Drilled Displacement Piles in Cohasset MN

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ABSTRACT: Drilled Displacement (DD) piles have become common in North America since the 1990s. Although primarily used for structural piles in coarse-grained materials, they have also proven to be an economical solution in some fine-grained soils, primarily elastic silts

The Clay Boswell Power Plant in Cohasset MN has had numerous additions in the past decade primarily related to installing new equipment to meet environmental requirements. These recent additions have been installed on DD piles, primarily designed by the author in conjunction with the overall facility designer, Burns & McDonnell. This paper will present an overview of the design and performance testing of DD piles at this facility with piles bearing in both sands and stiff silts. Installation challenges during the different construction phases will also be addressed including installing piles over water for a utility bridge and installing displacement piles through dense sand fill into the underlying natural soils.

1. INTRODUCTION/PROJECT DESCRIPTION

The Clay Boswell Power Plant has undergone significant expansion and environmental remediation in the past decade. Expansions have consisted of the addition of several new facilities across the project site. A schematic of the first expansion from 2006 is shown on Figure 1. The site is located just east of a tributary of the Mississippi River and was slated to span a small finger of this tributary in at least one new location. The project team was tasked with proposing an appropriate foundation solution for the new structures, proving the applicability and suitability of the system along with production foundation installation. Piles were to support compression design loads of 60 tons to 70 tons in most areas and up to 80 tons in the Southside SCR area.

2. SUBSURFACE INFORMATION

Borings completed for a 2006 site characterization are shown on Figure 1. Subsurface materials consisted primarily of variable amounts of granular fill overlying predominantly low plasticity alluvial silts. Often, high plasticity clay was encountered immediately below the fill above the silts. In some cases, alluvial silty sands were encountered within the silt profile. Cleaner alluvial sands were typically encountered below the silts, in some cases within the expected pile installation depths (NeSmith and Burton, 2008). Figure 2 includes composite plots of SPT results in the Southside SCR Area and the borings in the remaining areas across the site. General soil profiles are included on the plots.

Figure 1 – Proposed Facilities and Boring Location

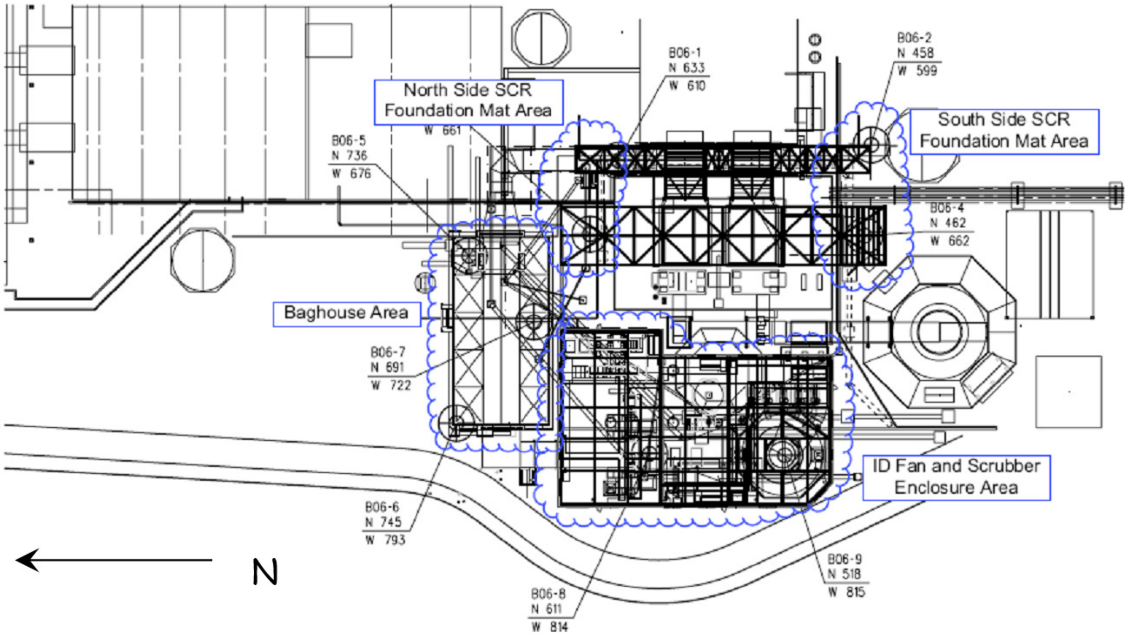
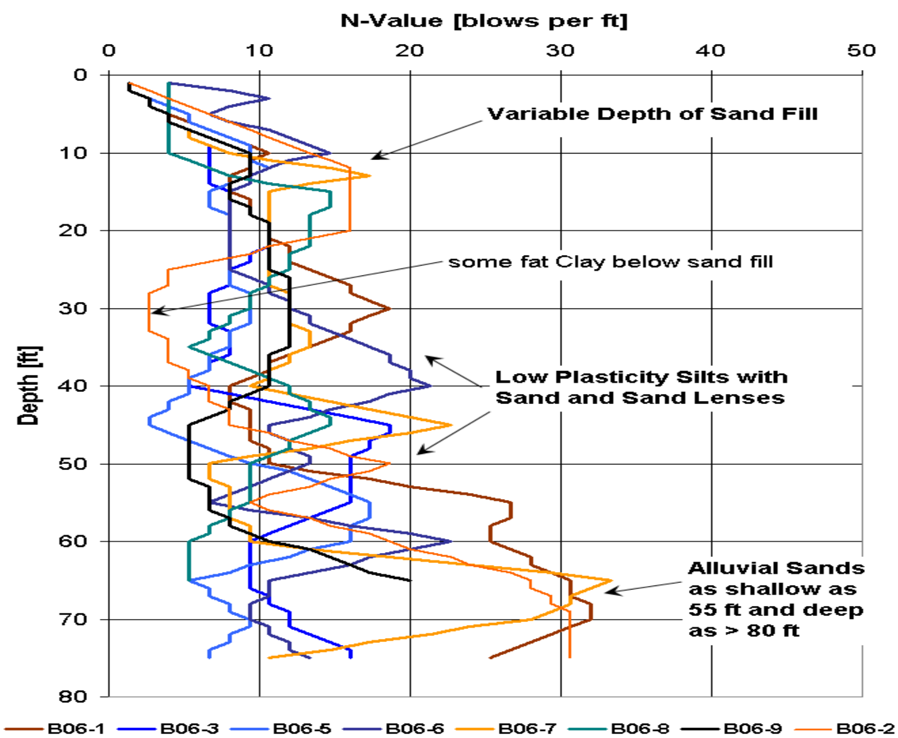


Figure 2 – Composite SPT Results and Generalized Soil Profile
(Note: automatic hammer efficiency ~ 80% efficiency)



3. DRILLED DISPLACEMENT PILES

"Drilled Displacement pile" is a general industry term encompassing a variety of proprietary drilled and cast-in-place pile systems. The piles employed here were Auger Pressure Grouted Displacement (APGD) piles. APGD piles are constructed by drilling a displacement auger into the ground utilizing a track-mounted, fixed-mast, hydraulic drilling machine.

Once the required penetration is achieved, fluid grout is pressure injected through a grout pipe located centrally within the drill stem and out a port located at the tip of the displacement auger as the displacement auger is slowly retracted. Once the displacement auger is fully retracted, reinforcing steel is inserted into the fluid grout column prior to initial set (NeSmith, 2015). Schematics of the APGD tool and installation platform are shown in Figure 3 and Figure 4 respectively.

Figure 3 – Displacement Tool

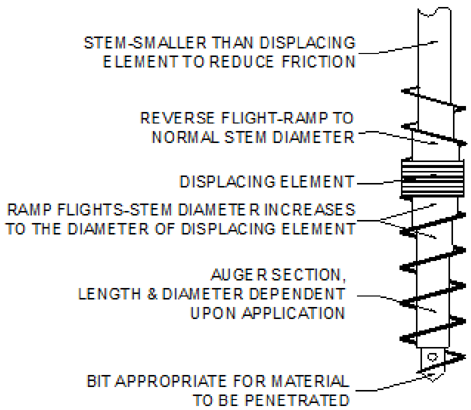
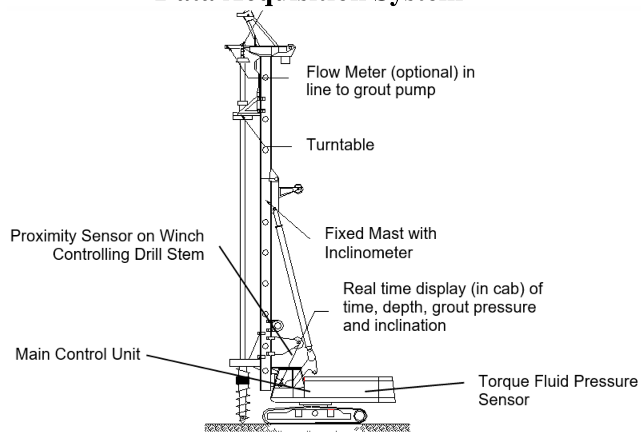


Figure 4 – Schematic of Drilling Platform and Data Acquisition System



4. APPLICATION OF APGD PILES TO THE PROJECT SITE

APGD pile capacity was evaluated according to the methodology detailed in NeSmith, 2002. Shaft and toe resistances were estimated from the SPT results from the 2006 borings, with modifiers appropriate for the characteristics of the expected materials.

Evaluation of the in situ data available based on the method described indicated that 16-in diameter APGD piles installed to between 55 ft and 75 ft below the installation surface would yield allowable compressive capacities as required for the project (60 tons to 80 tons). There was a good bit of variation in density of the alluvial silts and in elevation of the underlying sands. It was thus deemed appropriate to use an automated monitoring system to collect drilling parameters during the probe and test pile installation and to use this data to set final toe elevations.

5. DATA ACQUISITION

The drilling platform incorporated into the foundation construction for this project included a data acquisition system for real-time measurement, display and recording of drilling parameters including depth, torque (as estimated as a function of the hydraulic fluid pressure driving the rotation and downward force of the drill stem, referred to as the KDK pressure) and grout pressure. The schematic of the drilling platform in Figure 4 includes the basic layout of the sensors included on the platform. The system is described in detail in NeSmith and NeSmith (2006). In addition to collecting and displaying the data mentioned above, the system was programmed for the real-time estimation of rig energy expended during the advancement of the drill stem. All of this data is displayed in real time on both the drilling platform and a remote monitor for simultaneous viewing by the drilling platform operator and inspector.

6. INSTALLATION EFFORT

Based on the data collected as described herein, it is possible to estimate the total energy required to advance a drilled pile tool through a given subsurface profile and to correlate this energy to the pile's capacity (similar to using hammer energy for driven pile capacity, NeSmith and NeSmith, 2008).

In the aforementioned reference this estimation of energy has been termed Installation Effort (IE). The Incremental IE is calculated every second from the individual recordings of penetration rate of the drilling stem and hydraulic fluid pressure (KDK pressure) applied to the rotary head to rotate the drilling stem. Incremental IE is calculated for each record and plotted versus depth. Cumulative IE is an integration of the Incremental IE curve, also plotted versus depth.

7. PROBE AND TEST PILE DETAILS – 2006 EXPANSION

Initially, seven probes were drilled across the site. Probes were not drilled in the Southside SCR area (see Figure 1) due to access restrictions. The probes confirmed the variations in density in the alluvial silts that was expected from the available site characterization data.

Test pile T-1 (in the Southside SCR) was expected to terminate with the pile toe in sand and was installed to a Cumulative IE value expected to provide a working compressive load of 80 tons based on Berkel's database of IE vs. Capacity. Test piles T-2, T-3 and T-4 were installed to a variety of Installation Efforts to evaluate an IE vs. Capacity relationship for this site with regard to the 60 ton to 70 ton design compressive loads. The 16-in diameter test piles were installed to the IE and depths shown in Table 1.

Table 1 – Test Pile Details

Test Pile	Depth [ft]	Nearest Boring	Cumulative IE	Strain Gage Locations		
T-1	55	B6-02	421	4	25	53.5
T-2	55	B6-08	461	-	-	-
T-3	60	B6-06	510	4	30	58.5
T-4	70	B6-07	550	4	40	68.5

Installation details for test piles T-1 (pile toe in sand) and T-4 (pile toe in silt) are presented in Figures 5 and 6. All load tests were performed in general accordance with the ASTM D1143 - Quick Load Test Method.

Figure 5 – Test Pile 1 Installation Details

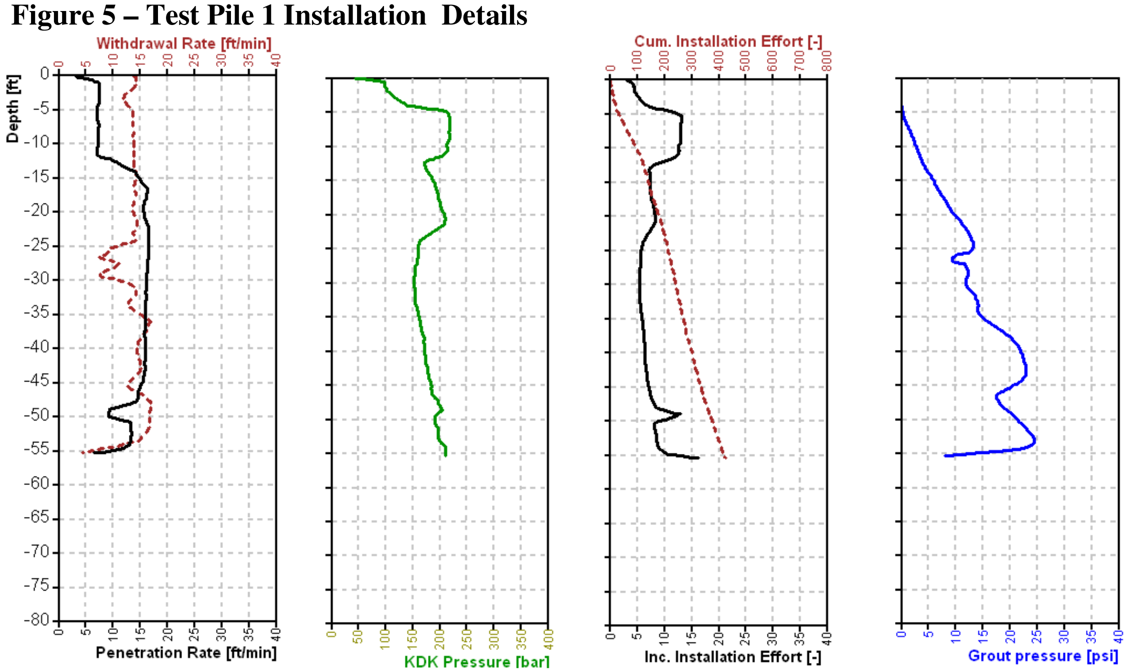
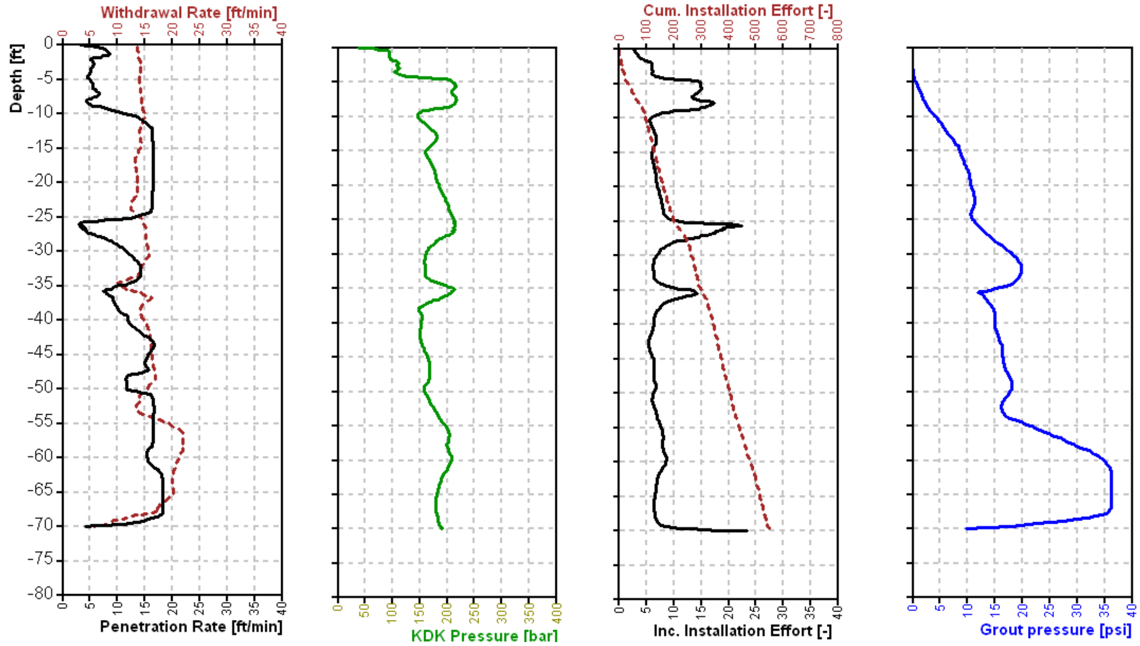


Figure 6 – Test Pile 4 Installation Details



8. LOAD TEST RESULTS AND ANALYSIS

Ultimate compressive load (capacity) of the test piles was taken as the lesser of the following two loads (NeSmith, 2002 and 2003):

- The load at which the slope of the hyperbolic model of the pile head load-displacement relationship becomes 0.02 inches/ton
- The load at which the pile head deflection is equal to 6% of the pile diameter

It is noted that the procedure described above typically yields an ultimate load estimate similar to that from the Butler-Hoy criterion, which has been recently recommended as the most appropriate method of those listed in the International Building Code as most appropriate for rotary drilled, cast-in-place piles (Studlein, et al, 2014).

Toe and shaft components of the test piles were determined from the available strain gage data. Ultimate loads were determined according to the above criteria and are presented in Table 2.

Table 2 – Ultimate Load Estimates

Test Pile	Total Ultimate Load [tons]	Ultimate Shaft Load [tons]	Ultimate Toe Load [tons]
T-1	227	196	31
T-2	175	167	8
T-3	224	208	16
T-4	204	196	8

9. PRODUCTION PILE INSTALLATION CRITERIA

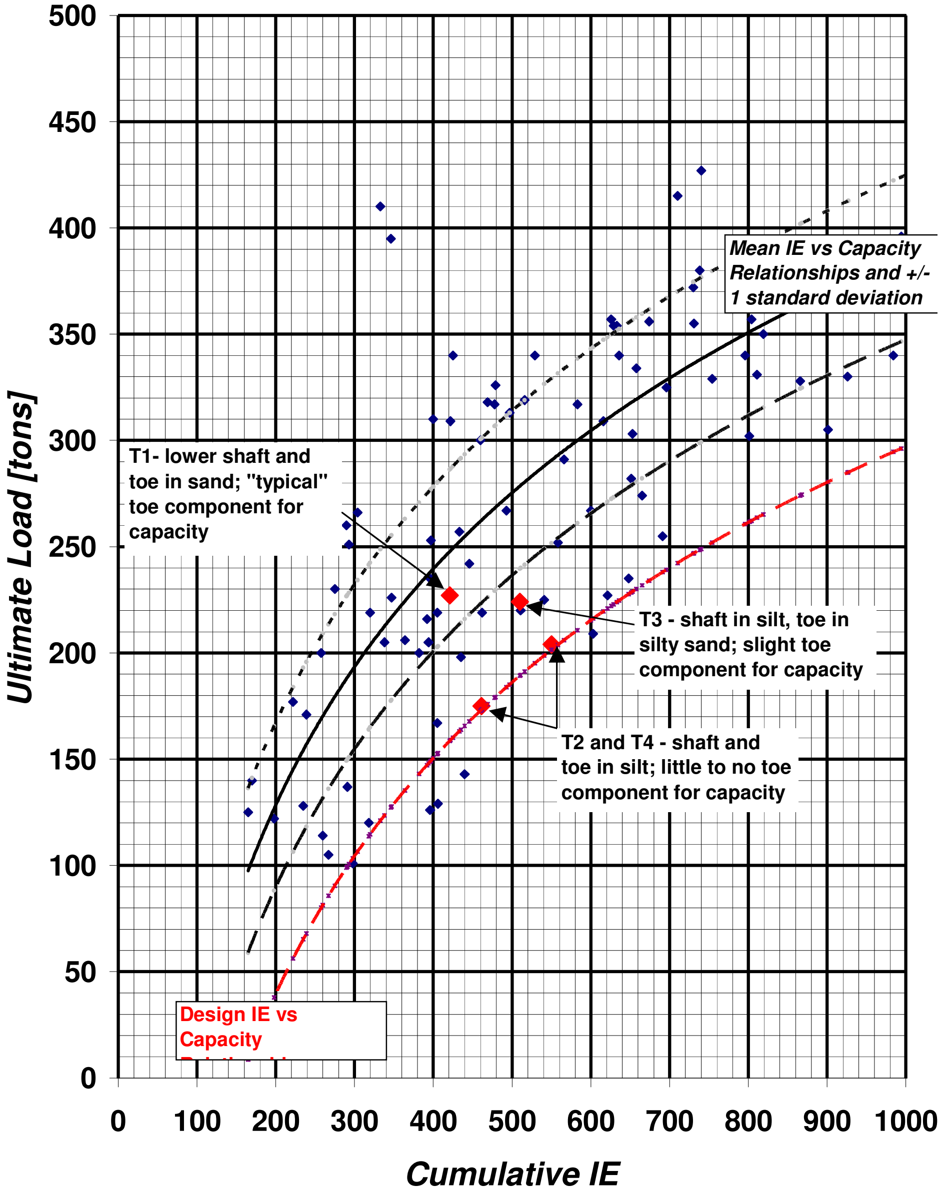
9.1 Minimum Pile Toe Level

The required compressive loads for piles ranged from 80 tons in the Southside SCR to 60 tons to 70 tons in the north and west project areas. However, both 55 ft test piles (T-1 and T-2) demonstrated capacities in excess of 2 times the required loads of 60 to 80 tons. As such, a ***minimum pile installation depth of 55 ft*** below the ground surface at the time of installation was deemed appropriate for the project (NeSmith and Burton, 2008).

9.2 Termination of Production Piles

The Cumulative IE (CIE) of the test piles installed at the subject site was presented in Table 1. Figure 7 is a plot of an internal database of measured CIE vs. estimated pile capacity, with the results from this project shown in red. The plot includes the mean relationship of the data and plus and minus 1 standard deviation of the mean. The relationship developed specifically for the two piles (T-2 and T-4) bearing in silt is also shown as the red dashed line.

Figure 7 – Database of Installation Effort vs Capacity

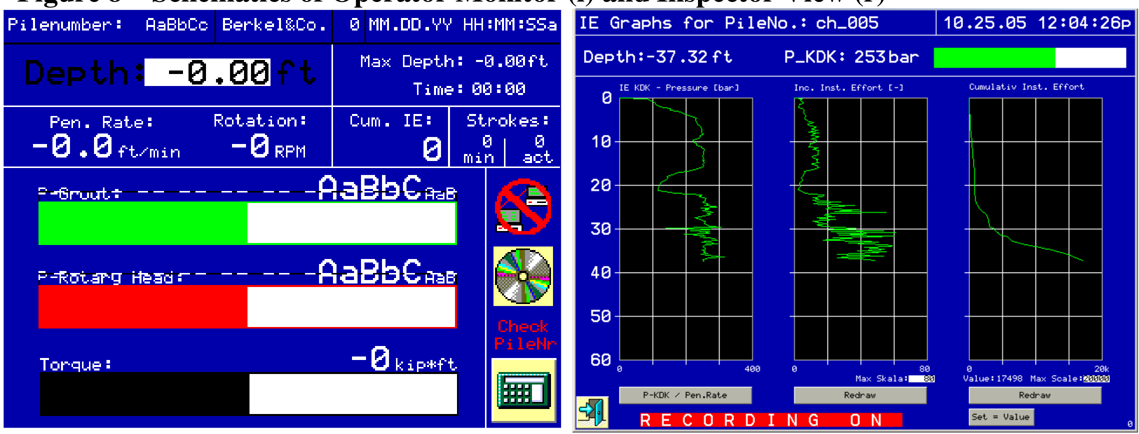


Referring to the database, the required working loads of 60 tons to 80 tons could be provided (with factors of safety in excess of 2) by installing piles to a measured CIE of about 420 if the piles were installed with the toe in the underlying sands. Piles installed with the toe in the silts could provide these loads with a CIE of about 460. ***For simplicity, a termination CIE of 460 was adopted for all piles across the site*** to account for the possibility of sand not being encountered, even in areas where it was anticipated. In areas where sand was encountered the CIE increased from 420 to 460 within a few feet of encountering the sand and thus did not add significant overall drilled footage (NeSmith and Burton, 2008).

9.3 Real Time Field Monitoring

Figures 8 includes schematics of the data acquired during pile installation as displayed on the both the operator's and inspector's monitors. The drilling operator can monitor the numerical value of CIE displayed in the upper right corner of the monitor of the platform, while the inspector views a plot of Incremental IE and CIE vs. Depth as the drilling tool is advanced. On this project, the minimum depth of 55-ft below drilling level AND the required minimum CIE were verified by the inspector viewing the remote monitor, before grouting of the pile commenced. The inspector also monitored grout pressure during pile casting from this remote monitor as described in NeSmith and NeSmith (2006).

Figure 8 – Schematics of Operator Monitor (l) and Inspector View (r)



10. LOSS OF SHAFT RESISTANCE IN OVERBURDEN

In the ID fan building area (near TP-3), the presence of electrical duct banks and pipe trenches resulted in pile cutoffs (bottom of mat) about 18-ft below grade. As piles were to be installed from the existing site grade, the question of how to evaluate the allowable load for production piles in this area considering the loss of the 18-ft of material to be excavated after pile installation was considered.

A review of the test pile and probes in the area indicated a CIE value of about 500 at 60 ft, a CIE value slightly greater than 600 at about 72.5 ft and a CIE value of 700 or greater at the maximum drilling depth of 77.5 ft below grade. The strain gauge data indicated a minor amount load transfer to the tip at a 180 ton load (three times the allowable load in this area).

It was determined to install these piles to the maximum available installation depth of 77.5 ft and to monitor and manually note the CIE values at the overburden depth of 18 ft and the final pile toe elevation. The CIE developed only between the top-of-pile (18-ft below grade) and pile-toe-level (77.5-ft below grade) was used to estimate ultimate load and to ensure that these piles met the 1200-ton ultimate load requirements for this structure.

11. PHASE 2 - UTILITY BRIDGE

A subsequent phase of work included installing piles across a shallow tributary of the neighboring stream, to support a utility bridge connecting to portions of the site. A boring from the middle of the tributary is included as Figure 9 and shows the upper soil bed to consist of very soft alluvial and swamp deposits of soft alluvial and lacustrine deposits with a potentially suitable bearing layer of alluvial sand with increasing density beginning at about 42.5-ft below the water level. To install the piles, a pad was built across the tributary by placing coarse aggregate on the soil bed and once above the water table, compacting and reinforcing with geogrid to about 3-ft above the water level. Incremental IE was used to ensure the piles were installed to a sufficient depth in the bearing sand layer (Figure 10) regardless of Cumulative IE.

Figure 9 – Typical Boring from Utility Bridge over Water and Tributary Bed

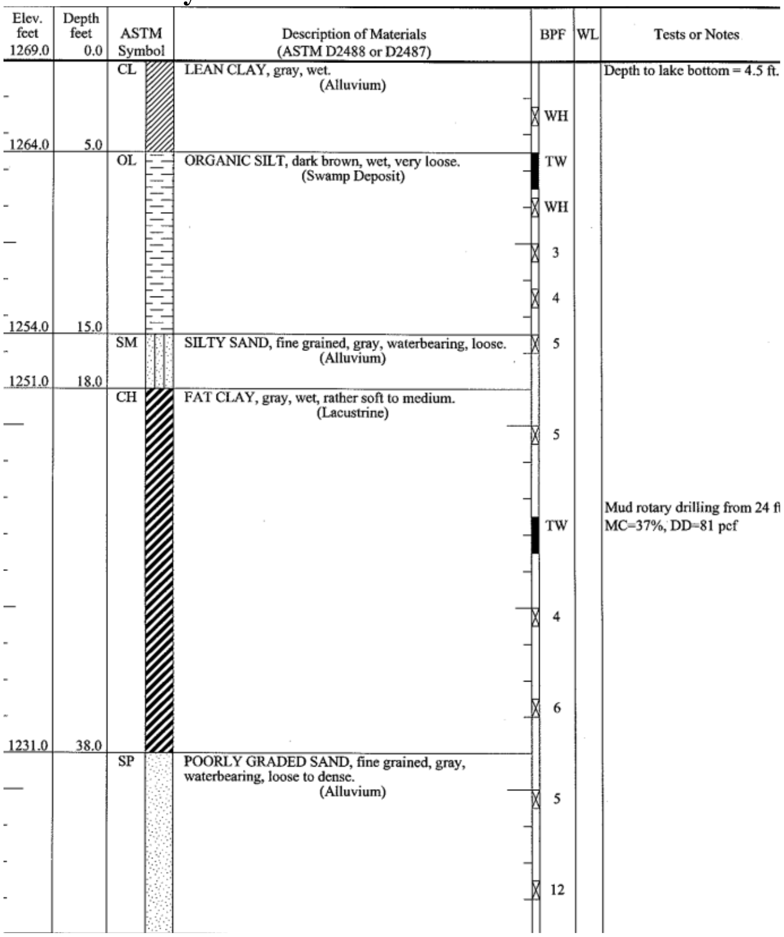
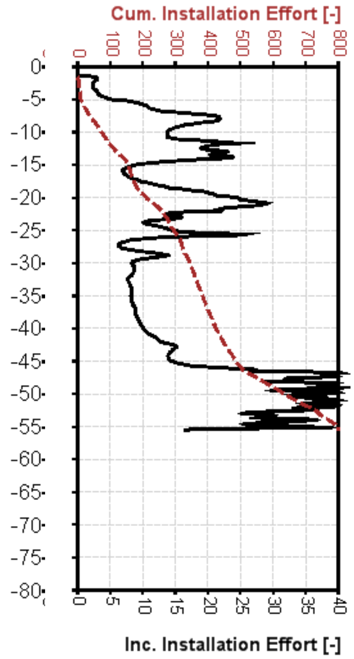


Figure 10 – Installation Effort



12. PHASE 4 – DENSE SAND FILL

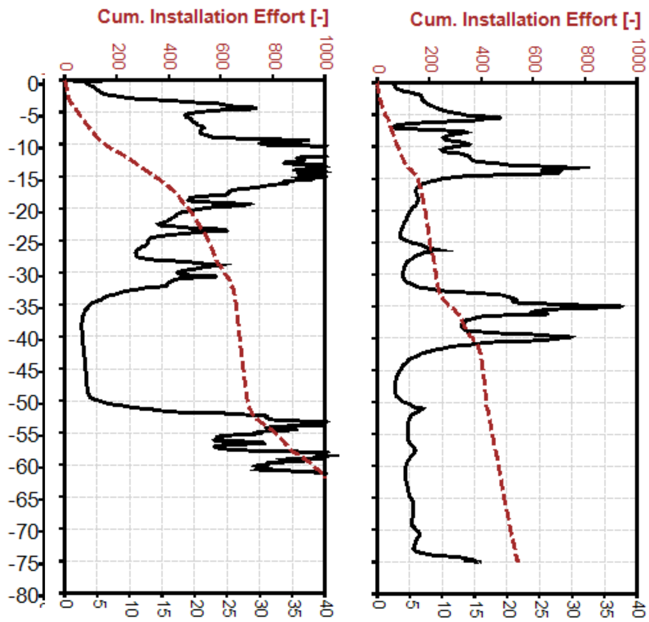
Most recently, an additional phase of work was completed which included installing piles closer to the water than previous phases. The natural ground sloped from the level of the previous phases down to the water level and was raised to the same level as the remainder of the site by installing sheet piles and placing clean granular fill. The fill was placed in a dense condition which lowered the efficiency of the APG-D pile installation. Probes were installed to gage the difficulty of penetrating this fill and the effects of predrilling the fill and natural sands below (Figure 11). Ultimately, CIE was used to verify that piles installed to the maximum extent of the tooling would have the same resistance through predrilled soil as had been established in the previous phases for piles with the toe in natural silt.

13. SUMMARY AND CONCLUSIONS

APGD piles are often used in North America in granular materials where significant shaft capacity can be achieved due to soil densification during pile installation. The load test program at the subject site confirmed the general shaft capacity in the silts estimated from in situ data. The estimation of rig energy, Installation Effort (IE), proved to be a useful tool to confirm stratigraphy and to set variable final pile toe depths based on local site variations in soil type and density. Additionally, IE was used to provide confidence in the capacity of the production piles that were extended due to top-of-pile elevations well below the working surface or where pre-drilling was required to penetrate dense granular fill as well as to establish penetration into the appropriate bearing stratum at the utility bridge.

Real-time acquisition and display of drilling parameters along with the calculated Incremental and Cumulative IE profiles provided access to this data by both the operator and inspector, which allowed for the implementation of the IE-based pile termination criteria decribed.

Figure 11 – Installation Effort Through Dense Fill (l) and Predrilled Holes (r)



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