CASE HISTORY: UTILIZING LOAD TEST DATA TO VALUE ENGINEER DRILLED SHAFT FOUNDATIONS

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ABSTRACT

A case history is presented of a project where load test data obtained from an O-cell® load test was used to value engineer the drilled shaft foundations for the project. An acceptable and common conservative engineering practice of neglecting skin friction in soil above a rock socket was used in design. The load test data showed that at this site significant skin friction could be mobilized in the soil materials overlying bedrock at relatively small displacements. The skin friction was mobilized within the required maximum settlement criteria of one-quarter inch. The results of the load test allowed for the shaft diameters to be reduced and the augercast piles planned for part of the project to be replaced with drilled shafts, reducing the foundation costs.

INTRODUCTION

Bryant-Denny Stadium in Tuscaloosa, Alabama is the home of the Alabama Crimson Tide football team. In January of 2005 plans were being completed to enclose the upper deck of the north end zone to provide additional seating. Elevated luxury suite boxes were included in the project. The foundations consisted of drilled shafts for the more heavily loaded suite box structures and augercast piles for the relatively lightly loaded stadium seating columns. Russo Corporation (ADSC Contractor Member) was the low bidder for the drilled shaft package; however, due to access considerations involving working heights and widths, the overall foundation package was over-budget.

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FOUNDATION DESIGN

The stadium expansion was a fast-track project, and the nature of the structure and the number of parties involved required a very iterative design process. When the geotechnical exploration for the project was performed in July of 2004, the column locations or loads had not been determined. Since the site was relatively small and the geotechnical engineer, (TTL, Inc., ADSC Technical Affiliate Member) had a significant number of previous borings around the stadium, the borings for this expansion were drilled to provide appropriate coverage of the site area. The subsurface conditions consisted primarily of sandy clays at the surface, underlain by dense silty sand and gravel with some rock fragments increasing with depth. Below this level and near the shaft tip, weathered sandstone was encountered.

As a result of the iterative design process, the as-bid design of the drilled shafts resulted from several months of design changes and refinements. The recommendations for drilled shaft foundations included in the geotechnical report were: allowable end bearing of 60 ksf (2,873 kPa), allowable skin friction of 4 ksf (192 kPa) in weathered rock, and allowable skin friction of 8 ksf (384 kPa) in sound rock. The end bearing values used for the drilled shafts were based on results of compressive testing performed on rock cores obtained from the stadium site during the east side expansion constructed in 1996.

With the foundation package being over-budget, a post-bid meeting was held with the construction manager (Brice Building), general contractor (Duncan & Thompson), structural engineer (LBYD), TTL, Inc., and Russo Corporation personnel to discuss value engineering options. Russo Corporation suggested that significant savings could be possible if the drilled shafts were re-designed to utilize skin friction in the soil above bedrock to mobilize their full load bearing capacity.

Skin friction was neglected in the soil overburden above rock, as is often the case with rock-socketed drilled shafts. There is disagreement among the geotechnical engineering community concerning the use of skin friction on shafts socketed into rock. Some engineers disregard the skin friction in the soil believing that the amount of deflection required to mobilize skin friction in the rock socket is less than that required to mobilize the skin friction in the soil. TTL used this approach and initially used only the rock skin friction for shaft design on this project.

As LBYD was completing the design in December of 2004, a maximum settlement criteria of 0.25 inch (6.4 mm) was established for the shafts. TTL and LBYD proceeded to modify the shaft designs using the design column loads and the established settlement criteria to reduce the amount of rock excavation. Many of the shafts were designed to bear on the weathered rock with a larger diameter, but still neglecting skin friction in the soil. Skin friction of up to 4 ksf (192 kPa) was utilized for rock sockets in the weathered sandstone; however, the actual amount of unit skin friction allowed in a shaft was restricted by the settlement criteria.

The resulting as-bid design called for drilled shafts with diameters ranging from 30 inches (762 mm) to 108 inches (2,743 mm,) and rock sockets ranging from 2 feet (0.61 meters) to 15 feet (4.57 meters). All shafts were approximately 62 feet (18.9 meters) in length. As originally designed and bid, the shafts were to be installed in the dry using a temporary casing set into the weathered rock. A visual inspection of each shaft base, including drilling a probe hole in the weathered rock, was also included in the original bid. The 16-inch (406 mm) diameter augercast piles were designed for a 120 ton (1.07 MN) capacity based on successful load tests of similar piles at other projects on campus.

FIELD LOAD TEST AND SHAFT REDESIGN

Russo Corporation recognized that the shafts could potentially be resized to smaller diameters and some or all of the rock sockets could be eliminated if the skin friction in the soil overburden was utilized in the design. Russo Corporation suggested that an O-cell® load test be performed to provide the appropriate skin friction data for the soil overburden, believing that the cost savings for the project would more than compensate for the cost of the load test. Russo also requested that the design team allow the shafts to be installed using drilling slurry, rather than casing the shafts and inspecting the base of the shaft. The design team agreed that if a load test of a shaft installed using slurry yielded sufficient allowable skin friction values, the designs could be modified and the slurry method of installation could be accepted.

LOADTEST, Inc. (ADSC Associate Member) performed the O-cell® test on a 48-inch (1,220 mm) diameter shaft. This shaft was a non-production shaft installed solely for the load test. The load cell used for the test is shown in Figure 1. The shaft was drilled to a depth of 59.8 feet (18.21 meter) and socketed 2 feet (0.61 m) into weathered rock. The shaft was constructed in the wet using polymer slurry. The shaft excavation was allowed to sit over night. On the following day, the bottom of the shaft was cleaned with a 40-inch (1,016 mm) cleaning bucket. The concrete was placed in the bottom of the shaft by tremie pipe, which extended past the O-cell® until the top of the concrete reached the cut-off elevation.

A 2,515 kip (11.19 MN) bi-directional load was applied to the shaft. At the maximum load, the displacements above and below the O-cell® were 0.64 inches (16.3 mm) and 0.78 inches (19.8 mm), respectively. The corrected maximum applied end bearing pressure was 181.5 ksf (8,690 kPa) at the above noted displacement.

For a top loading of 2,140 kips (9.52 MN), the adjusted test data indicates the shaft would settle approximately 0.25 inches (6.4 mm) of which 0.11 inches (2.7 mm) is estimated elastic compression. For a top loading of 3,300 kips (14.68 MN), the adjusted data indicates the shaft would settle approximately 0.50 inches (12.7 mm) of which 0.16 inches (4.1 mm) is estimated elastic compression. It was noted that significant creep for the test shaft will not begin until a top loading exceeds 4,905 kips (21.8 MN) by some unknown amount.

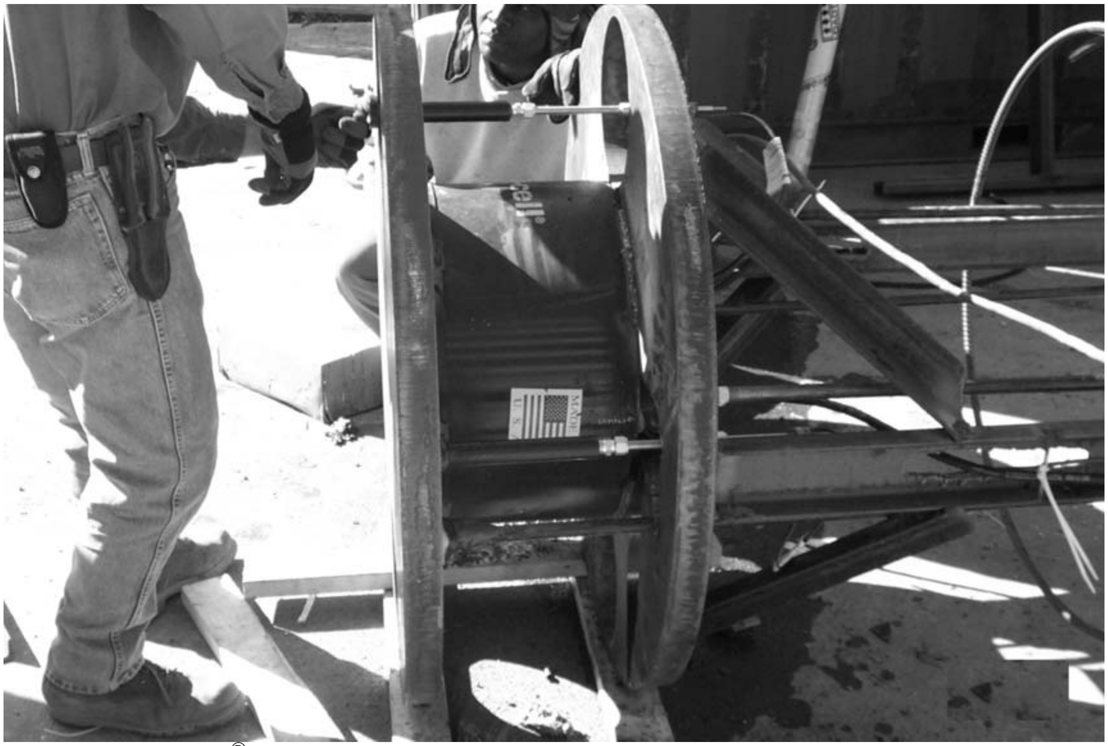

Figure 1 – O-cell® being prepared for installation into drilled shaft.

Diameter (in)	Rock Socket (lf)	As-Bid Capacities (kips)	Post Loadtest Capacities (kips)
48	2	760	1860
48	3	800	n/a
48	4	860	n/a
48	5	900	n/a
48	6	960	n/a
48	7	1000	n/a
48	8	1060	n/a
48	9	1100	n/a
48	10	1160	n/a
48	11	1200	n/a
48	12	1260	n/a
48	13	1300	n/a
48	14	1360	n/a
48	15	1400	n/a

Table 1 – As-Bid Capacities for 48-inch Diameter Shaft

Diameter (in)	As-Bid Capacities (kips)	Post Loadtest Capacities (kips)	Post Loadtest Diameter (in)
30	300	986	30
36	420	1253	30
42	580	1545	30
48	760	1860	30
54	960	2198	30
60	1180	2560	36
66	1420	2946	42
72	1700	3355	48
78	2000	3788	54
84	2300	4244	60
90	2660	4724	66
96	3020	5228	72
102	3400	5755	78
108	3820	6305	84

Table 2 – As-Bid and Post Load Test Drilled Shaft Capacities

After the load test, the drilled shafts were re-designed utilizing an average 2.2 ksf (105.3 kPa) skin friction value for soil along 40 feet (12.2 meters) of the shaft and a 60 ksf (2,873 kPa) end bearing value. These values were determined using the load test data and applying the 0.25 inch (6.4 mm) deflection criteria established by the structural engineer. The values were not adjusted for shaft diameter, but were applied uniformly for all production shaft diameters. Table 1 lists the as-bid capacities of various rock socket lengths for a 48-inch (1,220 mm) diameter drilled shaft. Table 2 lists the as-bid capacities for the various planned shaft diameters, the post load test capacities for the same diameters, and the redesigned shaft diameters corresponding to the as-bid diameters. The as-bid capacity of 760 kips (3.38 MN) for a 48-inch (1,220 mm) diameter shaft was planned to be carried in end-bearing only. At the specified 0.25 inch (6.4 mm) deflection, the load test data indicated that the design bearing pressure of 60 ksf (2,873 kPa) was appropriate at the specified deflection, yielding 760 kips (3.38 MN) in end bearing; however, the test data also indicated that an additional 1100 kips (4.89 MN) of skin friction was available for the 48-inch (1,220 mm) diameter shaft. The total shaft capacity of 1860 kips (8.27 MN) was greater than required for the column loads. The last column in Table 2 illustrates the smaller diameter shafts that were used to carry the design loads for the various as-bid shaft diameters based on using the skin friction capacity in addition to the end bearing capacity.

Based on the loadtest results, the diameters of the drilled shafts were reduced significantly. The reduction of the drilled shaft diameters yielded a savings of over 700 cubic yards (535 m^3) of concrete. The reduced diameters also equate into less spoil removal, less slurry, smaller tools, and faster production. For the drilled shaft portion of the project alone, the value engineering recommendation saved the University approximately \$200,000 (25% of the drill shaft bid), excluding the cost of the loadtest which was approximately \$70,000. An additional \$50,000 was saved in the concrete, but that figure has not been included since the concrete was donated to the project.

The initial intent of the value engineering suggestion was to reduce the cost of the drilled shafts. However, Russo Corporation speculated that the increased drilled shaft capacities may allow the drilled shafts to be more economical than the augercast piles. After calculating the savings from eliminating the augercast pile caps, the shoring required for the deep caps, the reduction in concrete/grout, and the faster production schedule; it was determined that drilled shafts could be constructed on the project more economically than augercast piles, providing additional cost savings to the owner. A complete foundation re-design occurred and the entire project is being constructed on drilled shafts. Figures 2 and 3 illustrate some of the confined conditions within the shafts were eventually installed. The replacement of augercast piles with drilled shafts resulted in an additional \$50,000 savings to the project.

Figure 2 – Lo-Drill operating in confined work area.

Figure 3 – Installing Drilled Shaft in Upper Deck Ramp Structure.

CONCLUSION

The as-bid design relied on end bearing and skin friction only in the rock sockets based unconfined compressive tests of rock from the site and the experience of the engineers on the project. On this project, an acceptable and common conservative engineering practice of neglecting skin friction in soil above a rock socket was used in design. Engineers use this approach due to uncertainties in the amount of relative displacement required to mobilize skin friction in soil versus in rock. The load test data showed that, in the soil materials at this site, significant skin friction could be mobilized at relatively small displacements. For this project in particular, the skin friction was mobilized within the required maximum settlement criteria of one-quarter inch.

The drilled shaft specification for this project was focused on the quality of the bottom of the drilled shaft by allowing visual observation and providing a test hole below the bottom of the shaft. In reality, the load test indicated that the load would have never reached the bottom of the drilled shaft for the as-bid design. Since the redesign was based on a single, albeit sophisticated, static load test, it was important for TTL’s engineering technicians and Russo’s project superintendent to assure that the production shafts were constructed using the same procedures as were used to construct the test shaft. Maintaining the procedures was important to avoid inadvertently reducing the available skin friction below the redesign values due to changes in construction methods.

It is not uncommon for geotechnical engineers to completely neglect skin friction in the type of soil present at this project. As a result, the full structural capacity of drilled shafts is often not considered on a project, allowing competing foundation products to come in at a lower cost than drilled shafts. It is one thing to get beat on a bid, but how many times is the drilled shaft industry getting beat before having a chance to bid. LOADTEST, Inc. has performed numerous O-cell® tests on drilled shafts that have consistently shown shafts are being under-designed for skin friction. The drilled shaft industry needs to encourage geotechnical engineers to better utilize load test data and empirical data to provide more efficient capacity designs for drilled shafts, allowing drilled shafts to remain economical and competitive.

We don’t want to design on paper what we have to wish into the ground---but if we don’t properly design the drilled shaft on paper, the drilled shaft may not get a chance to go in the ground.

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