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Challenging Use of Immersed Tubes in the Fort Point Channel, Boston, MA

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Summary

This paper is focused on the design challenges and solutions related to the Fort Point Channel immersed tubes, the first large concrete tubes in the U.S. Six tubes will be fabricated in three stages in the adjacent casting basin. Later the casting basin will be used as an excavation support for the cut-and-cover tunnel.

The tubes will be placed in two parallel rows at a skewed angle across the Channel. Dredging to a depth of 4.8m (16 ft.) will precede the placing. The constructed tubes will be placed over an operating subway tunnels just with a 1.5m. (5 ft.) vertical gap between the existing and the new tunnels. Construction of the large immersed tubes in restricted conditions created a several challenging technical problems which have been solved during the design and are discussed below.

1.0 Introduction

The Fort Point Channel (FPC) tunnels are one of the most technically challenging part of the multi-billion Massachusetts Highway Department's (MHD) Central Artery (I-93)/Tunnel (I-90) Project in Boston. The FPC crossing is located in close proximity to the viaduct of I-90/I-93 Interchange and just about 91.4m (300 ft.) from railroad tracks of the South Station. The FPC is also an important historical site in downtown, placing serious restrictions to the roadway alignment. This required that the roadways in this area had to be designed as a tunnel.

Tunnel design was complicated by many factors. One factor is the presence of two existing MBTA Red Line subway tunnels in the FPC. These tunnels were built in 1915 by the shield method under compressed air, and are 7.3m (24 ft) in diameter. Each tube has a primary wooden liner and the 0.3m (2ft)- thick secondary liner from unreinforced concrete.

2.0 ITT Alignment

Several tunnel alternatives for crossing the Red Line tunnel were considered. Cut-and-cover tunnel construction in a dewatered cofferdam was unacceptable because removal of surcharge and dewatering would have caused excessive soil displacements which the existing tunnels could not withstand. Therefore, the immersed tube method of construction (ITT) has been chosen over the Red Line Tunnel. The ITT alternative also helped to mitigate the problem of global stability of the soft Boston Blue Clays as will be discussed below. The proposed roadway alignment crosses the 1133m (400ft)-wide Channel with a skew of 45 degree angle and includes five roadway lanes for the West bound and six lanes for the East bound.

Two parallel rows of concrete rectangular immersed tubes with a width up to 48.5m (160 ft) each, accommodate this alignment. The rectangular shape of the tunnels also satisfied limited clearance between the navigational channel at El.87 and the top of the Red Line tunnel at El.56. The vertical size of the tubes was limited to 7.9m (26 ft) just to accommodate a minimal vertical roadway clearance ,4.3m (14 ft), and to provide minimum soil cover over the existing Subway tunnels, 1.5m (5 ft).

The length of the alignment for the immersed tubes (ITT) was reviewed several times during the design. At the beginning the intention was to use the immersed tubes method of construction only to cross over the Red Line Tunnels without subjecting the tunnel to the negative impact of the dewatering of the underline soils. Two parallel tubes, 121.2m (400 ft) long, would satisfy this purpose. However, later, it was recognized that the excavation support system for the westerly adjacent cut-and-cover tunnel would be excessively expensive due to instability of the deep Boston Blue Clay in this area. To avoid dewatering it was decided to use dredging and extend the immersed tubes an additional 91m (300 ft) further west. During the dredging and placement of the ITT the hydrostatic pressure is permanently applied against the unbalanced soil pressure, to mitigate instability.

The eastern closure also caused a problem. Because of the skewed ITT alignment, the eastern seawall, which will be constructed on the ITT roof, is also skewed to the ITTs. A significant unbalanced horizontal hydrostatic force would be applied transversely to the eastern ends of the ITTs. To minimize this force it was decided to extend the ITTs further into the casting basin. This solution also significantly improved the construction schedule, allowing the early construction of the cut -and-cover tunnel in the dewatered eastern portion of the casting basin. The final length of the ITT alignment was increased to 333.3m (1100 ft) , and six tubes instead of two tubes have been proposed to cross the Channel. (See Figure 1.)

3.0 Ventilation Building

Extension of the ITT's also helped to successfully solve a problem requiring deep foundation under the Ventilation Building #1, which has to be located on the west shore of the FPC. The challenge was to build the underwater portion of the building in the dry, means as a snorkel on the top of the ITT constructed in the casting basin. This allows for the elimination of the very costly and elaborate cofferdam. The foundation for the ventilation building was designed as two independent rectangular snorkels which are constructed on two parallel immersed tubes (See Figure 1). The snorkels are basically extensions of the tunnel external walls, the appropriate transverse walls, creating a large open well. The tops of the snorkel walls project above the high tide water elevation, allowing subsequent construction of the building in the dry. The snorkel walls carry all loads from the Ventilation Building, transferring them into the immersed tube tunnel foundation system (See Figure 2).

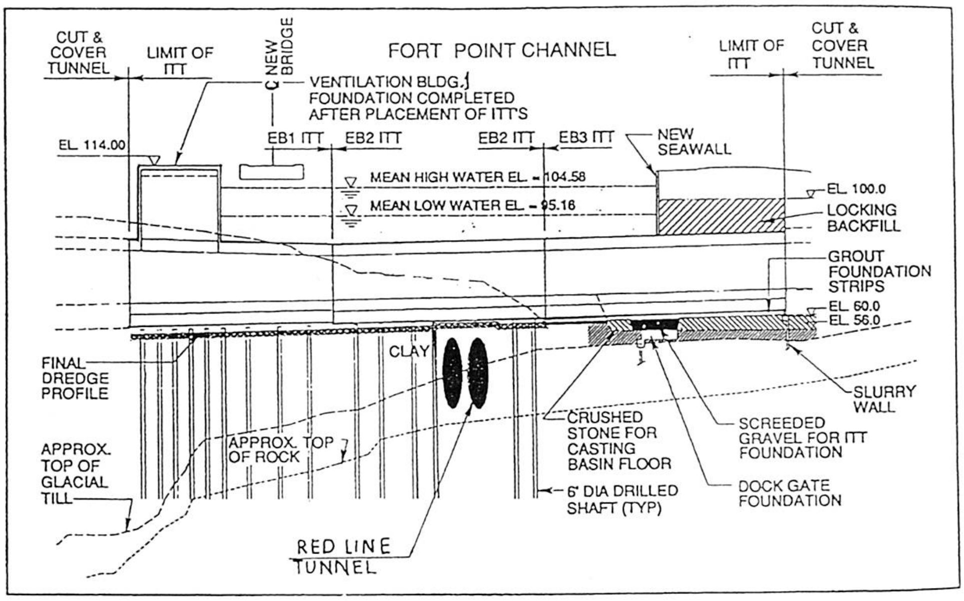

Figure 2. Longitudinal section I-90 EB in the FPC

4.0 Cofferdam

Normally immersed tubes are fabricated in offsite shipyards. In this case it was unacceptable because three upstream existing bridges lack sufficient navigational clearances for such large tubes. Therefore, it was decided to utilize the adjacent excavation of the future cut-and-cover tunnel. The available sizes for a long term excavation were not enough for fabrication of all six tubes. So, the tubes will be fabricated in three stages assuming subsequent dewatering and flooding of the basin after each stage. The casting basin, 19.7m (65 ft)-deep, was formed by reinforced concrete slurry walls with the tie-backs and the 19.7m (65ft)-diameter cellular cofferdams. The cofferdams separate the casting basin from the FPC and will be partially removed and restored after each float out. The removal of several cells provide the exit for the floating tubes from the casting basin in the Channel.

5.0 Foundations

Two types of foundations have been utilized for the immersed tubes. Two western tubes and two middle tubes are supported by drilled shafts embedded into the bedrock. Two eastern tubes have a base foundation (See Figure 2).

For the first 2 tubes the drilled shafts were required to avoid the differential settlements induced by the presence of the Ventilation Building atop the tubes. For the second 2 tubes the drilled shafts were required to provide protection for the Red Line tunnels from overloading due to accidental flooding of the ITT. Flooding of the ITT's would cause the subgrade load to increase by up to ten times and, as the analysis indicates, the subway concrete liner would be significantly overstressed. Hence, the tunnel was designed to span the Red Line Tunnels in this case and be founded on the drilled shafts.

For all four tubes, the drilled shafts were positioned under the ITT longitudinal walls. This allowed to minimize the reinforcement in the tube base slab, and also considerably simplify the performance of the connections between the ITT and the drilled shafts (up to 40 shafts for each

ITT). The 70mm (4in)-diameter plastic sleeves, will be positioned in the walls during ITT fabrication. These sleeves allow for grout to be placed in the gap between the ITT and the shafts directly from the ITT roof (See Figure 3).

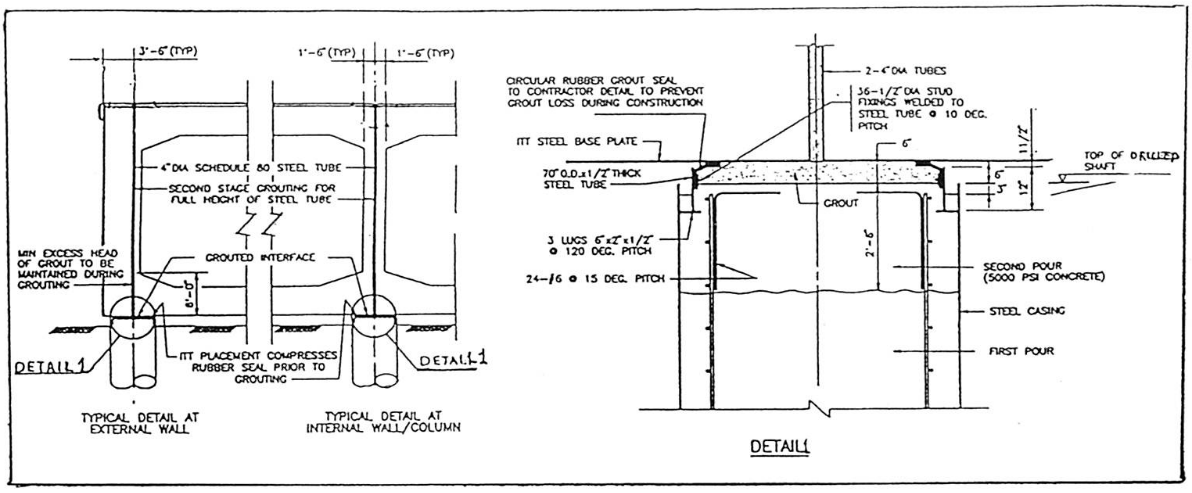

Figure 3. ITT - Drilled shaft Connection

To bridge the Red line tubes, the 36.4m (120ft.) span between the shafts must be provided. This span has different locations under each wall since the Red Line tubes are at an acute angle to the ITT alignment. This required that the tube be designed for torsion. Three dimensional finite element analysis was used to locate the drilled shafts at positions where the loads would be as equal as possible. Several runs were required to reach this objective. The final layout of drilled shafts is shown on Figure 4.

As noted previously two eastern ITT's placed in the vicinity of casting basin have a base foundation. The properties of underline soils in this area are much better than on the eastern side of the FPC. The glacial marine (till) and bedrock stratums here approach the tunnels invert elevation (See Figure 2). Several base support systems have been considered during the design, including sand jetting, flowable sand, gravel or pea-stone bed and the grouting. It was recognized that the grouting alternative is more acceptable for this particular case. The sand alternative was rejected because of potential liquefaction during earthquake. The successful placement of screeded gravel base under such wide parallel tubes was also a concern. Also access for screeding equipment into the casting basin is problematic due to the proximity of the previously placed tubes.

The grout foundation was designed as several longitudinal strips, which are located under the external and the internal walls. The required width of the strips under the external and the internal walls are 3.3m (11 ft) and 4.5m (15 ft.) respectively. A special inflatable grout bags with the sizes 3m x 4.5m (11ft x 15ft) and 4.5m x 6m (15ft x 20ft) will be used to form these strips. The bags will be attached to the tube bottom (steel plate) and properly secured before the concreting of the tubes has begun. Similar to the other tubes, the plastic vertical sleeves will be embedded in the walls to supply each bag. Using a specific sequence, the bags will be filled with grout while the ITT is temporally supported on jacks. After the grout is cured the temporary jack-supports will be released and the load from the ITT will be transferred to the foundation.

6.0 Floating and Placing

The combination of such factors as the relatively short distance of the ITT alignment 333.3m(1100 ft), large width of the ITT's up to 48.5m (160 ft), narrow channel 121m (400 ft), and small gap between the ITT rows 1.2m (4 ft) cause a several construction challenges. Six large tubes have to be placed in this very restricted area. Some of these challenging problems are discussed below.

- The traditional methods of towing and placing immersed tubes are not applicable in this design. A special system of cables and winches, which propels the floating of tubes from the casting basin to their project position, has been developed. This system assumes numerous locations of the anchor points all around the FPC and also the installation of the anchor tower in the middle of the Channel.

- Because the last two tubes have to be placed partially in the Channel and partially in the casting basin (after final removal of the cellular cofferdam), the WB2 tube has to be temporary stored in the Channel to give the other one (EB2 tube) the priority for maneuvering and placement (see Figure 1). The storage area has to be predreged to allow the moored tubes to float during low tides. This area accommodates two tubes to give the flexibility for construction schedule in case if the drilled shaft foundation should not be completed in time.

- Considering the narrowness of the channels flat pontoons or vertical cylinders should be used for the tube immersion. The pontoons or the cylinders will be installed on the top of the ITTs in the casting basin. During immersion of the two western tubes, the snorkels (underwater part of the Ventilation Building) will act as a large vertical cylinder (See Figure 5).

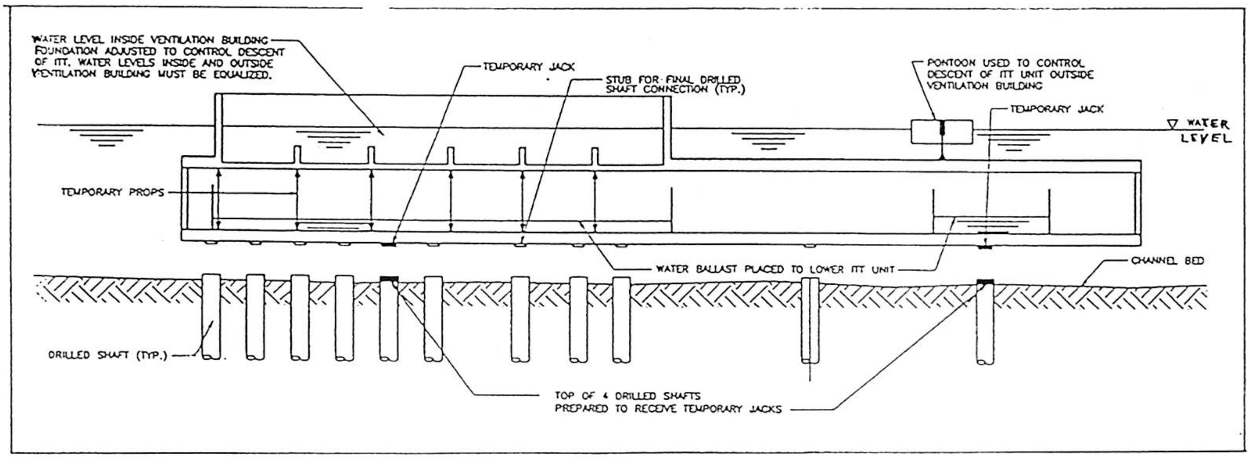

Figure 5. Immersion of the ITT with snorkel

- A challenging placement procedure has been developed for the west bound (WB) tubes, because east side of the WB2 tube has to be connected to both, the previously built cut-and-cover tunnel and to the WB1 immersed tube (See Figure 1). At first, the WB1 tube will be floated from the casting basin and placed forward of it's final position, ballasted with water and not connected to the drilled shafts. Then, the WB2 tube will be floated from the casting basin, placed into position, connected to the receiving cut-and-cover tunnel through the Gina seal, and then connected to the drilled shafts as shown on Figure 3. After that, the WB1 unit will be deballasted to be neutrally buoyant and will be connected to the WB2 unit through the Gina seal. In this operation the WB2 tube serves as a receiving unit. Even though the units are connected unsymmetrically, theoretically they are perfectly balanced. However, for safety reasons, the WB2 tube will be preballasted to increase it's stability prior to receiving the WB1 unit.

- The final stage of the ITT construction, the east and west closures, also presented a challenge. The necessity to maintain minimum vertical navigational clearance preclude placement of the backfill on the top of immersed tubes. The friction forces underneath the tubes, which are necessary for the ITT horizontal stability, is minimal. On all stages of placement the tubes are not subjected to any unbalanced horizontal forces. However, when all units will be in place and the cut-off walls will be erected on the western and eastern tubes to provide the dewatering of the east and the west closures, the situation is changed. A significant horizontal longitudinal unbalanced force directed to the west is developed. This occurs because the east and west tubes have different areas exposed to the hydrostatic pressure. Analysis indicates, that the friction forces underneath preballasted tubes, and the friction forces between the walls and the locking fill, do not safely counteract the unbalanced force. To gain a sufficient factor of safety against tube sliding the following measures have been provided.

1.The dewatering of the east and the west closures will be simultaneous with the strict control to keep the water table in the closures equal. The allowed diversity in the levels is 1.5m (5ft).

2. Temporary steel straps will be installed across all joints between the tubes, to protect the Gina seal from decompression.

3. All tubes will be sufficiently preballasted by the water tanks during dewatering of the closures.

4. To increase the safety factor against sliding, the shear keys were introduced in the connections between the western tubes and the drilled shafts.

7. Conclusion

At the time this paper was written, the Final Design of the Fort Point Channel Crossing has been completed. The Bechtel/ Parsons Brinckerhoff (B/PB) Joint Venture performed the preliminary design as well as 25% of the final design for the Fort Point Channel Crossing. ACER Engineers and Consultants Co. provided the final design for the immersed tubes and B/PB has coordinated and reviewed the final design. Recently the Massachusetts Highway Department awarded the Construction Contract to the "Modern Continental Construction Co. Inc. ". At the present time, the contractor is in the process of reviewing the proposed construction methods with the intent to reduce the construction cost and schedule. Presently, the casting basin is nearing completion and construction of the immersed tubes will start in the September 1997.

Acknowledgments

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