Section A5.2.1

Systems and System Integration

GLP is providing MBTA and its customers a systems design that provides a safe ride and environment coupled with an experience that is well-informed and an expedient mode of transportation to their destination.

Section Highlights

- GLP has designed resilient systems that prevent single-point failures from causing any effect to GLX operations.
- GLP's design of the track work for the commuter rail relocation has reduced the undercutting to save time and cost.
- GLP has designed the signal system to interact and to work seamlessly with the existing Green Line signal system.
- GLP provides MBTA with common parts and systems that will make maintenance easier for the MBTA to implement when the system becomes operational.
- GLP systems experience on similar projects, including LA's Expo 2, has proven successful in incorporating interfaces with existing signaling, communications, and traction power operating technologies.

INTRODUCTION

The Green Line Partners ("GLP") Team approaches systems design as a holistic function, meaning that the systems elements, including signaling, track, communications, traction power, corrosion control, and overhead contact system ("OCS"), are closely linked to one another, but also to other design disciplines. Based on our review of the RFP documents and associated reference plans, the MBTA has taken a similar approach to Systems design for the Green Line Extension Design Build Project ("GLX Project" or "the Project"). GLP's design was developed based on the RFP documents with optimizations made for a new, efficient project design. For example, GLP has designed the OCS pole layouts for the revised Vehicle Maintenance Facility ("VMF") and approach tracks. GLP will use a Task Manager for the GLP Systems Team, along with a System Integration Manager to direct and check the designs to make sure they fit and function within the overall GLX Project. The key element is the System Integration Program described below.

The GLP Team approaches system integration as a process to be followed across all disciplines throughout the delivery of a project. It begins with the earliest design phase and carries through until project completion and acceptance. For the GLX Project, this began during the preliminary phase, and the GLP Team will use the RFP and attachments as a starting point to define the requirements for system integration. The process we will follow, based on the International Council on Systems Engineering (INCOSE), is illustrated in **Figure A5.2.1-1**. The functional criteria (listed on the left side of the V in the figure) are developed during the design process and validated during implementation (right side of the V). Through this process, the functionality of the system is well-defined and validated at each stage of implementation.

System integration generally refers to verifying that all traditional systems such as communications, security, train control, supervisory control and data acquisition ("SCADA"), and electrical work together in the manner agreed upon in the design. In addition, these systems must fully integrate into the facilities that house them, including stations, the VMF, Operation Control Center ("OCC"), and backup OCC, as well as with track and infrastructure. GLP will include these physical interfaces into the documentation as described to ensure that the interfaces are documented and addressed throughout the GLX Project.

A5.2.1.A
LIGHT RAIL TRANSIT ("LRT") SYSTEMS

A5.2.1.A.1
DESIGN METHODOLOGY AND APPROACH

The MBTA has defined a well-thought-out process that the GLP Team will follow as described herein to achieve the goals of overall system integration with not only the systems elements of the GLX, but also in connecting the extension to the operating Green Line system and other top-level MBTA systems such as closed circuit television ("CCTV"), access control, signaling, Public address ("PA"), traction power substations ("TPSS"), traction power, OCS, and SCADA.

The various systems and subsystem providers will use the Requirements Traceability Matrix ("RTM") and System Integration Plan to produce their Subsystem Hardware/Software Requirement Specifications. This interface guidance is performed through workshops that will provide an organized, sensible, accountable, and workable approach to the interaction of all the systems on the Project. System integration will check/review the Subsystem Hardware/Software Design Documents for compliance with the subsystem interface requirements generated in the aforementioned documents. The process will use established requirements management procedures and tools to track and provide traceability from design through the system integration testing in the field.

IMPLEMENTATION PROCESS

This process will use a building-block approach called Stages. These are progressive, with each Stage building on the previous, from components and subsystems to full system commissioning. Each Stage has its own set of verification documents that fully test the design submitted per the specification. These verification documents are outlined in detail in the Project Inspection, Testing, and Demonstration plans. The Inspection and Testing plans will define the tests that need to be performed for each location and/or device. The Demonstration plans will lay out in detail what needs to be done to make sure that all system tests are performed, and provide detailed directions on how the Pre-Revenue Operations and Emergency Drills will be conducted.

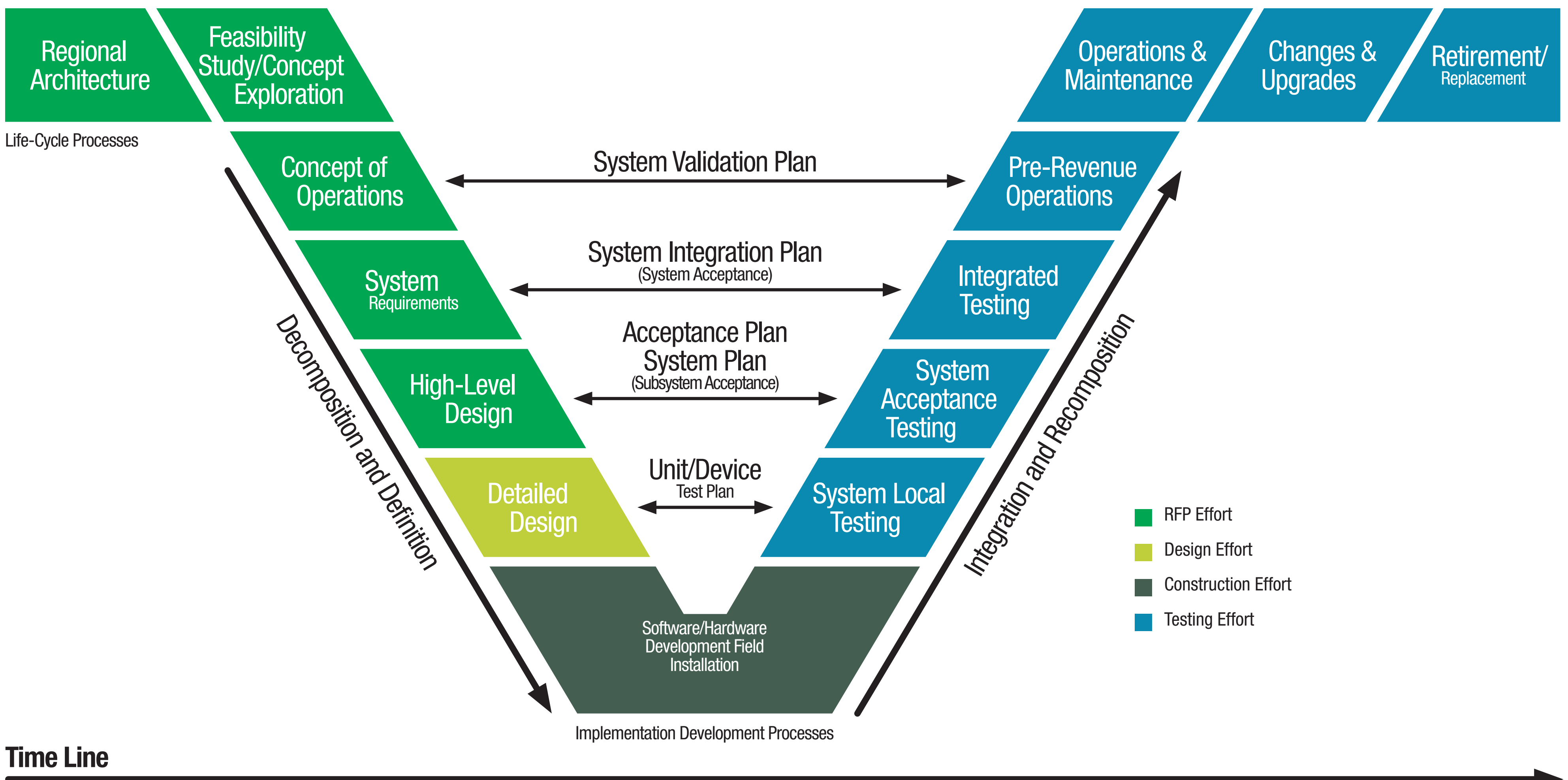


Figure A5.2.1-1: GLP will implement INCOSE processes to safeguard MBTA systems goals throughout the implementation process to provide successful delivery.

These test Stages are:

- **Design Compliance, Qualification, and Product verification**
- **Factory Verification Testing –** Component factory test results
- **Factory Acceptance Testing ("FAT") –** Testing of subsystems
- **Contract Acceptance Field Testing –** Testing of interacting subsystems
- **Installation Verification Testing –** Verification of component installation with reference to installation drawings
- **Demonstration Testing –** System Testing, Pre-Revenue Operations and Emergency Drills
- **Pre-Revenue Operations –** System Operations utilizing final user

The test Stages directly relate to the project design process. Prior to testing, the design is checked to ensure compliance with GLX Project design principles and the sub system detail design documents. Factory Verification Testing will then prove compliance with the subsystem hardware requirements. FAT will prove compliance with subsystem requirements. Contract Acceptance Field Testing will prove compliance with system requirements. The Demonstration Testing will prove compliance with all remaining requirements in the customer specification.

Installation Verification Testing is a subset of the Contract Acceptance Field Testing. Typically, these tests are component-driven. These tests will be performed when pieces of equipment are installed without interfacing the system. Tests within the Contract Acceptance Field Testing will test the component within the system parameters.

Pre-Revenue Operations will use MBTA staff for operations and maintenance ("O&M") prior to carrying passengers in order to train MBTA staff and prove operations further with the actual O&M crew.

Each testable requirement derived from the specifications will be mapped (using a requirements management database described below) to the test procedure or test step proving compliance with said requirement.

GLP's implementation of the INCOSE processes has been used throughout the U.S. on large transit infrastructure projects that GLP Team members have worked on, including New York City's Second Avenue Subway.

A5.2.1.A.1.A SYSTEM ENGINEERING MANAGEMENT PLAN

The System Engineering Management Plan ("SEMP") will guide all activities throughout the life-cycle of the systems engineering effort, from concept generation to dismantlement or disposal. The SEMP will capture what activities must be done, as well as how they will be done. The SEMP also will define the way that the effort will be managed, to include assignment of roles and responsibilities, decision making, conflict and issue resolution, communication and feedback, formal and informal reviews, risk management, and other management activities to effectively deliver the GLX system.

GLP systems professionals tailor each SEMP plan for individual projects to customize for the needs of each client and end user and has been used on various systems including Minneapolis's $1 billion Blue Line project.

A5.2.1.A.1.B REQUIREMENTS MANAGEMENT PLAN

GLP will capture all final railroad systems requirements, based on MBTA Technical Provisions ("TP") and referenced codes and standards, in an RTM. This matrix serves as the basis for providing a record that all Project requirements are met. All requirements in the RTM will be verified and validated via one or more of the following tests or activities:

- Factory/installation/system testing
- System operability testing
- System functionality demonstration/testing
- System interfaces
- Commissioning and final demonstration testing

Our System Integration Lead, Michael Venter, will manage this process starting with the RTM development, as he did for New York's Metro-North Railroad. The RTM is a key tool that tracks all requirements and provides a means to track and make sure that the requirement has been met and proven to MBTA.

Generally, the RTM requires approval by MBTA, since it is used as the basis of the design. Identification and coordination of the Project-level interfaces from the RTM is performed by system integration personnel and generally requires an approval by the MBTA agency engineers. This effort leads to preparation of an Interface Decision Log ("IDL"), which captures the potential interface issues. The log is a dynamic document and updated as new interface issues are identified.

The safety- and security-related items will be extracted from the Specifications, to form a separate safety and security checklist ("SSC"). The SSC will be used to make certain that all safety precautions have been taken throughout the life-cycle of the Project.

Maintaining the RTM database is a safe, secure, and worthwhile practice, which GLP will pursue consistently from the beginning of this Project. We will also store RTM, SSC, and other pertinent information in a comprehensive compliance matrix as a management tool to track Project elements and documentation.

A5.2.1.A.1.C
SYSTEM INTEGRATION MANAGEMENT PLAN

In addition to the RTM discussed in the previous section, a separate management for systems interfaces will be developed.
This plan will include the following components:

1. Develop Integration Control Definitions ("ICD") that will define all interfaces in terms of the varying systems and the interface resolution.
2. Develop schedule of activities for system integration.
3. Develop system integration test forms.
4. Initiate and execute coordination meetings with all subcontractors to help each to better understand and identify the System Integration Plan, and the requirements for each system to be tested.
5. Perform system integration testing of all controls and indicators from the subsystems to the OCC via the SCADA system. This process will verify the proper operation of the complete system from OCC to the field equipment along the wayside.

A5.2.1.A.1.D
VERIFICATION AND VALIDATION

The GLP Team will use the RTM, described above, to demonstrate compliance with the Project requirements. This is the means by which the MBTA can track and validate that we have met the contract requirements. The RTM defines the method of verifying compliance for each element, and the means by which validation is demonstrated.

Methods of verification include the following:

- **Documentation –** This includes analysis, shop drawings, design specifications, and drawings.
- **Qualification Tests –** These are tests that are done to prove a requirement on a material or component, such as life-cycle testing or smoke and flammability of material tests. Only documentation of the test that was performed is required for this activity.
- **Factory Acceptance Tests –** Tests to prove the functionality of the piece of equipment prior to installation.
- **Site Inspections –** To verify that the installation was performed correctly, and to check color, size, and similar visual items of verification.
- **Site Tests –** These prove that the installed system meets the contract requirements.
- **System Integration testing –** To verify that each component of a subsystem works together with other systems as defined in the ICDs per the RTM requirements.
- **Commissioning and Demonstration Testing –** To prove to the MBTA that the system performs as specified in the Contract Documents.
- **Training –** Provided to MBTA staff for O&M activities.

A5.2.1.A.2
SYSTEMS INTEGRATOR AND KEY SYSTEM SUPPLIERS

The GLP Team has extensive experience providing integrated solutions for the various systems that make up the GLX Project. GLP Lead Designer, WSP, is the lead for system integration oversight as defined in the TP Exhibit 2H – Project Standards Section 9.9. WSP's role is to develop the plan and monitor the design and implementation to verify compliance.

As illustrated in **Figure A5.2.5-2**, GLP Systems Team members have extensive rail experience with projects of a similar size and complexity as the GLX Project. In addition, they have direct relevant experience working in this environment and with the MBTA on similar project types. In addition, WSP has worked on multiple projects with each of these Team members as either the designer of record, or during the construction phase as the Program Manager or Construction Manager, which provides familiarity and the ability to more easily coordinate efforts and integrate solutions.

Firm	Role		Experience
WSP USA	System Integration Oversight, Plan Development, Compliance Monitoring		**LA Metro Expo 2 LRT DB Project:** Project is a 6.6-mile extension of the 80-station Metro Rail System where WSP provided design integration, and verification activities for all systems including traction power, OCS, communications and signals.
			Minnesota Blue Line Light Rail Transit (BLRT) Extension Project: Provided design and systems integration services of the new for systems including traction power, signaling, OCS, and communications systems, intergrating the new systems into the existing BLRT system.
			LA Metro Regional Connector: – Project involved installing a LRT system to allow passenger to connect between the Red, Blue, Expo and Purple lines. Provided design integration, and verification activities for all systems including traction power, communications and signals. The integration work involved tying systems into the three existing rail lines.
Siemens	Signals and Train Control System Supplier		**MBTA Old Colony Railroad Project:** Provide interlocking, automatic signal, electric locks and highway grade crossing controls, and wayside signaling for rehabilitating three lines on the Old Colony Railroad.
			TriMet Portland Milwaukee Orange Line Extension: Design, furnish, install, train, and test/commission for signal, communications, traction power, and OCS.
			Port Authority Trans-Hudson ("PATH") Automatic Train Control System Project: Design and furnish engineering circuit design, detailing, material, assembly and wiring, and factory and field testing of an iVPI based system for the project.
FTG Security	Communications System Integrator		**MBTA CCTV & SCADA Maintenance:** Providing preventive maintenance, troubleshooting, and repair/replacement of MBTA CCTV and SCADA equipment at over 100 MBTA locations throughout Greater Boston.
			MBTA PA/ESS at 45 Stations: Performed installation of new ARINC cabinets containing digital signal processors ("DSPs"), amplifiers, and Ethernet switches/routers at 45 MBTA transit stations, to interface to a new public address/electronic security system ("PA/ESS") head-end system.
			MBTA Wellington Yard Security Improvements: Design, furnish and install new CCTV and access control systems for the Wellington Yard Facility.
Powell	Traction Power Substations		**Long Island Railroad:** Provided two TPSSs with connections back to the railroad SCADA systems.
			Metro-North Railroad: Replacement of 18 TPSSs on the Hudson and Harlem lines, including connections to the railroad SCADA system.
			Dallas Area Rapid Transit ("DART"): Supplied 16 prepackaged TPSSs with energy management and SCADA.

Figure A5.2.1-2: GLP's Systems Integration Team brings more than a quarter of a century of combined experience providing systems, testing and management for MBTA and other national transit agencies with similar size, scope, and integration challenges.

A5.2.1.B
TRAIN CONTROL SYSTEM DESIGN

A5.2.1.B.1
OVERALL APPROACH TO SIGNALING AND TRAIN CONTROL

System signals facilities and equipment for the GLX Project will extend from the existing Green Line light rail vehicle ("LRV") control system to provide for a safe and seamless transition of the LRVs between the existing Green Line and the GLX territory. Operational interface to the VMF Yard will be provided in each of the yard lead tracks, and will not interfere with the operation of the mainline system.

The signal system will support the safe operation of LRVs, at the headways identified in TP Section 1.3.1.1, and with the prescribed travel times.

GLP's design approach is customer-oriented, with system integration considerations incorporated from the start of the design process. Early customer design feedback, informal over-the-shoulder reviews, and formal reviews are encouraged for continuing communication; awareness of system designs; conveyance of Project progress; and to assure compatibility with the overall system and provide for smooth, efficient integration testing.

CONFORMANCE TO REQUIREMENTS

The proposed system will be designed in accordance with Volume 2 TPs and the associated contract drawings, and adhere to the American Railway Engineering and Maintenance-of-Way Association ("AREMA") 2014 Communications and Signals Manual Section 2, Railway Signal Systems, and TP Exhibit 2A Section 16, Vital Circuit and Software Design; as well as Federal Railroad Administration ("FRA") rules Parts 233, 234, and 236. Closed-circuit principles, using industry-proven fail-safe practices, will be used for the signal system design.

The proposed system will match the existing Green Line operation per the RFP. The trains will operate over a double mainline track, with movement of mainline trains governed by the wayside signal system and Automatic Vehicle Identification ("AVI") system. The proposed system design is for single direction running and uses home and automatic signals. Communication of movement authority to the vehicle operator from the signal system will be by display of the signal aspects, while the AVI system uses both wayside and car-borne components.

In preparation for the signal system design, the existing Green Line design will be reviewed, and products chosen for compatibility.

BLOCK DESIGN

The block design will be created using a rail operational simulator in compliance with TP Section 11.5.4.3 Block Design, to assure safety and compliance with the prescribed headways.

The block design will interface with the existing signal system adjacent to the extension. The block design will need to tie into the Science Park central instrument house ("CIH") in terms of logic and signal wire connections during construction. Medford and Union Square branches will be designed for an operational headway of five minutes. Between Science Park and Red Bridge Interlocking, an operational headway of 2.5 minutes will be provided. A minimum recovery buffer of 25% headway time will be provided in the design to permit closer LRV headways for recovery of the scheduled headway after resolution of a service disruption. Travel time, inclusive of "on-station" dwell time, not including turn-back operation at each end-of-line station to turn LRVs from outbound to inbound direction of service will be as follows:

Distance	Travel Time Not to Exceed
Union Station to Lechmere Station	4.75 min
College Station to Science Park	14.0 min
Science Park Station to College Avenue Station	14.0 min
Lechmere to Union Square	4.75 min

VITAL PROCESSOR

Vital microprocessor interlocking systems will be as specified in Section 16859 Vital Microprocessor Interlocking Systems. Ansaldo's Microlok II equipment is proposed for the vital microprocessor system. CIH locations will have the Microlok II vital microprocessor, in a hot standby redundant configuration. All equipment will be modular in design and no single component failure will cause the vital interlocking to fail in an unsafe manner causing a less restrictive state on the railway.

The vital processor will implement and manage all interlocking functions, including route requests and alignment, switch control, and signal control. The microprocessor will enforce all locking functions (Detector, Approach, Indication, and Route). Typical vital processor interface and input/output ("I/O") includes, but is not limited to: switch-and-lock movements, Vital Microprocessor Interlocking System ("VMIS") transfer, line circuits, lock relay, track relays, switch position and locking (Back) repeater relays, line relays, vital power off stick relays, maintenance PC, status, and control panel.

NON-VITAL PROCESSOR

The interlocking and station CIHs will include a non-vital microprocessor based on the GE RX3i platform in a hot standby redundant configuration. In addition, to ensure a redundant system, a third cold standby unit will be installed and include two processor units with all the same boards specific to the VMIS units installed at the specific location.

The non-vital programmable logic controllers will receive inputs from the various control devices on the local control panels and from the OCC. Control outputs will be processed and routed to the VMIS for routing to the field equipment. The non-vital programmable logic controllers ("NVPLC") also receive inputs from the VMIS, and process outputs for indications on the Local Control and Maintaine's Panels as well as the OCC.

The NVPLC communicates with the VMIS module directly via a serial connection as shown in the contract drawings. The communication protocol between the NVPLC and VMIS will be Ansaldo's Genisys protocol. The NVPLC I/O will be fully redundant and both the normal and stand-by units will communicate with this I/O via GE Profinet controllers and scanners.

The NVPLCs will communicate with the OCC via normal and stand-by fiber optic, serial communications links, which will use the GE Remote Terminal Units ("RTU") protocol.

Each NVPLC will communicate via Redundant Ethernet network with all nodes on the networks as shown in the contract drawings and as specified herein.

TRAIN DETECTION

Track circuit equipment will be provided in accordance with the applicable requirements and recommendations of the AREMA C&S Manual, Section 8, Track Circuits.

The proposed track circuits are SIEMENS SE-3 100 Hz, steady energy, single and double rail track circuits illustrated in **Figure A5.2.1-3**, configured to have a shunting sensitivity of 0.25 to 0.5 ohms. These units will be installed at all locations provided from the contract drawings, and tested to validate that they are functioning before they are brought into service.

TRACK CIRCUITS

Double-rail, 100 Hz, phase-selective, steady-energy track circuits will be implemented within interlocking limits using SE-3 as manufactured by SIEMENS according to TP Exhibit 2A Section 16819.

Figure A5.2.1-3: Track circuits proposed by GLP have been successful on various projects, have no moving parts and require no regular maintenance.

Track circuits will be designed to detect insulated joint failure and to tolerate the effects of current imbalance without reliability failure. Lightning arrestors and fuses will be used for circuit protection on all track circuits per the contract drawings.

100 HZ FREQUENCY CONVERTERS

In compliance with the specification TP Exhibit 2A Section 16862, 60 Hz to 100 Hz frequency converters will be provided. Pacific Power Source Model 390G, installed at the normal and secondary source location, is proposed. These units supply normal and secondary feed to the 100 Hz signal power lines.

IMPEDANCE BONDS

In compliance with the specification TP Exhibit 2A Section 16823, the impedance bonds provided will be tuned for 100Hz, double rail, steady energy AC track circuits. Impedance bonds mounted between the rails will be protected against dragging equipment in both directions by steel ramps.

AUTOMATIC VEHICLE IDENTIFICATION

An H&K Model HCS/R based system will be used for the AVI system. The H&K system that is being provided will be fully compatible and also integrated with the existing system currently in place on the Green Line.

The H&K equipment and the design functionality being used for the AVI system will comply with the requirements of TP Exhibit 2A Section 16821 and the contract drawings provided.

WAYSIDE PUSH BUTTONS

The Motor person's Route Select Push Button boxes will be used to request train routing from the train operator. The Motor person's Route Select Push Button boxes and components boxes will comply with the requirements of TP Exhibit 2A Section 16821 and the contract drawings provided.

Each push button assembly will consist of a push button box, equipped with recessed buttons, illuminated light-emitting diode ("LED") indicators, identification plates, and all necessary appurtenances and wiring required to install a fully operational device.

SWITCH AND LOCK MOVEMENTS

All switch mechanism components will comply with the requirements of TP Exhibit 2A Section 16811 and the contract drawings provided. Power switch-and-lock mechanisms will meet the requirements established by AREMA C&S Manual Part 12.2.1, where the AREMA requirements do not conflict with any requirement specified in this Section.

Alstom Model 5F Dual Control Switch Machines are proposed, and will include all ancillary equipment that the GLP Design Team deems necessary, with the approval of MBTA.

Power switch-and-lock movement layouts will include an electric switch-and-lock movement, pedestal mounted junction box, throw rod, insulated hinged front rod, point lug, lock rod, detector rod, shims, identification numbers and letters, all required screws, nuts, washers, pins, grease fittings, cotter keys, plates, adjusting brackets, extension plates, saddle plates, and all hardware to mechanically couple the power switch-and-lock movement layout to the track switch points, and to mount the movement on the ties.

Complete hand throw switch-and-lock movements with electric lock layouts, intended to be used for emergency operations only, will be provided as crossover locations at Red Bridge interlocking and just east of Magoun Square Station.

SWITCH HEATERS

All snow melter components will comply with the requirements of TP Exhibit 2A Section 16850 and the contract drawings provided.

Snow melter layouts will consist of electric-type heater units functioning in a manner to keep the switch points free and clear of snow or ice to the extent necessary to permit free and unobstructed operation under all weather conditions.

Each switch snow melter layout will have the following components: heating elements, external cable, conduit, rail connections, and other miscellaneous hardware required to mount and interconnect it to the rail and the associated snow melter control case.

RELAYS

Vital relays will be SIEMENS ST1 (equivalent to Ansaldo PN150B) and ST2 (equivalent to Ansaldo PN250B).

SIEMENS Type ST1 and ST2 Vital Circuit Signal Relays are compact plug-in circuit switching elements housed within a clear plastic case for use in modern railway systems. These relays incorporate the required control characteristics as well as operating security for this application. Type ST1 and ST2 relays fit into the common size 1 and 2 sockets. The relays are interchangeable with existing types of relays and carry a registration plate unique to that specific relay type.

GLP proposed relays have been in service for more than 10 years on the following freight and transit railroads: MBTA, Southeastern Pennsylvania Transportation Authority (SEPTA), Norfolk Southern (NS) Railway, Union Pacific Railroad (UPRR), BNSF Railway (BNSF), New York City Transit (NYCT), Metro North Railroad (MNRR), New Jersey Transit (NJT), San Diego Metropolitan Transit System (MTS) Corporation, Chicago Transit Authority (CTA), and Phoenix's Valley Metro Rail (VMR). In addition, SIEMENS relays have been successfully interfaced to the following vital microprocessors: Microlok II, VHLC, VPI, and iVPI. Mean Times Between Failures for the various relays average greater than 300,000 hours.

PANELS

Local Control, Maintainer's, and Status and Indication Panels will be provided in compliance with TP Exhibit 2A Section 16838 and the basic requirements in TP Exhibit 2A Section 16801.

MAINTENANCE COMPUTERS

Maintenance computers will be designed as an integral part of the processor-based systems. Two maintenance computers, each with its own monitor, keyboard, and mouse, will be associated with each field location to allow for the simultaneous monitoring of redundant systems or the simultaneous monitoring of the online VMIS and non-vital system. The maintenance computers will have all necessary applications installed for monitoring all processor-based systems. They will also have all application tools needed for remote access and management of systems on the same network. Capabilities other than system monitoring will require authentication.

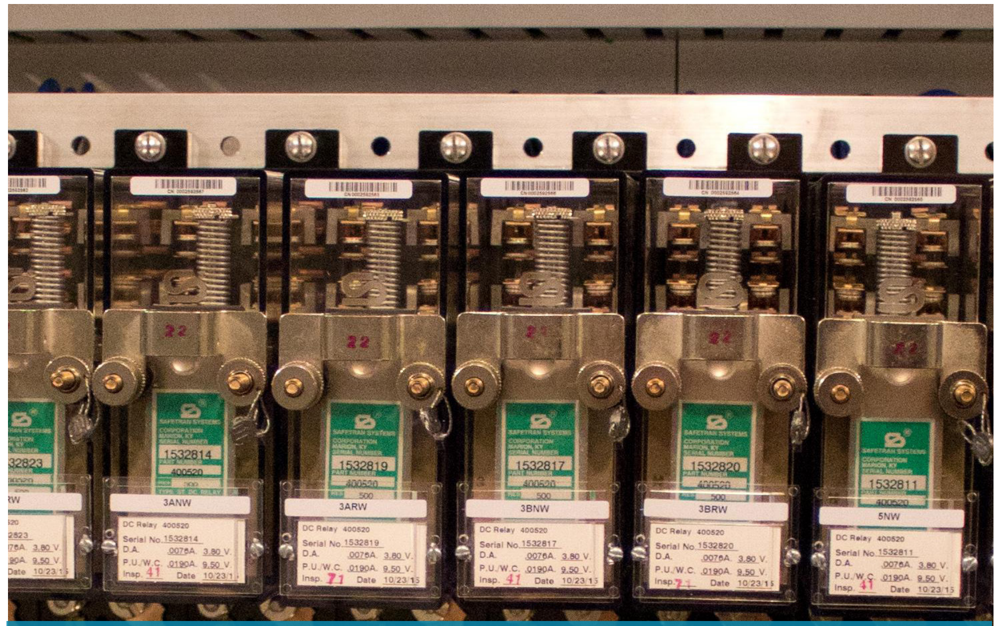


Figure A5.2.1-4: GLP proposed relays have successfully been in service for various agencies around the U.S., including MBTA.

The maintenance computers will be solid-state hardened equipment designed to function in the harsh environment of an electrified transit system, without requiring a fan for internal cooling.

EQUIPMENT HOUSINGS

CIHs, typically 10 feet by 40 feet, located as shown on the drawings, will house all functional signal system elements. CIHs will be sized to accommodate all signal equipment, plus 20% usable spare capacity for future equipment.

CIHs will be located in the vicinity of stations, at interlockings, and as needed to avoid cable runs of excessive distances.

Equipment racks will have standard open frame configuration, be shock mounted, and isolated from ground. All racks and equipment chassis will be discretely grounded to the CIH ground bus with ground cable, using pre-wired connections tested during the FAT.

CIHs will include all necessary electrical sources; lighting; heating, ventilation and air conditioning ("HVAC") systems, means of cable entry, pre-wired cable racks, and fire suppression systems. The HVAC system will be a two-part system and will not use air transfer with the outside as a means of cooling or heating.

CIHs will have a minimum of two entry doors that both lock and will be installed on foundation piers with cable entry from below.

Junction boxes will be used as needed and provide adequate space for triple or double post terminals as needed, terminal boards, cable slack, and all other necessary appurtenances. Insulated “gold” test nuts will be used instead of test links.

CENTRAL INSTRUMENT HOUSE POWER

Power for CIH lighting, utility outlets, HVAC, and the fire protection system will come from a separate dedicated 480 V AC 3-phase ungrounded system power feed from the closest substation.

The 480 V AC feed will interface with the primary side of the automatic transfer switch that selects the power source for the stations, unlike the signal power feeds that receive their power as a single phase and ungrounded from two different substation sources.

The 480 V AC utility feed with ground will provide power to the CIH utility loads through the required disconnect switches, transformers, breaker panels, etc. The design and sizing of the utility power delivery system will be based on the design and calculated utility loads in the CIHs. The CIH with the greatest load will be used as the basis for the other CIHs.

LOW-VOLTAGE SIGNAL SYSTEM POWER

Vital Systems (B12)

All vital systems internal to the CIH will operate on a 12 V DC battery system (“B12”). The B12 source will be ungrounded.

The battery bank will be of sufficient capacity to support all systems powered by the B12 for a minimum of eight hours. The batteries will be lead-acid-based, and sealed for ease of maintenance. The design will be supported by calculations that project the entire load that must be supported by the B12 power source, as well as the proper size for all components and cabling.

The batteries will be charged by redundant battery chargers connected to the batteries in parallel. Each battery charger will be capable of individually supporting the full system load plus 50% for expansion, in addition to charging a completely discharged battery bank. The chargers, together and individually, will be capable of supporting the entire load with the batteries disconnected.

The B12 battery chargers will be powered from the 60 Hz BX120 source, and will be wall- or rack-mounted.

The batteries and charging system will be designed so that the batteries and chargers can be isolated through the use of fused disconnect switches for maintenance or replacement.

Non-Vital Systems (B24)

All stand-alone non-vital systems internal to the CIH, if used in the design, will operate on a 24 V DC battery system (“B24”). The B24 source will be ungrounded.

The battery bank will be of sufficient capacity to support all systems powered by the B24 for a minimum of eight hours. The batteries will be lead-acid-based, and sealed for ease of maintenance. The design will be supported by calculations that project the entire load that must be supported by the B24 power source, as well as the proper size for all components and cabling.

The batteries will be charged by redundant battery chargers connected to the batteries in parallel. Each battery charger will be capable of individually supporting the full system load plus 50% for expansion, in addition to charging a completely discharged battery bank. The chargers, together and individually, will be capable of supporting the entire load with the batteries disconnected.

The B24 battery chargers will be powered from the 60 Hz BX120 source. The battery chargers will be wall- or rack-mounted.

The batteries and charging system will be designed so that the batteries and chargers can be isolated through the use of fused disconnect switches for maintenance or replacement.

Line Battery (LB12)

A 12 V DC Line battery (“LB12”) will be provided to support low-voltage functions external to the CIH. Redundant 12V DC power supplies will generate/charge the LB12. The LB12 source will be ungrounded.

The LB12 system will be sized according to the calculated load plus 50% spare capacity for expansion. These calculations will also determine the proper size for all cables and fusing.

The power supply will be wall or rack mounted.

Operations Control Center Interface

The non-vital systems will interface directly to 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.

Control and indication functions included in the non-vital system will be per the design and interface requirements with the OCC.

Code-Bit Assignment Sheets will be developed in conjunction with MBTA OCC staff, to define all control and indication data bits to be transmitted and received.

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 designed to manage all vital and non-vital communication between the CIHs. A separate OCC Field Network will be designed to manage communication between the respective CIH and OCC.

The design will partition the network bandwidth through the use of secure local area networks (“S-LANs”). The design will identify all data to be transmitted over the network including origination and destination, frequency, and packet size to determine the necessary bandwidth for each type of data. The data will be functionally isolated so that a failure that disables one functional path will not degrade the overall functionality of the signal system and its support of service. The redundant path with its data will support full system functionality.

Figure A5.2.1-5: GLP will provide reliability through battery backup power to safeguard the integrity of the signaling system

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.

Signals

All signals supplied will be in accordance with AREMA 2014 Communications and Signals Manual Part 7.1.1, Recommended Design Criteria and Functional/Operating Guidelines for a Color Light Signal, Doublet-Lens Type, with the lenses arranged in a vertical row. The Signals Components for the signals listed below will also comply with the requirements of TP Exhibit 2A Section 16817 and the contract drawings provided.

- **Wayside Signals –** The color light signal layouts will be both wall- mount and pedestal-mount type, and use LED lighting if this allowance is selected.
- **Train Approach Indicator (“TAK”) –** In compliance with the specification, the color for the TAK will be clear or lunar white and use LED lighting

SIGNAL SYSTEM TESTING

The signal system will undergo standard MBTA static testing as an independent GLX system. Once the system has been verified to function with the static test, then the dynamic test will proceed. with the operation of trains on the GLX. Once the dynamic testing is completed, the signal system will be cut over and tested to operate with the rest of the Green Line. This will be performed with assistance from MBTA with operating trains once all safety aspects have been verified. In addition to signal system testing, the entire system will be subject to the System Integration Tests described earlier in this section.

CIRCUIT PROTECTION

The grounding system for signal houses, signal cases, signal racks, and signals will comply with the specification TP Exhibit 2A Section 16803.

All signal cases, houses, racks, and equipment rooms will be designed, fabricated, and installed in accordance with AREMA 2014 Communications and Signals Manual Parts 11.1.1 (Recommended Functional/Operating Guidelines for Electrical Safety), 11.2.1 (Recommended General Practices for Electrical Surge Protection for Signal Systems), and 11.3.1 (Recommended Design Criteria and Functional /Operating Guidelines for Primary Surge Protectors for Electrical Surge Protection of Signal Systems).

All track circuits will be protected from lightning, and all electronic equipment will be protected by secondary surge suppressors in addition to primary lightning arrestors.

A5.2.1.B.1.A
S&TCS ARCHITECTURE

The overall architecture of the Signaling & Train Control System ("S&TCS") will comply with the design requirements by MBTA in the RFP.

Specifically, the S&TCS system will comprise track circuits and other wayside equipment, including signals and switches. These devices will be connected to a computer-based interlocking system through a communications network composed of fiber optic cable, network switches, and other related equipment. Two critical interlocking houses are located at Red Bridge and Brick Bottom. For example, Red Bridge will control the critical turnout for the division between College Avenue and Union Square.

The two interlocking plants will communicate through a fiber optic network to the central dispatch system at the OCC. The OCC will be the primary interface between dispatchers and the train control system. The dispatch system will provide higher functions, such as route setting, that will allow dispatchers to monitor and control rail operations.

Figure A5.2.1-6 illustrates the signal system layout as currently designed by GLP.

A5.2.1.B.1.B
INTERACTION

As discussed previously, the proposed wayside signal system is a single-direction, color light, two block signal system that communicates movement authority by means of various signal aspects conveyed to the vehicle operator, while the AVI system uses both wayside and car-borne components. Interaction of the S&TCS and the revenue and maintenance vehicles occurs by use of the Thumbwheels (No. 7 Vehicle) or Touchpads (No. 8 Vehicle). These are used to set a route code on the car-borne equipment. At AVI locations, this code is transmitted to the wayside equipment, which reports the vehicle location to the OCC and

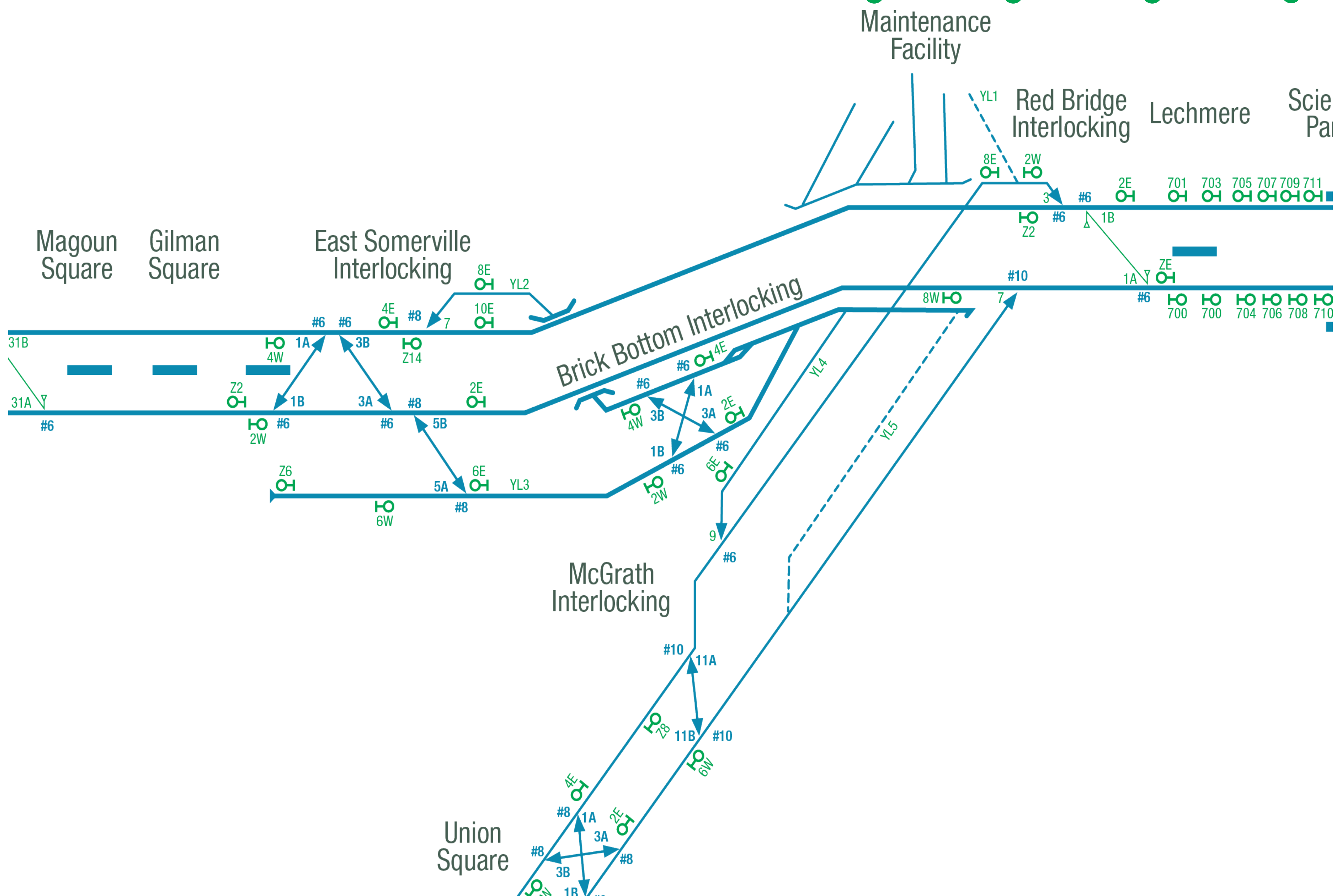


Figure A5.2.1-6: GLP has designed the signals system to seamlessly integrate and allow easy MBTA Operations and Maintenance.

makes requests to the signal system to clear and line the appropriate routes. Maintenance vehicles and yard operation are controlled by MBTA staff under the MBTA operating procedures for the VMF.

Train Status Display

The train status display system will provide a complete visual indication of track block occupancy, switch positions, train identification, signal indications, as well as other field conditions and alarm indications.

Power Control Display/Control Panel

This system is a function of the power dispatchers that are located at the OCC, and provides a display and the appropriate console detail for full control and monitoring of the TPSSs. Control of the OCS is also maintained through this system for all segments of the OCS-equipped rail and bus network, which includes the MBTA Green Line.

A5.2.1.B.1.C
FALLBACK OPERATION

The S&TCS will be designed with subsystem redundancy to ensure high reliability of rail operations. These subsystems are as follows:

Communication System: the communication system will comprise of redundant fiber cables, network switches, backbone switches, and communication ports to the different subsystems.

Computer-Based Interlockings: the interlocking plants will have redundant modules such that a failure of one will result in a seamless failover to the other module. Redundant power supplies and communications lines with also ensure high reliability.

Dispatch System: the dispatch system will contain two separate processors, memory units, power supplies, and communication ports.

In the event of a subsystem failure the overall design will be such that system safety will not be compromised, and system reliability will be maintained.

A5.2.1.B.1.D

YARD CONTROL STRATEGY AND INTERFACE

Yard Control Strategy: The VMF will be designed such that LRVs operate in the VMF yard compliant with MBTA operating rules contained in Exhibit 2H without impact to revenue service of the system, with train movements in the yard under the control of the yardmaster. The limits of VMF yard operations will be the points on the yard lead tracks where LRVs are "clear" of revenue service on the Branch lines.

Interface to Mainline S&TCS: Interface to the mainline is via the three proposed yard lead tracks. A single track yard lead will be provided to directly connect VMF yard operations to the Union Square Branch outbound track. A two-track yard lead will be provided to connect VMF Yard operations to the Medford Branch at Brickbottom Interlocking. Yard leads will support LRVs operating in either direction; either entering service or exiting service.

Wayside push buttons and AVI points will be installed where trains enter and exit from the yard lead tracks to the mainline. Wayside push buttons will function as the primary route request where trains enter service from the yard, with AVI route selection and functionality as an override to cancel or change a route request. The AVI system will decode the route number from the vehicle and transmit route requests to the non-vital systems based on the Code Control Box ("CCB") settings on the vehicle, and transmit vehicle and route data to the OCC for integration into system data and dispatcher display.

The AVI field equipment will be supported by an uninterruptible power source and will keep the AVI system online for the same duration that the vital systems within the CIH remain online.

A5.2.1.B.2

S&TCS INTEGRATION WITH VEHICLES

All activities and provisions for controlling inspections and for testing Project supplies and services related to the vehicles for the purpose of validating the GLX is described in a Project Test Plan ("PTP"). The PTP defines the overall approach, and the organization necessary to consistently carry out inspections and tests on all components of the system to demonstrate compliance with contract requirements, and to enable commissioning. The PTP refers to specific test plans that implement the inspection and test process for each individual subsystem and/or area of activity.

Inspection and testing activities for the Project are organized around the two main levels of the test and commissioning process:

- Factory inspection and acceptance tests are carried out at the subsystem level by Verification and Validation engineers, supported by System Engineers.
- Inspection and testing on-site is performed by a dedicated Test and Integration Team.

Once the factory-validated system is shipped to the field site, further testing validates the system's functional operation with the actual field equipment. Site integration and site validation testing takes place, after which the system-level integration testing begins. This project phase is necessary to allow for resolution of any interface or operational concerns discovered in the field. A database is established to track any issues that may arise through to mutual resolution and acceptance. At this point in the Project, the system will be commissioned for service operation.

Inspections and tests are conducted during manufacturing, construction, installation, and on-site to ensure compliance with those requirements and a test or inspection plan will be completed prior to start. These plans detail their objectives and success criteria as well as the methodology by which the test or inspection is conducted. Inspections are focused on verifying that the products satisfy the specifications and conform to applicable standards. Management reviews are also used to control the Project through adequate allocation of resources. A generic Master Test Plan, Factory Test Procedures, and Field Test Procedures will be provided. Datasheet results for factory ("FAT") and field testing will be submitted.

The vehicle interface with wayside signaling systems can often present problems. For example, there is an interface between train wheels and the rail whereby the train shunts, i.e. completes the electrical circuit, of a track circuit. Proper shunting is necessary for the signaling system to locate train position within the system. Shunting can often present problems where there is insufficient contact with the rail. This may be caused by various problems, including rust, corrosion, or materials such as dust and sand. Rail grinding or cleaning is usually performed to resolve this problem.

Communication problems can exist between train-to-wayside radio-frequency ("RF") transponders and train-borne antennas when used for additional train positioning. This is often caused when the transponders do not emit a field sufficient for the train to read. Antenna-to-transponder communications are usually resolved by increasing the gain from the transponder (if energized) or the antenna (if the transponder reflects the signal).

Problems can occur with train-to-wayside radio communications, and usually these problems occur within tunnels. Proper positioning of wayside antennas is the key to ensuring adequate communications with the rolling stock to eliminate dead zones of coverage.

A5.2.1.C

COMMUNICATION SYSTEMS DESIGN

The communications systems will provide all the necessary functions to support the operational requirements of the GLX. A redundant and resilient fiber optic backbone will be routed along the LRT alignment with a combination of aerial and underground installations throughout the alignment and into the VMF, Transportation Building, signals and communications systems, TPSS, and passenger stations for the new extension, routing back to the Remote Office Control Center ("ROCC") at 45 High Street. In addition, a separate fiber optic cable will be installed to support the signal system. The Systems Connection Diagram in **Figure A5.2.1-7** identifies the communication subsystem that will be procured, installed, configured, and tested along the new MBTA GLX.

All voice, video, and data signals from the communications systems will be routed over the fiber optic backbone via the new and existing high-speed Ethernet ("SWAN"). The CCTV system will provide real-time Internet Protocol ("IP') cameras at every station and TPSS, and at the VMF and Transportation Building. The CCTV system will provide a deterrence to crime, a sense of security to the passengers, situational and operational awareness to ROCC operators, and forensic evidence.

GLP is experienced managing S&TCS integration with vehicles on various projects similar to GLX, including Phoenix's Central Valley LRT, Los Angeles' Blue Line, and Dallas' DART system. We will implement the PTP to identify potential risks and use lessons learned and knowledge to successfully integrate the MBTA vehicles of varying with the new rail extension.

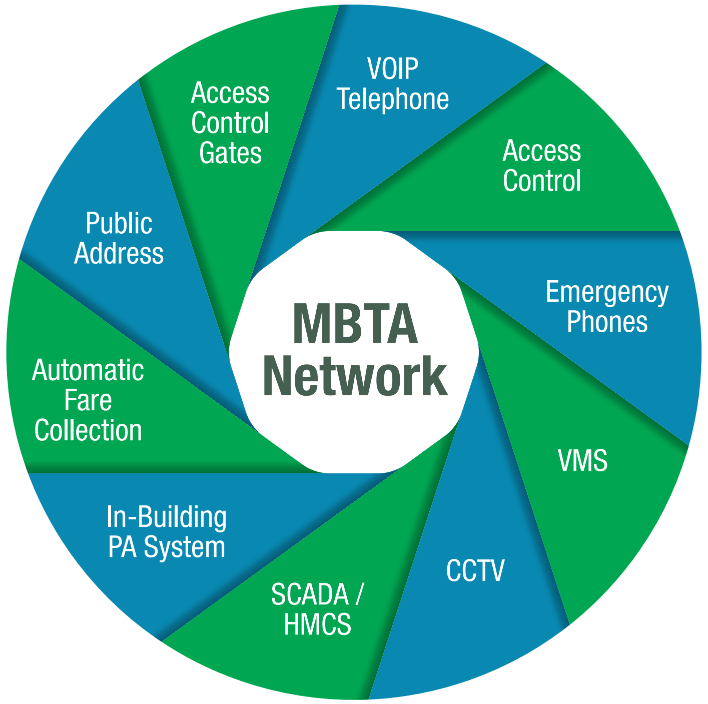


Figure A5.2.1-7: GLP has designed a resilient network that does not allow any single-point failures to effect the overall communications system.

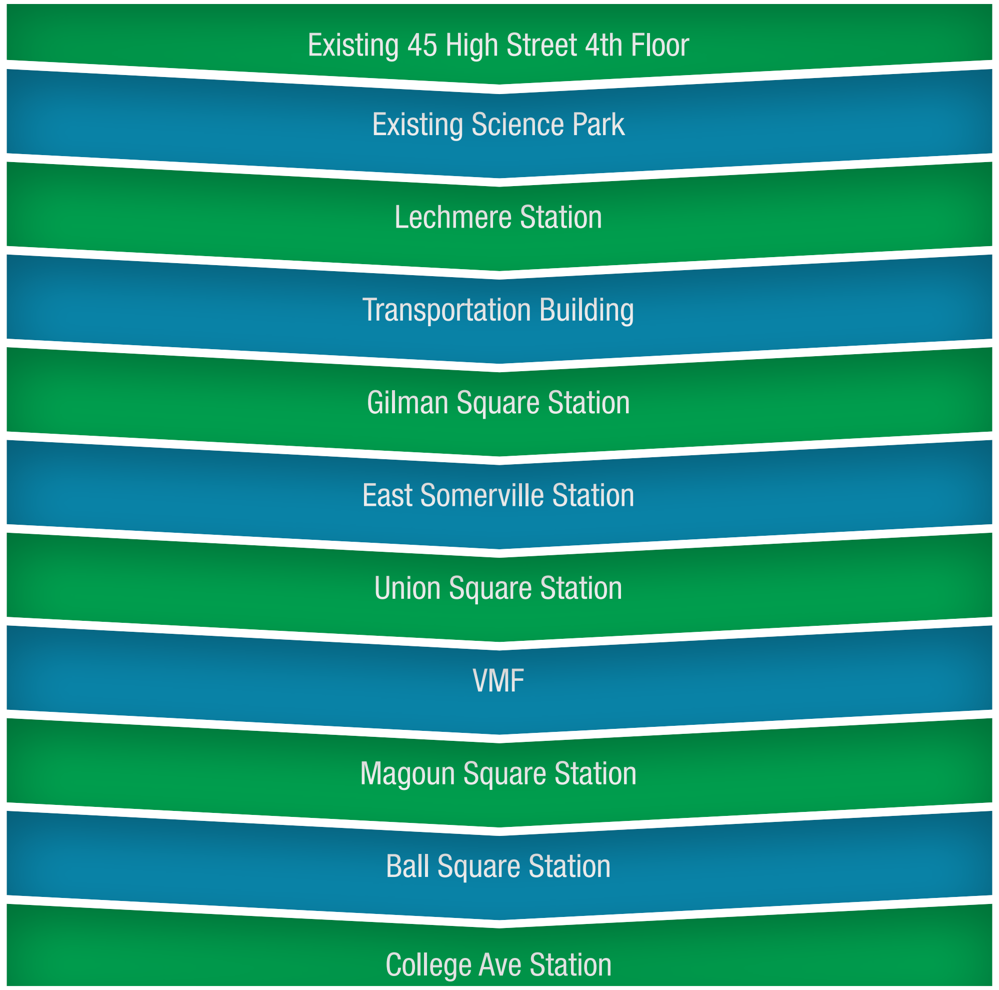


Figure A5.2.1-8: GLP has designed the communications system to seamlessly integrate and allow easy MBTA Operations and Maintenance.

The Public Address Customer Information System ("PACIS") will provide audio and visual messages regarding MBTA LRT operations to passengers at the new stations. The messages will be both prerecorded and live messages from ROCC operators. The passenger assistance telephones at each station will allow passengers to request assistance from the operators at the ROCC. The access control and intrusion detection systems on all MBTA facilities and gates along the MBTA corridor will prevent unauthorized personnel from entering the facility and possibly being injured by maintenance and operations activities.

A5.2.1.C.1
SYSTEMS TOPOLOGY/SYSTEMS CONNECTION

System communication facilities for the GLX Project will extend the existing network by providing a new 10-Gb/s Ethernet network between communication, signal, station, and traction power facilities. The 10-Gb/s backbone network will interconnect communication equipment between all stations and facilities to the ROCC for remote monitoring and control. A fiber optic cable design will consist of a 96-strand single mode backbone fiber that will interconnect all the GLX stations' communication rooms while providing lateral connections of single mode fiber optic connections to signal houses, TPSSs, Transportation Building, and the VMF, providing a communication medium back to the ROCC and police.

The fiber optic and copper communication cables will be physically separated on opposite sides of the right of way ("ROW") on messenger cable installed on the OCS poles, and in new cable troughs, where available, along the new GLX alignment. New fiber optic cables will primarily be installed on aerial messenger cables along the GLX corridor as appropriate.

The new 96-strand fiber optic cables will provide network connectivity to SWAN and WAN networks. The fiber optic network will support the corporate network, the SWAN for the CCTV network, connectivity to the SCADA Hub Monitoring and Control Systems ("HMCS"), automatic fare collection system, PA/variable message signs ("VMS"), access control, passenger/elevator emergency telephone, and Voice over Internet Protocol ("VoIP") telephone systems at the GLX stations and facilities.

The lateral fiber connections will provide connectivity from the backbone network switches in the communication rooms to the signal houses and cabinets, as well as TPSSs and access control gates along the new GLX alignment. Lateral fiber connections from the fiber distribution cabinets to the communication closets within the VMF and Transportation Building will also be provided to enable communications to the indoor PA system, CCTV system, and access control system.

The GLX network is designed as a dual self-healing ring that connects each of the facilities shown in **Figure A5.2.1-8**, GLX Connected Facilities. This is a resilient backbone network that allows ongoing communications with Operations given any failure in a facility or segment of the network.

A5.2.1.C.2
DESIGN AND FUNCTIONALITY

GLP's communications systems design provides the necessary communication specific elements for the new proposed stations as well as the VMF and Transportation Building.

To allow for the new GLX, the following systems will be expanded:

- Genetec Video Management System
- Genetec Access Control System
- ARINC/Rockwell Collins SCADA System
- Avaya Telephone Management System
- ARINC/Rockwell Collins PACIS System
- Cubix Fare Collection Management System

The existing ARINC/Rockwell Collins SCADA system will carry out data acquisition, processing, alarm monitoring, presentation, and archiving functions. Major application functions will include enhanced train tracking, passenger station facility monitoring, TPSS monitoring and control, determination of rail energization status, and information storage and retrieval. The SCADA system will also interconnect with the Enterprise Network for secure access by a variety of corporate users. The SCADA system user interface will consist of local operations consoles and mimic displays. High-performance consoles will be used by ROCC operations personnel to monitor and control the train control system, traction power system, and passenger stations.

The SCADA system will be designed for ease of expansion and alteration in an economical and efficient manner. Expansion and alteration include adding and removing monitored and controlled points from database and displays, adding and removing system functions, altering computer memory and input/output hardware, and expanding inter-computer data communications.

New fiber will be installed on both sides of the ROW to provide physical separation of the fiber optic network along the full length of the alignment. Station communication elements will be placed on new lighting poles throughout each station. Access control controllers, readers, and gates will be installed at all wayside locations to provide security for the facility sites. The Network Management System ("NMS") will provide maintenance staff indications of field equipment monitored by this system. Network communications between NMS and the SCADA system will be established such that selected events received by the NMS may be transmitted to SCADA for display on the SCADA workstations and recorded in the SCADA logs for historic reference and playback. The IP telephones will provide VoIP telephone communications at every station, CIH, TPSS, VMF, and Transportation Building.

A communications transmission system ("CTS") will be installed along the ROW to interconnect the various field SCADA, CCTV, data, and voice signals between the field and the ROCC. The CTS includes a fiber optic cable plant, optical and electronic transmission equipment, and other equipment necessary to provide communications between sites.

The backbone IP network system will be configured to continue to operate normally on loss of a single fiber or any single equipment module. One high-speed IP network will be provided for all data, voice, and CCTV. The Communications System Network ("CSN") will consist of an IP-based 10-Gb/s WAN in a ring configuration supporting 1-Gb/s linked spur sites, control system workstations, control system servers, video cameras, IP audio, IP telephony, and other systems. Network switches connecting local and remote sources of the Control System will be monitored and alarmed at the ROCC by the NMS.

A5.2.1.C.3

OPEN-DATA LINK

There are many design approaches that can be taken to design the open data link. The GLP Design Team will work closely with MBTA to discuss the design approach that works best for MBTA. The design will be developed to ensure expansion and that the technology used will be available after revenue service.

Vehicle and system scheduling announcements can be provided to the trains throughout the GLX alignment using an enterprise WiFi/Wireless Local Area Network ("WLAN") wireless communications link that will provide industry-leading bandwidth from each train back to the office servers at the headend. The wireless link will be designed to allow the headend servers at the office to talk to the train onboard PA/video message board system providing both audio and visual communications to the speakers and signs on board each train. Hotspot coverage can be designed along the GLX alignment with multiple overlapping access points as required by MBTA. The WiFi/WLAN wireless system will conform to IEEE 802.11 standards. This link will be designed with open architecture to allow for varying systems to use this link with proper authentication by the MBTA.

A5.2.1.C.4

INTERFACE WITH EXISTING SYSTEMS

GLP will develop the design to ensure that expansion and the the MBTA's selected technology to will be available after revenue service. All wayside communication systems proposed for the GLX will be run back to 45 High Street to interface with the existing SCADA, CCTV, PACIS, telephone, access control, and fare collection systems.

All systems will be put on the backbone network at each communication house and transported on the network back to the ROCC at 45 High Street, where each system will branch off to the appropriate server structure.

The existing ARINC/Rockwell Collins SCADA system will require additional software programming at the headend to integrate the new Green Line stations and facilities into the system. Code charts will be required to identify new control and indication points that will need to be programmed into the system. Additional graphics will be required on the Overview Display, as well as at each Dispatcher Console position, to properly display the new stations and facilities at the ROCC.

The existing ARINC/Rockwell Collins Public Address Customer Information System, including VMS, will be expanded to include the new stations and facilities at each Dispatcher Console position at the ROCC. Additional software programming will be required to add the new stations onto the existing system.

The indoor PA speaker system will be designed to provide adequate coverage for the VMF, Transportation Building and other GLX facilities, and will meet NFPA 72 requirements. Moreover, the system will be designed to meet the Massachusetts Fire Marshall requirements when used as part of the combined building fire alarm system.

The existing Genetec Video Management System will require additional licenses and software programming to include the new cameras required for the expansion. Additional Network Attached Storage ("NAS") and Recording Servers will be required to support the new cameras for the stations, VMF, and Transportation Building.

The existing Genetec Access Control System will require additional licenses and software programming to include the new controllers, card readers, and gates for the new stations and facilities.

The existing Avaya Telephone Management System will require additional licenses and software programming to include new PBX and Emergency phones for the new station and facilities.

A5.2.1.D

TRACK WORK SYSTEM DESIGN

A5.2.1.D.1

OVERALL APPROACH AND DETAILS OF TRACK WORK SYSTEM

GLP's Lead Designer, WSP, earned its experience with Green Line track design through its work on the North Station project, the environmental phase of GLX, and the 30% design for Lechmere Station when it was part of the NorthPoint development project.

The GLX Project involves two rail systems, each with its own track work design standards:

MBTA Commuter Rail Standards include:

- MBTA Commuter Rail Design Standards Manual ("CRDSM")
- MBTA Book of Standard Plans, Track and Roadway ("BSP")
- MBTA Track Maintenance Standards
- MBTA Railroad Operations Directorate
- MBTA MW-1
- NFPA 130
- AREMA Manual for Railway Engineering and Portfolio of Trackwork Plans
- MBTA Green Line Rail Standards include:
- MBTA Maintenance of Way (MoW) Division Green Line LRT Track Maintenance and Safety Standards ("LRTMSS")
- MBTA MoW Book of Standard Track Plans ("BSTP")
- NFPA 130
- MBTA Material Spec 9251 – Subballast
- MBTA Railroad Operations Book of Standard Plans Dwg. No. 1030
- Transit Cooperative Research Program ("TCRP") Report 155
- TCRP Report 71
- ASTM

Figure A5.2.1-9: GLP completed a preliminary analysis of the track alignment and has developed enhancements to the GLX Project design.

GLP's approach to design of the relocated commuter rail tracks starts with the geometric design, which is constrained both horizontally and vertically by the multiple overhead bridges. Track vertical and horizontal alignments will be designed for FRA Class 5, which is the standard of the MBTA commuter rail system.

GLP's approach to GLX track design started with analyzing the current design. In most cases, we found that the current design is adequate, and there is no need for further refinement.

GLP has analyzed the entire track alignment and found that some of the proposed undercutting may be reduced, and profiles can be optimized. After modeling the track alignments and profiles using CADD software, we found that the proposed alignment was set too low relative to some structures, and our design reduced the undercutting to save time and cost. We made use of the two site visits that the MBTA offered by physically confirming bridge horizontal and vertical clearances to help us to arrive at this interpretation.

GLP's proposed profile adjustments still conform to MBTA design criteria. This design will minimize the designated track outages dedicated to this activity. Our approach to geometric design also keeps one eye on the train performance simulation. While the general geometric design standard will be 50 miles per hour ("MPH"), near stations where actual train speeds will be reduced, geometrics will reflect the maximum possible speed.

Our model also gives us the ability to produce cross sections along the corridor to evaluate earthwork and assess how our new roadbed for the GLX will line up with the existing MBTA commuter rail tracks. This is important to GLP for constructability purposes, as well as to MBTA to clearly understand the permanent condition.

Once the track is built, it will meet all of the requirements set forth in the RFP. The commuter rail will include 132RE rail while the light rail tracks will use 115RE rail.

A5.2.1.D.1.A
TRACK BED STRUCTURE

The track bed provides the foundation for the track structure. The key elements include a well-compacted subgrade, well-drained subballast and ballast. A solid track bed will maintain line and grade, minimizing noise and vibration. Areas of excessive operational vibration (as defined in the Environmental Impact Report ["EIR"]) will be mitigated through the use of ballast mats.

The proposed track structure for the commuter rail tracks will consist of wood ties and ballast, and the roadbed will be in accordance with BSP Dwgs. No. 1000 and 1002. We will reuse as many existing ties as possible after visual assessments by experienced track inspectors.

The light rail tracks will also be wood ties and ballast, except within the limits of the VMF. Different cross sections are being considered in this area, including embedded track and standard track with commercial grade-crossing systems.

A5.2.1.D.1.B
SPECIAL TRACK WORK

Commuter Rail Track

Special track work includes the turnout to the Yard 10 lead, special details for curved track (rail head hardening, gauge adjustment), rail fastening systems, and ballast mats.

GLP has reviewed the various interlockings, including access to the Yard 10 facility from the New Hampshire Mainline ("NHML"), as they relate to the movements of the three operating railroads (Pan Am Railways, Amtrak, MBTA). GLP has also considered the removal of all of the retired sidings within the mainline as per Project requirements. GLP will coordinate with Pan Am Railways, Amtrak, MBTA, and any other stakeholders to make sure all operations are preserved or made better. Keolis will build and commission the new Tufts interlocking and retire the Somerville Junction interlocking. We will coordinate as needed in relation to our project.

All special track work for the MBTA commuter rail will meet current MBTA standards using the MBTA CRDSM and BSP.

Green Line Track

Special track work includes:

- Restraining rail
- Guard rail
- Turnouts
- Crossovers (revenue and non-revenue)
- Track crossings (at VMF)

For the viaducts, we have reviewed the use of direct fixation ("DF") vs. ballast deck. In consideration of design and construction considerations, we have concluded that ballast deck is both a better design and overall more economic considering construction cost. While the ballast deck results in a heavier structure, the added structural costs are offset by the savings in track construction costs. In addition, from a structural design perspective, the use of ballast deck eliminates the issue of handling rail stress associated with horizontal expansion joints on viaducts. From a track construction process, ballast track construction typically requires one crew for installation while DF involves two to three crews.

A5.2.1.D.1.C
NOISE AND VIBRATION

The design and criteria to meet the noise and vibration requirements are set forth in the EIR. We analyzed alternative methods to achieve the requirements, including the use of resilient fasteners in lieu of ballast mats. However, in consideration of the logistics and construction costs associated with the commuter rail track relocation and lowering, we concluded that the use of ballast mats was preferable in the locations indicated in the EIR.

A5.2.1.D.1.D
MINIMIZING RAIL CORRUGATION

Irregularities on wheels and rails, known as corrugations, can give rise to noise, ground-borne vibration, and more general dynamic loading, which increases damage to components of both vehicle and track. These quasi-sinusoidal irregularities can arise from minor irregularities in either the track or wheels.

Corrugations can be minimized through specific considerations in design and construction, but keeping corrugations in check also requires ongoing maintenance in the long term to preserve track alignment and proper superelevation.

A smooth rail profile is a key to minimizing the potential for rail corrugation. For this Project, we propose to maximize the use of continuous welded rail ("CWR") strings. We propose to have strings of CWR delivered by train to the Project site. This approach will minimize the number of thermite field welds and improve overall smoothness of the top of rail.

For curves, head-hardened rail will be used for the high rail. Another key consideration is to minimize actual superelevation (Ea) values in superelevated track. As we noted before, track design follows from consideration of train simulation results, so that the superelevation reflects achievable train speed, as excessive superelevation could lead to corrugations in curves. Finally, for tight curves, particularly near the VMF, we will consider the application of friction modification, which can reduce the likelihood of developing corrugations, while reducing rail and wheel wear, and reducing squealing through tight curves.

Finally, in both tangent and curved track it is necessary to avoid widening the gauge of the track. As part of the final track tamping and lining operation, gauge measurements will be verified, especially on all spirals and curves.

A5.2.1.D.2
END OF TRACK DEVICE

Figure A5.2.1-10 represents the MBTA standard bumping post for the Green Line. It is a fixed post with a head mounted at the height of the vehicle anticlimber. This detail conforms to the GLX Project requirements.

Per the MBTA CRDSM, for commuter and freight rail tracks, a Western-Cullen-Hayes Model WA bumping post or approved equal will be used on all stub end tracks. End of line stub end terminals will have energy absorbing impact attenuators capable of stopping a nine-car consistently and one locomotive traveling at 10 MPH. MBTA Reference Standard Plan 3010 and Specification 9206 will be used for the basis of design.

Per TP Section 10.2, sliding friction or hydraulic bumping posts will be installed at the ends of all stub-end tracks. Bumping posts will be designed to engage the anti-climber of the LRT vehicle. They will be designed to stop two fully loaded LRT vehicles (385 tons) traveling at 6 MPH without damage to the vehicle or the bumping post. Bumping posts will be bonded and electrically isolated from the traction power and train control systems. All bumping posts designed for the Green Line will conform to MBTA MOW Division Drawing No. 925. The lowered bumper and coupler heights on the GLX vehicles requires a bumping post designed specifically for the vehicle. The basis of design will be a Western-Cullen-Hayes Model WH or approved equal. Where standard

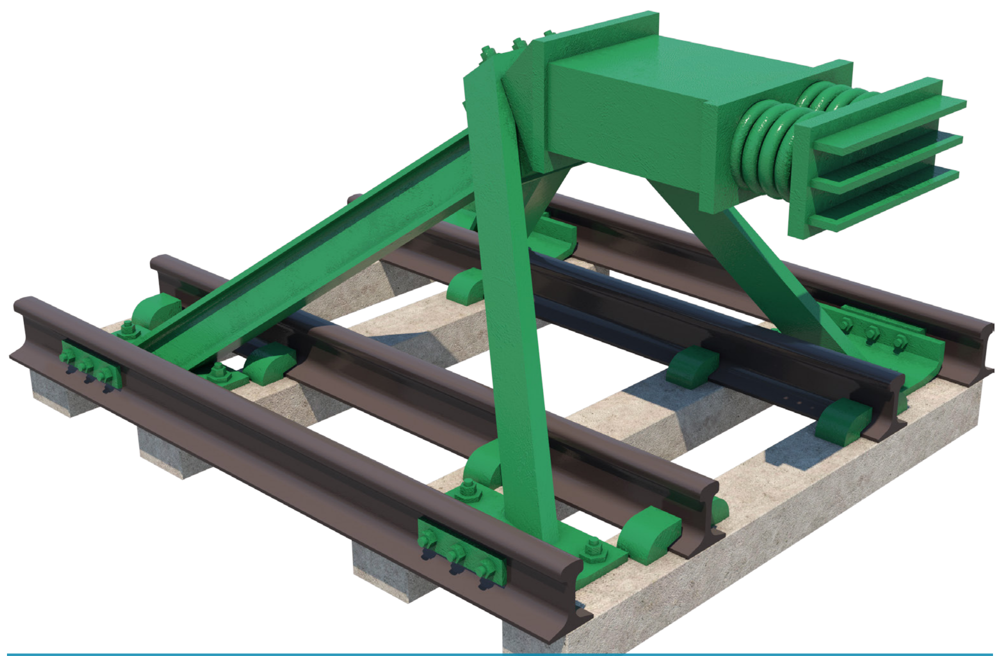


Figure A5.2.1-10: GLP is providing a standard MBTA-defined bumping post to eliminate additional staff training or special parts or tools for maintenance.

bumping posts are used on the GLX line, a Western-Cullen-Hayes Model WA or approved equal will be used as the basis of design.

A5.2.1.D.3

APPROACH TO MEETING REQUIREMENTS FOR SPECIAL TRACK WORK

Our approach for special track work is to assemble manuals for the track work standards and criteria for both commuter rail and Green Line track work. These will start with the respective MBTA standards, including any updated standards developed for the GLX Project. GLP will also consider any updated commuter rail standards that are being developed as part of the South Coast Rail ("SCR") project, for which GLP Team member WSP serves as the Owner's Representative.

These standards will be supplemented by AREMA standards where no MBTA standard exists. We will review our manual with the MBTA Track Department to confirm that GLP's design criteria and standards are acceptable to the MBTA.

As part of this process, we will consider any special requests for waivers to the MBTA standards. This process of requesting and approving design criteria waivers is being defined as part of the SCR project. We would adapt that process and waiver request form for the GLX Project.

A5.2.1.D.3.A

DESIGN METHODS AND STANDARDS

The commuter rail track design standards for special track work are included in the MBTA Commuter Rail Design Standards Manual. All turnouts will follow MBTA standards. For elements not defined by MBTA, AREMA standards will be used.

The criteria for special track work for the Green Line includes restraining rails and guard rails. These items will follow the MBTA standards for the Green Line as indicated in the TPs Section 10.2:

- Track having a centerline radius equal to or less than 1000 feet and greater than 100 feet will have restraining rail added to the gauge side of the inside rail.
- Track having a centerline radius equal to or less than 100 feet will have restraining rail added to both sides.
- Two emergency guard rails are required between the running rails on Bridge Decks, Elevated Structures and Viaducts, adjacent to Station Structures, Station Emergency Egress Structures and Fill Retaining Walls and Slopes, Bridge Abutments and Piers, and On Grades greater than 3%.

A5.2.1.D.3.B

APPROACH TO PROJECT OPERATIONS

On the Medford Branch, two interlocked No. 8 crossovers will provide universal routing will be located on the east side of the College Avenue terminal station. This provides a 15 MPH diverging speed for revenue trains that need to switch tracks to be right-hand running. This speed should be under the speed curve for the terminal operation, given the bumping post condition at the end of the tracks.

Maintenance hand throw No. 6 crossovers are located at both the Ball Square and Magoun Square stations. They interface with the Ball Square and Magoun Square CIHs, respectively. The next maintenance crossover is a hand throw No. 6 double crossover located west of the junction with the Union Square branch. When using maintenance crossovers for revenue service, a series of three stations—East Somerville, Gilman Square, and Magoun Square—will be located within one single-tracking segment. Both Ball Square and College Avenue stations will be within a single-tracking segment each.

West of the connections to the Union Square Branch is a No. 6 hand-powered crossover that will enable single-track operations at Lechmere Station and on the Lechmere Viaduct, while allowing double tracking on the Union Square Branch. This crossover is controlled by the Red Bridge CIH.

On the Union Square Branch, a powered No. 8 double crossover provides universal routing west of the Union Square terminal station in the event of single tracking on the Union Square Branch. The 15 MPH diverging speed for revenue trains should be under the speed curve for the terminal operation, given the bumping post condition at the end of the tracks. Further west is a single No. 10 interlocked crossover controlled by the McGrath CIH. A turnout to yard lead track 4 (YL-4) is located on the Union Square eastbound (US-EB) track.

The Union Square Branch eastbound track connects to the Medford Branch eastbound track with an interlocked No. 6 turnout, allowing for a 10 MPH diverging speed. The Union Square westbound track connects to the Medford Branch westbound track with a No. 10 turnout, allowing for a 15 MPH diverging speed.

A5.2.1.D.3.C

SPECIAL TRACK WORK DESIGN

As stated previously, special track work design will be in accordance with the design manuals assembled and reviewed with the MBTA.

A5.2.1.D.4

SPECIAL TRACK WORK DRAWINGS

GLP has provided special track work drawings in the end of this document on drawings of document. Drawings 000-K-3000, 000-K-3101, 000-K-3200,000-K-3201 indicate the following:

COMMUTER RAIL DRAWINGS:

- Typical detail of curved track inducing head-hardened rail and gauge adjustment based on degree of curvature
- Details of rail fasteners
- Details of ballast mat
- Detail for turnout
- Detail of insulated joint

Figure A5.2.1-11: GLP's approved Alternative Technical Concepts (ATC) offers prefabricated TPSSs that will allow MBTA to witness full functional testing in the factory, thereby eliminating unknown conditions and eliminating potential schedule impacts.

GREEN LINE DRAWINGS:

- Details for single and double restraining rail
- Details for guard rail
- Details for switches and frogs in turnouts
- Detail for crossover (revenue track)
- Detail for crossover (emergency/maintenance use)
- Detail of insulated joints, including joints in restraining rail.
- Detail for track crossing at VMF

A5.2.1.E

TRACTION POWER SYSTEM DESIGN

The GLP Team will verify and detail the traction power sectionalizing that is proposed, based on the load flow that was already prepared. GLP will incorporate the MBTA pre-purchased new equipment in one of the new TPSSs with the understanding that all detail information, such as schematics, wiring diagrams, manuals, etc., will be provided to us for the detail design. The remaining DC disconnect switches will be supplied by the GLP Team to complete the substations. The equipment for the two other TPSSs will be supplied as directed by the TPs. This combination will form three double-ended substations, each with two 3-MW transformer rectifiers with outdoor, oil filled transformers at Red Bridge, Pearl Street, and Ball Square sites.

A5.2.1.E.1

TRACTION POWER DESIGN PROCESS

The 13.8 kV network will be designed with redundancy as specified, and where possible the duct banks will be routed in the opposite sides of the right of way. Where this option is not possible to exercise, a 6-foot minimum separation will be planned to avoid single mode failure. GLP will verify that the alternate supplies from the Eversource Utility Company are from independent substations, or independent buses.

The design process will use the information compiled in the existing load flow study to verify the ampacity needed for all (typical) feeders. The ampacity calculations will use a commercially available computer program, CYMCAP by CYME, that will model the duct bank, and the surrounding soil thermal resistivity, for accurate assessment and adequate margin.

Each TPSS will be provided with a ground grid to assure safe step and touch potential. The ground grid will be designed per IEEE Std. 80 with a commercially available computer program, AutogridPro, by SES. GLP will conduct soil resistivity tests at each substation location, and following the installation, will verify the calculated ground grid resistance by conducting tests at each site in conformance with IEEE Std. 81. The ground grid design will be based on the maximum short circuit data provided by the power utility company.

Each TPSS will be equipped with 125 V DC battery sized per IEEE Std. 485 to meet the needs of the substation for a minimum of eight hours following a battery charger failure. Also, each TPSS will be equipped with emergency trip station ("ETS"), and transfer trip capability to isolate the adjacent substations if needed.

A5.2.1.E.2
TRACTION POWER DESIGN, FAILURE MODES, AND MITIGATIONS

The failure modes are anticipated in the existing load flow study for the first and second contingency operation for a 5-minute headway. Provision will be made as required in TP Section 11.1.2.1 paragraph b) (i) to close the tie switch at each end of line location (Union Square and Ball Square) in order to connect the OCS of each track together. This provision is in addition to bypass switches at the TPSSs. The bypass switches will be equipped with an auxiliary switch to change the normal relay settings to the contingency operations relay setting automatically. For this purpose, the desirable location for the disconnect switch is at the substation.

A5.2.1.E.3
TRACTION POWER DIAGRAM

Traction power is located on Drawing SYS-TP-0033.

A5.2.1.F
OVERHEAD CONTACT SYSTEM ("OCS") DESIGN

A5.2.1.F.1
OVERALL APPROACH

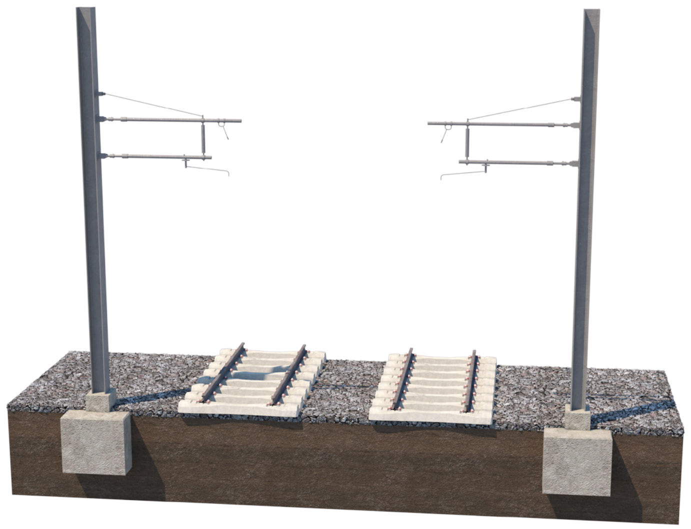
The following is an overview of the OCS system being proposed:

- On the mainline, a simple auto-tensioned OCS comprising a 4/0 bronze alloy 80 contact wire and a 19 strand copperweld 4/0 messenger wire will be used. All components will be designed in accordance with MBTA standards, and will be compatible with the existing MBTA system.
- In the yard, a single trolley wire will be used with a spring tensioning system.
- A pantograph security analysis will be performed in accordance with UIC 606-1 to determine maximum pole spacing on curves to maintain the contact wire height between 12 feet-6 inches and 19 feet-0 inches, with a nominal contact wire height of 15 feet-0 inches. MBTA LRVs and trolley pole-equipped work vehicles will be considered in the analysis.
- Mechanical non-bridging section insulators will be used to sectionalize electrical sections at TPSSs and in crossover tracks. No insulated overlaps will be used for sectionalizing.
- On approaches to overhead bridges, the OCS will be graded in accordance with MBTA's standard contact wire gradients, and special hardware/OCS designs will be utilized to accommodate any reduced clearances.
- OCS poles will be tubular or wide flange, located on the outside of the tracks, using base plates, anchor bolts, and embedded poles. Tubular poles will only be used to replace the existing tubular poles over the viaduct section, with wide flange poles to be used throughout the rest of the Project.
- Weight stacks for tensioning will be suspended from wide flange poles. Between East Somerville Station and College Avenue, where clearances are tight, weight stacks cannot be installed. It is proposed that large spring tensioners be used at these locations.
- The sectionalizing on the existing section on the historic viaduct between North Station and Land Boulevard will be revised to electrically separate the two tracks. The OCS will be designed to permit the existing system to remain in service until the cutover of the new system.
- Components of the OCS design include:
  - Pantograph security analysis
  - Conductor tension calculations
  - Typical arrangements
  - Pole details
  - Foundation details
  - Pole grounding
  - Surge arresters
  - Mainline layout plans
  - Yard layout plans
  - Mainline and yard sectionalizing
- OCS design will be based on the following criteria, adapted to local conditions as needed:
  - RFP
  - MBTA Design Criteria
  - National Electric Safety Code ("NESC")
- GLP's design will provide for a robust OCS to meet Project criteria, withstand local climatic conditions and integrate with the existing OCS and traction power systems.
- GLP's design will use industry tested and proven materials, compatible with existing MBTA components and MBTA specifications, that are constructed by experienced contractors.

A5.2.1.F.2
OCS SECTIONALIZATION

OCS sectionalizing will be provided using non-bridgeable section breaks and manual disconnect switches. Section breaks will be provided at TPSSs and interlockings, and will be coordinated with the signal system design to provide maximum operational flexibility when sections of

A



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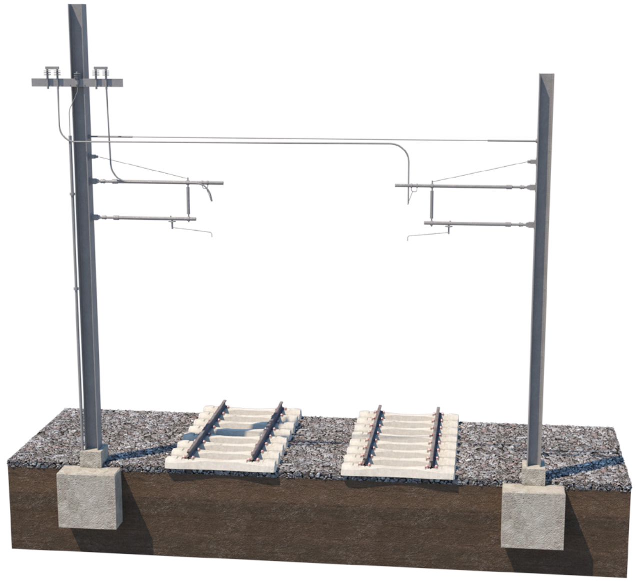

Figure A5.2.1-12: GLP has utilized common MBTA pole arrangements to ease training requirements for maintenance staff shown in A. In B, GLP is using MBTA common hardware to simplify maintenance after revenue service begins.

track must be removed from service either for fault isolation or routine maintenance. Sectionalizing will also be coordinated with the interfaces with the existing system, and with the proposed phasing in of the new systems. Section breaks will be located to avoid areas where trains are stopped or traveling at low speeds.

A5.2.1.F3
POLE ARRANGEMENTS

There are two basic OCS pole arrangements. **Figure A5.2.1-12 (A)** depicts a typical arrangement in areas of dual track with independent poles serving each track. **Figure A5.2.1-12 (B)** shows an OCS pole arrangement at a typical location where a feeder is connected to each track contact wire. Additional information on pole arrangements are located on drawings 000-C-0001 TO 0028.

A5.2.1.G
AC VOLTAGE DISTRIBUTION

A5.2.1.G.1
AC VOLTAGE SERVICES

The AC voltage will be distributed at 13.8 kV from independent utility supply buses. The Pearl Street substation (#53) will also act as an AC switching station to feed Ball Square substation (#54). A load flow and short circuit study will be performed to optimize the cable sizing for the AC distribution system. The distribution circuit breakers will be equipped with appropriate logic and protective relays to maintain selective tripping of the effected sections to avoid nuisance tripping. RTU at each substation will monitor the circuit breaker position via a normally open and a normally closed contact for notification at the OCC. In addition, alarms and indication of the protective relay operation will be available at the OCC.

A5.2.1.G.2
REDUNDANCY AND UPS

All essential power supplies will be serviced from double ended buses, with independent sources. For example, Eversource will be providing two separate feeds from different substations to feed the TPSS at Pearl Street and Red Bridge. Tow ring feeders will be installed by GLP between Pearl Street and Ball Square TPSSs.

Essential functions such as SCADA will have a dedicated internal battery, and Uninterruptible ("UPS") backup for reliable remote operation. The battery will be sized for eight hours of continuous operation.

Other essential services, such as emergency lighting, will use UPS units, which will be stand-alone or an integral part of the equipment, and have a redundant inverter system that is battery-backed. GLP is providing emergency lighting that will be sized for 90 minutes to permit egress only.

A5.2.1.H
CORROSION CONTROL

All corrosion control work will be performed based on the RFP documents. Corrosion control systems will prevent premature corrosion failures, minimize stray current effects on transit and other underground structures to a negligible level, and be economical to install, operate, and maintain.

Types of corrosion control are stray current mitigation, protective coating, and cathodic protection. GLP's corrosion control directive drawings and specifications include all three of these categories. We place all corrosion control devices and materials underground to avoid any possible destruction by storms.

A5.2.1.H.1
CORROSION CONTROL STRATEGY

The corrosion control measures not only apply to utilities (electric, gas, water, sanitary, and storm sewer, etc.), but also to the transit structures. Metallic and concrete structures must be protected from stray current effects, as well as from underground and atmospheric corrosion.

In order to perform corrosion control engineering for this Project, a corrosion control baseline survey will be conducted. It consists of three parts: 1) Collection of voltage potentials on existing utility structures along the Project alignment and yard area; 2) Determination of soil corrosion characteristics; and 3) Determination of atmospheric characteristics.

Specific corrosion control measures to address likely Project risks are described in the following section.

A5.2.1.H.2
METHODOLOGY AND DESIGN

During design, the Corrosion Control Team will evaluate all possible corrosion control measures to be applied to the relocated underground, new, and existing utilities, and will select the most effective and economical method to protect these structures from underground and stray current corrosion. These measures will include:

- Coating of underground piping and pipe appurtenances
- Electrical isolation of new pipes from existing structures
- Electrical bonding across mechanical and push-on joints
- Establishing of test facilities on new relocated pipes and existing structures
- Cathodic protection of new and relocated underground metallic pipes

Existing utilities located along the ROW will be identified and test stations will be installed to monitor possible stray currents. If stray current surveys after revenue operations show stray current problems, corrective measures to protect existing structures will be implemented. It is recommended to perform stray current surveys on a yearly basis. All corrosion control measures on utilities owned by others should be coordinated with the utility owner.

Corrosion control measures will be designed to protect concrete reinforcement of various structures from environmental and stray current corrosion. The most important part of stray current mitigation is the

Figure A5.2.1-13: GLP has included stray current protection as part of our corrosion control techniques to reduce impacts from induced currents caused by the GLX traction power system that could lead to corrosion of nearby utility and systems that are susceptible to stray current.

isolation of rail tracks from the ground. **Figure A5.2.1-13** is a sketch of isolation of "bathtub" used for special track work.

The other measures will include a bonding of steel reinforcement, establishing of test facilities along the track alignment at about 300 feet apart, and provision of a reliable grounding for all Project structures.

The hydraulic elevator must have a casing, and be installed within a sealed PVC enclosure inside an outer non-metallic casing.

GLP will provide a commissioning of all tests related to the corrosion control system during construction.

Deliverables include:

- Baseline Corrosion Survey and Report
- Directive drawings
- Specifications
- Design drawings
- Post-Installation Testing and Survey Report
- Operation and Maintenance Manual

A5.2.1.H.3

STRAY CURRENT APPROACH AND DESIGN

In addition to the bonding of steel reinforcement, and the provision of reliable grounding for all structures, as mentioned in the previous section, a waterproofing membrane will be installed under the track on existing bridge decks to prevent stray current corrosion on bridge steel reinforcing, thereby reducing the effects on associated stakeholders and systems sensitive to stray current.

A5.2.1.H.4

STRAY CURRENT MONITORING

As noted previously, the GLP Team will provide commissioning of all tests related to the corrosion control system during construction. Track-to-earth resistance tests permit the verification of the level of rail's isolation from the ground and therefore the level of traction current leakage. Stray current monitoring on underground utilities and reinforced concrete structures allows us to identify an excessive stray current level and provide measures to control it.

A5.2.1.H.5

STRAY CURRENT BEST PRACTICES

GLP will use best practices for stray current based on lessons learned from previous LRT projects worldwide. The following is a list of best practices that can be applied to the GLX Project, and have already been employed to the extent possible prior to award:

- The running rails will be constructed as an electrically continuous power distribution circuit through use of CWR, impedance bonds, rail joint bonds, or a combination of the three.
- Mainline track will be electrically insulated from the yard and shop tracks by use of insulated rail joints in both rails of each track.
- Crossbonding will be provided to meet guidelines for traction power, signaling, and other considerations. Track crossbonds will be provided rail-to-rail and track-to-track between mainline inbound and outbound tracks in order to maintain equal potentials on all rails for stray current control.
- Switch machines, signaling devices, train communication systems, and other devices or systems that may have contact with the rails will be electrically isolated from earth.
- Mainline operational rectifiers will be electrically separate from the yard and shops.
- Rails will be properly isolated from the ground to minimize stray current leakage.
- Reinforcing steel in track slabs, in underground trackway structure inverts, or in bridge decks will be made electrically continuous.
- Steel reinforcing of new cast-in-place retaining walls will be made electrically continuous.
- All new and relocated metallic underground utilities will be designed with corrosion control measures, including cathodic protection design.

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Section A5.2.2

Elevated Guideway and Structures along the Guideway

GLP's design provides an optimization of the bridges, viaduct guideway and walls along the GLX Corridor by using innovation, and was achieved by certifying the viaduct design and rethinking what was needed along the corridor to support efficient construction techniques and prepare the corridor for track work and support an enhanced Community Path.

Section Highlights

- The use of innovative lightweight materials such as expanded polystyrene ("EPS") to support the Community Path, reducing heavy construction along the corridor
- GLP's optimization of the retaining wall types along both corridors to ensure beneficial cost savings
- GLP's design usage of precast elements for the underpasses at Medford and School streets.
- GLP's Walnut Street Community Path ATC provided opportunity to have an at-grade crossing of the Community Path and reduce risk to the MWRA 48 in hps water main
- GLP is using a secant pile wall at Lowell Street to eliminate the need for temporary SOE, resulting in reduced cost and schedule savings.

INTRODUCTION

The GLP Design Build Team comprises some of the most experienced firms in the industry. We have developed an innovative design for the GLX Project that meets all TP requirements, optimizes the site layout and use, enhances the experience for users, and provides for long-term system efficiency. Our design considers structural issues in coordination with global Project constraints, such as systems integration, constructability, and maintenance requirements. Specifically, our Team has achieved significant savings through our proposed changes to the retaining walls and our Alternative Technical Concept ("ATC") to alter the horizontal and vertical geometry of the Community Path.

Viaducts, walls, and bridges are discussed in detail below. Stations and other structures are discussed in other sections (e.g., OCS in A5.2.1, Stations in A5.2.3, and VMF in A5.2.5).

Viaducts: The viaducts consist of nearly 1 mile of elevated structure to carry light rail service over Leighton Street, East Street, Water Street, and the Fitchburg Line. While the viaduct structures all connect, they have been divided into four major segments in the RFP: the Lechmere Viaduct, Medford Branch Viaduct, Union Square Eastbound Viaduct, and Union Square Westbound Viaduct see **Figure A5.2.2-1**.

Walls: The 2016 redefinition retaining wall drawings were used as a baseline when laying out the walls for the 2017 alignment, including the transit system, railroad, and Community Path. This baseline contained approximately 3.25 miles of retaining walls. We made every effort to remove walls where they were no longer necessary due to 2017 scope and alignment changes. This initial effort reduced the length of retaining walls to approximately 2.65 miles, saving 0.6 miles of wall. Additionally, modifications to the Community Path alignment and profile resulted in schedule reduction, scope reduction, and improvements to the final product for community use.

Bridges: There are a total of 13 bridges along the Medford Branch corridor and two bridges along the Union Square Branch corridor. Of these 15 total bridges, nine bridges along the Medford Branch and one bridge along the Union Square Branch will require modification as part of the Project. These modifications vary in scope from approach slab reconstruction to complete replacement, as discussed later in this section. Wherever possible, a philosophy of scope minimization was employed to limit construction cost and duration. For example, our modification to the profile of the Community Path at Walnut Street Bridge eliminates the majority of bridge construction scope at this location.

A.5.2.2.A STRUCTURES ALONG THE GUIDEWAY

A5.2.2.A.1 CONFORMANCE TO STRUCTURAL REQUIREMENTS

VIADUCTS

GLP's viaduct design meets all TP requirements, including the codes and standards outlined in Section 8.7.2, such as the MBTA Light Rail Code, and follows the base design from the 2016 redefinition plan set, which simplifies future expansion of yard leads shown in the 100% design.

The base design of each viaduct is as follows:

Lechmere Viaduct: The proposed Lechmere Viaduct extends from the existing East Cambridge Viaduct to the west side of Water Street. The 1,800-foot-long proposed structure carries both tracks of the proposed GLX alignment, with the tracks diverging for nine spans on either side of the new Lechmere Station. Critical to the construction of the Lechmere Viaduct is the installation of the CIH at Lechmere Station. The GLP Team has elected to use steel members in lieu of precast girders to support the structure between Piers 7 and 8 to expedite the installation of the CIH. The use of steel allows for a temporary shoring tower to be installed while the existing viaduct is being demolished. While the CIH is temporarily supported, all associated utility work required to connect the conduits can be completed, resulting in a significant schedule savings.

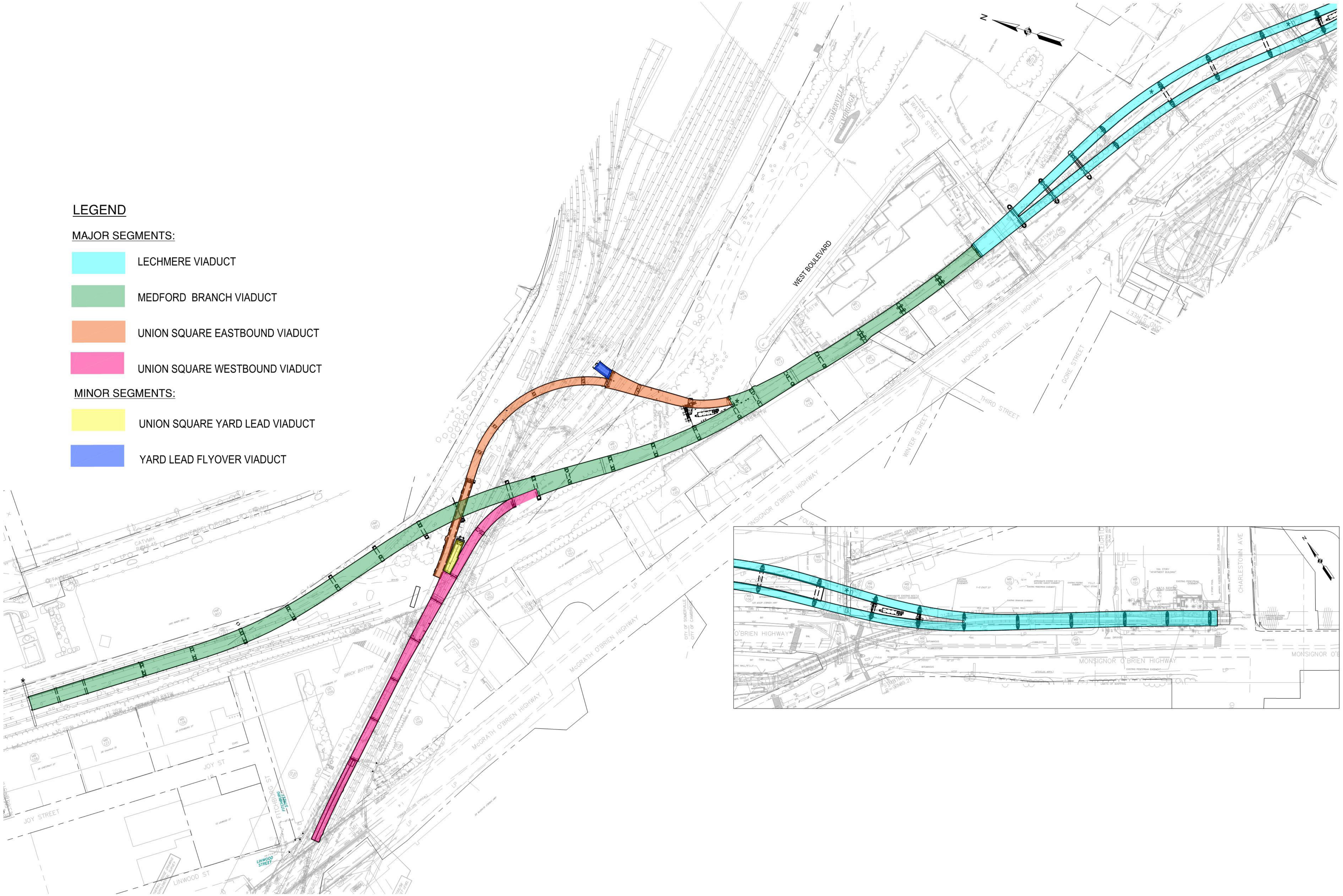
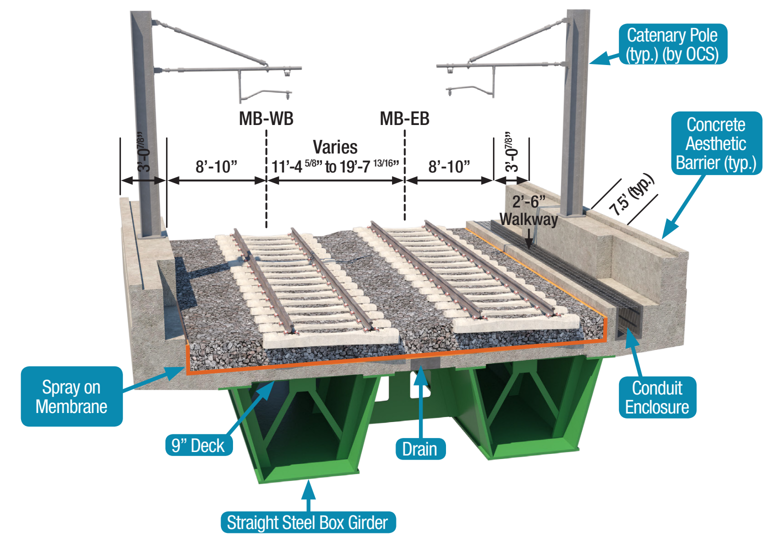


Figure A5.2.2-1: This key plan illustrates the different viaduct segments in the project; Lechmere (color), Medford (color), Union Eastbound (color), Union Westbound (color), Union YL (color), and the Yard Lead Flyover (color).

Typical Section (From Station 183+56.27 to Station 184+82.34)



Typical Section (From Station 184+82.34 to Station 185+88.38)

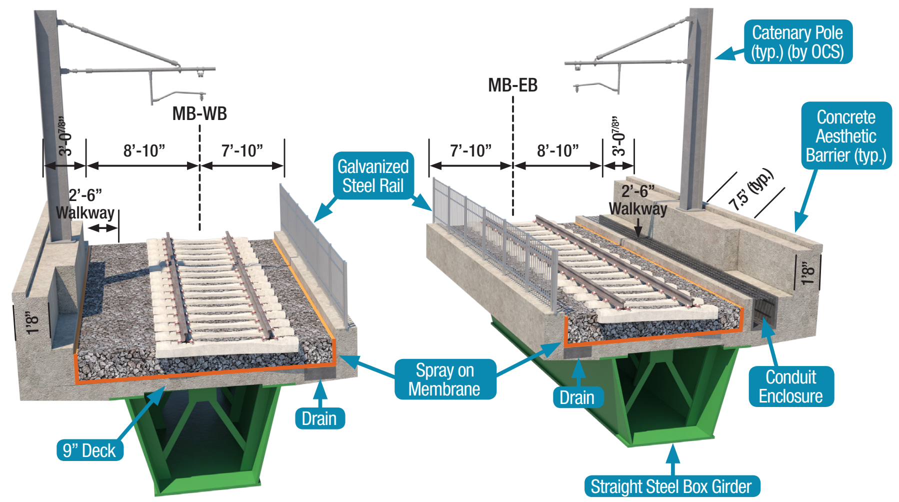


Figure A5.2.2-2: GLP has recertified the design of the viaduct as a cost- and schedule-effective solution.

Medford Branch Viaduct: The Medford Branch Viaduct extends west from the end of the Lechmere Viaduct at Water Street. The structure consists of 21 I-girder spans, with a total length of approximately 2,200 feet. Since the steel has been previously procured, our Team does not anticipate significant revisions to the superstructure or span arrangement.

Union Square Eastbound Viaduct: This viaduct diverges from the Medford Branch, extending over the yard and passing beneath Pier 30 of the Medford Viaduct. The sharply curved alignment of the structure is dictated by the site constraints of the rail yard and restrictive ROW near the adjacent Brickbottom property. The 733-foot-long viaduct consists of eight simple spans followed by a 240-foot retained approach wall section.

The viaduct accommodates the future construction of a flyover connecting the eastbound alignment to the rail yard. This will be accomplished by providing additional structural width and constructing the first span of the future structure.

Union Square Westbound Viaduct: This viaduct diverges from the Medford Branch at Pier 29, crossing over the Fitchburg Line and Drill Track, before running parallel to the Union Square Eastbound alignment. The total length of the viaduct is approximately 720 feet, followed by a 208-foot retained approach wall section. The superstructure consists of I-girders, with spans 1 and 2 being continuous and spans 3 through 7 being simply supported.

The TPs require that this viaduct accommodate the future construction of a yard lead connecting the Union Square Westbound alignment to the rail yard. This will be accomplished by providing additional structural width and constructing the first span of the future yard lead structure.

RETAINING WALLS

GLP explored every option to creatively delete walls, simplify construction, and reduce cost and schedule, while remaining compliant with all project requirements. As such, all cast-in-place ("CIP") walls that would have required extensive support of excavation ("SOE") and construction duration were changed to soldier pile and lagging ("SPL") or modular precast block ("MPB") walls. Additionally, walls of any type were eliminated wherever possible due to our proposed track alignment changes. The final step was to conduct a process of structural and geotechnical design optimization for each wall. Our optimization was performed in accordance with the codes in TP Section 8.1.2.

Retaining Wall Optimization: Most of the retaining walls throughout the Project are SPL walls. The construction effort required for SPL walls is heavily dependent on the drilled shaft size, spacing, and embedment depth. We reanalyzed the walls to optimize the design and eliminate unnecessary construction costs resulting from over-conservative assumptions.

Following the review of the geotechnical data at each wall location, the drilled shaft spacing was increased from the 6-8 feet depicted on the 2016 design to a standard 10 feet. Similarly, in most locations, the embedment depth was reduced by several feet and the pile size included in the drilled shaft section was reduced as well.

The soil nail wall that comprises all 1,100 feet of wall MW-19 at College Avenue Station was also optimized to save effort and reduce cost. The 2016 design featured soil nails every 5 feet longitudinally, with a 35-foot embedment. The optimized design increased the spacing to every 6 feet and decreased the embedment to 30 feet. Additionally, the quantity of concrete required was reduced from 10- inches of CIP over 10 inches of shotcrete to 8 inches of CIP over 4 inches of shotcrete.

NOISE WALLS

Since the noise wall locations were dictated in the RFP with respect to the provided 2017 alignment, there was no flexibility for noise wall length reduction. There were two areas, however, where cost saving could be realized: 1) the optimization of the drilled shaft/pile size and spacing, and 2) modification of the connection detail for the mounted noise walls. The connection design on the 2016 redefinition plans featured the noise wall anchored to a CIP cap beam, which transferred the forces to the retaining wall below. Our design simplified the connection detail by introducing a steel moment connection, standardizing the noise wall panel lengths and using a precast cap beam. Switching to a precast cap has significant schedule benefits since CIP construction would require accessing a difficult site location several times over an extended period. Using the precast cap and steel connections allows us to complete all the work in one access period.

Walls Removed (FT)	Optimization
Walls Removed (FT)	3295.00
Walls Added (FT)	625.00
CIP to SPL (FT)	625.00
CIP to MPB (FT)	175.00
SPL to MPB (FT)	1200.00
Piles Removed (EA)	105
Drilling Avoided (FT)	2,710.00
Steel Saved (LB)	532,506.50

* SPL Optimization only quantified for wall that remained SPL between RFP and WSP designs

** Union Branch Savings not Included

*** Noise Wall Savings not included

Figure A5.2.2-3: GLP's structural optimization effort has resulted in significant cost savings throughout the GLX Project.

SPECIFIC WALL CASES / SOLUTIONS

EPS Path Support: We have optimized the layout of the Community Path by shifting it back to the west side as was indicated in the 100% plans and as desired by the community. The use of expanded polystyrene ("EPS") allows this to take place at no additional cost. This solution consists of a short retaining wall at the toe of the existing slope to stabilize it, followed by approximately 10 feet of EPS block to support the path.

Using EPS instead of traditional fill has several benefits, particularly with regards to constructability. Assembling EPS does not require any specialty labor or equipment, and can easily be performed under all weather conditions. This provides schedule advantages and cost savings. In addition, EPS is structurally self-stable, does not require any additional lateral support, and does not exert lateral pressure. The material's extremely low unit weight of 2 pounds per cubic foot has little to no impact on the existing ground conditions.

EPS Rail Support: The benefits of EPS are also applied in another portion of the Project, along the Union Square Branch. An existing CIP

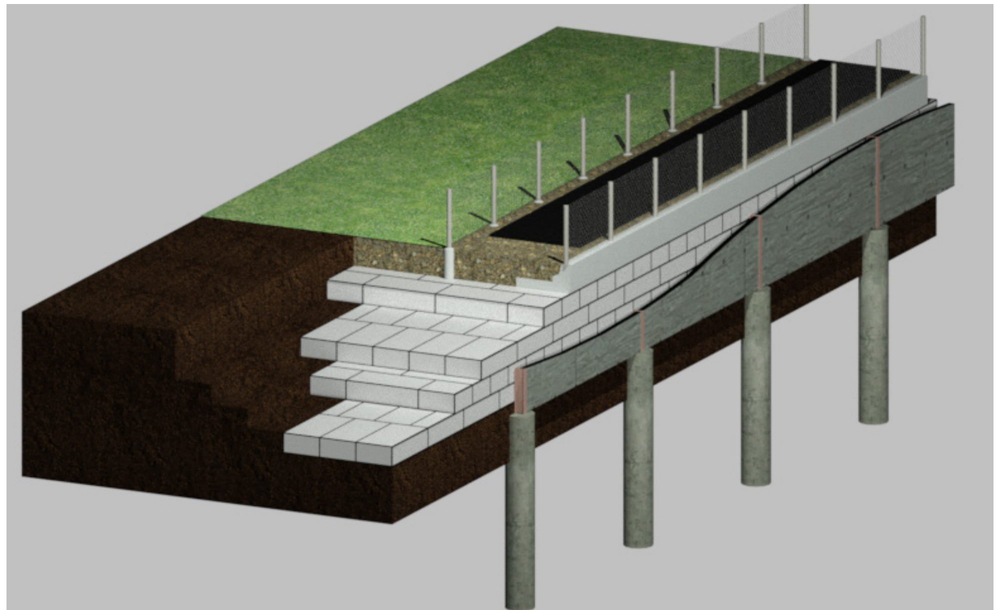


Figure A5.2.2-4: The EPS path support system allows the GLP to provide a better Community Path product by maintaining it on the west side of the alignment.

wall that must be replaced per the TPs is founded on deep foundations in extremely soft soils. Preventing excessive settlement with traditional approaches would be both expensive and time consuming. To avoid this, we decided to use EPS and a light SPL wall in an innovative solution. The EPS won't incur additional settlement since significant dead load due to soil fill, while the SPL wall will provide support for the wall facing.

Large CIP with SPL Replacement: Replacing large (some 15-25 feet tall) CIP retaining walls with SPL walls is a cost-saving measure that removes the need for extensive SOE and formwork during construction. While SPL would traditionally not be able to retain this height of fill, backfilling these locations with EPS rather than soil drastically reduces the demand on the wall, allowing reasonably sized SPL walls to be used.

Crib Wall Rehabilitation: GLP's innovative concept for rehabilitating existing crib walls proposes using tilt-up precast concrete panels as an aesthetic fascia. These panels are not load bearing/structural, instead they are supported by a small footing at the base and a simple connection to a cap beam at the top. By backfilling the space with a crushed stone material and casting generous weep holes in the panels, the free-draining nature of the crib wall can be maintained. The precast panels that are used at these locations will be used at several other locations along the Project and share the same striation pattern as all other new and rehabilitated retaining walls. This will give the entire corridor a cohesive aesthetic appearance.

Micro-Pile Wall: The existing crib wall on the east side of the Medford Branch corridor between Cross Street and McGrath Highway is in particularly poor condition. While the TPs call for a partial replacement and rehabilitation of the remainder, our Team opted to replace the wall in its entirety, providing an improved final product. The ROW revenue tracks, and existing utilities prohibit the typical solutions of constructing

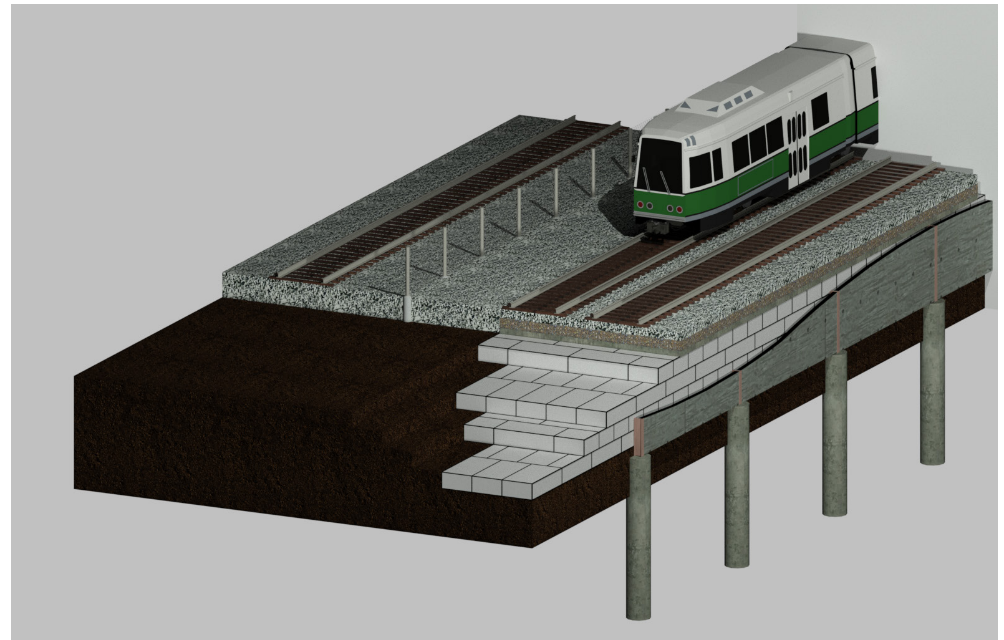


Figure A5.2.2-5: The EPS rail design solves poorly consolidated solis problems

an SPL wall in front of the existing wall or demolishing the wall in-place and constructing a new wall. Our solution is to use an innovative micro-pile wall, which has been successfully implemented on previous projects. The smaller pile and equipment sizes will allow us to easily place micro-piles inside the crib wall and bury the existing wall with minimal space requirements. The wall is composed of a CIP or shotcrete facing attached to the studded micro-piles.

A5.2.2.A.1.A
DESIGN CRITERIA

At the beginning of the Project, GLP will develop a design criteria manual that all design work will follow, in order in ensure that the Team is abiding by the requirements as set forth in the RFP. Some of the criteria that will be included in the manual are discussed below.

Viaducts: The design of the viaducts will comply with all the requirements identified in TP Section 8.7.2, addressing Codes, Standards, and Manuals. It will comply with all Project Specific Requirements of Section 8.7.3 addressing design methodology, Stray Current Protection per Section 8.9, and the design of foundations and geotechnical elements in accordance with Section 15.1.

Retaining Walls: The design of the retaining walls will comply with all the requirements identified in TP Section 8.1.2 addressing Codes, Standards, and Manuals. It will comply with all Project Specific Requirements of Section 8.1.3 addressing the requirements for track clearances, clearance for Community Path, design loadings, materials, and finishes.

Noise Walls: The design of the noise barrier walls will comply with all the requirements identified in TP Section 8.2.2 addressing Codes, Standards, and Manuals. It will comply with all Project Specific Requirements of Section 8.2.3 addressing the requirements for track clearances, clearance for Community Path, design loadings, materials,

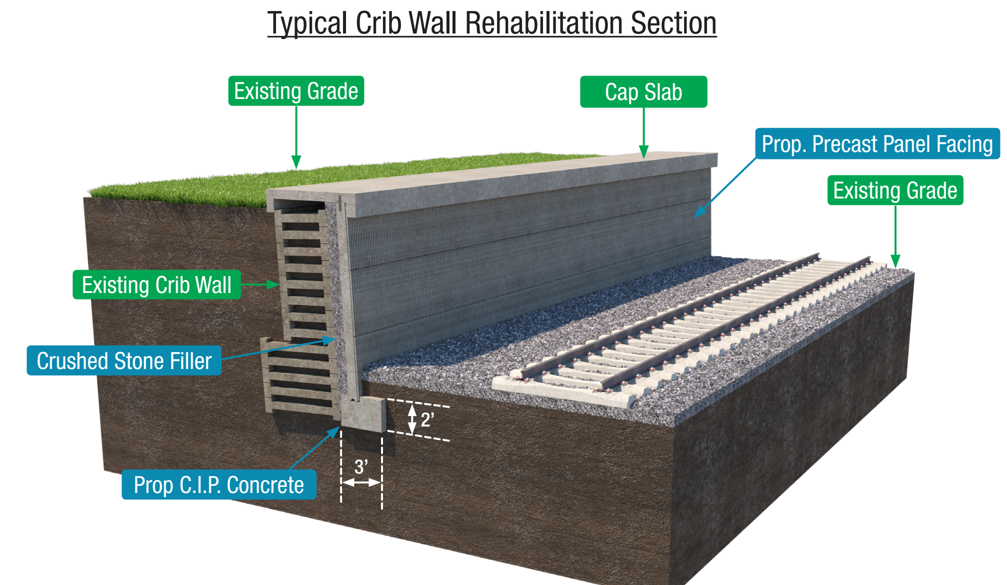


Figure A5.2.2-6: Crib wall rehab encapsulization design exceeds the 25-year design life requirements of MBTA.

Figure A5.2.2-7: In designing for restricted access in busy urban environments similar to the GLX project alignment, GLP has incorporated micro-pile walls in restricted access similar to the ones seen here from New York's Second Avenue Subway Project.

and finishes. Noise barriers will satisfy the requirement to be designed as stand-alone walls, or be mounted on retaining walls. They will comply with all Project Specific Requirements of Section 8.2.3 addressing design methodology for Geotechnical Elements, Concrete Components, and Structural Steel Components.

A5.2.2.A.1.B
MEETING SERVICEABILITY CRITERIA

Viaducts: The design of the viaducts will comply with the requirements of Section 8.7.3.1 to provide a minimum design life of 80 years, in accordance with the Guide Specifications for Structural Design of Rapid Transit and Light Rail Structures. All steel elements on the viaducts will be constructed using weathering steel to reduce maintenance and increase service life. Additionally, all rebar in the decks will be epoxy-coated to prevent corrosion.

Walls: The design of the retaining walls as new wall systems will comply with the requirements of Section 8.1.3.1 to provide a minimum design life of 75 years. Existing wall systems to remain or to be retrofitted for use permanently will be designed for a 25-year design life. All steel used in wall structures will be galvanized to ensure maximum design life.

The design of the precast modular noise barrier walls will comply with the requirements of Section 8.2.3.2 to provide a minimum design life of 75 years.

Figure A5.2.2-8: On the Whittier Bridge project, GLP designer WSP used EPS block to widen 2,000 feet of I-95 adjacent to wetlands, which aided construction in the existing ROW and accommodation of poorly consolidated soil.

A5.2.2.A.1.C
DRAINAGE AND WATERPROOFING SYSTEM

The design of the viaducts and wall structures (retaining walls and noise barrier walls) will incorporate all the drainage and waterproofing requirements identified in the TPs. All retaining walls will be constructed as free-draining. The backfill behind the walls will consist of a layer of free-draining crushed stone material.

The ballasted viaduct superstructures will be waterproofed using details similar to those shown on the 2016 redefinition plans. This includes the use of spray-applied membrane waterproofing and protection board beneath the ballast. Any conduit penetrations through the ballast retainer wall will be adequately sealed to prevent water from entering the conduit enclosure. Additional details relating to drainage and waterproofing can be found in Section A5.2.7.

A5.2.2.A.1.D
CONSTRUCTION WITH THE ROW

From the start of design, GLP has held constructability review meetings to assure that any proposed design was constructable within the ROW and revenue track constraints so that the entire GLX Project can be built within the provided ROW. There are several locations where SPL walls were chosen over MPB or CIP walls due to ROW constraints. Similarly, as discussed above, there is a crib wall location in which a drill rig for an SPL would not fit within the ROW, so we modified the design to a micro-pile wall. ROW was also one of the key reasons behind avoiding the use of construction that requires temporary SOE. The additional space needed to install and work within SOE leads to a high risk of construction activity falling outside of the allowable ROW.

A5.2.2.A.1.E
FROST HEAVE

Most structures along the guideway are constructed on deep foundations and are not subject to frost heave. However, MPB walls and the EPS block path support require frost protection. This protection is provided by placing the base of the structures at least 4 feet below grade. When this depth of excavation needs to be avoided, the frost protection is provided by using a crushed stone base. Crushed stone (e.g., No. 57 MassDOT materials specification M2.01.0) is a free-draining material that is not susceptible to volume change from frost/thaw actions. The stones are typically wrapped in filter fabric or a geotextile to prevent fines from migrating into the voids between the stones.

A5.2.2.A.2
DRAWINGS

The GLP Team has developed structural drawings to illustrate our approach to the proposed work and outline the scope of the Project. Additionally, our proposed structures are shown in the composite plan set on sheets (000-C-0001 TO 0028), illustrating the interaction between the structures, utilities, and proposed stations along the corridor.

A5.2.2.B
BRIDGE AND UNDERPASS STRUCTURES

A5.2.2.B.1
GENERAL APPROACH TO MEETING THE REQUIREMENTS

The design of the bridges and underpasses will comply with all the requirements identified in TP Section 8.4.2 Articles (a) and (b), respectively; addressing Codes, Standards, and Manuals. It will comply with all Project Specific Requirements of Section 8.4.3.1 Articles (a) and (b) addressing Design Methodologies for Bridges and Underpasses; respectively. It will also comply with the Design Methodology requirements for the foundations and geotechnical elements in accordance with Section 15.1 of the TPs. It will comply with all Project Specific Requirements of Section 8.4.3.2 addressing General Bridge and Underpasses, and the Specific Bridge Requirements of Section 8.4.3.3. The design of the Bridges and Underpass structures will satisfy the design service life requirements identified in the American Association of State Highway and Transportation Officials Load and Resistance Factor Design ("AASHTO LRFD") and Massachusetts Department of Transportation ("MassDOT") LRFD Bridge Manuals. The design of the pedestrian bridge at College Street will comply with the standards and manuals outlined in TP Section 8.6.

A5.2.2.B.1.A
ACCOMMODATING PEDESTRIAN AND REVENUE TRAFFIC

There are three locations where new underpass structures were indicated in the RFP to accommodate the revenue tracks and/or Community Path. These locations are Walnut Street, Medford Street, and School Street. Using our approved ATC Community Path Elevation Increase design change, we removed the need for an underpass at Walnut Street, avoiding work under the Massachusetts Water Resources Authority ("MWRA") 48 inch water main and reducing the underpass scope to two bridges. Bringing the Community Path to grade allowed GLP to maintain the higher path elevation along much of the corridor.

This change reduced project risk to existing infrastructure and improved the Community Path experience and safety of the users.

At Medford Street, our design consists of a precast concrete three-sided frame behind the existing south abutment to accommodate the Medford Branch-Eastbound revenue track. The benefit of this approach is that no significant structural work is needed on the existing bridge. Additionally, the new structure will not require the level of long-term maintenance expected of a bridge structure. Moreover, the Community Path Elevation Increase allows us to reduce the span of the precast structure.

Figure A5.2.2-9: An east elevation (looking west) showing the existing Walnut Street Bridge. The GLP Community Path Elevation Increase ATC significantly reduces work at this location by having the path go up and over rather than tunneling underneath the street.

Figure A5.2.2-10: An east elevation (looking west) showing the Medford Branch Westbound rail line passing below the new additional span of the School Street Bridge. The existing superstructure (darker concrete) remains along with the existing granite north abutment, the new span (lighter concrete) is supported by a secant pile wall abutment on the south side, and a wall pier that will support the new span and the south side of the existing superstructure. Bollards for the Community Path are shown behind and above the secant pile wall abutment, which will act as barriers for the path.

At School Street, our approach consists of a new short concrete slab span to accommodate the MB-EB revenue track. GLP proposes an innovative solution using a secant pile abutment for the new south abutment **Figure A5.2.2.-10**. This allows us to avoid costly SOE and excavation work typical of traditional abutment construction.

A5.2.2.B.1.B
TRACK STRUCTURE AND RAIL FASTENING SYSTEMS

All the track in our design is composed of a ballast and tie system. As such, independent expansion of the rail and structures is guaranteed without any additional work or maintenance that is required with direct fixation systems.

A5.2.2.B.1.C
WATERPROOFING

All bridges will be waterproofed in accordance with the TPs and the MassDOT Bridge Manual. Membrane waterproofing and a Hot Mix Asphalt (“HMA”) wearing surface will be provided on bridges where all portions of the deck have profile grades of 4% or less. Decks that have greater than 4% grades will have a ¾-inch sacrificial wearing surface in lieu of waterproofing in accordance with Art. 3.5.2.2 of the MassDOT Bridge Manual. On the underpass structure at Medford Street, positive side waterproofing will be provided to prevent seepage through joints of the precast concrete three-sided frame units.

A5.2.2.B.2
SITE SPECIFIC APPROACH

A5.2.2.B.2.A
WASHINGTON STREET RAILROAD BRIDGE

The Washington Street Railroad Bridge carries the Commuter Rail, the Green Line, and the Community Path over Washington Street. The proposed structure follows the Base Technical Concept included in the 2016 redefinition plans: a steel through-girder superstructure supported on drilled shafts located behind the existing abutments. Since the steel has already been partially fabricated, GLP plans on reusing the previously procured steel. The existing abutments will be left in place as retaining structures, and the low retaining walls below the existing piers will be replaced to support the sidewalks. The proposed design minimizes costly excavation of the contaminated soils around the bridge, and minimizes disturbance of the existing utilities.

A5.2.2.B.2.B
WALNUT STREET

The Walnut Street Bridge carries Walnut Street over the railroad tracks. Due to **GLP’s ATC Community Path Elevation Increase** design change, the Community Path will cross Walnut Street at roadway level, instead of requiring an underpass as in the 2017 Definition Plan. Because of this change, no modifications of the Walnut Street Bridge are anticipated. Frost protection beneath the south abutment is required due to the track profile changes.

GLP’s Community Path ATC provides a better product at Walnut Street by bringing street access to the path, which more effectively connects and serves the community in the area.

A5.2.2.B.2.C
MEDFORD STREET

The Medford Street Bridge carries Medford Street over the railroad tracks. The bridge is proposed to be lengthened by the addition of a precast concrete three-sided frame span behind the existing south abutment. The new Green Line westbound track will pass under this frame span. Modifications to the existing Medford Street Bridge will be limited to modifications to the abutment required to accommodate the proposed underpass.

5.2.2.B.2.D
SCHOOL STREET BRIDGE

The School Street Bridge carries School Street over the railroad tracks. The bridge is proposed to be lengthened by the addition of a precast concrete slab span behind the existing south abutment. The new Green Line westbound track will pass under this new span. The existing granite block south abutment will be replaced with a concrete pier. The

Figure A5.2.2-11: An east elevation (looking west) showing the existing Broadway Bridge. GLP will replace the existing bridge with a two-span continuous structure with a sufficiently long span to accomodated the two new GLX tracks as they diverge coming in to Ball Square Station.

Figure A5.2.2-12: An east elevation (looking west) showing the existing College Avenue Bridge. GLP will maintain the existing bridge structure and remove a sidewalk to accommodate a new right-turn lane. We will also provide a new pedestrain bridge on the west side of the bridge to provide pedestrian access from the west side of the alignment on Boston Avenue, near the new College Avenue Station to the east side of the aligment on College Avenue.

Figure A5.2.2-13: An east e levation (looking west) showing the railroad tunnel behind and against the south abutment of the Medford Street bridge carrying the Medford Branch Westbound rail line. The tunnel is composed of precast concrete arch segments supporting 5 feet of soil above, retained by the headwall shown above the tunnel.

existing School Street superstructure will be temporarily shored during replacement of the existing south abutment. GLP's design proposes using a secant pile abutment for the new south abutment. This allows us to avoid costly SOE and excavation work typical of traditional abutment construction.

A5.2.2.B.2.E

CEDAR STREET BRIDGE

The Cedar Street Bridge carries Cedar Street over the railroad tracks. The existing structure is wide enough to accommodate the additional Green Line tracks, but the minimum horizontal clearance of 8.5 feet is not achievable at the south abutment. Safety niches will be cut into the south abutment to mitigate this clearance problem, and the southwest wingwall will be demolished. A new retaining wall will retain the fill at this location instead.

A5.2.2.B.2.F

LOWELL STREET BRIDGE

The Lowell Street Bridge is supported on drilled shafts at both abutments, and a granite block retaining wall is in front of the drilled shafts at the south abutment. The new Green Line westbound tracks conflicts with this retaining wall and it must be removed. A secant pile retaining wall will be installed behind the existing south abutment and will be made integral with the existing drilled shafts to provide the necessary lateral support for this hybrid stub abutment. The space between the drilled shafts and secant wall will be filled with concrete to ensure the modified abutment meets AREMA "heavy construction" collision design requirements.

Figure A5.2.2-14: GLP has evaluated every bridge along the alignment to develop and refine cost-effective, innovative solutions.

A5.2.2.B.2.G
BROADWAY BRIDGE
The Broadway Bridge will be replaced in its entirety with a two-span steel stringer bridge. The new structure will span over both the Commuter Rail and the Green Line tracks, and the roadway will be narrower than the existing structure as specified in the TPs. There is an existing temporary utility bridge that has already been constructed, which will be painted and retained in the final condition.

A5.2.2.B.2.H
COLLEGE AVENUE BRIDGE
College Avenue will be modified by the removal of the existing north sidewalk to create space for a right-turn lane. A new pedestrian bridge north of the existing utility bridge is required to accommodate pedestrian and bicycle traffic. The new pedestrian bridge will be a prefabricated truss spanning approximately 70 feet over the rail corridor. The structure will be 12 feet wide and will be fabricated from weathering steel to ensure the new structure meets the 75-year design life with minimal required maintenance. Retaining walls will be needed to support the approaches to this truss bridge.

A5.2.2.B.2.I
HARVARD AND MEDFORD RAIL BRIDGES
In accordance with the TPs, new approach slabs will be constructed beneath the tracks at the Medford and Harvard Street rail bridges constructed in the previous GLX contracts. These approach slabs will be designed in accordance with AREMA and MBTA guidelines.

A5.2.2.B.3
DRAWINGS
Drawings WAS-S-2000, WSB-S-2000, MEB-S-2000, MEB-S-2001, SCB-S-2000, SCB-S-2001, LSB-S-2000, CED-S-2000, BRB-S-2000, BRB-S-2001, COB-S-2000 included in the drawings section of this technical solutions package depict our approach to each bridge. Additional details are included as applicable for each bridge location.

A5.2.2.C
GEOTECHNICAL ENGINEERING
Foundation design and construction for the GLX is one of the most challenging elements, and if not managed well, could involve great risk to schedule and cost. Recognizing the critical importance of geotechnical and foundation engineering for the Project, our Team has developed unparalleled foundation and retaining wall solutions that ensure high performance, consistency with RFP requirements, and installation schedule certainty, including:

- Reduction of required retaining wall quantities, and heights (see wall optimization table previously shown in **Figure A5.2.2-3**).
- Use of modular type fill walls in lieu of cast in place gravity retaining walls, and drilled solider pile and lagging fill walls.
- Simplified installation of retaining wall foundation elements through the use of EPS (ultralight weight) material.
- Rehabilitation of existing crib walls using small equipment, micro-pile, and precast units to minimize the need for use of heavy equipment in a tight ROW.
- Viaduct drilled shafts embedment has been optimized and reduced by 20% on average, based on available full scale Osterberg (O-cell) data results.
- Use of drilled displacement (“DD”) ground improvement techniques such as controlled modulus column (“CMC”) for the VMF in lieu of proposed drilled shafts.
- Use of tangent or secant pile wall for bridge abutments that serve as both temporary SOE for top down excavation, as well as permanent abutment support.
- Use of non-displacement driven H-piles or W-flange for noise wall where ground conditions allow.
- **Figure A5.2.2-15** summarizes key innovations and take aways that will benefit MBTA, MassDOT, and other stakeholder.

A5.2.2.C.1
IDENTIFIED GEOTECHNICAL CONDITIONS
Figures A.5.2.2-16 through **A5.2.2-18** illustrates our current understanding of the subsurface conditions based on the proposal-stage subsurface investigation data provided by MBTA and MassDOT, which serves as the basis for our optimized foundation design. The profiles show deposits of miscellaneous fill overlaying deposits of clay, organic peat, glacial till, highly weathered rock, and bedrock. The thickness and extent of the soil deposits vary across the Project alignment. Rock at the Project site consists of argillite, sandstone, and siltstone. In the southern portion of the Project, the rock surface is as deep as 120 feet below existing grade; on the northern end of the Project, rock is at or near the ground surface. A significant issue is the potential variability of the rock conditions at the viaduct alignment.

As outlined in the TPs, the wide range of subsurface conditions will require supplemental subsurface investigations to characterize the soil and rock at specific locations, as the subsurface conditions can change significantly over a relatively short distance, with a corresponding impact to the design and construction of various foundation elements. The range of conditions also requires our Team to develop and implement a foundation testing program that will allow us to establish foundation performance requirements.

In addition to the ground condition, GLP has identified a number of geotechnical constraints that will affect the design and construction of the different foundation elements. **Figure A5.2.2-19** identifies these challenges, and summarizes approaches to mitigate the impacts.

GLP’s Design Team has encountered these same issues on several recent projects and we have successfully implemented the planned mitigation measures to reduce and eliminate the impacts.

A5.2.2.C.2

INTERPRETATION OF GEOTECHNICAL AND HYDROGEOLOGICAL CONDITIONS

In general, there are several broad areas of the Project where the ground conditions and constraints dictate different foundation solutions. This includes:

- Areas where rock is deep, but reachable with conventional or low head piling equipment
- Areas where structures can be founded on shallow rock
- Areas where structures can be founded on glacial till and/or suitable overburden material and
- Areas, such as the VMF, where soft compressible soils are encountered, and ground improvement could be utilized

A discussion of the specific soil and rock strata and how they affect the design and construction of the foundations and retaining walls is presented in **Figure A5.2.2-20.**

A5.2.2.C.3

GEOTECHNICAL AND HYDROGEOLOGICAL DESIGN PROPERTIES

The GLP Team of geotechnical experts and senior construction engineers have performed extensive engineering analyses and have collaborated in weekly task force meetings narrowing foundation and retaining wall alternatives to our proposed cost-effective, low-risk, and low-impact systems.

Groundwater Control and Dewatering – The Project site is located in depressed zones, and has large drainage areas. The groundwater depths range from approximately 3 feet to 20 feet at Project planned foundations. Since excavation below groundwater level will generally be avoided, dewatering and permits associated with disposal of groundwater during construction will be limited. However, surface runoff and groundwater control using ditches, drains, and sump pumps is anticipated for dry and safe work zones. The necessary surface and subsurface drainage, and erosion control, will follow Federal Highway Administration ("FHWA") soil slope and embankment design.

Deep Foundations – The design of viaduct pile foundations and bridge foundations fully complies with the standards and requirements of the AASHTO LRFD for highway bridges, AREMA's Allowable Stress Design (ASD) for railroad bridges, MassDOT requirements , and other standards and references listed in the Project requirements, such as FHWA manuals. GLP Team member WSP has led the development of more than a dozen FHWA manuals of practice, and is therefore thoroughly familiar with these documents.

- **Retaining Walls Criteria –** Retaining wall design will address internal, external, and global stability, and settlements (differential and total) in accordance with AASHTO and MassDOT standard specifications. Cantilever soldier pile and lagging top lateral deflection (with or without noise barrier) will be limited to 1% of the exposed height with a maximum limiting value of 3 inches. Gravity modular retaining wall total long-term settlements will be limited to 2 inches, and more importantly, differential settlements will be limited to 1 inch.
- **Slope Stabilization –** GLP evaluated the stability of existing and new (permanent and temporary) slopes within or affected by the Project (Medford depressed alignment) . A majority of the existing slopes were assessed to be stable for both static and seismic loading conditions. Few locations will require earthwork grading, or placement of short toe retaining wall based on the available topographic information. Slope stability during final design in the deep cut areas will be in accordance with MassDOT standards. Reinforced slope design, if required, will meet the requirements of FHWA.
- **Reuse of Excavated Material –** The available geotechnical reports at different locations indicated that some of the excavated material

Figure A5.2.2-15: GLP's development of design and construction plan for the GLX Project has resulted in the cultivation of key innovation and takeaways that will benefit the MBTA, MassDOT and other stakeholders.

Foundation Innovations and Key Takeaways	Main Feature	Performance Consideration	Schedule & Cost Impacts
Reduce retaining wall quantities	› In analyzing the existing conditions, modified track profile, and ROW, our design optimizes retaining wall limits and reduces heights wherever possible. Our design work also found areas where approximately 20% of 2016 retaining wall length could safely and successfully be eliminated	› Reducing the total length of walls reduces impacts to railroad operation, as well as environment and community	› Minimize the amount of force account work to be performed by MBTA › Reduce the amount of maintenance MBTA must do by constructing less retaining walls › Reduce retaining wall installation schedule
Select retaining wall types that limit ROW needs during construction	› Expand use of MPB retaining wall types such as T-wall › Use EPS type retaining walls that reduce lateral load demand; driving forces on existing slope › Use short SPL in lieu of MPB and CIP to be able to construct in tight ROW	› High-quality, durable products › Exceeds 75-year design life › Able to accommodate sound attenuation barrier/wall and utilities › GLP's use of precast components reduces corrosion potential	› Use smaller equipment for installation because wall units are easily procured in multiple sizes › Minimizes excavation and soil spoil management
Employ ground improvement for VMF foundations	› Use drilled displacement grouted columns to support structural columns, track pits, and portion of the structural slab	› Minimize short- and long-term settlement to less than 2 inches › Use of load transfer platform with geogrids eliminate the need for uplift resistance	› Enhance construction schedule certainty by installing displacement grouted columns in between existing deep building foundations › Minimize drilling spoils and contaminated soils transport › Reduce costs significantly compared to conventional foundation systems
Use drilled tangent or secant pile wall at Lowell and School Street bridges	› Use wall as both temporary SOE as well as permanent abutment	› Steel is fully encased in concrete, mitigating stray current concerns › Eliminates the need for temporary SOE	› Reduce soil excavated quantities › Allow for partial opening of the bridges during construction
Reduce drilled shaft socket lengths for viaducts	› Reduce drilled shaft socket lengths by more than 500 feet based on O-cell results and knowledge of the geological conditions	› Optimized lengths will be verified by performing full-scale load test as per TP requirements	› Shorten viaduct construction schedule › Reduce foundation cost

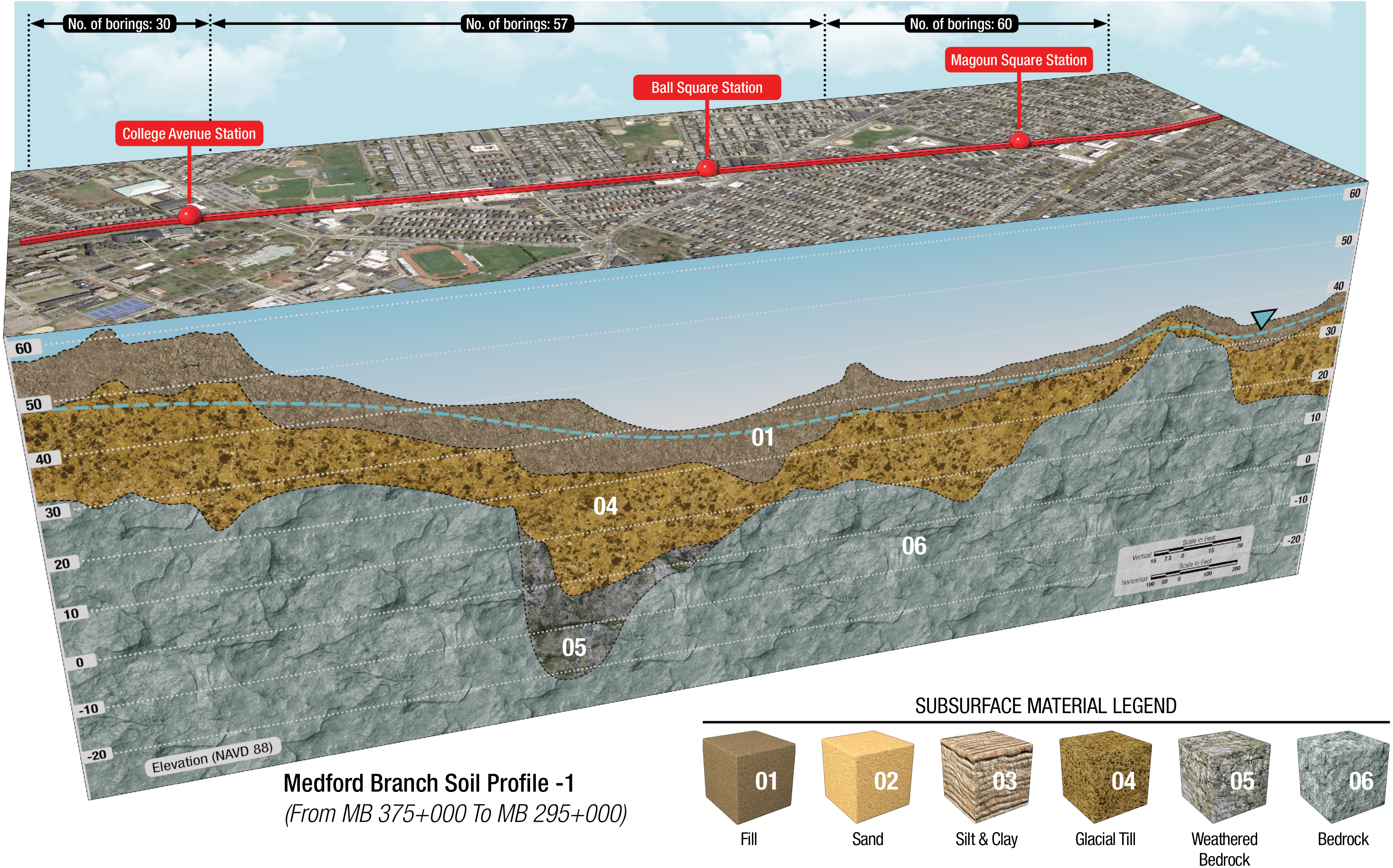


Figure A.5.2.2-16: Based on the proposal stage data provided by the MBTA and MassDOT for GLX area, GLP has developed an understanding of the ground conditions and have incorporated that knowledge in the foundation design.

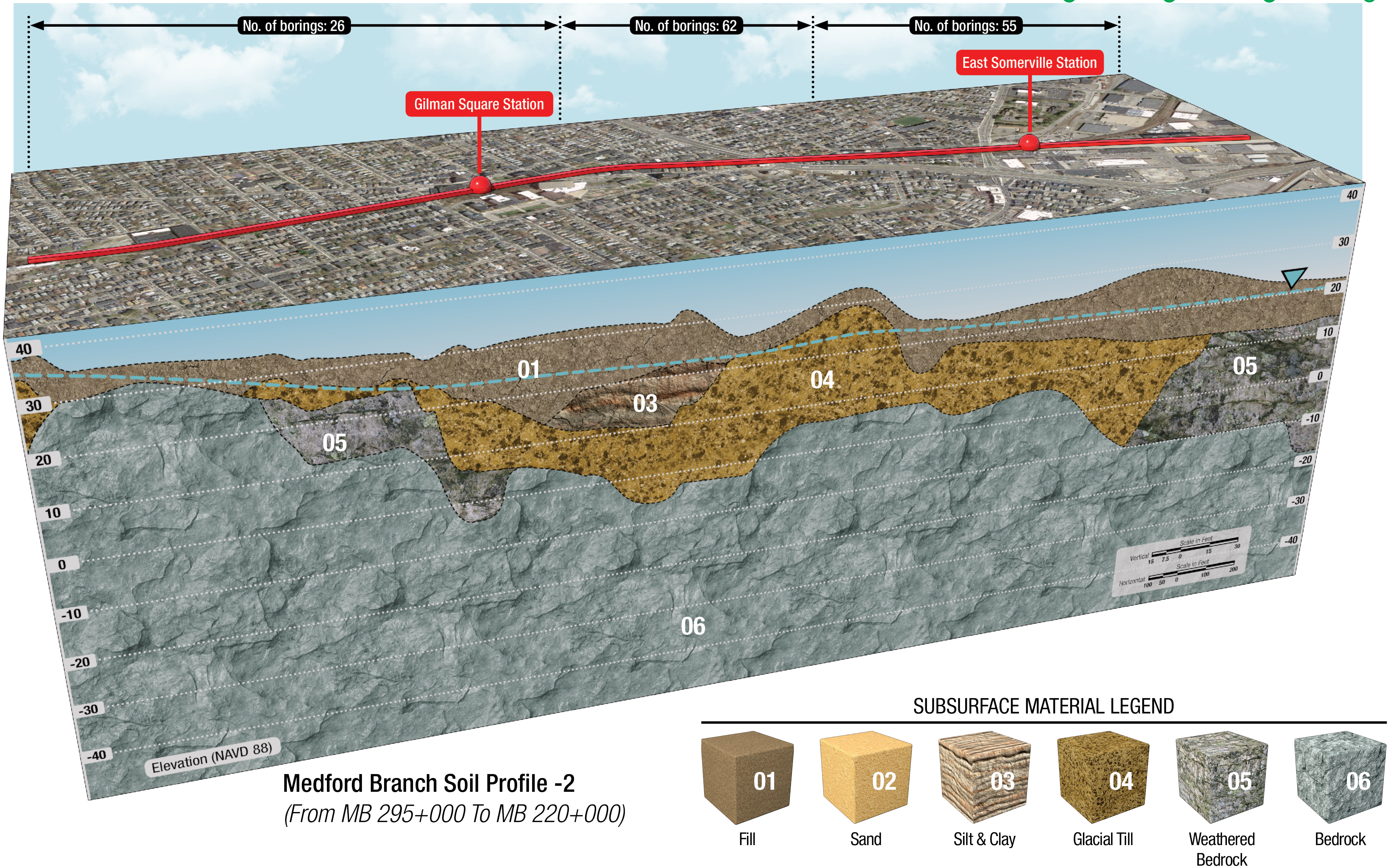
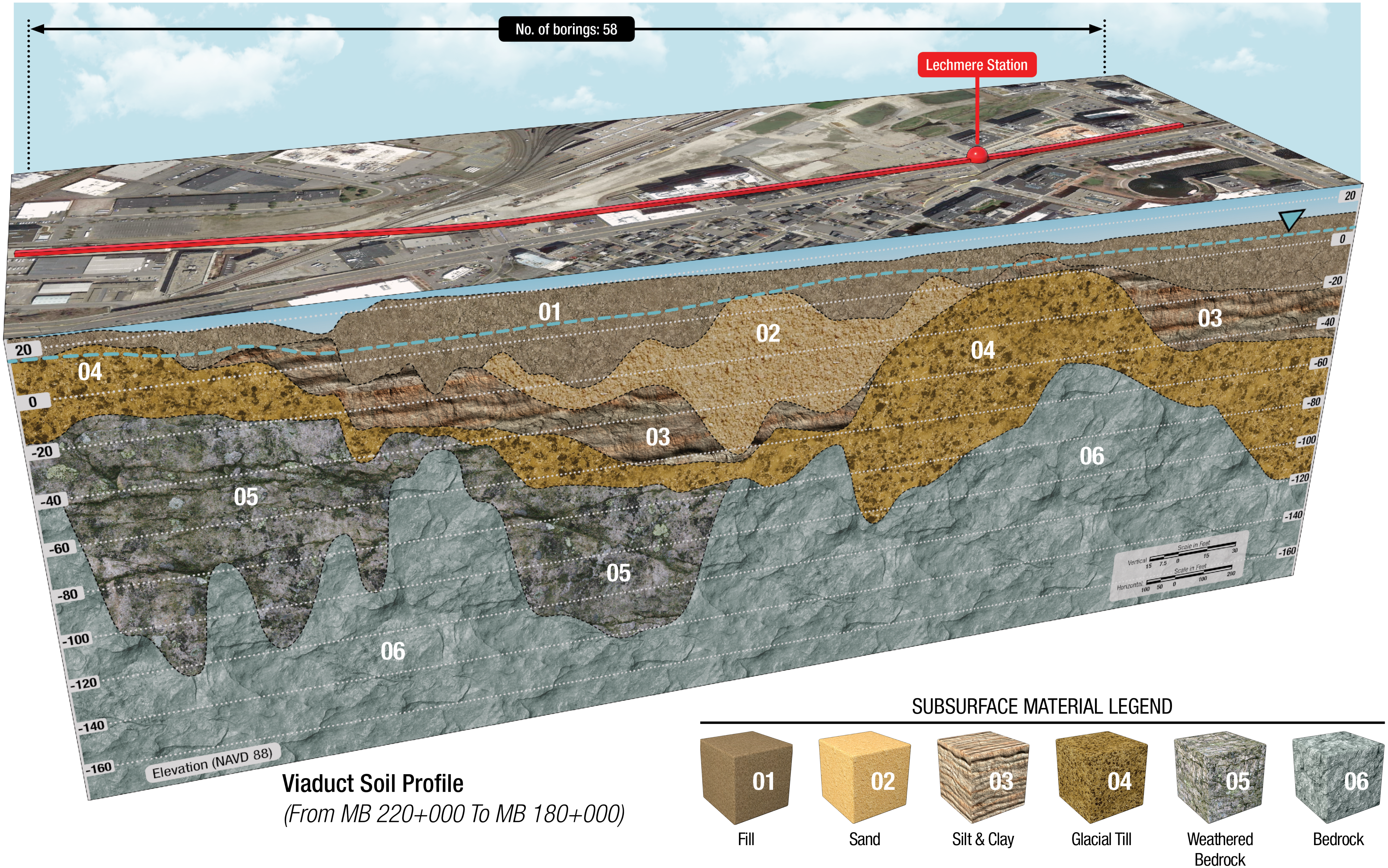


Figure A.5.2.2-17: Based on the proposal stage data provided by the MBTA and MassDOT for GLX area, GLP has developed an understanding of the ground conditions and have incorporated that knowledge in the foundation design.



Viaduct Soil Profile

(From MB 220+000 To MB 180+000)

Figure A.5.2.2-18: Based on the proposal stage data provided by the MBTA and MassDOT for GLX area, GLP has developed an understanding of the ground conditions and have incorporated that knowledge in the foundation design.

Design Consideration	Strategy / Mitigation Approach
Durability of foundation for 75-year & 100-year design life	› Use high-density, low-permeability concrete › Use precast concrete when conditions allow › Use steel pipe piles with additional sacrificial steel thickness, and stray current cathodic protection as needed › Design foundations to perform elastically even under extreme event load conditions
Settlement of foundations in clayey soil deposits in the south portion of the Project	› Utilize ground improvement systems such as compacted aggregate piers and drilled displacement (CMC) in transition zones of deep foundation › Provide superstructure design to accommodate anticipated differential settlement › Utilize lightweight backfill material to reduce settlement › Select foundation size that will limit differential settlement to design tolerances
Close proximity of new foundations to existing foundations/structures	› Focus on construction impacts throughout design development › Use drilling or non-displacement piles to minimize vibration-induced improvements › Implement a comprehensive structural and geotechnical monitoring program for timely identification of impact on existing structures
Space constraints and interference with railroad infrastructure	› Use mico-pile in lieu of drilled piles when applicable to reduce size of equipment › Stage sequencing of retaining walls and abutments to minimize impacts to railroad and traveling public › Develop designs that can be constructed with small equipment
Achieving necessary pile and drilled shaft capacity in wide range of ground conditions	› Perform supplemental geotechnical investigation to define location specific conditions › Perform foundation testing in each soil and rock stratum to calibrate design parameters, and refine installation criteria › Inspect pile and drilled shaft installation to verify consistency in foundation construction and compliance with installation criteria

Figure A5.2.2-19: Through our thorough design development process, GLP acknowledges the key geotechnical constraints in the Project area. We have developed a mitigation plan to address these constraints in our design.

Stratum	Design Consideration
Soft to medium Stiff, Silt and Clays, (with organics) (Stratum 03)	Econcountered few feet below grade and extent to a depth of approximately 40 feet. Low shear strength and high compressibility, limiting bearing capacity and lateral load resistance for these deposits. Our Team has experience in ground improvement techniques that can be used to improve these formations.
Glacial Till (Stratum 04)	Glacial till varies in thickness from a few feet to more than 50 feet, and overlies the rock surface along much of the alignment. Depending on its local decomposing and thickness, this stratum can provide considerable end bearing resistance for piles and drilled shafts. Our Design and Construction Team members have considerable experience in these formations.
Bedrock (Stratum 06)	Highly variable sedimentary, intermediate to hard un-weathered to exteremly weathered. Pile driven to rock can achieve very high-end bearing resistance at the rock surface. The observed highly variable weathered of rock would require variable socketed depths for drilled piles.

Figure A5.2.2-20: Consideration of major Strata Prameters and their effects is crucial for the development of an efficient design for the GLX Project.

could be suitable as backfill material. Gradation curves show that Gravely Sands and Silty Sands (SP, SM) with varying amounts of fines could be staged, screened, and recycled (with additives) for general site backfill as well as engineered backfill material. This assumption will be verified through the proposed supplemental subsurface investigation program.

- **Temporary Shoring–** Support of excavation will be required when the bottom of excavation is within the influence zone of the active tracks or adversely impacting existing structures' foundations. A number of SOE alternatives are technically feasible and were considered in our analyses, including pre-engineered trench shields, steel soldier pile and lagging, and steel sheet piles. In areas where excavation is outside the track influence zone, the excavation will be benched or sloped at a ratio of 1 Vertical to 1.5 Horizontal or flatter to minimize the use of SOE.

A5.2.2.C.4

ADDITIONAL GEOTECHNICAL INVESTIGATIONS AND TESTING

The proposal-stage geotechnical studies provided useful information for defining subsurface conditions across the Project. However, additional explorations are essential for final design to provide more detailed information on the subsurface condition at each viaduct pier and in areas where there are gaps in the geotechnical information. These data, along with the proposal-stage data, will be used to confirm the selected foundation type and estimated lengths of piles and drilled shafts, and to better predict foundation behavior, both during installation and in the long term. The supplemental subsurface investigation program will include the following methods:

- **Rotary Wash Boring-** With recovery of both standard split-spoon samples and undisturbed samples (ASTM D 1557 and ASTM D 4321)
- **Cone Penetration Test ("CPT") Sounding-** CPT soundings provide a continuous record of soil resistance with depth that will be used to develop a continuous profile of soil stratification
- **Seismic Cone Penetration Test ("SCPT")-** SCPT sounding will be performed at selected locations
- **Rock Coring-** Continuous rock coring (nominal NQ diameter) will be performed using double-tube or triple-tube core barrels to maximize recovery and reduce core disturbance

GLP will provide full-time inspection and coordination for boring and testing activities in the field by experienced geotechnical engineers or engineering geologists.

The location and number of the supplemental explorations have been developed following RFP requirements, and are summarized in **Figure A5.2.2-21**. In addition to these in situ tests, the disturbed and undisturbed soil samples recovered during the field investigation will be tested in the laboratory.

The proposed laboratory tests on disturbed soil samples recovered during drilling include grain size analysis (ASTM D422), Atterberg limits (ASTM D4316), and moisture content (ASTM D2216) tests. When fine-

Figure A5.2.2-21: To prepare a quality design GLP has prepared a Supplemental Subsurface Investigation Program that will be developed upon Notice to Proceed.

Location	Proposed Number of Borings
Viaducts and Abutments	25
VMF	8
Medford Branch Retaining Walls	4
Union Square Retaining Walls	22

grained soils are encountered during drilling, undisturbed soil samples with Shelby tubes will be recovered to assess the soil compressibility by consolidation tests (ASTM D2435), and soil shear strength by unconsolidated undrained ("UU") triaxial shear tests (ASTM D2850). The results from these tests will be used to derive geotechnical design parameters.

Required Foundation Testing During Construction

Axial Static Load Tests will be performed in accordance with the requirement of the RFP to verify pile and drilled shaft performance, verify and calibrate pile design lengths and drilled shaft socket lengths, and aid in developing pile and drilled shaft installation criteria. Piles and shafts will be instrumented to determine load transfer and end bearing. The number and locations of the test piles will follow AASHTO and MassDOT guidelines.

Wave equation analyses ("WEA") will be used to predict the behavior of piles during installation for specific site conditions and driving equipment, and will be calibrated with the results of the static load testing discussed above.

O-cell load tests have proven to be a practical and effective method for performing static load tests on high-capacity drilled shafts. The O-cell load test will verify the required drilled shaft axial resistance and the design rock socket length of the production shafts.

Integrity testing is an essential element to verify the necessary structural strength and the long-term durability of the drilled shafts. Integrity testing will include cross-hole sonic logging ("CSL") to access concrete quality within the shaft reinforcement cage, and thermal integrity testing to assess the quality of the concrete cover outside.

A5.2.2.C.5
HYDROGEOLOGICAL IMPACT AND ASSOCIATED RISK ASSESSMENTS

A5.2.2.C.5.A
CONSTRUCTION PERIOD SOIL GROUNDWATER CONTROL STRATEGY

Excavation below groundwater level will generally be avoided and dewatering of groundwater during construction will be limited to shallow pile caps; grade beams; and deep foundation elements, including drilled displacement piers for the VMF.

A5.2.2.C.5.B
PERMANENT CONDITION GROUNDWATER CONTROL STRATEGY

Due to the nature of our foundation elements and predominantly staying above the groundwater level, we intend to avoid any active groundwater control systems in our final design for the permanent condition. We will provide appropriate waterproofing details for below-grade structures, such as elevator shaft pits and work pits in the VMF, to ensure waterproofing of structure. Dry wet wells will be installed in these below-groundwater-level structures for any emergency dewatering required due to unanticipated or natural events.

A5.2.2.C.6
PRELIMINARY GEOTECHNICAL IMPACT ASSESSMENT AND ASSOCIATED RISK ASSESSMENT

Recognizing that foundation construction represents a significant risk potential for the successful completion of the Project, our Team conducted a risk assessment workshop to identify the likely risks and to define appropriate mitigation measures to address these risks. The risk assessment workshop highlights are summarized in the geotechnical risk assessment table shown in **Figure A5.2.2-22**.

During final design, the GLP Team will meet with MBTA and MassDOT to further expand and refine the risk assessment table as additional risk items are identified. This process will be led by GLP staff who specialize in facilitating risk assessment workshops, and have successfully employed this approach for other major transportation projects. The GLP Team will use this proactive process to anticipate likely risks, and will incorporate appropriate mitigation methods using the "Bowtie method"

Figure A5.2.2-22: GLP recognizes the importance of identifying risks that will effect the project, and has developed a risk mitigation plan to avoid or limit impacts on the GLX Project advancement.

Risk Item	Variable Parameter	Mitigation Measure	Likelihood of Occurance	Potential Impact
Post-award differeing site conditions	Subsurface program to identify conditions different from pre-bid information	Verify or modify foundations, piles, shafts, subgrade, and retaining wall design	Medium	Medium
Field investigation program	Delays on start and progress of investigation to support accelerated design and construction schedule	Authorized early subcontract mobilization at Notice to Proceed, mobilize multiple drilling subcontractors, prioritize early construction work areas	Medium	Medium
Subsurface obstructions	Presence of abandoned timber crib walls, ties, steel, and other buried material and abandoned foundations which may be present	Include variable design details to work around buried obstructions. Perform additional investigations to further delineate the obstruction boundaries	High	Medium
Lack of as-built and pre-bid condition assessment for existing structures, walls, and slopes	Potential repair, reinforcement, and/or underpinning	Take test pits for existing structures; site recon for slopes and crib walls; modify design to accommodate unaccepted conditions	Medium	High
Existing structures impacts	Disturbance or damage to existing walls, buildings, tracks, and active utilities due to excessive vibrations and settlements	Use drilling equipment to predrill pile holes, minimize use of vibratory and impact hammers. Use small diameter mini-piles, monitor structures and ground vibration. Develop and implement action plan for response value exceedances	Low	High
Unexpected utilities	Re-design and construction schedule impacts	Use standard solutions previously used within MBTA ROW, perform early utility investigation and test pits	Medium	Medium
Community impacts	Excessive noise and vibration	Use drilling equipment (instead of pile driving equipment) wherever practical, monitor noise and vibrations, use ballast mats, and early installation of noise walls	Low	Medium
Railroad fouling envelope	Impact on railroad operation and flagmen availability	Utilize type of wall that does not require large rigs to construct; Use mini-pile with small equipment for retaining wall rehabilitation; reduce quantity of retaining walls by modifying track alignment and slope grading	Medium	High

to reduce risks for geotechnical investigation, foundation design, presence of unexpected conditions, unknown condition of existing structures, and in the means and methods of construction, to avoid problems that could affect Project cost and schedule certainty.

Geotechnical Instrumentation

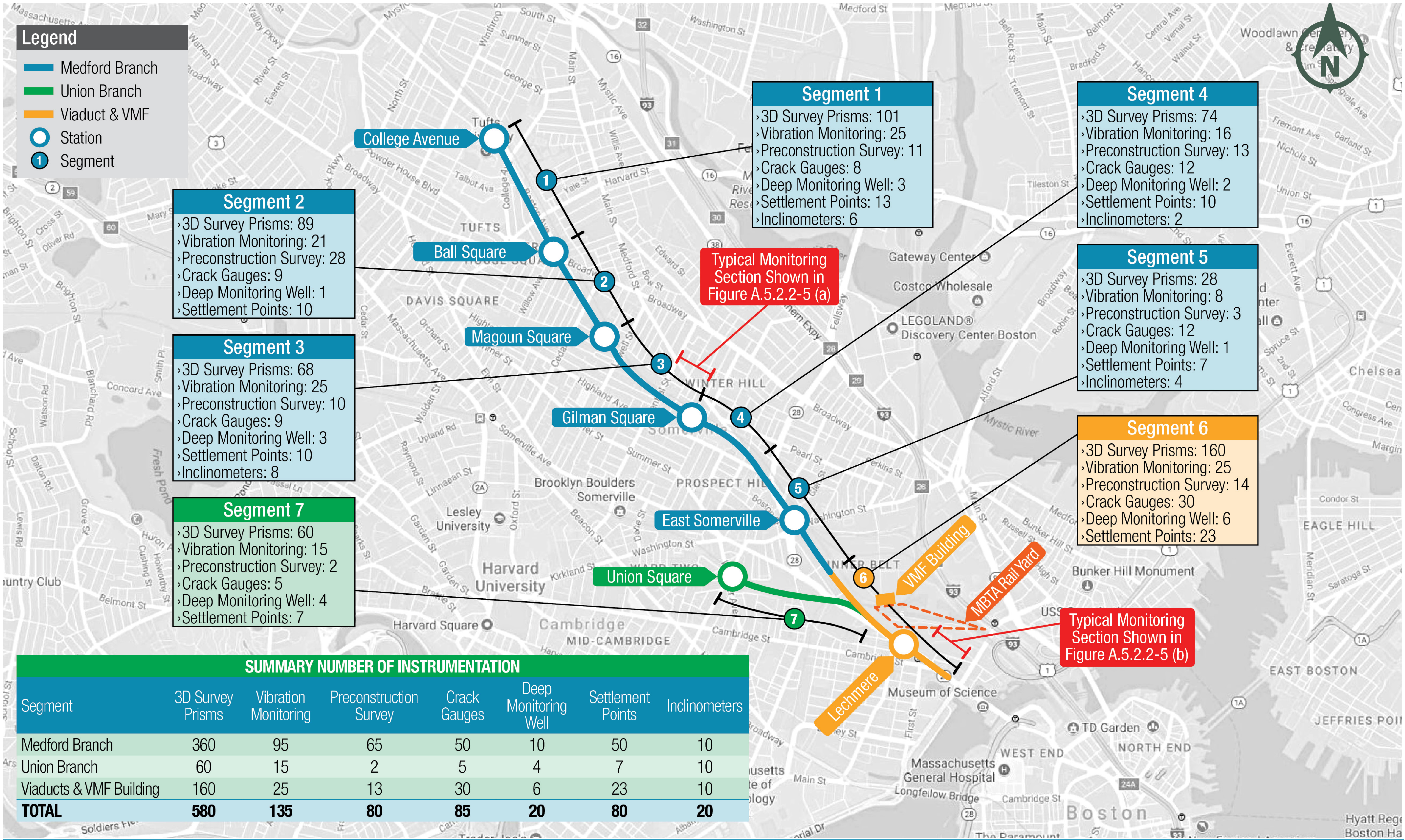
A planned and executed geotechnical monitoring program is a crucial element of work for GLX construction. Existing in-service structures affected by construction activities must be monitored during construction operations to provide early detection of movements and vibrations before structural damage occurs. GLP will monitor settlement and lateral movement of the adjacent existing tracks to identify any movement caused by construction activities and allow timely implementation of corrective measures. High-precision optical prisms secured adjacent to wood or concrete ties will be placed along existing track every 31 feet in areas where significant construction vibration is a concern. Automated Motorized Total Stations ("AMTS") will be used for unattended 24/7 on-line continuous monitoring of track infrastructure. An AMTS provides wireless communication for data transfer, and automated least-square processing to improve accuracy.

Vibration monitoring using seismographs will be used during pile drilling and SOE installation activities, and will be limited to construction zones.

GLP will perform pre- and post-construction surveys to document the existing condition of the impacted structures, including residential and commercial buildings, existing ROW retaining walls, bridges, viaducts, overpasses, stations, utilities, and other ancillaries. The surveys—coordinated with MBTA outreach—will include photo and video documentation, and installation of crack-gauges and high-precision prisms for continuous monitoring.

Settlement plates, inclinometers, and observation wells are anticipated to be installed to monitor existing slopes, ground supporting utilities, and foundations.

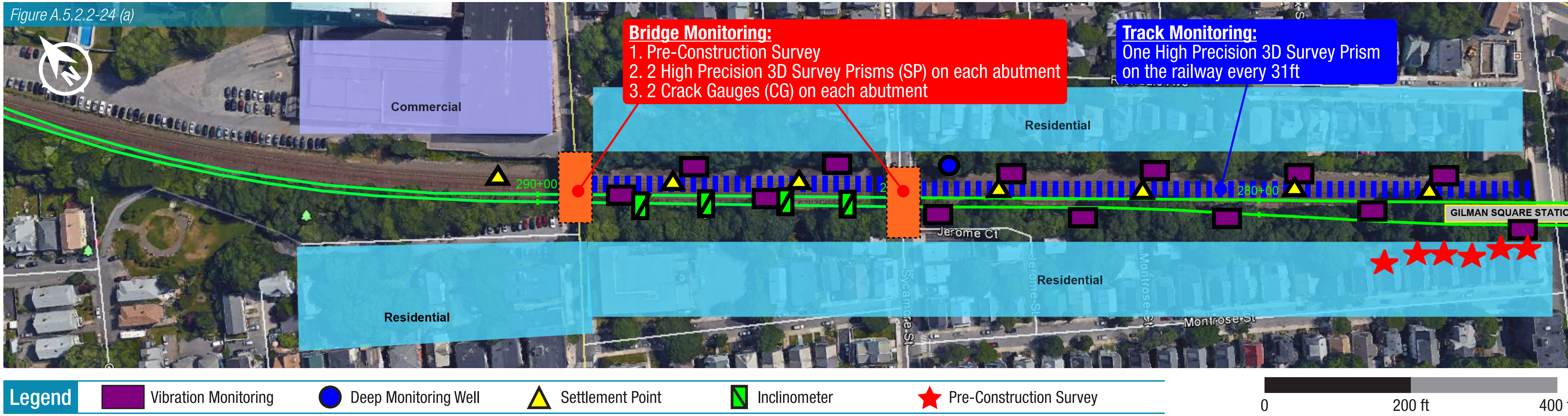
The instrumentation program shown in **Figures A5.2.2-23 and A5.2.2-24** is the first line of defense against potentially damaging movements. GLP's program detects movements when they are still small, allowing modification to construction procedures or other mitigation action before movements grow large enough to constitute real issues. This provides certainty in our foundation approach.



SUMMARY NUMBER OF INSTRUMENTATION

Segment	3D Survey Prisms	Vibration Monitoring	Preconstruction Survey	Crack Gauges	Deep Monitoring Well	Settlement Points	Inclinometers
Medford Branch	360	95	65	50	10	50	10
Union Branch	60	15	2	5	4	7	10
Viaducts & VMF Building	160	25	13	30	6	23	10
TOTAL	**580**	**135**	**80**	**85**	**20**	**80**	**20**

Figure A.5.2.2.-23: GLP's proposed monitoring and instrumentation plan alleviates the mitigation of possible construction and community risks around the GLX Project.



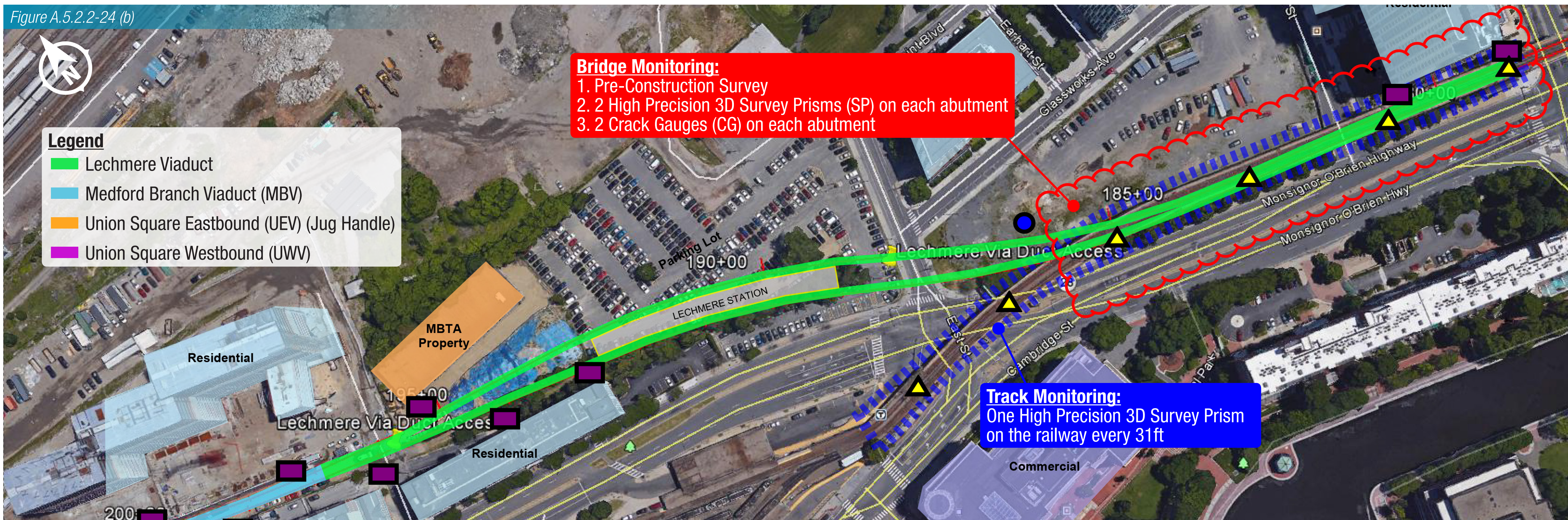


Figure A.5.2.2-24: Based on proposed construction activities, GLP has developed instrumentation plans to monitor potential impacts (Typical).

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Section A5.2.3

Stations

GLP's station design provides patrons with safe and efficient accessibility to the Green Line. By providing a heightened customer experience at the stations, the stakeholders and community will be able to fully embrace the convenience of the GLX services.

INTRODUCTION

GLP's Stations Team has reviewed in detail the Final RFP, Addenda, Questions and Answers, and the Project Definition Plans to develop stations exceeding the MBTA's requirements and customer expectations. Seven island platform stations, one elevated, and six at-grade will be constructed at strategic locations along the Green Line as it is extended north from Boston to Medford. The stations will be fully Americans with Disabilities Act ("ADA") accessible; employ durable, low-maintenance materials; and incorporate MBTA design standards.

The stations' name, type, and location are as follows:

- Lechmere Station (Elevated)
  North 1st Street and Msgr O'Brien Boulevard
  - Relocated station that serves both the Medford and Union Square branches. Elevators and stairs from both the north and south headhouses provide access to the platform.
- Union Square Station (At-grade)
  Prospect Street and Bennett Court
  - The only station on the Union Square Branch. Primary entrance is from the intersection of Prospect Street and Bennett Court. A sloped walkway provides access to the platform.
- East Somerville Station (At-grade)
  Washington Street and Joy Street
  - New station on the Medford Branch. Primary entrance is from the proposed Community Path, which connects to the Washington Street bridge.
- Gilman Square Station (At-grade)
  Medford Street and School Street
  - New station on the Medford Branch. Primary entrance is from the Medford Street Bridge. Stairs and an elevator provide access to the platform.
- Magoun Square Station (At-grade)
  Lowell Street and Vernon Street
  - New station on the Medford Branch. Primary entrance is from the Lowell Street Bridge. Stairs and an elevator provide access to the platform.
- Ball Square Station (At-grade)
  Boston Avenue and Broadway
  - New station on the Medford Branch. Primary entrance is from Boston Avenue. Ramps and stairs provide access to the platform.
- College Station (At-grade)
  Boston Avenue and College Avenue
  - New station on the Medford Branch and terminus of the GLX. Primary entrance is from Boston Avenue. Stairs and elevators provide access to the platform.

The station design features a 225-foot-long precast concrete platform with LED lighting, weather shelters, benches, and signage. All stations have a single entry point and two means of egress, and to ensure ADA accessibility, five stations are served by elevators and stairs and two are served by sloped walkways.

The RFP calls for station designs that allow for both extending and raising the platforms in the future. The platforms will be lengthened by 75 feet for a total distance of 300 feet (except Lechmere Station, which is 333 feet long in the base design), and the platforms will be raised an additional 6 inches to support level boarding of future vehicles. In order to accommodate the additional platform length, the GLP Design Team will include foundations for future lighting structures, provide empty conduits for power and communications, and locate pedestrian track crossings beyond the extension. This work will reduce construction time in the future, thereby reducing the impact to Green Line operations and passengers.

Section Highlights

- All stations are fully ADA accessible.
- GLP's station plan promotes intuitive passenger flow.
- The design accommodates future construction and expansion.
- Precast concrete elements and modular structures improve construction efficiency.
- Durable and sustainable materials ensure the station will withstand daily use and reduce maintenance costs over the long term.

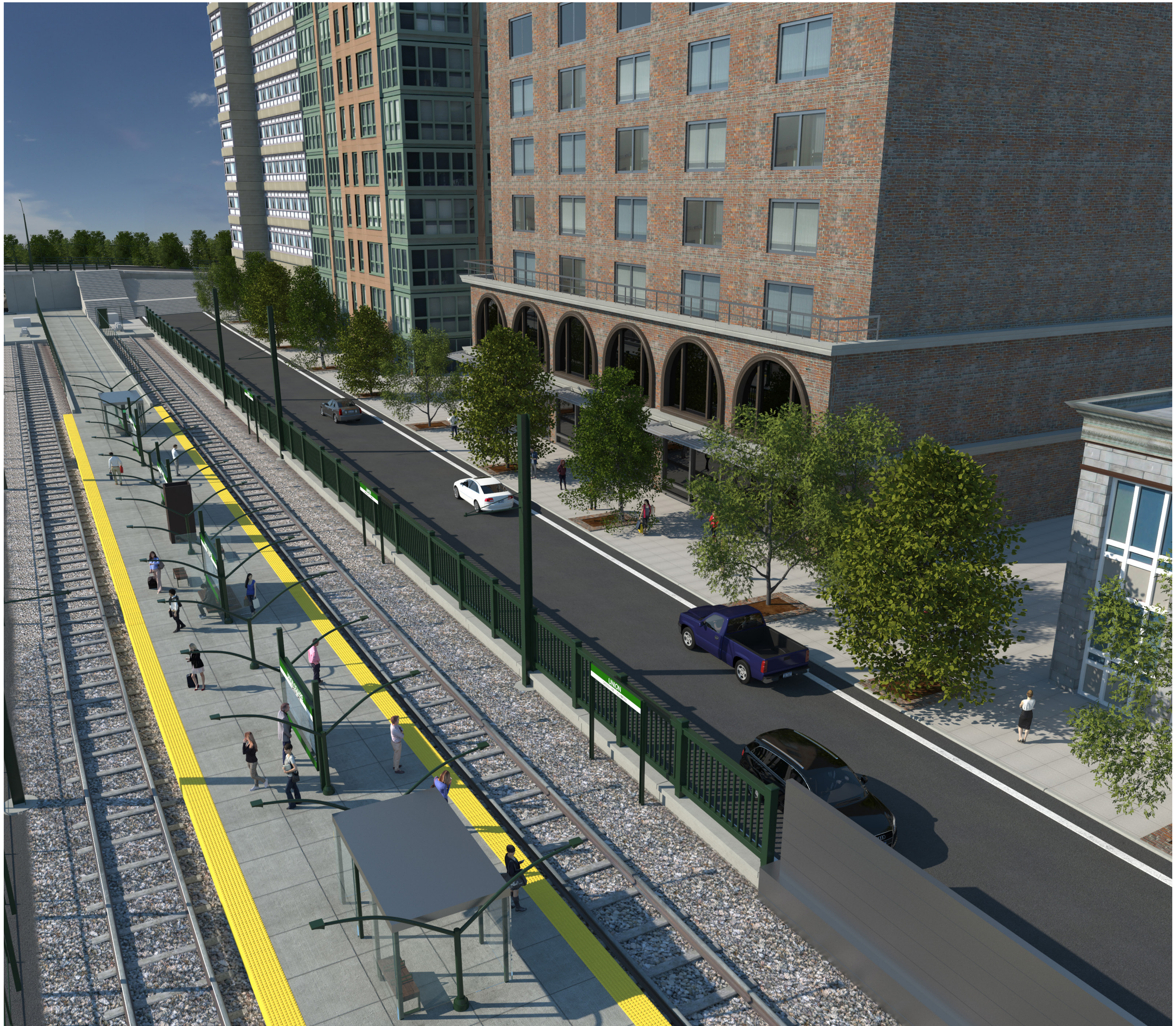


Figure A5.2.3-1: GLP has designed island platforms with a single row of station amenities and furnishings, which is the most efficient platform design for passenger access, station maintenance, and vehicle operations.

Another innovation being pursued by the Station Design Team is the incorporation of sustainability concepts. Although the Project is not pursuing Leadership in Energy and Environmental Design ("LEED") certification, we feel that there are opportunities to maximize the efficiency of the stations and their support buildings. Some examples of sustainability practices that GLP will incorporate into the station design include:

- Neighborhood development location
  - Encourages walkable communities
  - Provides access to transportation,
  - Provides access to civic and recreation activities
- Bicycle facilities
  - Supports the MBTA Pedal and Park Program
- Construction and demolition waste management
  - Diverts 50% of waste material from landfills
  - Reduces total construction waste material
- Light pollution reduction
  - Employs LED lighting and controlling beam spread
- Storage and collection of recyclables

A5.2.3.A
APPROACH TO STATION DESIGN

GLP's design concept is to create stations that integrate into the existing line vernacular; are reflective of the history of the Green Line; and employ modern, sustainable materials. The overall station layout will employ Universal Design principles—accommodations for all riders will be integrated into the design as opposed to being added to the design.

Figure A5.2.3-2: - There are seven principles of Universal Design that, when employed early in the design process, ensure equal and intuitive use by all persons.

Figure A5.2.3-3: - Precast concrete platform panels with the tactile edge installed prior to delivery at the job site. This method was used on Southeastern Pennsylvania Transportation Authority (SEPTA) to provide high-quality fabrication and improve construction efficiency.

Universal Design - The design of products and environments to be usable by all people, to the greatest extent possible, without the need for adaptation or specialized design.
- NC State University, The Center for Universal Design

The design will also conform to the current versions of international building codes, and the accessibility laws adopted and enforced by the Commonwealth of Massachusetts, the City of Boston, and the other municipalities the Green Line will serve. These codes and laws will serve as the prescriptive approach, and Universal Design will be the descriptive approach. In other words, the station design will be directed by the building codes, particularly the number, size, and location of the platform exits. These items will be integrated into the design using Universal Design principles so that they appear as natural components and not add-ons.

GLP's design will also employ proven and efficient materials throughout the station, not only for durability and maintenance reasons, but also to streamline the construction of certain elements. The efficiency will be achieved by using precast concrete panels with the tactile edge already installed for the platforms, and by contracting with a single source for the weather shelters, starters booths, and bike cages, all of which will be prefabricated structures that are delivered to the site when ready.

A5.2.3.A.1

PASSENGER FLOWS

Critical to the success of the station design is the complete passenger experience from street to platform to LRV. The path will be arranged logically and intuitively, starting with a clearly defined entrance with signage, lighting, landscaping, and other visual cues. Moving into the station, the vertical elements will be clearly visible with sufficient space in front of elevators for queuing, and protection from the elements. As part of the Universal Design concept, the vertical elements will be accessed directly from the entrance without multiple changes in direction or floor level. The vertical circulation elements will provide direct access to the platform as well, minimizing the travel distance

Although the station design is intended to be intuitive, signage will also be provided to support the design concept at key decision-making points along the path. Before entering the station, passengers will know

Figure A5.2.3-4: The design of the station entry sequence and path to the platform for all users is direct, efficient and supported by minimal signage. The rendering is the view of the Magoun Square Station entrance from the Lowell Street Bridge.

Figure A5.2.3-5: Bus shelter and fencing at the 35th and Allegheny Bus Loop. The solid glass block and open picket fencing provides visual surveillance for passengers approaching and waiting in the shelter.

Figure A5.2.3-6: Low plantings do not block passengers' views across the station, nor do they allow anyone to hide behind them. This is an example of Natural Access Control and is most successful with a maintenance plan to manage the height of the plantings.

the station name; immediately after entering, they will know where the elevator and stairs to the platform are located. Upon reaching the platform, signs will direct passengers to the fare vending equipment, correct platform side for reaching their destination, and Customer Assistance Area ("CAA"). In support of life safety and in the event of an emergency, signage will direct passengers to the nearest point of egress, and for passengers in wheelchairs, signage will inform them where Areas of Refuge are located and how to contact emergency personnel.

A5.2.3.A.1.A
CRIME PREVENTION

A clear direct path to the platform is not only about Universal Design, but safety as well. Just as direct visual contact to the platforms guides passengers to their destination, this same concept allows law enforcement and citizen "eyes on the street" the same access, cutting down on vandalism and other crimes. For this reason, the Community Path serving the East Somerville station entrance from Washington Street will be open on the sides instead of using a tunnel. This concept is called Natural Surveillance and is one of the five key components of Crime Prevention Through Environmental Design ("CPTED") principles identified by American Public Transit Association ("APTA"); the other four criteria are:

- Natural Access Control
- Territoriality
- Activity Support
- Maintenance

When built into the design early in the Project, these principles provide cost-effective solutions for reducing crime and promoting a safe environment for passengers and neighborhood residents and businesses.

A5.2.3.A.1.B
FULL ACCESSIBILITY

Throughout the design process, the Team has consulted not only the ADA Standards for Accessible Design (U.S. Department of Justice) but also the MBTA Guide to Access, the ADA Standards for Transportation Facilities (U.S. Department of Transportation) and the Boston Center for Independent Living Agreement ("BCIL"). As a result, each station will be fully accessible via an 8-foot-wide path from the sidewalk and nearby bus stops to the platforms. At most stations, the path to the platform includes an elevator that is in direct line of sight from the station entrances. The height of these entrances make them easily recognizable even before entering the station. Not only is a direct path efficient for persons with mobility disabilities, but also for persons with vision issues where multiple turns can be disorienting and cause confusion.

Accessible Path Parity

Another critical aspect to the accessible circulation path is that it closely resembles the path non-disabled passengers will use to get to the platforms. For this reason, the stations with elevators have the main stairway directly adjacent so the paths are nearly identical. For stations without an elevator like East Somerville, the entrance is served by the Community Path, and all passengers, disabled and non-disabled, take the same path to get to the station entrance.

Station Elements

The station circulation is not the only part of the design that is required to be accessible. The egress points from the station will be accessible in two ways: at the elevators, an "Area of Refuge" will be provided with two-way communications, and a second means off the platform will be provided in the form of a path leading to nearby streets. Accessibility will also be provided in the station shelters, at the CAA, and at the LRV boarding locations.

There will be instances where the path to the platform will cross the tracks, and not only will the flangeway width conform to the accessibility guidelines, but tactile warning strips will be provided to alert visually impaired passengers of the crossing. These same tactile strips will be used along the length of the platform edge, and serve as a reminder to non-visually impaired passengers as well. The platforms will feature shallow cross slopes of 0.45% to 1.9% maximum, which will allow the platform to drain, but will not be too steep for a person using a wheelchair.

Future Construction

The platforms and the path to them are being designed to accommodate future construction, which will affect the platform elevation and the length of the platforms. The platform and the path to it is being designed for a future 6-inch rise (14 inches above top of rail) for level boarding into the Type 9 LRVs. This means there is a sloped sidewalk connecting the elevator landing to the platform with a maximum slope of 8%. This sloped area is free of all fixtures, furnishings, and equipment, which will be installed on the platform or the entrance plaza.

As mentioned in the introduction, the platforms are being designed so they can be extended from 225 feet to 300 feet in length to support four-car trains. To minimize the impact on passenger access to and egress from the stations, the pedestrian track crossings will be located beyond the final 300-foot length.

A5.2.3.A.1.C

CUSTOMER EXPERIENCE IN THE DESIGN OF STATIONS

The station design is focused on the passenger experience. The station circulation path will be arranged in a clear and logical fashion, with no unnecessary turns or bends to get to the platform. This ease of circulation will be reinforced by the open and transparent design, allowing for clear visual access to all station elements. The experience begins at the station entrances,which feature roll-down security grills so that even at night when the station is closed, the station area remains visible from the outside.

Figure A5.2.3-7: Platform elevation showing the sloped transition from the stair/elevator landing to the platform level. Future construction involves adding a 6-inch slab of concrete to achieve level boarding into the future LRVs.

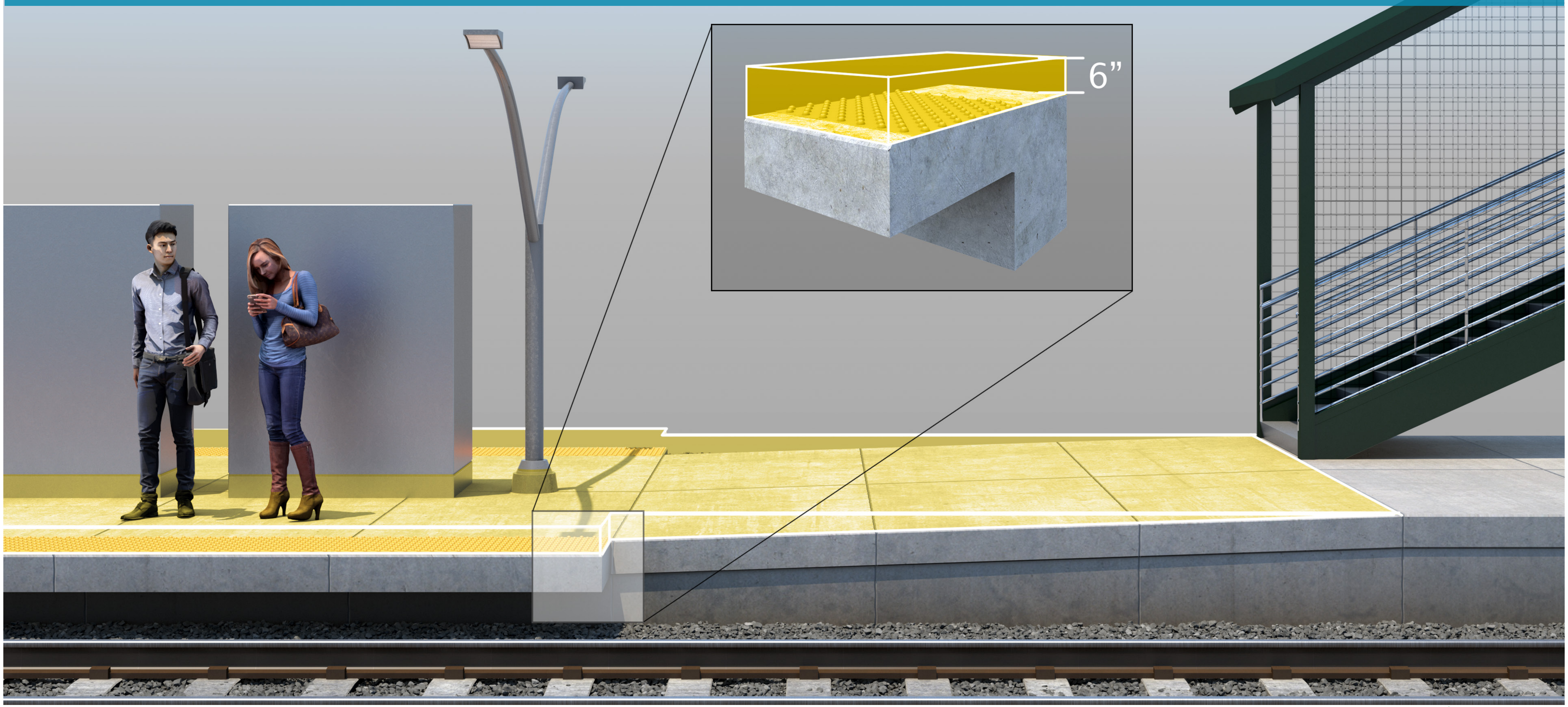


Figure A5.2.3-8: Stations will be easily identifiable and through civic engagement, GLP will develop a design that will instill a sense of ownership by the community.

Figure A5.2.3-9: GLP's proposed MBTA Green Line platform and other station signage. Font type, height, materials, and colors will match MBTA standards.

In addition to providing clear and direct ***access to*** the station, GLP is also focused on providing clear and direct ***egress from*** the station in the event of a fire or other emergency. The occupancy is based on year 2030 ridership projections and is broken down further to maximum three-hour period and 10-minute occupant loads, which will be used to determine life safety/egress requirements.

Station	3-Hour periods	10-minute occupant loads
Lechmere	1,820	954
Union Square	900	204
East Somerville	860	501
Gilman Square	780	396
Magoun Square	200	225
Ball Square	370	199
College Avenue	510	119

Figure A5.3-8: GLP uses Peak Station Occupancy to determine the width of egress components.

A5.2.3.A.2
STATION IDENTITY

The intent of the station design is to provide stations that are easily identifiable as part of the Green Line, and at the same time, set them apart from each other to serve individually as neighborhood landmarks. Civic engagement is critical for the overall success of the Project. This will instill a sense of ownership in the station in the community, and establish the station's place on the line and within the Boston metropolitan area as well.

In addition to the stations identifying the communities they serve, they will also clearly indicate that they are a part of the existing Green Line. This will be achieved by employing the MBTA Guidelines and Standards, which provides information such as line colors, signage materials and construction, fare equipment, etc. Employing the standards will connect the individual station to the overall line, enabling passengers to orient themselves within the transit system. The use of standard colors and furnishings provides a sense of familiarity for the passengers, so they will know where to find information about the station, line, and their surroundings based on consistencies in platform layout.

A5.2.3.A.3
INTERFACE WITH EXISTING RIGHT-OF-WAY

The primary entrance to each station will connect to sidewalks and paths, providing direct access for pedestrians and cyclists. Bicycle users will have access to secure, enclosed bike storage facilities directly adjacent to the station entrance so riders will not be required to bring bikes down stairs or onto elevators. To further define the station location along the existing ROW, stainless steel bollards with lighting will be installed. These bollards will be K4-rated for the safety of the pedestrians on the sidewalk as vehicles stop at the curb to drop people off.

GLP's design also includes a change in the alignment of the Community Path, which is raised up to platform level at the East Somerville Station. This access greatly enhances neighborhood connectivity and links the Green Line to passengers outside the immediate station vicinity.

A5.2.3.A.4

SHELTER DESIGN

The primary function of the platform shelters is to protect passengers waiting on the platform from the elements. The shelters will have walls on three sides, a roof, and seating for passengers (including spaces for those in wheelchairs). The shelters will be installed on the platform surface so they can be removed and reinstalled after the platform is raised to support the future Type 9 LRVs.

A5.2.3.A.4.A

APPROACH TO THE MATERIALS AND FINISHES, ENVELOPE, AND WEATHER PROTECTION

The platform shelters will be prefabricated aluminum structures with laminated glass walls. The shelters will feature LED lighting and a built-in bench, and be sized to accommodate two wheelchairs. The use of glass in the walls is another CPTED concept, enabling passengers approaching the shelter to see if it is occupied, and allowing waiting passengers to see around them. The shelters' roof edges will be painted the green color standard for the line to further emphasize the stations' placement in the system.

A5.2.3.A.4.B

METHODOLOGY USED TO DETERMINE THE NUMBER AND SIZE OF SHELTERS AT EACH STATION

The number of shelters shown in the platforms was determined by the RFP. Lechmere, which has a 300-foot platform, will have four shelters and all other stations will have three shelters. When these other platforms are extended to 300 feet in length, an additional shelter may be added to support the increased passenger load.

Figure A5.2.3-10: Entrance to Magoun Square Station showing bollards and the interface of the highway ROW and the station entry.

The size of the shelters is 13 feet, 8 inches long by 6 feet wide. This size was determined by the spacing of the platform light poles: 15 feet center-to-center and the width of the clear path along the platforms is 8 feet. A shelter of this size provides protection for six people on benches and two 30-inch by 48-inch clear wheelchair-accessible waiting areas.

A5.2.3.A.5
ORGANIZATION OF PLATFORM EQUIPMENT AND ELEMENTS, INCLUDING AMENITIES

The platform will accommodate equipment, furnishings, and other site elements to support MBTA operations, and provide for passenger movement and comfort. These elements will be located on the platform in a logical sequence, and provided in a quantity sufficient for the ridership. All items available for public use will have the required accessibility clearances, and be located to avoid interfering with the main path of travel and to avoid unnecessarily blocking egress routes.

EQUIPMENT

Fare equipment will be installed at most stations on the platform at the end closest to the station entry. The quantity will be determined by the MBTA based on ridership, but no fewer than two for redundancy purposes.

FURNISHINGS

In addition to the shelters, each platform will have a CAA and trash receptacles that will comply with MBTA standards.

The CAA will have a bench, signage, and a customer assistance phone in the event of an emergency.

Each platform will have a minimum of two trash receptacles located just off the path of travel near entrances, shelters, and pedestrian overpasses. The receptacles will be blast-/explosion-proof, fixed to the platform surface, vandal-resistant, and will include a weatherproof cover to keep the contents dry.

OTHER SITE ELEMENTS

Each platform will have equipment supporting MBTA operations, including sand and salt storage bins. These items will meet the following criteria:

- Will be installed away from the path of travel, but easily accessible by MBTA employees
- Have a capacity of 11 cubic feet (“CF”)
- Will be a covered, lockable, corrosion resistant container, with stainless steel hinges; contents must be kept dry
- The container shall be made from industrial grade polyethylene and therefore resistant to sunlight (UV), oils, saltwater, and chemicals

Terminal stations such as Union Square and College will have starter booths at the end of the platform in the direction of outbound travel. These booths will be modular units completely assembled and fitted out a desk and cabinetry per MBTA Operations standards and shipped to the site for installation. The booths will include a complete HVAC system, three electrical receptacles, one phone and one data receptacle, and a door with MBTA standard hardware.

Figure A5.2.3-11: The platform shelters will feature a painted steel frame with translucent infill panels and built-in benches for passenger use.

A5.2.3.B
DRAWINGS

The station architectural drawings included in the proposal demonstrate our understanding of the Project scope and the needs of the MBTA. The drawings show that our proposed design meets or exceeds the requirements of the Technical Proposal.

A5.2.3.B.1
CONTEXT PLAN

Context plans on Sheet A-2000 show the station and its relationship to its immediate environment, including surrounding streets, adjacent structures, property lines, etc.

A5.2.3.B.2
SITE PLANS AND SECTIONS

The architectural site plans on drawing sheets LES-A-2010, UNS-A-2010, ESS-A-2010, GSS-A-2010, MSS-A-2010, BAS-A-2010, COS-A-2010 show all station elements from the shelters to the OCS poles. In addition, these drawings show the station landscaping and wayfinding strategies.

A5.2.3.B.2.A
SHELTERS, FURNISHINGS, FINISHINGS, FIXTURES, AND EQUIPMENT

Drawings STA-A-8000 show the typical platform arrangement of the shelter, furnishings, fixtures, and equipment. Material and finish information will also be noted to ensure compliance with the RFP.

A5.2.3.B.2.B
SIGNAGE, LIGHTING, CATENARY, AND FARE COLLECTION EQUIPMENT

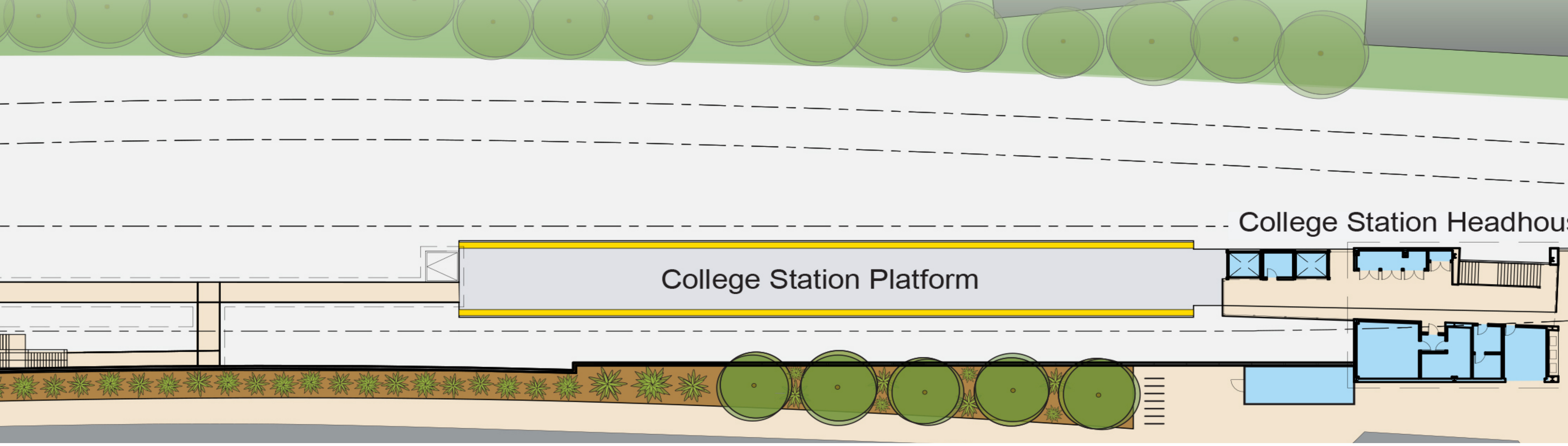
Station site plan drawings LES-A-2010, UNS-A-2010, ESS-A-2010, GSS-A-2010, MSS-A-2010, BAS-A-2010, COS-A-2010 show lighting and fare collection equipment. In addition, drawing STA-A-8000 show the typical platform relationships of signage, lighting, and other station appurtenances in elevation views.

Catenary poles are shown on Corridor Plans 000-C-0001 through 000-C-0028.

A5.2.3.B.3
ADDITIONAL DETAILS AND/OR KEY DIMENSIONS

In addition, the site plan drawings LES-A-2010, UNS-A-2010, ESS-A-2010, GSS-A-2010, MSS-A-2010, BAS-A-2010, COS-A-2010 show the following information:

- Station landscaping and wayfinding as detailed in the RFP
- Typical platform elevation showing the height of the lighting fixtures, the sloped transition from the stair/elevator landing, and other platform elements noted in the RFP
- Floor plans with overall dimensions of the headhouses at Lechmere and College stations



Section A5.2.4

Landscaping and Station Signage Design

GLP's landscape design, in part, will provide shade, screening slope stabilization and stormwater absorption as well as provide a transition from the existing streetscapes to the new GLX facilities. The plantings are hardy, native species which will thrive without irrigation and have low maintenance requirements. The signage and wayfinding elements will clearly identify routes and circulation paths for GLX users to and from the stations to adjacent pedestrian spaces. The signage/wayfinding elements will also provide clear brand recognition for the GLX corridor and facilities.

INTRODUCTION

The landscaping and signage systems layout are important components of station design. The landscaping provides greenery to soften the concrete and steel station vocabulary, contributes to the stormwater Best Management Practices ("BMPs") at the VMF, and are an attractive means to support sloped topography without additional retaining walls. At specific stations, where space allows, landscaping may provide shade for riders approaching the station, and other plantings may provide visual screening of adjacent industrial land uses. In some locations, the use of street trees will enhance the pedestrian experience and provide a transitional element from the new site to the existing street scape. Prudent use of climbing vines to cover and soften the faces of retaining walls may also be effective in reducing or eliminating graffiti along Community Path and rail overpass structures.

Signage and wayfinding systems guide the passengers into and through the station and identify key elements and important decision-making points, such as the accessible path, ticketing, points of emergency egress, the station name, and train direction. Combined with an efficient overall station design, lighting, and communications package, navigating the GLX will be simple and straightforward, and aesthetically pleasing for all passengers.

The landscaping and station surroundings are also designed to enhance safety. Using the basic principles of CPTED, the approach paths, plaza layout, connection elements, and landscape will be designed with surveillance, access, and territoriality in mind. The station areas will have visible forms of surveillance cameras and audio systems to demonstrate that the facility is being monitored and observed. This will provide a level of comfort to passengers and warning to criminals. The access to and from the stations will be clearly visible from the adjacent roadways, sidewalks, and public ROWs. This will be accomplished by carefully placing site paving and selecting landscape elements to demonstrate that the space is owned by the MBTA, and allowing for ease in approaching and rapidly evacuating the station platforms should this be necessary.. Stations and platforms will be designed with territoriality in mind, reducing opportunities for graffiti and vandalism by using durable

Figure A5.2.4-1: GLP has successfully designed low-maintenance native landscapes on transit facilities nationwide, including the Illinois High Speed Rail Corridor.

and easily cleaned and maintainable materials. Adequate lighting will further dissuade vandals from defacing station property.

A5.2.4.A

LANDSCAPE ARCHITECTURE

A5.2.4.A.1

LANDSCAPE ARCHITECTURE

The landscape design will be unique to each station and structure based on the available space for planting beds, the topography, and other site characteristics. However, at all stations, the design will employ plant material and trees from a common design palette comprised of low-maintenance, drought tolerant, native vegetation.

A5.2.4.A.1.A

SITE-SPECIFIC LANDSCAPING

The RFP outlines general requirements for the plantings at each of the structure types found on the GLX: stations, the VMF, the TPSSs, the Community Path, and the Corridor. A summary of the guidelines for each of these structures is as follows:

Section Highlights

- Landscape and signage systems will contribute to a low maintenance, safe and visually pleasing rider experience.
- Canopy trees will provide filtered shade for riders at some stations, reducing direct solar exposure.
- Use of plantings to stabilize slopes and absorb stormwater will reduce capital cost by eliminating engineered solutions.
- Signage and wayfinding elements provide users with clear guidance for circulation to and from stations and facilities.
- Design of signage and wayfinding elements reinforces the GLX brand and provides clear identity of GLX facilities from adjacent transportation networks.

Figure A5.2.4-2: As demonstrated by the Beckley Intermodal Gateway in West Virginia, GLP designers have successfully designed slope stabilization and stormwater management plantings that use low-maintenance native plant species.

- Stations
  - Shrubs, ground covers, and trees planted in appropriate soil depths within planting areas.
  - Slope stabilization through landscaping employed at select stations.
  - Existing plantings preserved where possible, and new plantings provided where space allows, and where plantings will benefit the rail users within and around selected stations.
  - Plantings designed to provide clear sight distances for operators, passengers, and security cameras, and conform with CPTED principles.
  - Landscaping design coordinated with third party developers at select stations where transit-oriented development ("TOD") opportunities exist.
- VMF
  - Planting beds employed around buildings and parking lot islands.
  - Lawn areas placed adjacent to the Transportation Building, and at the VMF entrance.
  - Tree, shrub, and ground plane plantings provided as indicated in Project Definition plans — principally to soften building foundations along access drive and within parking facilities.
- TPSS
  - Low-maintenance native plantings incorporated into the landscape design to screen TPSS locations where there is adequate space.
  - Plantings located such that they will not adversely affect operational safety or maintenance access to the facilities.
- Community Path and Transit Corridor
  - Low-maintenance native plantings incorporated, as space allows, into the improvements along the Community Path corridor to highlight connections to stations, and at adjacent walkway intersections.
  - Plantings include slope stabilization, groundcovers, and shrub and tree plantings.
- Transit Corridor
  - Overall assessment conducted of existing landscape assets within the corridor, primarily on the Project sites, but also those materials immediately adjacent to the corridor on abutting properties. The primary focus of the assessment is to determine the appropriate measures to maintain and protect these assets during construction.
  - Vegetation protection plan prepared to assess the health,safety, and suitability of retaining existing plantings, and to provide recommendations/direction for the removal, protection/ preservation, and corrective pruning of existing plantings and canopy tree assets proximate to the VMF, stations, Community Path, and immediately abutting properties.
  - As a subset of the corridor and station landscape design activity, the landscape plan, where possible, will identity plantings for placement adjacent to the Community Path, creating an appropriate transition from the adjacent community into the new station environs.
  - Plant selection designed to create visual cues informing path users of the adjacent station access ways.
  - Planting types varied depending upon location and availability of adequate space to install and sustain the plantings.
  - Plantings placed such that all path safety setback requirements are maintained.
  - Plantings enhance, and are coordinated with, wayfinding and station signage systems leading from the Community Path to the stations.
  - Plantings designed to provide clear sight distances for pedestrians and adjacent motorists, and conform with CPTED principles.

A5.2.4.A.1.B
PLANTING CRITERIA

The plant material employed on the Project will satisfy the following criteria:

- Plantings are low-maintenance and drought-tolerant.
- Employ native vegetation, suitable for Zone 5 Plant Hardiness.
- Trees installed to minimize pruning, and to avoid species which drop seeds, blooms, nuts, or have large leaves which might accumulate on sidewalks, walkways, and track beds.
- Shrub selection includes species with growth habits and rates that reduce the need for intense pruning, and allow for clear lines of sight within the station and access pathway locations.

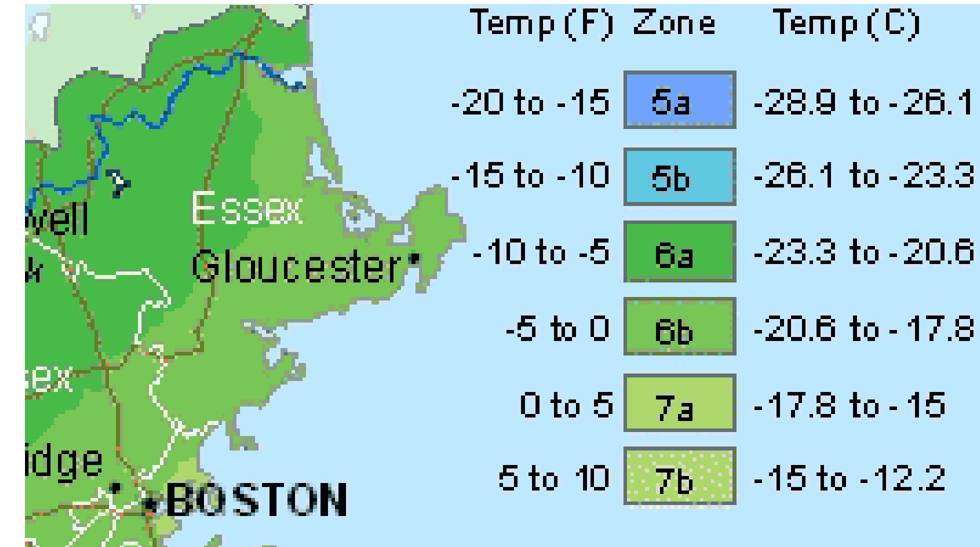


Figure A5.2.4-3: GLP designers have incorporated a plant selection into the proposed design that has demonstrated hardiness for GLX sites while conforming to the TPs set forth by MBTA.

- Shrub and groundcover plantings are durable, low-maintenance, and capable of exposure to winter snow storage and de-icing materials.

A5.2.4.A.1.C
SITE AMENITIES AND FURNISHINGS

In addition to the furnishings on the platforms described in Section A5.2.3, site furnishings and amenities will also be provided on the Community Path. Benches and trash receptacles will be installed for the length of the Community Path in a single style employed for uniformity and maintenance/replacement reasons. The design of the receptacles will conform to the City of Somerville standards.

A5.2.4.A.1.D
THIRD PARTY AGREEMENT REQUIREMENTS

The stations at Lechmere and Union Square provide opportunities for TOD, and the landscape design will be coordinated with the designs proposed by the developers, pursuant to the a. Agreements that have been will be made between the MBTA and the adjacent property owners pursuant to the MBTA standards and regulations confirming third party Real Estate agreements.

A5.2.4.A.2
LANDSCAPE DRAWINGS

The landscaping information is shown on the Drawing UNS-A-2010 for Union Square Station, COS-A-2010 for College Avenue Station and MAF-A-2010 for the VMF site.

A5.2.4.A.3
LANDSCAPE RENDERINGS

The landscape renderings are shown in **Figures A5.2.4-4 through A5.2.4-6.**

Figure A5.2.4-4: GLP has developed an aesthetic landscape design that incorporates a local plant selection that is low maintenance.

Figure A5.2.4-5: Rendering of the Magoun Square station entrance at night showing the standard MBTA lollipop sign and the impact-resistant stainless steel bollards with lighting.