DESIGN AND CONSTRUCTION OF URBAN TUNNELS THROUGH PILE FOUNDATIONS: CASE STUDIES AND APPLICATIONS – THE GATEWAY PROGRAM IN NEW YORK CITY, MANHATTAN CONTRACT P1B

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ABSTRACT: Urban tunneling increasingly demands excavation through complex subsurface environments characterized by soft ground, saturated soils, and existing, often deep foundations. As underground space becomes more congested, tunneling through pile-supported structures has become challenging, as the supported structure needs to remain functional during and post construction. Very strict deformation limits are imposed. This paper presents two case studies that illustrate successful approaches to such challenges: the MBTA Silver Line Phase II project in Boston and the Long Island Rail Road underpass beneath Northern Boulevard in Queens, part of the East Side Access project in New York. In Boston, conventional tunneling using a binocular cross section was undertaken through timber foundation piles, with ground freezing applied for both building support and soil stabilization beneath historic structures built at the end of the 19th century. In Queens, in New York, a large-diameter conventional tunnel was constructed in soft ground by cutting through and integrating pile foundations, which supported a major subway viaduct of the Brooklyn Line, into the final tunnel lining. Ground freezing, permeation grouting, and compensation grouting were employed to ensure stability and mitigate surface and structure settlement. Underpinning was partially used to ensure a risk-managed tunneling system. The experience from these projects informed the design-build procurement documents for the Manhattan Tunnel Contract P1B. Contract P1B is a key element of the Gateway Program in downtown Manhattan and was based on the use of conventional tunneling, with permeation grouting and ground freezing for ground improvement. The contractor elected to utilize open-face digger shield tunneling with precast segmental linings and the same level of ground improvement to tunnel through dense timber pile foundations for a bulkhead structure at the Hudson River waterfront. The paper outlines key design principles, construction methodologies, and ground treatment techniques that provide a practical framework for future tunneling through pile-supported foundations in urban environments. It will also report on the status of the Gateway program, which has started major tunneling contracts simultaneously.

1. INTRODUCTION

The 2018 Revision of World Urbanization Prospects, developed by the United Nations Department of Economic and Social Affairs, estimated that 55% of the world's population currently lives in urban areas, up from 30% in 1970 and with the urban population percentage expected to increase to 70% in 2050 (United Nations 2019). As urban centers continue to expand and develop, available space becomes more limited in efforts to improve and upgrade existing infrastructure. This has led to an increase in the utilization of subgrade space, with unique challenges and solutions in the context of underground construction and tunneling. Several considerations and concerns when performing tunneling in highly overbuilt urban settings include: (1) limited available space, (2) nearby subgrade structures must be considered more frequently, (3) low ground cover is often unavoidable, (4) challenging geological and hydrological conditions, (5) foundations of structure above must be traversed, (6) adjacency of surface and subsurface structure requires construction methods that strictly control allowable deformations.

Limited space is a typical concern in dense urban areas as cities attempt to utilize as much available subgrade real estate as possible. Nearby underground structures may include transit stations and lines, roadway tunnels, utility lines, sewers, and abandoned structures and foundations. Low ground cover may be a requirement based on spatial constraints. Challenging geological and hydrological conditions, including running/flowing ground, soft ground, mixed face conditions, high hydrostatic pressure, and the presence of heterogeneous artificial fill, construction debris, and reworked sediment may complicate an urban tunneling project and exacerbate settlement concerns. Additionally, tunneling may occur near and even through foundations of existing buildings based on space constraints. At the same time, requirements concerning the utilization of surface space must be obeyed and often historic features must be preserved.

1.1 URBAN TUNNELING SPOTLIGHT: THE GATEWAY PROGRAM

A contemporary archetype of urban tunneling in the United States today is the Gateway Program in the New York City metropolitan area. The Gateway Program is a set of rail infrastructure projects between Newark, New Jersey and Penn Station in Manhattan, New York City along the Northeast Corridor. This corridor is the most heavily used passenger rail line in the United States, with over 2,000 trains and 800,000 daily passengers using this critical connection within the Northeast Megalopolis, the densest region in the nation. A main component of this program is the addition of two new tracks beneath the Hudson River, parts of suburban New Jersey, and some of the densest neighborhoods in Manhattan to connect existing Northeast Corridor tracks near Secaucus, New Jersey to Penn Station in Midtown Manhattan. This will aid in improving train capacity between New York City and New Jersey and allow for the existing 120-year-old North River Tunnels to be rehabilitated without meaningfully impacting passenger service.

The tunnels will be constructed in three main sections as identified in Figure 1: (1) a portion mainly through hard rock in New Jersey from the western portal to a shaft in Hoboken, known as P1A (2) a portion in the fluvial and glaciofluvial sediments beneath the Hudson River between New Jersey and Manhattan, known as P1C, and (3) a small shallow portion in fluvial, alluvial, and fill deposits beneath Manhattan, beginning at the shore of the Hudson River and extending to near Penn Station, known as P1B.

Figure 1. Alignment of the Gateway Program's twin tunnels showing the three contracts: the Palisades [P1A], Manhattan [P1B], and Hudson River [P1C] segments. Image modified after the Gateway Development Commission.

In addition to highly varying site and ground conditions throughout its alignment, the project will be constructed with a large variety of tunneling methods, including single shield hard rock tunnel boring machines (TBMs), drill and blast, variable density TBMs, excavation with a digger shield, cut-and-cover, and conventional tunneling (Sequential Excavation Method - SEM) excavation of cross passages. Ground improvement strategies will include ground freezing, jet grouting, and permeation grouting. Overall, this project's construction showcases innovation in numerous aspects of urban tunneling, incorporating lessons learned from the two case histories presented below, and offering a blueprint for the execution of highly complex projects in dense, urban areas.

2. RELEVANT CASE HISTORIES FOR TUNNELING THROUGH PILES

While the Gateway Program is the forefront urban tunneling project at this time in the United States, specifics of its development have built upon experience acquired in projects previously executed in high density urban environments elsewhere in the country, especially with respect to tunneling through foundational piles. This paper presents two case histories of tunnels constructed in dense urban settings in the U.S.A. that faced these considerations, including tunneling through existing support piles with the aid of ground freezing as the primary means of ground improvement. These projects, found in Table 1, were successfully completed using conventional (SEM) methods with unique solutions developed specifically for these projects, including innovative design decisions and instrumentation and monitoring schemes that enabled their success.

Table 1:Selected case histories in the United States presented in paper – historic development

Project	Location	Timeframe	Geology	Additional Notes
Russia Wharf, Silver Line Phase II	Boston, Massachusetts	Mid 1990s - Early 2000s	Silt, marine clay, glacial till	Utilized ground freezing and jacking system to compensate for building settlements; support wooden piles of Russia Wharf, Graphic Arts, and Tufts building rests on lining
East Side Access - Tunneling under Northern Blvd and NYCT Subway	Queens, New York, New York	Late 2000s - Early 2010s	Mixed glacial deposits, sandy silts, clays, some bedrock	Utilized ground freezing, compensation grouting under subgrade subway; support of elevated subway support and underpinning piles rests on lining
Gateway Program	Manhattan, New York to New Jersey	Mid 2010s - Ongoing	Hard rock; unconsolidated sands, silt, and clays; artificial fill	Includes sections done by hard rock TBM, variable density TBM, digger shield, and SEM cross-passages; includes ground freezing and jet grouting for ground support for tunneling through wooden and steel support piles

The first of these, beneath Russia Wharf in Boston, Massachusetts for the Massachusetts Bay Transportation Authority (MBTA) Silver Line Phase II busway, piles of existing historical buildings were integrated into the final shotcrete lining of the tunnel, with ground freezing utilized for temporary underpinning along with jacking to compensate for settlements. The second of these is tunneling beneath Northern Boulevard in Queens, New York City, for the Long Island Rail Road (LIRR) and New York City Transit (NYCT), where infrastructure above included (1) a subway tunnel, (2) a major at-grade road, and (3) an elevated subway line, all of which were to remain operational during construction of the tunnel. Ground freezing alongside compensation grouting was utilized for pre-support, with temporary underpinning of the elevated subway line above. Following tunneling, the piles of the elevated subway line were rested on the final shotcrete lining.

2.1 MBTA SILVER LINE PHASE II (RUSSIA WHARF)

The Russia Wharf segment of the Massachusetts Bay Transportation Authority (MBTA) Transitway project is located in a heavily urbanized area in Boston, Massachusetts's Central Business District. The Silver Line Phase II project connects the Central Business District with the growing South Boston Piers area, which has expanded as available residential and commercial space has dwindled in more dense areas of Boston (Gall et al. 2000). The MBTA initiated a feasibility study to evaluate potential alternatives for transportation options to serve the South Piers area in 1987. An underground option was agreed upon by 1993, with initial alignments showing the Russia Wharf segment to be passing through the ventilation buildings of the Central Artery Project, commonly known as the "Big Dig." MBTA chose to relocate this portion of tunnel, with the twin travel way tunnel structure moved to beneath the Russia Wharf Complex.

The tunnel was constructed beneath the historical Russia Building and Graphics Arts building in the Russia Wharf complex. The structure is in close proximity to but not directly beneath the Tufts building.

Each of the buildings are founded upon timber piles, which were affected by tunnel construction (Gall et al. 2000).

2.1.1 An Innovative Design beneath Russia Wharf

Various options were considered and eliminated, including methods that would require partial demolition of buildings to feasibly construct. Instead, an innovative solution was developed that would ensure the protection of the historic buildings above while executing tunneling beneath Russia Wharf in a time and cost-efficient manner. The solution came in the form of SEM with ground freezing; often considered a last resort due to high costs, ground freezing provided temporary underpinning of the pile foundations as well as ground support. This method was used abroad previously, but this was the first time it had been used in the United States (Munfah et al. 2016). After ground freezing provided temporary underpinning, the loaded timber piles in the tunnel zone were cut and then integrated into the tunnel lining and imposed their load onto the final shotcrete lining. Jacking was also utilized to relevel buildings due to settlement during construction and deformations caused by frost heave and thaw of the frozen ground (Lacy et al. 2000). The proposed combination of integrating the loaded timber piles during tunneling and rest them on the final tunnel lining for permanent support once the soil body thawed, in which case the tunnel structure acted as a large-scale concrete strip foundation was a unique engineering concept once conceived (Gall et al. 2000). An overview of the final support of the Russia Building can be seen in Figure 2.

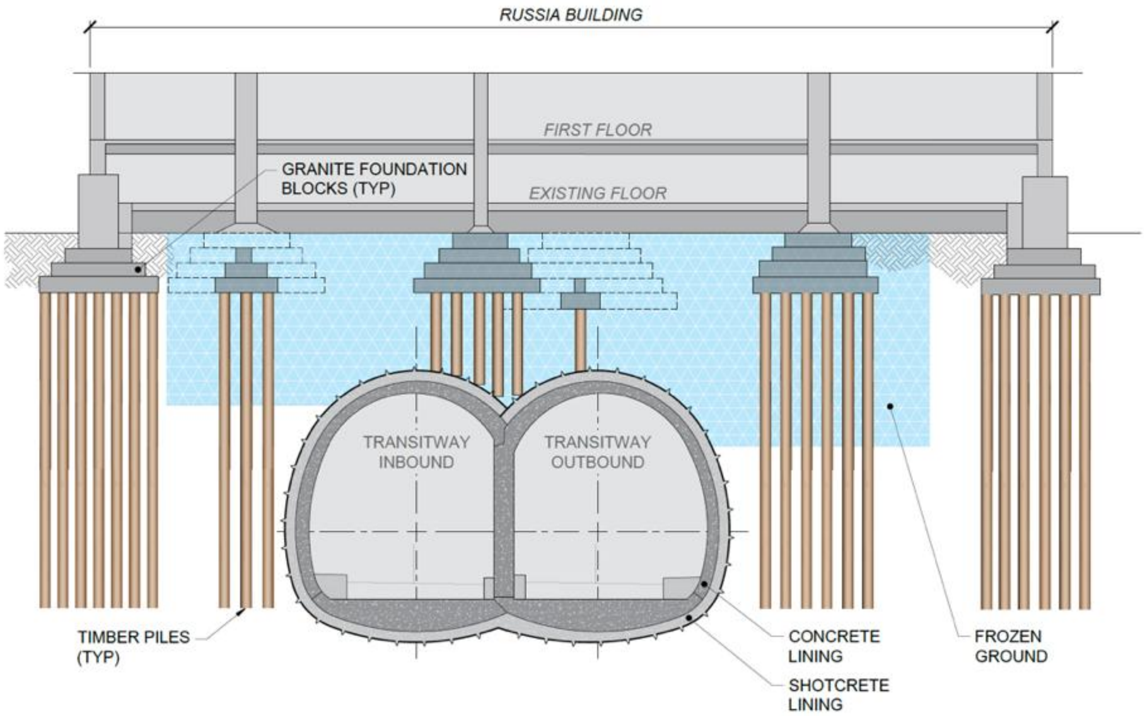

Figure 2. Cross-section of the tunnels underneath Russia Wharf (after Zeidler and Jäger 2007).

During construction, settlements in the Russia Building and Graphic Arts Building were monitored under a robust instrumentation and monitoring plan. The jacking system allowed for compensation due to heave from ground freezing and settlement from the tunnel excavation and thawing of the frozen ground. Figure 3a shows a diagram of the temporary pile supports and jacking operation to compensate for ground movement, as well as the ground freezing pipes. Figure 3b presents an image of this operation during construction.

With the ground frozen, the foundation was appropriately underpinned and the piles in the tunnel excavation zone could be cut and integrated into the final tunnel lining. When the ground was thawed, the load from the piles were transferred to the tunnel structure. When thawing the ground, it was critical to ensure that the piles did not migrate laterally. This was of greatest concern under the Graphic Arts Building, where each pile was outfitted with pile shoes, holding the piles in place and preventing lateral movement.

Displacements were well managed and monitored during construction, with notable, yet slight, heave observed during the ground freezing initialization and minor settlements observed during excavation and ground thawing. The jacking system was found to compensate for these displacements, with maximum displacements not exceeding one inch from baseline. All deformations were kept well within the limits tolerable to the building.

2.1.2 Lessons Learned

Overall, it was found that SEM in connection with ground freezing and jacking, along with the integration of the support piles for the Russia and Graphic Arts buildings into the tunnel structure, was successful for controlling settlements during excavation and minimizing impact on the buildings on the wharf above. Due to the complexity of the required tunnel construction and underpinning scheme, an outreach and prequalification plan was implemented to identify contractors that were able to undertake this task (Haywood 2000). This endeavor, combined with a robust design based in successful projects worldwide, as well as a comprehensive instrumentation and monitoring plan, brought innovative solutions that could be mirrored in similar conditions in future projects.

2.2 EAST SIDE ACCESS – TUNNELING UNDER NORTHERN BOULEVARD AND THE NEW YORK CITY SUBWAY

The East Side Access project was an undertaking in the New York City boroughs of Manhattan and Queens by Metropolitan Transit Authority Capital Construction (MTACC) and the Long Island Rail Road (LIRR) to provide direct access to Grand Central Terminal in Manhattan to LIRR commuters traveling from Queens and points east on Long Island. At the time of its construction, it was the largest infrastructure project in the United States and opened to passenger traffic in January 2023. It required extensive tunneling in highly urbanized neighborhoods in Manhattan and Queens, including tunneling under Northern Boulevard and the New York City subway in the latter borough. This portion of the project, known as Contract CQ039, included a 36.9 m tunnel for grade separation beneath Northern Boulevard, which required excavation beneath an existing New York City Transit (NYCT) subway tunnel, an at-grade roadway, and an elevated NYCT subway structure with foundation piles within the excavation envelope that required integration into the design. Below Northern Boulevard at the ground surface, seven geological stratigraphic units were identified. Bedrock was found between 20 – 30 m below the surface, with glacial stratigraphy (e.g., glacial till, reworked till, outwash, and mixed glacial deposits) overlying decomposed rock found near the top of rock. Artificial fill was found just below the surface (Gall & O'Brien 2013).

2.2.1 Innovative Design for CQ039

Contract CQ039 was excavated through conventional methods with unique ground support and pre-support measures undertaken. This project required careful consideration of the excavation's effect of several different structures, including an elevated subway structure which had foundation piles located in the excavation envelope that required integration into the CQ039 structure. As mentioned above, this contract involved tunneling under three critical and sensitive structures: (1) a NYCT subway tunnel, (2) Northern Boulevard, and (3) a NYCT elevated subway structure.

Restrictions on dewatering for the site required implementation of a pre-support system that would limit the groundwater drawdown on site while ensuring a stable excavation face. Ground freezing was selected to meet this requirement. This created an arch of frozen ground around the cross section of the excavation, effectively isolating the excavation from the surrounding water table, allowing the contractor to implement dewatering measures within the tunnel during excavation. This limited the effect of dewatering outside of the excavation while creating a stable excavation face (Gall & O'Brien 2013).

In addition to utilizing ground freezing to isolate the excavation face from the surrounding water table, a row of horizontal settlement compensation grouting pipes was installed beneath the NYCT subway tunnel to mitigate deformation due to settlement during excavation and void filling after thawing the frozen ground. In addition to this comprehensive ground improvement and pre-support system, settlement was also limited by subdividing the excavation face into seven smaller drifts, limiting the potential and extent of soil unraveling (Gall & O'Brien 2013).

2.2.2 *Elevated Subway Structure Pile Integration*

While the existing NYCT subway tunnel above CQ039 was successfully supported by compensation grouting and by managing the effect of tunneling on the structure through isolation of the cross section via ground freezing, the existing elevated NYCT subway structure required additional consideration and the development of new strategies to underpin the structure and integrate its foundation into the completed tunnel. Four sets of the existing foundation piles for the elevated structure were within the excavation envelope for CQ039. To ensure the stability of the elevated structure during excavation, steel underpinning piles were socketed into bedrock prior to the start of construction, temporarily underpinning the structure. The location of these relative to the excavation and existing structures is shown in Figure 3.

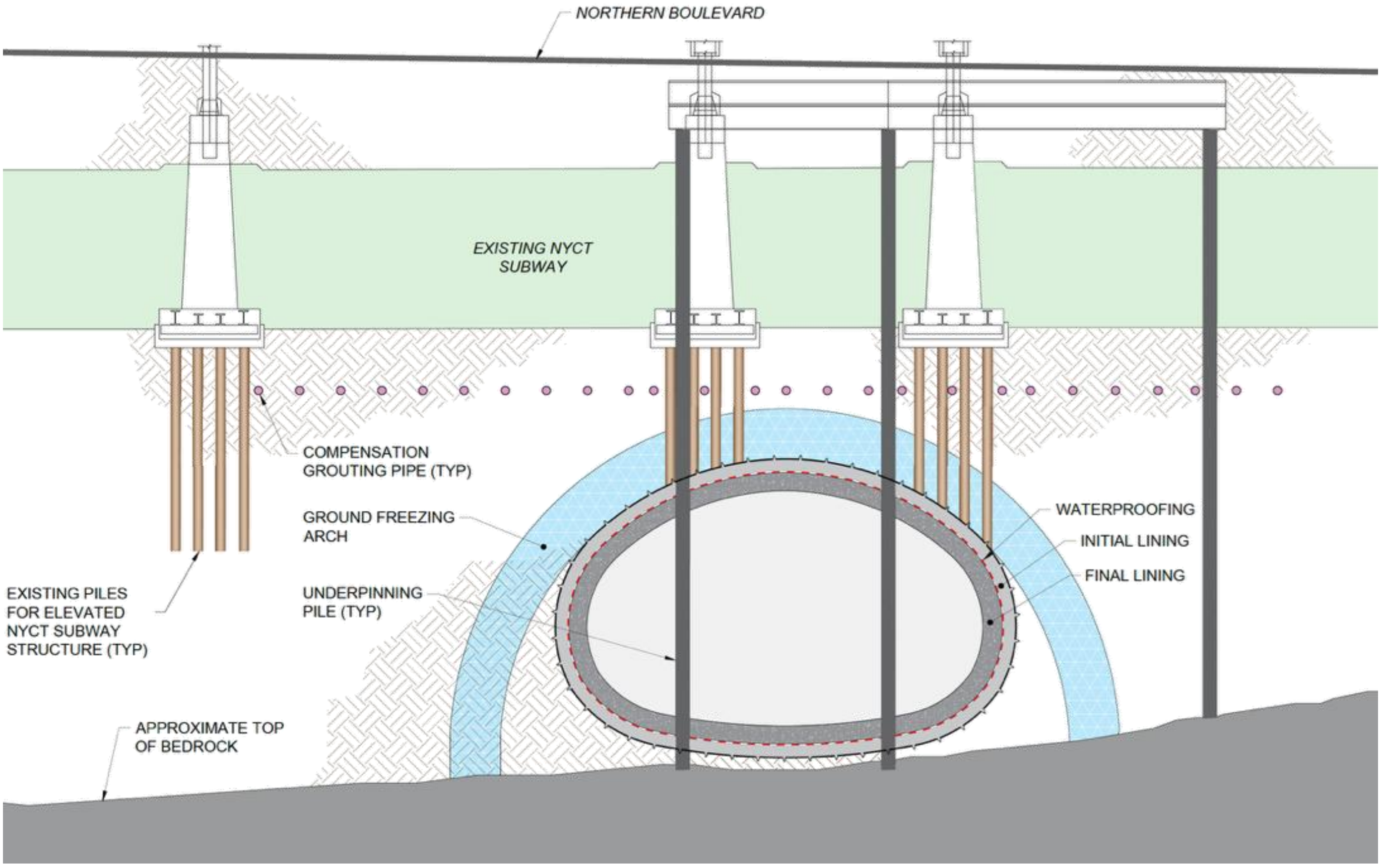

Figure 3. Cross section of CQ039 showing existing structures and the process of protecting and underpinning them, including compensation grouting, the extent of frozen ground, and the underpinning temporary support piles for the elevated subway structure.

With the temporary piles in place, the existing foundation support piles could be cut and integrated into the lining of the new tunnel, which would ultimately bear the load of the elevated subway structure above. The elevated structure was lowered onto the pilaster seats, and a jacking system was installed. The temporary underpinning system was removed, and the drilled underpinning piles were then cut. The frozen ground was then thawed, and settlements were observed and corrected as needed via both the local flat jacks and the compensation grouting pipes (Gall & O'Brien 2013).

A robust instrumentation and monitoring system was developed and executed. Deformation was monitored on critical structures, including buildings, the elevated structure, and the subway tunnel continuously, outputting data to web-based data management system. The system was designed to provide alerts to personnel if certain thresholds were exceeded, and included extensometers, inclinometers, strain gauges, seismographs, piezometers, and other components (Gall & O'Brien 2013). Through the duration of the project, values were found to be well beneath established tolerance thresholds and were even found to be lower than outputs expected from numerical modeling (Munfah et al. 2016).

2.2.3 Lessons Learned

Contract CQ039 of the East Side Access Project presented a unique set of challenges for tunneling beneath three critical structures: one below grade, one at grade, and one above grade with subsurface foundation piles. This was successfully accomplished through SEM, with a comprehensive ground improvement and pre-support plan and a robust instrumentation and monitoring system. Like beneath Russia Wharf, ground freezing was utilized, although a primary purpose of ground freezing in this instance was the isolation of the tunnel face from the groundwater table rather than predominantly the underpinning of nearby structures. As at Russia Wharf, a comprehensive system was developed involving a jacking system for control and management of settlement. Additionally, the support of the structure above was ultimately integrated into the final shotcrete lining of the tunnel.

The elevated subway structure was temporarily underpinned by new piles constructed prior to excavation, which were removed when the existing support piles were integrated into the final tunnel lining. Additionally, compensation grouting was used to control settlement and fill voids after the frozen ground was thawed. These measures added in an important level of redundancy to ensure that all nearby structures would be unaffected and remain operational throughout the duration of the project.

3. GATEWAY PROGRAM PROJECT STATUS AND LESSONS LEARNED

As of early 2026, this project is fully funded by the Federal Transit Administration and preliminary works are currently underway. Notably, construction of the Hudson Yard Concrete Casing Section 3, also known as HYCC-3, is in progress to construct the final section of right-of-way beneath Hudson Yards on the approach to Penn Station. This portion is being constructed by cut-and-cover, with jet grouting used for ground stabilization in addition to secant pile walls for the support of excavation. Other works at other locations along the alignment include deep soil mixing in the Hudson River for ground support, procurement and delivery of two of the four TBMs, construction of shafts in Manhattan and New Jersey, and the creation of a TBM launch box near the western portal. Specific construction methods for the three major contracts are presented in the following sections, as well as activities that have been completed through early 2026.

3.1 CONTRACT P1B – MANHATTAN TUNNELS

The Manhattan portion, Contract P1B, faces challenges similar to the work involved in tunneling beneath the Russia Wharf and historic buildings in Boston as well as the structures at Northern Boulevard in Queens. It is through the lenses of these previously completed projects that engineers could confidently account for the complex requirements of constructing this portion of tunnel and ensure minimal impact on the structures and operations above. This section includes a portion of twin-track tunnels that connect to the Hudson River tunnels (P1C) and a set of tunnels that lead toward Penn Station. The tunnels west of the 12th Avenue Shaft will then be backfilled with lean concrete to be traversed by the variable density TBMs, which will eventually be removed through the 12th Avenue Shaft. This section is fully located in New York and in the borough of Manhattan. Serving as a crucial connection between Penn Station and the Hudson River tunnels on the west side of the island of Manhattan, Section P1B will be excavated beneath critical structures including the Manhattan Bulkhead and 12th Avenue. The Manhattan Bulkhead is over 100 years old and contains a “forest” of piles along the shoreline of the Hudson River. 12th Avenue is a major roadway for those on Manhattan’s west side; though called 12th Avenue, this roadway is effectively a core component of the West Side Highway, paralleling the Hudson River and connecting Downtown, Midtown, and Uptown Manhattan. Due to the heavy use of this roadway, it was important to minimize the effect of construction to traffic.

3.1.1 Design in Bridging Documents and Proposed Alternative

The Gateway Development Commission issued Contract Section P1B as a Design-Build framework to allow potential Contractors to state their means and methods and to identify schedule and cost advantages. The bridging documents called for the entirety of Contract Section P1B to be excavated using conventional methods (i.e., SEM). A permanent shaft would be constructed just east of 12th Avenue with a temporary shaft constructed on the west side of the avenue. From this temporary shaft, horizontal ground freezing would be performed ahead of the excavation and through the foundation piles for the

Manhattan Bulkhead. To the east of the permanent 12th Avenue shaft, jet grouting would be used for ground support. The entire portion would be constructed using SEM.

The Gateway Development Commission received three bids from pre-qualified bidders. One bidder proposed alternative methods to both the type of ground improvement and the method of tunneling. In lieu of horizontal ground freezing from a temporary shaft west of 12th Avenue, jet grouting and ground freezing would be performed from the surface. Additionally, ground freezing would only be utilized beneath the Manhattan Bulkhead. Instead of SEM, a digger shield would be utilized (Frontier-Kemper-Tutor Perini 2024), which possesses a shield like a TBM, but the face is open and the excavation is carried out by an articulated arm as opposed to a cutter head. Figure 4 shows the plan and longitudinal view of the proposed alternative, while Figure 5 shows a view of the 12th Avenue shaft under construction.

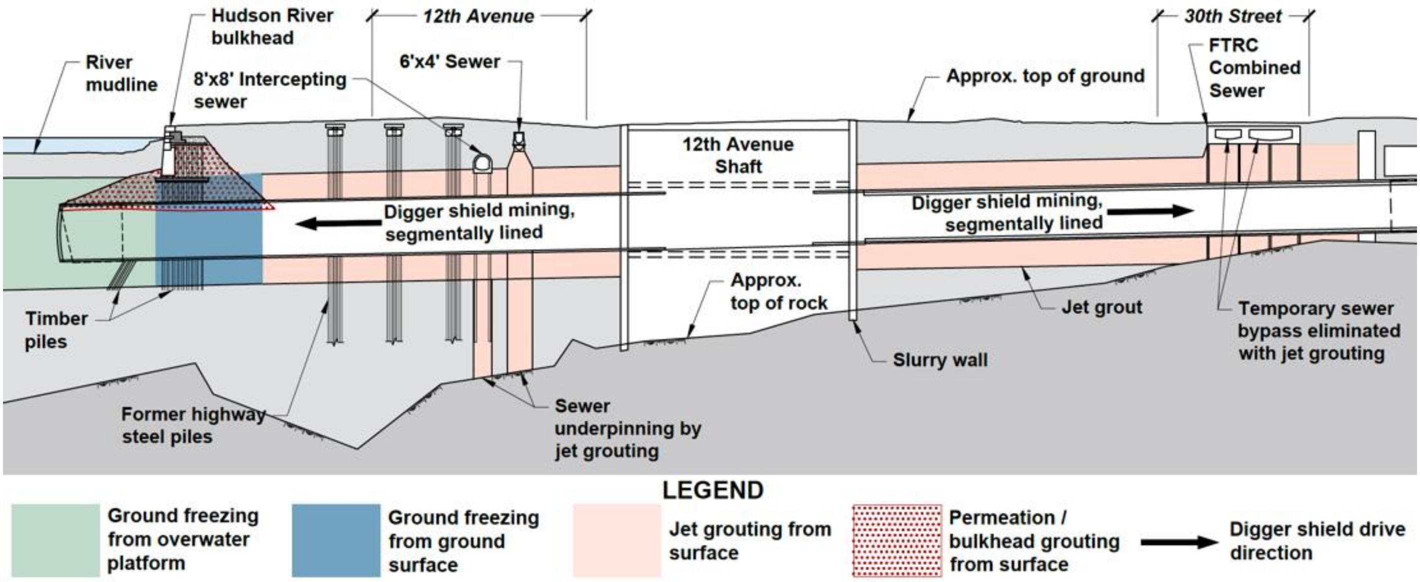

Figure 4. Proposed alternative construction and ground improvement methodology for Contract Section P1B in plan and longitudinal view (after Frontier-Kemper-Tutor Perini JV, 2024).

Figure 5. The 12th Avenue shaft under construction (photo courtesy of the Gateway Development Commission).

This proposed alternative eliminates the temporary shafts west of 12th Avenue and removes ground improvement from the critical path as this is now performed from ground level. With this method, ground freezing occurs parallel to the foundation piers for the Manhattan Bulkhead, while the indicative design involves ground freezing perpendicular to these piles.

3.2 CONTRACT P1A – NEW JERSEY PALISADES TUNNELS

Contract P1A, all of which is within the state of New Jersey, includes all tunneling between the western portal in North Bergen to a shaft in Hoboken. The majority of Contract P1A is to be excavated through the Palisades Diabase, a hard igneous rock that intruded into nearby sedimentary rock units. A small of this contract is within the Stockton Formation, the sedimentary rock in which the Palisades Diabase intruded. This formation is predominantly sandstone and siltstone beds with areas of conglomerate, mudstone, and shale. Also contained in this zone are hornfels due to contact metamorphism from the intrusion. This section is to be excavated with single shield hard rock TBMs, with SEM via drill and blast used for construction of the cross passages in the Palisades Diabase (GTHB 2018a). As of 2026, preliminary works are underway to construct a portal launch box for the TBMs, both of which have been procured and are in the testing phase.

3.3 CONTRACT P1C – HUDSON RIVER TUNNELS

Bridging Contracts P1A and P1B, Contract P1C stretches from the Hoboken shaft in New Jersey to the 12th Avenue Shaft in New York. These tunnels will mostly traverse complex beds of unconsolidated glacial, fluvial, lacustrine, and estuarine sediments. The exception is between the Hoboken Shaft and the Hudson River, where mixed face geology will be encountered, with the sedimentary rocks introduced in 3.2 underlying sediments from the paleo Hudson River. Contract P1C will be excavated using variable density TBMs while the cross-passages will be constructed using SEM with ground freezing and local jet grouting for substrate support. Pre-excavation work includes deep soil mixing in the Hudson River sediments for ground stabilization as well as construction of the Hoboken Shaft, which will receive the hard rock TBMs from Contract P1A and provide the launch point for the variable density TBMs to excavate P1C to the 12th Avenue Shaft. As of 2026, the Hudson River Ground Stabilization Project has been actively performing soil mixing and the Hoboken shaft is under construction.

3.4 APPLYING LESSONS LEARNED TO THE GATEWAY PROGRAM

Both the indicative design and the proposed alternative for Contract P1B build generally upon methodologies utilized at Russia Wharf and East Side Access beneath Northern Boulevard. As of early 2026, the detailed design for tunneling, and in particular, tunneling through the piles supporting the New York City Department of Environmental Protection (NYCDEP) sewer, as well as the piles supporting the Manhattan Bulkhead, are under development. Details for integrating the cut-off piles into the future tunnel lining and to rest on the tunnel have been developed and successfully implemented on both Russia Wharf and the Northern Boulevard crossing. These, in combination with lessons learned, may serve as reference points to develop such design detailing for the Manhattan tunnels for the Gateway Program. Similarly, a comprehensive instrumentation and monitoring program is being developed to observe the performance of nearby infrastructure, including utilities, NYCDEP sewers, the 12th Avenue roadway, Hudson River park authority, and the Manhattan Bulkhead. While the Contractor has selected shield-driven tunneling, the observational character remains in place due to open face conditions. Probe drilling to explore ground conditions and ground improvement performance ahead of the advancing face will be employed along with toolbox items such as grouting, localized dewatering, and other contingency measures to assure a fully risk-managed tunneling process.

4. CONCLUSION

As available space underground becomes scarcer in our densest urban areas, it is becoming more likely that tunneling works in urban areas will become increasingly complex, including placing underground space in close proximity to and intersect foundational piles from buildings and other structures above. Through experience at Russia Wharf in Boston and Northern Boulevard in New York City, it has been demonstrated that with proper ground improvement strategies, a comprehensive instrumentation and monitoring scheme, and selection of qualified contractors, SEM is an adaptable method that can be used to incorporate existing foundational piles into the final tunnel lining. Regardless of the final design selected for Gateway Contract Section P1B, the lessons learned from Russia Wharf and tunneling beneath Northern Boulevard will be incorporated into the Gateway Program, particularly ground improvement strategies, working in environments with low cover, and interfacing with existing support piles. With these incorporated, the construction of the Gateway Program and the lessons learned from this project will aid in developing and ensuring the success of future projects in the United States and abroad.

5. ACKNOWLEDGEMENTS

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