Installation Effort as an Indicator of Displacement Screw Pile Capacity

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ABSTRACT: In the United States, displacement screw piles are often viewed as a member of the auger, cast-in-place (ACIP) pile family and are thus subject to some of the same criteria by Geo-professionals. Commonly, a single compression load test is performed at the “worst case” condition, and a pile tip level is set on that basis. While this practice may not be unreasonable for conventional ACIP piles in many cases, it can lead to a significant increase in installation time and equipment stress for displacement screw piles. In some cases, the tip 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 tip 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 concept of using installation parameters as a control process for screw piles is not new. This paper, however, describes a simplified method by which normalized values of torque and tool penetration rate are combined to develop an index that can be related to subsurface conditions and pile capacity. The analytical method of combining torque and penetration rate are described, and examples of the application of the method are given.

1 INTRODUCTION

The capability to measure and record installation parameters during the installation of displacement screw piles gives rise to the possibility to use these parameters to rationally assess ground conditions and relative pile capacity. If one has spent any significant time observing the installation of displacement screw piles, with some knowledge of the ground conditions where the piles are being installed, a sense of the nature of the materials penetrated can be gleaned intuitively from the rate of penetration and speed of rotation of the tooling and from the sound of the elements driving the tooling.

An examination of torque (implied from the fluid pressure of the hydraulic motors driving the tooling) as an indicator of subsurface conditions, and a process for calculation of Specific Energy, which includes vertical thrust, tool penetration and rotation rates, and torque have been presented by Van Impe (1988). It was suggested that Specific Energy with depth be correlated with information from the subsurface exploration. The prospect of using data from pile installation as an adjunct to existing subsurface information has practical application in the deep foundation industry. Implementation of such a process would allow an analytical evaluation of significant changes over the range of expected conditions and the occurrence of unexpected conditions. Additionally, the total effort expended in pile installation could be related to pile capacity (at least on a site-specific basis), and decisions relative to pile toe levels could be established on that basis.

2 TORQUE

The use of high-torque, fixed-mast equipment with the capability to exert a downward force (crowd) on the tools is relatively new to the cast-in-place industry in the United States, and was initially used in the installation of displacement screw piles. Early in the implementation of these systems it was clear that the ability to monitor torque was valuable.

Toe levels on some projects were set on the basis of a minimum elevation and on achieving a specified torque level. The emergence of automated data acquisition systems allowed the monitoring of more sophisticated torque-related installation criteria.

Figure 1 shows the results of a cone penetration test along with torque and penetration rate versus depth during installation of a test pile at a site in the mid-western United States. At this location, there was about 3 meters of fill, then loose clayey sand to about 5 meters. The prominent dense sand zone, which began at about 5 meters at the test pile location, occurred across the site. The depth at which it occurred varied significantly, but there was a consistent torque signature as the tool passed through the loose sand into the dense sand. Pile toe levels were set on the basis of penetration into the dense sand layer, as evidenced by a threshold torque level of 200 bars. The pile toe levels were originally set at 10.7 meters based on the worst case condition defined during the exploration. Using the embedment criteria of 2 meters into the dense sand zone, the average depth for this 2000+ pile project was 8.8 meters.

3 INSTALLATION EFFORT

While the implementation of torque-related criteria met with some success on sites with relatively simple, well-defined strata, it became clear that it was not applicable to more complex conditions, and that differences in operator techniques could be a significant variable. After several iterations, it was found that the combination of torque (t_{fp}) and tool penetration rate (PR) provided a relatively simple, reliable indicator of subsurface conditions and relative capacity over a fairly wide range of conditions.

The data base from which the process evolved is for pressure grouted displacement piles installed by Berkel & Company Contractors, using the process described by NeSmith (2002). The piles considered in the current work were installed primarily in granular deposits of Tertiary age or younger. The majority were in relatively recent alluvial deposits adjacent to major rivers. Installation platforms were either Bauer BG 25s or Casagranda 220s. Data was acquired and processed using G&H hardware and software, with readings at 1-second intervals.

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), in this case 6.1 meters (20 feet) per minute.

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

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) of 100 bars.

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

The product of PRI and TI gives the Installation Effort (IE). The relationships for PRI and TI arise from the fact that neither penetration rate nor torque is linearly related to soil strength.

4 IE AS AN INDICATOR OF STRATIGRAPHY

The methodology has been applied to a variety of projects where good quality subsurface information is available. Figure 1 shows the IE versus depth chart for the project discussed previously. The IE data agrees well with CPT cone resistance, even in reflecting the relatively thin medium dense zones that occur within the otherwise dense sand layer. Figure 2 shows IE charts for 2 load tests on a project in New York City and the corresponding CPT data. At this site, fill 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 IE charts mirror the CPT data very closely. Ultimate loads for TP-1 and TP-2 were 2653 kN and 2788 kN respectively.

Figure 3 shows a set of CPT data and IE charts for two load tests from another site in New York City. At this site, fill is present to about 3 meters and is underlain by a soft to medium clay layer that extends to about 4.5 to 5 meters. Indication of a cobble zone that occurs sporadically at about 5 meters can be seen in CPT B.4-8. Below about 5 meters, medium dense to dense sand is present. In this case the movement of the tool from the soft to medium clay into the medium dense sand can be detected from the IE charts; however, the IE relationships do not reflect the same level of difference as does the CPT data. In passing through the fine-grained zone, the penetration rate was high, but the torque was also relatively high.

Figure 4 is from a project in a coastal area in Texas, where the materials are primarily fine-grained. Dredged fill occurs to about 4 meters, below which soft to medium silt and clay are present. The thin medium dense sand layer indicated by the CPT data at 10 meters was a consistent feature at the site, and TP-1 terminated in that layer. TP-2 was extended through the layer to a toe level 15.2 meters below the surface. The occurrence of the granular layer at 10 meters can be gleaned from the IE charts even though is less than 1 meter thick.

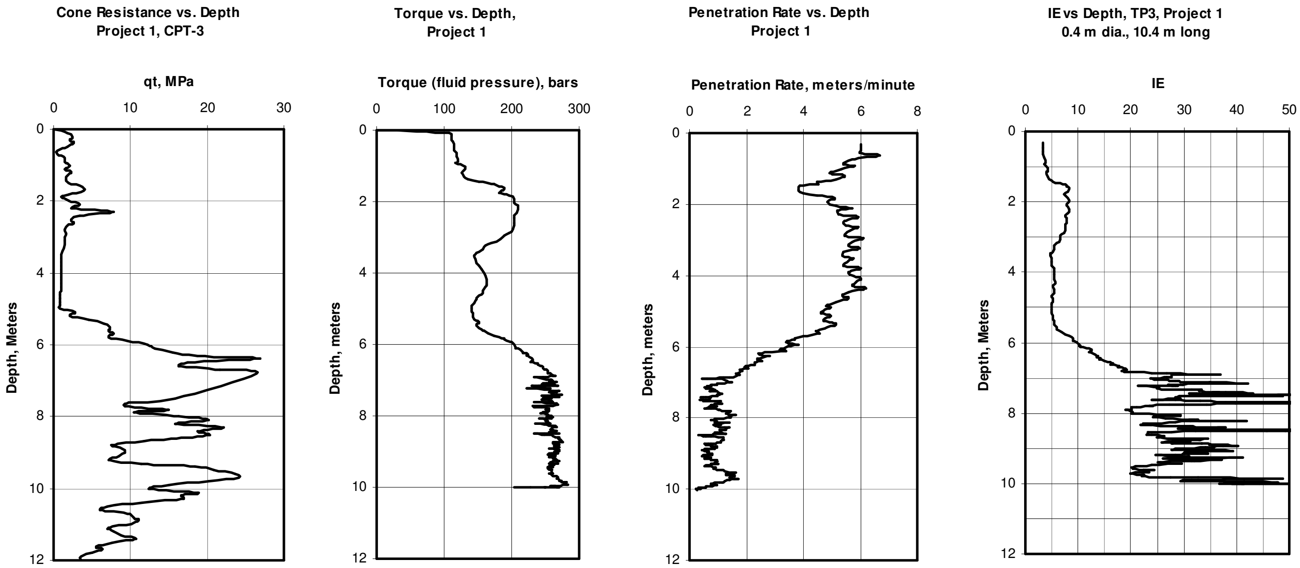

Figure 1. CPT, Torque, PR and IE Charts for Project 1

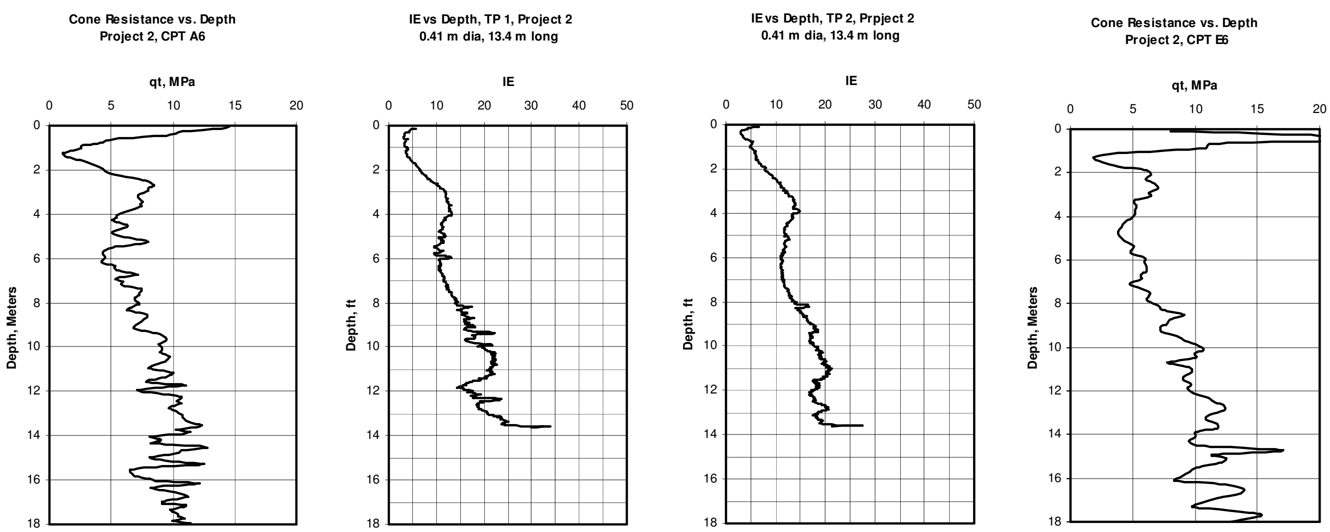

Figure 2. CPT and IE Charts for Project 2

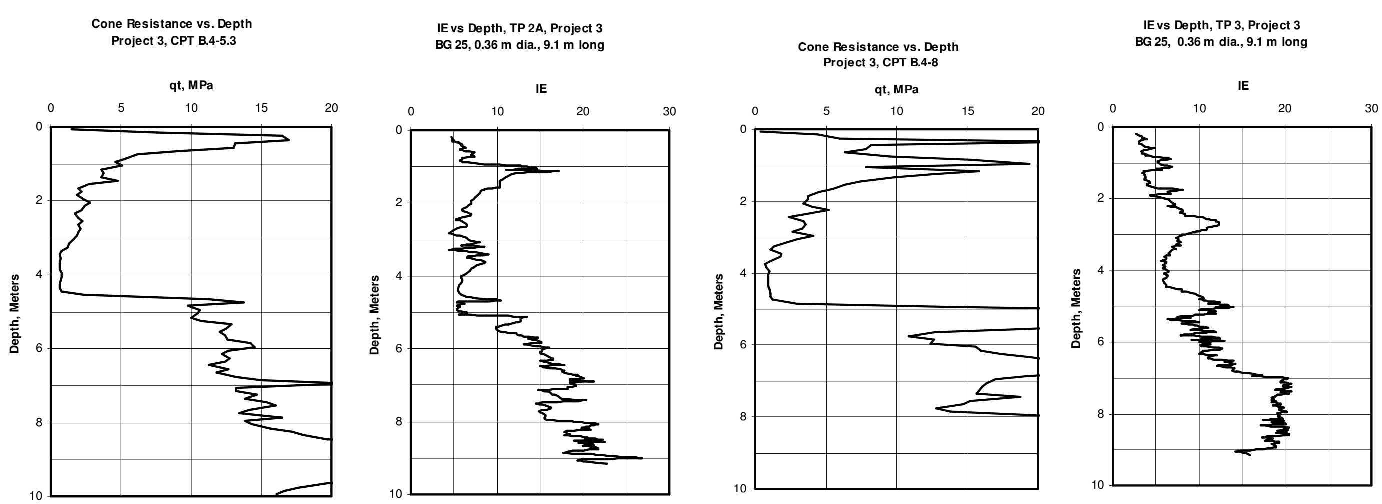

Figure 3. CPT and IE Charts for Project 3

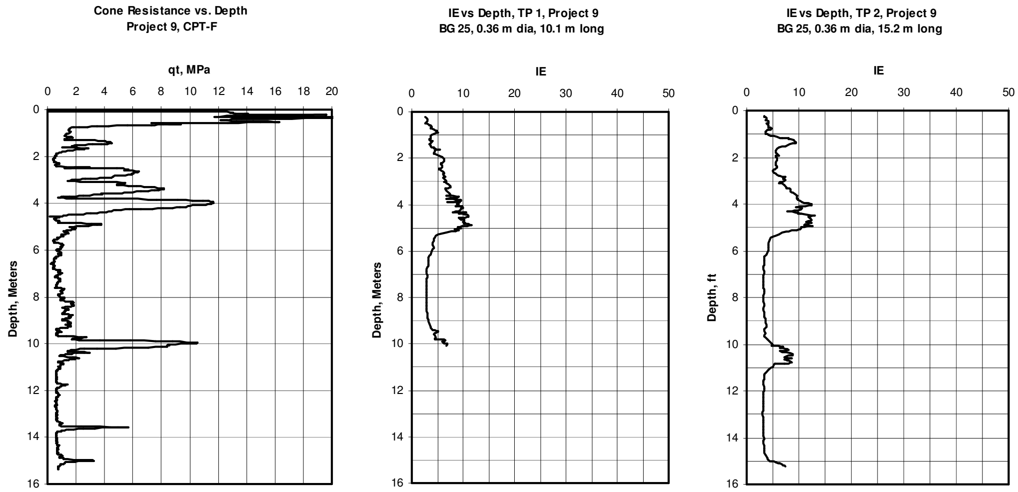

Figure 4. CPT and IE Charts for Project 9

5 IE AS AN INDICATOR OF CAPACITY

It has been demonstrated that instantaneous installation effort (IE) is a good indicator of subsurface stratigraphy over the range of conditions examined. It seems reasonable then that the total effort required to extend the tool to the toe level should have some relationship to pile capacity. On the face of it, the total effort should be an indicator of shaft resistance, and the effort just prior to reaching the toe level should be related to toe resistance. The data base for this work, which included 15 load tests on 9 sites, is shown on Table 1.

Figure 5 shows the relationship between total installation effort (SumIE) and ultimate shaft resistance. While the general trend is reasonable, the scatter is quite high. The relationship shown is the best of many combinations of total effort and the shaft component examined for the data base, including those with modifications taking into account the total volume of the pile.

Several combinations of installation effort in the final stages of drilling and toe resistance were examined but no meaningful correlation was found. This could be related to the quality of the data although strain gauge information was available for many of the load tests. A relationship between total effort and shaft resistance, and between effort near the toe level and toe resistance may exist, but it was not defined during this work, even with manipulation of IE to account for total pile volume, and other modifications.

The most consistent relationship that emerged from examination of the data base is between total installation effort (SumIE) and ultimate capacity (Q_{ult}). A plot of SumIE versus Q_{ult} is shown on Figure 6.

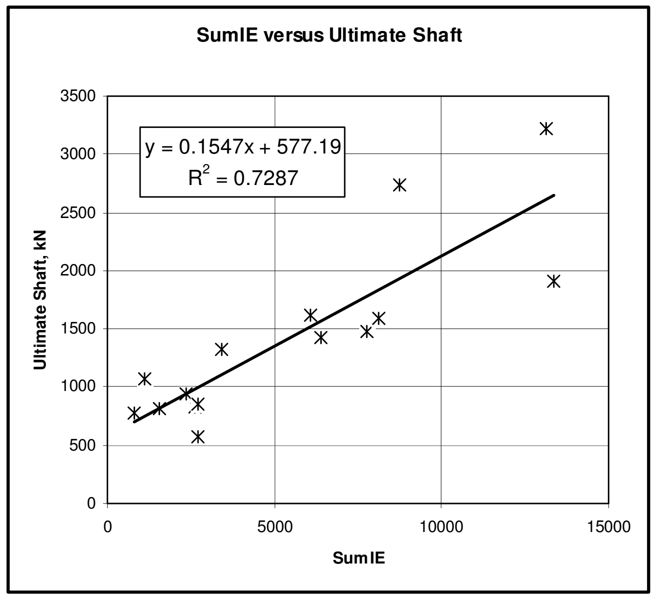

Figure 5. Total IE versus Ultimate Shaft Capacity

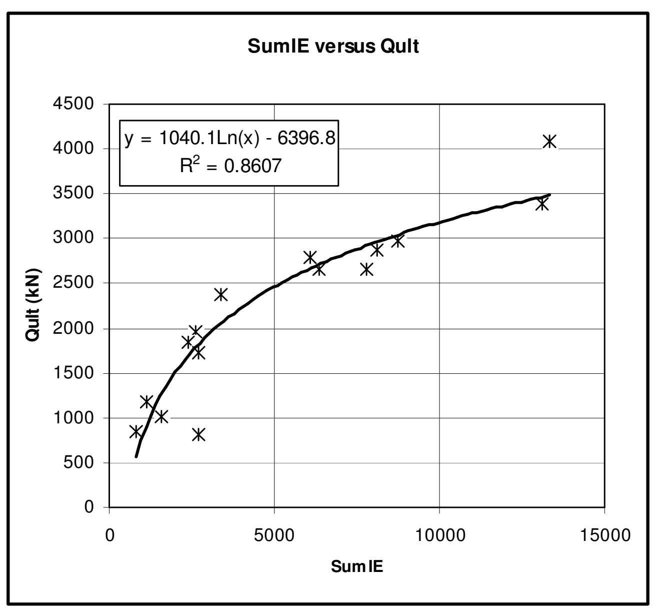

Figure 6. Total IE versus Ultimate Capacity

Project No.	Test No.	Length meters	Diameter meters	Ultimate kN	Unit Shaft kPa	Unit Toe MPa	Sum IE	Sum IE/Sum Vol IE	Vol. FT^2 Last 5'	Last 1.5 m IE
1	4	10.4	0.41	2653	88.1	6.7	7787	164.0	7.0	31.6
2	1	13.4	0.41	2653	66.1	7.5	6373	103.7	7.0	21.56
2	2	13.4	0.41	2788	74.7	7.2	6082	99.0	7.0	19.02
3	2	9.1	0.36	1956	64.2	9.0	2601	81.1	5.3	19.6
3	2A	9.1	0.36	1843	72.8	7.2	2371	73.9	5.3	19.8
3	3	9.1	0.36	1731	66.1	7.0	2710	84.5	5.3	18.8
4	1	7.3	0.30	809	65.1	2.5	2700	143.2	3.9	15.45
4	2	8.2	0.30	1012	81.4	2.2	1567	73.9	3.9	11.88
5	1	12.2	0.41	3383	163.7	1.0	13126	235.0	7.0	21.1
5	2	12.2	0.36	2967	159.0	1.8	8722	204.0	5.3	31.2
6	1	11.6	0.46	4080	91.0	7.7	13350	198.8	8.8	35.8
7	1	9.8	0.41	2372	84.3	6.4	3397	76.0	7.0	17.7
8	1	9.8	0.46	2877	90.0	6.9	8114	143.5	8.8	13.2
9	1	10.1	0.36	843	54.6	0.5	813	23.0	5.3	5
9	2	15.2	0.36	1180	49.8	0.9	1107	20.7	5.3	4.8

Table 1. IE Data Base

6 CONCLUSION

During the installation of displacement screw piles, the simple combination of torque and rate of tool penetration can be used to develop an index that is a reliable indicator of subsurface stratigraphy over a wide range of conditions. Such a relationship would certainly need to be process specific, and variations related to operator technique and characteristics of the installation platform may occur.

In the data base examined, there was not a coherent relationship between installation effort and the shaft and toe capacity components. There was however, a reasonably well-defined relationship between total installation effort and ultimate capacity.

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