For More Details ...

This research is documented in Report 3940-1, *Axial Performance of Continuous Flight Auger Piles*
Related research is documented in Report 3921-1, *Specification and Design Criteria for the Construction of Continuous Flight Auger Piles in the Houston Area*

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TxDOT Implementation Status January 2001 . . .

Implementation of Project 5-3940 was approved in June 1999. The 5-3940 implementation agreement with the University of Houston was begun in September 1999, under the direction of Mike O'Neill. University and/or TxDOT work tasks include selection of an appropriate Houston bridge for continuous flight augercast (CFA) pile construction, CFA pile foundation design, development of project-specific construction specifications, cost comparisons, instrumentation and monitoring, and report submittal. Implementation of project 5-3940 is scheduled to terminate FY04.

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PROJECT SUMMARY REPORT

CENTER FOR INNOVATIVE GROUTING MATERIALS AND TECHNOLOGY
UNIVERSITY OF HOUSTON

Project Summary Report 3940-S
Project 7-3940: Axial Capacity of Augercast Piles for Bearing

Authors: Michael W. O'Neill, Cumaraswamy Vipulanandan, Alaa Ata, and Feiming Tan

Augered Piles: An Alternative Foundation for Bridges

Foundation systems for bridges are usually selected based on the ability of the foundation to carry the load, on the anticipated structural integrity of the foundation during its service life, and on economics. In the Houston District these criteria most often lead to the selection of driven, prestressed concrete piles. In some situations, especially where large foundations are needed, drilled shafts may be specified.

A third alternate is possible — the "augercast" or "augered, cast-in-place" (ACIP) pile. ACIP piles are installed by rapid drilling of a borehole with a continuous flight auger, backfilling the hole with pumped, fluid cement grout as the auger is withdrawn, and placement of a reinforcing cage by thrusting it into the fluid grout immediately after completing grouting.

There are situations in which ACIP piles may be preferable to either driven piles or drilled shafts. For example, the noise produced by pile driving is eliminated and the potential for adulteration of the ground surface associated with the use of drilling slurry, often needed for drilled shaft construction in the Houston District, is removed. There may also be situations in which ACIP piles are more economical than driven piles or drilled shafts.

Unfortunately, there have been documented instances in the past where ACIP piles have experienced structural distress due to the presence of voids, necks or other features that have been produced during construction. For that reason public agencies have been reluctant to specify ACIP piles for major structures, although they are used heavily in the private sector where the owner is willing to take whatever risks are associated with pile construction.

In the past several years, however, excellent construction specifications have been developed, and positive, automated quality control equipment has been introduced that significantly reduces the risk of structural inadequacies,

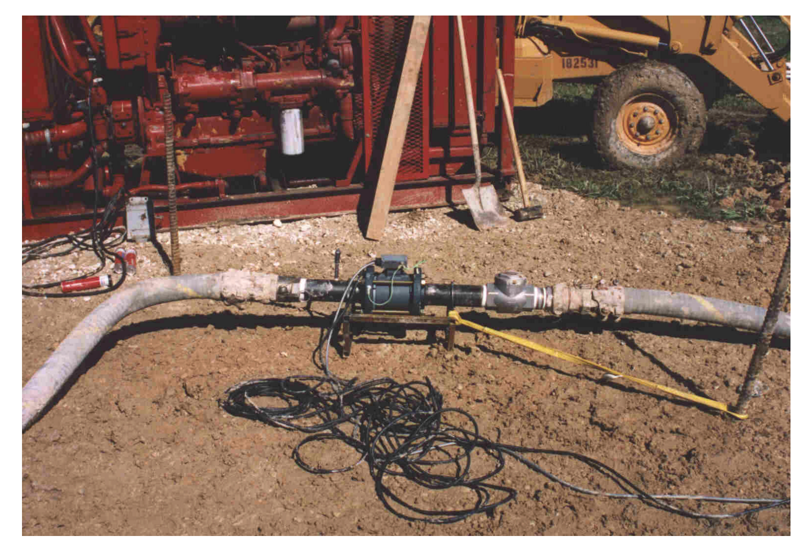

Figure 1. Instruments for monitoring grout during construction

making the use of ACIP piles for future TxDOT work attractive.

What We Did . . .

The principal means of gathering both constructability and load-carrying-capacity data was to

- construct instrumented test piles at three geologically diverse sites in the Houston District;
- observe the construction practices of the contractor;
- evaluate the performance of newly-developed, commercial, automated grout monitoring equipment during construction of the test piles;
- verify the structural integrity of the constructed piles by means of cross-hole sonic logging; and
- load the test piles to failure over a relatively short period of time (1 to 2 hours).

The three test sites were in stiff clay (Univ. of Houston); stiff clay and loose, waterbearing sand (north approach to the Fred Hartmann Bridge on S. H. 146); and medium dense moist sand (U. S. 90A west of Rosenberg). We examined the automated grout monitoring test records of these test piles to verify that systolic grout line pressures at the elevation of the ground were continuously maintained at 250 psi (1.7 MPa) or above. This condition was indeed the case for all test piles, and post-construction ultrasonic logging indicated that maintaining such pressures led to excellent piles structurally.

We also concluded, based on observations in the test piles, that the grout ratio (grout volume pumped/theoretical volume of borehole) should be at least 1.2 (*for that part of the pile)* below the depth of the tip of the drilling auger at the time grout flow begins to return to the surface if the soil is not loose, waterbearing sand (i. e., typical site conditions in the Houston District). In the unusual, loose waterbearing sands at the Fred Hartmann Bridge site, grout ratios of about 1.6 appeared to be more appropriate for quality control. The value of 1.2 was verified by observing the grout ratio records for several hundred ACIP piles that were installed for an industrial facility south of Houston.

Design methods were evaluated by first selecting seven common methods from the literature for establishing the ultimate capacities of driven piles and drilled shafts and denoting them as candidate design methods. This approach was taken since there is no standard method for computation of the static capacity of ACIP piles in soils of the type found in the Houston District (clay and layered sand-clay profiles). Following loading of the test piles to plunging failure, their capacities were calculated from each of the candidate design methods from subsurface data acquired at the test sites and compared with the measurements to evaluate each design method.

In order to enhance the reliability of the evaluation of ACIP pile design methods in this way, other load test data were sought and acquired from contractors and consultants in the geographic area. A data base consisting of 46 ACIP load tests was developed, and the candidate design methods were evaluated against the entire data base.

We found that the most accurate design methods were the Tomlinson alpha method for driven piles (for ACIP piles in clay profiles) and the Federal Highway Administration (FHWA) method for drilled shafts (for ACIP piles in layered sand and clay profiles). These methods are described in the documentation report.

The current TxDOT pile design method also performed well for the three test piles and at purely clay sites that were characterized by unconfined compression and triaxial shear test results. It could not be verified against the data base at sites that contained sand, since the TxDOT cone test had not been used to characterize the soil at the test sites represented in the data base, and transformation methods from standard penetration tests (SPT) (available at those sites) to the TxDOT cone appear to be inconsistent.

As the field study was progressing, a parallel laboratory study was performed to evaluate the performance of grouts with materials and mixes typical of those used for ACIP piles. The performance of grout samples exposed to acids, salts and sulfates through immersion in solutions for periods of time between one and two years was studied (strength changes, weight gain or loss, modulus changes, leaching of calcium).

Similar studies were performed on typical concrete samples. Both the ACIP pile grouts and concrete samples performed similarly except in the case where the solution was sodium sulfate, in which the grout samples lost considerable weight and strength (to about 22 percent of initial compressive strength). Exposure of the auger grout samples to sulfates also increased leaching of calcium by a factor of three compared to concrete samples.

Based upon the field and laboratory studies summarized here, we modified the draft construction specification that we had prepared for Project 7-3921 and included the modified specification in the documentation report for this project.

What We Found...

In this project and in the preceding research project on ACIP piles (5-3921), we observed that continuous monitoring of volumes of grout placed incrementally along the length of the pile and the associated line pressures could be associated with good structural integrity, as well as with good load-carrying conditions in the surrounding soil. That information, plus other observations that were made during pile construction, allowed us to strengthen a draft construction specification for ACIP piles developed initially by the Houston District and later upgraded during Project 5-3921. The modified specification is presented in the documentation report.

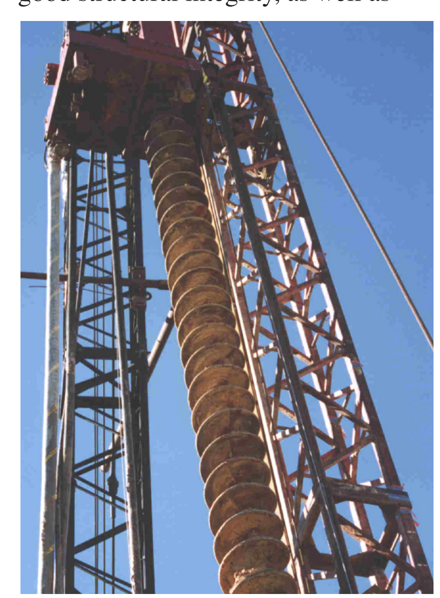

Figure 2. ACIP pile rig

We also discovered that the high-cement-content grouts used in ACIP piles are more vulnerable to sulfate attack than normal concrete of the type used in prestressed concrete piles or drilled shafts. This vulnerability will make it necessary to evaluate the aggressiveness of the soil and groundwater at sites where ACIP piles are planned and to use sulfate-resistant cement if necessary.

We also found that several common design methods that are used to compute the axial capacity of driven piles and drilled shafts work well in the prediction of short-term axial capacity of individual ACIP piles, implying that ACIP piles interact with the soil in a manner similar to the other pile types despite differences in their methods of construction.

The Researchers Recommend...

Since the results of this study were highly positive, we recommend that ACIP piles now be implemented on a TxDOT project within the Houston District. Their installation and performance under load should be carefully monitored. At the end of this implementation project, TxDOT should decide whether ACIP piles can be integrated into the array of foundations that are permitted for the support of bridges.

During execution of the implementation project, we recommend the following approaches.

- The piles should be designed according to an appropriate procedure identified in the documentation report.
- The draft construction specification should be referenced in the bid documents in order to determine if its use causes unforeseen problems with construction. This specification requires the use of automated grout volume and pressure monitoring equipment.
- Actual costs of ACIP piles for the implementation project should be compared with costs for other foundation systems that might be used,
- The long-term performance of the ACIP foundation system should be monitored to be certain that the conclusions developed in this study, based on short-term test loading of individual piles, are applicable to long-term loading of closely spaced piles in a real bridge in the Houston District.
- A photographic record of the steps in the construction of the ACIP piles, as well as the use of instrumentation for the long-term observations, should be made to be used in the training of bridge designers, area engineers and field inspectors.