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Underpinning Of Red Line South Station

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Summary

The paper discusses the design and construction details for the underpinning system used for the underground Red Line Transitway station at South Station.

1.0 Introduction

The Massachusetts Highway Department's (MHD) Central Artery / Tunnel (CA/T) project in Boston is one of the largest highway projects ever undertaken to solve the traffic congestion problems of a large metropolis. This $10.5 billion project replaces the aging elevated Interstate Highway I-93 through downtown Boston and extend the Massachusetts Turnpike I-90 to Boston's Logan International Airport through a new tunnel under Boston Harbor. The project will reconstruct approximately 12 kilometer of Interstate highway-- half of which will be in tunnels. The project will keep the existing elevated roadway in service until the underground replacement is available for traffic. Of the many technical features of the CA/T project is the underpinning of the Red Line Transitway South Station which happens to be one of the more challenging and interesting construction operations.

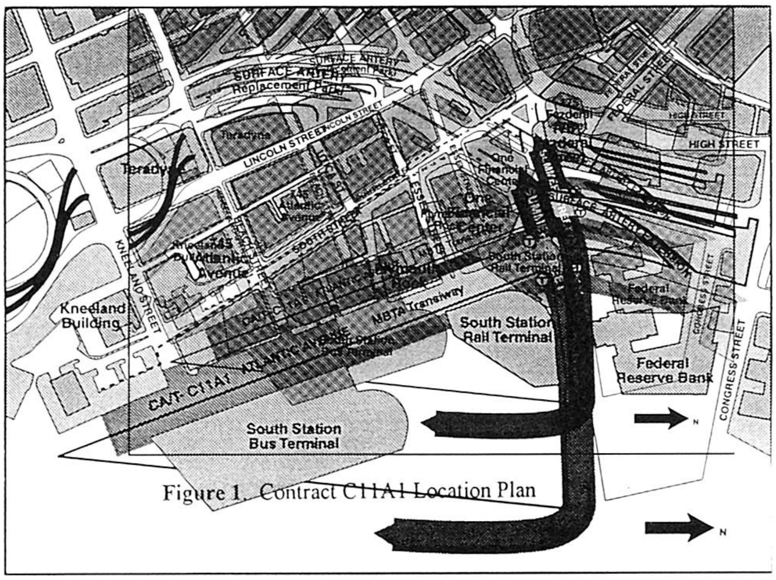

Figure 1. Contract C11A1 Location Plan

The underpinning of Red Line South Station is one of the components of C11A1 construction contract. Perini, Kiewit and Cashman, a Joint Venture (PKC) was the low bidder for a $378 million contract. The contract includes approximately 600 meter long of cut-and-cover mainline tunnel from Kneeland Street to Congress Street below Atlantic Avenue. Approximately 360 meters of the CA/T tunnel will support the new Massachusetts Bay Transit Authority's (MBTA) Transitway tunnel which will be used for electrically operated busses. Figure 1 shows the Contract C11A1 location. On the east side there are three major buildings - the recently completed two- story South Station Bus Terminal supported on pile foundation; the five story South Station Rail Terminal, approximately 80-years old and supported on timber piles; and the 32-story Federal Reserve Bank (FRB) building with a two level underground garage extending to the curb line. On the west side there are many old multistory brick historic buildings including the 10-story framed building at the intersection of Kneeland Street and Atlantic Avenue; the 46-story One Financial Center building and Dewey Square Tunnel. The Red Line underground Transit Station is located at the intersection of CA/T tunnel with Summer Street. Figure 2 shows an artist's rendering along the centerline of CA/T tunnel. At this location there will be three tier tunnels under the underground Red Line/ Transitway Lobby. The new Transitway tunnel along Atlantic Avenue crosses the existing Red Line Transitway at the mezzanine level of the existing station. Most of the existing Red line Station above the Red Line tunnel will be rebuilt.

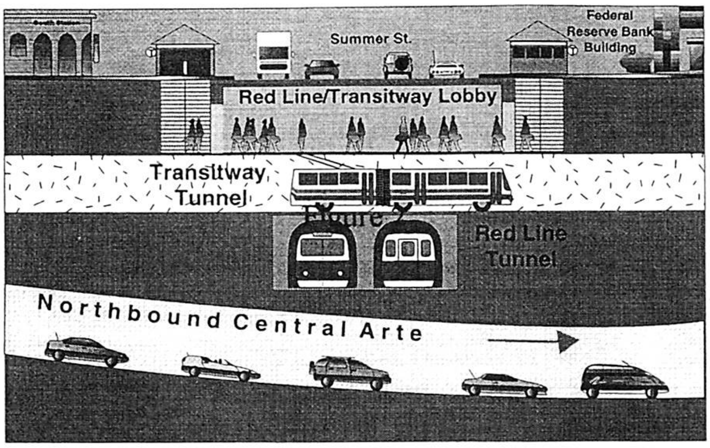

Figure 2. Artist rendition of CA/T Tunnel Crossing under MBTA Red Line Tunnel and Transitway Tunnel.

The northbound CA/T tunnel passes directly under the MBTA Red Line South Station, located below the intersection of Atlantic Avenue and Summer Street. The existing station is soil supported within the glacial till stratum. Underpinning of the existing station is required to allow excavation for construction of the tunnel structure directly below. The original underpinning system consists of post-tensioned concrete box girders jacked in place and supported on drift walls.

2.0 Site Geology

The subsurface explorations performed by GEI Consultants, Inc. from April, 1991 to March, 1992 indicated that the South Station is founded in glacial till above bedrock. The glacial till varies in particle size and density. Till in the area is very stiff and has a blow count of more than 50 (using a standard hammer), except in some pockets. Some boulders and cobbles are present in the Till. Due to a relatively high fine content, the till has low permeability.

The bed rock is classified in three categories, i.e. B1, B2 and B3.

B1 Completely weathered Argillite
B2 Severely or severely to moderately weathered Argillite
B3 Moderately or slightly weathered Argillite

Groundwater levels in the fill and organic soils are high and within 3-5 meters below surface. Piezometric water levels in the deeper observation wells are approximately 5-7 meters below grade. The Piezometric levels in the till and bedrock are lower than in the fill.

3.0 Design Criteria

The design of the underpinning structure was governed by the structural characteristics of the existing Red Line South Station foundation consisting of slab on grade, isolated column footings and the clearance between the bottom of the keel and the access tunnel. The settlement or camber of the keel and the slab supporting the tracks (both sides of keel) were important operational considerations for Red Line Transitway. Cracking of the slab would permit groundwater penetration thus flooding the station.

The protection of the station and other adjacent structures (5-story South Station Rail Terminal, Federal Reserve Bank, One Financial Center building and Dewey Square Tunnel) were of paramount importance. In addition, the MBTA station must remain operational throughout the duration of construction. Therefore, the following criteria was prepared in consultation with MBTA, the operating agency for the Red Line transit station:

Construction Conditions

	Threshold Value	Limiting Value	Operating Limits
Deflection	6-mm	10-mm	0
Camber	6-mm	10-mm	0

Maximum deflection was expected when the underpinning post-tension girders are fully tensioned, excavation for the CA/T tunnel has been completed, all post-tensioning losses have occurred and full dead/live loads are acting. Maximum camber was expected when the underpinning post-tension girders are fully tensioned, all post-tensioning losses have occurred and portions of Red Line South Station has been demolished for rehabilitation.

4.0 Existing Station Conditions

A review of the original 1914 design drawings indicate the following conditions.

1. The bottom slab reinforcing steel was placed in two layers; however, the reinforcing steel was not developed beyond the haunches. Therefore, the section cannot be considered as a reinforced concrete slab.

2. The main reinforcing steel parallel to the tracks, under the center wall were 3.81 meters long and centered under each column. Since the column spacing is 4 meters and the reinforcing is not continuous, the section cannot be considered as reinforced.

3. The column footings were individually placed on the till

4. The bending stiffness of the grade beam located in the center wall between the tracks is considerably reduced due to niches in the wall.

The most critical location or the area of possible cracking and potential water infiltration is the slab between columns.

The as-built drawings indicate that the strength of concrete is 20 Newton per square millimeter (n/sq.mm) but recent core tests from concrete from other structures of MBTA tunnel shows concrete strength in the existing structure of 40 n/sq.mm. Thus, the project utilized 30n/sq.mm as the average concrete strength to analyze the existing tunnel structure.

The analysis indicated that for a 10-mm or less settlement, no cracks are expected in the Red Line South Station bottom slab. This analysis is very conservative because it assumes that the station is simply supported with no soil springs. No analysis was performed for the structure above the base slab because the geometry of the structure is too complicated to obtain a reasonable solution and most of the structure above the roof of the Transitway will be replaced by a new facility.

5.0 Final Design

The detailed design and the preparation of the contract documents for C11A1 was carried out by Seelye Stevenson / DeLeuw Cather, a joint venture (SS/DC) under the direction of the Massachusetts Highway Department (MHD) and the Management Consultant, Bechtel / Parsons Brinckerhoff (B/PB). The final design consisted of two grouting/ access tunnels (east access tunnel, 4.88-meter wide X 4.12-meter high for jacking and west access tunnel 3-meter wide X 4.12-meter high for receiving) approximately 30 meter long directly under the Red Line Station and three drift walls on each side of the CA/T tunnel as shown in Figure 3. The drift walls were provided to support thirteen post-tensioned underpinning girders, 2.44 X 2.44 meter in cross-section with a clear span of 21.85 meters. The seven odd numbered girders jacked in place and the space between the jacked girders hand mined for the six even number girders. It was anticipated that the grouting galleries will be enlarged to form east and west access tunnels. The Contractor proposed to combine the excavation of grouting galleries and the access tunnels into one operation using 5.9-meter wide X 4.27-meter horse shoe tunnels; and substitute thirteen post-tension segmental girders with eleven cast-in-place post-tensioned horse-shoe shaped girders. The odd numbered girders have the same size as the original segmental girders, but the excavation in between is enlarged to 3-meters. The steel ribs in the crown extends beyond the effective girder depth. The girders were redesigned by SS/DC. Figure 4 shows conceptually the layout of access tunnels, multiple drifts and underpinning roof girders. The structural design of the post-tensioned girders included spare ducts for providing additional post-tensioning. It was recommended that the post-tensioning be applied in 20-percent increments symmetrical about the centerline of each girder and the tendon ducts grouted.

To monitor the movement of the existing structures and buildings around the South Station area, an extensive instrumentation program was developed. It included installation of Single Position Bore Hole Extensometers (SPBX), Displacement Monitoring Points (DMP), Vibrating Wire Strain Gauges, Tilt Meters and Piezometers. The SPBX's are also used as a bench mark for monitoring vertical movement. These instruments are read on a regular basis to determine the ground movement and groundwater levels.

6.0 Construction

The west and east access shafts 33.5 meter deep were constructed using slurry wall panels. The support of excavation include steel ribs at 900 mm on center and steel liners for the access tunnels, drifts 1 & 2 and the post-tension roof girders. The space between the steel liners and excavated ground was filled with pea gravel and cement grout soon after excavation.

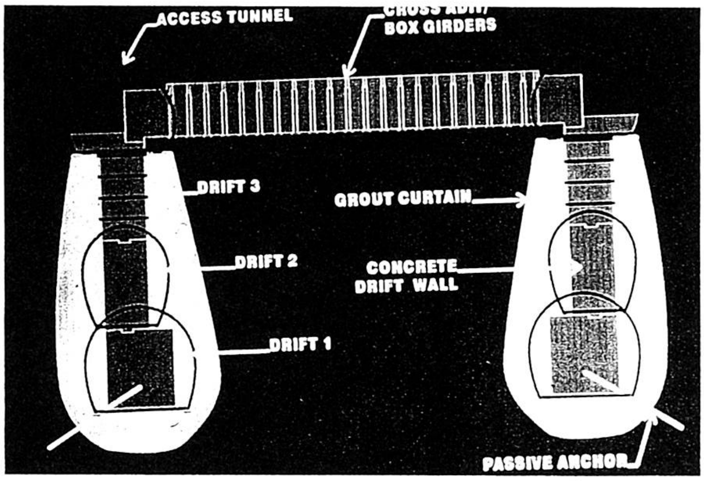

Figure 3. Cross-Section of Underpinning Systems with Drift Walls, Grout Curtain and Post-tension Box Girder Roof.

The access tunnels were excavated using multiple bench mining technique. The length of tunnel excavation in each bench was approximately 3 meters. The front face was breasted whenever the excavation was stopped for an extended period of more than 24-hours.

The water table was lowered 600 mm below the invert of the access tunnel excavation. At an average 6.3 liters per second, water was pumped from four dewatering wells. The dewatering provides good dry conditions for excavation and minimizes the chances of ground movement due to inflow of water. The access tunnel is used to grout its periphery and create an envelope around drifts 1, 2 and 3. Once grouting has been completed, the dewatering will be stopped to bring the water table to its natural position. Figure 3 shows the grout curtain.

Drifts 1 and 2 will be excavated from the access shafts but drift 3 will be excavated from the access tunnel. The supports for drift 3 consist of horizontal ribs and lagging. Then the odd numbered post-tension girders will be excavated from the access tunnels. The even number girder excavation will be supported from the framing of odd number girders.

7.0 Contingency Plan

The Contractor developed a contingency plan for the face stability during excavation. The plan includes the following steps. If the first step is not successful, the second and subsequent steps will be implemented.

I. Breasting the face
II. Shotcreting and/or additional pre-stabilizing grouting of the face
III. Pressure relief system
IV. Backfill excavation

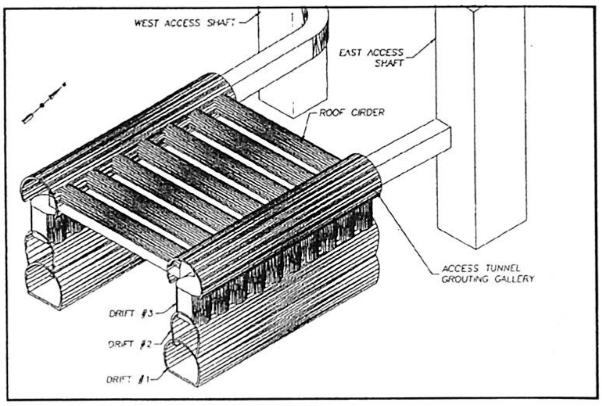

Figure 4. Conceptual Layout of Underpinning of South Station

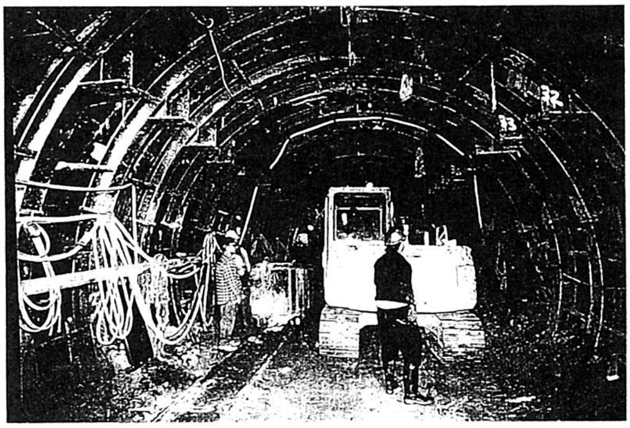

Figure 5. Access Tunnel Excavation

8.0 Conclusion

The contractor has completed construction of both access tunnels as of July 1997 and sodium silicate grout is being placed for the construction of drifts 1, 2, 3 and the post-tension girders. Figure 5 shows east access tunnel during construction with steel rib and steel liner support of excavation. In addition to sodium silicate grouting, the contractor has made multiple passes to grout the annular space around the steel liner of the access tunnel with cement grout.

Acknowledgments

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