# THE EFFECT OF DRILLING FLUID ON AXIAL CAPACITY, CAPE FEAR RIVER, NC

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Two drilled shaft foundations were subjected to axial load tests in order to measure the influence of drilling fluid on performance. Other than the differing drilling fluids, the shafts were constructed with great care to ensure identical conditions. The results indicate superior performance in both side shear and base resistance of the shaft constructed using a polymer over that of the shaft constructed using bentonite drilling slurry.

## Introduction

The U.S. 17 Wilmington Bypass project includes a 9 km (5.5 mile) bridge over the Northeast Cape Fear River near the North Carolina coast. This bridge is currently under construction and, when completed will include over 500 drilled shaft foundations. The shafts range from 1.2 m to 2.4 m diameter and lengths typically ranging from 22 to 30 m to bear into a dense silty sand known locally as the PeeDee Formation. Although the NCDOT specifications only provided for construction using bentonite drilling slurry, subcontractor TREVIICOS proposed to use polymer fluids to construct the shafts. To gain acceptance for this alternate from the DOT, a load test program was performed on a pair of 1.2 m diameter drilled shafts constructed under identical conditions except for the drilling fluid.

## Soil Conditions

Soil Conditions at the test shaft locations are composed of silty fine sands as indicated on Figure 1. The alluvial sands above –11 m are subject to scour during the design loading (includes hurricane conditions) and are not considered for design. Underlying these shallow sands are dense to very dense silty sands of the Pee Dee Formation. These sands are calcareous with lightly cemented layers and phosphate particles. Standard penetration test (SPT) values generally ranged from 50 to 100 blows/30cm (b/f).

## Construction of Test Shafts

Two test shafts were constructed at locations about 6 m apart. The shafts were constructed with care so as to produce identical conditions except for the differing drilling fluids. Test shafts were full size at 1.22 m diameter and 24 m length, and constructed under conditions identical to those proposed for production shafts on the project.

A schematic diagram of the test shafts is illustrated on Figure 1. Each shaft was constructed using a permanent steel liner to elevation –13.8 m, as specified for production shafts. The test shafts also utilized a larger diameter isolation casing to elevation –10.8 m to separate the scourable overburden materials through this zone.

The test shafts were constructed using a SoilMec R-825 hydraulic track mounted drill rig. The excavation within the bearing formation was made using a drilling bucket with soil cutting (spade type) teeth that extended to a width beyond the diameter of the bucket. The base of each shaft was cleaned using a flat bottom bucket, followed by a hydraulic pump. Following cleanout, the base was inspected using a downhole camera and sediment measurement system (miniature shaft inspection device, or mini-sid, Figure 2). Shaft bottom cleanliness was controlled to a have less than 12 mm of loose material the base. Both shafts were cleaned to near identical conditions. In addition, the consistency of the bearing materials was checked by performing an SPT at the bottom of each shaft. SPT values were 41 and 52 b/30cm (b/f) for the polymer and bentonite shafts, respectively. Soil conditions during drilling appeared identical for the two shafts.

The polymer slurry used was a liquid polymer manufactured by KB Technologies with a density of 1.01 kg/m3, marsh funnel viscosity of 65 s/.95l (65 s/qt), pH=10.5, sand content of 1%. The bentonite was Baroid Aquagel with a density of 1.05 kg/m3, marsh funnel viscosity of 35 s/.95l (35 s/qt), pH=9, sand content of 0.5%.

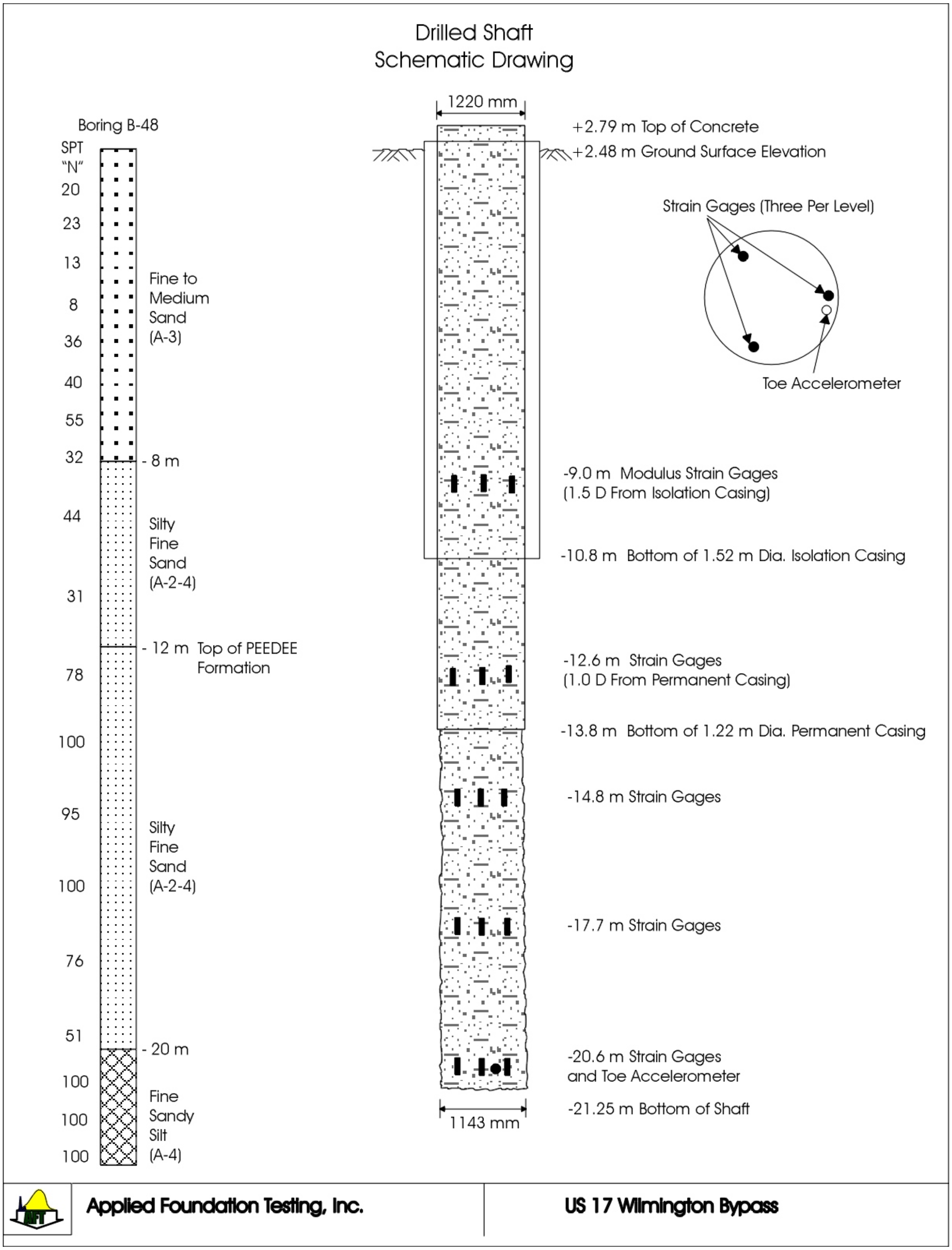


**Figure 1 Soil and Test Shaft Conditions**

**Figure 2 Mini SID Device for Inspection Of Shaft Base Conditions**

In order to keep the construction time constant between the two test shafts, each shaft was drilled, cleaned, and poured during a single 12 hour construction period. Concrete met the standard NC drilled shaft requirements with 31 MPA compressive strength (4500 psi), slump of 183 to 222 mm (7 to 9 inches) and 19mm (3/4 inch) maximum aggregate size. The rebar cage was the same as for production shafts except for the additional strain gauge instrumentation. Longitudinal bars were epoxy coated (green), with 20 #36(metric) bars with approximately 133 mm clear spacing (5 inches). Spirals were SP-1 type (cold drawn wire type, not rebar) with metric designation #16 at 125mm (5 inch) pitch. Four 50mm diameter steel tubes were included within the cage for crosshole sonic logging (CSL).

Concrete volume measurements on the two shafts were near identical and within 4% of theoretical volume for both shafts. CSL tests after completion of the test shafts indicated good quality concrete for the full length of the shafts.

## Test Setup and Instrumentation

Axial load tests were conducted using the rapid load test method utilizing a statnamic device, shown on Figure 3. This device is capable of applying downward load to the top of the shaft of up to 18 MN (2000 tons). A mechanical catching mechanism allowed multiple load cycles to be applied in a quick and efficient manner.

Instrumentation included sister-bar mounted strain gauges at the elevations shown on Figure 1. The strain gauges are included to provide determination of base and side shear resistance. The sister bars included full bridge resistance type strain gauges. The full bridge (four active gauges) provides stable strain measurements to a precision of less than ½ microstrain and inherent temperature compensation. The resistance gauges allow high frequency data logging during the rapid load testing. A base accelerometer was also included to allow direct measurement of motion at the shaft base.

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 capacitive type accelerometers provide redundant measurement of displacement and also measure any eccentricity at the shaft head.

A high speed data acquisition was used to monitor all instrumentation with a measurement frequency of 5000 samples per second. Traditional survey was performed before and after each test to provide a check on permanent displacements.

**Figure 3 Statnamic Rapid Load Test Device**

## Test Results

The axial load tests were conducted 12 and 20 days after completion of construction of the polymer and bentonite test shafts, respectively. All of the instrumentation performed very well and redundant measurements provided excellent agreement. The uppermost strain gauge measurements provided calibration of the concrete modulus for interpretation of axial forces from the strain data. All of the gauges worked well and indicated very little eccentricity in the shafts. These measurements suggest that relatively uniform base resistance was mobilized during the test loading. Overall static load vs deflection response is provided on Figure 4. The derived static forces were determined from the statnamic test measurements using the segmental unloading point method (Mullins et al, 2002). Note that two cycles of load were applied to the polymer shaft in order to mobilize capacity at higher displacements (consistent with the FHWA failure criteria of displacements equal to 5% of the shaft diameter).

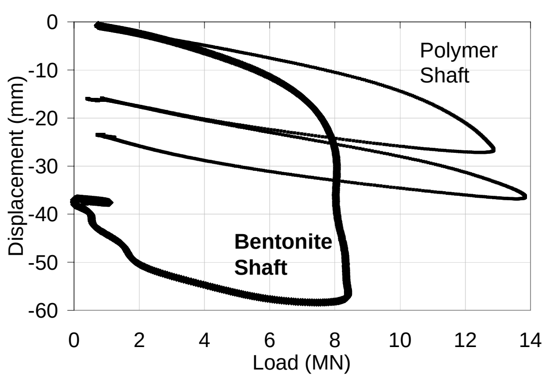


**Figure 4 Static Load Deflection Response**

The polymer shaft mobilized a maximum static capacity of 13.8 MN (1550 tons) at a deflection of 37 mm (1.5 inches), and a total permanent displacement of 24 mm (1 inch). The bentonite shaft mobilized a maximum static resistance of 8.4MN (940 tons) at a deflection of 58 mm (2.3 inches). Note that the load vs deflection curve appears to plunge at a displacement of around 25 mm (1 inch).

The strain data provide a measure of the mobilized base resistance and the mobilized average unit side shear resistance in the Pee Dee Formation, as indicated on Figures 5 and 6. The deflections for the base movements are computed from measurements with adjustments for elastic shortening of the shaft based upon strain measurements. The displacements shown for the side shear curves are average relative displacements for that shaft segment. Maximum unit values are summarized on Table 1.

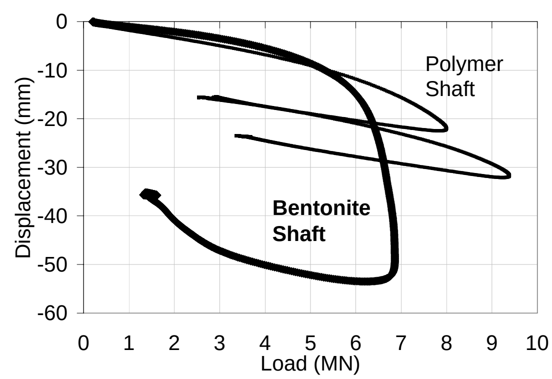


**Figure 5 Base Load Deflection Response**

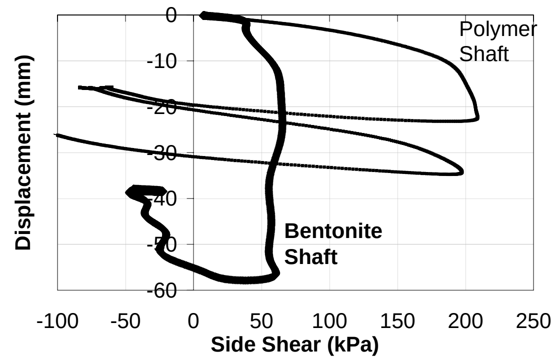


**Figure 6 Side Shear Load Deflection Response**

The base resistance curves show significant residual forces after loading, which are reflected in the termination of the test at nonzero load magnitude in the base. These residual forces are indicated in the side shear by negative residual side shear stresses as the side resistance acts to “hold down” the shaft base after unloading. Note also that most of the side shear is mobilized at around 10 to 15 mm (½ inch) of displacement. The base resistance of the bentonite shaft appears to plunge at around 15 to 20 mm (½ to ¾ inch), or between 1% and 2% of the shaft diameter. The base of the polymer shaft was loaded to a maximum of around 2.5 % of the shaft diameter and showed no indication of plunging failure at that point.

The differences in unit side shear between the two shafts are substantial, with the polymer shaft mobilizing approximately three times larger unit side shear than the bentonite shaft. This trend is consistent with that noted by Brown (2002) for silty soils in the Southeastern Piedmont Formation. In that study the bentonite was observed to leave a thin residual film at the shaft/soil interface in silty soils, even with limited exposure times.

The higher base resistance for the polymer shaft was somewhat surprising, in that the SPT resistance at the bottom of this shaft was slightly lower than for the bentonite shaft. Both shafts show good bottom resistance curves with no indication of soft material present. It seems plausible that an increase in bond between the concrete shaft and the bearing formation could contribute to an increase in base resistance, but the magnitude of the differences observed in these two shafts appears larger than would be expected from surface bond differences alone.

## Summary and Conclusions

Two instrumented test shafts were constructed under identical conditions except for the use of bentonite drilling slurry in one shaft and polymer slurry in the other. The results of the load testing program indicate a three fold increase in side shear resistance in the dense silty sands for the shaft constructed with polymer over that of the shaft with bentonite. This difference is thought to be due to improved bond at the shaft/soil interface. The base resistance was also higher for the polymer shaft, although the difference appears to be larger than can be logically attributed to improved bond at the interface.

## References


MULLINS, G., LEWIS, C., and JUSTASON, M.D. 2002. Advancements in Statnamic Data Regression Techniques. ASCE Geotechnical Special Publication 116, pp. 915-928.

BROWN, D, 2002. Drilled Foundations in Piedmont Residual Soils: Effect of Construction on Axial Capacity, accepted for publication, Journal of Geotechnical and Geoenvironmental Engineering, ASCE (to be published in Dec., 2002)


Table 1
Unit Side Shear and End Bearing Load Transfer Summary

| Shaft Location | Polymer | Bentonite |
|---|---|---|
| -9.8 to -14.8 meters | 33 kPa @ 12 mm | 10 kPa @ 12 mm |
| -14.8 to -20.6 meters | 208 kPa @ 23 mm | 65 kPa @ 23 mm |
| End Bearing | 8,970 kN @ 32.1 mm | 6,572 kN @ 32.2 mm<br>6,754 kN @ 58.4 mm |