The Breach Problems in the Tunnels of the Boston Central Artery/Tunnel Project (Big Dig)

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Abstract. The Boston Central Artery/Tunnel (CAT) project consists of some 200 lane-kilometers of bridges, tunnels, and surface roadways. The central part of the project involves constructing two directions of multi-lane roadway to depths exceeding 30 m beneath the existing city by means of the slurry wall technique. The resulting walls, called Soldier Pile Tremmie Concrete (SPTC) walls, held back the *in situ* soils, supported an existing elevated roadway during construction, and form the final walls of the new tunnels. In September 2004 a breach occurred in one panel in the deepest section of the tunnel, spewing water onto the roadway and creating a crisis of public confidence in the project. Investigation revealed that the breach resulted from a series of shortcomings in construction and inspection, for which the relevant parties took responsibility. Three alternate repair schemes were proposed. Selecting the best procedure involved not only technical considerations but also impacts on neighboring high-rise buildings. The incident has implications for the construction of deep slurry walls in congested areas.

Key words: slurry walls, tunnels, construction, dewatering.

1. Introduction

The Boston Central Artery/Tunnel Project (CAT) is one of the largest civil engineering projects in history. The project consists essentially of three parts: (1) construction of an underwater vehicular tunnel under the harbor to connect the end of the Massachusetts Turnpike (Interstate Route I-90) to Logan Airport and other points in East Boston, (2) replacing the existing elevated vehicular expressway (Interstate Route I-93 – known as the "Central Artery") with a system of underground tunnels, and (3) replacing a set of roads and bridges that connects the northern end of the Central Artery to other roads. Originally authorized in 1986 at US$ 2,6 billion and scheduled for completion in 1998, the project is now budgeted at US$ 14,625 billion with a completion date in 2006. Because of these escallations and public disputes over several of the proposed design schemes, the project has become the focus of wide-ranging and continuing controversy. In this context, the appearance in September 2004 of breaches with flowing water in a wall of the deepest section of the I-93 tunnel was the subject of intense scrutiny in the press and by regulatory agencies. How had the breach occurred, and how could it be repaired?

2. Project Configuration

The project takes place in an exceptionally crowded urban environment, with high rise buildings, critical operating plants, and railroad facilities located within meters of the proposed rights of way. Furthermore, it was necessary to keep the existing elevated expressway operating until the new road could be completed to a stage that could accommodate the high desity of traffic.

The solution adopted for the main I-93 tunnels was to install slurry walls along the new right of way with 0.91 m (36 in) H-piles placed in the slurry on approximately 1.52 m (5 ft) centers and bearing on the bedrock. A small protion of the walls incorporated reinforcing cages as well. In each panel concrete was trimmed in to replace the slurry, and, after all panels were completed, the resulting wall consisted of a thickness approximately 1.07 m (3.5 feet) of concrete

Figure 1 - Map of CAT Project.

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with steel H-piles embedded along its length. The major structural loads were carried by approximately 9600 steel H-piles, and the concrete acted primarily in shear to transfer the loads of soil and water to the piles. These composite walls would become the final walls of the tunnels. The tunnels were constructed by a top-down procedure with cross-lot bracing installed as the excavation proceeded. Upon completion of the tunnel sections, the overlying region was backfilled. The walls are known in the terminology of the project as Soldier Pile Tremmis Concrete (SPTC) walls. Figure 2 shows a simplified cross section of the tunnel.

The existing elevated expressway had been supported by columns that in turn carried the loads to the bedrock. The construction procedure was to transfer the loads from the existing piles to the new H-piles in the slurry walls. Thus, once the tunnels had been completed, the traffic could be diverted into the new tunnels and the previously existing elevated structure demolished.

A further complication is that the elevation of the tunnels vary considerably over their lengths. As can be seen in Fig. 3, the I-93 tunnel comes from the south (the left of the figure), drops to its deepest point to pass under the existing red line metro line, rises nearly to the surface to pass over the blue metro line, drops down again to pass under the access ramps for the existing Sumner and Callahan tunnels across the harbor, and rises to connect to the new Zakim bridge across the Charles river. Thus, a considerable variety of loadings and soil conditions occurs even in this short distance. The section that is the principal subject of this paper is in the deepest part of the project just north of the red line.

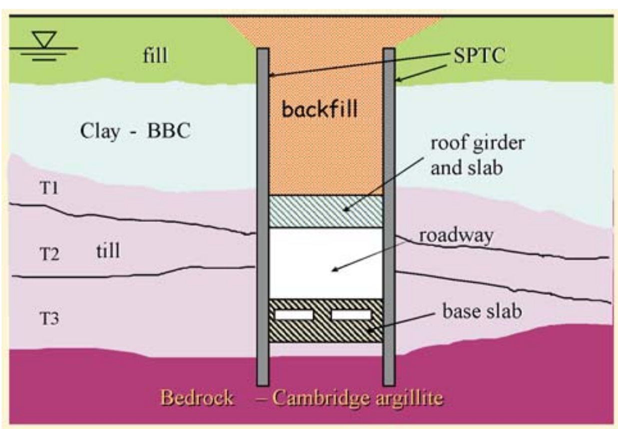

Figure 2 - Simplified cross-section of tunnel.

3. The Breach and its Cause

In September 2004, after the tunnel had been opened to traffic for nearly a year, a breach occurred in one of the tunnels walls. Water gushed onto the roadway, forcing the authorities to close the tunnel to traffic and to initiate emergency procedures to stanch the flow.

Investigation revealed that the breach had occurred at a point in the tunnel where the soil outside the tunnel is the T3 till (Fig. 2). Although all three of the tills are sense as a result of compaction under the weight of Pleaistocene glaciers, the T3 segment consists of sands and gravels with little or no silt and clay, so that the permeability of the soil is much higher than that of the other tills and the overlying clay. Since the water table is at or near the surface, the head of approximately 21.3 m (70 ft) can drive a substantial flow of water. The questions then was to discover how the breach in the concrete had come about.

Figure 4 illustrates the construction sequence for the soldier pile tremmie concrete (SPTC) walls. When the soldier piles are placed in the slurry, the space between the outside flanges is filled with an inert granualr material and the space closed off with an end stop, which is made of plywood or thin steel plate. When the secondary panel is excavated,. it is essential that the end stop and the granular material be removed so the concrete for the secondary panel makes good contact with the steel pile.

In the present case the contractor for one section of the tunnel poured too much concrete at the end of the last

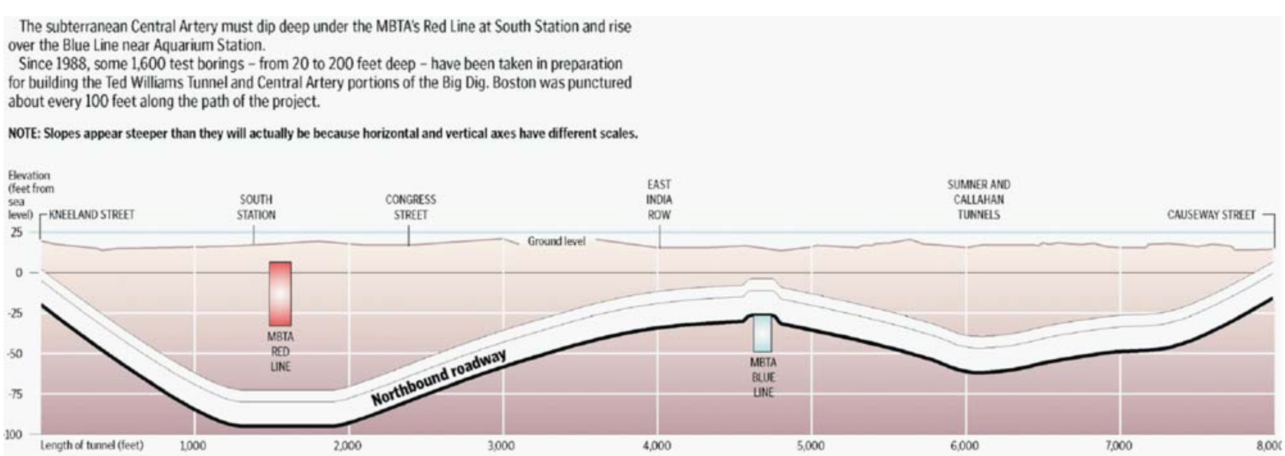

Figure 3 - Elevation along length of I-93 tunnel.

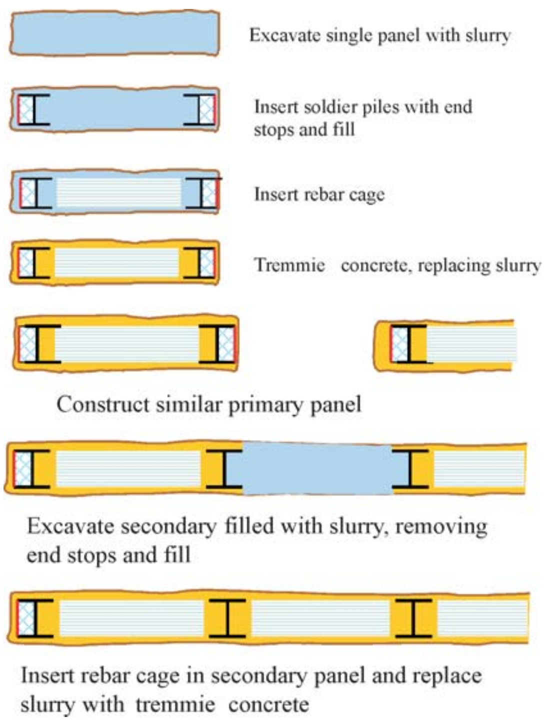

Figure 4 - Construction sequence for SPTC wall.

primary panel, creating a mass of concrete that intruded into what would become a secondary panel placed by the contractor for the next section. Rather than excavating the block of extra concrete, that contractor simply tried to excavate under it. This was not successful, so a portion of the soil lying under the excess mass was never excavated and was incorporated in the final wall. Part of this material was T3 till, through which the flow eventually occurred.

The configuration of the leak is depicted in Fig. 5, which shows an elevation as seen from the inside of the tunnel and a horizontal section through the breach. This was clearly the result of faulty construction and inadequate inspection; both the engineers and the contractor accepted responsibility for repairing the wall. Unfortunately, all this had to be done in a highly politicized environment with constant attention from the press.

4. Repair Alternatives

Three alternatives presented themselves for repairing the wall. The first was to construct a new slurry wall panel outside of the damaged panel. This was rejected because no one could devise a method of creating a water-tight connection to the rest of the wall and because it would be necessary to place construction machinery on a busy street and in the entrance to the Federal Reserve Bank.

The second proposed solution was to excavate all of the damage section of the wall and replace it with a reinforced concrete panel. This would have required building the new wall section in horizontal lifts over several weeks since the continued operation of the tunnel meant that work had to be done in four hour windows in the early morning hours. A more serious problem with this solution was that it required dewatering the work area by lowering the water table by approximately 70 ft. In addition to the difficulty of the dewatering itself, this raised the prospect of settlement damage to neighboring structures and the hazards associated with the possible failure of the pumping system during the protracted construction. During the construction the stability of the wall would depend entirely on the continued operation of the pumping system. At least one prominent consultant to the project argued forcefully for this solution, but the consensus of the other engineers was to use the final alternative.

The third alternative, which was adopted, was to keep the damaged section in place and to place a reinforced plate in front of it to contain the water forces. Figure 6 illustrates the details. The plate consisted of a steel plate stiffened by 0.20 m (8 in) steel beams and encased in concrete. The panel was designed to carry all the loads for which the origianl panel was designed, so that any capacity in the damaged section provided an additional margin of safety. The replacement panel was designed by one structural engineering firm and the design checked by two others. The project engineers concluded that this solution represents a conservative, robust solution. The panel has been installed, and is functioning well.

5. Conclusions

Aside from the issues addressed during the design for this particular problem, some more general conclusions can be drawn. Among them are:

(a) Installing slurry walls at depth is difficult. It is hard to control the excavation and construction processes at depths greater than about 20 m (65 ft). Engineers contemplating installing walls below this depth should consider carefully how the wall will be designed and built and how the performance of the wall will be assured.

(b) Both construction and inpection of deep walls shuld meet the highest standards.

(c) If the wall is to serve as the final wall and snot simply an interim construction measure, the wall should be power washed before acceptance. In the present case the materials in the wall section were concrete, some slurry, and the unexcavated till. All of these are grey, and, in the dim light in the tunnel excavation, it is not easy to tell them apart without washing the wall vigorously.

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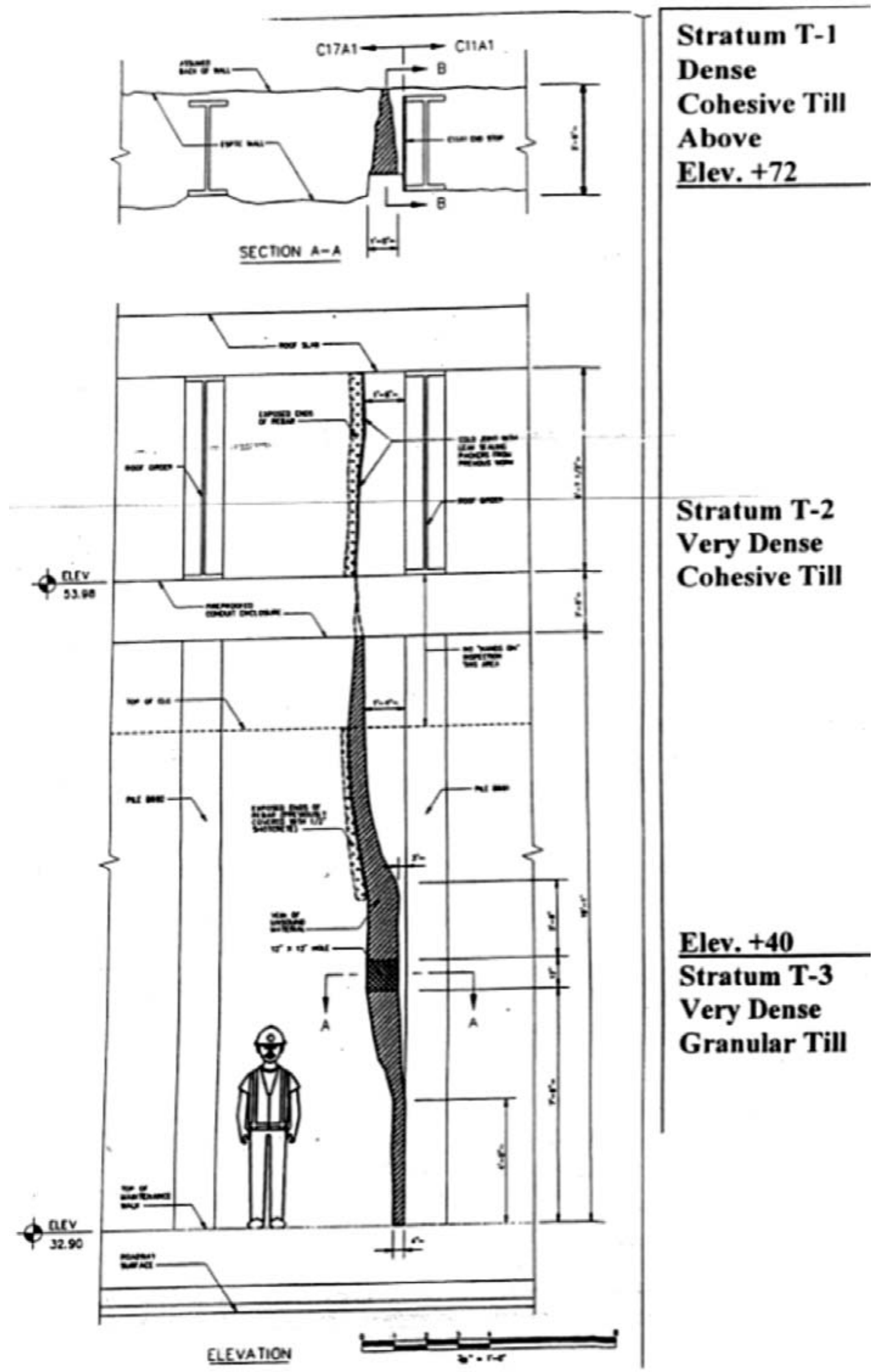

Figure 5 - The breach in the SPTC wall.

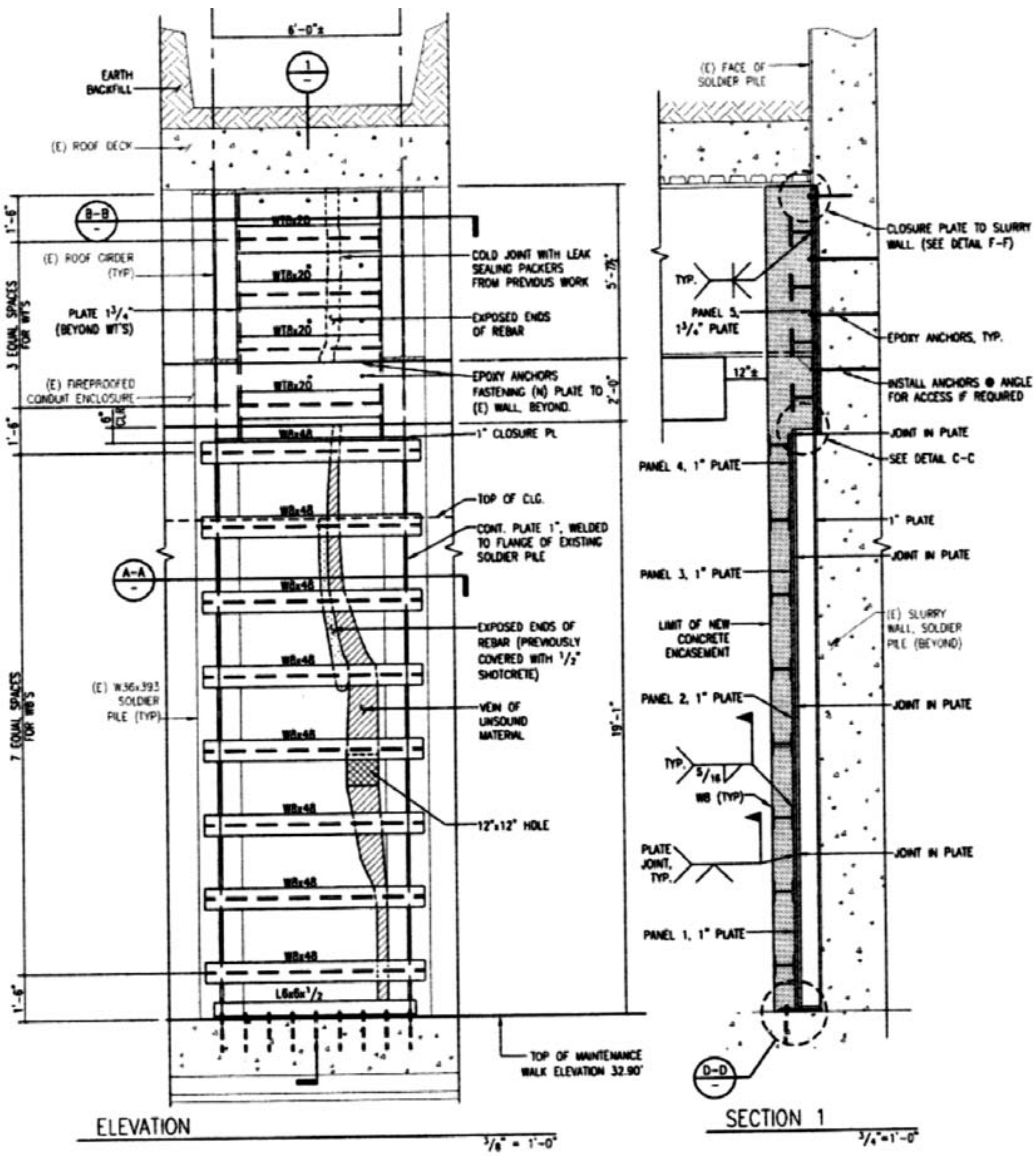

Figure 6 - The solution adopted.