Pier Pressure in Natchez, Mississippi

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Geotechnical Engineers Wake Up!
Pier Pressure in Natchez, Mississippi
Post Grouted Drilled Shafts Pass Test

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Introduction

Post grouting of drilled shaft tips as a means of increasing capacity and quality assurance is gaining great popularity from designers and contractors alike. ADSC Associate Member firm, Applied Foundation Testing, Inc. has recently been involved with five such projects, all of which, including the Natchez Trace Parkway, have given drilled shafts a new competitive edge.

The team of Wilbur Smith Associates and Hill Brothers, Inc. was selected by the Eastern Federal Lands (EFL) Highway Division of the Federal Highway Administration (FHWA) to design and build the project. The project entailed construction of the final 4.3 mile segment of the Natchez Trace Parkway. Seven new bridge structures were required to complete the highway construction, one of which was a 1,700 foot long bridge crossing Catherine Creek and Melvin Bayou. The foundations of this bridge will potentially be subjected to 30 to 65 feet of scour, requiring the use of 6 foot diameter drilled shafts. ADSC Contractor Member, A.H. Beck Foundation Co., Inc., the team’s drilled shaft specialty contractor, proposed their patented post grouted drilled shaft process as a cost saving and value added alternative to the specified conventional drilled shafts. Applied Foundation Testing, Inc. provided turn-key post grouted shaft design engineering, load testing and post grouting services.

The successful implementation of the alternate included performing post grouted drilled shaft design calculations, installation and performance of a load test program, establishment of a production grouting criteria and quality assurance program.

Using a post grouted shaft design methodology developed by The University of South Florida and the Florida Department of Transportation, shaft length reductions as much as 35 feet could be attained by grouting the shaft tips in the founding silty soil materials.

To corroborate the design, an out of position test shaft was installed, (continued on page 13)
post grouted and load tested with a 1,600 ton STATNAMIC axial compression load test. After the load test program, shaft tip elevations were refined and grouting criteria were established.

Perhaps the greatest benefit of post grouting drilled shafts is the unparalleled quality assurance of knowing the side shear and end bearing capacity of every shaft to a level proportional to the applied grout pressure.

**Soil Conditions**

The regional geology consists of alternating layers of sands, silts, and clays of the Catahoula formation overlain by a loess formation. The Loess formation is a deposit of wind blown silt with SPT N-values generally less than 25 bpf. This material had a unique characteristic of forming vertical faces when cut or eroded. The Catahoula formation underlies the loess formation which consists of dense to very dense sands, very stiff to hard clays, and both elastic and inelastic silts. SPT N-values ranged from 49 to 100+ bpf.

**Post Grouted Shaft Design Method**

The end bearing component of drilled shafts is not fully utilized in most design methods due to the large displacement required to mobilize ultimate capacity. Consequently, a large portion of the ultimate capacity necessarily goes unused. In an effort to regain some of this unusable capacity, mechanistic procedures to integrate its contribution have been developed using pressure grouting beneath the shaft tip. The post-grouting process entails: (1) installation of a grout distribution system during conventional cage preparation that provides grout tube-access to the bottom of the shaft reinforcement cage, and (2) after the shaft concrete has cured, injection of high pressure grout beneath the tip of the shaft which both densifies the in-situ soil and compresses any debris left by the drilling process. By essentially pre-loading the soil beneath the tip, higher end bearing capacities can be realized within service displacement limits.

The design approach for post grouted drilled shaft tips developed by The University of South Florida makes use of common parameters for a conventional drilled shaft design. In this methodology, the available side shear is an important step in determining the pressure to which the grout can be pumped to the base. Interestingly, the grouted end bearing capacity is strongly dependent on available side shear. However, it is relatively independent of the ungrouted end bearing capacity when in sandy soils. As such, the end bearing in loose sand deposits can be greatly improved in both stiffness and ultimate capacity. In silts and clays significant improvement in stiffness can be realized resulting in greater usable end bearing capacity. In all soil types, post grouting shaft tips provides a capacity verification to a level proportional to the applied grout pressure for every shaft grouted.

**Foundation Description**

The 6-foot diameter shafts were designed and constructed to resist a design load of 675 tons beneath the 100 year scour elevation. Due to the heightened quality assurance from load testing and post grouting every shaft, a safety factor of 1.8 was applied to the design load. Considering all design conditions, post grouted shaft lengths ranged from 61 to 100 feet. In addition, USF’s design method predicted grout pressures ranging from 275 to 325 psi to achieve an ultimate capacity of 1215 tons in the scoured condition.

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Regardless of the post grouting improvement with respect to axial load resistance, lateral capacity demands for the design scour condition dictated a minimum shaft length. Therefore, the post grouted shaft length savings was limited by the minimum tip elevation for lateral stability. Shaft reinforcement was also governed to resist lateral loads and consisted of 24 - #11 longitudinal bars with #5 shear hoops. It was anticipated in the original design that conventional shafts would have needed to extend 25 to 35 feet below minimum tip to adequately resist the required loads. Consequently, post grouting resulted in a savings of 25 to 35 feet per shaft.

Construction

A.H. Beck used much of their own manufactured equipment including a crane mounted drilling rig fitted with various custom 72 inch diameter drilling tools to excavate the soils. Hole stabilization was maintained with a Bentonite drilling slurry, mixed and processed with their own manufactured slurry plant system. Slurry testing was routinely performed to ensure its effectiveness consisting of density, viscosity, PH, and sand content. Because of the stable nature of the upper Loess material, the 26 production shafts did not require use of temporary construction casing. Only the test shaft utilized casing in the construction process to isolate the scourable soils during the load test. After the shafts were drilled to tip and mechanically cleaned, a submersible pump was used for final clean out. The cages were lifted with multiple point picks. Once vertical, the grout plates were installed on the bottom of the cage. After the cages were lowered to rest firmly on the bottom of the excavation, a 10 inch diameter tremie was used to place the 9 inch slump concrete via a pump truck. Concrete quality assurance testing included slump, air, unit weight, and compressive strength.

Load Test Program

To confirm the design and construction method, an out of position test shaft was installed, post grouted and load tested. The test shaft was instrumented with multiple levels of strain gages, telltale, crosshole sonic logging tubes, and a grout distribution system at its base. The test shaft construction was performed using the same procedures as the production shafts with the exception of an isolation casing in the upper 40 feet to eliminate resistance from the scourable soil during the load testing. Shortly after construction of the test shaft, it was post grouted.

The shaft response during post grouting was measured with high precision instrumentation and a data acquisition system. Grout pressure was measured with an electronic pressure transducer. Back up pressure readings were recorded from the certified dial gage. Strain measurements allowed upward side shear and a lower bound base resistance to be determined during post grouting. For measurement of upward shaft
displacement during grouting, an independent reference beam was set up over the shaft on which LVDT’s were mounted. Back up displacement measurements were made with a surveyor’s level. Grout volume measurements were made manually by recording the levels in the graduated holding tank.

The shaft was then subject to a 1,600 ton STATNAMIC axial compression load test. As is typical with the rapid load test setup, load was measured with a calibrated load cell and displacement was measured with a photo-voltaic sensor triggered by a stationary laser reference. Three motion sensors provide redundant measurement of displacement and also measure any eccentricity at the shaft head. Traditional survey was performed before and after the test to provide a check on permanent displacement. The strain gauges provided a determination of base and side shear resistance. All instrumentation was monitored with a data acquisition system which allowed immediate results in the field.

**Post Grouting the Shafts**

Applied Foundation Testing, Inc. used a HANY grout plant supplied by ADSC Associate Member, American Commercial, Inc. The plant was made of three components including a colloidal mixer, agitated holding tank, and a hydraulic actuated piston type pump capable of 1,500 psi grout pressure. Neat cement grout of Type I/II Portland cement with a water/cement ratio of 0.5 was pumped to the base of each shaft. On average each shaft was post grouted 3 to 5 days after construction. Detailed documentation were made for each production shaft including, at least four separate measurements of grout pressure, grout volume, and shaft upward displacement that represent the range of grout pressures delivered to the shaft.

**Setting Up The Grouting Criteria**

Using the load test data, grouting criteria were developed consisting of three main components: 1) Grout Pressure; 2) Upward Displacement; and 3) Minimum Grout Volume. The grout pressure is the most important component since the capacity improvement is directly proportional to the applied pressure. Grouting of the test shaft was used as a basis for establishing the required pressure. Since the shaft began to displace upward at an applied grout pressure of 310 psi, the maximum achievable pressure was limited by the available skin friction. Although the STATNAMIC load test proved the shaft could support over 1,600 tons in a scour simulated condition, it was thought that higher pressures may be achievable in the production shafts which will have additional skin friction from the scorable zone. For this reason, Wilbur Smith Associates specified that the first production shaft be instrumented with strain gages and monitored during the grouting application.

Evaluation of the skin friction behavior was also necessary to determine the target maximum upward shaft displacement criterion. The grouting and load test results suggest that the skin friction was very predictable both in the upward and downward loading direction. The upward friction capacity during grouting, downward friction capacity during the load test, and the predicted friction capacity using O’Neill and Hassan, 1994 were nearly identical. Further, it did not appear to degrade or go residual within a 1/2 inch of displacement. Therefore a conservative upward displacement limit of 0.25 inches was set for production grouting. If this upward displacement was met prior to achieving design grout pressure, grouting was to be stopped, the lines (continued on page 16)
flushed, and the shaft was to be re-grouted after the data was evaluated. In three cases, stage grouting was performed and the shafts were shown to have sufficient capacity.

Lastly, a minimum grout volume was set to ensure that lines were not blocked and grout was reaching the shaft tip.

Summary and Conclusions

Post grouted drilled shafts were successfully implemented as a cost saving and value added alternate to the specified conventional drilled shafts. It was made possible through a systematic approach consisting of post grouted drilled shaft design calculations, installation and performance of a load test program, establishment of production grouting criteria and a comprehensive quality assurance program.

Using a post grouted shaft design methodology developed by The University of South Florida, capacities, tip elevations and grout pressures were able to be predicted accurately for estimation purposes. Incorporating load test data into the design models allowed even closer correlation.

Successful installation and performance of the load test program provided validation of the grouting method and confirmed shaft length reductions of 25 to 35 feet. Therein, required Grout Pressure, Upward Displacement, and a Minimum Grout Volume criteria were established for production shafts.

One of the most significant benefits of the post grouted drilled shaft construction method is the quality assurance that is achieved. As such, the side shear and end bearing capacity of every shaft can be assured to a level proportional to the applied grout pressure. The enormous statistical reliability of knowing every shaft's capacity was merited with the use of a 1.8 safety factor on the axial service load. However, load testing and post grouting results suggest that most of the shafts will have a safety factor of 2.0 or greater in the scoured condition.

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**PROJECT TEAM**

**Project Name:** Natchez Trace Parkway, Bridge over St. Catherine Creek and Melvin Bayou

**Location:** Natchez, Mississippi

**Owner:** Federal Highway Administration, Eastern Federal Lands Highway Division

**Project Engineer:** Jeffery Schmidt

**Design Build Team**

**General Contractor:** Hill Brothers Construction & Engineering

**Project Manager:** Sterling Akers

**Designer/Geotechnical:** Wilbur Smith Associates

**Project Manager:** Michael Montgomery, P.E.

**Drilled Shaft Contractor:** A.H. Beck Foundation Co., Inc.*

**Project Manager:** Gary Phillips

**Project Superintendent:** Tim Beavers

**Load Testing & Post Grouting:** Applied Foundation Testing, Inc.*

**Project Manager:** Mike Muchard, P.E.

*Denotes ADSC Members.