MASSACHUSETTS HIGHWAY DEPARTMENT

MASSACHUSETTS TURNPIKE AUTHORITY

CENTRAL ARTERY (I-93) / TUNNEL (I-90) PROJECT

INSTALLATION OF TUNNELS UNDER RAILROAD TRACKS

AT

SOUTH STATION; BOSTON, MA

By

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ABSTRACT

This paper discusses the evolution of the Central Artery/Tunnel Project design and installation of multiple highway tunnels under railroad tracks of the Northeast Corridor at its terminus at South Station, Boston, Massachusetts. A Project commitment was to progress all work over, under, or adjacent to railroad facilities in a manner which maintains safe and efficient rail operations. Design changes described herein for the tunnel installation were made to reduce the potential unique construction impacts associated with the tunnel installation. These design developments enabled the successful installation of the highway tunnels to be realized.

PROJECT DESCRIPTION

The Central Artery/Tunnel Project, located in Boston, includes the construction of tunnels for Interstate 93 which is currently carried on viaduct through the center of the City; extension of Interstate 90 (the Massachusetts Turnpike) through South Boston to Logan Airport and Route 1A in East Boston via a newly completed immersed tube tunnel across Boston harbor; and reconfiguration of the Interstate 93 and Interstate 90 interchange to the south, and the Interstate 93 and Route 1/Tobin Bridge interchange to the north (Figure 1). The Massachusetts Highway Department (MHD) directed preliminary and final design and initial construction efforts. The Massachusetts Turnpike Authority (MTA), which will operate the completed system, has assumed responsibility for completion of the Project. The Federal Highway Administration funds a substantive portion of the Project and provides direct oversight of all aspects of the Project.

The Project shares many of the same transportation corridors with the Massachusetts Bay Transportation Authority’s (MBTA) commuter rail and transit systems. The most significant interface between the MBTA and the Project is the installation of three I-90 highway tunnel sections (one each for the eastbound and westbound mainlines and one for connecting Ramp D) under MBTA’s five mainline
tracks of the Northeast Corridor, also used by Amtrak, and three mainline tracks of MBTA’s Dorchester Branch in the area where they converge and enter South Station (Figure 2). Construction of the tunnels is included in the Project’s contract known as I-93/I-90 Interchange - Southbound (C09A4). The largest tunnel is I-90 eastbound with a cross-section of 79 feet wide by 36 feet high. The segment under the rail tracks will be over 350 feet long when installed. The depth to the top of the three tunnels below the top of rail will range from a maximum of 24 feet to a minimum of 10 feet. (Figure 3)

The magnitude of the Project required that the design and construction of the Project be progressed in individual sections. Bechtel/Parsons Brinckerhoff (B/PB), as Management Consultant to MHD (and now MTA), completed preliminary design for each section of the entire Project. Final design for individual sections was then developed by additional consultants under contract to MHD and managed by B/PB.

JACKED TUNNEL METHOD DESIGN
Following the selection of the joint venture of Maguire/F.R. Harris as Section Design Consultant (SDC) for final design, the SDC proposed to install the tunnels under the railroad tracks by jacking full-section tunnel segments under the existing tracks at South Station. The tunnel sections would be constructed in excavated pits adjacent to the tracks. (Figure 4) This method has been used successfully in other locations principally outside the United States. The method minimized interdependence of work by the railroad to support construction. Advance track improvements were required to increase operational flexibility to route trains away from jacking pit construction adjacent to the rail tracks.

The area of the tracks was originally within Boston Harbor and is now on historic fill and adjacent to the existing Fort Point Channel waterway. Geological conditions consist of bedrock located approximately one hundred and twenty (120) feet below the surface. Approximately twenty (20) feet of glacial deposits are on top of the bedrock followed by approximately seventy (70) feet of marine clay, then approximately fifteen (15) feet of organic deposits support approximately fifteen (15) feet of historic fill (Figure 5).
A principal issue with the use of the tunnel jacking method was the removal of obstructions including, but not limited to, timber piles and decking, granite blocks, concrete blocks, granite tunnel of an abandoned depressed railroad track, previous seawalls, and a railroad bridge foundation. Since the tunnel jacking method eliminates any relocation of the railroad tracks, the possibility of pre-excavation for obstruction removal was eliminated mandating that all obstructions be removed from the face of the tunnel as it is jacked. A metal jacking shield placed on the lead tunnel section would be constructed with multiple cells that provide work stations at any location of the tunnel face for mining and obstruction removal. (Figure 6) As excavation ahead of the cutting plate is not permitted, ground which supports and surrounds obstructions must first be stabilized by both mechanical means and grouting prior to removal to prevent unacceptable loss of ground with resulting excessive surface and subsurface movement. The design for removal of the depressed trackway specified the soil underneath to be grouted to fill any voids and provide support after its supporting piles are cut out in advance of the jacking. As noted above, the tunnel jacking method requires that the soil face at the tunnel jacking shield be fully stabilized to allow the face to stand fully unsupported. The proposed measures to stabilize the soil face included dewatering, grouting, soil nailing, and use of retractable support grillage in each compartment of the jacking shield.

A soil stability test program in the area of the tunnel jacking confirmed the need for dewatering of the granular materials prior to the tunnel penetrating the headwall at the start of jacking. The relatively high gravity water table and close proximity to the Fort Point Channel dictated the design of grouted ground water cut-off walls. As dewatering is not effective in the Boston Blue Clay, the use of soil nails was proposed to stabilize the clay. These would be installed horizontally from the excavated pit through the headwall and from within the tunnel shield as jacking is progressed.

The other major issue associated with tunnel jacking requiring mitigation was the predicted settlement of railroad tracks of up to fourteen (14) inches during dewatering and tunnel jacking (Figure 7). After extensive discussions with MBTA and Amtrak officials, it was agreed that a program for monitoring and controlling this rate of settlement, combined with an active program for re-ballasting and re-leveling the tracks, would be an acceptable means to allow the jacking to occur and maintain railroad operations. To define the limits of track movements and required responses for the jacking contractor and the railroads, a Track Monitoring Flowchart (Figure 8), using the Federal Railroad Administration Track Safety
Standards as a basis, was developed that identified three categories of required responses based on track movements. The green condition requires no immediate action, the amber condition requires the contractor to initiate actions to minimize further ground movements to allow for re-ballasting and re-leveling during non-peak traffic hours, and red defines emergency conditions requiring immediate actions by the contractor to prevent further ground movements and mandating immediate action by the railroads to restore acceptable track conditions or impose restrictions on train operations. The speed of trains in the area of the tunnel tracking was 15 mph for passenger trains. No freight trains operate in the area. The limits that correspond to green, yellow, or red conditions were established to allow identification of track locations that were experiencing movement caused by construction. The limits were not established to correspond to any specific limits of an FRA track Safety Standard class. It was intended that the indications would normally be used to schedule track maintenance by railroad forces. The emergency condition criterion was established to identify when immediate action was required by the Contractor, the Resident Engineer and the Railroad. The emergency condition would require stoppage of all trains and cessation of tunnel tracking operations. During tunnel jacking operations, railroad track foreman qualified to inspect track was assigned to be on site. To facilitate communication between all parties, a daily meeting was held with representatives from the Contractor, the Resident Engineer, the Project’s Geotechnical Engineer, and the Railroad. During the daily meetings construction activity for the day and planned construction for the next three days were reviewed, ground movements have evaluated, and planned track maintenance by railroad forces was scheduled.

To provide track measurements for the Track Monitoring Flowchart, the Project surveyed tracks up to three times per day. The survey data was inputted to a specifically designed computer program which performs the track movement calculations and displays the track geometry information of the Track Monitoring Flowchart by locations and the green, amber, and red criteria. The monitoring program was available to the Railroads, Contractor, and Resident Engineer staff (Figure 9). To respond to predicted and unexpected track settlements, the Contractor was required to develop and implement specific mitigation measures to prevent track settlements from reaching emergency (red) conditions. To mitigate impacts to railroad operations caused by track settlements, railroad forces and equipment were assigned directly to the Project to insure immediate response for required track maintenance.
The CA/T Project contract for the tunnel jacking work was bid in late 1996 and the mitigation measures discussed above where integrated into the contract documents. A final mitigation measure deemed necessary to provide for successful installation of the tunnel was a requirement for prequalification of the tunnel jacking subconsultant based on previous experience in tunnel jacking. As the tunnel jacking effort would be the largest and most complex installation to date, the prequalification specification was implemented to guarantee that an experienced contractor and staff would be directing the actual jacking operation.

**CONTRACTOR VECP PROPOSAL - GROUND FREEZING**

Following award of the CA/T Project C09A4 contract to the joint venture of Slattery, Interbeton, J.F. White & Perini (SWIP), the Contractor submitted a Value Engineering Cost Proposal (VECP) to stabilize the soil by use of ground freezing. The VECP was recommended as a means to achieve maximum security for railroad infrastructure and operations by significantly increasing the strength and stability of the soil at the tunnel jacking face. Following evaluation by the Project and Railroad staff, it was agreed that the freezing method would result in a more predictable and controllable construction method. The use of ground freezing was used to replace all stabilization methods identified in the baseline design. The freezing method increased the efficiency of obstruction removal by holding obstructions in place. Although, the freezing method positive benefits associated with tunnel jacking, it still required mitigation to address issues unique to its installation.

The major issue that threatened approval of the ground freezing proposal was the heaving of the soil caused by ground freezing which in turn would lift the railroad tracks. Settlement of tracks, as anticipated in the Final Design, could be handled by re-ballasting and surfacing (raising) the tracks. However, lowering of tracks necessary to maintain rail profiles during the freezing process could not be accomplished except by undercutting of the tracks. The substantial amount of switches, double slip switches and special facilities in the area of the jacked tunnels precluded the use of mechanical track undercutting equipment. The option of track removal, excavating ballast, and replacing the track was
determined to be impractical because the effort would require significantly more time than would be available and the expense would be unacceptable. MBTA and Amtrak performed an analysis of the maximum heave that could be accommodated by raising tracks in the approach areas to the zone of freezing and determined that a maximum of seven (7) inches would be allowed. However, the prediction of maximum heave ranged from a low of 3.2 inches to a maximum of 11.7 inches. Acceptance of the ground freezing proposal was reached following development by the C09A4 contractor of a contingency plan to control the heave and insure that the heave did not exceed seven (7) inches. The solution, to be implemented if observations of the actual heaving produce trends over seven (7) inches, was to provide the ability to shorten every other vertical freeze pipe. The effect of this would be to create staggered patterns of frozen ground and reduce heave associated with the completely frozen condition. The staggered pattern would avoid open pathways of unfrozen ground thereby maintaining the desired stabilized tunnel jacking face.

The installation of freeze pipes was also presented a major obstacle to utilization of ground freezing. To freeze the ground vertical pipes to carry chilled brine needed to be installed approximately six feet on center over the entire area through which the jacked tunnels would pass. This required placement of freeze pipes in the track areas. The vertical pipes also needed to be connected with supply lines to circulate the chilled brine (Figure 10). The placement of freezing pipes was developed and mockups of the installation were made on out of service track adjacent to live track areas. The installation was further complicated by the addition of a catenary system for Amtrak’s Northeast Corridor Electrification Project. The installation of the catenary system required substantial advance coordination and planning with Amtrak and its electrification design-builder. Specific interface items included placement of catenary portal frame supports on tunnel jacking pit walls and installation of sleeves in catenary portal spread footings to allow installation of freeze pipes through the footing.

In working with the Railroads, it was determined that a maximum leave of seven inches could be accepted. This would allow for limited surfacing to maintain cross-level and adjust profile as required. The critical areas for heave were the EB and WB tunnels as they were located close to the Dorchester Railroad Bridge over the Fort Port Channel. This was considered a fixed point for determining maximum heave. Actual heave from freezing was 8.3 inches at Ramp D, and I-90 EB and I-90 WB was 4 inches and
4.6 inches respectively. The higher heave at Ramp D was accommodated by selective surfacing by railroad forces.

**TUNNEL JACKING INSTALLATION**

The full width tunnel sections were constructed in pits excavated adjacent to the railroad tracks. The pits also acted as thrust pits for the hydraulic jacks used to move the tunnel sections forward (Figure 11). The thrust pits were constructed using slurry wall techniques. The floors of the jacking pits consisted of heavily reinforced concrete slabs. The tunnels were constructed in lengthwise sections. Intermediate jacking stations were installed between the sections. This allowed individual sections to be jacked in a sequential manner. By jacking individual sections, the total jacking force could be reduced and additional control of the jacking alignment was realized. To minimize jacking forces and prevent horizontal movement of soil above the tunnels, an anti-drag system was employed. This system utilizes a series of cables that were threaded through the front of the tunnel and to the top of the tunnel. The cables were placed adjacent to each other to form a continuous interface between the tunnel roof and the soil above. Lubricant was applied to the cables to assist with the sliding of the cables over the top of the tunnels. A second series of cables was utilized on the bottom of the tunnel to reduce friction between the supporting soil and the bottom of the tunnel.

The front of each tunnel section was fitted with a steel shield. The shield was divided into six compartments configured two vertically and three horizontally. This allowed individual work platforms from which the frozen soil was excavated. The removal of soil and most obstructions was done utilizing mining machines with a rotary cutting head (Figure 12). Obstructions included wood pilings and brick seawalls.

The primary hydraulic jacks were located at the base of the tunnel section. For each of the tunnels, 25 primary jacks were used. Each jack had a stroke of 42 inches. Intermediate jacks between tunnel sections varied between 26 and 32. The primary jacks remained in place as the tunnel jacking progressed. At the completion of a push, the hydraulic rams were retracted and spacers were placed between the jacks and the base of the tunnels. The jacking of the tunnels was made after sufficient soil or obstructions had been excavated in front of the shield at the face of the tunnel. Typical jacking progress
was 3 ft per 24 hours. The work progressed six days per year utilizing two crews working 10 hours per shift.

The first tunnel to be jacked was Ramp D. It was installed between October 9, 1999 and December 10, 1999. The I-90 EB and WB tunnels were installed between May 31, 2000 and February 5, 2001.

CONCLUSION

The installation of highway tunnels under the tracks at South Station remains was one of the most challenging aspects of the Central Artery/Tunnel Project. The absolute requirement for maintenance of railroad operations, combined with the safe and economical construction of the tunnels, mandated that the design of the installation be constantly evaluated. As discussed above, the substantive and joint effort of the design teams, railroads, and contractor to evaluate and improve the design resulted in a plan that all parties agree managed risks (Figure 13). All parties involved were proud that the goals for the safe, economical, and timely installation of the highway tunnels at South Station were realized.

ACKNOWLEDGMENTS

The author acknowledges the Massachusetts Highway Department, the Massachusetts Turnpike Authority, the Federal Highway Administration, and the Management Consultant, Bechtel/Parsons Brinckerhoff, for the organizations’ support in preparation of this paper.
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## C09A4 Railroad Monitoring Software

### Route 5 Status

The FRA metrics are listed by station for Route 5. All figures are in inches, calculated from DMP8 elevations. Follow the instrument station link for more information.

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