DRILLED DISPLACEMENT PILES IN THE NORTHEASTERN UNITED STATES

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ABSTRACT

Drilled Displacement piles are a product of screw pile technology originally developed in Europe. The process involves rotating tool into the ground that displaces the soil laterally as it advances, then grouting or concreting through the hollow stem of the tool as it is withdrawn. They were first introduced in the United States in the 1990's and have become a mature and accepted technology since that time. They are now used to support a variety of heavily loaded structures including electric power and LNG facilities, stadiums and arenas, airports and mid- to high-rise commercial and residential facilities. In urban environments, the technique has a number of advantages including, low noise and vibrations, no removal of the existing soil, and reduced pile material cost due to the improved stress state of granular soils after installation (smaller or shorter piles can be used). For these reasons, displacement piles have been used to support various facilities in Northeastern United States (US). The paper presents case histories of the performance of displacement piles in the Northeastern US including the use of full displacement elements as a settlement limiting ground improvement system.

Keywords: Deep Foundations, Piles. Drilled Displacement, Auger Pressure Grouted Displacement, APGD

INTRODUCTION

"Drilled Displacement" (DD) is an industry umbrella term for a number of proprietary or commercially available cast-in-place pile installation systems which involve a hollow-stem tool that laterally displaces soil as it advances and the placement of grout or concrete through the hollow-stem tool as it is withdrawn. The systems include grout/concrete placement methods by both sand-cement grout pumped under pressure and tremie grout/concrete placement through bottom-hole discharge. The system discussed in this paper includes grout pumped under pressure, also referred to as Auger Pressure Grouted Displacement (APGD). A schematic of the APGD tool is shown in Figure 1. The tools require significant torque and downward force to advance; a typical installation platform is shown in Figure 2.

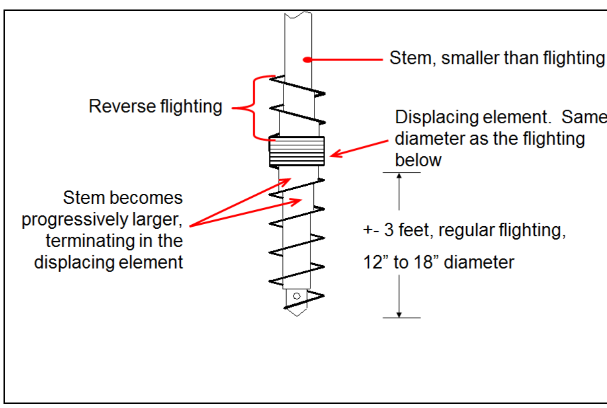

FIGURE 1 – APGD Displacement Tool

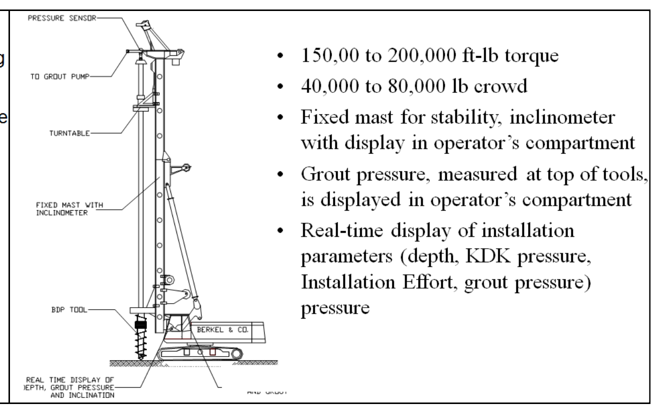

FIGURE 2 – APGD Installation Platform

Similar to Augered Cast in Place (ACIP) piles, DD piles are a single-pass process. The piles are drilled with one tool penetration and cast during the subsequent withdrawal. This can be more efficient when compared to other bored and cast-in-place piles (drilled shafts, micropiles) which are typically installed segmentally and require casing. Also, ACIP and DD piles are installed with low noise and vibrations when compared to driven piles and the price of grout/concrete compares favorably with driven steel piles on a per foot basis.

The general principal separating DD pile systems from ACIP pile systems is the soil improvement aspect of the installation of DD piles (densification of granular soil, low plasticity fine-grained soil or man-made rubble fill) that allows for increased shaft and toe resistances compared to ACIP piles. In improved soils, they can then support higher loads than ACIP piles, allowing for fewer piles; or they can support similar loads with smaller or significantly shorter piles. Additionally, since no soil is excavated during the process, DD piles can offer savings in some heavily contaminated soils, particularly in urban areas where soil removal from a site may be expensive, time-consuming and generally unwieldy.

Most DD pile installation platforms include standard Automated Monitoring Equipment (AME) that allows for the measurement and real-time display of drilling and grouting parameters as the piles are constructed. These parameters can include time, tool depth, calculated penetration and withdrawal rate, tool-rotation rate, the hydraulic pressure applied to rotate and apply downward force to the tools and grout pressure (grout flowcan be measured but is not considerd standard). Examples of the display of these parameters for an APGD system are presented in the case histories.

ENERGY FACILITY – DAGSBORO DE

The first project presented was an expansion to an energy facility in Dagsboro DE, near Indian River Bay on the Atlantic Coast. The site sits firmly in the Coastal Plain geologic region of the east coast of the US. An example Seismic Cone Penetration Test (SCPT) result from the site is presented in Figure 3 and shows soft upper sandy silt sediments underlain by loose sand and silt mixtures, transitioning to medium dense, relatively clean sands with depth. As loose to medium dense sands are most affected by the displacement process, this is an ideal setting for maximizing the load placed on a DD pile.

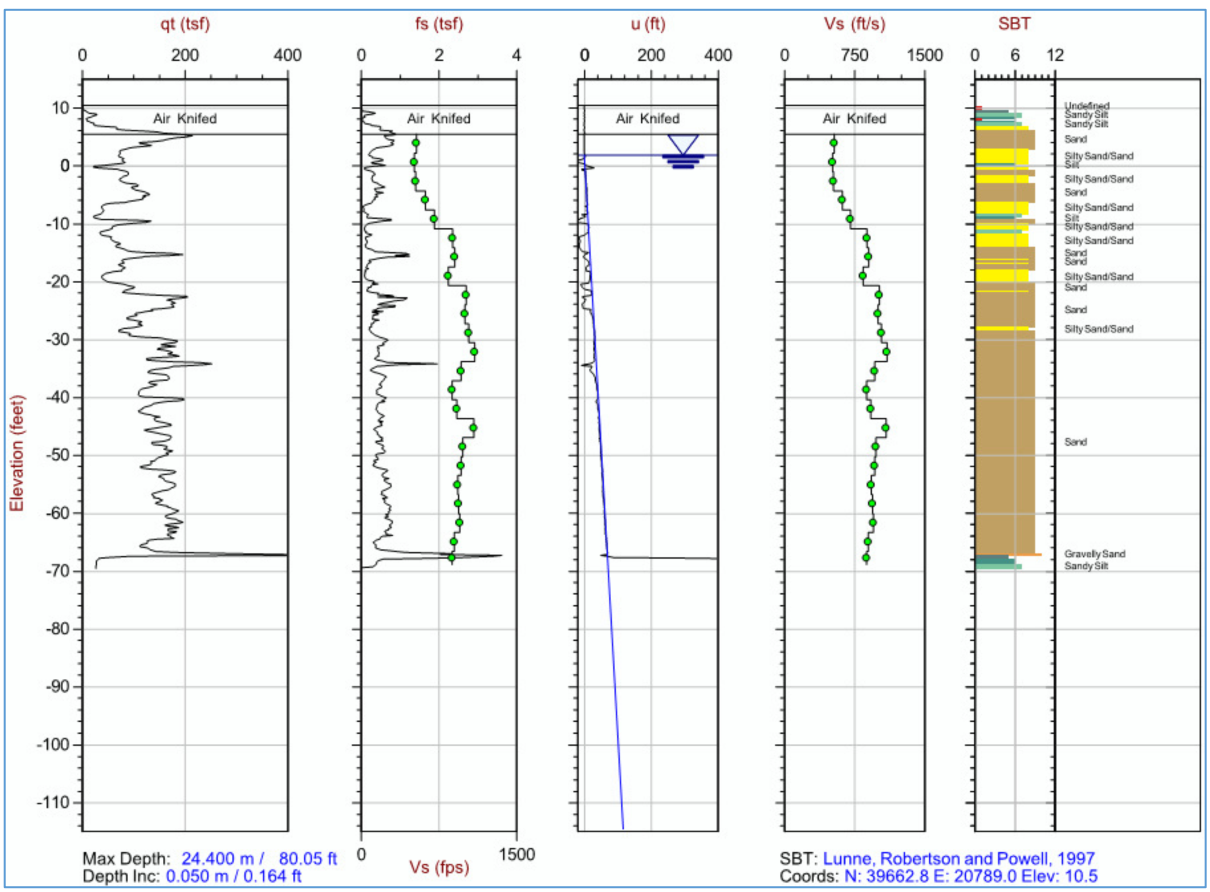

FIGURE 3 – Example Stratigraphy at Dagsboro DE

APGD piles were proposed to support compression loads of up to 150 tons. Preliminary analysis according to NeSmith (2002) indicated that 16-in piles installed 50-ft below the SCPT elevation could support these loads. A portion of the test pile installation record is shown in Figure 4. This information was available to the inspector and drilling contractor in real-time during the pile installation and, in general, shows a decrease in penetration rate and increase in hydraulic fluid pressure applied to the tooling (shown as KDK pressure in this example) with depth, as would be expected with the transition from loose to medium dense sand.

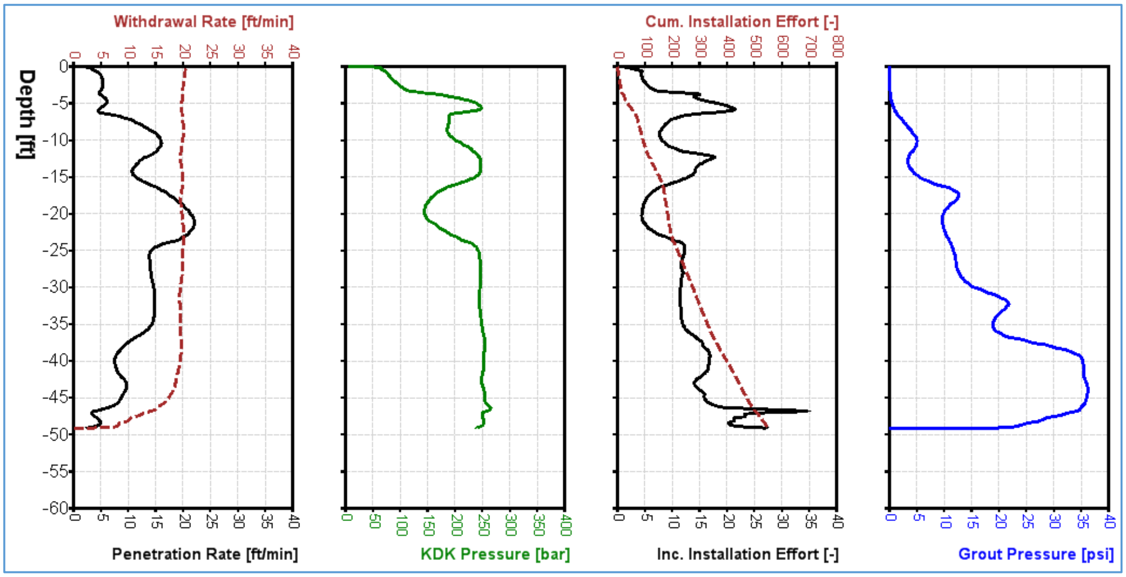

FIGURE 4 – APGD Pile Installation Record – Dagsboro DE

Also shown is an estimate of the energy expended by the installation platform to advance the tooling, both at 1-second intervals (Incremental Installation Effort, IE) as well as the total effort expended with depth (Cumulative IE, NeSmith and NeSmith, 2008). Figure 5 shows the compression load test results to the maximum applied load of 350 tons (at which load the pile broke) along with the estimated ultimate loads from the current International Building Code. A database of APGD pile capacities along with measured Cumulative IE is shown in Figure 6. Such a database can be used to establish a typically hyperbolic relationship between Cumulative IE and pile capacity for a given site. Production piles can then be installed to a specific stratum, using Incremental IE as an indicator (the higher the IE, the denser and more granular the soil) as well as to a specific energy level expended by the rig (similar to using hammer energy to establish driven pile toe levels) to take advantage of variations in density and stratigraphy across a given site, to maximize the efficiency of the system.

Also shown in Figure 6 are two examples of multiple test piles installed to different Cumulative IE values. One is from an alluvial flood plain and glacial outwash in ND and the other is from the Coastal Plain in central FL. They are examples of how a site specific IE value can be determined to provide a specific pile capacity and also an example of how geologic setting should be considered by an experienced design professional who is familiar with the performance of different types of DD piles.

At the subject site, final production pile lengths ranged between 45-ft and 55-ft depending on the density of the sand encountered at each facility. By comparison, 16-in diameter ACIP piles were to be about 70-ft in length across the site to support the same 150-ton design load. In this case, there was an average 20-ft reduction in pile length with a corresponding estimated 1.5 yd^3 less grout, along with a 25-ft shorter center-bar (#11, 75 ksi steel) per pile (about 1300 yd^3 of total grout and 18,000 l.f. of center bar). Additionally, no spoils were removed during DD pile installation eliminating the disposal of 4,500 yd3 of soil. The final foundation cost was 10% to 20% less expensive than a corresponding ACIP pile foundation.

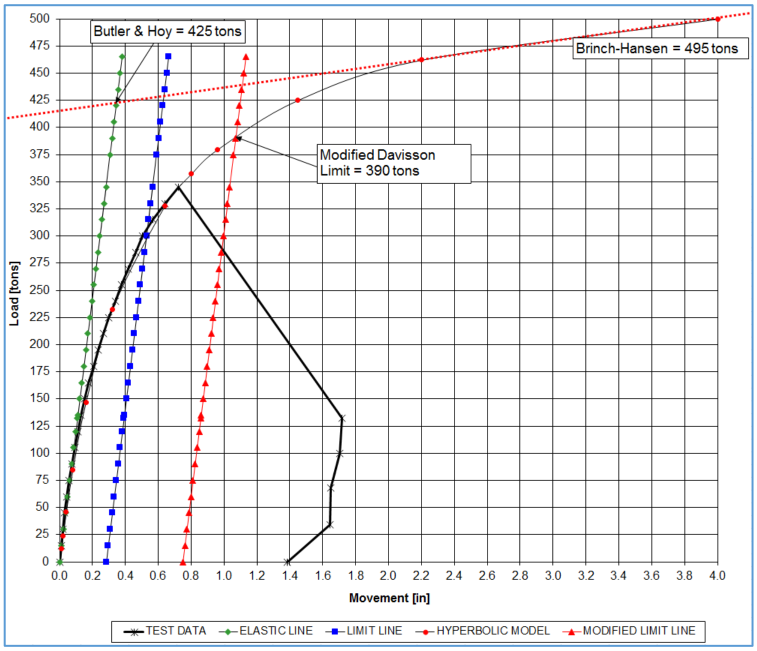

FIGURE 5 – Compression Load Test Results and IBC Ultimate Load Estimates – Dagsboro DE

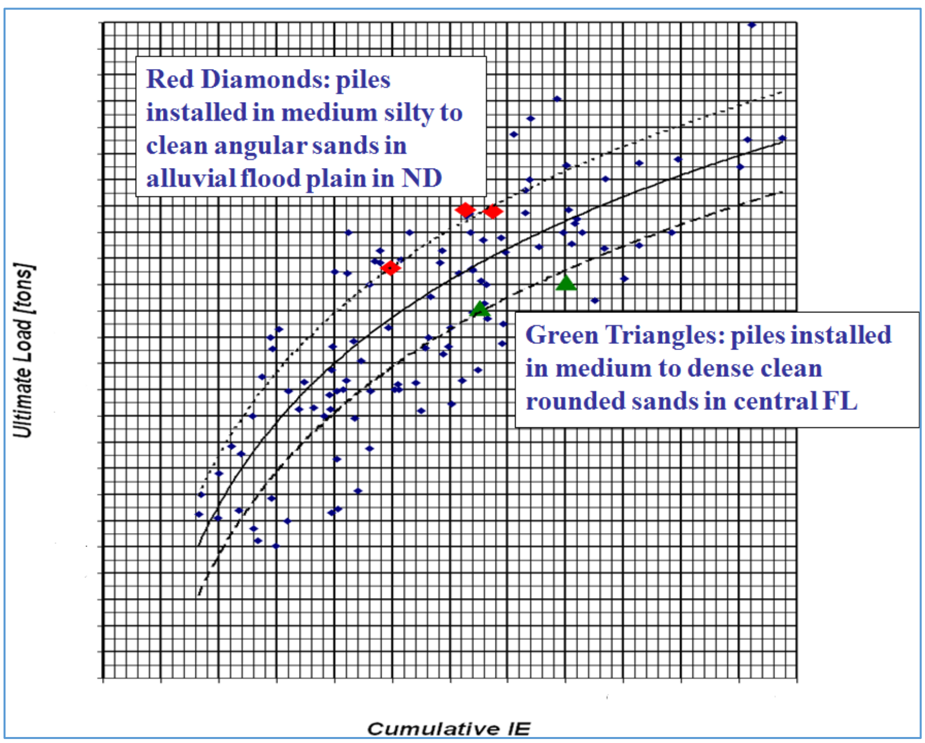

FIGURE 6 – Example Collection of Drilling Platform Installation Effort and APGD Pile Ultimate Load

MEDICAL FACILITY – CAMDEN NJ

The second example project was a large new medical facility in Camden NJ, relatively close to the Delaware River, just east of Philadelphia. The subsurface profile consisted of urban rubble fill over upper alluvial clay and sand deposits of variable density and stiffness.

Coastal plain sands underlay the alluvial soils. A table of N-Values from Standard Penetration Tests (SPT) as well as the generalized soil profile is shown in Figure 7.

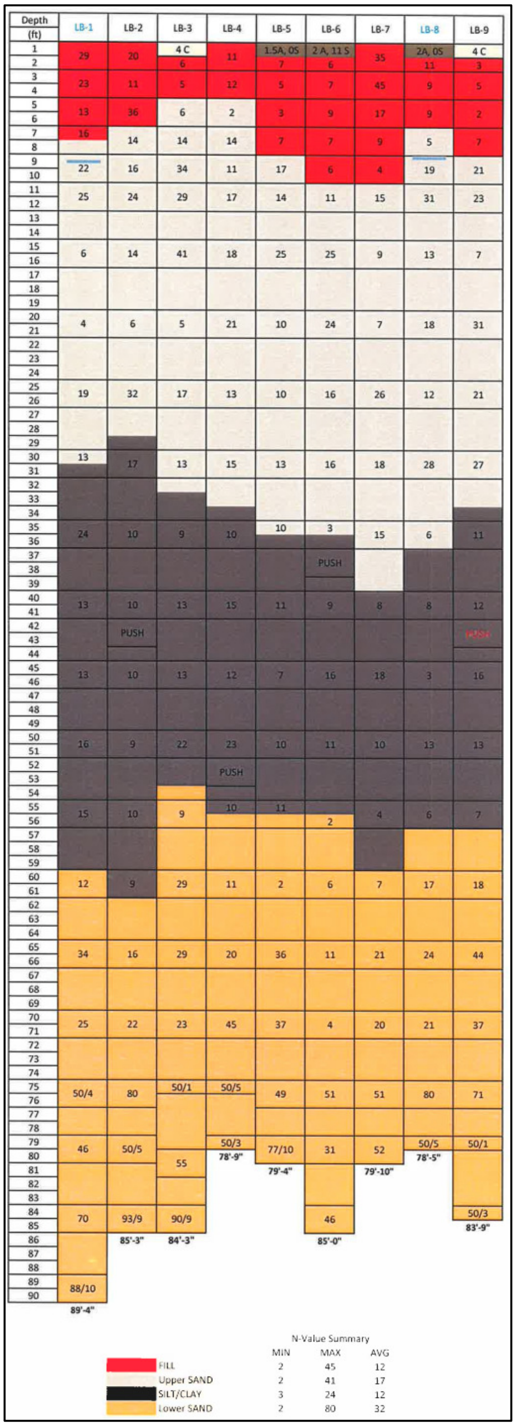

FIGURE 7 – Generalized Stratigraphy at Camden NJ Site

APGD piles were proposed to replace 90-ft long, concrete-filled, driven, closed-end steel pipe piles to support compression loads of 110 tons per pile. Preliminary analysis indicated that 14-in APGD piles could be used. A series of APGD probes were installed to collect drilling and grouting parameters prior to test pile installation. Based on the relatively similar IE values observed and the preliminary capacity analysis, the compression test pile was installed to 70-ft to exceed the required capacity of 220 tons, with the possibility of reducing production pile lengths based on the test pile results. Recorded installation parameters from the compression test pile installation are shown in Figure 8. Of note are the recorded grout pressures and volumes, the latter of which are significantly lower than might be expected for other grouted, cast-in-place pile systems. DD tools typically establish a pile diameter very close to plan in granular and firm to stiff fine-grained soils. Minimum incremental grout volumes for DD piles range from just greater than 100% of theoretical to a minimum of 105% of theoretical volume.

Load test results to the maximum applied load of 280 tons are shown in Figure 9 and evaluations of ultimate load are presented in Figure 10. The estimated ultimate loads are well in excess of the single pile requirements. For production, minimum Incremental and Cumulative IE values were employed to establish pile toes in the lower dense sands indicated on Figure 7 and by the Incremental IE towards the bottom of the compression test pile.

The efficiencies in this case were the elimination of the closed-end pipes and using slightly more grout vs. concrete per pile (90-ft x 12.75-in diameter pipe piles replaced with 70-ft x 14-in diameter DD piles). Elimination of the lead time for pile fabrication and delivery also advanced the construction schedule. Equivalent 14-in diameter APG piles were estimated to be about 85-ft in length.

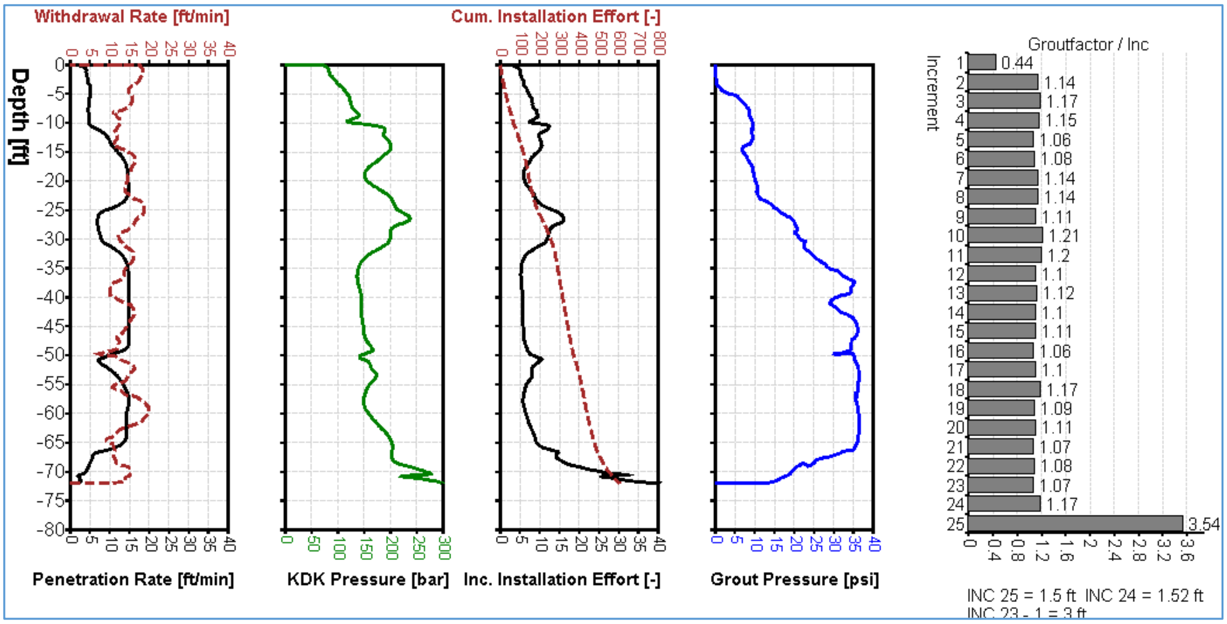

FIGURE 8 – Installation Parameters for Compression Test Pile – Camden NJ

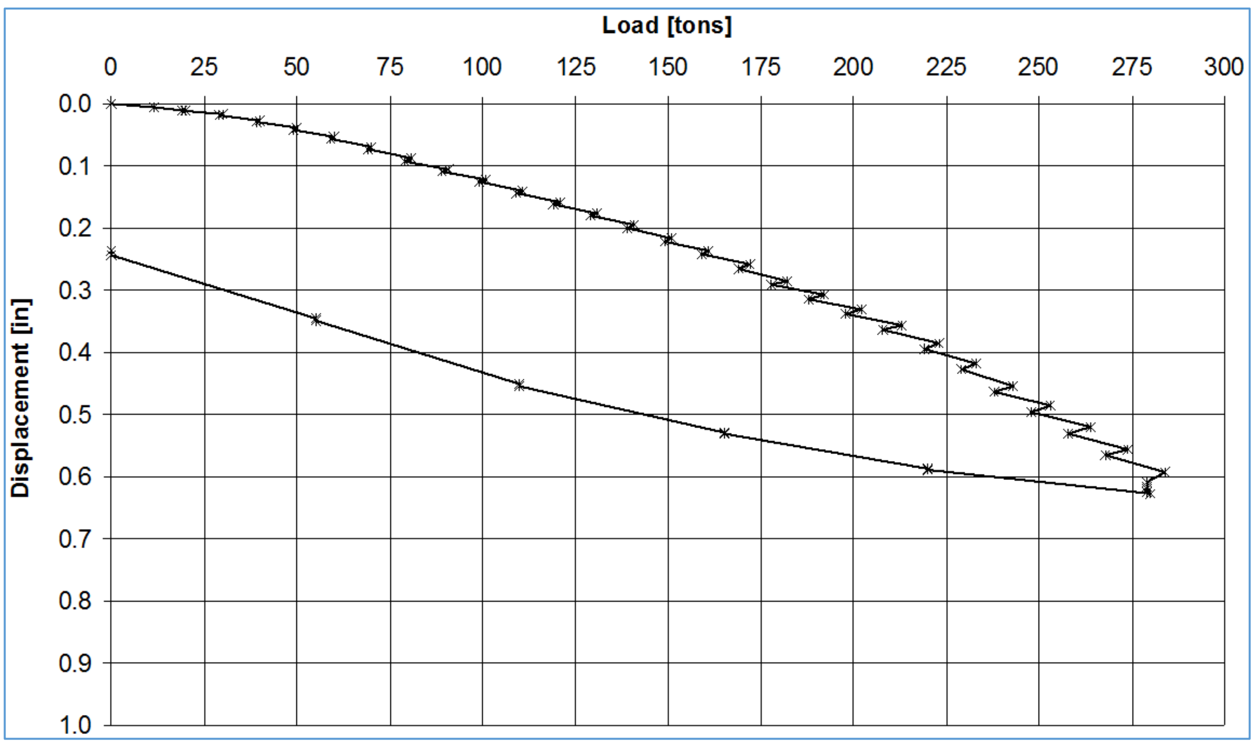

FIGURE 9 - Compression Load Test Results – Camden NJ

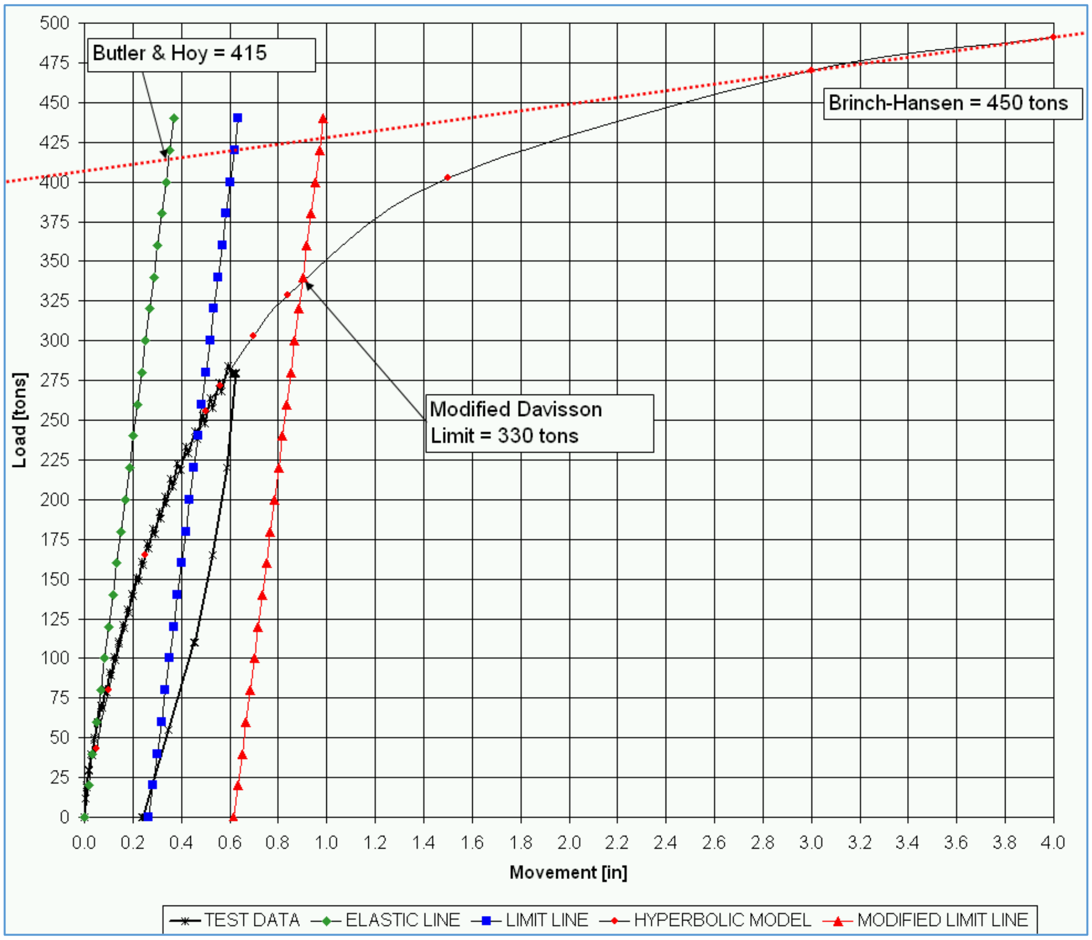

FIGURE 10 – Ultimate Load Estimates – Camden NJ

SETTLEMENT LIMITING ELEMENTS – WOODBRIDGE NJ

The final example project involved the use of APGD elements installed to limit settlement below a new energy facility in Woodbridge NJ, just west of the Raritan River and Sandy Hook Bay, as well as being west of the southern tip of Staten Island.

A generalized subsurface profile is shown in Figure 11 and consisted of urban rubble fill from the demolition of the previous structures at the site, loose to medium alluvial sands underlain by denser coastal plain sands and saprolite, weathered in place from the underling parent rock. The groundwater at the site was highly contaminated and a slurry wall had been previously installed around the site to contain the groundwater in the alluvial and coastal plain sands.

Any foundation system considered was to remove no soil or groundwater during installation. The system was also not to penetrate the saprolite, which was considered to be a natural lower barrier for the contaminated groundwater.

A review of the proposed structures indicated that due to their size and weight, they would predominantly be supported by large, significantly reinforced, concrete mats (Figure 12). APGD elements (commercially referred to as Cast-in-place Ground Improvement Elements or CGEs) were proposed to increase and standardize the density of the fill and loose sand to both increase the bearing capacity of the underlying materials and limit settlements to within tolerable project levels for a range of bearing pressures between about 3000 and 4200 psf.

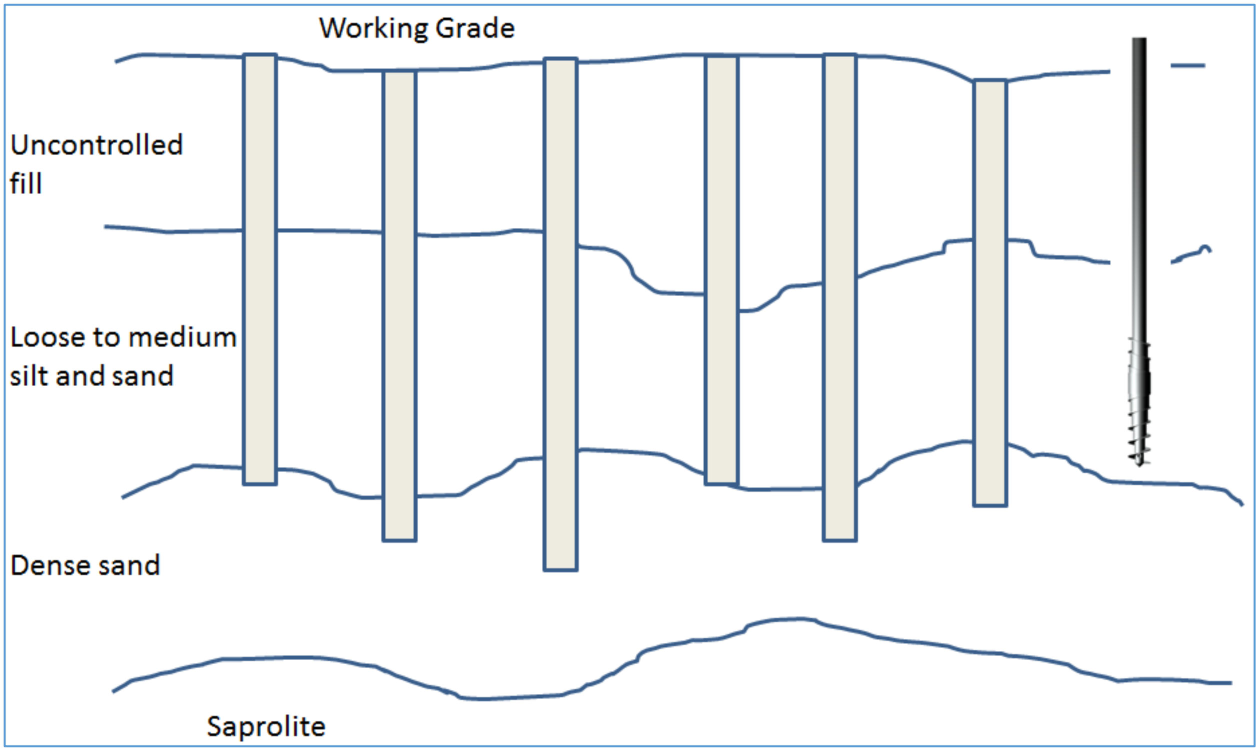

FIGURE 11 – Generalized Subsurface Profile – Woodbridge NJ

An example of the densification effect of a group of CGEs is shown in Figures 13 and 14. Two additional displacement elements were installed outside of an APGD compression test set-up to form a 6-ft square group (Figure 13). CPTs were performed at small distances from a single element as well as in the middle of the 6-ft square group. The increase in tip resistance from 3-diameters outside a single element (considered to be the pre-installation condition) and in the middle of the group is shown on Figure 14.

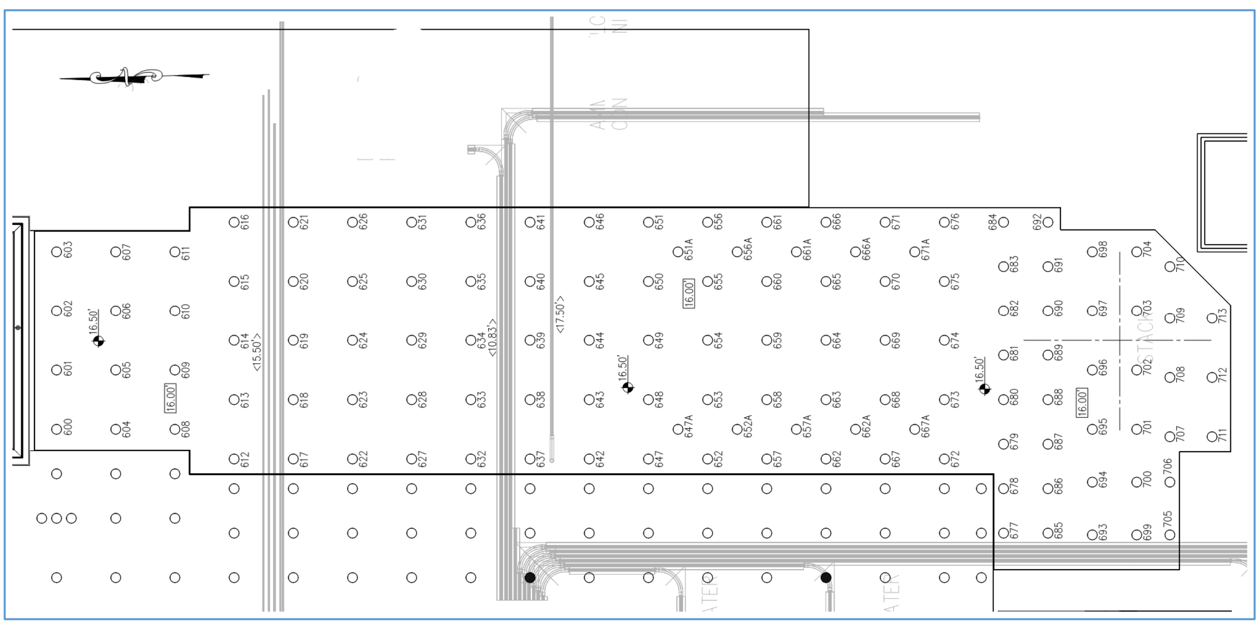

FIGURE 12 – Example Mat for One Structure for New Energy Facility – Woodbridge NJ

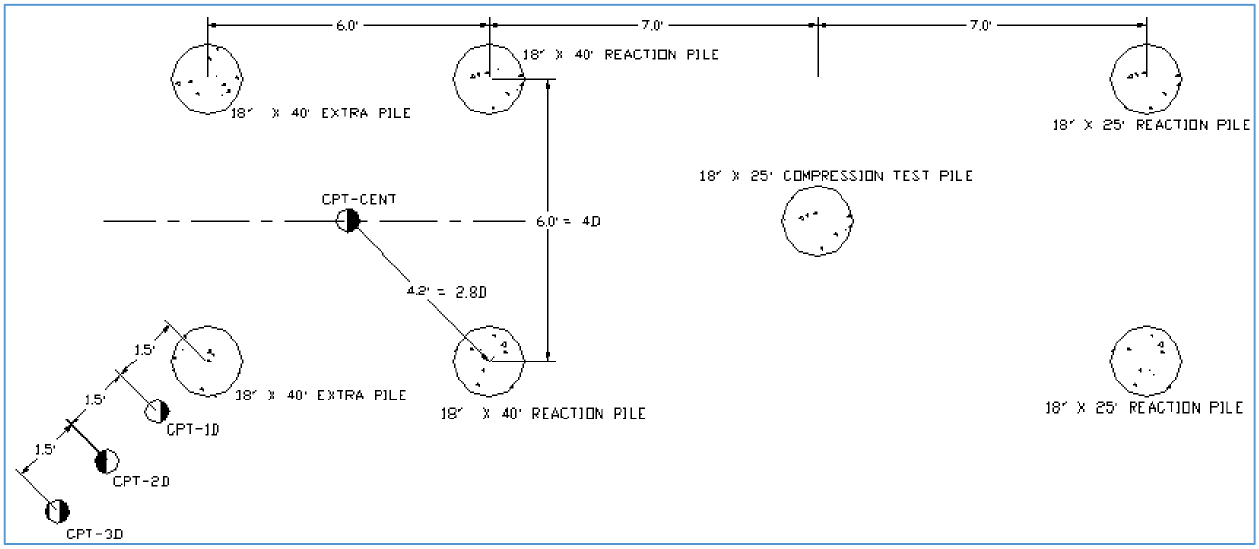

FIGURE 13 – APGD Test Pile Layout with Additional CGEs installed for Densification Testing

By using a database established from a number of these pre- and post-installation SPTs and CPTs, it is possible to predict the increased density of soils improved by CGE installation (Siegel et al, 2007a and 2007b). Considering CGE installation into the dense coastal plain sands above the saprolite, this database was employed at the subject site to establish appropriate CGE sizes and layouts under the various structures to provide the required allowable bearing pressures across the site. IE obtained from the AME system described previously was used to establish CGE toe levels in the dense sand above the saprolite. It is noted that a similar analysis can be employed for liquefaction mitigation in seismically affected regions.

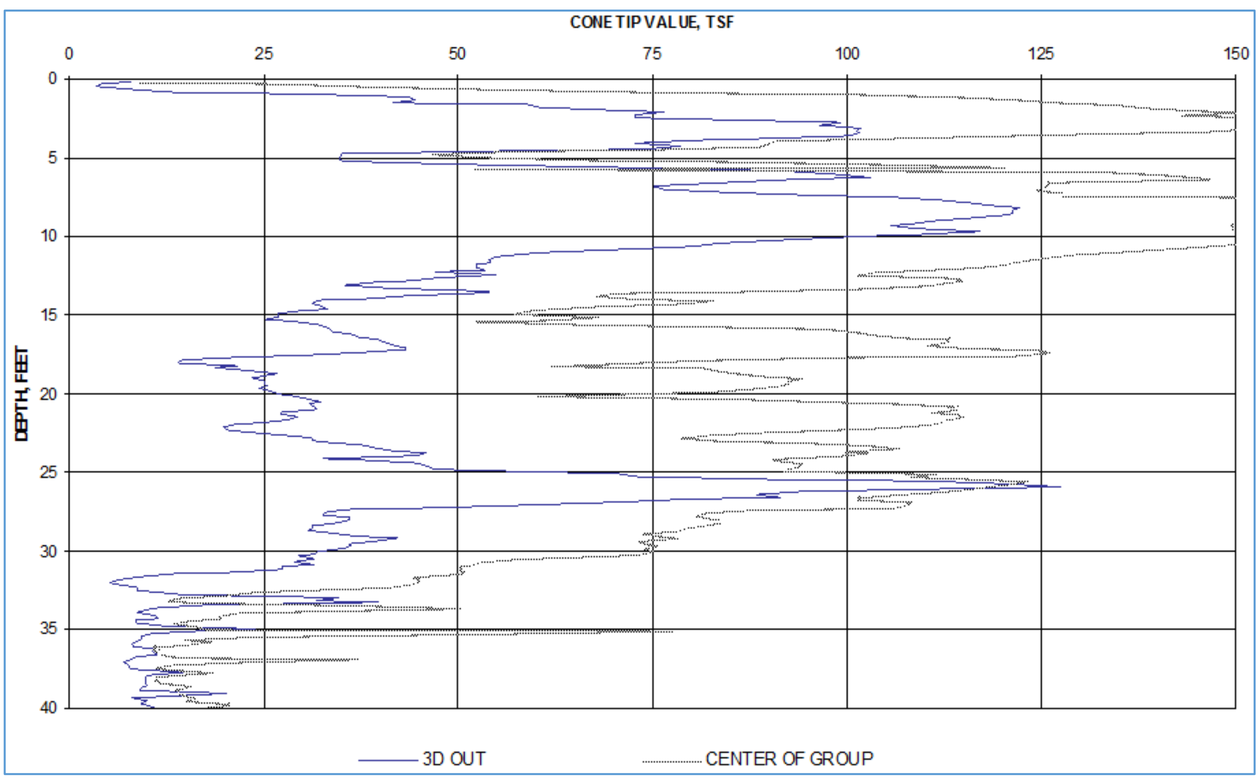

FIGURE 14 – CPT Tip Resistance Results in "Ambient" Condition and at Center of Pile/CGE Group

More recently, the ambient and increased shear wave velocity, Vs, have been obtained from both Seismic CPTs and refraction microtremor (ReMi) tests and used in a similar manner to establish increased resistance to liquefaction as well as increased allowable bearing pressure due to CGE installation. Measurement of Vs is considered to capture some of the effects of increased horizontal stress in addition to increased density that may not be captured by the tip resistance values from CPT tests alone.

CONCLUSIONS

Where they can be successfully installed, the single-pass nature of DD piles can reduce pile installation times when compared to segmentally installed, bored and cast-in-place piles. The densification and increase in horizontal stress that occurs upon installation in some alluvial and coastal plain sands and low-plasticity fine-grained soils can increase the load per foot that can be resisted by the piles, allowing for smaller diameter and shorter piles for equivalent ACIP piles, or fewer piles with larger loads.

The standard AME on board the installation platforms employed for DD pile installation can help maximize this efficiency by producing indications of stratigraphy and pile capacity in real-time to allow for variable toe levels to be set on a pile-by-pile basis taking advantage of the variation in stratigraphy across a given site. DD elements can also be effectively employed as a ground improvement system, either by bracing fine-grained soils or increasing the density and horizontal stress in urban fill and predominantly granular soils. The piles and elements can be particularly beneficial in heavily contaminated sites where spoil removal may be costly and time-consuming.

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