UNITED STATES CAPITOL VISITOR CENTER - DRILLED SHAFTS, UTILITY CONFLICTS, AND COMMUNICATION

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The United States Capitol Visitor Center (USCVC) is one of the largest underground structures ever constructed in the Washington, DC, metropolitan area. The 600,000 ft^2 (55,750 m^2) structure is entirely underground and immediately adjacent to the shallow foundations of the existing U.S. Capitol building. Interior building columns for the USCVC were supported on 186 drilled shafts that varied in diameter from 4 to 9 ft (1.2 to 2.9 m) and in length from 15 to 45 ft (4.6 to 13.7 m). The vast majority of the building utilities were located beneath the basement floor slab. It was decided at the onset of the project to proceed with construction prior to completion of the design drawings, and coordination between the underslab utilities and the drilled shafts had not yet been finalized at the onset of drilled shaft installation. Given depth and location restrictions of the outlets, relocation of the bulk of the utilities was not possible. Almost half of the drilled shafts were affected, leaving redesign as the most feasible remedial solution.

The redesign involved adjustments to the shaft length, diameter, and bell. It took place on a case-by-case basis, sometimes only minutes before installation began. Coordination between the field and design team was excellent, and delay associated with the redesign efforts was minimal. In addition, the detailed, high-quality field records kept by both the contractor and field engineers allowed for accurate and fair estimations of the added drilled footage and concrete volumes placed. The additional service fee, which was minimal, was settled quick and fair.

INTRODUCTION

The U.S. Capitol, along with its stately dome, is one of the most visible structures in the modern world. Although the building has evolved with the changing and growing needs of Congress, it has failed to keep pace with the ever-increasing number of visitors. Therefore, under Congressional direction, a visitor center separate from the existing Capitol building was proposed. This structure is referred to as the United States Capitol Visitor Center (USCVC), and when completed, will include space for exhibits, visitor comfort, food service, two orientation theaters, an auditorium, gift shops, House and Senate offices, storage, security, a service tunnel for truck loading and deliveries, and mechanical facilities.

The USCVC is one of the largest underground structures ever constructed in the Washington, DC, metropolitan area. The building footprint is about 230,000 ft^2 (21,368 m^2), making it about 65% larger than the existing Capitol building. The usable space of the building is about 600,000 ft^2 (55,742 m^2), compared to about 420,000 ft^2 (39,020 m^2) for the existing building.

The USCVC structure is located on the eastern side of the existing U.S. Capitol building, immediately adjacent to its foundations (Figure 1). The main excavation support and water cut-off mechanism is a slurry (diaphragm) wall (Figure 1). Tiebacks were installed to support the wall during the temporary construction stages. Interior building columns were supported on drilled shafts.

Figure 1 – Site Location (courtesy of AOC)

Contract documents originally called for a "top down" construction sequence. This sequence involved installing the drilled shafts for the interior columns, along with a diaphragm wall, at the onset of construction. The drilled shafts and slurry walls were to be constructed using the slurry method. Steel columns would be lowered through the slurry and embedded into the drilled shafts. Excavation would then lower the grade a few feet for installation of the plaza (roof). Excavation would proceed under the plaza and around the steel columns in the northwest quadrant of the building, with installation of tiebacks and bracing as the excavation advanced downward. A fixed wall support, emergency access, and cover of the construction activities would then be in place along the entire eastern front of the existing building.

A modified "bottom up" construction sequence was proposed by the general contractor shortly after the contract was awarded in June 2002. A detailed submittal and review process followed, and a revised construction sequence was accepted by the owner in July 2002, with the condition that the construction start date not be pushed back.

A schematic chronology of the revised construction sequence is shown in Figure 2. First, the slurry walls were installed across the entire site. Excavation then took place within the building interior, and tiebacks were installed as the soil was removed. Guidelines regarding the depth and lateral extent of the excavation had been developed by the general contractor prior to the onset of soil removal. The drilled shafts were installed in the dry once the excavation had reached the service level, and the steel columns were then attached to the top of the drilled shafts via steel embeds. The plaza deck was installed in the northwest and southwest quadrants. All tiebacks and interior bracing were removed once the interior slabs were installed.

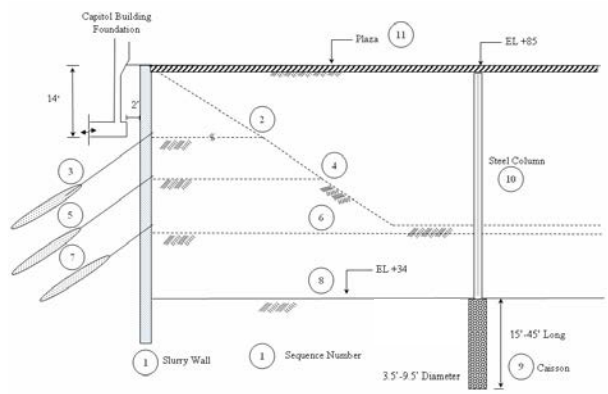

Figure 2 – Actual Construction Sequence

In order to optimize building space, the vast majority of the utilities were located beneath the basement floor slab (Figure 3). It was decided at the onset of the project to proceed with construction prior to completion of the design drawings. Coordination between the underslab utilities and drilled shafts had not yet been finalized at the beginning of the drilled shaft installation. Given the depth and location restrictions of the outlets, relocation of the bulk of the utilities was not possible. A majority of the drilled shafts were affected, leaving redesign as the most feasible remedial solution.

Figure 3 – Below-Slab Utility Trench

The contractor had mobilized the installation equipment and personnel to the site, and delay charges and their effects on the schedule were of concern to all parties. Redesign consisting of adjustments to the drilled shaft length, diameter, and bell took place on a case-by-case basis, sometimes only minutes before installation began.

Given the magnitude of the project, the owner mandated that senior members of the design team be present on site throughout construction. Their presence proved to be particularly valuable with regard to the topic of this paper; without question, it significantly aided the long-term project cost and schedule.

The remainder of this paper focuses on the effects of the utility coordination on the drilled shafts. It also discusses the design efforts, coordination among all the parties involved, and general schedule and cost impacts.

SITE CONDITIONS

The U.S. Capitol sits at the apex of Capitol Hill, which rises about 88 feet (26.8 m) above the nearby Potomac River. Up to 10 feet (3.1 m) of a fill deposit consisting of a variety of soil types and construction materials was encountered below the ground surface in isolated areas across the site. The variety of these soil types is indicative of the various construction and backfilling activities that have taken place in the vicinity of the existing building in the past. The geotechnical investigation revealed a water table elevation of about 30 feet (9.1 m) below the ground surface.

Terrace Formation soils were located either at the ground surface or below the fill soils. This unit was about 15 to 20 feet (4.6 to 6.1 m) thick and predominantly granular in nature. It contained some interbedding of fine-grained particles, indicative of a fluvial depositional environment. A dense gravel, cobble, and boulder layer was present at the base of this formation.

The Potomac Formation was encountered stratigraphically below the Terrace Formation. The upper portion of the Potomac Formation consisted of a 20 to 24 foot (6.1 to 7.3 m) thick layer of very dense sand and clayey sand (P2), and the middle portion consisted of very stiff lean clay to fat clay soils (P3). A dense well-graded to clayey sand was encountered in the lower portion of this unit (P4). A lower water table, combined with a significant pressure head, was also encountered in this unit.

In general, the majority of the drilled shafts were contained within the upper or middle portions of the Potomac Formation. In a few cases, especially in the northeast corner of the site, the bases extended into the lower Potomac sands. Water control and basal stability were especially challenging in these areas.

About 400,000 yds^3 (305,800 m^3) of soil, which corresponds to about 50,000 truckloads, were excavated for the building. Average haul volumes were about 125 trucks per day, at about three trips to the site per truck. Without exception, all construction vehicles, including excavation vehicles, were subject to off-site security screening prior to entering the site.

DRILLED SHAFT INSTALLATION

Drilled shaft installation began in August 2003 and finished in November 2003. A total of 186 drilled shafts were installed at the interior column locations within the building footprint.

All drilled shafts were installed after the excavation had reached the service level (Figure 4). Drilled shafts ranged in diameter from 3.5 to 9.5 ft (1.1 to 2.9 m) and in length from 15 to 45 ft (4.6 to 13.7 m).

Figure 4 – Drilled Shaft Installation

Due to the revised construction sequence, all holes were drilled in the dry, with the vast majority of holes terminating in the very stiff P3 clay soils. The subgrade of each drilled shaft was manually inspected to confirm the presence of competent soils (Figure 5). The presence of the design engineer on site essentially eliminated any delays associated with the down-hole inspection.

Figure 5 – Drilled Shaft Installation and Inspection

The shaft reinforcement was lowered into the hole using plastic guide wheels clipped every 2 feet (610 mm) along the length of the cage (Figure 6). The steel reinforcement was set 6 inches (152 mm) above the bottom and below the top of the drilled shaft. A 1% area-of-steel-to-area-of-concrete ratio was maintained for the steel rebar reinforcement.

Temporary steel casing was inserted in all holes to provide a water cut-off and allow for down-hole cleaning and inspection. The temporary steel casing was pulled incrementally during the concrete placement to avoid soil and water contamination of the concrete. Any water that ponded on top of the concrete during the casing pulls was pumped off prior to the placement of additional concrete.

All concrete used for the project was obtained from an off-site source. Concrete delivery was sporadic, leaving the quality assurance/quality control of the contractor and engineer critical during operations. Site congestion and construction logistics were also issues, and coordination among all the parties on site was essential to the quality of the concrete placed and to production rates.

The concrete was placed using a free-fall method for all drilled shafts less than 30 ft (9.1 m) long, and a tremie was used for greater lengths. Concrete cylinders cast using concrete obtained through free-fall and tremie-placement techniques showed a negligible difference in strength. Care was taken during all concrete placement to ensure that the concrete did not hit the rebar cage during its free fall to the hole bottom.

Figure 6 – Drilled Shaft Reinforcement

Prefabricated templates of threaded steel bars were carefully inserted into the concrete once the concrete had reached the top of the drilled shaft (Figure 7). A cap was formed around these bars, and the steel columns were eventually set and bolted to the top of the cap.

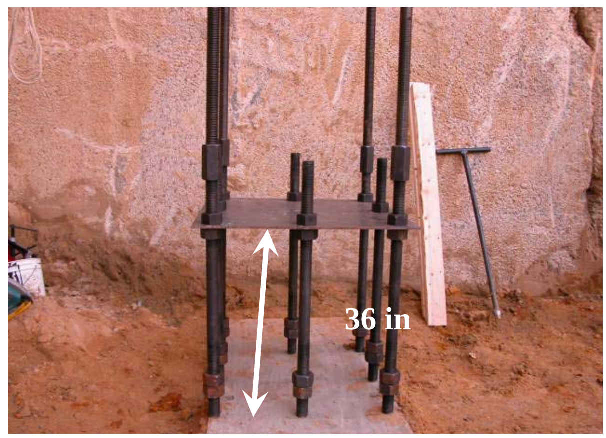

Figure 7 – Template of Embed Bars

Contract documents called for drilled shaft load tests in each of the four building quadrants. The tests were performed per ASTM D1143 to confirm the geotechnical design parameters defined in the baseline report. All four load tests were originally intended to be performed at production drilled shaft locations. As described below, however, the last load test was performed at a non-production shaft location because of utility conflicts.

All load tests were performed using an Osterberg load cell placed near the tip of the drilled shaft (Figure 8). Linear Vibrating Wire Displacement Transducers (LVDTs) and a minimum of three strain gauges were attached to the rebar cage to measure the displacement and the skin friction along the length of the shaft. Because three of the four load tests were performed on production drilled shafts, all drilled shafts were post-grouted to maintain shaft integrity.

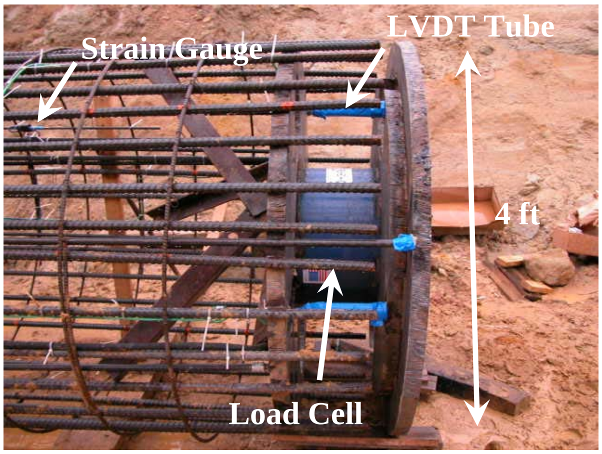

Figure 8 – Drilled Shaft Load Test

DRILLED SHAFT/UTILITY CONFLICTS

As noted above, it was decided at the onset of the project to proceed with construction prior to completion of the design drawings. Consequently, coordination of the drilled shafts with the depth and location of the underslab utilities had not yet been finalized at the start of the drilled shaft installation.

Project guidelines defined the lateral zone of influence of the drilled shaft as two pile diameters from the drilled shaft edge. Under these guidelines, a total of 78 drilled shafts, or 42% of the total, were affected. The majority of the cases were in the northwest quadrant, where the utility depths were greatest (Figure 9).

The depth of the utilities, particularly the sewer line, dropped across the site to meet the gravity drainage requirements of the line. The drilled shafts in the northwest quadrant were particularly affected, resulting in exposures of 33% to 75% of the shaft length (Figure 10).

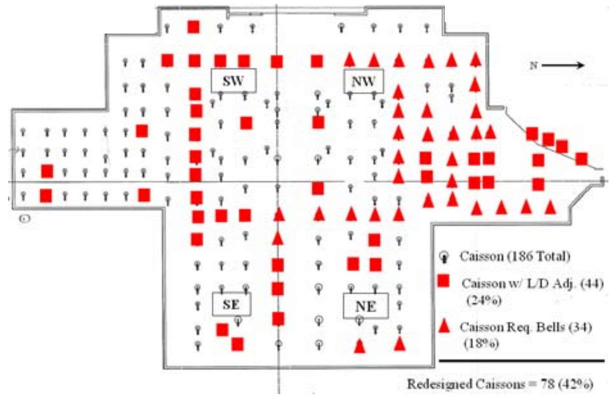

Figure 9 – Summary of Impacted Drilled Shafts

The depth and location restrictions of the wet utility inverts made efforts to move the bulk of the utilities fruitless. Redesign of the majority of the drilled shafts, therefore, was the only feasible option.

The construction schedule dictated that the drilled shaft installation begin at the southern end of the site. Fortunately, utility depths in this area were shallow. Redesign of the drilled shafts involved adjustments to the length or diameter, based on the soil parameters defined in the baseline geotechnical report. The depth of the utility cuts was deeper to the north, however. Conventional redesign efforts using the soil parameters from the geotechnical baseline report resulted in modified depths and diameters that were incompatible with the local geology and the equipment on the site.

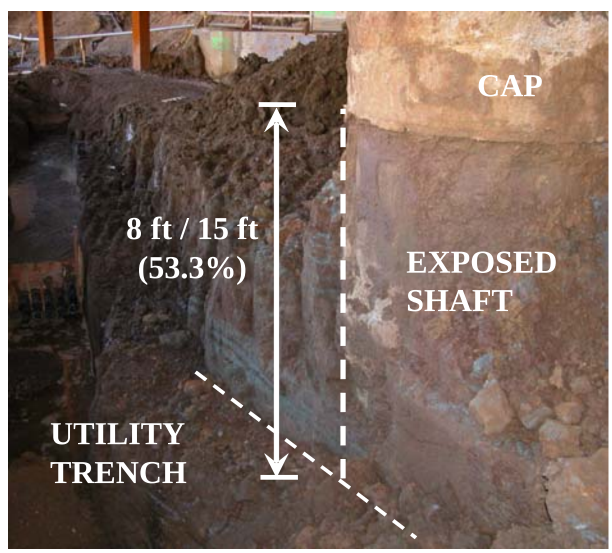

Figure 10 – Exposed Drilled Shaft in Northwest Corner of Site

The soil strength parameters defined in the geotechnical report were confirmed through the initial three load tests. The design team considered increasing the strength parameters based on the load tests. As noted above, however, all of these tests were performed at a production drilled shaft location and taken to loads only high enough to confirm the design values. A sacrificial drilled shaft was therefore installed for the fourth load test. The loads used in this test were adjusted in an attempt to fail the drilled shaft and allow for adjustment of the strength parameters.

The sacrificial load test revealed a higher end bearing value than that originally recommended for design. The design end bearing value was therefore adjusted, resulting in a reduction in the number of overall drilled shafts affected by the utility cuts. Length and depth adjustments were made to the drilled shafts in areas where the depth of the utility cuts was too deep (Figure 9).

In several areas of the site, particularly in the northwest quadrant, the cuts for the utilities resulted in exposures of 33% to 75% of the shaft length. Length and diameter modifications of the drilled shafts, combined with the increased strength parameters, were inadequate to accommodate the design requirements. Bells were therefore added to the base of the drilled shafts to meet the design needs (Figure 11). Bells, with diameters ranging from 7 to 10 feet (2.1 to 3.1 m), were added on a case-by-case basis at the direction of the design engineer. A total of 34 drilled shafts, or 18% of the total, were modified to include bells (Figure 9).

Figure 11– Drilled Shaft Belling Tool

PROJECT IMPACTS

Time and the corresponding project schedule were of concern to all involved, and financial impacts of the additional coordination efforts were of concern to the owner. Fortunately, coordination among the owner, construction manager, general contractor, contractor, structural engineer, and other field and design team members was excellent. Field adjustments of the drilled shafts were made on a case-by-case basis, and high-quality field records were kept by both the contractor and engineer. Additional lengths, diameters, and bells were tracked for each drilled shaft, and subsequent additional installation times and concrete volumes were easily computed. The additional service fee, which was settled shortly after the completion of the drilled shaft work, did not include delay related charges. Cost for the additional work was about 15% of the drilled shaft contract amount, which was one third that of the original drilled shaft contract proposed using top down construction. All things considered, the fee for the additional services was nominal relative to the potential overall impact had construction delays been included in the fee.

SUMMARY AND CONCLUSIONS

1- The movement of any project into construction prior to completion of design drawings may lead to unexpected challenges. The impact of subsequent coordination problems can be potentially significant to a project schedule and budget and may offset the benefit of early construction starts.

2- Coordination of utilities with the structure foundations is especially important for wet utilities where the grade/slope of the utility is critical.

3- The use of production drilled shafts for load tests did not allow for adjustment of the strength parameters due to the limited load applied to the drilled shafts. It is the experience of the authors that the information obtained from load tests performed on sacrificial shafts more accurately reflects the true strength parameters of the soil.

4- The free-fall technique used for concrete placement did not appear to adversely affect concrete quality, provided that the concrete did not hit the rebar cage during placement.

5- Down-hole inspection of the drilled shafts can serve as a useful quality assurance tool during drilled shaft installation, especially in belling operations where the bell diameter can vary and soil can pack at the bottom of the drilled shaft. Unqualified and inexperienced inspectors, however, can negatively affect project costs and schedule.

6- A tight network of representatives of the subcontractor, contractor, construction manager, design team, and owner was established early in the project. This group was in constant communication during construction, essentially eliminating the bureaucracy and delays often associated with traditional transfer-of-information processes. This would not have been possible, however, if trust among the parties and a sound working relationship had not been established during the early construction phases.

7- The owner's requirement that senior design team members with authority to perform design modifications be on site during construction significantly aided the overall project cost and schedule.

8- The detailed field records and the working relationship between the contractor and field engineers allowed for accurate and fair estimations of the added footage drilled and concrete volumes placed. The fee for additional services, which was settled quickly, was nominal due to the elimination of delay-related charges.

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