TEMPORARY EARTH RETENTION FOR THE UNDERWOOD CREEK WEST DIVERSION STRUCTURE, MILWAUKEE, WISCONSIN

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Abstract: The West Diversion Structure of the Milwaukee Metropolitan Sewerage District's Underwood Creek Flood Control Project was designed to collect floodwater from adjacent Underwood Creek and divert it through a 5.2 m (17 ft) inside diameter soft ground tunnel to a detention basin 1200 m (3/4 mile) downstream on the northeast side of the Milwaukee County grounds. To allow construction of the large, dog-legged intake structure and provide an exit portal for the tunnel, the project documents called for the construction of a 94 m (308 ft) long by 10.4 m (34 ft) to 21.3 m (70 ft) wide temporary earth retention system (ERS). The ERS was to range from a depth of 11.3 m (37 ft) at the tunnel portal to a depth of 7.3 m (24 ft) at the opposite end of the excavation. The documents suggested a secant pile ERS to allow construction in the dense/hard ground conditions and shallow groundwater table depicted in the soil borings, and that it be designed using at-rest earth pressures and a groundwater table 1.5 m (5 ft) below the ground surface, even though local flooding above was occasionally observed in the area. Given the shallow groundwater table, and the local experience of the authors with the presence of nested cobbles and boulders in the very dense glacial till profile, specialty contractor Edward E. Gillen Company presented an alternative ERS design to Tunnel Contractor Shea/Kenny J.V. consisting of steel sheet piling inserted in a cement-bentonite slurry wall. Given the absence of adjacent structures, the authors proposed that the ERS be designed using active lateral earth pressures. This alternative approach substantially reduced the boulder obstruction risk and related quality assurance issues, expedited construction and significantly reduced the cost of the temporary ERS.

INTRODUCTION

The overall concept of the Underwood Creek Flood Control Project is to alleviate frequent local flooding by allowing retention of storm water within the watershed, and by cutting flow into the Menomonee River by half during flood events.

This is to be accomplished, in part, by directing excess storm water into a large diversion structure, through a 5.2 m (17 ft) dia. x 0.8 km soft ground tunnel and into a 26 ha (65 acre) detention basin on the Milwaukee County Grounds. See Figure 1.

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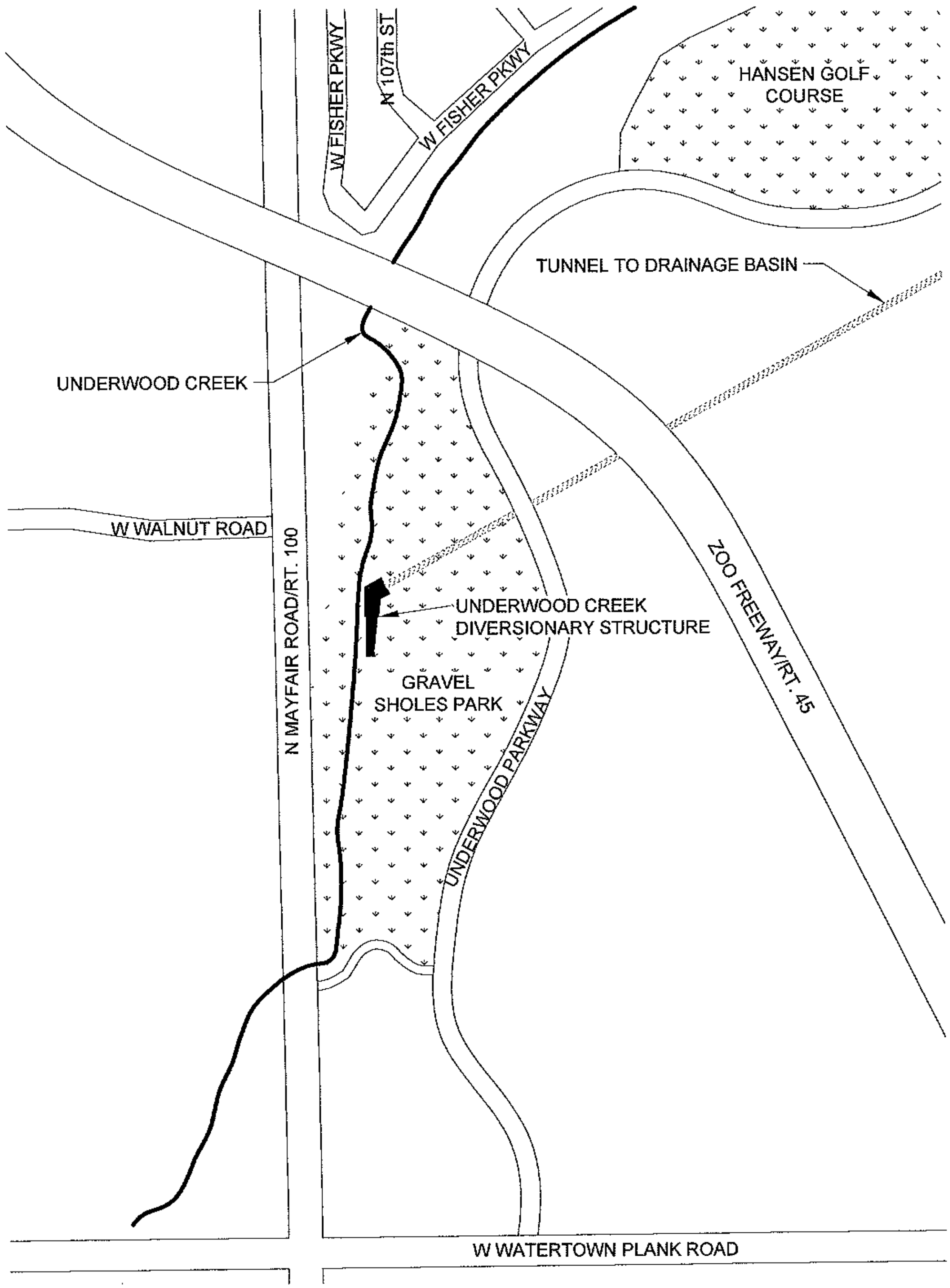

FIGURE 1 - LOCATION PLAN

A temporary earth retention system was required to allow construction of the dogleg shaped 94 m x 10.4 m to 21.3 m wide x 7.3 m to 11.3 m deep (308 ft x 34 to 70 ft x 24 to 37 ft) diversion structure in a dry, stable excavation adjacent to a historically temperamental creek.

PROJECT DESCRIPTION

Initially, the owner's design engineer intended that a secant pile wall ERS be designed to be both the temporary earth retention system and the structure's permanent subgrade wall, with a poured concrete facing. The secant wall was to include one level of tiebacks. However, due to unanticipated high initial bids, the project was re-offered incorporating contract changes that would require the design/build construction of a temporary earth retention system by the contractor that was independent of the permanent structure.

Two conditions dictated the viability of the temporary ERS design:

1. <u>Constructability</u>

   - The subsurface conditions consist of extremely dense and bouldery till beginning at a depth of 9 m (30 ft) that promised to be difficult for any earth retention system.
   - Although a traditional steel sheet piling system could satisfy the design requirements, the ability achieve the necessary toe penetration by traditional installation methods was doubtful due to the extreme density of the till and anticipated obstructions.
   - While a drilled secant wall could penetrate these adverse conditions, the rate of productivity would be highly dependent upon the unknown frequency and matrix of the cobbles and boulders.
   - Considering the adverse conditions, the wall system that could most confidently be installed in a reliable cycle time would dictate the design.

2. <u>High Water Table</u>

   - By specification, the earth retention system was to be designed to accommodate a two-year flood (Elev. 690). In addition, the general contractor required that the at-grade working surface be located five feet higher--at the ten-year flood level—such that it was possible for the river to rise above the specified design level.
   - Concern for penetrating the earth retention wall for the tiebacks below the local water table would create constructability problems that would best be solved by avoiding the condition.

SUBSURFACE CONDITIONS

Soil borings completed in areas adjacent to the West Diversion Structure depict a layered profile of glacial till and outwash deposits. See Figure 2. The granular soils range from a medium to very dense condition, and the clayey soils range from stiff to hard. Two of the borings drilled adjacent to the deeper end of the excavation indicate the presence of very dense sandy soils just below excavation base grade at Elev. 654 to 655 (USGS Datum). Working grade on the site was set at Elev. 695 in the contract documents, 0.5 m to 1 m below original site grade. Refer to Fig. 2.

Although not specifically noted on the boring logs, the Geotechnical Data Report (GDR) and Geothechnical Baseline Report (GBR) both indicated that boulders ranging from 0.3 m to over 1.2 m should be anticipated. Based on the author's experience on nearby projects, boulders exceeding 1.5 m (5 ft) could also be expected. The contract documents identified a design groundwater level at Elev. 690, 1.5 m below the planned working grade.

EARTH RETENTION DESIGN—INITIAL BID

The earth retention design for the initial bid consisted of a secant pile wall, utilizing 1.5 m (5 ft) dia. shafts at 1.3 m (4'-4") centers penetrating to Elev. 640. One tieback was required in alternating shafts, each with a design load of 902 kN (205 kips) at Elev. 686.5. A minimum 0.3 m (12 in.) thick concrete facing with a single layer of mesh reinforcing steel was to be placed on the inside face of the concrete wall.

CONTRACTOR EARTH RETENTION DESIGN

General

The authors had the following concerns about the secant pile earth retention proposed in the project documents:

1. The propensity for boulders in the profile would have a significant impact on the quality of the construction, potentially creating unwanted windows or gaps between individual piles. Based on the experience of the authors, boulders in the profile could range significantly in size, frequency, and composition. Of additional concern was the high probability that nested boulders would be encountered while excavating for the retaining walls, as experienced on previous nearby projects completed by the author's company.

2. The design of a temporary earth retention system using at-rest lateral pressures would add substantial cost to the project. The authors believed that a safe, cost-effective retention system could be constructed using active pressures since the temporary retention system would have a relatively short life.

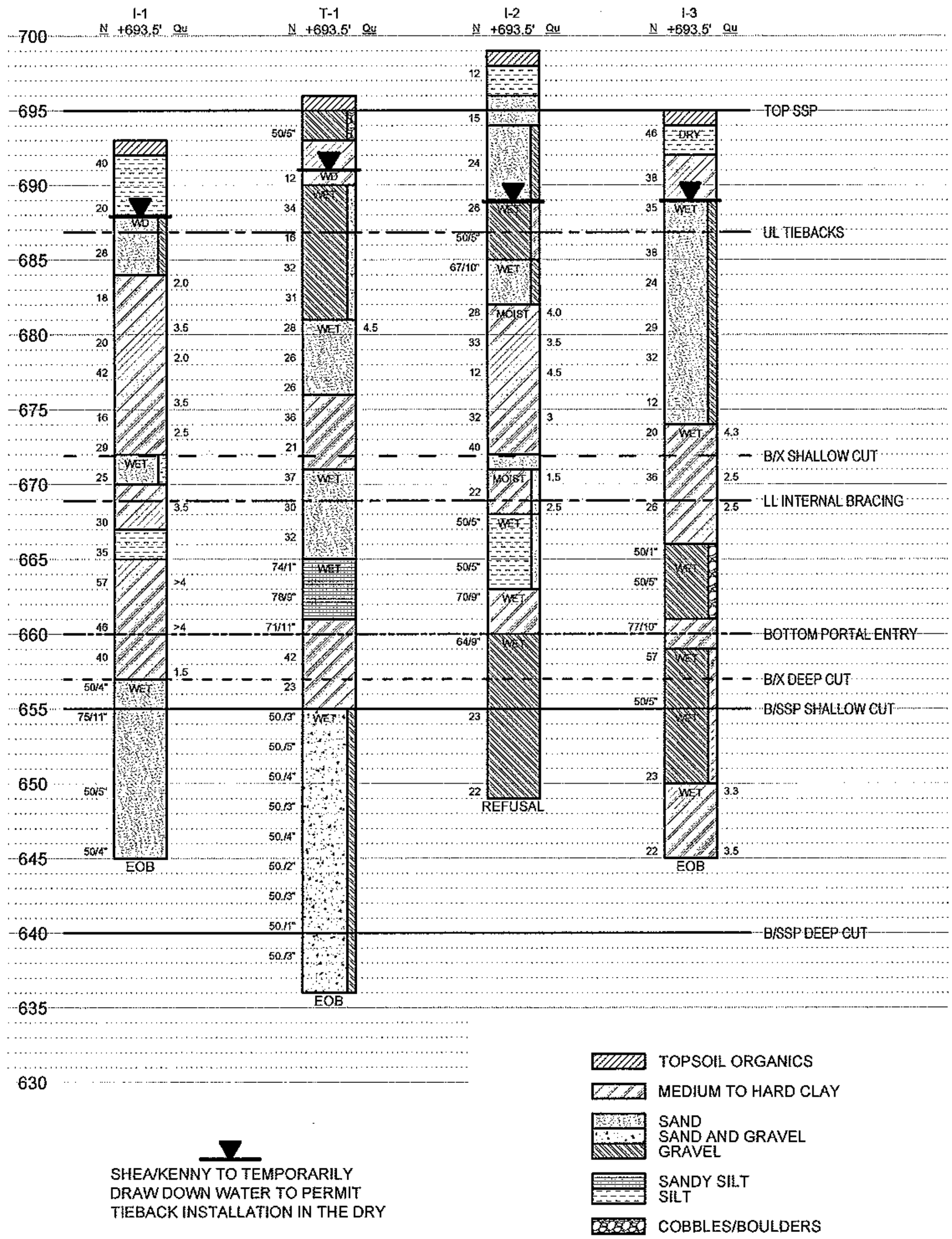

FIGURE 2 - SITE SOIL PROFILE

3. The design groundwater table elevation, Elev. 690, could pose a significant design and safety issue if nearby Underwood Creek crested its banks and rose above this level. For example, if floodwaters reached Elev. 695 at site working grade (and the top of the earth retention system), there could be as much as 1.5 m (5 ft) of additional hydrostatic pressure on the on the retention system. Given that flooding in the area was a substantial problem in recent years, it was our professional opinion that the retention system should be designed using a groundwater level at working grade (Elev. 695), or that other measures be taken to safeguard the retention system in the event that this occurred.

The author's solution was to design/construct a cement-bentonite slurry (CB) wall to provide groundwater cut-off and allow placement of a steel sheet pile wall within the slurry-filled trench to serve as the structural wall. The ability of a 1,320-kN (150-ton) backhoe to excavate the boulder-laden dense soils minimized the boulder obstruction risk, assured the necessary wall penetration depth and ensured the quality of the constructed wall. The CB material was designed for an unconfined strength of 2.9 kPa (20 psi), similar to that of the natural soil.

The retention system was laterally restrained with one level of tiebacks installed at Elev. 687 after temporary dewatering outside of the excavation, and one level of internal bracing at Elev. 669 on the deep (north) end of the excavation. The tiebacks had design loads in the 590 to 902 kN (134 to 205 kip) range, and the internal bracing consisted of 600 mm (24 in.) dia. pipe struts and W24 wale sections. Refer to Figs. 3 and 4 for cross sections through the deep and shallow ends of the excavation.

<u>Lateral Earth Pressures/Wall Design</u>

The temporary loading diagrams in the bid documents assumed at-rest conditions, a triangular lateral earth pressure distribution, a groundwater table at Elev. 690 and a 13 kPa (250 psf) uniform surcharge. The resulting total force for the deep end of the excavation was 940 kN/m.

The sheet pile wall was designed assuming active earth pressure conditions, a trapezoidal soil pressure distribution (Sabatini, et. al, 1999) and a groundwater table at a slightly higher Elev. 692. The surcharge load assumed in our design was similar to that indicated in the project documents. To address flooding conditions, the retention system was designed with 0.6 m dia. drainpipes with an invert of Elev. 692 extending through the west side of the retention system at 16 m centers. The drainpipes would allow the excavation to flood and minimize an imbalance in hydrostatic pressure. On the deep end of the excavation, using active pressures and a design groundwater table at Elev. 692 resulted in a resultant lateral force of 765 kN/m, roughly 20 percent less than the total force computed from the at-rest pressure diagram in the project documents. Refer to Fig. 5. Although the hydrostatic and surcharge loads considered were very similar, consideration of trapezoidally distributed, active soil pressures resulted in a substantially smaller lateral load on the retention system.

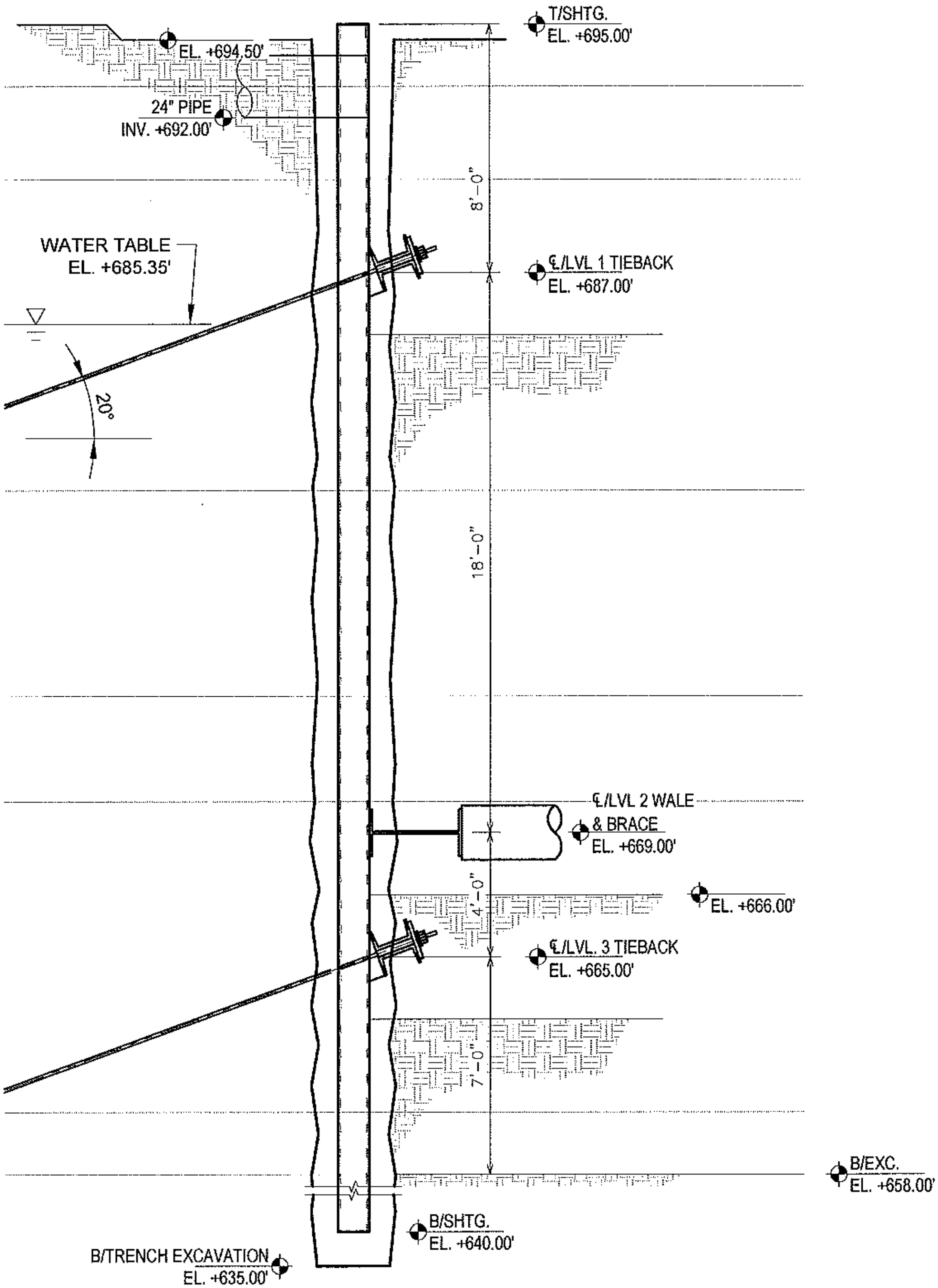

FIGURE 3 - DEEP CROSS-SECTION

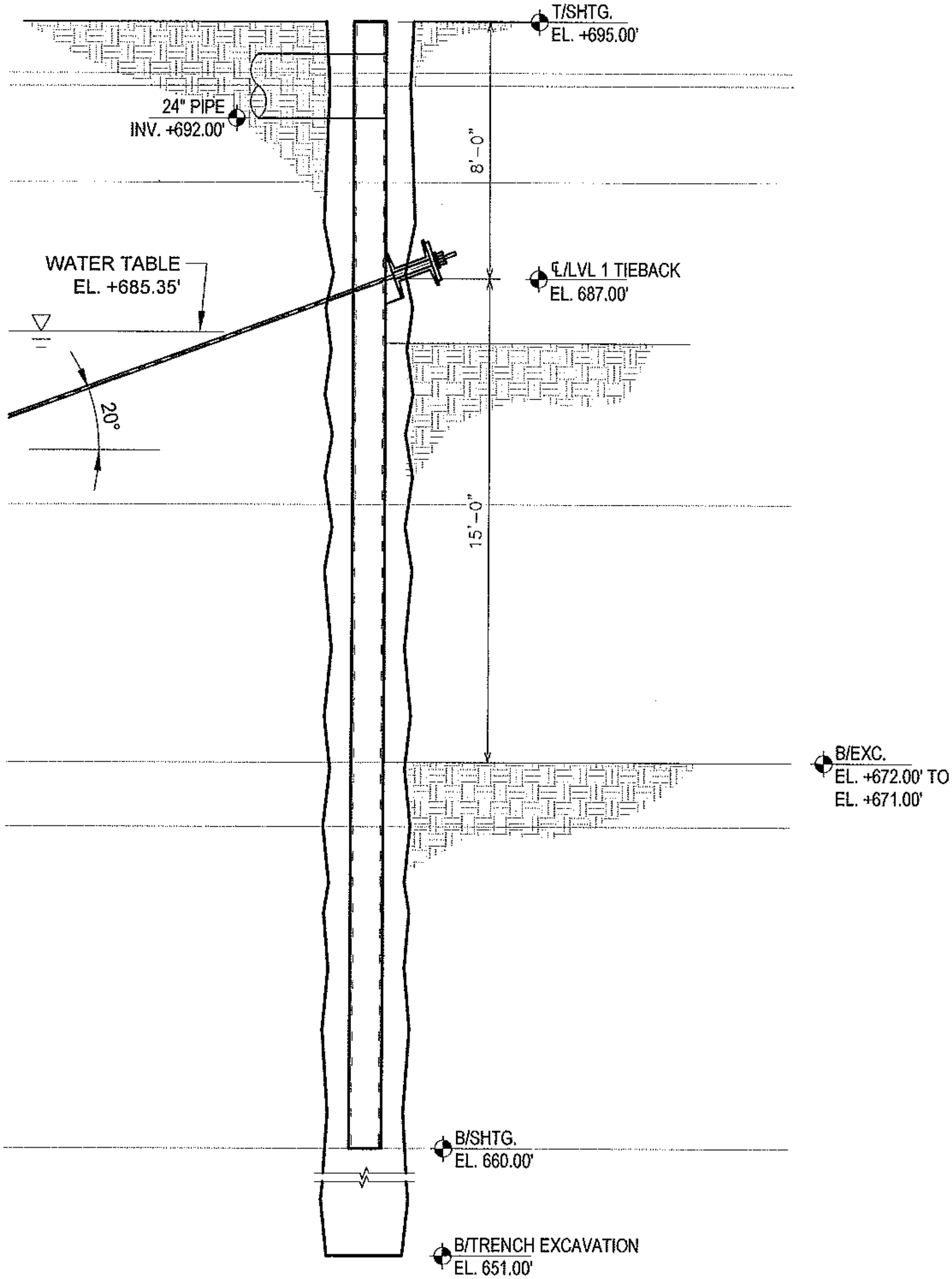

FIGURE 4 - SHALLOW CROSS-SECTION

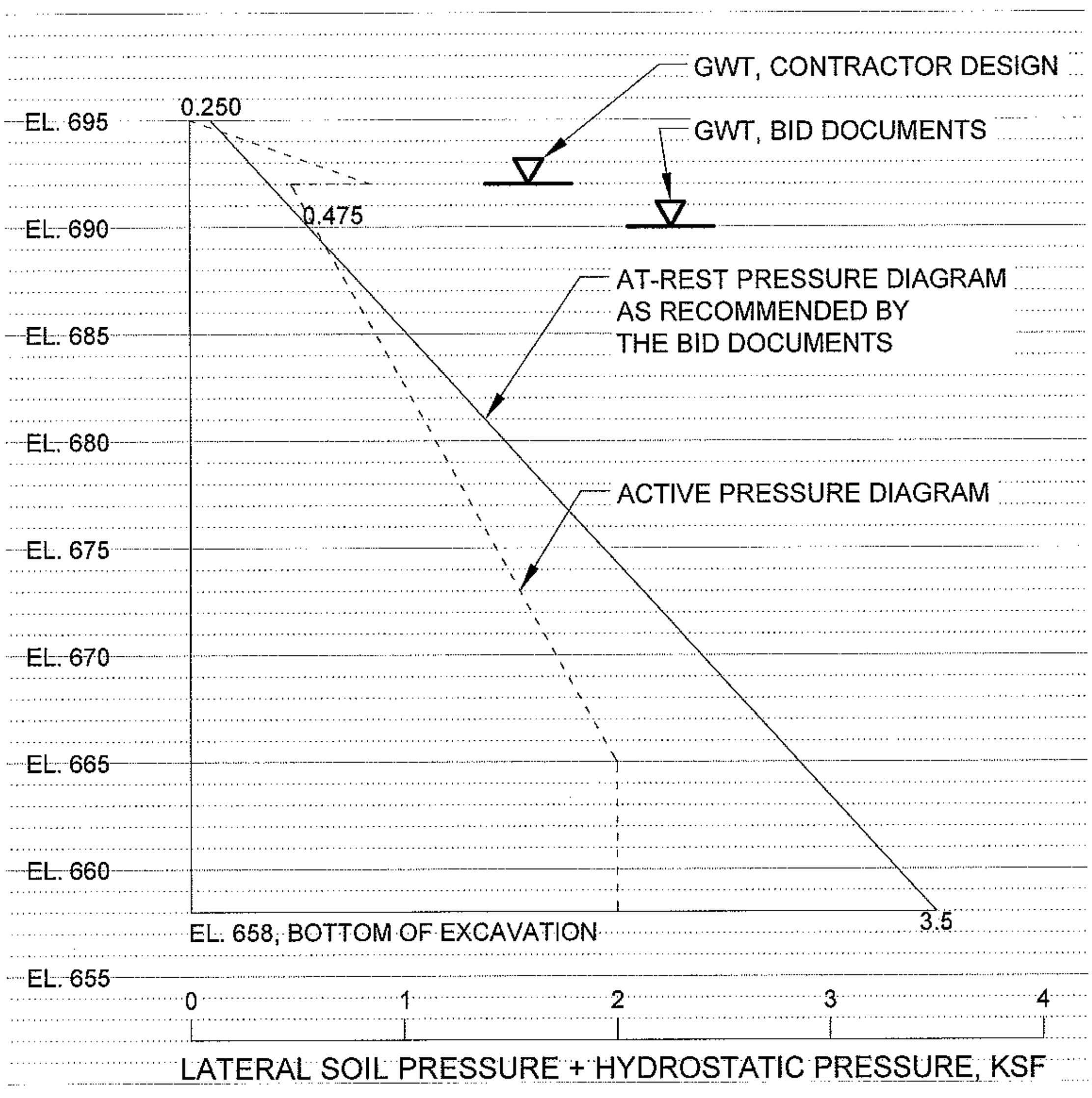

FIGURE 5 - COMPARISON OF AT-REST & ACTIVE PRESSURE DIAGRAMS

Groundwater Cut-off/Toe Embedment

In acknowledgement of granular soils below the excavation base grade, the CB cutoff wall was advanced to Elev. 651 on the shallow end and Elev. 635 on the deep end to ensure sufficient basal stability. The minimum structural toe embedment for the steel sheeting ranged from Elev. 651 on the shallow end to Elev. 635 on the deep end of the excavation and was computed assuming the presence of granular soils (conservative) using methods described in Goldberg et. al (1976) and other classic references in the geotechnical engineering literature.

RETENTION SYSTEM CONSTRUCTION/PERFORMANCE

Construction of the CB wall and installation of the sheeting generally proceeded without incident. However, nested boulders in two small areas prevented excavation advancement to the targeted cutoff wall elevation and installation of the steel sheeting to the targeted structural toe elevation. In these instances, supplemental exploratory drilling confirmed that the cutoff wall was terminated in relatively impervious dense sandy silt and very stiff to hard clay till, negating piping and bottom stability concerns. Supplemental tiebacks were installed in these areas to ensure structural stability of the retention system in the affected areas. See Fig. 3.

Although the retention system was not subjected to a rigorous monitoring program, visual observation and very limited optical survey data indicate that the retention system performed satisfactorily. Only limited leakage was noted at tieback locations and this leakage gradually subsided after grouting was completed. Observations at base grade indicated that seepage into the excavation was satisfactorily controlled. Once the excavation was completed, the exposed subgrade was protected with a 24 in. thick lean concrete mud mat.

CONCLUSIONS

As of this writing, the excavation is complete, the concrete mat poured and backfilled up to a level of 8.8 m (29 ft) below working grade, and the internal bracing has been removed.

The described earth retention has provided excellent performance for its intended use. That is, the slurry trench/sheet piling solution was both the most economical and safe cofferdam for the excavation and the structure within it.

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