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EXCAVATION SUPPORT AT THE CAPITOL VISITOR CENTER IN WASHINGTON, DC

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In 2002, excavation support work commenced on the Capitol Visitor Center project located adjacent to the nation's Capitol building in Washington, D.C. The outlying work (Slurry Wall Work at Main Site is not discussed) consisted of providing excavation support for a new truck tunnel approximately 1,900 feet long up to 50 feet deep as well as support for the new underground auditorium and Library of Congress tunnel. The excavation support consisted of a combination of conventional drilled in soldier beams, lagging, tiebacks and braces; intricate underpinning inside the existing Capitol building; support of an existing Russell Tunnel; soil nailing and tiebacks underneath the existing Russell Tunnel; two temporary bridges; and a deep soil mixed wall with lateral support provided by braces. As part of an on-going research program, some of these braces were instrumented with strain gauges. The deep soil mixed wall was approximately 300 feet long and 65 feet deep on either side of the truck tunnel. Approximately 34,000 sf of deep soil mixed wall, 90,000 sf of conventional excavation support, 200 braces, and 320 tiebacks were installed. This paper describes the large scope and breadth of the project that required a variety of excavation support techniques. A few of the challenges in designing and installing the support of excavation are discussed. This paper also presents the results of the instrumentation program conducted on the deep soil mixed wall, which stood open for more than a year.

INTRODUCTION

Working on one of the world's most historic buildings is always a privilege and a challenge. The new Capitol Visitor Center (CVC) main section is a 50 foot deep underground facility which will front the east side of the existing Capitol Building. It will be the single largest addition since its initial construction in 1800. The CVC will more than double the existing Capitol footprint from 175,000 square feet to 368,000 square feet. Once completed, it will also increase its usable total area 75 percent from 775,000 to 1,355,000 square feet. The new three-level underground facility is currently scheduled to be open to the public in July of 2007.

In order not to detract from the Capitol's existing grounds and landscape, and East Front surface plaza deck forms the roof of the main structure. To the northwest will be a new underground vehicle truck tunnel. East of the plaza will be a two-level underground congressional auditorium. When the CVC is complete, it will house the Great Hall, exhibition galleries, two auditoriums, gift shops, service tunnels, storage, and much needed space for the House and Senate.

Excavation support work for the Capitol Visitor Center commenced in 2002. The outlying work consisted of providing excavation support for a new truck tunnel roughly 1,900 feet long and up to 50 feet deep as well as support for a new auditorium and tunnel to the Library of Congress. The excavation support consisted of a combination of conventional drilled in soldier beams, lagging, tiebacks and braces; intricate underpinning inside the existing Capitol building; support of an existing Russell Tunnel; soil nailing and tiebacks underneath the existing Russell Tunnel; two temporary bridges; and a deep soil mixed wall with lateral support provided by braces. Some of these braces were intrumented with strain gauges. Approximately 34,000 square feet of deep soil mixed wall, 90,000 square feet of conventional excavation support, 200 braces, and 320 tiebacks were installed.

The main body of this paper is divided into three parts. Part 1 presents an overview of the scope of work and general construction methods used. Part 2 addresses specific construction techniques used and challenges encountered, while Part 3 describes the instrumentation program and presents the results of that program. Finally, conclusions are given at the end of the paper.

PART 1: SCOPE AND CONSTRUCTION TECHNIQUES OVERVIEW

In this part, an overview of geo-support work for the Capitol Visitor Center job will be discussed followed by a description of the support of excavation work done. Attention is paid to the work outside of the main site slurry wall work. To help better understand the scope we also discuss the soil conditions, contract requirements, and design parameters.

There was an enormous amount of geo-support work for this job and this work was divided amongst three subcontractors: Schnabel Foundation Company (SFC), Nicholson, and McKinney. This paper focuses only on Schnabel Foundation Company's work which could be divided into six individual "pieces" (see Figure 1 and Table 1).

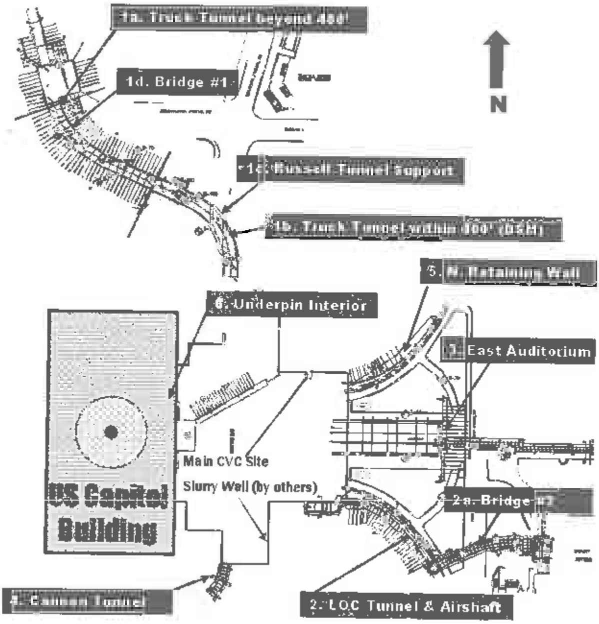

Figure 1 - Excavation Support Plan Overview

Table 1 shows the wide range of construction techniques used to accomplish this job. There were at least four different support of excavation systems utilized: a) Soldier Beams, Lagging, and Tiebacks; b) Soldier Beams, Lagging, and Bracing; c) Deep Soil Mixing (DSM) with Bracing; and d) Soil Nailing. In addition to the shoring systems, at least four different types of underpinning and/or traffic support were used: a) Bridges on Piers; b) Internal Tunnel Shoring; c) Steel Beams and Hanging Tie Rods from Piers; and d) Traditional Concrete Underpinning Pits.

	Description	Area of Shoring or Under-pinning (SF)	Typical Shoring Depth (LF)	Qty Soldier Beam & Piers (LF)	System Installed
1a	Truck Tunnel (beyond 400' of Capitol)	45,000	50	5,700	Drilled Soldier Beams/ Lagging/ Tiebacks/ Bracing
1b	Truck Tunnel (within 400' of Capitol)	34,000	50	8,750	Deep Soil Mix (DSM) using wet mixing method / Cross-lot Bracing / Tiebacks / Soil nails
1c	Russel Tunnel Support			700	Internal Bracing/ External Bracing with piers and hanging tie rods
1d	Constitution Ave Bridge			540	Crane Mats/Beams on Drilled Piers
2	LOC Tunnel	25,000	30	3,700	Drilled Soldier Beams/Lagging/ Cross-lot Bracing
2a	A Street Bridge				Crane Mats/Beams on Drilled Piers
3	East Auditiorim	7,000	58	1,100	Drilled Soldier Beams/Lagging/ Tiebacks
4	Cannon Tunnel	2,600	17	450	Drilled Soldier Beams/Lagging/ Cross-lot Bracing
5	North Retaining Wall	3,000	17	850	Drilled Soldier Beams/Lagging/ Tiebacks
6	Interior Underpinning	2,000	10		Concrete Underpinning Pits
	Approximate Totals	118,600 SF of Shoring		21,790 LF of Drilling	

Table 1 - Quantity of Work Overview

Subsurface Conditions: The soil profile at the truck tunnel (see Figure 2) which was the deepest excavation discussed consisted of four (4) distinct soil strata: 1) fill; 2) dense to very dense sand layer with gravel (T3); 3) dense to very dense clayey silty sand layer with variable amounts of cobbles and boulders (P2); and 4) hard clay layer (P3). The top fill layer was up to 10 feet deep. The underlying sand and gravel (T3) layer was up to 35 feet deep below the fill and could not stay open during installation of the soldier beams. Casing or continuous flight augers (CFA) had to be used to advance the holes. Below the T3 layer, the P2 layer was mainly clayey or silty sand (SM, SP).

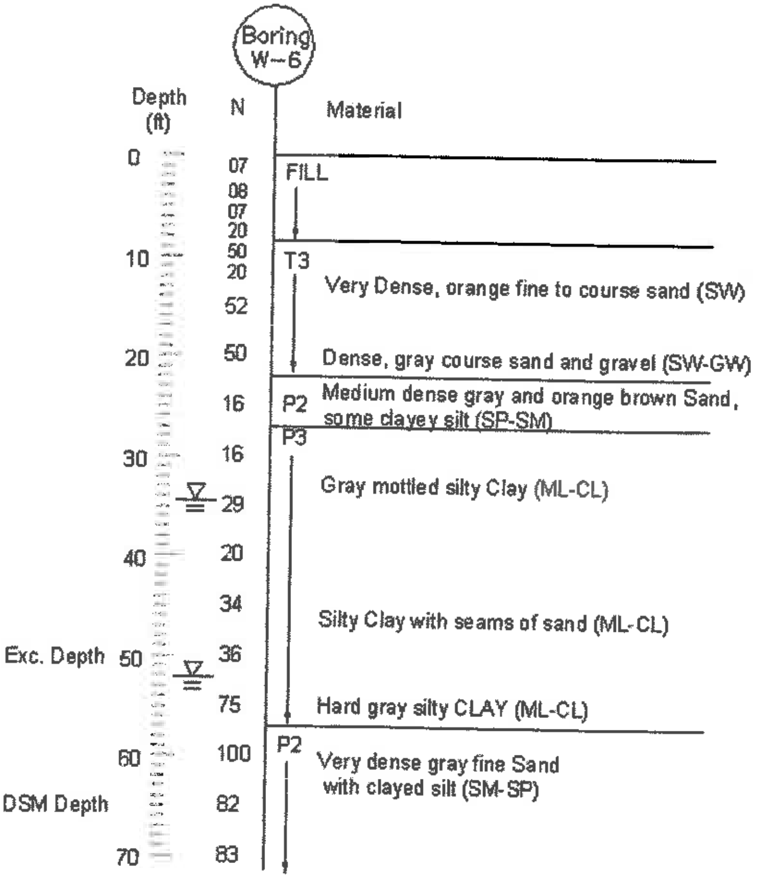

Figure 2 - Boring Log at Truck Tunnel

During installation of soldier beams through the P2 layer the holes stayed open without using casing. Intermixed below the P2 was an extremely hard clay layer (P3) classified as CL. Since these distinct layers were so different from one another, different construction tooling was required to handle each type. Specifically, the Deep Soil Mix (DSM) augers were modified to handle both a hard gravel layer at the bottom of the T3 layer and then the dense clay of P3 below that. Perched groundwater was found to be at varying elevations.

Contract Requirements: The contract design requirements called for a water cutoff wall within 400 feet of the Capitol Building's existing foundation to prevent possible settlement. A slurry wall (not discussed here) handled this requirement for the CVC main structure to the east. A subcontractor designed Deep Soil Mix (DSM) system was used to handle this for the truck tunnel. Beyond this 400 foot water cutoff circumference, drained shoring systems were allowed. For these outlying areas, subcontractor design/built systems of soldier beam and lagging were used with a combination of braces and tiebacks.

The specified allowable movement for any shoring system had to meet the following criteria. The "threshold" movement values were 2¾" for horizontal movement and ¾" for vertical movement. If these threshold values were detected, the contractor was to immediately investigate possible reasons for these movements and make design or construction changes if needed. The "limiting" values were 3" for horizontal movement and 1" for vertical movement. If these limiting values were exceeded, then the contractor was to immediately stop and take all necessary corrective measures. Since the depths of excavation varied up to 58' deep, the horizontal movement criteria were no more stringent than 0.43% of the shoring height. Fortunately, neither threshold nor limiting value movements were ever detected during construction.

Design: For the free draining support of excavation systems consisting of soldier beams, wood lagging, tiebacks, and braces, a 25H trapezoidal earth pressure diagram plus surcharges was used to determine brace and tieback loads. The design of the DSM cut-off wall used a rectangular 28H diagram plus surcharges to the top of the water table. The lower portion of the pressure diagram consisted of a reduced rectangular earth pressure (due to the buoyant weight of the soil) plus a hydrostatic head of 27 feet. Although a toe embedment of 7 feet was derived from the design, an actual toe embedment of 15 feet was used to comply with the minimum specified contract requirements.

PART 2: SPECIFIC TECHNIQUES AND CHALLENGES

On paper, the unique challenges for such a job at first seemed quite daunting. There were the burdensome (but necessary) security issues to work around, the DC downtown area to keep open, the numerous levels of coordination, the tight schedule, a few tricky design requirements, and working on arguably the most historic building in the country. When you throw all these challenges into the pot with constructing the CVC during one of the wettest years on record, it created a recipe for premature aging for most managers and foremen.

1) Security Issues: Before any worker was allowed on site, he needed to first go through a (roughly) week long background check to get his mandatory security badge. Before bringing in any equipment or materials, all drivers with detailed vehicle information needed to be announced for security screening 48 hours before showing up to the first of two security checkpoints. This was not as bad as it sounds once we got used to it, but it was a continuing challenge for those unforeseen emergencies that often popped up. Also, the security paperwork/instructions often intimidated suppliers who had to complete them.

This resulted in additional coordination, and sometimes higher pricing for even getting the basic supplies, equipment, and personnel to the job on time.

2) Keeping the Capitol and Downtown DC Operational: This was especially tricky for the truck tunnel that wound its way from the VIP parking area of the Capitol to a block or so north. The work areas and access were always extremely tight. Cutting through Constitution Avenue, a major downtown thoroughfare, required phasing so at least four lanes were open during all daytime hours. The shoring contractor designed and constructed a four-lane bridge to handle this problem. Also, the Deep Soil Mixing equipment used to construct the cut-off wall in the truck tunnel occupied lots of real estate. Squeezing a batch plant and operating a monster 230 ton crane amidst the Capitol's working VIP parking area was problematic. Figures 3 and 4 try to show the deceptively large size of the DSM equipment used. Also, one-lane access down certain stretches of the tunnel meant that you not only had to coordinate deliveries for security, but also with other contractors who may have the access blocked for their work on that particular day. However, the biggest challenge was all of the active utilities and existing structures to work over, under, or around. Many utilities and obstructions were known ahead of time - many were not. Whenever a utility that crossed the path of the new tunnel could not be quickly supported or relocated during construction, work was stopped in that particular area. This created a fair amount of non-productive and out-of-sequence work.

Figure 3- Deep Soil Mix (DSM) View with Capitol

3) Coordination: There were many different entities involved in the design, management, and oversight of this job. There was a definite chain of communication for all geo-support subcontractors to follow, but when issues arose needing coordination beyond the general contractor, it could often take some time to get resolved. "It's literally going to take an Act of Congress" was an overused joke in the early stages of the project.

4) Rain and Snow: Washington DC averages about 40 inches of precipitation per year. Unfortunately, from October 2002 through October 2003, Washington DC received over 62 inches, or 55% above average, of precipitation making it the wettest year on record. Heavy rain days caused obvious down days for shoring and excavation. However, the unusual amount of persistent rain meant that even on days without rain, the muddy conditions played havoc with maintaining the tight schedule.

Figure 4 - Closer view of DSM Augers at Work

TRUCK TUNNEL TECHNIQUES AND CHALLENGES

As mentioned above, the Vehicle Truck Tunnel was built to allow deliveries from an above ground entrance a few blocks north of the Capitol. This truck tunnel is about 1900 feet long, 34 feet wide, and up to 50 feet deep. Most of this tunnel was traditional soldier beams and lagging supported by tiebacks and braces. A significant portion of this new tunnel had to be designed and installed below an old existing tunnel (Russell Tunnel) and will be discussed in more detail below. The shoring subcontractor also designed and built a temporary four-lane bridge across Constitution Avenue to keep downtown traffic going during construction.

Deep Soil Mix (DSM) Portion: The DSM wall was constructed using the wet mixing method. The mixing tool consisted of four counter-rotating shafts. The shafts are equipped with a pilot bit and a short section of auger flighting at the bottom end to enable penetration into the soil. The remainder of each shaft is equipped with inclined mixing paddles. Each shaft has a hollow core through which neat cement grout is pumped out the bottom. The grout acts as a flushing medium during drilling by moving the soil cuttings away from the auger flights. The grout is then thoroughly combined with the soil cuttings as it passes by the mixing paddles. The mixing shafts create 36" diameter soil mix columns spaced on 27" centers.

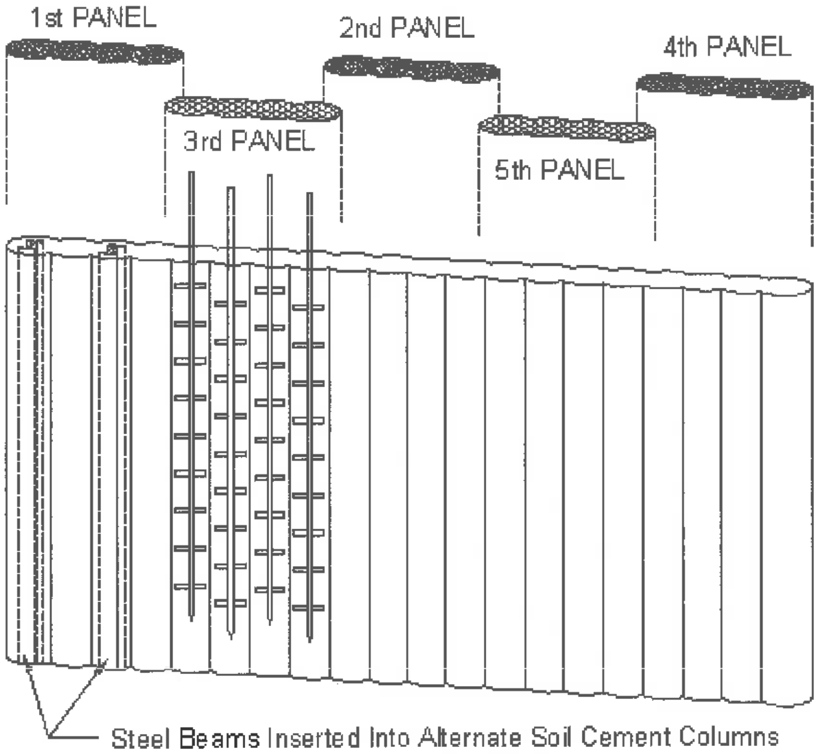

Figure 5 - DSM Panel Construction Sequencing

The DSM wall was constructed in panels as illustrated by Figure 5 above. Primary panels 1 and 2 were mixed first. Secondary panel 3 was mixed between the two primary panels. Primary panel 4 was mixed next, followed by secondary panel 5, etc. In this manner the mixing process achieved excellent continuity between panels. Soldier beams were installed in the fluid soil mix just behind the mixing operation while the mix was still fluid and in a coordinated location not to interfere with overlapping panels. The soldier beams were W24x84 Gr.50 beams installed at 4.5 ft spacings.

Steel pipe braces provided lateral support to the DSM wall as excavation progressed. Figure 6 below shows the two tiers of braces that were installed. The top tier braces were 18 in diameter spiral welded pipe with ½" wall thickness. The lower tier braces were 16 in diameter spiral welded pipe with 0.316" wall thickness. The braces had an average length of 30 ft and were not preloaded. The DSM wall transferred load to the braces through a continuous wale connected to each soldier beam.

The DSM system worked quite well except for one unexpected problem — spalling due to freeze/thaw cycles. The original DSM construction was scheduled to be accomplished within a four month period from March to June. However, when unexpected delays occurred, the DSM portion was partially excavated in April and remained exposed for over a year through May of the following year. The DSM material had to endure a number of freeze/thaw cycles over the course of the fall, winter, and spring of 2002/2003. When spring approached and tunnel construction was still ongoing, there were localized spots with large amounts of spalls and flakes averaging four inches in size. Since the DSM was wall-line construction, a variety of repair procedures were accomplished to allow the smooth, wall-line water-proofing system to work correctly. Most repairs were done with reinforcements spiked in the spalls to tie the fresh shotcreted voids to the existing DSM walls.

Figure 6 - Truck Tunnel Bracing at DSM

Russell Tunnel: The largest underground obstacle for the new Truck Tunnel was a 22 foot wide structure called the Russell Tunnel. This old tunnel connects the Capitol to a Senate building and hit the new truck tunnel at an awkward skew that affected over 100 feet of the new tunnel within the DSM portion. There were three main challenges working around the existing Russell Tunnel. The first challenge was to analyze the construction method and install an internal shoring system to support the weight of the heavy DSM installation equipment. This equipment weighed in excess of 500,000 pounds and would be operated on top of this tunnel prior to excavation. The second challenge was to design an adequate support structure so excavation could proceed below the tunnel. An investigation of the existing tunnel floor revealed a thin unreinforced slab that had extra leveling slabs poured on top of it over the years when it was converted from a slanted train tunnel to flat office space. To overcome this problem, a system of closely spaced beams below the overloaded "eggshell" floor were supported directly on piles or hung from structures that were installed above (See Figure 7). In order not to undermine too much of the floor at one time before the supporting beams could be installed, very careful hand excavation was required. The spoils were removed beyond the tight spaces below the tunnel via conveyor belts. Once this tunnel was successfully supported, the third challenge was to shore below it without overhead access to install piles. Due to these space and access constraints, a combination of reinforced horizontal concrete beams with tiebacks, shotcrete, and soil nails was designed and installed. This system shown below worked quite well.

Figure 7 - Russell Tunnel Support System

PART 3: INSTRUMENTATION AND PERFORMANCE OF THE DSM WALL

Instrumentation: An instrumentation program was undertaken to measure the performance of the DSM wall during excavation and construction. The instrumentation consisted of inclinometers both inside and behind the wall, as well as vibrating wire strain gauges installed on the lateral braces.

The first inclinometer casing was installed through the center of the DSM wall about four weeks after mixing was completed. The drilling through the soil mix was performed using an HQ wire-line diamond core barrel with water flushing. The core barrel recovered generally high quality soil cement cores. The coring method also achieved a very straight vertical alignment. The initial inclinometer reading indicated that the hole drifted less than 2 inches from vertical over the length of the core hole. After coring was completed, the hole was over-reamed and advanced another 30 ft below the soil mix using mud rotary drilling methods to enable placement of the inclinometer casing.

The second inclinometer casing was installed 6 ft behind the face of the DSM wall. This hole was drilled to a depth of 90 ft using mud rotary drilling methods. Standard penetration tests and split spoon sampling were conducted on 5 ft intervals.

The inclinometer casings were read using a 24" long wheeled inclinometer probe attached to a digital datalogger. The data was downloaded to a PC for analysis and graphing.

Vibrating wire strain gauges with integral thermistors were attached to five pipe braces near the location of the inclinometers. Two of these braces were on the top tier and three braces were on the lower tier. The vibrating wire strain gauges were mounted to the braces using weld-on brackets. Three gauges were spaced evenly around the perimeter of each brace. The gauges were mounted to the braces soon after brace installation and before excavation continued below each brace elevation.

Performance: The braced DSM wall behaved as a stiff wall system and limited the movement at the top of the wall to about 0.0008H. Temperature changes had a significant influence on the loads in the steel braces and the movement of the wall.

The movement of the DSM wall at various stages of excavation is illustrated in Figs. 8a-8d. The inclinometer casing embedded in the soil mix was used to plot movement. The two inclinometer casings were in close agreement with each other. The locations of the lateral braces are also shown, as well as the temperature of the braces and the total brace loads measured by the strain gauges. The total brace loads include earth, water, and surcharge pressures, as well as any temperature induced loads due to thermal expansion or contraction of the steel brace. It was not possible to separate the temperature induced loads from the total loads because an inadequate number of readings were taken. This prevented the development of an accurate temperature adjustment. Nevertheless, it is possible to make qualitative observations of the behavior of the wall and braces based on total brace loads and measured brace temperatures.

The initial 11 ft of excavation resulted in less than 0.1 in of cantilever movement at the top of the wall prior to installation of the top tier of braces. The movement at the top of the wall increased as excavation proceeded, as expected. The maximum movement measured by the inclinometer at the top of the wall was about 0.4 in. This occurred on Day 218 when the excavation was 30 ft deep and the outside temperature was 52 degrees lower than when the top braces were installed. It is believed that thermal contraction of the steel braces contributed to the movement of the wall. On Day 334 the inclinometer showed the wall being pushed back about 0.3 in by the top braces after the brace temperature rose 52 degrees. This occurred despite the excavation being deepened to 50 ft. It is believed that thermal expansion contributed to the reverse movement of the wall away from the excavation.

Movements extended below the toe of the wall. Most of these movements occurred between Days 198 and 334 as the excavation was extended to 50 feet. The large span between the lower brace and subgrade (23 feet) and the installation of a deep sewer in the center of the tunnel contributed to these movements.

Table 2 compares the total loads measured in the braces with predicted brace loads. Predictions are made for two different lateral pressure diagrams. The first pressure diagram is a 25H trapezoidal earth pressure diagram with no water pressures included. Predicted brace loads from this diagram were made for each day shown in Figs. 8a-8d. The second pressure diagram consists of a 28H rectangular diagram above the assumed water table elevation. Below the water table the pressure diagram consists of a 14H rectangular diagram plus a triangular water pressure diagram. Predicted brace loads from this diagram were made for Day 334 only. Table 2 also presents the measured brace temperatures.

The measured total loads in the top braces on Days 126 and 218 are lower than expected. The brace temperatures on these days were 34F and 52F lower, respectively, than when the braces were installed. Although we are unable to accurately estimate the temperature induced loads, it is believed that thermal contraction of the steel contributed to the low total load.

Similarly, the measured total loads in the lower braces on Day 334 are higher than expected. The brace temperature on this day was 42F higher than when it was installed. In this case, thermal expansion of the steel brace likely contributed to the higher total load.

The measured total loads in the top braces on Day 334 are less than the predicted brace loads from the 25H pressure diagram. The total loads measured on this day do not require an adjustment for temperature, since the temperature was nearly identical to when the braces were installed. The total measured load was 12.5 kips/LF and the predicted load was 15.4 kips/LF. This translates to a factor of safety of 1.23 for the 25H trapezoidal earth pressure diagram.

Day	B1 (2 Braces)			
	Brace Temp. °F	Average Measured (klf)	Predicted	
			25H (klf)	CVC Design (klf)
49	97.7	0	0	0
126	63.5	1.24	8.13	--
218	46.2	2.96	13.11	--
334	98.4	12.50	15.38	28.54
Day	B2 (3 Braces)			
	Brace Temp. °F	Average Measured (klf)	Predicted	
			25H (klf)	CVC Design (klf)
49	--	--	--	--
126	--	--	--	--
218	42.1	--	--	--
334	84.4	32.86	25.59	31.08

Table 2 Brace Loads

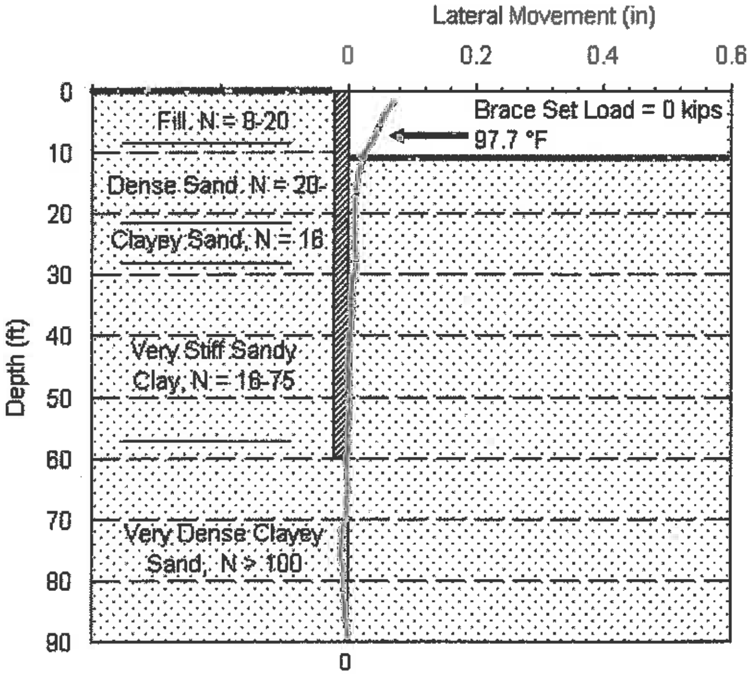

Fig. 8a - Lateral Movement - Day 49

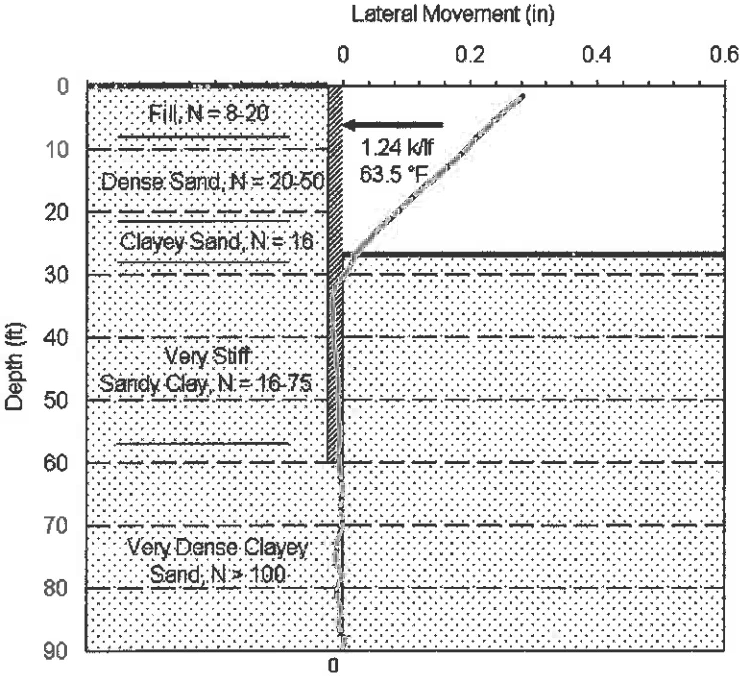

Fig. 8b - Lateral Movement and Brace Load - Day 126

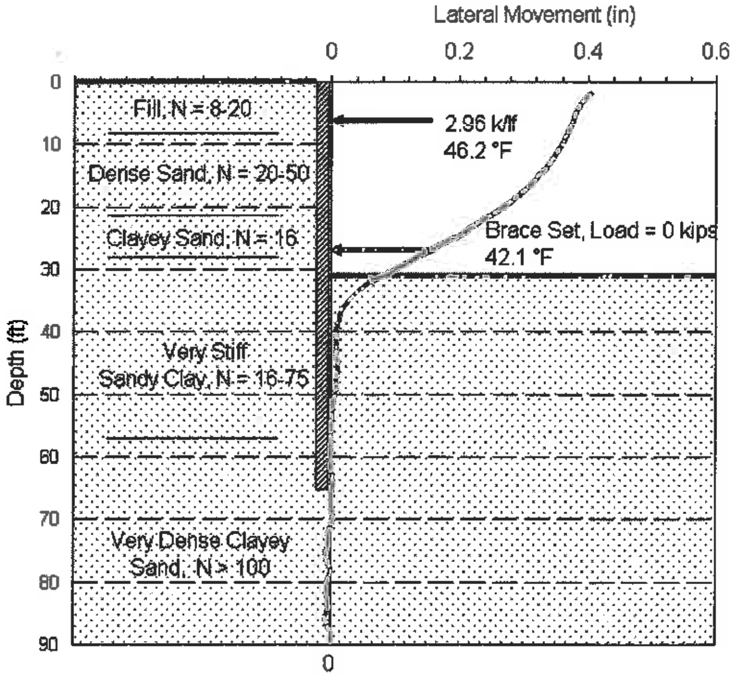

Fig. 8c - Lateral Movement and Brace Load - Day 218

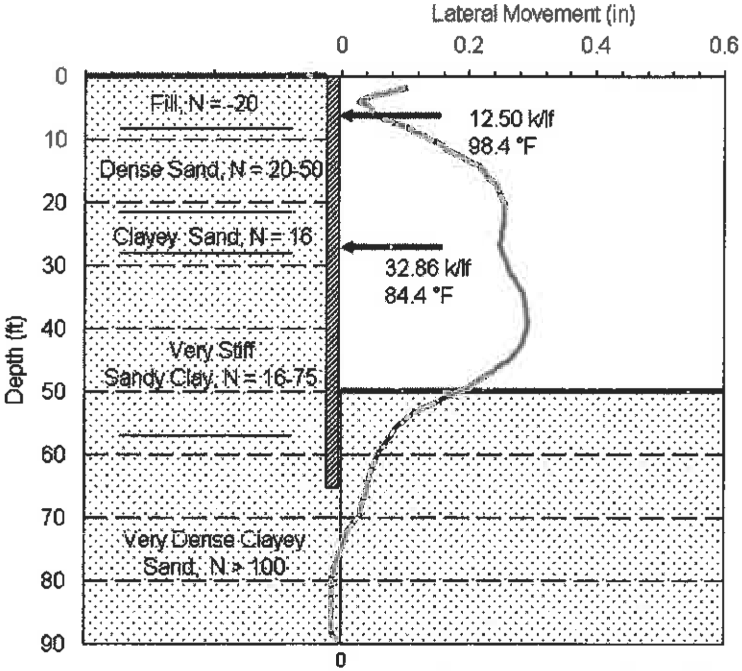

Fig. 8d - Lateral Movement and Brace Loads - Day 334

CONCLUSION

A variety of excavation support systems was used to provide support for several different areas at the Capitol Visitor Center - the Truck Tunnel, the LOC Tunnel, the East Auditorium, the Cannon Tunnel, the North Retaining Wall, and the interior of the existing Capitol Building. The excavation support consisted of a combination of drilled in soldier beams, wood lagging, tiebacks, braces, underpinning, support of the existing Russell Tunnel, soil nailing, shotcrete, and a deep soil mixed wall. Although some aspects of the construction were very challenging, the performance of the different excavation support systems was very good. Instrumentation of a piece of the DSM wall showed that it acted as a very stiff wall system with top of wall movements limited to .08%H. The measured total upper brace loads correlated very well with those predicted by a 25H trapezoidal earth pressure diagram.

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