Field Load Testing of ACIP Pile in Clay Soil Profile

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Abstract

In this study, supporting a state highway bridge with auger cast in-place (ACIP) piles in clay soil replacing the drilled shafts that were used in the preliminary design for supporting the bridge was investigated. Hence this study was a multi-phase study where the design capacity of the ACIP pile had to be verified with many other factors that control the rapid construction of the bridge. A full-scale load test was performed to verify the constructability, curing, axial capacity and skin friction developed in the ACIP pile supported in clay soil was investigated. The design load for the 760 mm (30 in) pile was 1150 kN (130 tons) but the test pile was loaded to 4600 kN (520 tons), four times the design load, and the settlement was 17 mm Vipulanandan p-q model and three parameter correlation model were used to model the curing and the performance of the tested ACIP pile.

1. Introduction

Based on the project type, loading conditions, geological features and available resources, there are many options to select the supporting foundation systems. Non-displacement augered cast-in-place (ACIP) piles are increasingly used for supporting building, bridges, sound barrier walls and many other structures around the world (Neely, 1991; O'Neill, 1994; Vipulanandan, 2005). These piles have been used in the private sector in the United States for over 50 years (O'Neill, 1999) and became very popular in the early 1990's because of the developments in the construction quality control systems. Fast installation, low cost and minimum environmental impact are some reasons for the tremendous growth in ACIP pile usage. ACIP piles can be distinguished geotechnically from drilled shafts and driven piles by the magnitude of effective stress changes they produce in the surrounding soil during the construction (O'Neill, 1994). In an ACIP pile, depending on the soil type and rate of the auger advance, ground stresses are maintained near the value that existed before construction by using a continuous flight auger, which is never withdrawn until the cementitious material (fluid Portland cement grout) is placed by pumping the grout beneath the withdrawing auger under pressure through the hollow stem of the auger (Vipulanandan et al., 2005-2012). Therefore, considering the principle of effective stress, the load-displacement behavior of the ACIP pile falls in between that of a drilled shaft and a driven pile (O'Neill, 1999).

Load-displacement measured at the pile head provides the capacity of the pile but gives no information on the load transfer mechanism which is shaft resistance distribution and toe resistance separately. This information is needed in order to design a safe and economical pile. Therefore, conventional pile load tests are being instrumented more frequently to provide the load transfer along the pile.

Instrumenting the piles using vibrating wire strain gages is a preferred method because of the durability and the accuracy of this type gages. Vibrating wire strain gages operate on the vibrating wire principle rather than the electric resistance principal common to most strain gages. The vibrating wire sister bars measures strain in a member by measuring the change in frequency of a tensioned piano wire clamped in a fixture securely attached to the member. Strain obtained from gages was then multiplied by the product of the equivalent elastic modulus for the cross section and the nominal cross-sectional area to obtain load in the pile at the depth of the strain gage. Load difference between levels gives the amount of load carried by the friction at the pile-soil interface. Instrumentation mainly provides the skin friction developments at each load increment applied during a load test to verify the capacity of a pile. This information can then be used to evaluate the design equations accuracy.

Every ACIP pile would become a “verified” pile (Brettmann, et. al. 2005), since the construction quality was monitored using the automated monitoring system where the volume of the grout pumped and the pressures are monitored with the depth. One of the main concerns when using ACIP piles is the possibility of decompression of soil surrounding the pile during drilling. Control of the rate of penetration of auger will avoid decompression of the ground, loosening of the in-situ soil, and ground subsidence (Brown, 2005).

2. Objectives

The overall objective was to monitor the performance of newly constructed ACIP pile in clay soil. The specific objectives were as follows:

(i) Instrument and monitor the curing of the ACIP pile in CH clay soil.

(ii) Perform a load test on the ACIP pile after complete curing.

3. Field Testing

This study was focused on verification of design capacity of ACIP piles based on instrumentation and monitoring. The first phase of the study included a full-scale load test to not only to verify the constructability, curing, axial capacity and skin friction developed in the ACIP pile based on the construction method used in the clay soil but the earliest time it can be loaded. The earliest time to carry the load by the ACIP piles will also control the rapid construction of the bridge and the supporting structures.

Soil Borings

The bridge site consists of a mixed soil profile of generally soft to stiff clays and loose sands. Two soil borings were performed to design the ACIP piles and the typical soil profile with the Texas Cone Penetrometer (TCP) readings is shown in Fig. 1. In this borehole, the top 3 m (10 ft) layer consists of loose gravelly sand, under laid by a very stiff clay layer. Stiff clay layer was observed below the depth 8.5 m (27.5 ft). Test pile was 12 m (39.1 ft) long and almost 5.5 m (18 ft) long part was socketed into this layer. Figure 1 shows the schematic view of the instrumentation and geotechnical profile.

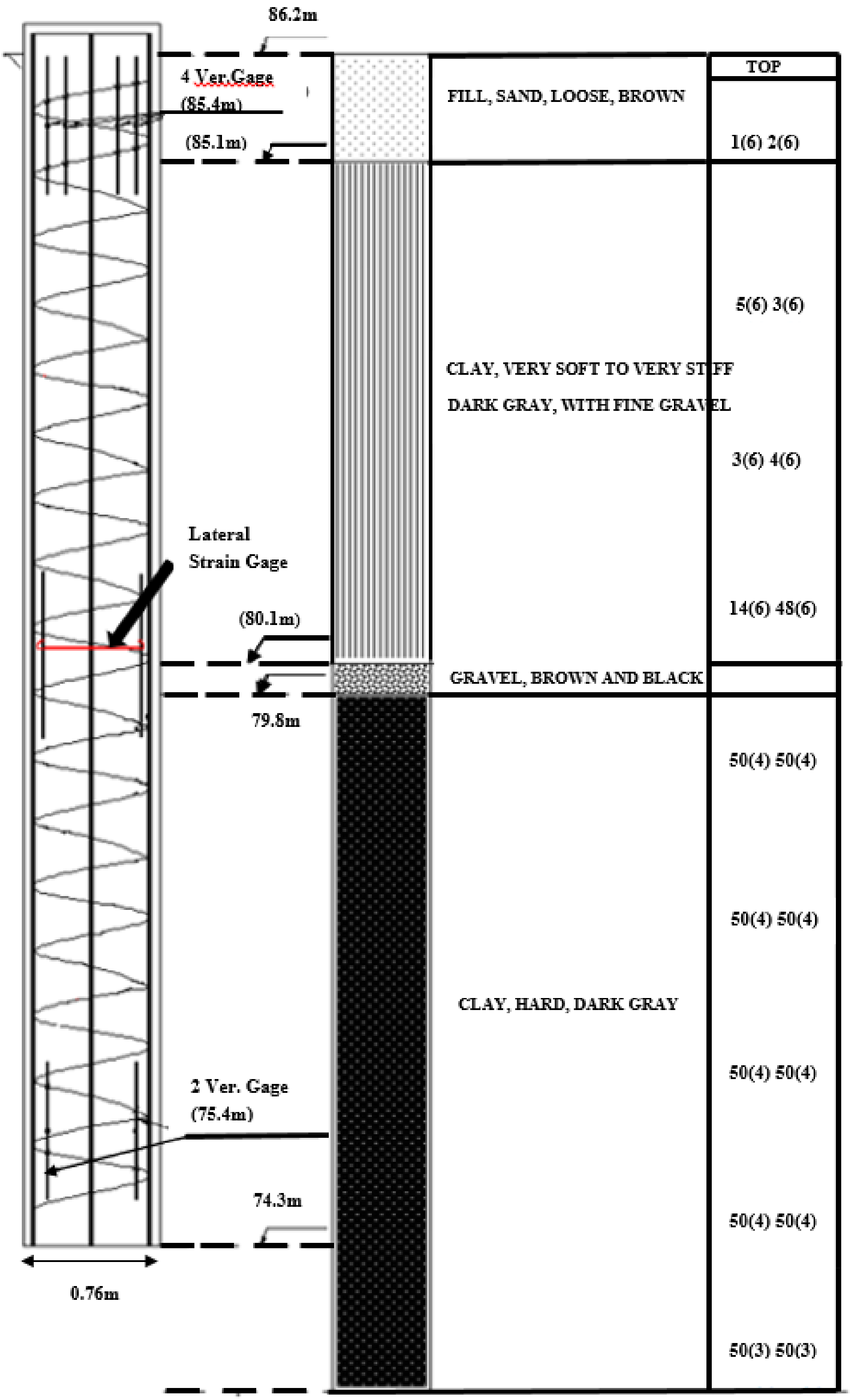

Figure 1. Geotechnical Profile and Instrumentation of the Service Piles

4. Results and Discussions

Curing and Environmental Effect

The pile curing was monitored during the initial 7 days of curing. The patterns of the temperature variation with time is shown in Figure 2. The time to reach the maximum temperature was 9.4 hours. The time-temperature relationship for the ACIP pile is shown in Fig. 2. The maximum average temperature measured was 63˚C. The maximum temperature measured was over 45˚C higher than the surrounding ground temperature.

Temperature with time was modeled using the Vipulanandan p-q curing model using Eqn. (1) (Vipulanandan et al. 1990, 2015) and the prediction is compared to the experimental results in Fig. 6. Integration of this curve with time will give the maturity.

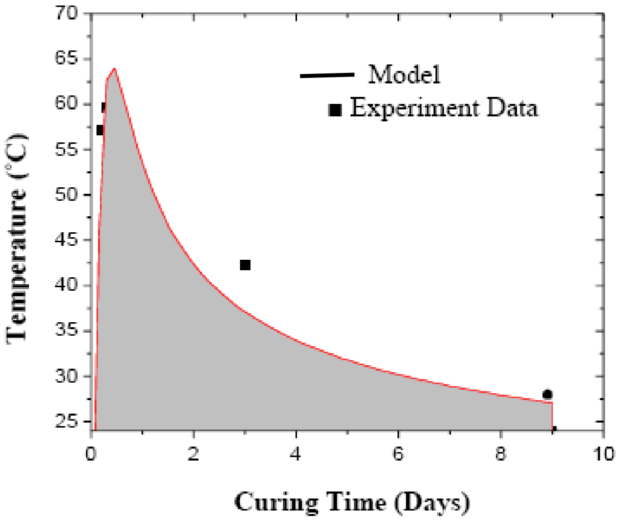

Figure 2 Measured and Predicted Curing of the Pile

The Vipulanandan p-q curing model is as follows:

$$T = \left[\frac{\frac{t}{t_p}}{q + (1 - p - q)\frac{t}{t_p} + p\left(\frac{t}{t_p}\right)^{\frac{(p+q)}{p}}} \right] T_p \qquad (1)$$

where p, q are material parameters, T_p and t_p represent the peak temperature and the corresponding time respectively. In this case the parameter "q" was 0.8 and the parameter p was 0.2.

Load Test

The conventional load-deformation measured at the pile head during full-scale load test establishes the capacity of pile, but it does not give quantitative information on the load-transfer behavior over the length of pile. Hence, instrumentation and monitoring of the test pile plays an important role in understanding the load transfer mechanisms and curing of the grout in the ACIP pile so that it can be loaded. This paper discusses not only the instrumentation of 760 mm (30 in.) diameter and 12 m (39 ft) long test ACIP pile supported on hard clay but also eight reaction piles used to provide adequate reaction capacity. The test pile was instrumented with load cell and head settlement gauges, in order to measure applied load and settlement during the load test. Also, vibrating-wire sister bars with thermocouple were attached along the length of the test pile and selected reaction piles. Also in the test pile vibrating-wire sister bars were placed horizontally to quantify the lateral deformation of the pile during loading and determine the curing of the grout in the middle of the pile. The load distribution along the length of the test piles and reaction pile were determined from the strain measured from the sister bars. Strain values were measured using the vibrating wire gages at four levels along the test pile and three levels along the reaction piles. The design load for the pile was 120 tons.

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The full-scale axial load test was performed in general accordance with ASTM D1143, “Standard Method of Testing Piles under Static Axial Compression load” to better characterize the behavior of ACIP piles under axial loading. Eight reaction piles (RP, 457 mm in diameter and 12 m long) were used for ACIP pile (Test Pile, TP)load test to provide adequate reactive capacity. Figure 3 shows the schematic view of load test set up.

The test pile was loaded in 180 kN increments up to 4600 kN and unloaded in four equal steps. The pile was loaded more than four times the design load of 1150 kN. The deflection at the design load was 2 mm and the maximum deflection measured was 17 mm at the final load of 4600 kN and a residual displacement of 9.7 mm after unloading. The load settlement curve of the test pile is shown in Fig. 3. The ultimate capacity of the pile was estimated as 5916 kN (667 tons) based on the pile-displacement property correlation model in Eqn. (1) (Vipulanandan, 2005).

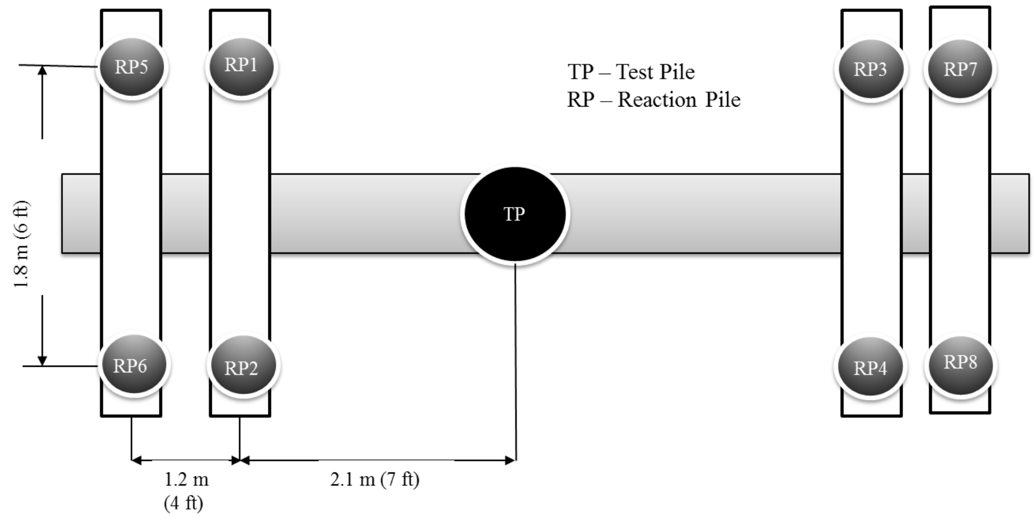

Figure 3 Schematic View of Load Test Set up

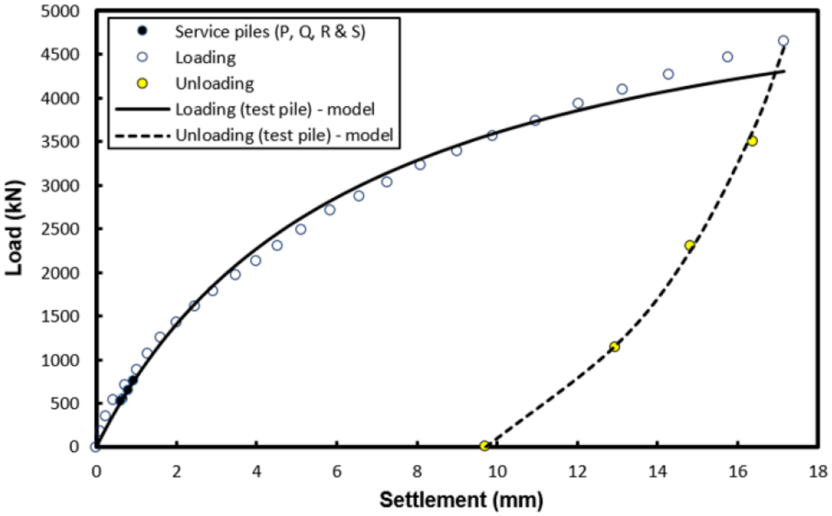

Figure 4 Load-Settlement Relationship for the ACIP Test Pile

$$(Q/Q_{ult}) = (\rho/d)/(\alpha+\beta(\rho/d)) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots \quad (2)$$

Where Q is the load and Q_{ult} is the ultimate load at very large settlement. The settlement is ρ and ρ_{50} is the settlement at 50% of the ultimate load. The loading model prediction using Eqn. (2) and the parameters summarized in Table 1 is shown Fig. 4.

Table 1. Summary of the Pile Load-Displacement Relationship Parameters

Description	Q_{ult}(kN)	d(mm)	α	β	RMSE
Test Pile	**5916**	**760**	**0.0084**	**1.0**	**25.3**

When unloading from test load Q* and settlement ρ* the model used to predict the relationship is as follows (Eqn. (2)):

$$(Q/Q^*) = ((\rho-\rho_o)/\rho^*)/A'-(B'(\rho-\rho_o)/\rho^*) \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

The loading model prediction using Eqn. (1) and the parameters summarized in Table 2 is shown Fig. 4.

Table 2. Summary of the Pile Unloading Displacement Relationship Parameters

Description	Q^* (kN)	ρ_o(mm)	ρ^*(mm)	A'	B'
Test Pile	**4610**	**9.7**	**17.0**	**1**	**1.28**

5. Conclusion

Based on the instrumentation and monitoring of the full-scale load test and performance of the 760 mm diameter ACIP service piles for 600 days in clay soils following conclusion are advanced:

1. Monitoring the curing of the grout not only helped in determining the quality of the pile but also to decide on the earliest time the pile can be loaded. The ACIP pile showed complete curing in 7 days.
2. Based on the full-scale load test, it was determined that when the pile was loaded to the design load of 1150 kN the settlement was about 2 mm. The settlement was 17 mm at a load of 4600 kN, four times the design load. With the instrumentation of the piles it was possible to quantify the skin and tip load transfers in the test pile and service piles.
3. Vipulanandan p-q model and property correlation model were used to predict the curing and performance of the load tested pile and all at the service piles.

6. Acknowledgement

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