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Application of Data Acquired During Drilled Displacement Pile Installation

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Abstract

The gathering of information relative to the casting process has long been the major thrust of quality control for cast-in-place pile evaluation, and there have been significant advances that enhance the quality of data obtained during casting. Additionally, systems are now available that provide the capability to electronically gather information such as applied torque, crowd, and tool rotation and penetration rates in a form which also allows for a quantitative examination of the drilling process. In general, this aspect of installation has been heretofore evaluated only subjectively in the United States, if at all.

New processes for drilled displacement pile design and verification are emerging as a result of the quantity and quality of data that can now be made available. This paper describes how the collected and processed installation data can be used as an adjunct to Geotechnical site characterization and as a verification tool with respect to pile capacity. The analytical development of the methodology for processing the acquired data is discussed and application is illustrated through examples using specific project information from a variety of geologic settings.

Introduction

The installation of drilled displacement piles in the United States typically includes hydraulic installation platforms that have their roots in European Continuous Flight Auger (CFA) technology. Beginning in the early stages of their development, these installation platforms were outfitted with data acquisition systems that collected and recorded basic installation parameters during drilling and casting. The data acquisition systems have advanced along with the installation platforms and currently it is possible to record, process, and distribute a vast amount of data related to pile installation (NeSmith and NeSmith, 2006). The use of information such as pile installation depth, grout pressure, and grout volume with depth is immediately obvious; however, there are far reaching potential applications for the use of data obtained during the drilling phase. Two such applications are the delineation of stratigraphy and estimation of ultimate pile capacity from information gathered during drilling. It is these applications that are the focus of this paper.

Installation Effort

Early in the evolution of hydraulic installation platforms, attempts to relate drilling effort to stratigraphy were based on the total hydraulic pressure developed with depth. Van Impe (1988) refined the process, suggesting the concept of "specific energy" diagrams, which were developed using six drilling parameters. Gouvenot, et al (1990) defined "characteristic soil resistance" in terms of the torque required to turn the tooling, and the penetration and rotational rates of the tooling, and added a modification to account for the torque lost between the driving element and the tip of the tools. Both of these processes were for application to European CFA instillation using fixed mast, hydraulic equipment. Brettman (2004) defined "Drilling Resistance" in terms of normalized values of the fluid pressure of the motors turning the tooling and the tool penetration rate. This process was based on research using crane-mounted equipment for installation of conventional auger, cast-in-place (ACIP) piling.

A methodology developed specifically for drilled displacement piles was described by NeSmith (2003). Installation Effort was defined in terms of the product of normalized values of torque and penetration rate. In this process, the values of torque and penetration rate are modified mathematically in an attempt to reflect their relative roles. The penetration rate index (PRI) is calculated as the inverse of the square root of the penetration rate (PR) normalized by a base penetration rate (PRBase), as follows:

$$PRI = 1/(PR/PRBase)^{0.5}$$

The torque index (TI) is calculated from the measured fluid pressure of the motors driving the tools (t_{fp}), normalized by a base torque level (TBase):

$$TI = 2.78(t_{fp}/TBase)^{1.36}$$

Installation Effort (IE) is the product of PRI and TI:

$$IE = (PRI)(TI)$$

The data collection system used to gather the information that is the basis for this paper records information at one-second intervals. As a first step in processing, any time interval for which there is no tool penetration is deleted from the data. Additionally, torque data is averaged over a four-second interval to lessen the impact of large, short-term variatiations in torque and thus soften the IE graph.

Delineation of Stratigraphy

Although some information relative to the soil profile being penetrated can be gleaned by simply observing the rates of tool penetration and rotation, the installation of cast-in-place piles is often referred to as a "blind" process since there has traditionally been no usable rational feedback during drilling. Processing the information that can now be gathered during drilling using Installation Effort methodology allows for a rational, real-time representation of the soil profile being penetrated. The IE methodology has been applied to projects in a variety of geologic settings in order to demonstrate the nature of the information that is produced.

New York City-Urban Fill/Glacial Outwash

At this site, urban fill (gravel, brick and concrete fragments, asphalt fragments) is present to about 4 meters. Below the fill, there is a natural sand deposit that is initially loose to medium, and becomes transitionally more dense with depth. The pile was terminated at 13.4 meters. There is no distinctive "bearing layer" at this site, and pile toe levels were set based on the toe level of the test piles.

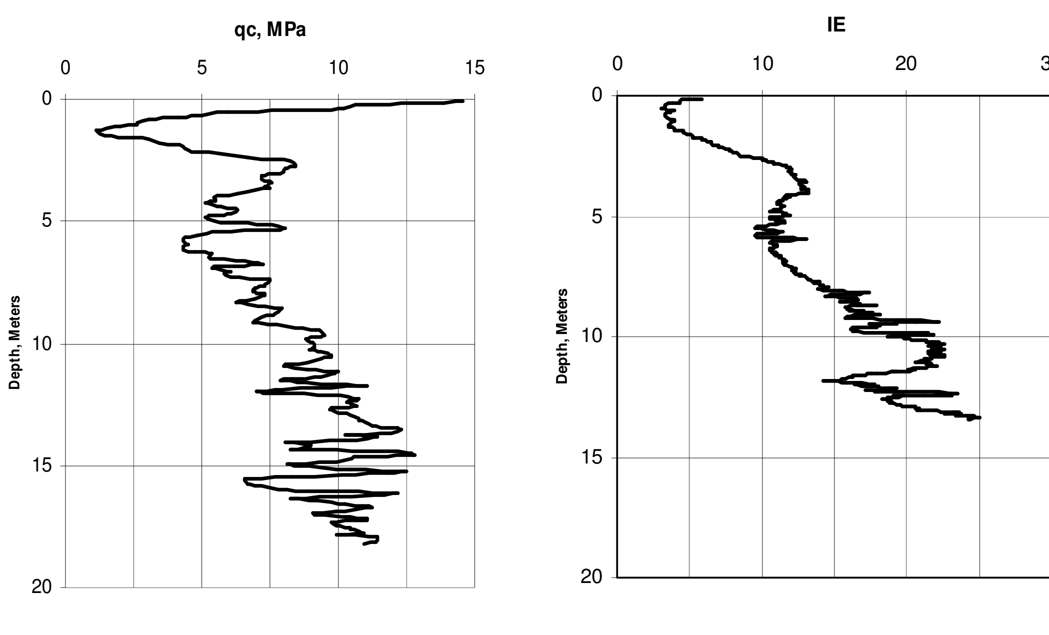

Figure 1. CPT and IE Charts, New York City Glacial Outwash

Florida Gulf Coast-Barrier Island Deposit
Barrier island deposits along the Gulf Coast in the Florida panhandle typically have an upper zone of medium to dense sand to about 8 to 10 meters, then a loose zone of loose sand, often with significant fines content. A second dense sand zone, starting at about 12 to 15 meters is a common termination strata for deep foundations. At the site illustrated in Figure 2, the upper sand zone is less dense than normal, however, the loose zone, and the target bearing strata, beginning at about 13 meters, can be seen clearly from the IE chart.

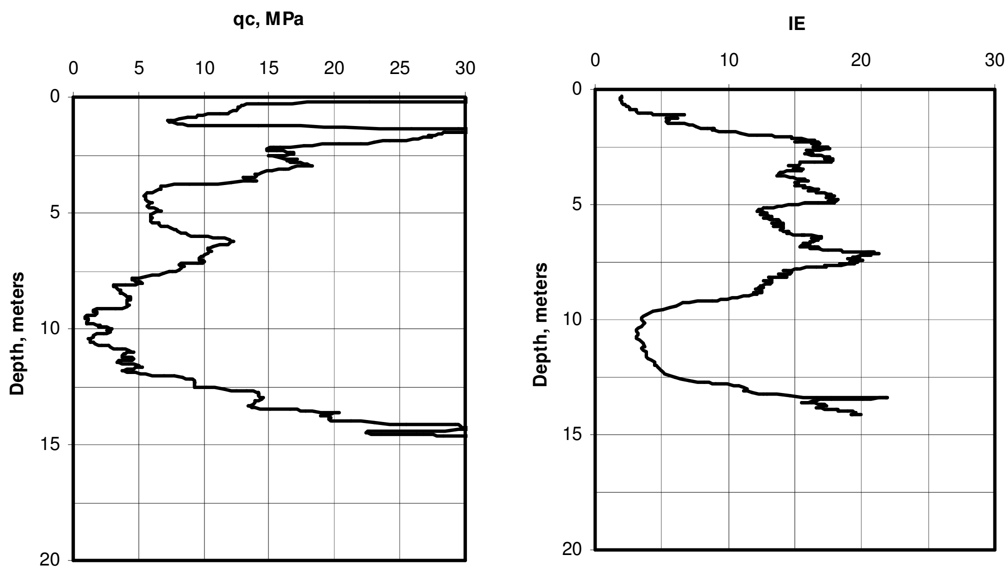

Figure 2. CPT and IE Charts, Barrier Island, Florida Panhandle

Washington, DC,-Fill/Anacostia River Alluvium/Pleistocene
At the site from which the information shown in Figure 3 was gathered, fill is present to about 3 meters, and overlies (primarily) loose alluvial sands and silts which extend to about 6 meters. Pleistocene-age sands and gravel (locally referred to as "Terrace Deposits") are present to about 12 meters. The basal portion of this stratum is marked by dense sand and gravel, and often cobbles. The CPT at this location refused at about 9 meters, however the test pile was taken to 10 meters. The development of the IE relationship includes the averaging of the penetration rate and torque indices over a four-second time interval to soften the graphs. In this case, the IE plot implies that the transition from the fill to the alluvium and from the alluvium to the Pleistocene are more gradual than is indicated by the CPT data. However, entry of the tooling into the lower dense sand and gravel zone is very clear.

Estimation of Ultimate Capacity

As discussed previously, Installation Effort as defined in this paper is based on data collected at one-second intervals, with those points where there is no advance of the tooling being deleted. The dimentionless index IE then, reflects the effort required to turn the tooling during a productive one-second interval. The Cumulative Installation Effort (CIE) is the sum of the instantaneous IE values. The prospect of relating total drilling effort during the installation of cast-in-place piling to ultimate pile capacity is not common, and there are many variables that can impact this relationship. For a well-defined set of conditions, however, reliable relationships for drilled displacement piles can be developed.

The graph shown in Figure 4 was an early relationship developed at Berkel & Company Contractors for a set of installation platforms with similar performance characteristics, and sites where the primary shaft component, and the toe component were developed in granular materials. Ultimate load for this data was defined as the lesser of 1) the load at which the displacement rate reached 0.057mm/kN (.02 in/T) or 2) the load at which the gross pile head movement was equal 6% of the pile diameter. A discussion of the evolution of these criteria, as well as a description of the system on which the IE relationship is based can be found in NeSmith (2002).

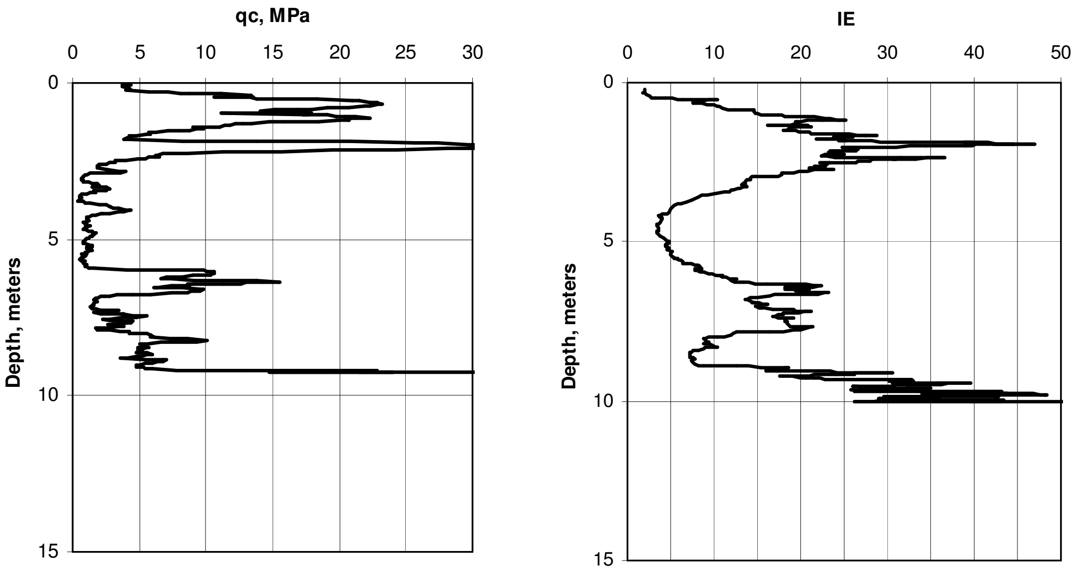

Figure 3. CPT and IE Charts, Recent Alluvium and Pleistocene, Washington, DC

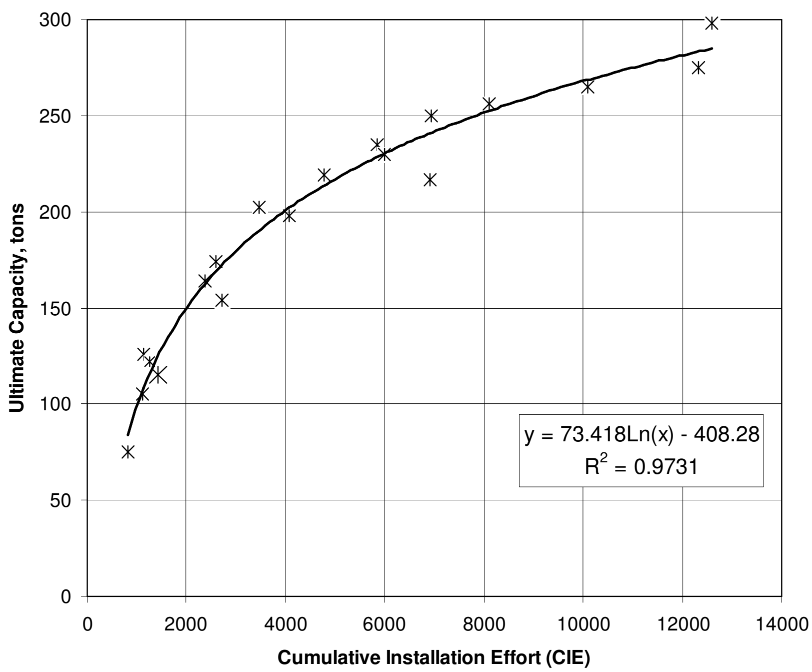

Figure 4. Early Version of Installation Effort versus Ultimate Capacity Relationship

As newer installation platforms with better performance characteristics were added, it was clear that a one-size-fits-all relationship was not feasible, and that reliability would come only through installation platform-specific relationships. Formulating such relationships involves builings a data base of good quality load tests correlated with Cumulative Installation Effort during test pile installation. However, it was found that the general form of the relationship was consistent through all installation platforms. Thus, an installation platform-specific relationship could be developed with only a few load tests.

The applicability of a given installation platform relationship is confirmed during the load test program. Obviously, a greater-than-normal number of load tests, on piles installed with a range of CIE values would be most desirable, and rapid testing methods make this kind of approach feasible. However, the form of the relationships is so consistent that the conservative application of a single load test may be sufficient to establish a site-specific relationship. An example application is shown on Figure 5. The "fleet" relationship, which is for installation platforms with performance characteristics similar to the one used at the site, is modified based on recent load tests installed with the installation platform and the load test performed at the site in the example. In this case the target working capacity was 100 tons, so the target CIE was set at 6000, corresponding to an ultimate capacity of 210 tons.

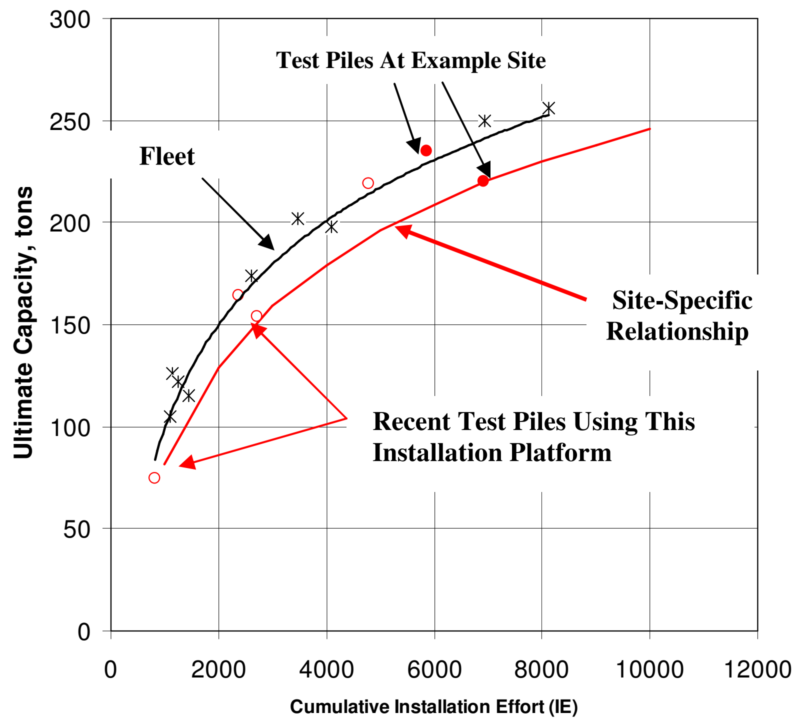

Figure 5. Example Site Specific CIE Relationship

Control of Pile Depth Using Installation Effort

For projects on which cast-in-place piles are used in the United States, it is not uncommon to perform a single compression load test at a perceived worst case condition, and then set a single pile toe level on the basis of a successful load test. While this practice may not cause an unreasonable hardship for the installation of conventional ACIP piles in many cases, it can lead to a significant increase in installation time and equipment stress for drilled displacement piles. In some cases, the toe level of the test pile simply cannot be reached at other locations due to the presence of very dense materials that were not present at the test pile location. Where a well-defined dense layer underlies much weaker material, torque alone may be used as a marker, and toe levels defined on the basis of penetration below some threshold torque value. Where there is a transitional increase in strength with depth, or more complex stratigraphy, the use of torque alone becomes less reliable, and is subject to variation in operator technique.

The application of an Installation Effort methodology can provide a rational approach to setting the termination level for drilled displacement piles that is based on the soil profile at the location of the pile being installed. A successful IE-based installation begins with a thorough site characterization program. Information on stratigraphy can be determined from the drilling process; however, characterization "on-the-fly", without the benefit of detailed information on the major subsurface features and how they vary across the site is a highly suspect proposition at best.

Rather than attempting to simply prove the performance of the piling system by putting a test pile at a perceived worst case condition, it is more instructive to select test pile locations, and instrumentation and procedures in order to gather useful information relative to the role the various strata play in developing pile capacity. A minimum pile toe level can be set based on stratigraphy and group issues, if appropriate. Below the minimum pile toe level, termination of drilling can then be based on 1) verification that the stratigraphy is consistent with the design assumptions by observing a real-time display of IE with depth 2) achieving the target Cumulative Installation Effort and 3) reaching an instantaneous IE indicative of material consistent with the target bearing strata.

Conclusion

The installation platforms used for installation of drilled displacement piles allow for the collection and processing of large ammount of data during drilling and casting. The Installation Effort methodology described in this paper provides real-time information on the soil profile at the pile location, and Cumulative Installation Effort can be a reliable indicator of ultimate pile capacity. With good site characterization, and a thougthful test pile program, these parameter can be used as a control process for setting pile toe levels during production installation of drilled displacement piles.

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