COMPARISON OF LOAD TEST RESULTS BETWEEN ACIP PILES INSTALLED IN SAND IN PRE-DRILLED HOLES VERSUS CONVENTIONAL INSTALLATION

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Augered Cast-in-Place (ACIP) piles have long been used for deep foundation support in sands due to their high capacity and speed of installation. Very little information exists on the effects on capacity if the auger needs to be withdrawn from the hole prior to grouting. This condition can occur due to various reasons including grout plug ups, equipment issues, and grout supply delivery problems. It can become a major problem for the project team if this happens during production because the capacity of that pile is then in question, potentially resulting in re-design, installation of replacement piles and/or schedule delays. This paper compares the results of two high capacity test piles installed into a dense sand where one test pile was installed by first completely withdrawing the auger from the hole after drilling to the pile tip depth and the other test pile was installed utilizing conventional industry standard methods. Identical load tests were then performed on both piles to compare the effects of the two different installation procedures. The load test results were surprisingly similar in this case although the grout take required for the test pile installed in the pre-drilled hole was significantly higher to produce a similar grout return depth.

Introduction

Augered Cast-in-Place (ACIP) piles are used extensively along the Texas Gulf Coast due to their combination of high capacity and speed of installation resulting in one of the most cost effective deep foundation systems relative to other options. Soil conditions in this region typically consist of alternating layers of sand and clay in the upper several hundred feet. ACIP piles are routinely installed to depths of over 100-ft to achieve the required capacity depending on the site specific soil conditions and therefore typically extend through and tip into sand layers. Occasionally, due to various reasons like equipment issues and plug-ups, the auger is withdrawn from the hole without grouting. Significant sand in the soil profile could lead to questions about the effect of the auger withdrawal on the pile capacity and load-deflection relationship.

This paper summarizes the results of two identical pile load tests performed on adjacent piles of the same length with the main difference being one was installed using the standard installation procedure and the other was installed by first completely withdrawing the auger from the hole after drilling to the pile tip depth. The load test results were then evaluated using load transfer analyses to estimate the effect of the withdrawal of the auger on the load-deflection characteristics and capacity.

Engineers have had difficulty evaluating this condition when it occurs during production pile installation due to a lack of published technical information on the subject. The resulting concern is the loosening of the sands due to the auger removal without grouting and the subsequent re-drilling causing further loosening decreasing the pile capacity. Even if a pile load test was performed for the project using standard procedures the results wouldn't apply since the test pile was installed without the re-drill process. This can potentially lead to re-design, installation of replacement piles and schedule delays. Although integrity testing could be performed, it is often not possible to test the suspect production pile's capacity since it is typically in a pile group with reinforcing steel projecting out the pile top.

Pile Installation Process

ACIP piles are constructed by rotating a hollow stem, continuous flight auger into the ground to the required tip elevation. When the required depth is reached, a high strength, fluid grout is pumped under pressure through the hollow stem of the auger exiting through the tip (or bit). A pre-established amount of grout is initially pumped prior to lifting the auger to build up a "grout head" around the outside of the auger. The auger is then withdrawn in a slow continuous manner slowly rotating clockwise as the grout pumping continues to both (1) maintain the head of grout and (2) prevent any intrusion of water or soil into the grout column.

Upon grouting completion spoils are removed and the upper portion of the pile is then screened of any debris that may have fallen in while the spoils were removed from the pile location. The reinforcing steel is then placed through the fluid grout column, and the pile top elevation is established by either dipping out or adding fluid grout to the pile. The hole is never left open in this process so there is never a need for casing or slurry to be used. The project site is shown in Figure 1.

Figure 1. Project Site

Site Soil Conditions

The project site is located on the Beaumont Clay Formation with soils dating to the Pleistocene period. The Beaumont Clay Formation generally consists of thick layers of fine grained clay with interbedded layers of sands and silts. The clays located within this formation are overconsolidated due primarily to dessication. The course grained sands and silts of the Beaumont formation vary in density from loose to very dense.

The subsurface conditions of the site were explored by performing two soil borings (B-1 and B-2) to a depth of 100-ft below existing ground surface. As is typical for the Beaumont Clay formation the stratigraphy consisted of defined alternating layers of clay and sand. The soils consist of a firm to very stiff consistency lean and fat clays to a depth ranging from 27-ft to 47-ft, followed by medium dense to dense silty sand/clayey sands to depths of about 57-ft to 63-ft, underlain by stiff to very stiff fat clays to a depth between 72-ft and 75-ft, and terminating in dense to very dense sand and silty sand to the 100-ft explored depth. Groundwater was encountered between 15 to 16 feet below the existing ground surface at the time of the field exploration.

For the purpose of this study and analyses described here, the soil conditions from Boring B-2 were used, due to its proximity to the locations of the test piles (TP-1 and TP-2). TP-1 had the auger withdrawn due to mechanical issues and TP-2 was installed with conventional methods.

The soil conditions for Boring B-2 used in the analyses are defined by clays with shear strengths ranging from 0.6 to 1.2 tsf to a depth of 27-ft followed by sands with SPT "N" values ranging from 11 to 21 blows per foot to a depth of 57-ft, underlain by clays with shear strengths ranging from 1.0 to 1.5 tsf, with piles terminating in sand with SPT "N" values ranging from 40 to 70 Blows per foot to the boring termination depth of 100-ft.

Test Pile Installation

The project specifications required that one 18-inch diameter by 90-ft long ACIP test pile be installed and then tested axially in compression utilizing static load testing methods to confirm that the pile would achieve twice the required design load. To resist the compression load, four reaction piles of similar length were designed and installed the previous day prior to the test pile installation. One of the reaction piles was taken to the same depth as the test pile to observe the soil conditions throughout the full length of the pile. Drilling a full length reaction pile aids in determining the soil conditions, penetration rates, equipment capabilities, total grout volume, and grout return expected and observed. This same procedure is then implemented or adjusted to install the test pile. The production piles are then installed following the same procedures and the test pile.

Test Pile 1 (TP-1) was installed the following day after the reaction piles. During the drilling of TP-1 the Pile Installation Recorder (PIR) was losing signal during the penetration and it was not clear if it was recording data properly. As we reached the 90-ft tip depth according to the marks on the leads, the PIR indicated we were only at about 75-ft depth. After discussions amongst the engineers and supervisors on the crew, it was determined to proceed with placing the grout utilizing the pump strokes per 5-ft interval as derived from the calibration of the grout pump. However, when the grouting commenced, the auger tip was determined to be plugged. At this point, the only option was to remove the entire string of auger from the hole without placing grout to clear the plug from the equipment.

The plug was cleared, equipment cleaned, and system re-primed after arrival of additional grout. This process took about 3 to 4 hours leaving the excavated hole open for the same duration.

The grout arrived on site and flow was tested at 17 seconds using a calibrated ¾-inch orifice flow cone. The auger was placed in the same excavated hole (TP-1) and previous tip was reached. The operator, utilizing the PIR, was asked to pump the pile “heavier” than the anticipated production piles due to the auger being withdrawn and the hole being open for an extended period of time. The pile was completed with a pile volume of 162 percent of theoretical with a grout return of 8-ft.

Due to the issues encountered with the installation of TP-1 and the uncertainty of the effects on the true capacity, a second test pile was determined to be necessary. Two of the reaction piles from the original layout could be used as reaction piles and therefore two additional reaction piles and one test pile (TP-2) were added to the general test pile location.

TP-2 was installed a few days later with no issues. This pile was installed using conventional construction methods and durations similar to production pile installations. The grout for this pile had a flow of 17 seconds using the flow cone and the total grout placed in the pile was 142 percent of theoretical.

The compressive strength of the grout cubes at the time of load testing for TP-1 and TP-2 were 5,175 psi and 4,975 psi, respectively.

Load Test Results

Identical pile load tests were performed on the two test piles in accordance with ASTM D 1143 standards using Procedure A. The piles were loaded to 770 kips in 35 kip increments with 5 minute hold times. After the maximum test load was applied, the piles were unloaded in five equal decrements. The load test on TP-2 is shown in Figure 2.

Figure 2. Load Test on TP-2

The results of the load tests for TP-1 and TP-2 are shown in Figure 3. Also plotted in Figure 3 is the elastic deformation (PL/AE) of the pile, the Davisson offset failure criteria and the 5 percent of pile diameter failure criteria for reference.

The load tests produced virtually identical load-deflection results indicating there was no effect on capacity due to re-drilling TP-1 in an un-grouted hole. TP-1 did have 20 percent more grout volume pumped in it producing the same grout return depth as TP-2. Thus, TP-1 was a larger diameter pile than TP-2, which compensated for the loosening of the sands when the auger was withdrawn.

Per IBC code the maximum allowable stress (0.3 f'c) on the pile section results in a load of 385 kips using 5,000 psi grout. Even though the piles didn't reach a deflection based failure criteria at twice design (770 kips), the allowable pile capacity was nonetheless limited to the 385 kip load. Thus, there was no difference in the design capacity of the two test piles.

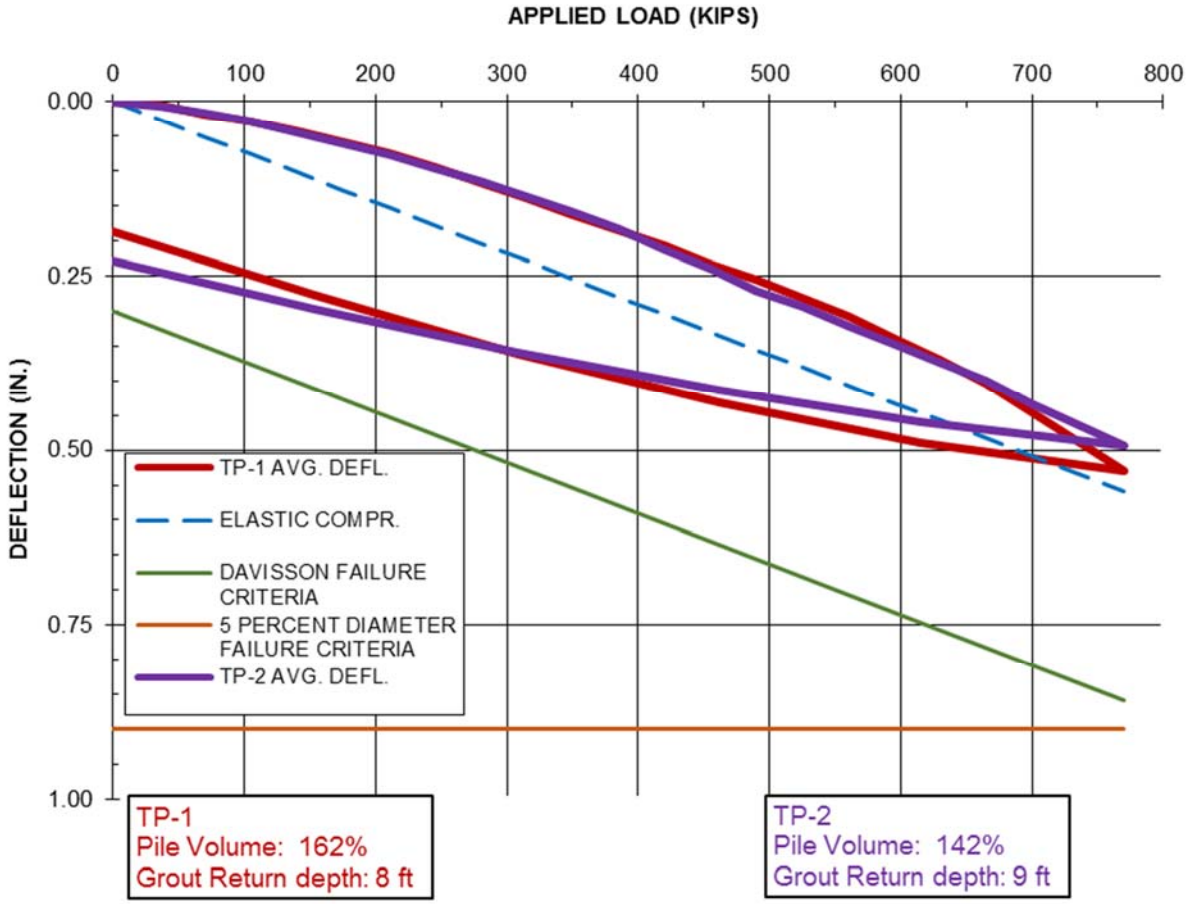

Figure 3. Load Test Results: TP-1 and TP-2

Load Transfer Analysis

Load transfer analyses were performed using the computer program APILE from Ensoft to better evaluate the effect of loosening the sand layers due to withdrawal of the auger and subsequent re-drilling. The angle of internal friction of the sand (Φ), limiting skin friction and end bearing components were varied to produce a computed deflection that matched the measured deflections for both load tests.

API Recommended Practice 2A (RP2A) load transfer curves were used for both the clay and sand layers in the analyses. The load transfer curves used for both piles are illustrated in figures 4 and 5 for TP-1 and TP-2, respectively. The soil profile used in the analyses was based on boring B-2 conditions discussed previously. This results in a profile that is 53 percent sand and 47 percent clay.

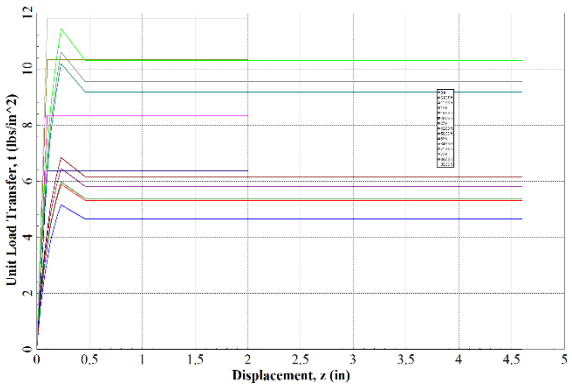

Figure 4. Load Transfer Curves for TP-1

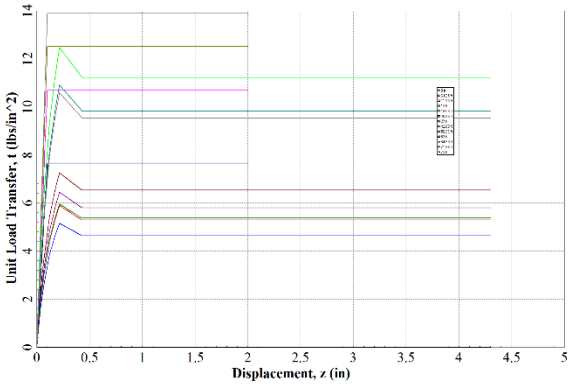

Figure 5. Load Transfer Curves for TP-2

The effective pile diameter used in the analyses was based on the actual measured grout volume pumped in each pile. Therefore, the diameter used for the pile model was 23.0 inches for TP-1 and 21.5 inches for TP-2.

The modulus of elasticity for the grout is typically assumed to be a constant value based on the grout strength. As discussed by Siegel (2010) the secant modulus of the grout used in ACIP piles decreases with increasing strain. At low strain values (less than about 200 microstrain) the modulus varies nonlinearly with strain and can be significantly higher than values computed from the grout strength. At higher values of strain the modulus still varies with strain but is more linear.

Typical load transfer analysis software does not allow for the input of a modulus that varies with strain. These analyses were performed using moduli corresponding to the strain associated with both design and twice design loads. The modulus used for the design load of 385 kips was 4,100 ksi. The modulus used for twice the design load of 770 kips was 3,800 ksi.

In order to get the computed top deflections to match the measured data, the skin friction values in the sand layers for the TP-1 analyses were reduced in an iterative process. The iterations were completed when the measured and computed deflections converged to the values shown in Table 1. For the final analysis the angle of internal friction of the sand (Φ) was reduced by 5 degrees and the limiting skin friction values ($f_{s\text{-}max}$) was decreased by 20 percent. No material property changes were made to the clay portions of the soil profile.

The results of the load transfer analyses compared to the measured values from load tests are summarized in Table 1.

Table 1. Results of Load Transfer Analyses

Pile	Load (kips)	Deflection (inches)			Average Axial Strain (microstrain)
		Measured Top	Computed Top	Computed Tip	
TP-1	385	0.184	0.172	0.030	131
	770	0.529	0.538	0.190	322
TP-2	385	0.183	0186	0.027	147
	770	0.493	0.484	0.096	359

There was no change made to the end bearing values or load transfer Q-w curve. Surprisingly, any minor changes in the end bearing component produced top deflections that were not even close to the measured values. Thus, the loosening effect of the sand due to the auger removal was limited to reducing the skin friction components only and had no effect on end bearing other than reducing the Φ angle by 5 degrees. However, the end bearing component was at the maximum limiting value at the pile tip depth so changing the Φ angle does not affect the end bearing Q-w curve.

Conclusions

Identical pile load tests were performed on two test piles that produced virtually identical load-deflection results, indicating there was no overall effect on capacity due to re-drilling one of the test piles in an un-grouted hole.

TP-1 did have 20 percent more grout volume pumped in it producing the same grout return depth as TP-2. Thus, TP-1 was a larger diameter pile than TP-2, which compensated for the loosening of the sands when the auger was withdrawn.

Load transfer analyses were performed to better evaluate the effect of loosening the sand layers due to withdrawal of the auger and subsequent re-drilling. The angle of internal friction of the sand (Φ) was reduced by 5 degrees and the limiting skin friction values ($f_{s\text{-}max}$) were decreased by 20 percent in the sand to produce computed deflections that matched the measured values. No material property changes were made to the clay portions of the soil profile.

The test piles were tipped into a dense sand. There was no change made to the end bearing values or load transfer Q-w curve in the analyses. Thus, the loosening effect of the sand due to the auger removal was limited to reducing the skin friction components only and had no effect on end bearing

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