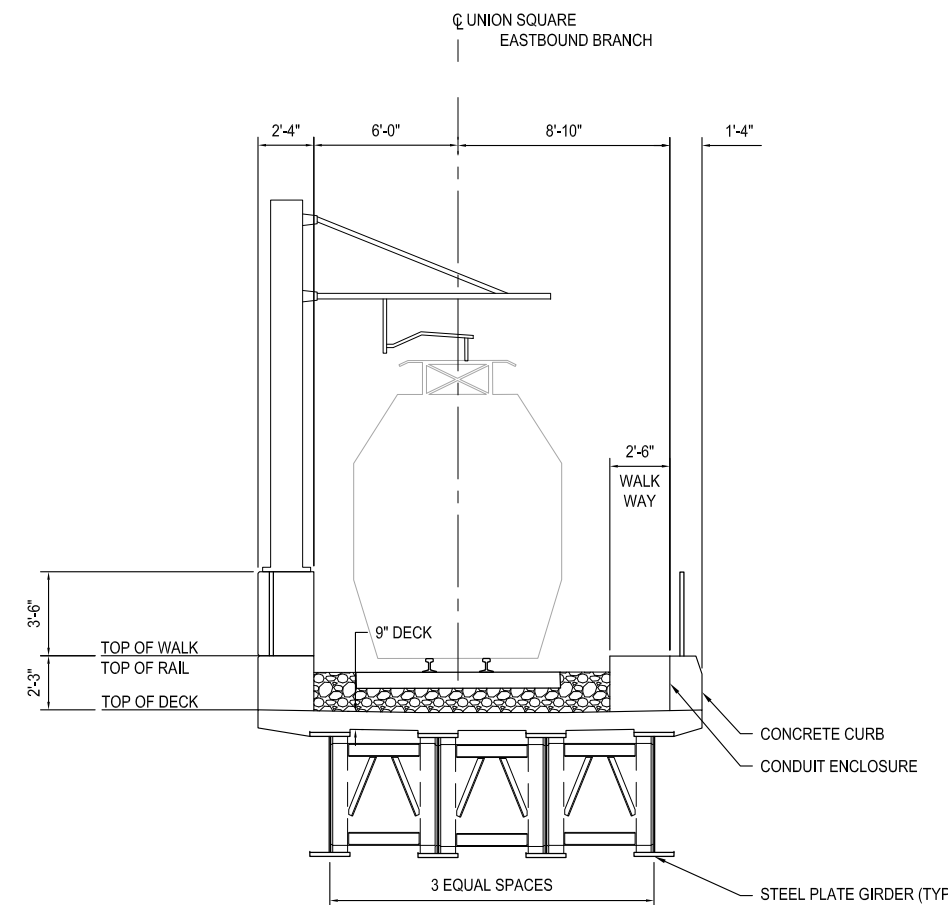
FROM UUV STA. 4+44.96 TO 4+96.20
(SECTION FROM STA. 4+96.20 TO STA. 5+14.96 SIMILAR)




FROM UUV STA. 4+01.96 TO 4+44.96



FROM STA. 3+99.92 TO 4+54.40



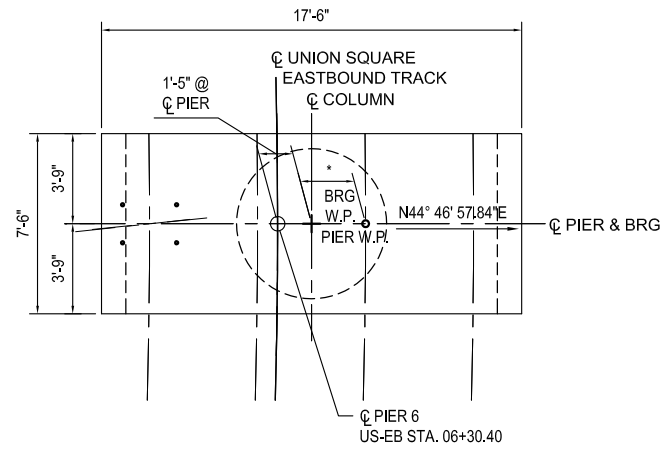
FROM STA. 1+57.23 TO 2+52.40

MASSACHUSETTS BAY TRANSPORTATION AUTHORITY

GREEN LINE EXTENSION PROJECT
 DESIGN BUILD - MBTA CONTRACT NO. E22CN07
 CAMBRIDGE/SOMERVILLE/MEDFORD, MASSACHUSETTS

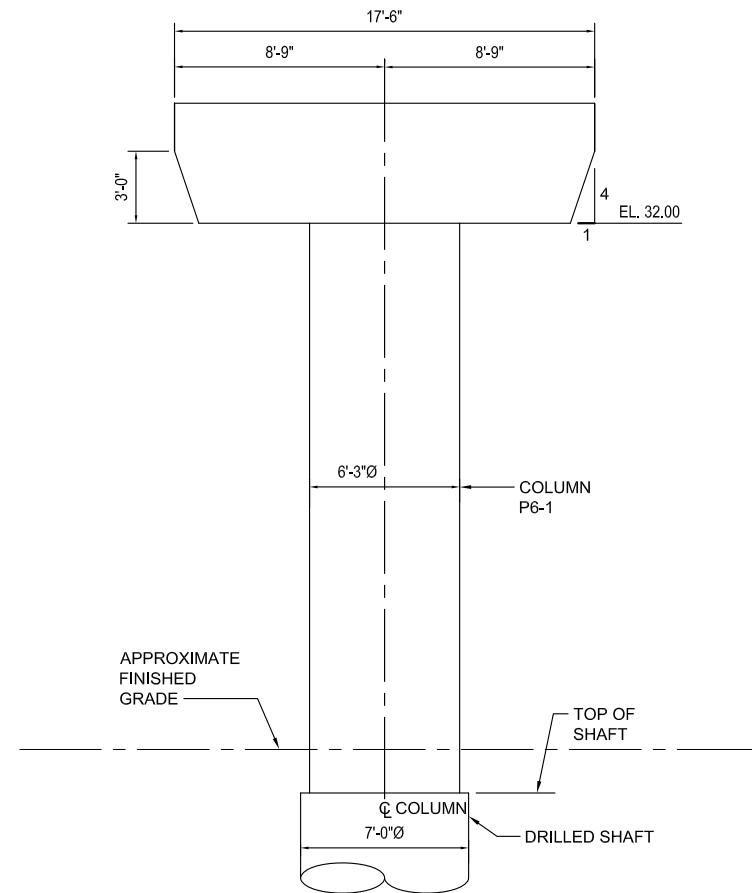

THE WALSH BARLETTA GRANITE
 Joint Venture Team

**UNION SQUARE EASTBOUND
 AND WESTBOUND VIADUCTS
 TYPICAL SECTIONS**

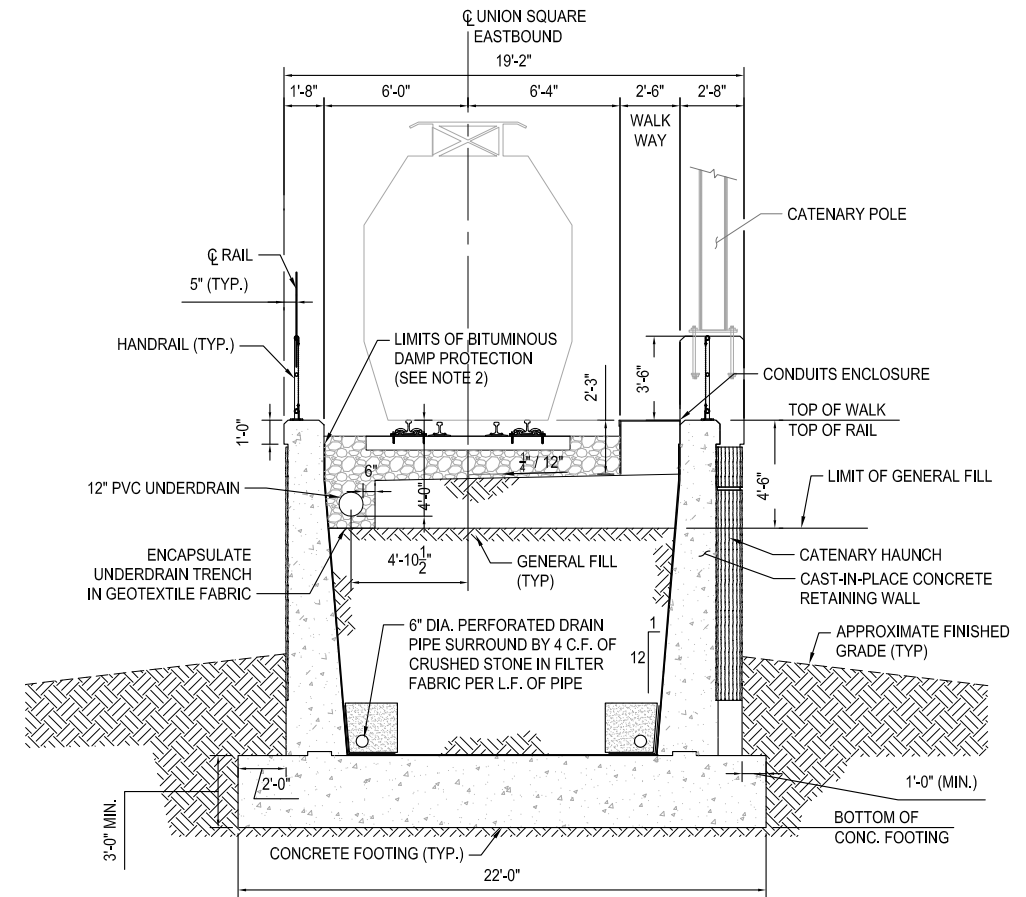
DATE: SEPT. 28, 2017 SCALE: 1/8" = 1'-0" SHEET **UUV-S-8001**



UEV PIER 6
PLAN



UEV PIER 6
ELEVATION
(LOOKING UPSTATION)



TYPICAL SECTION AT CATERINARY POLE HAUNCH



MASSACHUSETTS BAY TRANSPORTATION AUTHORITY

GREEN LINE EXTENSION PROJECT
 DESIGN BUILD - MBTA CONTRACT NO. E22CN07
 CAMBRIDGE/SOMERVILLE/MEDFORD, MASSACHUSETTS


THE WALSH BARLETTA GRANITE
 Joint Venture Team

VIADUCT RENDERING

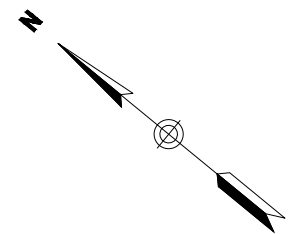
DATE: SEPT. 28, 2017

SCALE: NO SCALE

SHEET **000-S-0001**







TO LECHMERE STATION
 NOISE BARRIER N-1A
 NOISE BARRIER N-1B

MATCH LINE - SEE SHEET 2 FOR CONTINUATION

EAST SOMERVILLE STATION

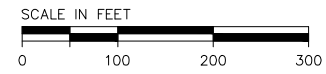
RETAINING WALL MW-1A

NOISE BARRIER N-2A
 (ON VIADUCT)
 RETAINING WALL MW-1B
 NOISE BARRIER N-2B
 RETAINING WALL YL-1

NOISE BARRIER N-3B
 (ON VIADUCT)
 NOISE BARRIER N-3A

MCGRATH HIGHWAY

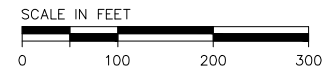
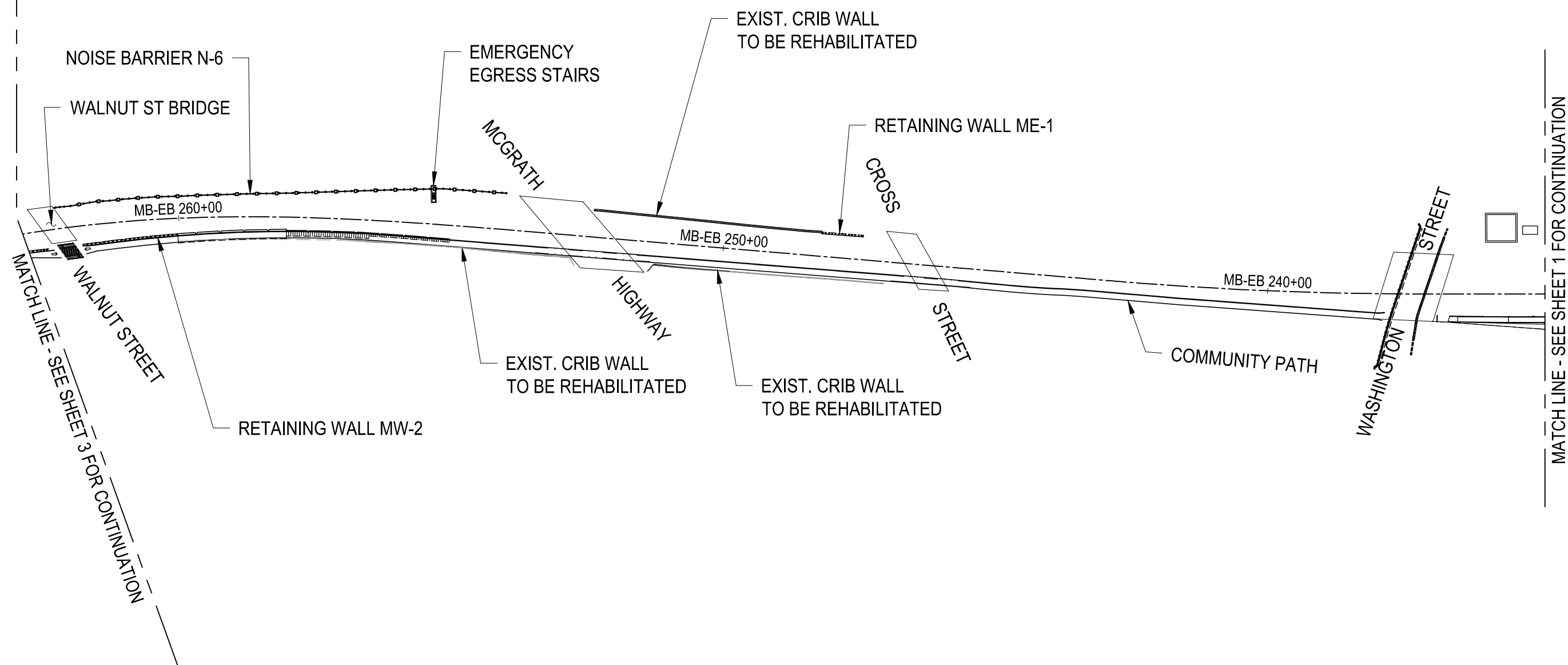
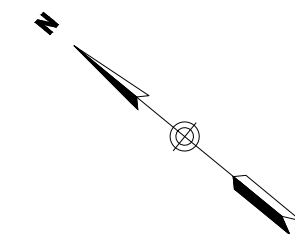
MATCH LINE - SEE SHEET 7 FOR CONTINUATION



	MASSACHUSETTS BAY TRANSPORTATION AUTHORITY
	GREEN LINE EXTENSION PROJECT
	DESIGN BUILD - MBTA CONTRACT NO. E22CN07 CAMBRIDGE/SOMERVILLE/MEDFORD, MASSACHUSETTS

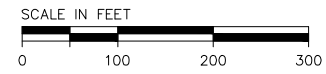
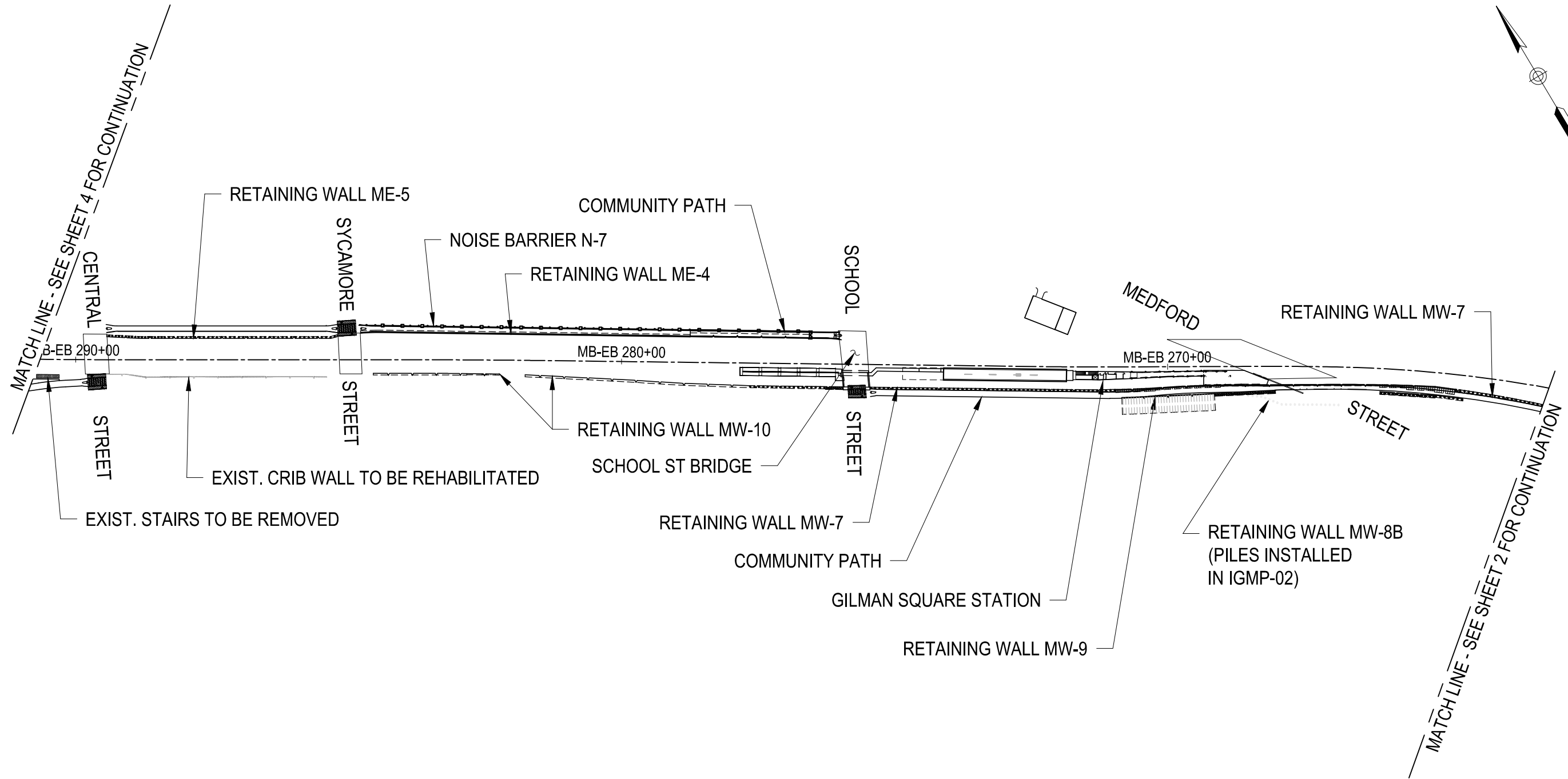
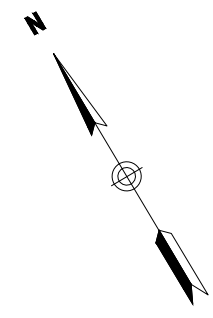
THE WALSH BARLETTA GRANITE
 Joint Venture Team


MEDFORD AND UNION BRANCH CORRIDOR WALL KEY PLAN SHEET 1		
DATE: SEPT. 28, 2017	SCALE: 1"=200'	SHEET RWS-S-1001

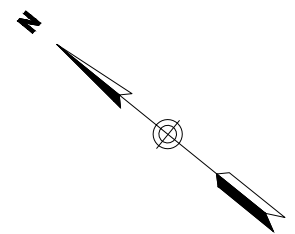


MASSACHUSETTS BAY TRANSPORTATION AUTHORITY
T
GREEN LINE EXTENSION PROJECT
 DESIGN BUILD - MBTA CONTRACT NO. E22CN07
 CAMBRIDGE/SOMERVILLE/MEDFORD, MASSACHUSETTS

**MEDFORD AND UNION BRANCH
 CORRIDOR WALL KEY PLAN
 SHEET 2**
 DATE: SEPT. 28, 2017 SCALE: 1"=200' SHEET **RWS-S-1002**



	MASSACHUSETTS BAY TRANSPORTATION AUTHORITY GREEN LINE EXTENSION PROJECT DESIGN BUILD - MBTA CONTRACT NO. E22CN07 CAMBRIDGE/SOMERVILLE/MEDFORD, MASSACHUSETTS
	MEDFORD AND UNION BRANCH CORRIDOR WALL KEY PLAN SHEET 3
DATE: SEPT. 28, 2017	SCALE: 1"=200'
SHEET RWS-S-1003	



MATCH LINE - SEE SHEET 5 FOR CONTINUATION

MATCH LINE - SEE SHEET 3 FOR CONTINUATION

RETAINING WALL ME-6

EMERGENCY
EGRESS STAIRS

NOISE BARRIER N-10

RETAINING WALL ME-5A

NOISE BARRIER N-9B

NOISE BARRIER N-9A

RETAINING WALL MW-13

MB-EB 310+00

LOWELL

MB-EB 300+00

MAGOUN SQUARE STATION

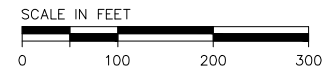
LOWELL
STREET

COMMUNITY PATH

SOUTH ABUTMENT RETAINING WALL

RETAINING WALL MW-12A

LOWELL ST BRIDGE



MASSACHUSETTS BAY TRANSPORTATION AUTHORITY

T

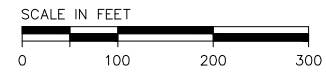
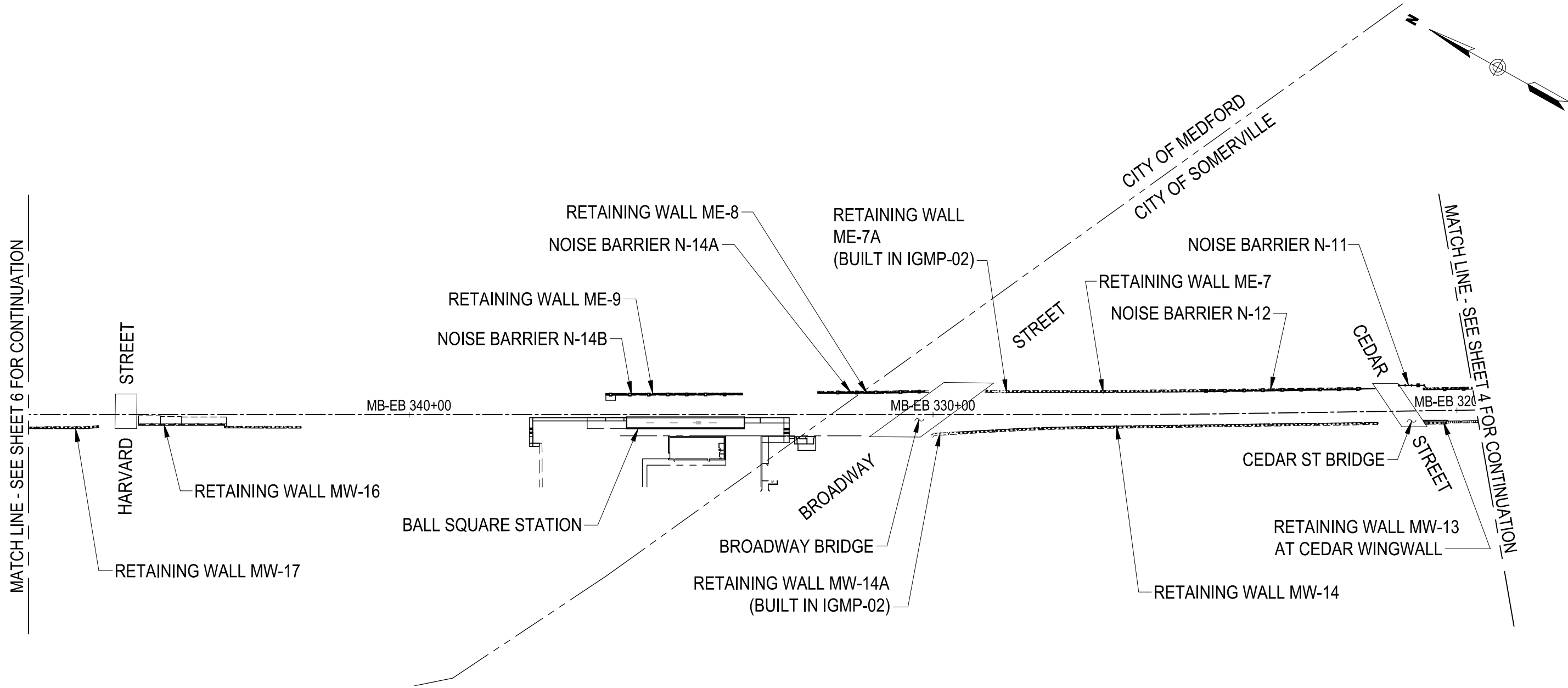
GREEN LINE EXTENSION PROJECT
 DESIGN BUILD - MBTA CONTRACT NO. E22CN07
 CAMBRIDGE/SOMERVILLE/MEDFORD, MASSACHUSETTS

**MEDFORD AND UNION BRANCH
 CORRIDOR WALL KEY PLAN
 SHEET 4**

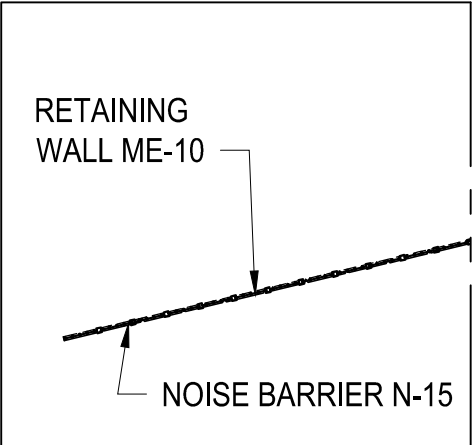
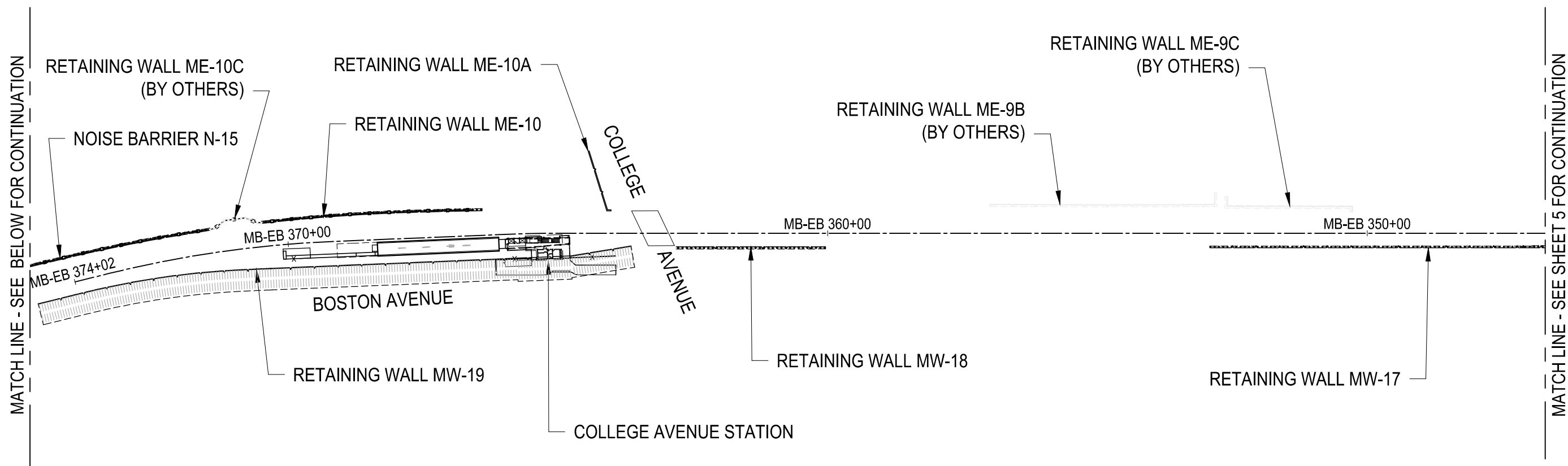
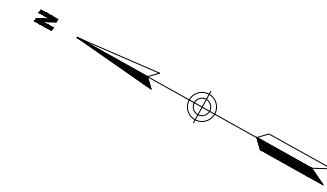
DATE: SEPT. 28, 2017 SCALE: 1"=200' SHEET **RWS-S-1004**

MATCH LINE - SEE SHEET 6 FOR CONTINUATION

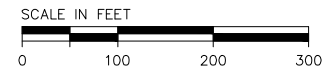
MATCH LINE - SEE SHEET 4 FOR CONTINUATION



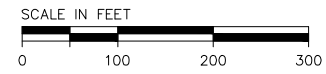
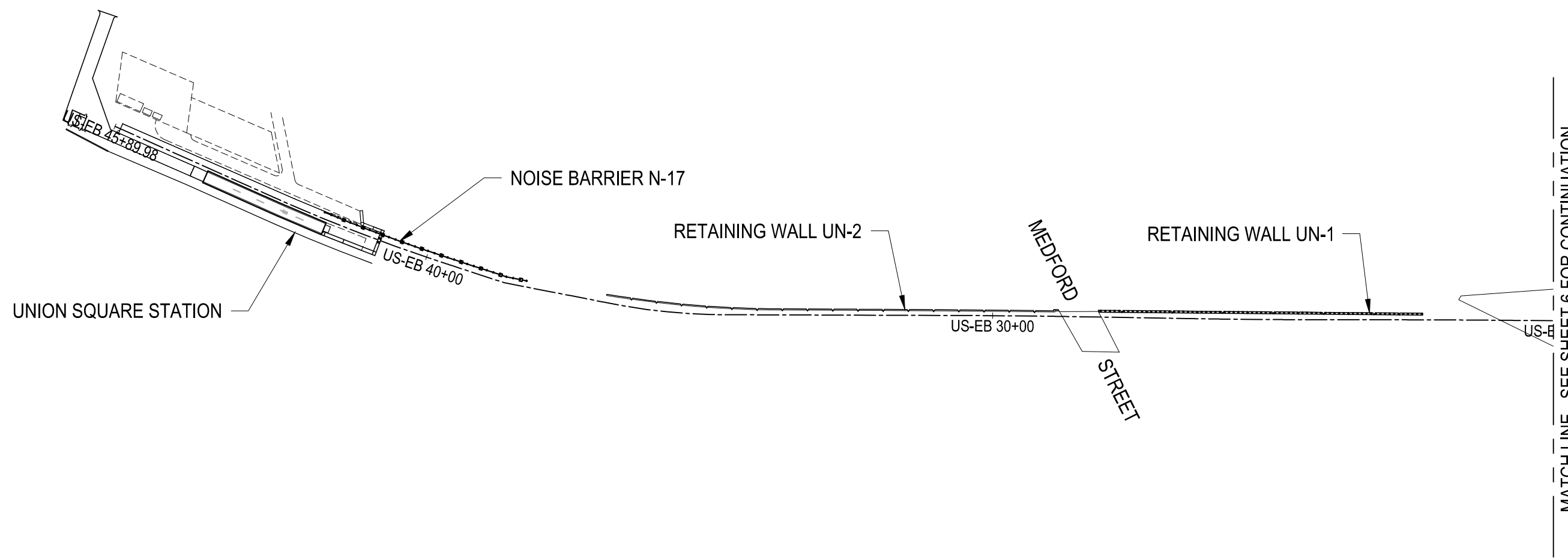
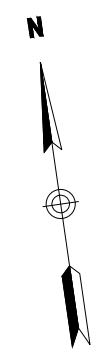
	MASSACHUSETTS BAY TRANSPORTATION AUTHORITY
	GREEN LINE EXTENSION PROJECT DESIGN BUILD - MBTA CONTRACT NO. E22CN07 CAMBRIDGE/SOMERVILLE/MEDFORD, MASSACHUSETTS
MEDFORD AND UNION BRANCH CORRIDOR WALL KEY PLAN SHEET 5	
DATE: SEPT. 28, 2017	SHEET RWS-S-1005



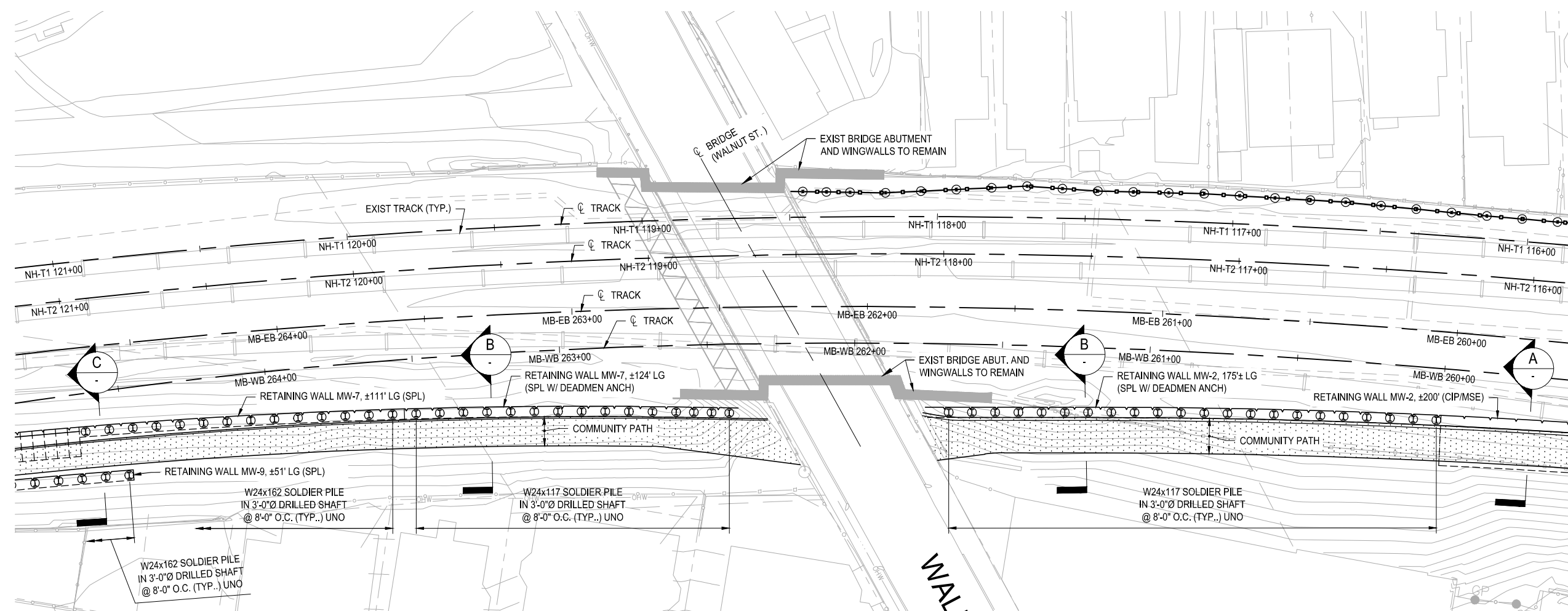
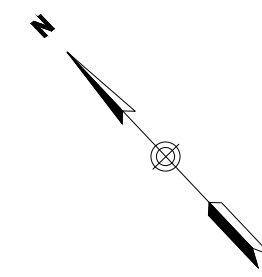
MATCH LINE
SEE ABOVE
FOR CONTINUATION



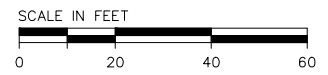
	MASSACHUSETTS BAY TRANSPORTATION AUTHORITY GREEN LINE EXTENSION PROJECT DESIGN BUILD - MBTA CONTRACT NO. E22CN07 CAMBRIDGE/SOMERVILLE/MEDFORD, MASSACHUSETTS	
	MEDFORD AND UNION BRANCH CORRIDOR WALL KEY PLAN SHEET 6	
DATE: SEPT. 28, 2017	SCALE: 1"=200'	SHEET RWS-S-1006



	MASSACHUSETTS BAY TRANSPORTATION AUTHORITY
	GREEN LINE EXTENSION PROJECT DESIGN BUILD - MBTA CONTRACT NO. E22CN07 CAMBRIDGE/SOMERVILLE/MEDFORD, MASSACHUSETTS
MEDFORD AND UNION BRANCH CORRIDOR WALL KEY PLAN SHEET 7	
DATE: SEPT. 28, 2017	SHEET RWS-S-1007



PLAN - RETAINING WALL MW-2, MW-7 & MW-9
SCALE 1" = 20'



MASSACHUSETTS BAY TRANSPORTATION AUTHORITY
T
GREEN LINE EXTENSION PROJECT
 DESIGN BUILD - MBTA CONTRACT NO. E22CN07
 CAMBRIDGE/SOMERVILLE/MEDFORD, MASSACHUSETTS

THE WALSH BARLETTA GRANITE
 Joint Venture Team

MEDFORD BRANCH
CORRIDOR WALL PLAN
MB-WB STA 259+75 to STA 264+75
 DATE: SEPT. 28, 2017 SCALE: AS NOTED SHEET **RWS-S-2001**