Continuous Flight Auger Pile Bridge Foundations (Phase II)

Project No. 5-3940-03

Implementation Report 5-3940-03-1

Texas Department of Transportation

by

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16. Abstract

This report discusses the behavior of ACIP piles in very dense sand and hard clay. Full scale load test was conducted on instrumented ACIP piles which were designed to support highway bridges on SH7 at East Cochino Bayou (ECB) and Cochino Bayou (CB) with a design capacity of 92 tons and 128 tons respectively. Construction quality control techniques for ACIP piles were reviewed and the installation of two piles were monitored and evaluated. Load tests were performed on 30 in. diameter and 33.1 ft (ECB) and 39.1 ft (CB) long ACIP pile to verify its design capacity. The pile was loaded over 350% of the design load. The loading frame was supported on 8 reaction piles with a diameter of 18 in. The test pile was instrumented using load cell and axial vibrating wire strain gages at four levels and lateral vibrating wire strain gages at two levels. The reaction pile was instrumented using vibrating wire strain gages at three levels. The load-settlement and load transfer relationships of the piles were investigated based on the load test. The long term behavior of 6 service piles was also studied for more than a year. Load on the service piles was 70 tons for ECB and 60 to 86 tons for the CB piles after 600 days.

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ENGINEERING DISCLAIMER

The contents of this report reflect the views of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Texas Department of Transportation. This report does not constitute a standard or a regulation.

There was no art, method, process, or design which may be patentable under the patent laws of the United States of America or any foreign country.

IMPLEMENTATION STATEMENT

This is an implementation project to demonstrate the potential of using continuous flight auger (CFA) pile/ auger-cast in place (ACIP) pile as an alternative to drilled shafts in the bridge foundation system. Based on settlement measurements over 600 days, the two bridges in dense sand and hard clay near Lufkin, Texas have performed very well.

The Report will be a guidance document to TxDOT engineers on the instrumentation and performance of ACIP piles in bridge foundation systems.

TABLE OF CONTNETS

INTRODUCTION

Continuous flight auger piles (CFA), also known as non-displacement augered cast-in-place (ACIP) piles are increasingly used for supporting buildings, bridges, sound barrier walls and many other structures around the world. 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. 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, 2005). 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. 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 instrumented to provide the load transfer along the pile (Fellenius, 2001).

OBJECTIVE

The overall objective of this study was to investigate the load transfer mechanism of ACIP piles. Specific objectives are as follows:

1) Review the construction quality control techniques for ACIP piles.
2) Compare the load transfer mechanism and load-displacement relationships in dense sand and hard clay for 760 mm (30-inch) diameter ACIP pile.
3) Long term monitoring of service piles in dense sand and hard clay

SITE INFORMATION

Two full scale load tests were performed on two ACIP piles for two bridges at East Cochino Bayou (ECB) and Cochino Bayou (ECB) in SH 7. The ECB site and the CB site are a quarter mile apart from each other along SH7 and located approximately 30 miles east of Crockett, Texas. Initial design called for drilled shaft which was replaced by ACIP piles. Drilled shaft design charts proposed by Texas Department of Transportation using TCP data were used for the design of the ACIP piles.

East Cochino Bayou

The East Cochino Bayou bridge site consists of a sand soil profile of generally loose to very dense sands. The site is located in the Crockett formation (soft clays, unconsolidated fine-grained sands, red soil, 125-450 ft. thick) which is an Eocene-aged deposit under Claiborne group. Two soil borings (EF-1 and EF-2) were performed to collect information for designing the ACIP piles. Characterization of the soils were completed using the Texas Cone Penetrometer (TCP). In this borehole, the top layer was loose sand to a depth of 5 m (17 ft) and underlain a 2.8 m (9 ft) thick dense sand layer below it. Very dense sand layer was observed starting from the depth 8 m (26 ft) and gives most of the carrying capacity of the test pile. Test pile was 10 m (33.1 ft) long with almost 3 m (10 ft) placed into the dense sand layer. Figure 1 shows the instrumentation and geotechnical profile of ECB.

Cochino Bayou

The Cochino Bayou bridge site consists of a mixed soil profile of generally soft to stiff clays and loose sands. Two soil borings (CB-1 and CB-2) were performed to design the ACIP piles. In these boreholes, top layer was loose gravelly sand to a depth of 3 m

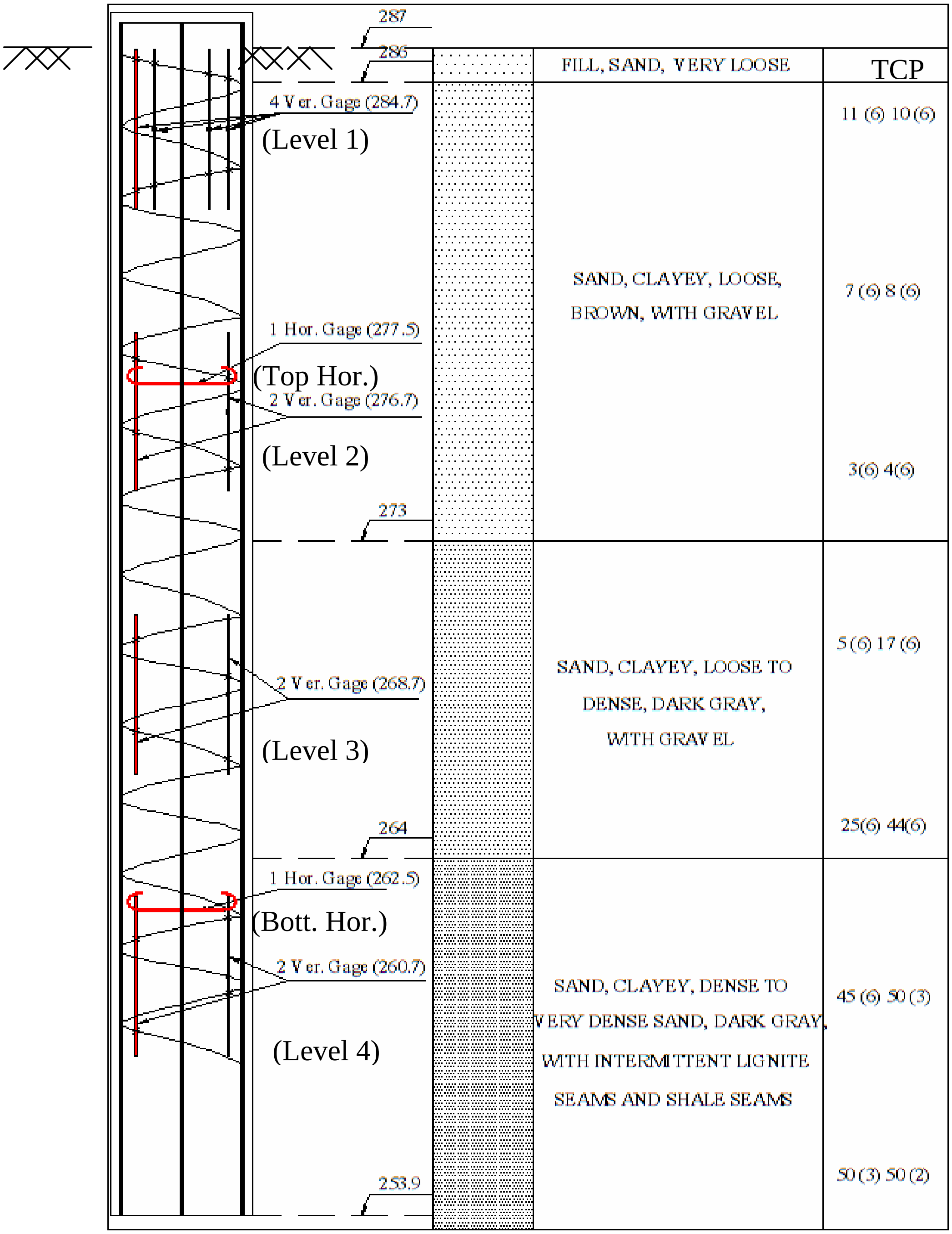

Fig. 1 Instrumentation and Geotechnical Profile at ECB Site

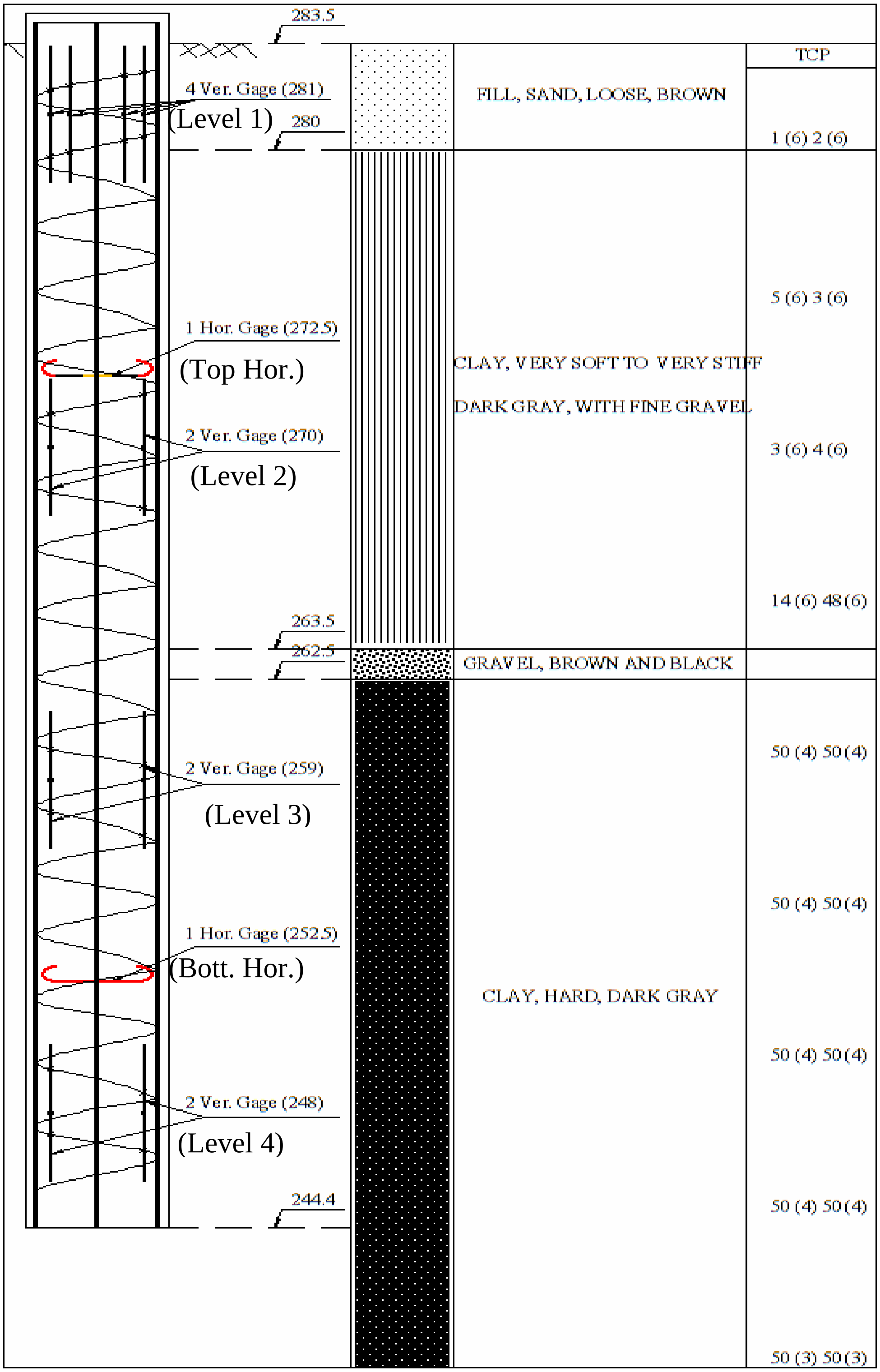

Fig. 2 Instrumentation and Geotechnical Profile at ECB Site

(10 ft) and underlain by a 5 m (16.5 ft) thick of very soft clay layer. Stiff clay layer was observed starting from the depth 8.5 m (27.5 ft) and gives the most of the carrying

capacity of the test pile. Test pile was 12 m (39.1) ft long with almost 5.5 m (18 ft) socketed into this layer. Figure 2 shows the instrumentation and geotechnical profile of CB. Steel reinforcement cage was instrumented with vibrating wire strain gages to measure the temperature and strains at various locations in the piles. Total of 10 gages were installed axially at four different levels along the pile. Besides this, 2 strain gages were installed horizontally at two different locations. Because the strain gages had their sensors at the center of the vibrating wire strain gages, readings taken from these gages were from the center of the pile cross section.

CONSTRUCTION, INSTRUMENTATION AND QUALITY CONTROL

ACIP piles can be installed more rapidly and relatively less disturbance to the surroundings and hence installation procedure and the quality of the material used in the construction have significant effects on the behavior of ACIP piles. Construction quality can be monitored using the automated monitoring system where the volume of grout pumped and the pressures are monitored with depth. Also the maximum and minimum pressure required to advance the auger was monitored with time. The critical rate of penetration of the auger was found to be 30 mm/sec with an auger revolution of 5 rpm which was held constant during the drilling for ECB. Maximum grout pressure was held almost constant and was around 1380 kN/m^2 (200 psi). Minimum grout pressure was fluctuating along the depth. The average min. pressure is higher at deeper levels due to the higher soil confinement. For CB the maximum and minimum grout pressures were held almost constant and were around 1655 kN/m^2 (240 psi) and 965 kN/m^2 (140 psi) respectively.

In addition to the standard quality control techniques described above, monitoring the curing phase of the ACIP piles was performed. Immediately after placing the instrumented cage into the grout filled hole, temperature and strain were monitored for the test piles. Valuable information was obtained for the curing stage of the piles. Both the temperature and the strains were monitored during the curing to observe the changes with time and to decide appropriate time for load testing the pile. A detailed study of pile installation and curing of the test pile on this site was documented by Vipulanandan, et al. 2007.

FULL-SCALE LOAD TESTS

In order to better characterize the behavior of Augered Cast in Place (ACIP) Piles under axial loading, two full scale load tests on instrumented ACIP Piles were performed at ECB and CB (both piles were 30 in. (760 mm) in diameter and 39.1 feet long in CB and 33.1 feet long in ECB). The instrumentation consists of vibrating wire strain gages placed at selected levels to determine the transferred load at that location for each load applied to the pile head. The gages provided values of strain which was multiplied by the cross sectional area and the elastic modulus of the pile to find the transferred load at each level.

In this study, load transfer mechanism and side friction development was studied for each load test in different soil profiles. Test piles were seated in very dense sand in ECB and hard clay in CB.

Two ACIP Piles were instrumented using vibrating wire strain gages at four different levels along the pile. 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. Load difference between levels gives the amount of load carried by the friction at the pile-soil interface.

Calibration factors obtained for vibrating wire strain gages from the laboratory tests were in agreement with the factory calibration factors. The average ratio of laboratory to manufacturer calibration factor was 1.012. The ratio varied from 0.96 to 1.08. The standard deviation and coefficient of variation were 0.027 and 2.6% respectively. Calibration factors were obtained by applying compression force in the laboratory while the manufacturer used tension force for calibration. Results showed that the same calibration factor can be used for both tension and compression forces.

Quick Load Test Method (ASTM D 1143) was used to perform the load tests. In this method, load is applied in increments of 10 to 15 % of the proposed design load with a constant time interval between increments of 2.5 min or otherwise specified. Figures 3 and 4 are schematic view of the pile load test setup. Load was applied to the piles by hydraulic jack acting against anchored reaction frame. 8 reaction piles (18 in. in diameter and 40 feet long) were used for each ACIP pile load test to provide adequate reactive capacity. Piles in both sites were instrumented with load cells and head settlement gauges, in order to measure applied load and settlement during the load test. Furthermore, vibrating-wire sister bars were attached along the length of the test piles' full-depth reinforcing cages, which were inserted in the grout column immediately after the auger's withdrawal. Load tests were performed by applying load increments, of about 10% of the expected ultimate capacity every 5 min, by jacking against pile-anchored reaction beams.

In ECB, pile was loaded in 10 tons increments up to 200 tons and the increments were then increased to 20 tons up to 320 tons. The pile was unloaded in four equal steps. In CB, pile was loaded in 20 tons increments up to 520 tons. Similarly in CB pile was unloaded in four equal steps.

The load-settlement curves from the load tests are shown in Fig. 5. None of the test piles failed according to the Davisson criterion (Davisson, 1972). The Davisson concept was to plot through the origin the pile elastic compression line (PD/AE), in which P = load, D = length, A = area, and E = Young's modulus. A second line would be drawn parallel to this elastic line, at an offset of 0.15 inches (4 mm) + B (diameter in inches or mm)/120. The maximum load applied during load tests were 320 and 520 tons in ECB and CB at 0.36 and 0.67 inches deflections respectively.

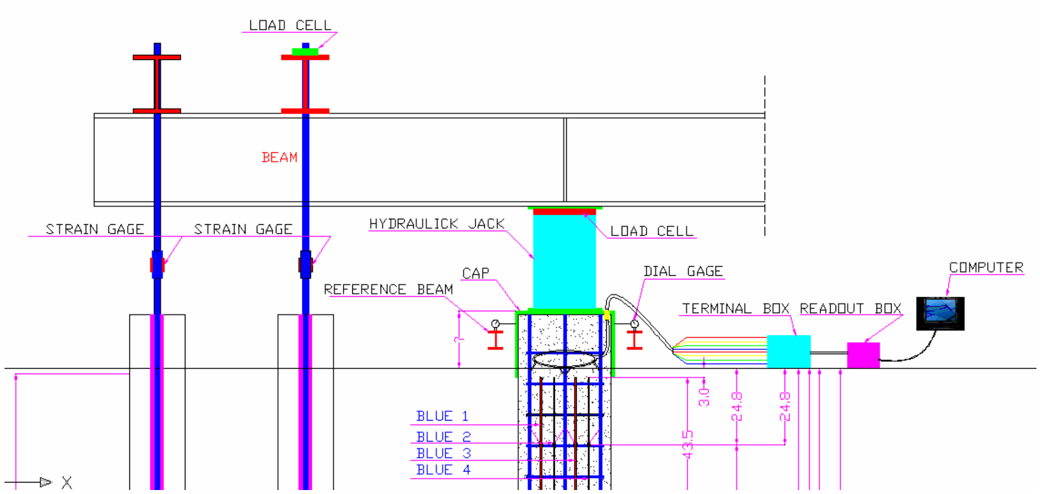

Fig. 3 Schematic Side View of the Pile Load Test Setup

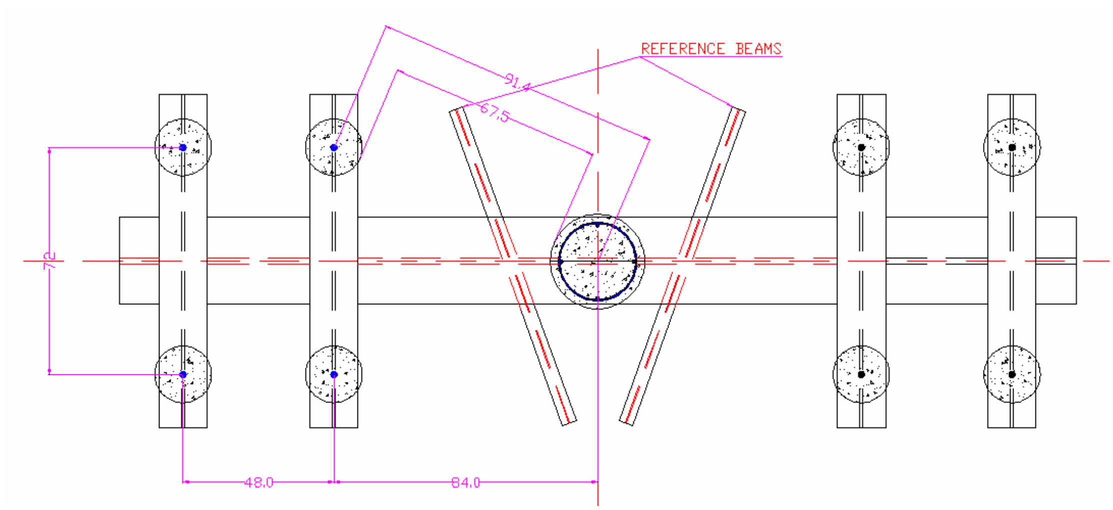

Fig. 4 Schematic Plan View of the Pile Load Test Setup

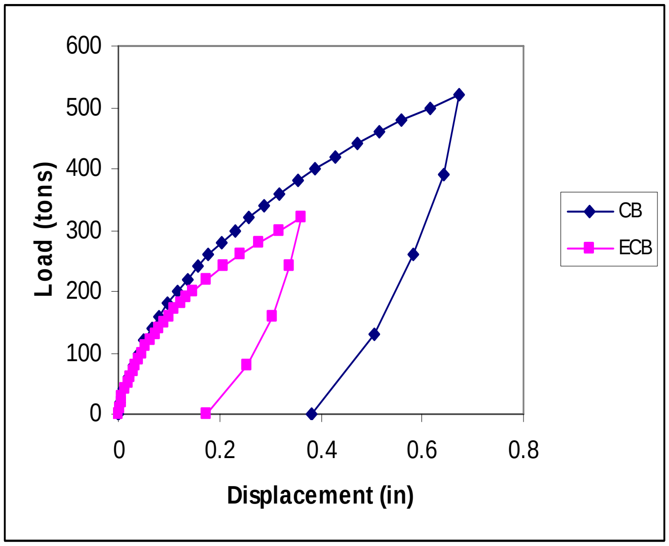

Fig. 5 Load-Displacement Behavior of the ACIP Pile at both sites

LONG TERM MONITORING

In order to better characterize the long term behavior of Augered Cast in Place Piles under axial loading, 6 ACIP piles were instrumented in two bridges (2 in ECB and 4 in CB). Two instrumented piles in ECB are (760mm) in diameter and 36.1 feet in length. All other four piles in CB are (760mm) in diameter and 39.1 feet in length. The instrumentation consists of vibrating wire strain gages placed at 3 levels vertically and one level at the middle, horizontally. Figure 6 shows the plan view of the service piles.

Service piles of ECB and CB were monitored for more than one year (600 days). Seven readings were taken as of July 2007. The strain calculated was converted to loads by comparing the strain at the top of the pile from the load tests. Initial 60 days of strain measured were assumed to be due to the construction stage of the bridge and loads were calculated based on the corrected strain. The stated working design load-for the ECB and CB piles are 92 and 128 tons respectively. Measured load on the service piles was 70 tons for ECB piles and 60 to 86 tons for CB piles. Figures 7 and 8 show the load measured on the service piles at ECB and CB respectively. Straight line in the figures shows the allowable design load for the pile.

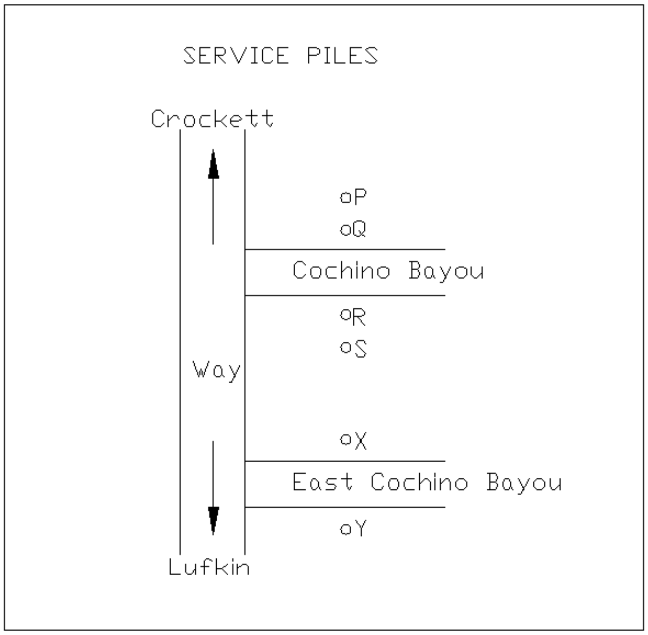

Fig. 6 Plan View of the Service Piles

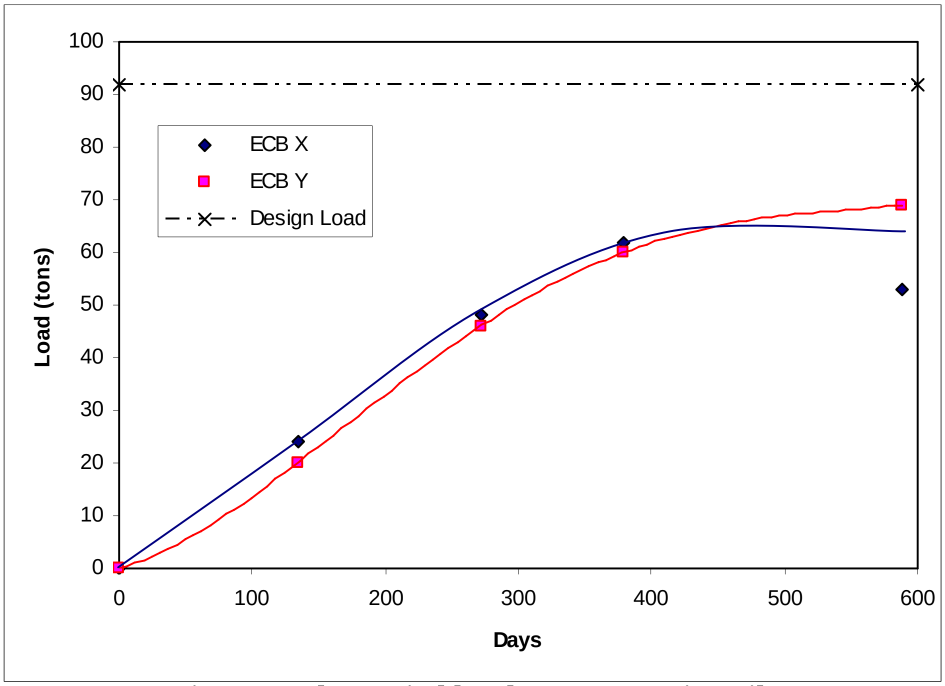

Fig. 7 Loads carried by the ECB Service Piles

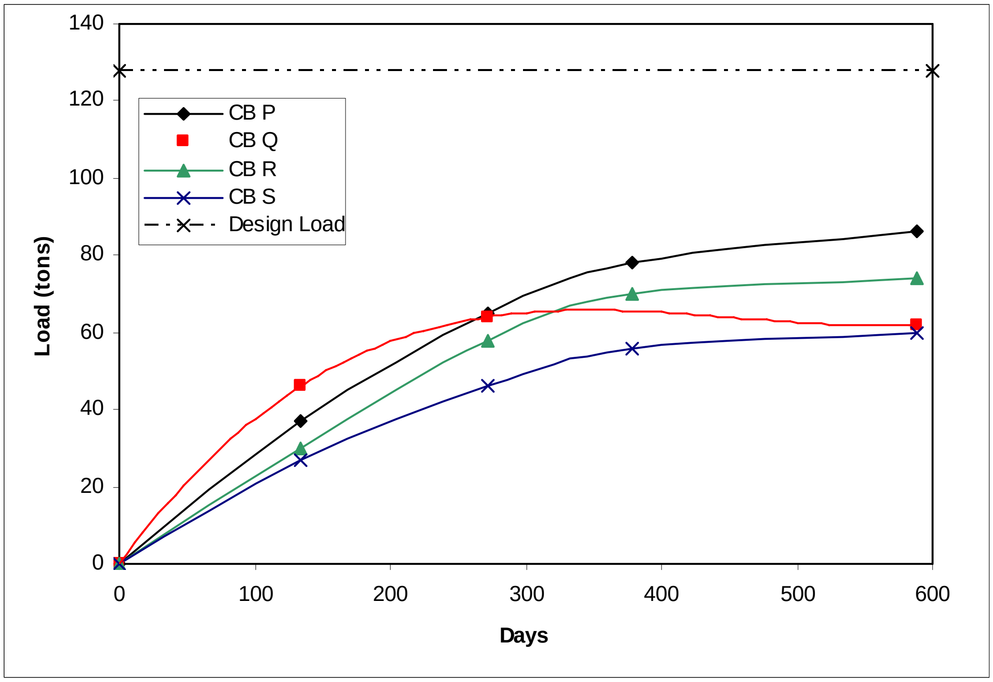

Fig. 8 Load carried by the CB service piles

CONCLUSIONS

Two full-scale pile load tests were performed on Augered Cast in Place (ACIP) piles which were seated in very dense sand and hard clay. Vibrating wire strain gages were used to measure the strains and the temperatures in the piles.

Quality of the ACIP piles was examined by monitoring the temperature and strain during curing of the grout in the piles for load testing and in service piles for 600 days. Both axial and lateral strains in the piles measured were compared to pile behavior in very dense sand and hard clay.

In order to better characterize the long term behavior of Augered Cast In Place (ACIP) Piles under axial loading total of 6 ACIP Piles were instrumented in two bridges. Four service piles were instrumented at Cochino Bayou (CB) and 2 at East Cochino Bayou (ECB). Two instrumented piles at ECB. were 30 in. in diameter and 36.1 feet in length. All other four piles at CB were 30 in. in diameter and 39.1 feet in length.

Based on this study, the following conclusions can be advanced:

1) End bearing developed in hard clay was 2.5 times higher than the end bearing developed in dense sand for the same displacement due to the higher stiffness of the hard clay soil. Based on the load testing the measured pile load at 0.4 in. deflection at the sand site (ECB) was 3.5 times the design load for the pile. The measured pile load in hard clay at 0.7 in. deflection was 520 tons, which was 4 times the design load.
2) Monitoring the curing of the grout can be helpful in deciding the right time to perform a load test or to continue on the super structure construction.

3) Long-term monitoring of the service piles at two bridge location showed that the measured load carried by the piles at ECB (sand site) was 70 tons and it varied from 60 to 86 tons at CB (hard clay site).

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