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The Effects of Drilling Slurry on Reinforcement in Drilled Shaft Construction

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The Effects of Drilling Slurry on Reinforcement

in Drilled Shaft Construction

by

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DEDICATION

I would like to dedicate my work to the people who mean the most to me, without them this accomplishment would not have been possible. My mother for her unyielding love and support throughout this entire process. My dad, which a day doesn't go by that I don't think of you and hope you are proud of the person I have become. My brother, Karl, and step-father, David, for your love and support.

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ABSTRACT

Drilled shafts are cast-in-place concrete, deep foundation elements that require high levels of quality control to ensure the borehole does not become unstable either during excavation or during concreting. Bentonite slurry is a popular choice among state DOT officials nationwide to maintain borehole stability as it has a long history with reasonable load carrying performance. However, specifications developed to replicate successful shaft construction are largely based on empirical data. Further, as slurry construction is a blind process, the final as-built shaft is rarely visually inspected and much of the perceived concrete flow and slurry interaction with rebar and the soil interface are largely unverified.

This thesis presents the wide range of nationwide specifications for slurry viscosities (upper and lower) and notes that in only one case out of a hundred (50 states with an upper and lower viscosity limit) is there a rational basis for setting the limit. To this end, the objective of this thesis was to provide compelling evidence to support or dispute present upper viscosity limits. The study was part of a larger scope to show the effects of high viscosity slurry on concrete / soil interface and rebar bond. However, this thesis addresses only the latter via large scale testing to show concrete flow patterns, the build-up of bentonite slurry on rebar, and the degradation of rebar pull-out capacity as a function of bentonite slurry viscosity.

Pull-out test results from 126 specimens, comprised of No. 8 rebar embedded in 42in diameter shafts, showed that rebar bond degraded as much as 70% and more when in the presence of bentonite slurry that conformed to most state viscosity specifications (40 to 90 sec/qt). Visual inspection which is rarely possible on drilled shafts showed convincingly that the

concrete that flowed through the cage to form the cover concrete does not fully encapsulate the rebar. In most cases a void/crease was formed reflecting the cage grid and which would provide a pathway from the soil pore water directly to the reinforcing steel.

While present specifications nationwide dictate bentonite slurry ranges from a minimum of 28 to a maximum of 60 sec/qt, the study findings indicate that only viscosity levels of 30 sec/qt and below are reasonable from both a bond and durability stand point. As pure water has a viscosity of 26 sec/qt, this leaves only a very slight window of acceptability which is unlikely to provide sufficient lateral borehole stability.

CHAPTER 1 INTRODUCTION

Drilled shafts are cylindrical, cast-in-place concrete, deep foundation elements that are typically selected over driven piles based on cost effectiveness, the soil stratum encountered, and/or to control vibrations due to sensitive surroundings. In general, the process of constructing shafts involves the drilled excavation of soil or rock using large diameter augers to form a deep cylindrical void space. Within the excavation the necessary reinforcing steel is placed followed by concrete (Figure 1.1). This process requires the in- situ soils to act as the formwork and define the shape of the concrete. The greatest concern during this process is maintaining the stability of the excavation walls (formwork) and preventing the collapse or sloughing of material into the boring during excavation or the concreting process. This thesis focuses on an application called wet construction where the water table is encountered.

Figure 1.1. Shaft construction: excavation (left), cage placement (center) and concreting (right)

The excavation stability is maintained mechanically, hydrostatically, or with a combination of both. Mechanical stability implies the use of a full length steel casing that holds the soil in place while the construction process is performed. Upon completion of concreting, the casing is often fully extracted before the concrete cures and the wet/fluid concrete pushes out against the excavation walls.

Hydrostatic stabilization is the process of using fluid within the excavation wherein the fluid level is maintained higher than the surrounding ground water table and thus, flow is always into the soil walls and not flowing out of the soil walls causing collapse. The fluid can be natural ground water, sea water, or a slurry formed by mineral or polymer additives. The selection of slurry products or additives is somewhat controversial as various states permit or restrict the use of some products. However, most commonly, the clay mineral bentonite is mixed with water to form a slurry with a density slightly higher than water, but with the added advantage of greatly slowing or completely stopping inflow rates into the surrounding soil or ground water. Polymer slurry products tend to only slow the inflow rate but do not completely seal off the excavation walls.

Although the term slurry can apply to the mixture of in-situ soil and water that forms without the use of additives, this thesis will restrict the definition of slurry to those fluids that are intentionally mixed from mineral or polymer additives.

With any slurry product, the ratio of product to water volume can be adjusted to meet the needs of the soil conditions encountered. For mineral slurries the ratio could range from 0.5 to 1.0 lb/gal while polymer products may only require $1/100^{th}$ of that required by mineral slurries. In all cases, a thick / viscous fluid results that is designed to aid the drilling process (i.e. thicker for more porous materials). Further, as various products may be more or less effective, the amount of material is not as crucial as the resulting properties, specifically viscosity and density.

State specifications are imposed to control the slurry properties with the aim of circumventing the potential for problematic shafts. However, despite these efforts (specifications), problems persist. Figure 1.2 shows an example of a shaft that exhibited concrete flow problems, either from fresh concrete or slurry properties.

Figure 1.2. Shaft exhumed to show poor concrete flow performance from slurry or fresh concrete properties.

To date, specifications throughout the Unites States vary from state to state whereby both minimum and maximum values of viscosity are dictated. Many of these values were established on the basis of experience and not science. A recent study (Mullins, et al, 2010) provided a rational explanation for the determination of lower viscosity limits for such specifications.

Therein, the viscosity was identified below which flow increased disproportionate to viscosity. The same study noted that no parallel study had been published to establish an upper limit and forms the basis of this thesis. To establish an upper limit two concerns arise: (1) at what point does the slurry become too thick or heavy to easily displace during concreting and (2) at what point does the slurry viscosity adversely affect the concrete bond with rebar or the surrounding soil.

This thesis discusses the types of testing that are necessary to define an upper viscosity limit. Such a threshold should ensure that slurry viscosity at or below the limit would not impede the overall shaft performance while also remaining cognizant of construction procedures (i.e. without needless restrictions). Of the two concerns identified above, this thesis focuses mainly into slurry testing and the testing of the bond between concrete and reinforcing steel. The organization of the thesis is broken into the four following chapters.

Chapter 2 defines the use of shafts and reasons for choosing drilled shafts over driven piles, the process of constructing drilled shafts, quality control, slurry products and testing. The variation in state specifications will also be presented which highlights the need for a rational upper limit specification.

Chapter 3 discusses the construction and fabrication of the testing beds for the scale model testing as well as the processes used to cast the model drilled shafts. The test matrix including the identified variables is stated along with the equipment and process utilized for the rebar pullout testing.

Chapter 4 discusses the results of the laboratory slurry testing as well as the rebar pullout test results. Post testing evaluation of the test specimens is also discussed as it pertains to integrity of shaft constructed using the wet / slurry method.

Chapter 5 provides a commentary and summary of the results as well as recommendations for defining an upper viscosity limit and future research or testing that may further the overall understanding of the phenomena observed.

CHAPTER 2 BACKGROUND

The following chapter provides a brief history of drilled shafts, and the role slurry plays in the construction of drilled shafts.

2.1 Drilled Shafts

When a traditional spread or shallow footing is unable to carry the required loads a deep foundation is required. Of the many types of deep foundations, two of the most popular are driven piles and drilled shafts. Driven piles are steel, timber or pre-cast concrete elements that are driven to the appropriate depth wherein the pile lengths are predetermined based on either capacity requirements, shipping limitations or physical constraints of the installation method. Drilled shafts, on the other hand, are cast-in-place concrete elements where the practical upper limit of length is 30 to 40 diameters of the shaft (e.g. 4-foot diameter can be 120 to 160-feet deep). The Federal Highway Administration (FHWA) defines a drilled shaft as a *"cast-in-place deep foundation element constructed in a drilled hole that is stabilized to allow controlled placement of reinforcement and concrete"* (FHWA 2010).

Drilled shafts have evolved from caissons which were first used during the late 1800's. Caissons were originally precast foundations that were sunk in place to a depth that provided suitable bearing or cast-in-place in a hand dug braced excavations that were progressively advanced in lengths equivalent to available board lengths used to provide lateral wall stability. The excavation techniques for drilled shafts have not been altered much since the 1940's but improvements in technology have allowed the process to become more efficient and a viable option for any type of construction.

Of the aforementioned deep foundations, the drilled shaft can be more cost effective than driven piles in some circumstances. This is due in part to the load carrying capacity of a drilled shaft versus that of a driven pile where large axial and lateral loads can be withstood and the moment capacities are significantly greater. This often allows for fewer elements when using drilled shafts and in turn, allows for an overall smaller cap. For example, in cases exposed to large vessel collision forces, hundreds of piles can be replaced with several drilled shafts.

Drilled shaft construction is also the preferred method when dealing with varying geological strata. Driven piles are restricted to handling and shipping lengths as well as driving criteria set to ensure the piles are not damaged during driving. This is particularly problematic when encountering denser layers near the surface that require drilling prior to driving. This is not an issue with drilled shafts since the elements are cast-in-place, and the boreholes are drilled to the proper depth (reported up to over 300 feet) to reach the required capacity.

Drilled shaft construction has other benefits over driven piles wherein minimal vibrations and noise are produced while drilling and placing concrete. This makes drilled shafts more conducive for environments (urban areas) where vibrations are a major concern and could damage sensitive structures.

Despite the possible advantages of drilled shafts, they must be constructed properly. This is where the design and quality control practices come to light. When designing foundations, drilled shafts have the same structural resistance (φ) factors as above ground columns that can be visually inspected; this highlights the need for quality assurance procedures and test methods to match the same level of above ground construction practices but for blindly constructed shafts.

2.2 Shaft Construction

Drilled shaft construction is performed in three basic steps: (1) excavation, (2) placement of reinforcing cage, and (3) concreting. The process requires a drill rig capable of drilling to the depth and diameters needed to achieve the design capacity. Drill rigs are typically mechanically or hydraulically driven with telescoping Kelley bars that will vary in length and capacity attached to a multi-flight auger (Figure 2.1). The auger is not continuous-flight, but rather 2 or 3 flights. Once the proper tip elevation is reached, the auger is replaced with a clean out bucket in order to remove any loose material from the bottom of the excavation.

The most important aspect of the construction process is maintaining the integrity of the excavation walls. This is done either mechanically, hydrostatically, or a combination of both. Mechanical stabilization is achieved by inserting a steel casing and drilling inside the casing. The steel casing can either be permanent or temporary. Hydrostatic stabilization (wet construction) involves introducing slurry into the excavation that provides a net outward pressure against the insitu ground water. Therein, the slurry inside the excavation is typically maintained 4 to 8-feet above the water table depending on the type of slurry. Of these methods, slurry type construction tends to be more cost effective; however, it requires more quality control. When using slurry, a temporary surface casing is often required for the upper portion of the shaft in order to raise the slurry level and increase the hydrostatic pressure on the walls of the excavation (Figure 2.2).

Although slurry is most commonly formed by adding dry clay powder with water, slurry can be categorized as mineral, polymer, or natural. Mineral implies that dry clay powder (sodium or calcium montmorillonite) was used to form the slurry; polymer slurries are typically

Figure 2.1. Clean out bucket(left) and flight auger (right) for shaft excavation.

Figure 2.2. Temporary surface casing providing containment for slurry.

a form of polyacrylamide and water; and natural slurries are formed when plain water mixes with the natural soil. Plain water is introduced only when mechanical stabilization is used to simply offset the inflow of ground water through the bottom of the casing which would needlessly loosen the soils below the shaft tip.

The use of slurry to maintain the boring plays several roles, depending on the type of slurry. When using mineral slurry, the slurry provides a method of transporting the cuttings from the excavation while also providing lateral stability. These cuttings are held in suspension, and discharged with the slurry during concreting. When excess sand is found to be present in the slurry, the slurry is de-sanded in order to reduce the potential of sand pockets from forming in the shaft concrete. In order for the mineral slurry to function properly, it must be fully hydrated which could take 24 hours or more depending on the mixing method. However, rapid hydration methods are available that perform this step in a matter of minutes (Mullins et al, 2010). Mineral slurries usually require a minimum of 4-feet of head differential relative to the ground water elevation.

Polymer slurry acts similarly to mineral slurries, in that it requires a minimum head to maintain the hydrostatic pressure on the excavation walls. However, polymer slurry requires a slightly larger head than that of mineral (e.g. 6 - 8-feet) due to the lower density. Where the mineral slurry suspends the solids by way of mineral gel strength, polymer slurry allows the cuttings to flocculate and fall-out through the material requiring only cleanout from the bottom of the excavation. Therefore, slurry de-sanding is not necessary.

Upon reaching the proper tip elevation, the excavation is cleaned with the clean out bucket and inspected for proper depth and dimensions. Once approved the reinforcement is lowered into the excavation. Prior to concrete placement the properties of the slurry are verified, and once approved, concrete is placed.

Concrete is placed via a tremie pipe in order to prevent segregation of the concrete; concrete is essentially pumped to the bottom of the excavation through a 6 - 12-inch pipe and the slurry is displaced as the concrete level rises. It was originally thought that as the concrete was placed there was a shearing effect on the walls of the excavation in turn scrubbing away any filter cake that may have formed (when mineral slurry is used). However, as concrete is placed, it has been shown to fill up the center of the reinforcement cage, and flow outwardly pushing through the reinforcement and then resting against the walls of the excavation (Mullins et al, 2005). This effect was increased with tighter cage spacing, as well as when the tremie pipe was not centered in the opening. When placing concrete, the tremie must be embedded into the rising concrete level to a depth sufficient to ensure that there is no unwanted segregation. However, until that depth of concrete is achieved within the excavation, some segregation must be expected. The tremie pipe must be removed at a rate that maintains this requirement. As the concrete level raises towards the top of shaft elevation, the slurry is collected; and concrete overflows from the excavation to ensure proper slurry removal.

2.3 Mineral Slurry

Mineral slurry is the most widely used material when employing wet construction methods. Sodium montmorillonite (bentonite) is a natural occurring mineral with a massive absorption capacity. This particular trait is beneficial in a drilling fluid. The majority of bentonite production in the United States is in the Black Hills area of South Dakota, Montana, and Wyoming (Grim, 1978). This particular bentonite contains higher amounts of the crystallite smectite. The amount of smectite within the bentonite is directly related to performance in that it enhances the absorption capacity of bentonite.

When bentonite is mixed with water, typically keeping a maximum of five percent solids, it creates slurry with properties conducive for drilling. Bentonite changes water from a Newtonian fluid to a non-Newtonian fluid with properties of a Bingham plastic. A Newtonian fluid will maintain the same viscosity regardless of the rate of shear (viscosity can vary with temperature), whereas a non-Newtonian fluids viscosity will vary as the shear rate is varied. A Bingham plastic is a fluid that can have plastic properties and would require a stress to begin flow. The stress required to begin the flow of the material is called the yield point of the fluid (Baker Hughes, 2006). It is these characteristics that allows for the fluid to have gel strength. Gel strength is the ability of the fluid to regain its viscosity after shear thinning and gel strength allows the slurry to carry the cuttings in suspension. According to the American Petroleum Institute (API), there are two gel strengths measured at 10 seconds and 10 minutes after the material has been agitated (API, 2009). The test requires a viscometer and it is recommended that the sample be mixed at 600 rpm, sit for the allotted time, then measure the maximum shear stress while rotating at 3 rpm.

When the mineral slurry is introduced into the excavation, it begins to form a thin layer, filter cake, along the walls as it deposits clay particles while flowing into the surrounding soils. This thin layer, along with the higher hydrostatic pressure of the slurry, prevents ground water intrusion. The filter cake strengthens the walls of the excavation which in turn helps to prevent the sloughing of material. As the geology changes the properties of the slurry must be monitored to ensure there are no adverse changes disabling the filter cake formation. For more porous soils additional bentonite is typically introduced into the suspension (CETCO, 2013).

2.4 Polymer Slurry

Polymer slurries are formed when polyacrylamide materials are mixed with water. The mixture forms long polymer chains that are vital for proper performance. When mixing polymer slurries it is preferred to not shear the polymer chains. This can be done by using a diaphragm pump during recirculation in lieu of more traditional centrifugal pumps. Like mineral slurry, polymer slurry requires a minimum head in order to provide the required hydrostatic pressure.

However with a lower density than that of mineral slurries and a lower pressure gradient at the soil-slurry interface, it requires a slightly larger head.

The performance of polymer slurry is based solely on the viscosity of the material. Where mineral slurries form a filter cake barrier, polymer slurry flows into the walls of the excavation in order to maintain stability; in turn prevents ground water intrusion. Since there is no gel strength with polymer slurries it cannot carry the cuttings in suspension. Therefore, all material can be removed more immediately without concern of trapping sand in the shaft concrete. This is also beneficial when reusing the slurry since it reduces the need for de-sanding the slurry.

2.5 Quality Control

When using slurry, mineral or polymer, quality control is needed to ensure that the material will function properly. It is common practice to verify the properties of the slurry prior to introduction into the excavation for viscosity, density, and pH in the field. The same tests are to be performed prior to the placement of concrete as well, but the sand content becomes more important at that time. These test methods are based on the American Petroleum Institute (API) test methods provided in API 13B-1.

2.6 Viscosity (API 13B-1.6, FM 8-RP13B-2)

The viscosity of a fluid is its ability to resist flow under shear stress. Viscosity that is verified with a viscometer is the ratio of shear stress to strain rate. When determining the viscosity in the field a Marsh funnel is used (Figure 2.3). This determines the time required for one quart of material to pass through a standard funnel (qt/sec). The material tested is passed first through a No. 12 sieve when introduced to the funnel. The Marsh funnel is based on the principles of the falling head flow; therein, fluid flows faster with higher pressure (when the funnel is full) and progressively slows as the pressure decreases (funnel empties) As a result, longer emptying times indicate higher viscosity, but the Marsh funnel test is not a true viscosity test (shear stress/strain rate). The test is simply an indicator of gel strength and/or the presence of clay mineral content.   However, the flow times can be affected by the presence of suspended solids.


Figure 2.3. Marsh funnel and cup for determining viscosity.

2.7 Density (API 13B-1.4, FM 8-RP13B-1)

The density of slurry prior to introduction to the bore hole, as well as prior to the placement of concrete is verified with a mud balance (Figure 2.4). Prior to introduction, the slurry must have sufficient density such that the net pressure across the soil/slurry interface maintains wall stability. Prior to concreting, the density should not be too high, whereby the slurry will not be easily displaced by the heavier concrete. There have been no studies to show at what level the slurry may be too heavy, but high density is more commonly attributed to high solids content.

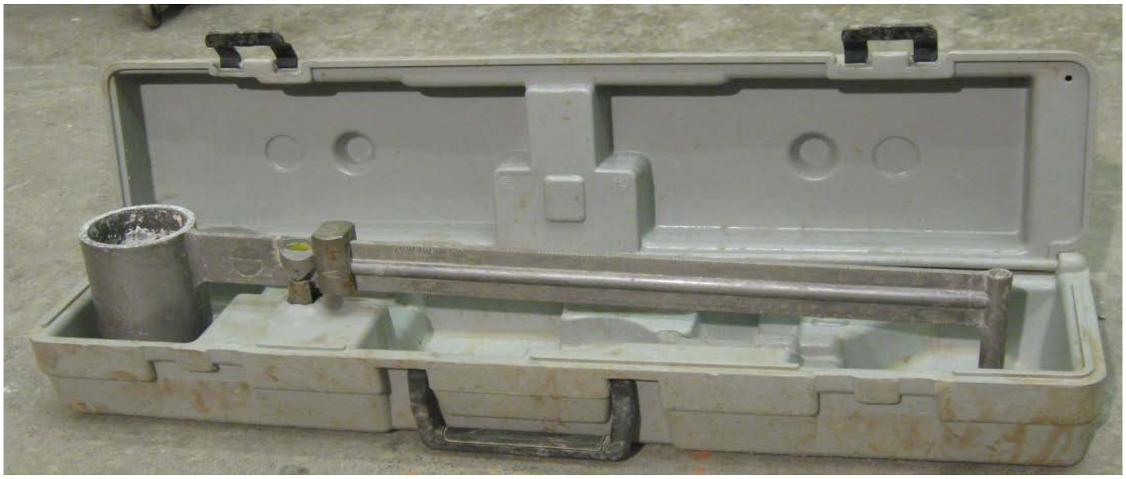

Figure 2.4. Mud balance for determining density.

2.8 Sand Content (API 13B-1.9, FM 8-RP13B-3)

The suspended solids are measured by the sand content test (API, 2009). Sand content is determined by filling a glass vial with a specified amount of fluid, pouring the fluid through a 200 mesh and rinsing the mesh back into the tube for a measurement of retained solids (Figure 2.5). The sand content is measured as a percent of total volume.

Figure 2.5. Test kit for sand content.

2.9 pH Test (API 13B-1.11, FM 8-RP13B-4)

The pH can be verified with either a pH meter or with litmus paper (Figure 2-6). The pH of the mixing water prior to introducing the bentonite powder is important to ensure that the mixing water meets the manufacturer's recommendations (e.g. CETCO, 2013). The pH can negatively affect the hydration of the bentonite if too low, or can hamper the ability of polymer slurry to achieve its desired viscosity.

Figure 2.6. pH meter (left) and litmus strips (right).

2.10 API Filter Press Test (API 13B-1.7.2)

The filter press is typically not mandatory for drilled shaft construction. The filter press is beneficial only for mineral slurry, as it determines the flow rate and filter cake formation. The test measures the time required to pass 25ml of fluid through a filter paper and the filter cake thickness is measured. The output is then 25ml/time elapsed. However, if the time exceeds 30 minutes, the amount of fluid is measured at this time and the filtrate volume/30 min is recorded (Figure 2-7).

Figure 2.7. Bench top filter press.

2.11 State Specifications

Each state provides specifications that limit the viscosity, density, sand content and pH of slurry prior to introduction into the borehole and prior to placement of concrete. FHWA also provides a range for each of the aforementioned tests. In general, state recommended ranges for density, sand content, and pH contents are all consistent with the values set forth by the FHWA. However, specifications for viscosity from each state show that there is quite a variance in the acceptable values that are permitted. Figure 2-8 illustrates the varying viscosities from state to state as well as that from FHWA. The large range of acceptable viscosities is presumably based on empirical data but the rationales are not published with the exception of the recent lower viscosity limit set in Florida (FDOT, 2013). In general, the lower viscosities are similar, but the upper viscosity limit can vary greatly and no rationale for these values is published. A breakdown of all state slurry specifications is provided in Appendix B.

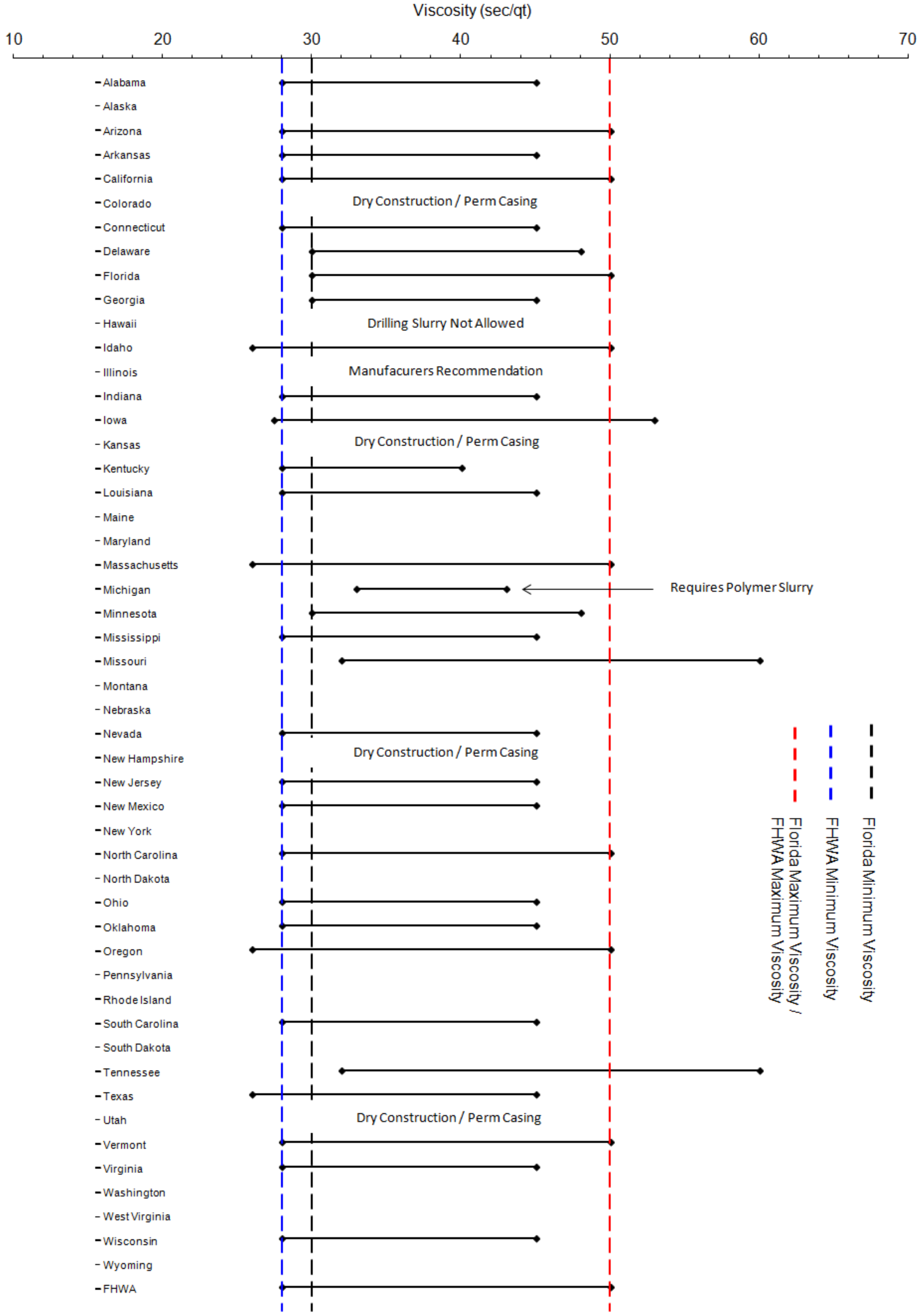

Figure 2.8. Breakdown of available state recommended viscosities.

2.12 Development Length

The development length of a deformed bar can be determined with the equation provided by the American Concrete Institute ACI 318-10 (Equation 1) stemming from ACI Committee 408 tasked with determining the bond strength between concrete and steel reinforcement. According to this committee, the bond strength is based on the friction between the concrete and the reinforcement which is affected by the strength of the reinforcement, surface deformation characteristics, system geometry and concrete strength. Any factor or material that interferes with this interface could adversely affect this friction, and in turn reduce the bond strength.

$$L_d = \left[\frac{3}{40}\frac{f_y}{\sqrt{f'_c}}\frac{(\psi_t\psi_e\psi_s\lambda)}{\left(\frac{c_b+K_{tr}}{d_b}\right)}\right]d_b \qquad \text{Equation 1}$$

According to ACI 408, there are several formulas to determine the bond strength. The equations use different coefficients, but the variables are consistent. According to the available equations, the main variables are the concrete strength, the concrete cover, clear spacing, and surface area of the reinforcement (Equations 2 - 5), but not steel strength when considering bond.

$$u = 0.083045\sqrt{f'_ç}\left[1.2 + 3\frac{c}{d_b} + 50\frac{d_b}{L_d}\right] \qquad \text{Equation 2}$$

(Orangun et al, 1977)

$$u = 0.083045\sqrt{f'_ç}\left[\left(1.06 + 2.12\frac{c}{d_b}\right)\left(0.92 + 0.08\frac{C_{max}}{C_{min}}\right) + 75\frac{d_b}{L_d}\right] \qquad \text{Equation 3}$$

(Darwin et al, 1992)

$$u = 0.265\sqrt{f'_ç}\left[\frac{c}{d_b} + 0.5\right] \qquad \text{Equation 4}$$

(Australian Standard, 1994)

$$u = 0.083045\sqrt{f'_c}\left[22.8 - 0.208\frac{c}{d_b} - 38.212\frac{d_b}{L_d}\right] \qquad \text{Equation 5}$$

(Hadi, 2008)

where,

$d_b = Bar\ Diameter$

$L_d = Development\ length$

$c = Minimum\ clear\ cover$

$f'_c = Compressive\ strength\ of\ concrete$

$c_{max} = Maximum\ of\ side\ cover, bottom\ cover, clear\ spacing/2$

$c_{min} = Minimum\ of\ side\ cover, bottom\ cover, clear\ spacing/2$

These equations were used to determine the bond strength for this project to both design the pullout equipment and to evaluate the actual measured values (Chapter 3 and 4, respectively).

2.13 Adverse Effects of Wet Construction

Even when following the recommended state specifications, unforeseen complications can still arise. For instance, the contact time for slurry in the excavation is referenced in the FHWA recommendations, and the specified maximum exposure time varies from state to state. FDOT limits bentonite exposure to 36-hours after which the borehole should be over-reamed to remove any filter cake. As some excavations take longer than 36-hours to complete, the bottom 5-feet must be drilled within 12-hours of concreting (FDOT, 2013). This in effect allows the upper most portion of the shaft to be exposed for longer exposure times and degraded side shear between the shaft and soil in those regions, but not in the lower 5 ft.

The plastic properties of the concrete can also affect flow and displacement of the bentonite slurry during concrete placement. FDOT state specification for drilled shaft concrete slump ranges from 7 to 10 inches (FDOT, 2013). However, slump loss is permitted to go as low as 5 inches during concreting. This low slump concrete has been shown to reduce flow resulting in near zero pressure against the soil walls, especially for full length temporary casing applications (Garbin, 2003). This also results in increased potential for anomalies in the concrete outside the cage. Figure 2.9 shows a shaft that was exhumed due to a mismatch in the theoretical and actual concrete volume placed. It clearly shows flow through the cage was compromised despite meeting state specifications at the time of the concrete placement. Additionally, there are indications that the suspended solids may have been too high as well.

According to FHWA, there is "no reduction in bond strength when using bentonite" (FHWA, 2010, Fleming and Sliwinski, 1975). This research was based on pullout tests that were performed on concrete panels. For the pullout tests that were performed, the bars that were to be in contact with the slurry were attached to the lateral reinforcing, and were cast in place, whereas the reinforcing that was not in contact with bentonite was pushed through the plastic concrete and not attached to the lateral reinforcement. It has been shown in previous work that the lateral reinforcement increases the pullout capacity of the reinforcement (ACI, 2003). Therefore, the results between the reinforcing in contact with bentonite, and the reinforcement not in contact with bentonite are not comparable. This research was based on pullout tests that were performed on concrete panels that were not poured in keeping with the drilled shaft concrete flow patterns as known today. Although there is no flow of slurry into the reinforcing steel, the rebar bond may also be affected by contact time.

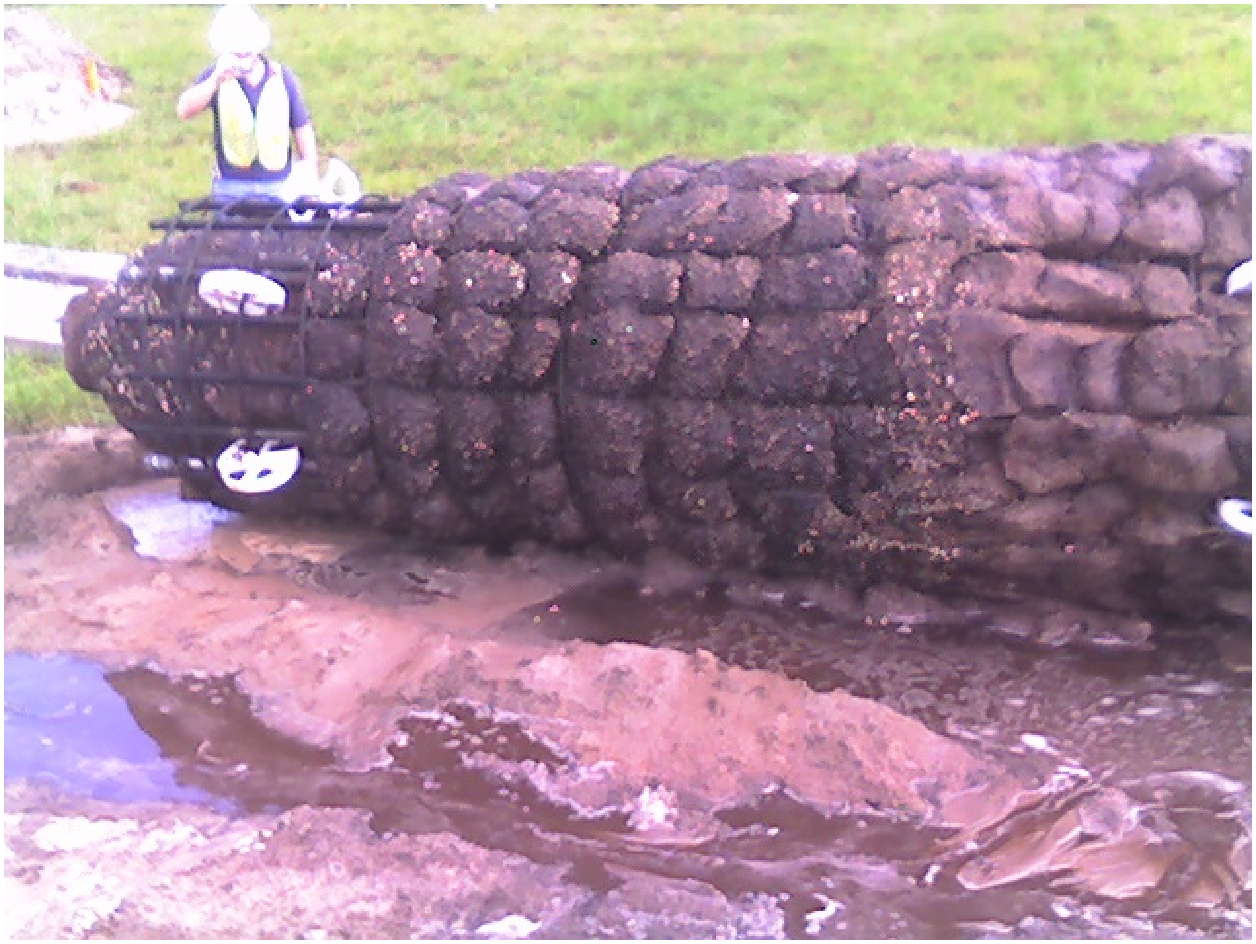

Figure 2.9. Exhumed drilled shaft displaying concrete flow issues.

It is the purpose of this thesis to determine if there are any adverse effects of the bond strength between the reinforcement and the concrete interface when using the wet construction method and specifically those involving bentonite. To this end, it is also a focus to define an upper limit above which the viscosity adversely affects the drilled shaft integrity or performance.

CHAPTER 3 LABORATORY TESTING

This chapter discusses the preparation of the bentonite slurry, the fabrication of the casting forms, as well as the process used for the pullout testing.

3.1 Bentonite Testing

In order to determine the amounts of bentonite required to obtain the varying viscosities, small scale (1 gallon) batches of slurry were mixed. Prior to batching slurry, the mixing water was mixed with soda ash to bring the pH within the required range and meet state specifications and manufacturer recommendations (for FDOT this is between 8 and 11, FDOT, 2013). For all slurry mixed during the following experiments the pH was increased to approximately 9.5. In order to encompass all viscosities currently recommended from state specifications the tests were performed as well as extending the testing to 90 sec/quart. The bentonite introduced was increased in increments of 0.1 pounds/gallon until the desired viscosity was obtained (Table 3.1). For the tests performed CETCO's PureGold Gel© was used. This particular brand was chosen based on previous research that indicated more product would be needed to produce comparable viscosities when compared to other brands (Yeasting, 2011). This in turn should provide a worst case scenario as far as percent solids in suspension of the slurry. As Figure 3.1 illustrates, these tests were required due to the non-linear characteristics. Along with the viscosities, the density, pH and temperature were recorded. For the laboratory testing a 100mL volumetric flask and a digital scale were used to determine the density. This method provided more accurate results and the volume could be more precisely determined. All small scale samples were mixed with a drill press and a paddle bit for a duration of 20 minutes to ensure a homogeneous mixture.

Table 3.1. Results for small scale testing to determine bentonite quantities.

Bentonite (lb/gal)	pH	Mass/ 100mL (g)	Density (g/mL)	Densit y (lb/ft^3)	Temp (C°)	Average Viscosity (sec)
0.1	8.34	1001.1	1.0011	62.50	25.0	30.70
0.2	8.34	1018.1	1.0181	63.56	22.1	29.79
0.3	9.13	1013.9	1.0139	63.30	25.0	29.27
0.4	9.10	1016.3	1.0163	63.45	25.0	29.93
0.5	9.11	1020.0	1.0200	63.68	25.0	30.57
0.6	9.16	--			25.0	33.04
0.7	9.09	1036.6	1.0366	64.71	25.0	35.33
0.8	9.04	1045.0	1.0450	65.24	25.0	39.23
0.9	9.05	1050.8	1.0508	65.60	25.0	46.07
1.0	9.16	1059.9	1.0599	66.17	25.0	59.87
1.1	9.12	1061.5	1.0615	66.27	25.0	98.16
1.2	9.09	1073.1	1.0731	66.99	25.0	359.30

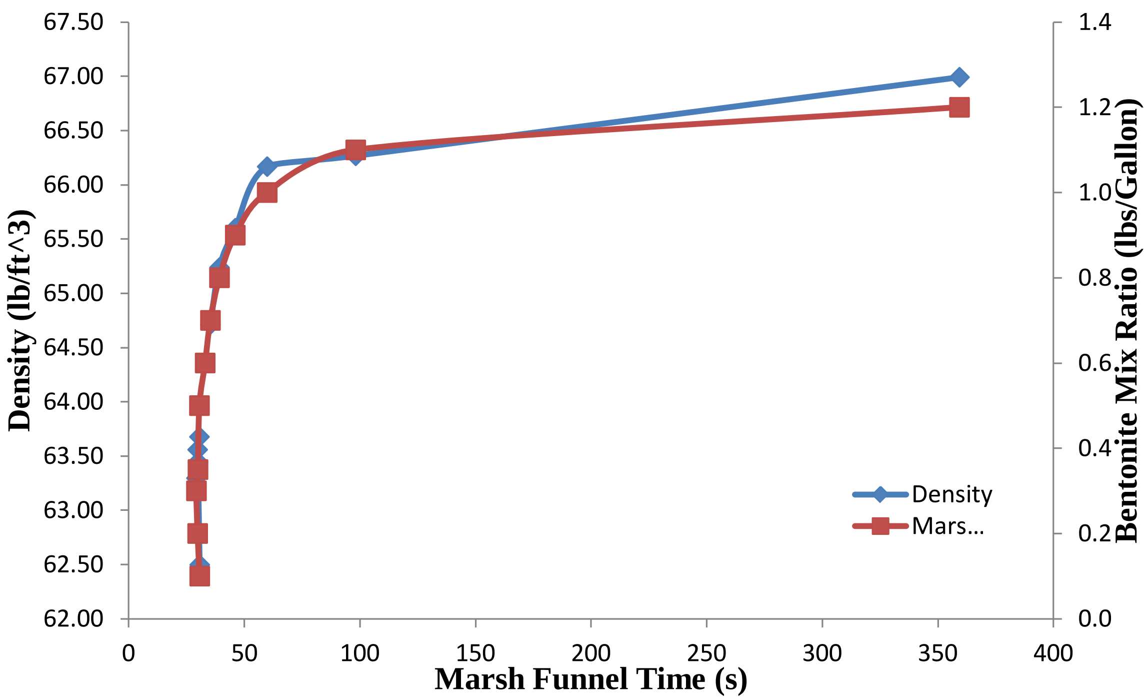

Figure 3.1. Plot of test results illustrating the non-linear relationship.

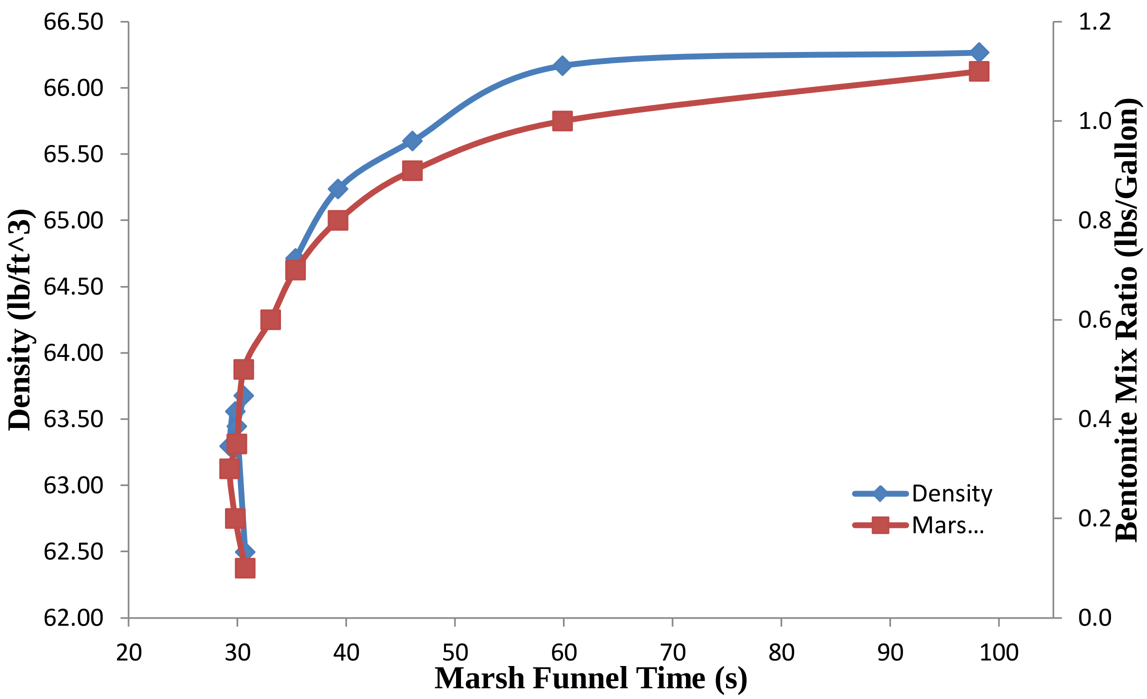

Figure 3.2. Test results focused on nation-wide current allowable viscosities.

3.2 Form Fabrication

The sizing considerations of the scale model shafts were two-fold: (1) the shafts should be large enough to maximize the sample size and use a full rebar cage to model a congested, within design constraints, reinforcement cage with minimum clearances and openings, and (2) concrete should be tremie placed to replicate field concrete flow conditions. The scale shafts were 24-inches tall, and 42-inches in diameter.

The sidewalls for the shafts were constructed from 18 gauge steel. The steel sheets were cut into 24-inch x 132-inch strips and rolled into a circular shape. Once the sheets were rolled, the strips were trimmed and 2-inch x 2-inch x 0.25-inch steel angles were welded to the edges in order to allow the repeated opening and closing of the forms (Figure 3.2).

Figure 3.3. 18 gauge steel rolled to 42-inch diameter.

Once the sidewalls were completed, ¾ -inch plywood sheets were cut into 4-foot x 4-foot sections and treated with polyurethane in order to achieve a non-absorptive surface. In order to increase repeatability, PVC caps were anchored and, silicon sealed to the plywood base as a means to locate the reinforcement. Once the plywood was treated and the PVC caps were installed, the sheets were framed out with 2-inch x 6-inch boards as to dam the flow of slurry during placement in order to pump evacuated slurry into holding tanks. In order to increase the sample numbers for a given pour, a total of six forms were fabricated.

Figure 3.4. Finished form prior to placement of reinforcement.

In order to prevent fluid loss during the testing process, each form was sealed with silicone around the base of the form. Once the material had time to cure, a water test was performed in order to ensure that each form was in fact water tight.

Figure 3.5. Silicon to seal form (left), water testing to ensure water tight seal (right).

3.3 Reinforcing Cage

In order to maximize the congestion, and still remain within state specifications, a reinforcement arrangement consisting of 14-No. 8 bars (1.0-inch diameter) vertically, and 2-No. 3 bars were used for the horizontal (stirrups) reinforcement. In addition to the steel stirrups, polyethylene pipe (PEX pipe) was incorporated as a second layer of horizontal reinforcement congestion. The vertical reinforcement was placed in two layers with a minimum of 6-inches of clear spacing between bars. The exterior layer was in place to provide structural reinforcement for the model shafts and was not used for the pullout testing. The steel stirrups were placed on the exterior of the outer layer of vertical reinforcement for confinement purposes, and did not come in contact with the vertical reinforcement to be tested. The PEX pipe was placed between the vertical reinforcement layers to provide congestion without providing any strength to the shaft. The stirrups were placed 6-inches on center. The PEX pipe was also placed 6-inches on center, however the PEX pipe, non-structural, was placed for the entire depth of the shaft, where the steel, structural, was placed only in the top 10-inches (Figure 3.5).

Figure 3.6. Structural, outer layer, reinforcement (left) and full cage (right).

Each of the vertical reinforcing bars was cut to a length of 4-feet in order to allow enough length for the hydraulic ram, and steel spacers during testing. Each bar to be tested was machined down to 0.865-inches for a length of 3-inches on the end. Once machined the bars were threaded for a 0.875-inch nut. This was to provide a point of resistance for the ram during the pullout testing (Figure 3.6).

Figure 3.7. Reinforcement after machining.

3.4 Slurry Preparation

In order to ensure proper hydration, all slurry was mixed a minimum of 24-hours prior to placement in the forms. To maximize the mixing hydration process during mixing, each batch was mixed using the rapid hydration Hootonanny® eductor. Four different viscosities were chosen to be tested (30, 40, 50, and 90-seconds). The current most prevalent upper viscosities, were tested at 40 sec/qt and 50 sec/qt corresponding to state and federal limits, respectively. The mix ratios were based on previous test data. The 30 sec/qt was achieved with 0.3 lbs/gallon of water, 40 sec/qt with 0.8 lbs/gallon of water, 50 sec/qt with 0.95 lbs/gallon, and the 90 sec/qt with 1.05 lbs/gallon.

Figure 3.8. Mixing mineral slurry with Hootonanny® eductor.

The bentonite slurry was mixed with a combination of 3-inch and 2-inch shear pumps. Each batch consisted of 150-gallons for the mineral slurries that were tested. For quality assurance, the viscosities were verified after mixing and again after a setting time of 24-hours to ensure full hydration as well as confirm the desired viscosities.

Figure 3.9. Batches of mineral slurry after mixing.

For comparison, the manufacturer's recommended minimum and maximum viscosities for polymer slurries were tested as well. Shore Pac® was the material chosen for the polymer testing performed. Due to the sensitive nature of the polymer chains a diaphragm pump, along with a bubbler system was used to mix and agitate the polymer slurries. The chosen viscosities for the polymer slurry were 60 sec/qt (lower end) and 135 sec/qt (upper end). The polymer mix ratios were 60 sec/qt mix required 0.21 lbs/gallon for the 60 sec/qt mix and 0.88 lbs/gallon for the 135 sec/qt mix again per manufacturer's recommendations. The polymer slurry was mixed in 300 - 400 gallon batches.

Figure 3.10. 60 sec/qt polymer slurry after mixing being agitated with bubbler system.

For every placement the slurries were tested for density, and viscosity at the time of introduction to the forms, and again prior to placement of concrete. The viscosities were measured by the Marsh funnel method, as well as with a viscometer. Prior to the placement of concrete the mineral slurries were tested with the filter press. In order to show the effects of exposure, the maximum permissible set time was used wherein the slurry was allowed to remain in the forms, and in contact with the reinforcement for 12-hours prior to placement of concrete (FDOT, 2013). Slurry was placed in the forms the night prior to the concrete placement with either the shear pump (mineral) or a diaphragm pump (polymer).

Along with the mineral and polymer slurries, two shafts were constructed using only water. This was done as a control sample to acquire test results without slurry, and in ideal conditions.

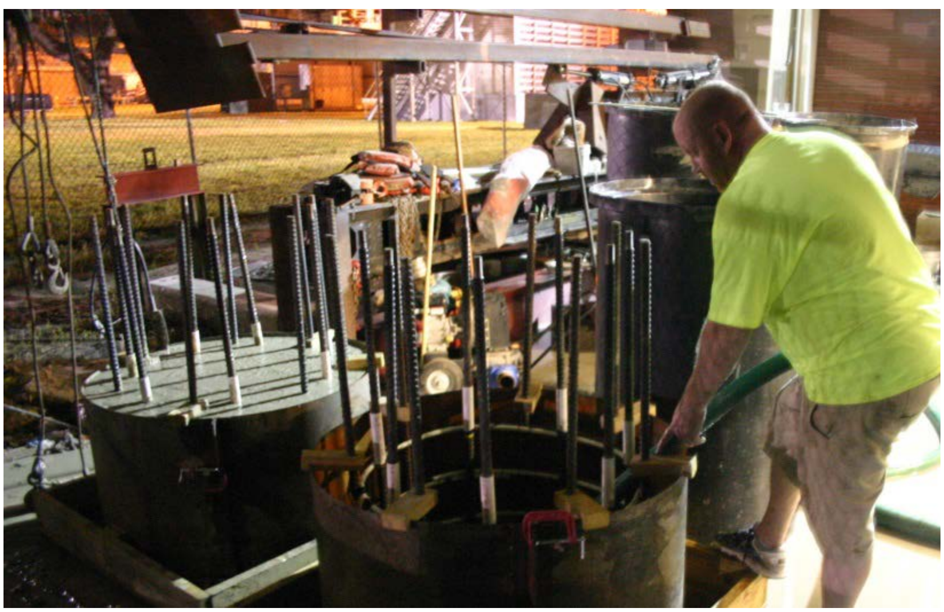

Figure 3.11. Placing mineral slurry in forms night prior to placement.

3.5 De-Bonding of Reinforcement

According to the American Concrete Institute (ACI) 318-11, the required development length for a deformed No.-8 bar is 47-inches and can be calculated with the development length equation provided (Equation 1). Due to the size of the shafts being constructed, this value is not attainable. The ACI Committee 408 has performed research to try to determine the force that is required to pullout a deformed bar. These equations were used to approximate the de-bonded region of the bars to be tested (Equations 2 - 5).

Throughout the project the de-bonded region was modified in order to ensure the best test results. For the initial placement, a bonded length of 18-inches was used, 2-inches at the bottom and 4-inches at the top of the shaft. The length was increased in the top of the shaft in order to protect against rupture of the concrete. Due to higher than expected pullout capacity, the de-bonded length was reduced to 10-inches for the following placement, and finally to 6-inches for all subsequent placements. De-bonding was achieved with the use of 1-inch thin-walled PVC pipe cut to length, sealed with tape, and tied in place with plastic ties.

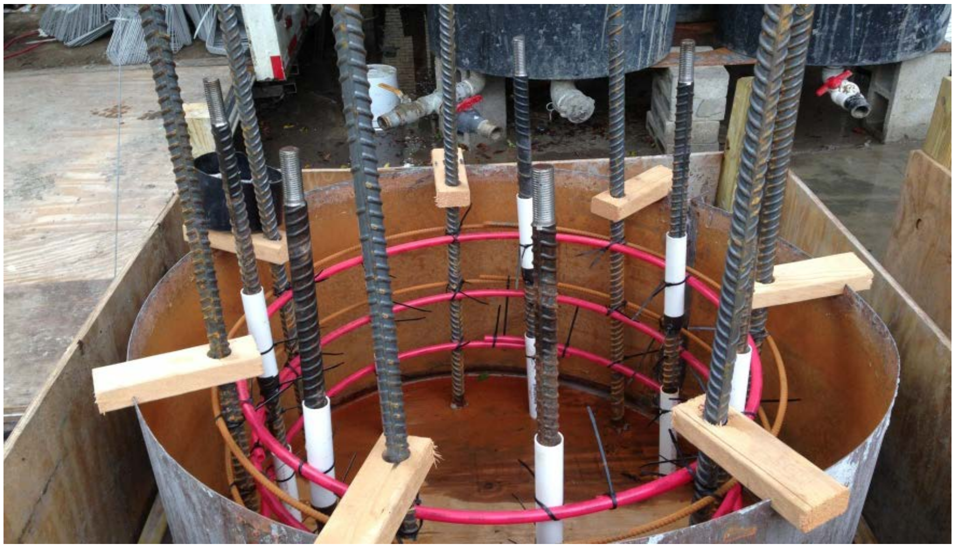

Figure 3.12. Reinforcement cage after de-bonding prior to slurry placement.

3.6 Concrete Placement

The concrete used to cast the model shafts was chosen based on the criteria that it was an FDOT approved mix with a 28 day compressive strength of 4000 psi, contained 20% to 30% flyash, and had a slump ranging from 7 to 10-inches. Preferred Materials, Inc. was chosen as the concrete supplier and provided a Class IV Drilled Shaft concrete, mix ID 01-1031-01. This FDOT approved mix had a 0.4 water to cement ratio and met the previous requirements.

The concrete placement began within the 12 hours of the slurry placement as previously discussed. The concrete was placed via tremie to simulate concrete placement in the field. For quality assurance the plastic properties of the concrete were tested, and 4-inch by 8-inch cylinders were cast in order to verify compressive strength prior to performing pull out tests. Once the concrete placement was completed the tops of the model shafts were leveled and finished for subsequent pullout tests.

Figure 3.13. Placing concrete via tremie.

Upon achieving appropriate compressive strength, the steel forms were removed from the shaft in order to visually inspect for anomalies and imperfections. Once the forms were removed and initial inspection had taken place, the shafts were then pressure washed in order to remove any remaining mineral slurry on the exterior or that was not displaced by the concrete placement.

Figure 3.14. Form removal after shaft achieves suitable compressive strength.

3.7 Pullout Testing

Pullout testing was performed with a hydraulic pump and a 30-ton hollow-core hydraulic ram. In order to capture the data, the hydraulic pump pressure was measured with an inline pressure transducer connected to computerized data acquisition system (Omega DAQ-55). Data was acquired at a sampling rate of 4-Hertz to ensure that the peak load was captured.

In order to determine the stiffness of the bond, a displacement transducer was attached to the ram to measure the bar pullout movement during loading. Pullout testing was performed after the concrete reached a minimum compressive strength of 4-ksi, and were all completed on the same day as the compressive strength testing. During testing, the ram was placed over the bar to be tested, and seated on the previously leveled concrete surface. A 0.375-inch steel plate was placed between the ram and the threaded region of the bar. In order to distribute the load along the entire threaded region 2 high-strength nuts were used to hold the steel plate in place.

Figure 3.15. Ram configuration during pullout testing with LVDT in place.

In all, a total of 126 pullout tests were performed on 18 different shaft specimens. The data acquired from each pullout test was then analyzed to show the effects of stiffness, ultimate capacity, and any trends associated with the bond of the rebar in the various environments.

CHAPTER 4 TESTING RESULTS

This chapter discusses the results of the testing that was performed. This includes: the properties of the slurry at preparation and prior to placement, concrete properties during placement, and concludes with the results of the pullout tests.

4.1 Slurry Properties

Prior to placing slurry in the forms, on the eve of the concrete placement, the viscosity was determined with the Marsh funnel method, and verified with a viscometer. In addition to the viscosity, the density was tested for each sample at the time the slurry was introduced into the form, as well as prior to concrete placement. Table 4.1 details the shaft number, as well as the anticipated slurry viscosity.

Table 4.1. Shaft number and viscosity by placement.

Placement 1	Shaft 1	40 Second
	Shaft 2	90 Second
Placement 2	Shaft 3	40 Second
	Shaft 4	50 Second
	Shaft 5	90 Second
	Shaft 6	26 Second (Water)
Placement 3	Shaft 7	30 Second
	Shaft 8	40 Second
	Shaft 9	50 Second
	Shaft 10	90 Second
	Shaft 11	60 Second (Polymer)
	Shaft 12	60 Second (Polymer)
Placement 4	Shaft 13	30 Second
	Shaft 14	30 Second
	Shaft 15	50 Second
	Shaft 16	90 Second (Polymer)
	Shaft 17	90 Second (Polymer)
	Shaft 18	26 Second (Water)

For the first concrete placement the viscosity was determined via the Marsh Funnel method, for all subsequent placements the viscosity was first determined via the Marsh Funnel followed by determining the plastic viscosity and gel strength with a viscometer. The subsequent tables provide a breakdown of the slurry properties at the time of slurry placement, as well as at the time of concrete placement (Table 4.2 - 4.4). For the first placement only the viscosity was verified to be 40 sec and 90 sec at the time of slurry placement for shafts 1 and 2, respectively.

Table 4.2. Breakdown of slurry properties for model shafts from placement 2.

Shaft Number	Sample Time	Viscosity (sec/qt)	Plastic Viscosity (cP)	10 Sec Gel Strength	10 Min Gel Strength	Density (lb/ft^3)	Yield Point
3	Intro	41.15	10.00	33	55.00	65.37	40.51
	Placement	43.81	11.50	0.00	58.00		39.67
4	Intro	51.57	12.88	64.00	66.00	65.29	84.98
	Placement	57.20	15.32	66.00	99.00		72.23
5	Intro	83.90	20.16	135.00	118.00	65.72	138.34
	Placement	108.39	23.99	118.00	180.00		122.77
6		26 (Water)	n/a	n/a	n/a	n/a	n/a

Table 4.3. Breakdown of slurry properties for model shafts from placement 3.

Shaft Number	Sample Time	Viscosity (sec/qt)	Plastic Viscosity (cP)	10 Sec Gel Strength	10 Min Gel Strength	Density (lb/ft^3)	Yield Point
7	Intro	30.01	2.80	0.00	4.00	63.21	5.19
	Placement	31.10	4.46	0.00	5.00		2.11
8	Intro	38.10	8.71	18.00	51.00	64.27	32.65
	Placement	41.73	11.74	22.00	55.00		31.16
9	Intro	48.76	14.03	53.00	103.00	64.61	62.88
	Placement	56.72	15.34	54.00	98.00		71.08
10	Intro	80.73	20.84	96.00	172.00	65.17	115.01
	Placement	119.59	22.97	107.00	178.00		130.71
11 Polymer	Intro	65.99	5.75	0.00	0.00	62.03	6.30
	Placement	64.89	5.37	2.00	2.00		8.58
12 Polymer	Intro	66.46	5.77	3.00	3.00	62.09	5..78
	Placement	65.97	5.30	2.00	3.00		9.15

Table 4.4. Breakdown of slurry properties for model shafts from placement 4.

Shaft Number	Sample Time	Viscosity (sec/qt)	Plastic Viscosity (cP)	10 Sec Gel Strength	10 Min Gel Strength	Density (lb/ft^3)	Yield Point
13	Intro	29.88	2.59	3.00	5.00	63.41	3.05
	Placement	30.43	3.31	4.00	5.00		4.18
14	Intro	30.22	2.16	3.00	7.00	63.41	11.77
	Placement	31.24	3.32	2.00	5.00		4.51
15	Intro	52.87	13.31	52.00	101.00	65.02	70.94
	Placement	61.37	17.18	48.00	78.00		75.21
16 Polymer	Intro	81.76	7.15	11.00	15.00	61.06	27.58
	Placement	86.76	7.59	10.00	15.00		26.31
17 Polymer	Intro	83.18	7.15	11.00	15.00	61.06	27.58
	Placement	85.05	7.48	10.00	15.00		30.16
18		26 (water)	n/a	n/a	n/a	n/a	n/a

4.2 Concrete Properties

During each concrete placement the plastic properties were tested to ensure compliance with FDOT specifications. This required a slump range of 7 to 10-inches (FDOT, 2013). The concrete properties are detailed in Table 4.5 through 4.8 for placements 1 through 4, respectively. For placement 1, only the slump data was recorded and cylinders were cast between the placement of shaft 1 and shaft 2, and for the subsequent placements the test times were recorded.

Table 4.5 Concrete plastic properties for placement 1.

Concrete Data					
Shaft Number	**Slurry Type**	**Viscosity (sec)**	**Slump (in)**	**Cylinders**	**Slurry Contact Time (hours)**
1	Bentonite	40	8.50	n/a	12
2	Bentonite	90	8.50	yes	12

The concrete slumps encountered during testing ranged from 4.5-inches to 9.5-inches upon arrival at the test site. The properties are specified in the mix design and were noted on the delivery tickets, (Appendix C) however, this variability was still encountered, and it is assumed that the same issues could arise in the field under normal drilled shaft construction.

Table 4.6. Concrete plastic properties for placement 2.

Concrete Data							
Shaft Number	**Slurry Type**	**Viscosity (sec)**	**Slump (in)**	**Cylinders**	**Slurry Placed**	**Casting Time**	
						Start	**Finish**
3	Bentonite	40	9.50	yes	10:04 PM	10:31 AM	10:36 AM
4	Bentonite	50	8.50	n/a	9:06 PM	9:43 AM	9:48 AM
5	Bentonite	90	9.25	n/a	9:35 PM	10:03 AM	10:07 AM
6	Water	26	8.50	yes	9:00 PM	10:57 AM	11:02 AM

Table 4.7. Concrete plastic properties for placement 3.

Concrete Data							
Shaft Number	**Slurry Type**	**Viscosity (sec)**	**Slump (in)**	**Cylinders**	**Slurry Placed**	**Casting Time**	
						Start	**Finish**
7	Bentonite	30	8.25	n/a	9:39 PM	11:03 AM	11:05 AM
8	Bentonite	40	7.75	n/a	10:05 PM	11:13 AM	11:15 AM
9	Bentonite	50	8.50	n/a	10:28 PM	11:20 AM	11:24 AM
10	Bentonite	90	8.00**	yes	9:17 PM	10:52 AM	10:56 AM
11	Polymer	60	7.75	n/a	10:49 PM	11:27 AM	11:29 AM
12	Polymer	60	7.75	yes	11:08 PM	11:38 AM	11:40 AM

** Added approximately 27 gallons of water to obtain slump.

Table 4.8. Concrete plastic properties for placement 4.

Concrete Data							
Shaft Number	**Slurry Type**	**Viscosity (sec)**	**Slump (in)**	**Cylinders**	**Slurry Placed**	**Casting Time**	
						Start	**Finish**
13	Bentonite	50	9.50	n/a	8:31 PM	9:02 AM	9:06 AM
14	Bentonite	30	9.50	yes	8:55 PM	9:17 AM	9:20 AM
15	Bentonite	30	10.00	n/a	9:13 PM	9:29 AM	9:31 AM
16*	Polymer	85	10.00	n/a	9:38 PM	9:38 AM	9:42 AM
17	Polymer	85	9.50	n/a	9:42 PM	9:49 AM	9:55 AM
18	Water	26	10.00	yes	9:22 PM	10:07 AM	10:14 AM

* 2 1/2 hour contact time due to form leaking.

Prior to performing any pullout testing the concrete cylinders cast during the concrete placement were tested to verify the compressive strength. A minimum of 4-ksi was needed in order to model field conditions, as well as to prevent major failure during pullout. Tables 4.9 through 4.12 provide the compressive strength data for the concrete placements.

Table 4.9. Compressive strength data from placement 1.

	Break Date	**Diameter (in)**	**Diameter (in)**	**Area (in^2)**	**Force (lbs)**	**Strength (psi)**
Average Compressive Strength						6150

Table 4.10. Compressive strength data from placement 2.

	Break Date	**Diameter (in)**	**Diameter (in)**	**Area (in^2)**	**Force (lbs)**	**Strength (psi)**
Set 1	5-14-13	4.025	4.049	12.800	56130	4385
Set 1	5-14-13	4.059	4.033	12.857	56050	4359
Set 2	5-14-13	4.063	4.023	12.838	54390	4237
Set 2	5-14-13	4.051	4.046	12.873	57290	4450
				Average strength		4358

Table 4.11. Compressive strength data from placement 3.

	Break Date	**Diameter (in)**	**Diameter (in)**	**Area (in^2)**	**Force (lbs)**	**Strength (psi)**
Set 1	6-25-13	4.075	4.067	13.016	54083	4150
Set 1	6-25-13	4.080	4.025	12.898	57098	4430
Set 2	6-25-13	4.022	4.000	12.636	62016	4910
Set 2	6-25-13	4.077	4.064	13.013	60180	4620
				Average strength		4530

Table 4.12. Compressive strength data from placement 4.

	Break Date	Diameter (in)	Diameter (in)	Area (in^2)	Force (lbs)	Strength (psi)
Set 1	10-18-13	4.000	4.000	12.566	61170	4870
Set 1	10-18-13	4.000	4.000	12.566	59050	4580
Set 2	10-18-13	4.000	4.000	12.566	60820	4810
				Average strength		4750

4.3 Pullout Data

Once the concrete achieved the desired compressive strength, the pullout testing could be performed. Pullout testing was performed on the same day as the compressive strength testing. The following tables detail the pullout data for each placement. The bonded length for placement 1 was 18-inches. The red shaded areas denote bars that failed in tension. All failures occurred in the threaded region due to the reduced cross section.

Table 4.13. Placement 1 pullout data.

Maximum Recorded Pullout Load		
Bar #	Bentonite	
	Shaft 1 40 sec	Shaft 2 90 sec
1	58.706	55.724
2	65.360	51.680
3	54.071	51.073
4	56.460	53.133
5	55.160	33.097
6	60.946	53.852
7	49.935	49.367
Max	65.360	55.724
Min	49.935	33.097
Average	57.234	49.704
std dev	5.003	7.604

For placement 2 the bonded length was adjusted from 18-inches to 10-inches based on the calculated values to determine the pullout strength. Again, the red shaded areas denote bars that failed in tension. The bonded length for the water shaft was varied where the shortest length was 8-inches, increasing in 2-inch increments up to 12-inches. Again, all the bar failures occurred in the threaded region of the bar where the cross section was reduced during machining.

Table 4.14. Placement 2 pullout data.

Maximum Recorded Pullout Load				
Bar #	**Bentonite**			**Water**
	Shaft 3 40 sec	Shaft 4 50 sec	Shaft 5 90 sec	Shaft 6 26 sec
1	40.88	29.36	35.08	54.65
2	40.70	34.68	36.46	51.19
3	37.22	34.56	35.81	55.73
4	40.52	38.96	46.21	54.34
5	33.23	31.62	42.37	51.83
6	26.99	34.17	35.80	55.46
7	38.71	25.52	34.93	56.93
Max	40.881	38.962	46.211	56.933
Min	26.994	25.523	34.927	51.194
Average	36.894	32.697	38.094	54.304
std dev	5.138	4.332	4.405	2.090

For placement 3 the bonded length was again adjusted based on previous test data to a length of 6-inches. Along with determining the pullout strength, for placement 3 the bar displacement was measured to determine stiffness of the bond between the concrete and reinforcement. Table 4.15 (below) provides the pullout testing data from placement 3, and is followed by the stiffness data in Table 4.16.

Table 4.15. Placement 3 pullout data.

Maximum Recorded Pullout Load (kips)						
Bar #	**Bentonite**				**Polymer**	
	Shaft 7 30 sec	Shaft 8 40 sec	Shaft 9 50 sec	Shaft 10 90 sec	Shaft 11 60 sec	Shaft 12 60 sec
1	23.559	26.970	23.998	20.639	32.886	30.233
2	31.575	26.018	18.836	29.715	34.133	42.584
3	22.707	25.242	24.218	20.932	26.757	25.488
4	34.929	24.708	24.117	25.910	41.109	29.595
5	32.530	18.320	20.893	18.518	24.431	36.973
6	28.293	20.599	12.657	27.736	32.836	38.471
7	27.687	27.627	18.947	18.519	34.216	34.244
Max	34.929	27.627	24.218	29.715	41.109	42.584
Min	22.707	18.320	12.657	18.518	24.431	25.488
Average	28.754	24.212	20.524	23.139	32.338	33.941
std dev	4.569	3.454	4.203	4.580	5.445	5.896

Table 4.16. Placement 3 Stiffness data.

Recorded Pullout Stiffness (kips/in)						
Bar #	**Bentonite**				**Polymer**	
	Shaft 7 30 sec	Shaft 8 40 sec	Shaft 9 50 sec	Shaft 10 90 sec	Shaft 11 60 sec	Shaft 12 60 sec
1	184.524	155.147	200.293	178.007	236.414	233.316
2	147.035	95.463	121.542	n/a	229.444	124.058
3	160.456	178.462	133.714	116.327	242.478	183.385
4	118.177	157.900	181.749	146.099	193.904	183.348
5	133.818	134.670	116.816	126.856	98.494	157.599
6	187.597	144.364	79.575	93.945	150.325	129.961
7	154.469	132.983	147.729	103.965	102.648	118.166
Max	187.597	178.462	200.293	178.007	242.478	233.316
Min	118.177	95.463	79.575	93.945	98.494	118.166
Average	155.154	142.713	140.203	127.533	179.101	161.405
std dev	25.273	26.006	40.838	30.666	62.217	41.640

The stiffness was determined by calculating the change in load in the linear portion of the following plots (Figures 4.1 - 4.6).

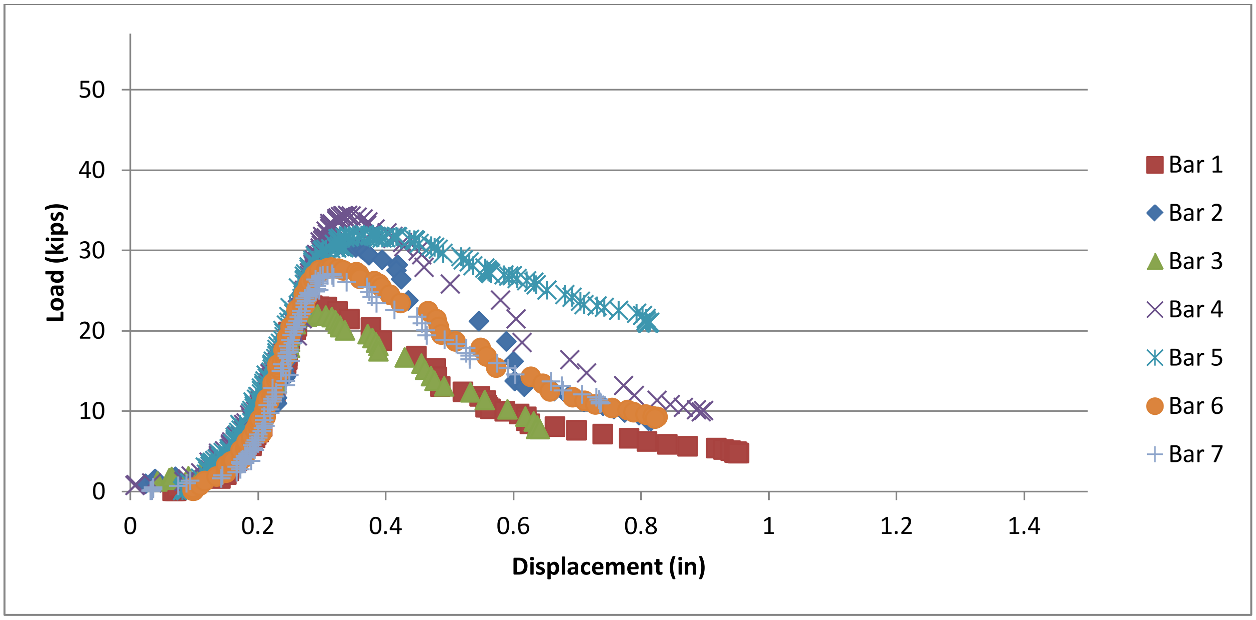

Figure 4.1. Plot of load vs. displacement for shaft 7 (30 sec bentonite).

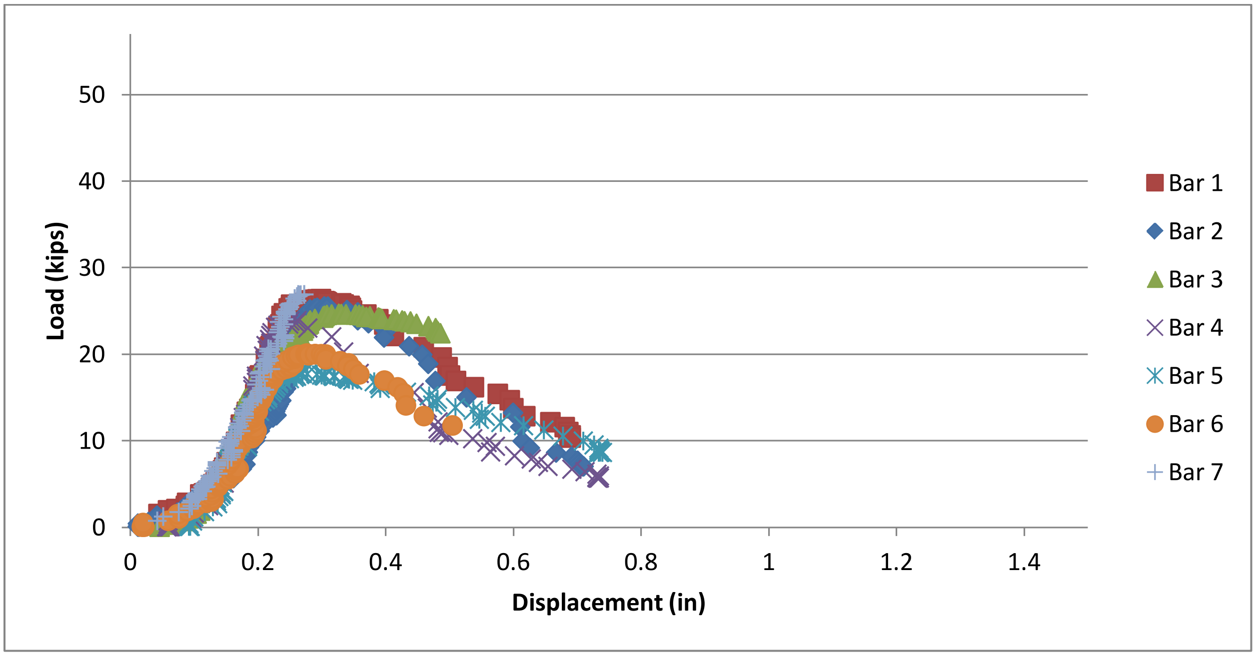

Figure 4.2 Plot of load vs. displacement for shaft 8 (40 sec bentonite).

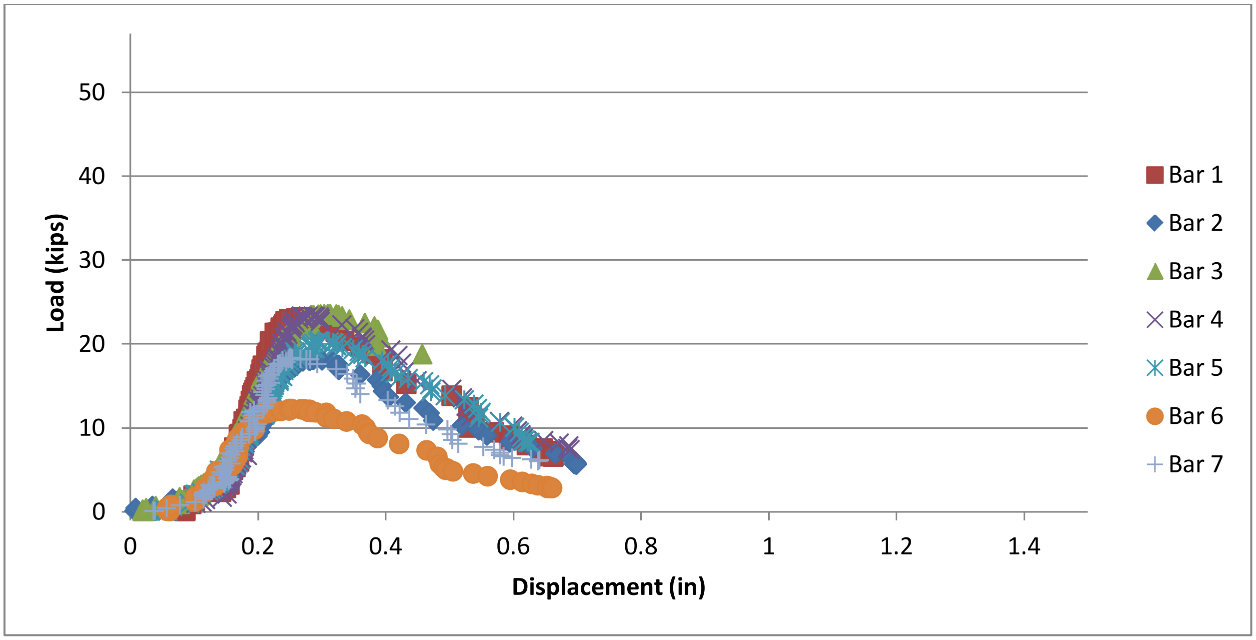

Figure 4.3. Plot of load vs. displacement for shaft 9 (50 sec bentonite).

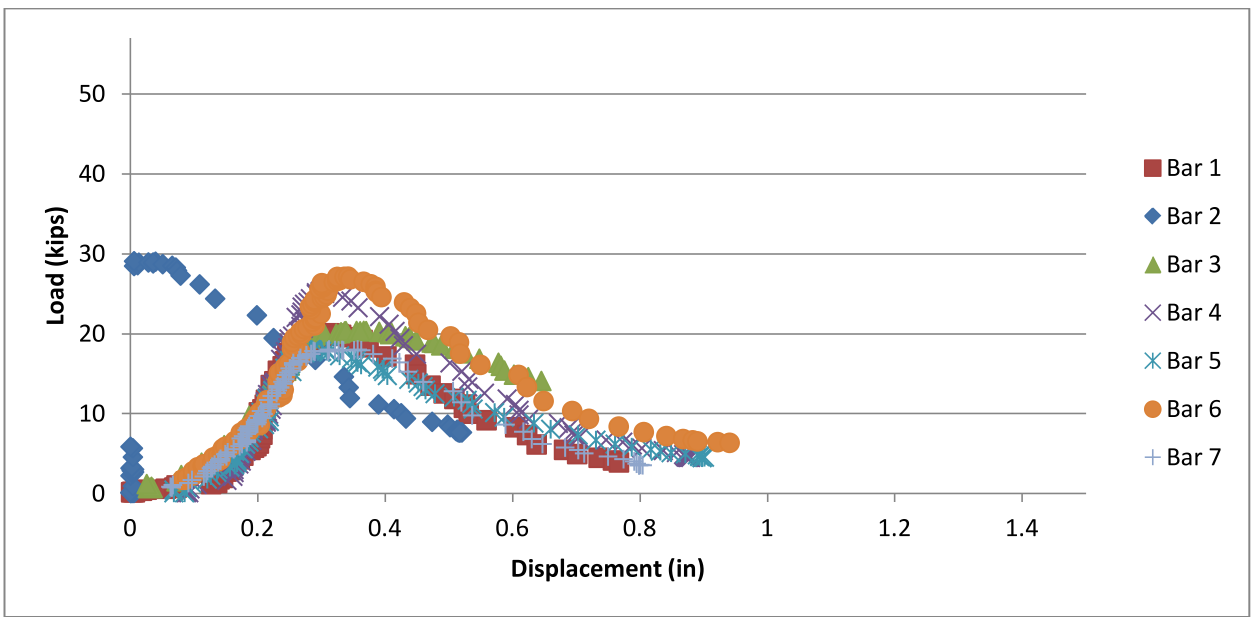

Figure 4.4. Plot of load vs. displacement for shaft 10 (90 sec bentonite).

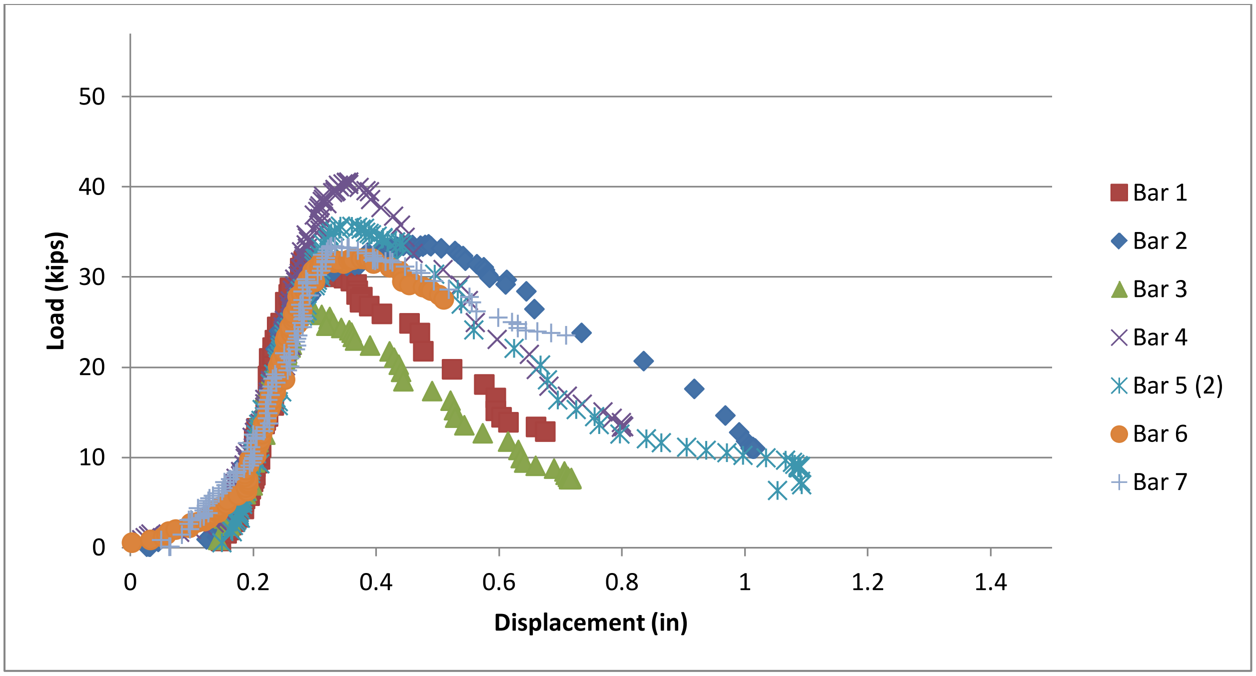

Figure 4.5. Plot of load vs. displacement for shaft 11 (60 sec polymer).

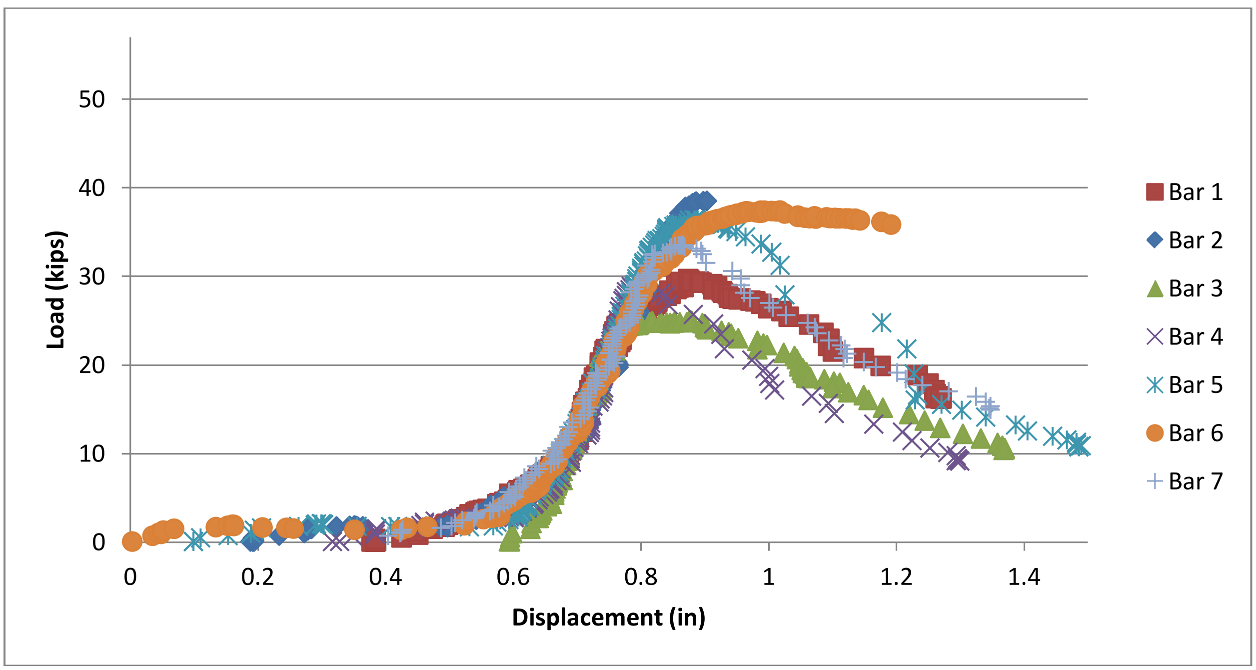

Figure 4.6. Plot of load vs. displacement for shaft 12 (60 sec polymer).

For the fourth and final placement, the bonded length remained 6-inches, however another water shaft was constructed in order to determine a control value for the bond strength due to the tensile failure of the bars in the previous tests. The threads for bar 2 failed and the data was unusable for that particular bar. Table 4.17 (below) provides the pullout testing data from placement four.

Table 4.17. Placement 4 pullout data.

Maximum Recorded Pullout Load (kips)						
Bar #	Bentonite			Polymer		Water
	Shaft 13 30 sec	Shaft 14 30 sec	Shaft 15 50 sec	Shaft 16 85 sec	Shaft 17 85 sec	Shaft 18 26 sec
1	20.000	24.960	21.000	25.590	25.460	37.410
2	25.050	29.210	18.590	24.180	19.110	
3	28.560	27.130	24.540	27.430	24.670	41.500
4	30.040	32.620	21.600	30.880	26.370	27.220
5	25.360	31.530	16.370	23.280	27.740	29.040
6	22.850	24.580	17.130	20.280	25.710	28.060
7	27.590	23.460	19.400	16.900	34.670	41.020
Max	30.040	32.620	24.540	30.880	34.670	41.500
Min	20.000	23.460	16.370	16.900	19.110	27.220
Average	25.636	27.641	19.804	24.077	26.247	34.042
std dev	3.457	3.575	2.819	4.590	4.610	6.678

4.4 Physical Defects

Once the forms were removed the shafts were inspected to check for any defects, anomalies, or buildup of material on the shaft. Once the surface was inspected, the shafts were then pressure washed in order to remove any residual slurry that was not displaced during the concrete placement. The following figures illustrate the amount of slurry that remained between the concrete surface and the forms during placement, as well as the voids caused by the slurry that was not displaced.

Figure 4.7. Illustrates the 90 second (left) and 40 second shaft (right) from placement one following form removal.

Figure 4.8. Buildup encountered at bottom of 90-second shaft from placement one.

Figure 4.9. 90-second shaft after pressure washing.

Figure 4.10. Slurry that was encapsulated in the concrete (90-second shaft).

The previous images were from the first placement, and were a recurring trend in subsequent concrete placements. Once this trend was noticed the shafts were cored to determine the depth of the visible crease, as well as determine if any slurry was present between the reinforcement and the concrete. As Figure 4.11 illustrates, the slurry was still visible on the two halves left and right. The crack that separated these halves was also still visible adjacent the cored hole (Figure 4.11 bot).

Figure 4.11. Slurry present at surface of reinforcement (top) depth of visible crease (bottom).

Upon inspection, the polymer slurry shafts showed no sign of structural deficiencies that were noted in Figure 4.11. Figure 4.12 shows a polymer shaft with no visible signs of cage effects. Images for all shafts constructed can be found in Appendix A.

Figure 4.12. Shaft cast with polymer slurry following pressure washing.

CHAPTER 5 CONCLUSIONS

It is commonly thought that if all the quality control measures are observed and met, that the overall product would be sufficient. This is true for most applications, however it is the blind construction of drilled shafts that introduces uncertainty. In this thesis, the methods used to secure the excavation walls may unwittingly cause unforeseen complications pertaining to rebar bond, concrete flow, and possible degraded corrosion resistance / durability.

5.1 Pullout Testing

Based on the collected data, the bond strength between the concrete and reinforcement was reduced up to 70% in some cases. This can be attributed to the buildup of slurry on the reinforcement. This effect is evident in the Figures 5.1 - 5.3. These images were taken after one of the concrete placements was aborted due concrete not meeting the specified requirements. These figures depict the amount of slurry that can adhere to the reinforcement.

Figure 5.1. Residual slurry noticed on reinforcement 30 second (left), 40 second (right).

Figure 5.2. Residual slurry noticed on reinforcement 30 second (left), 50 second (right).

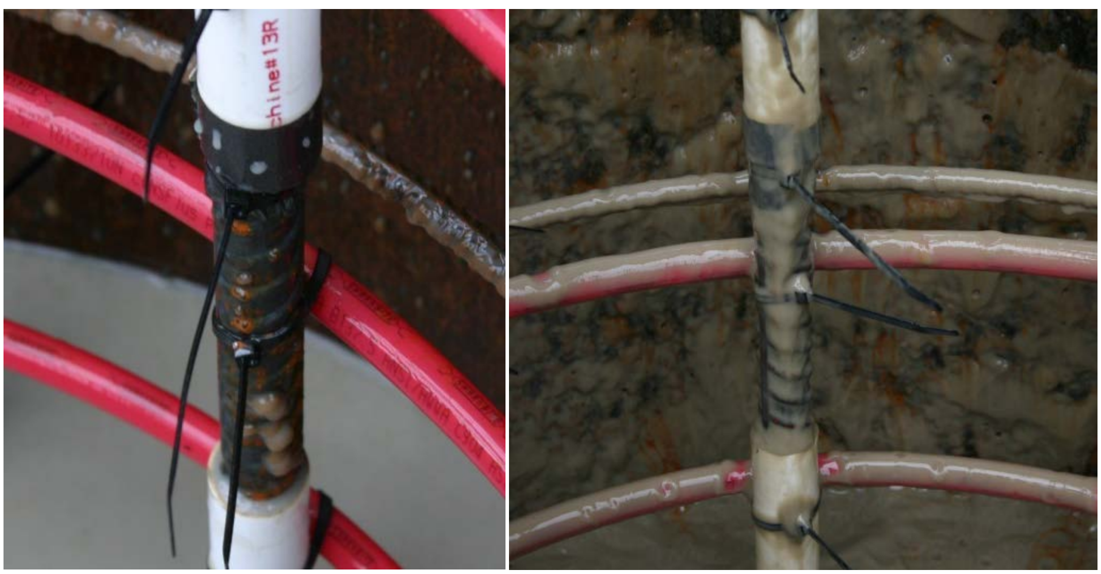

Figure 5.3. Residual slurry noticed on reinforcement 30 second (left), 90 second (right).

The residual slurry was reduced as the apparent viscosity was reduced, however was still noticeable.

Based on the results, it is assumed that this buildup is not removed during the concrete placement either, which is assumed to be the cause of the reduced bond strength. Figure 5.4 provides the overall loss of bond strength for bentonite slurry and Figure 5.5 for polymer slurry.

The viscosity values noted correspond to that measured at the time of concrete placement. There was a noticeable increase in viscosity between placement in the forms, and the placement of concrete for the higher viscosity slurry mixes.

The results indicate that as the apparent viscosity is increased the bond strength is decreased. This trend was replicated throughout the testing that was performed. These effects were more prevalent for the bentonite slurry, than the polymer slurry. The values were normalized by dividing the overall pullout load by a product of the contact surface area and the concrete strength.

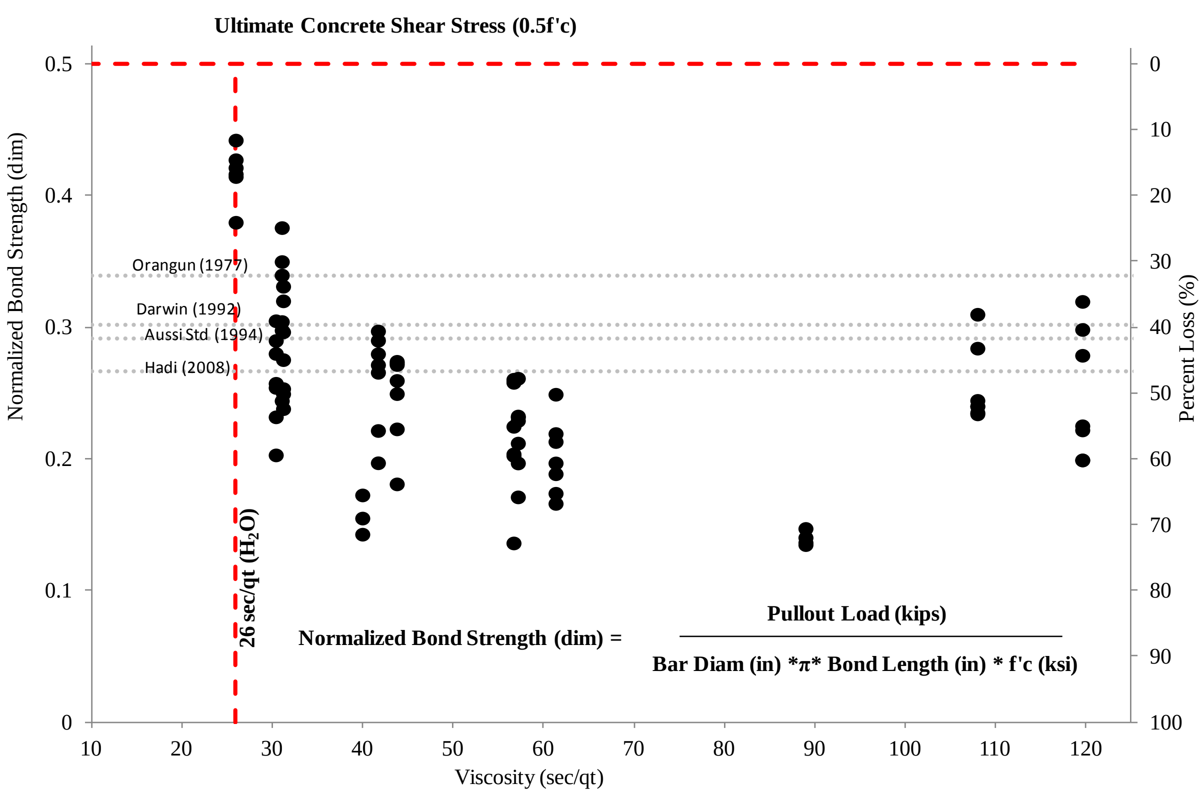

Figure 5.4. Comparison of pullout test results using bentonite slurry.

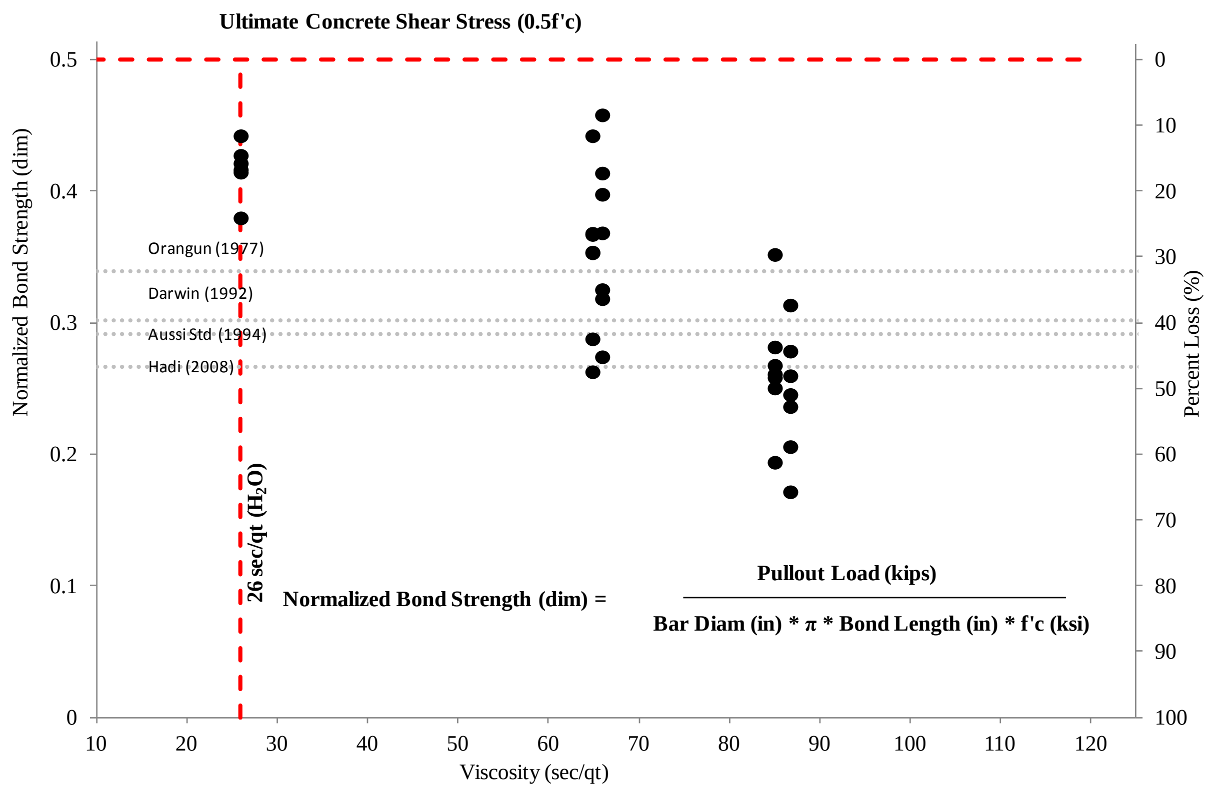

Figure 5.5. Comparison of pullout test results using polymer slurry.

Upon completion of the pullout testing, the shafts were cored in order to determine the amount of slurry that was still present after the concrete placement. This is evident in Figure 5.6. A thin layer of slurry was noticed around the reinforcement, as well as a layer encased in a fold in the concrete leading back to the reinforcement, which can lead to durability issues.

5.2 Durability

In addition to the loss of bond strength, the scale shafts revealed possible permeability issues with the hardened concrete. Due to the flowing action of the concrete, the bentonite slurry was encapsulated in the concrete, outlining each piece of reinforcement. The encased slurry provides a direct pathway between the exterior of the shaft and the reinforcement. This was

Figure 5.6. Layer of slurry encased in concrete.

verified when the coring was conducted. The cores split in half along the visible crease in the 50 sec/qt, as well as the 90 sec/qt shafts. The 30 sec/qt and 40 sec/qt cores did not split, however showed visible signs of poor consolidation around the reinforcement. The cores that were cut from the shaft cast with water, and polymer did not show any signs of poor consolidation, or any noticeable defects in the concrete. Figures 5.7 through 5.12 illustrate the encapsulated slurry in the shafts following form removal and cleaning, as well as in the cores. The poor consolidation is also illustrated.

Figure 5.13 provides an excellent illustration as to the flow of concrete during placement, as well as an explanation for the creases that were prevalent in all the shafts that were constructed during this project.

Figure 5.7. Illustrates the visible creases in the concrete from 90 sec/qt shaft.

Figure 5.8. Illustrates the consolidation of the 60 sec/qt polymer shaft.

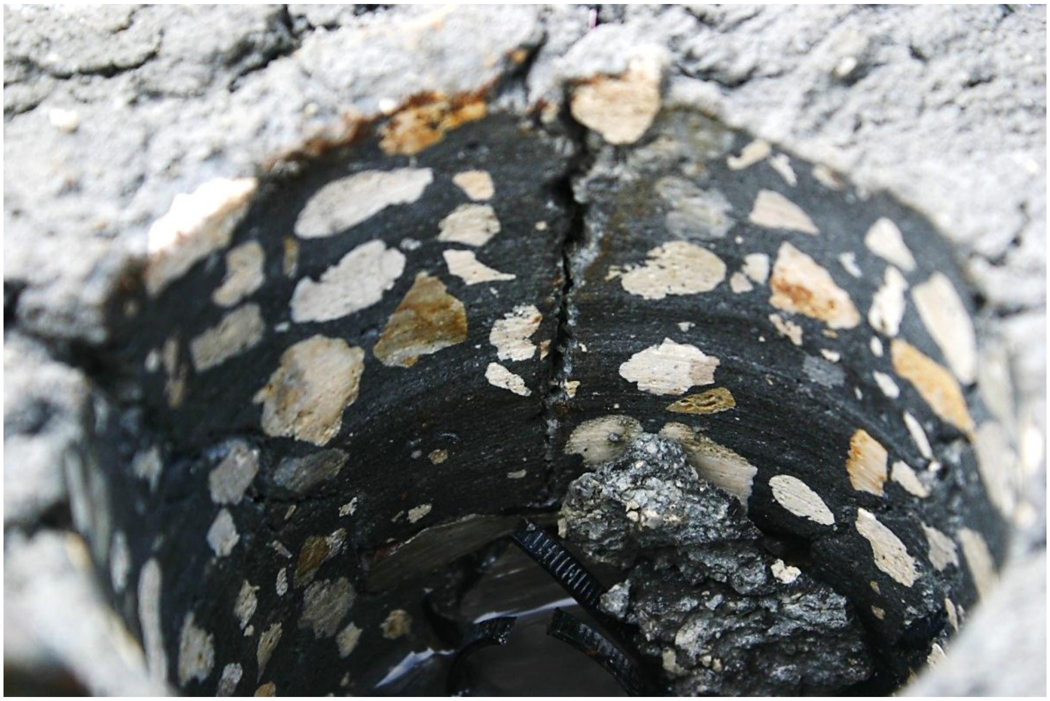

Figure 5.9. Core hole in 50 sec/qt shaft; crack corresponds to line formed by reinforcement.

Figure 5.10. Poor consolidation around reinforcement in 40 sec/qt shaft.

Figure 5.11. Encapsulated slurry in 50 sec/qt shaft core.

Figure 5.12. Slurry encased in void in 90 sec/qt shaft.

Figure 5.13. Flow of concrete around reinforcement during placement of 60 sec/qt polymer shaft.

5.3 Future Work

For this project a slump of 8-inches to 9.5-inches was used, also, the time the reinforcement was exposed to slurry was maximized but kept within the Florida Department of Transportation's drilled shaft requirements. Given the opportunity, it would be beneficial to vary the slump of the concrete in order to verify the trends noticed in the flow of the concrete. These trends could be verified with x-ray diffraction of the material encountered between the exterior of the shaft and the reinforcing in order to determine if bentonite is present and the amounts present. Further testing could be done on the polymer and water shafts in order to see if there is a localized higher water/cement ratio at these locations as well.

Varying the exposure time of the reinforcement with the slurry would also provide valuable information regarding the current specifications, and the allowable contact time. This could determine if the increased viscosity of the slurry that was noticed during the contact time has an effect on the bond strength.

In order to determine the severity of the creases that were encountered, it would be beneficial to perform chloride diffusion testing on the specimens in order to determine the permeability of the concrete where the bentonite was not displaced.

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APPENDIX A: PHOTO DOCUMENTATION

Figure A.1. Steel testing form, 42-inches in diameter.

Figure A.2. Steel testing form, 24-inches in height.

Figure A.3. Steel form, clamped, welded angle closures.

Figure A.4. Bottom of form after polyurethane and cap placement.

Figure A.5. Form with structural reinforcement prior to placement of pullout steel.

Figure A.6. Final reinforcement configuration prior to slurry placement.

Figure A.7. Typical de-bonding for reinforcement.

Figure A.8. Verifying water tight seal of form.

Figure A.9. Re-circulating mineral slurry prior to placement in form.

Figure A.10. Testing plastic properties of fresh concrete.

Figure A.11. Placing concrete for shaft 2, 90 sec/qt mineral slurry.

Figure A.12. Placing concrete for shaft 1, 40 sec/qt mineral slurry.

Figure A.13. Shaft 1 (right) and shaft 2 (left) after pressure washing.

Figure A.14. Form layout for placements 2 through 4.

Figure A.15. Shaft 6 (water) after pressure washing.

Figure A.16. Shaft 3, 40 sec/qt mineral slurry after pressure washing.

Figure A.17. Shaft 4, 50 sec/qt mineral slurry after pressure washing.

Figure A.18. Shaft 5, 90 sec/qt mineral slurry after pressure washing.

Figure A.19. Shaft 7, 30 sec/qt mineral slurry after pressure washing.

Figure A.20. Shaft 8, 40 sec/qt mineral slurry after pressure washing.

Figure A.21. Shaft 9, 50 sec/qt mineral slurry after pressure washing.

Figure A.22. Shaft 10, 90 sec/qt mineral slurry after pressure washing.

Figure A.23. Shaft 11, 60 sec/qt polymer slurry after pressure washing.

Figure A.24. Shaft 13, 30 sec/qt mineral slurry after pressure washing.

Figure A.25. Shaft 15, 50 sec/qt mineral slurry after pressure washing.

Figure A.26. Shaft 17, 85 sec/qt polymer slurry after pressure washing.

Figure A.27. Shaft 18, water shaft after pressure washing.

Figure A.28. Core from shaft 6, water.

Figure A.29. Core from shaft 11, 60 sec/qt polymer.

Figure A.30. Core from shaft 7, 30 sec/qt mineral slurry.

Figure A.31. Core from shaft 8, 40 sec/qt mineral slurry.

Figure A.32. Core from shaft 9, 50 sec/qt mineral slurry.

Figure A.33. Core from shaft 10, 90 sec/qt mineral slurry.

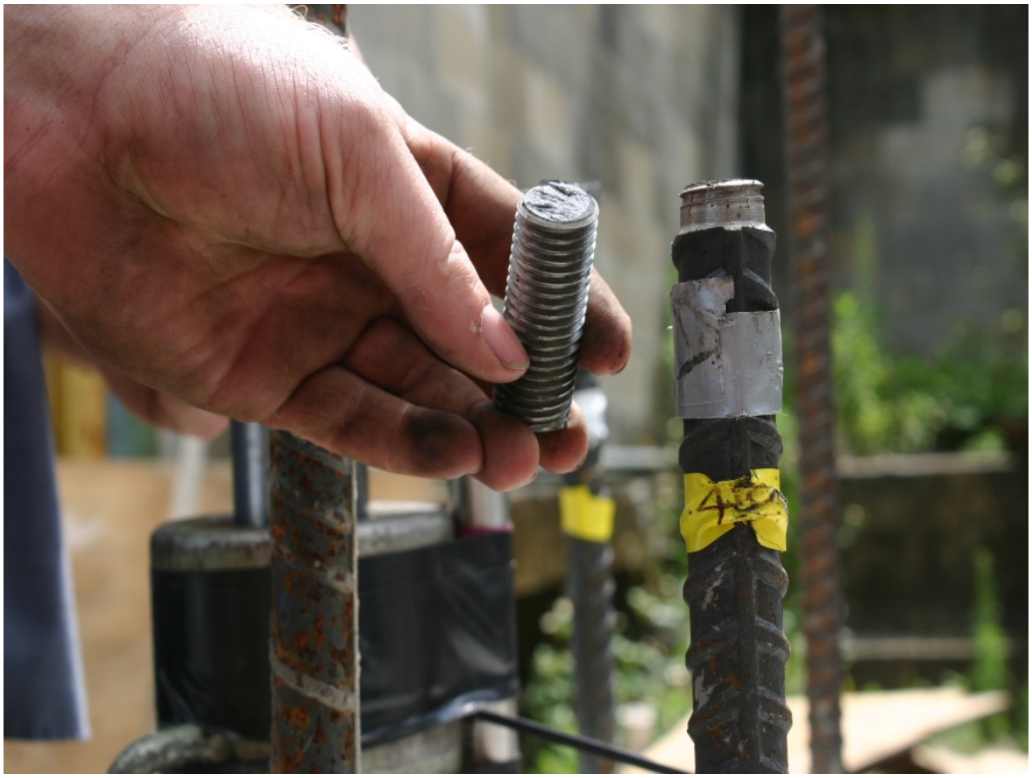

Figure A.34. Bar failure from shaft 6, water.

APPENDIX B: STATE SPECIFICATIONS

Table B.1. Alabama slurry specifications (ALDOT, 2012).

Mineral Slurry Specifications
(Sodium Bentonite or Attapulgite in Fresh Water)

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 {kg/m^3}	64.3** - 69.1** {1030* - 1110**}	64.3** - 75.0** {1030** - 1200**}	Density Balance
Viscosity Seconds/qt {Seconds/L)	28 – 45 {30 – 48}	28 – 45 {30 – 48}	Marsh Cone
pH	8 – 11	8 – 11	pH paper, pH Meter
Sand Content Percent by Volume	N/A	N/A	N/A

**Increase by 2 pounds per cubic foot {32 kg/m^3} in salt water
a. Tests should be performed when the slurry temperature is above 39° F.
b. If desanding is required, sand content shall not exceed 4 percent (by volume) at any point in the bore hole as determined by the American Petroleum Institute sand content test.

Polymer Slurry Specifications

<table>
<tr><th>Property
(Units)</th><th>At Time of Slurry
Introduction</th><th>In Hole at Time of
Concreting</th><th>Test
Method</th></tr>
<tr><td>Density
lb/ft^3
{kg/m^3}</td><td colspan="3" rowspan="4">Alabama has no polymer slurry specifications</td></tr>
<tr><td>Viscosity
Seconds/qt
{Seconds/L}</td></tr>
<tr><td>pH</td></tr>
<tr><td>Sand Content
Percent by Volume</td></tr>
</table>

Source: United States. Alabama Department of Transportation. *Standard Specifications for Highway Construction. 2012.*
Their 2012 is still the most current, so no change was made
http://www.dot.state.al.us/conweb/specifications.htm
http://www.dot.state.al.us/conweb/doc/Specifications/2012%20DRAFT%20Standard%20Specs.pdf

Table B.2. Alaska slurry specifications (AlaskaDOT, 2004).

Mineral Slurry Specification

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 {kg/m^3}	Alaska has no specification for drilled shaft slurry		
Viscosity Seconds/qt {Seconds/L)			
pH			
Sand Content Percent by Volume			

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 {kg/m^3}	Alaska has no specification for drilled shaft slurry		
Viscosity Seconds/qt {Seconds/L)			
pH			
Sand Content Percent by Volume			

Source: United States. Alaska Department of Transportation and Public Facilities. *Standard Specifications for Highway Construction.* 2004.

Their 2004 version is still the latest...
http://www.dot.state.ak.us/stwddes/dcsspecs/pop_hwyspecs_english.shtml

Table B.3. Arizona slurry specifications (AZDOT, 2008).

Mineral Slurry Specifications
(Sodium Bentonite in Fresh Water[a])

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	64.3 – 69.1	64.3 – 75.0*	Density Balance
Yield Point {Pascals} Or Viscosity Seconds/qt	Bentonite 1.25 – 10 28 – 50	10 Maximum 28 – 50	Rheometer Marsh Cone
pH	7 – 12	7 – 12	pH paper, pH meter
Sand Content Percent by Volume	0 – 4	0 – 2	API Sand Content Kit

* 85 lb/ft^3 maximum when using Barite.

a. Range of results above 68°F.

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	Arizona has no polymer slurry specifications. Only mentions: "The level of polymer slurry shall be maintained at or near the ground surface or higher, if required to maintain boring stability."		
Yield Point {Pascals} Or Viscosity Seconds/qt			
pH			
Sand Content Percent by Volume			

Source: United States. Arizona Department of Transportation. *Standard Specifications for Road and Bridge Construction*. 2008.

Their 2008 version is still the latest, no change in requirements
http://azdot.gov/business/ContractsandSpecifications/Specifications

Table B.4. Arkansas slurry specifications (Freeling, 2013).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 {kg/m^3}	64 – 75	None Specified	Mud Balance ASTM D4380
Viscosity (Seconds/qt) {Seconds/L}	28 – 45	None Specified	API RP13B-1 Section 2 Marsh Funnel and Cup
pH	8 – 11	None Specified	ASTM D4972
Sand Content Percent by Volume	4% Maximum	N/A	(Sand Screen Set) ASTM D4381

a. Range of results at 60°F (20°C).

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 {kg/m^3}	64 Maximum (fresh water applications)	N/A	(Mud Balance) ASTM D4380
Viscosity Seconds/qt {Seconds/L}	40 to 90 (or as approved by the Engineer)	N/A	API RP13B-1 Sect. 2 (Marsh Funnel & Cup)
pH	8-10	N/A	ASTM D4972
Sand Content Percent by Volume	1 % maximum	1% Max	(Sand Screen Set) ASTM D4381

a. Range of results at 60°F (20°C).

Source: United States. Arkansas State highway and Transportation Department. *Special Provision Job No. 110229 Slurry Displacement Drilled Shaft*. 2005.

Table B.5. California slurry specifications (Caltrans, 2010).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	64.3* – 69.1*	64.3* - 75.0*	Mud Weight (Density) API 13B-1 Section 1
Viscosity Seconds/qt	(Bentonite) 28 – 50 (Attapulgite) 28 – 40	None Specified	Marsh Funnel and Cup API 13B-1 Section 2.2
pH	8 – 10.5	8 – 10.5	Glass Electrode pH meter, pH paper
Sand Content Percent by Volume	Volume≤4.0	Volume≤4.0	Sand, API 13B-1, Section 5

* When approved by the Engineer, slurry may be used in salt water, and the allowable densities may be increased by up to 2 lb/ft^3. Slurry temperature shall be at least 40°F when tested.

Polymer Slurry Specifications

<table>
<tr><th>Property
(Units)</th><th>At Time of Slurry Introduction</th><th>In Hole at Time of Concreting</th><th>Test Method</th></tr>
<tr><td>Density
lb/ft³</td><td colspan="3" rowspan="4">The physical properties of synthetic slurries should be carefully monitored during drilling of the hole and before concrete placement. Because these slurries in general do not suspend particles, the permissible density and sand content values are much lower than those allowed for mineral slurries. The density and sand content values should be tested and the values maintained within the limits stated in the contract specifications to allow for quick settlement of suspended materials. The synthetic slurry’s pH value should be tested and maintained within the limits stated in the contract specifications to prevent destabilization of the slurry.</td></tr>
<tr><td>Viscosity
Seconds/qt</td></tr>
<tr><td>pH</td></tr>
<tr><td>Sand Content
Percent by Volume</td></tr>
</table>

If authorized, you may use salt water slurry. The allowable density of the slurry may be increased by 2 lb/ft^3.

Source: United States. California Department of Transportation Division of Engineering Services. *Foundation Manual*. 2010.
http://www.dot.ca.gov/hq/esc/oe/construction_standards.html

Table B.6. Colorado slurry specifications (CDOT, 2006).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density g/ml	Less than 1.10	Less than 1.10	Mud Weight (Density) API 13B-1 Section 1
Viscosity Seconds/qt	(Bentonite) 30-90 seconds Or less than 20cP	None Specified	Marsh Funnel and Cup API 13B-1 Section 2.2
pH	8 – 10.5	8 – 10.5	pH indicator paper Strips or electrical pH meter
Sand Content Percent by Volume	Less than 5%	Less than 5%	Screen

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density g/ml	No specification for Polymer Slurries		
Viscosity Seconds/qt			
pH			
Sand Content Percent by Volume			

Source: United States. Colorado Department of Transportation. *Permanent Changes to Project Dated Special Provisions, Revision of Section 503.* 2006.
http://www.coloradodot.info/business/designsupport/construction-specifications/2011-Specs/2011-specs-book/2011-Specs-Book.pdf/view

Table B.7. Connecticut slurry specifications (ConnDOT, 2009).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	64.3* – 69.1*	64.3* - 75.0*	Density Balance
Viscosity Seconds/qt	28 – 45	28 – 45	Marsh Funnel
pH	8 – 11	8 – 11	pH paper, pH meter
Sand Content Percent by Volume	N/A	N/A	N/A

* Increase by 2 lb/ft^3 in salt water.

Polymer Slurry Specifications

<table>
<tr><th>Property
(Units)</th><th>At Time of Slurry
Introduction</th><th>In Hole at Time of
Concreting</th><th>Test
Method</th></tr>
<tr><td>Density
lb/ft^3</td><td colspan="3" rowspan="3">Connecticut has no polymer slurry specifications.

“If polymer slurry, or blended mineral-polymer slurry, is proposed, the Contractor’s slurry management plan shall include detailed provisions for controlling the quality of the slurry, including tests to be performed, the frequency of those tests, the test methods, and the maximum and/or minimum property requirements that must be met to ensure that the slurry meets its intended functions in the subsurface conditions at the construction site and with the construction methods that are to be used. The slurry management plan shall include a set of the slurry manufacturer’s written recommendations and shall include the following tests, as a minimum: Density test (API 13B-1, Section 1), viscosity test (Marsh funnel and cup, API 13B-1, Section 2.2, or approved viscometer), pH test (pH meter, pH paper), and sand content test (API sand content kit, API 13B-1, Section 5).”</td></tr>
<tr><td>Viscosity
Seconds/qt</td></tr>
<tr><td>pH</td></tr>
</table>

Source: United States. Connecticut Department of Transportation. *Connecticut DOT Guide Drilled Shaft Spec.* 2009.
http://www.ct.gov/dot/cwp/view.asp?a=3195&q=300782
http://www.ct.gov/dot/lib/dot/documents/dsoils/ConnDOTGuideDrilledShaftSpec.pdf

Table B.8. Delaware slurry specifications (DELDOT, 2009).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 $\{kg/m^3\}$	63.55 – 68.51 {1025 – 1105}	63.55 – 74.41 {1025 – 1200}	Density Balance
Viscosity Seconds/ft {Seconds/L}	849.5 – 1359.2 {30 – 48}	849.5 – 1359.2 {30 – 48}	Marsh Cone
pH	7 – 11	7 – 11	pH paper, pH meter
Sand Content Percent by Volume	1 MAX	4 MAX	200 Sieve Retain

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density kg/m^3	No state specification pertaining to slurry parameters defined. Refers to FHWA guidelines.		
Viscosity Seconds/L			
pH			
Sand Content Percent by Volume			

Source: Keith Gray (Bridge Engineer, DELDOT), email message to author, March 7, 2009. http://www.deldot.gov/information/pubs_forms/manuals/standard_specifications/

Table B.9. Florida slurry specifications (FDOT, 2014).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 $\{kg/m^3\}$	64 – 73* 66 – 75** {1030 – 1170*} {1060 – 1200**}	N/A	Mud Density Balance FM 8-RP13B-1
Viscosity Seconds	30 - 50	N/A	Marsh Cone Method FM 8-RP13B-2
pH	8 – 11	N/A	Electric pH meter, pH paper FM 8-RP13B-4
Sand Content Percent by Volume	4% or less	N/A	FM 8-RP13B-3

* Fresh water @ 68°F (20°C)

** Salt water @ 68°F (20°C)

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 $\{kg/m^3\}$	62 to 64 lb/ft3 (fresh water) 64 to 66 lb/ft3 (salt water)	62 to 64 lb/ft3 (fresh water) 64 to 66 lb/ft3 (salt water)	Mud Density Balance FM 8-RP13B-1
Viscosity Seconds/qt {Seconds/L}	Range Published By The Manufacturer for Materials Excavated	Range Published By The Manufacturer for Materials Excavated	Marsh Cone Method FM 8-RP13B-2
pH	Range Published By The Manufacturer for Materials Excavated	Range Published By The Manufacturer for Materials Excavated	Electric pH meter, pH paper FM 8-RP13B-4
Sand Content Percent by Volume	0.5% or less	0.5% or less	FM 8-RP13B-3

a. Range of results at 68° F
b. The Engineer will not allow polymer slurries during construction of drilled shafts for bridge foundations.
c. Materials manufactured expressly for use as polymer slurry for drilled shafts may be used as slurry for drilled shaft excavations up to 60 inches in diameter installed to support mast arms, cantilever signs, overhead truss signs, high mast light poles or other miscellaneous structures.

Table B.9. continued

d. A representative of the manufacturer must be on-site or available for immediate contact to assist and guide the construction of the first three drilled shafts at no additional cost to the Department.

e. Use polymer slurry only if the soils below the casing are not classified as organic, and the pH of the fluid in the hole can be maintained in accordance with the manufacturer's published recommendations.

Source: United States. Florida Department of Transportation . *Standard Specifications for Road and Bridge Construction*. 2014. http://www.dot.state.fl.us/specificationsoffice/Implemented/SpecBooks/2014/Files/2014eBook.pdf

Table B.10. Georgia slurry specifications (GDOT,2006).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 {kg/m^3}	66 – 73 {1060 – 1170}	N/A	N/A
Viscosity Seconds/qt {Seconds/L}	30 – 45 {32 – 48}	N/A	Marsh Funnel
pH	8 – 11	N/A	N/A
Sand Content Percent by Volume	N/A	4%	N/A

a. Perform sand content tests on slurry samples taken from the bottom of the shaft after placement of the reinforcing cage, but immediately before pouring concrete. Do not place concrete until all testing produces acceptable results.
b. If sidewalls are unstable, or if artesian flow is present, use a weighing additive to increase the slurry density
c. pH may be adjusted with soda ash.
d. When sand content exceeds 4%, desanding or other equipment must be used.
e. Tests must be performed at 39°F (4°C), slurry temperature.

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 {kg/m^3}	64 – 67 {1025 – 1073}	N/A	N/A
Viscosity Seconds/qt {Seconds/L}	30 – 125 {32 – 132}	N/A	Marsh Funnel
pH	8 – 11	N/A	N/A
Sand Content Percent by Volume	N/A	≤ 1	N/A

A weighing additive may be used to increase the density of the polymer slurry if the sidewalls are unstable or if artesian flow is present.

Source: United States. State of Georgia Department of Transportation. *Special Provision Section 524 – Drilled Caisson Foundations*. 2006. http://www.dot.ga.gov/doingbusiness/theSource/Pages/specifications.aspx

Table B.11. Hawaii slurry specifications (HDOT, 2005).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 $\{kg/m^3\}$	Slurry Drilling is not permitted*		
Viscosity Seconds/qt {Seconds/L}			
pH			
Sand Content Percent by Volume			

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 $\{kg/m^3\}$	Slurry Drilling is not permitted*		
Viscosity Seconds/qt {Seconds/L}			
pH			
Sand Content Percent by Volume			

*Wet Construction Method – This method includes using water to maintain stability of shaft perimeter while advancing excavation to final depth, and placing reinforcing cage and shaft concrete.

Reuse drilling water only if permitted by the Engineer and contingent upon control of unit weight to no more than 62.5 pounds per cubic foot and Marsh funnel viscosity to not more than 27 seconds per quart, at the time drilling water is introduce into the borehole.

Source: United States. State of Hawaii Department of Transportation. *Standard Specifications*. 2005.

http://hidot.hawaii.gov/highways/s2005-standard-specifications/

Table B.12. Idaho slurry specifications special provisions (Buu, 2013).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	64 to 75	N/A	Mud Weight (Density) API 13b-1,Section 1
Viscosity Seconds/qt	26 to 50	N/A	Marsh Funnel API 13b-1, Section 2.2
pH	8 – 11	N/A	N/A
Sand Content Percent by Volume	N/A	4.0 Max	Sand API 13b-1 Section 5

Quality control testing will be by the contractor. Slurry temperature shall be at least 40°F when tested.

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density kg/m^3	No specifications pertaining to slurry parameters available at time of study.		
Viscosity Seconds/L			
pH			
Sand Content Percent by Volume			

Source: United StatesIdaho Transportation Department. *Special Provision S501-20A SP Bridge-Drilled Shaft -2013*.
Source: Tri Buu (Geotechnical Engineer, Idaho DOT), email message to author, July 26, 2013.
http://itd.idaho.gov/newsandinfo/docs/2012SpecBook.pdf

Table B.13. Illinois slurry specifications (IDOT, 2012).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density kg/m^3	No specifications pertaining to slurry parameters available.		
Viscosity Seconds/L			
pH			
Sand Content Percent by Volume			

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density kg/m^3	No specifications pertaining to slurry parameters available.		
Viscosity Seconds/L			
pH			
Sand Content Percent by Volume			

Source: United States. Illinois Department of Transportation. *Standard Specifications for Bridge Construction*. 2012.
http://www.dot.il.gov/desenv/spec2012/12specbook.pdf

Table B.14. Indiana slurry specifications (INDOT, 2013).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	64.3 - 69.1	N/A	Density Balance
Viscosity Seconds/qt	28 - 45	N/A	Marsh Cone
pH	8 – 11	N/A	pH paper or meter
Sand Content Percent by Volume	N/A	N/A	N/A

Polymer Slurry Specifications

<table>
<tr><th>Property (Units)</th><th>At Time of Slurry Introduction</th><th>In Hole at Time of Concreting</th><th>Test Method</th></tr>
<tr><td>Density kg/m^3</td><td colspan="3" rowspan="4">Drilled shafts not permitted.</td></tr>
<tr><td>Viscosity Seconds/L</td></tr>
<tr><td>pH</td></tr>
<tr><td>Sand Content Percent by Volume</td></tr>
</table>

Source: United States. Indiana Department of Transportation. *Standard Specifications. 728-B-203 Drilled Shaft Foundations* 2013
http://www.in.gov/dot/div/contracts/standards/book/sep11/sep.htm

Table B.15. Iowa slurry specifications (Iowa DOT, 2012).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 $\{kg/m^3\}$	64 – 75 {1030 – 1200}	64 – 75 {1030 – 1200}	Slurry Density Materials I.M. 387
Viscosity Seconds/gal {Sec./L}	104 - 201 (27.5 – 53)	104 - 201 (27.5 – 53)	Marsh Funnel and Cup Materials I.M. 387
pH	8 – 11	8 – 11	pH paper
Sand Content Percent by Volume	≤ 4	≤ 4	Sand Content Test Materials I.M. 387

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 $\{kg/m^3\}$	62-63 {995 – 1010}	62-63 {995 – 1010}	Slurry Density Materials I.M. 387
Viscosity Seconds/gal {Sec./L}	136-227 (36-60) 231-252 (61-66.5) (dry sand/gravel)	136-227 (36-60) 231-252 (61-66.5) (dry sand/gravel)	Marsh Funnel and Cup Materials I.M. 387
pH	8 – 11	8 – 11	pH paper
Sand Content Percent by Volume	< 2	< 2	Sand Content Test Materials I.M. 387

Source: United States. Iowa Department of Transportation. *Standard Specifications* 2012. http://www.iowadot.gov/specifications/Specificationsseries2012.pdf

Table B.16. Kansas slurry specifications (KSDOT, 2007).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density kg/m^3	Drilled shafts permitted but no specifications pertaining to slurry parameters available.		
Viscosity Seconds/L			
pH			
Sand Content Percent by Volume			

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density kg/m^3	Drilled shafts permitted but no specifications pertaining to slurry parameters available.		
Viscosity Seconds/L			
pH			
Sand Content Percent by Volume			

Source: United States. Kansas Department of Transportation. *Standard Specifications for State Road and Bridge Construction*. 2007.
http://www.ksdot.org/burconsmain/specprov/specifications.asp

Table B.17. Kentucky slurry specifications (KYTC, 2008).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density kg/m^3	No state specification pertaining to slurry parameters defined. Refer to FHWA Guidelines		
Viscosity Seconds/L			
pH			
Sand Content Percent by Volume			

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density kg/m^3	No state specification pertaining to slurry parameters defined.		
Viscosity Seconds/L			
pH			
Sand Content Percent by Volume			

Source: United States. Kentucky Transportation Cabinet. *Special Note 11C for Excavation and Embankment*. 2008.
http://transportation.ky.gov/construction/pages/kentucky-standard-specifications.aspx

http://transportation.ky.gov/Construction/Standard%20amd%20Supplemental%20Specifications/600%20Structures%20and%20Concrete%2012.pdf

Table B.18. Louisiana slurry specifications (LaDOT, 2006).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 {kg/m^3}	64.3 – 69.1 {1030 – 1107} (fresh water)	64.3 – 75.0 {1030 – 1202} (fresh water)	Mud Balance API 13B Section 1
Viscosity Seconds	28 – 45	N/A	Marsh Funnel API 13B Section 2
pH	8 – 11	8 – 11	pH paper, pH meter API 13B Section 6
Sand Content Percent by Volume	4	4	Sand Screen Set API 13B Section 4

a. Slurry shall not stand for more than 4 hours in the excavation without agitation.

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 (kg/m3)	63-64 (1010-1026) (fresh water)	63-64 (1010-1026) (fresh water)	Mud Balance (API 13B- Sec 1)
Viscosity Seconds	45 MIN	N/A	Marsh Funnel (API 13B- Sec 2)
pH	8 – 10	8 - 10	pH Paper pH Meter (API 13B-Sec6)
Sand Content Percent by Volume	1 MAX	1 MAX	Sand Screen Set (API 13B- Sec 4)

a. The slurry shall not stand for more than 4 hours in the excavation without agitation

Source: United States. Louisiana Department of Transportation. *Drilled Shaft Inspection Manual, Shaft Construction.* 2006.
http://www.dotd.la.gov/highways/specifications/documents/2006%20Standard%20Specifications%20for%20Roads%20and%20Bridges%20Manual/12%20-%202006%20-%20Part%20VIII%20-%20Structures.pdf

Table B.19. Maine slurry specifications (MDOT, 2002).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density kg/m^3	Drilled shafts permitted but no specifications pertaining to slurry parameters available.		
Viscosity Seconds/L			
pH			
Sand Content Percent by Volume			

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density kg/m^3	Drilled shafts permitted but no specifications pertaining to slurry parameters available.		
Viscosity Seconds/L			
pH			
Sand Content Percent by Volume			

Source: United States. Maine Department of Transportation. *Standard Specifications*. 2002. http://maine.gov/mdot/contractors/publications/standardspec/

Table B.20. Maryland slurry specifications (MDOT, 2008).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density kg/m^3	No specifications pertaining to slurry parameters available.		
Viscosity Seconds/L			
pH			
Sand Content Percent by Volume			

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density kg/m^3	No specifications pertaining to slurry parameters available.		
Viscosity Seconds/L			
pH			
Sand Content Percent by Volume			

Source: United States. Maryland Department of Transportation. *Standard Specifications for Construction and Materials.* 2008.
http://apps.roads.maryland.gov/BusinessWithSHA/bizStdsSpecs/desManualStdPub/publicationsonline/ohd/bookstd/index.asp

Table B.21. Massachusetts slurry specifications (MDH, 2012).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 { kg/m^3}	64-75 {1030-1200}	64-75 {1030-1200}	Mud Density API 13B- Sec. 1
Viscosity Seconds/qt {Sec./L}	26-50 {27.5-53}	26-50 {27.5-53}	Marsh Funnel and Cup API 13B- Sec. 2.2
pH	8 – 11	8 - 11	Glass Electrode, pH Paper, pH Meter
Sand Content Percent by Volume	4 MAX	4 MAX	Sand Content API 13B- Sec 5

* To be increased by 2 lb/ft3 (32 kg/m3) in salt water or brackish water.

Polymer Slurry Specifications

<table>
<tr><th>Property (Units)</th><th>At Time of Slurry Introduction</th><th>In Hole at Time of Concreting</th><th>Test Method</th></tr>
<tr><td>Density lb/ft^3 {kg/m^3}</td><td colspan="3" rowspan="4">Natural or synthetic slurry shall have specific properties at the time of mixing and of concreting that are in conformance with the written recommendations of the manufacturer and the Contractor’s Drilled Shaft Installation Plan. The Contractor shall perform the required tests at the specified frequency and shall provide slurry that complies with the maximum and/or minimum property requirements for the subsurface conditions at the site and with the construction methods that are used. Whatever product is used, the sand content at the base of the shaft excavation shall not exceed 1% when measured by the API sand content test, immediately prior to concreting.</td></tr>
<tr><td>Viscosity Seconds/qt {Seconds/L}</td></tr>
<tr><td>pH</td></tr>
<tr><td>Sand Content Percent by Volume</td></tr>
</table>

Water Slurry Specifications

<table>
<tr><th>Property (Units)</th><th>At Time of Slurry Introduction</th><th>In Hole at Time of Concreting</th><th>Test Method</th></tr>
<tr><td>Density lb/ft^3</td><td colspan="3" rowspan="4">The use of water slurry without full length steel casings will only be allowed if approved in writing by the Engineer. In that case, all of the properties of mineral slurry shall be met, except that the maximum density shall not exceed 70 lb/ft3 (1120 kg/m3). Mixtures of water and on-site soils shall not be allowed for use as a drilling slurry, since particulate matter falls out of suspension easily and can contaminate the concrete.</td></tr>
<tr><td>Viscosity Seconds/qt</td></tr>
<tr><td>pH</td></tr>
<tr><td>Sand Content Percent by Volume</td></tr>
</table>

Source: United States. Massachusetts Department of Transportation. *Standard Specifications*. 2012.
http://www.massdot.state.ma.us/Portals/8/docs/construction/SupplementalSpecs20120615.pdf

Table B.22. Michigan slurry specifications (MDOT, 2012).

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	< 63	< 63	Density Balance
Viscosity Seconds/qt	33-43	33-43	Marsh Cone
pH	8 – 11	8-11	pH meter, pH paper
Sand Content Percent by Volume	< 1	< 1	API 13B-1

a. Slurry temperature shall be at least 40°F when tested.
b. Use of mineral slurry in sat water installations will not be allowed.

Source: United States. Michigan Department of Transportation. *Standard Specifications for Construction.* 2012.
http://mdotcf.state.mi.us/public/specbook/2012/

Table B.23. Minnesota slurry specifications (MnDOT, 2005).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 $\{kg/m^3\}$	64.3 – 69.1 {1030 – 1107}	64.3 – 75.0 {1030 – 1201}	Density Balance
Viscosity Seconds/qt {Seconds/L}	28 – 45 {30 – 48}	28 – 45 {30 – 48}	Marsh Cone
pH	8 – 11	8 – 11	pH paper, pH meter
Sand Content Percent by Volume	N/A	N/A	N/A

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 $\{kg/m^3\}$	No specifications pertaining to slurry parameters available.		
Viscosity Seconds/qt {Seconds/L}			
pH			

a. Mineral slurries shall be employed in the drilling process unless other drilling fluids are approved by the Engineer.

Source: United States. Minnesota Department of Transportation. *Standard Bridge Special Provisions.* 2005.
http://www.dot.state.mn.us/pre-letting/spec/
http://www.dot.state.mn.us/pre-letting/spec/2014/2014-Std-Spec-for-Construction.pdf

Table B.24. Mississippi slurry specifications (MDOT, 2007).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 {kg/m^3}	64.3* – 69.1* {1030* – 1105*}	64.3* – 75.0* {1030** – 1200*}	Density Balance
Viscosity Seconds/qt {Seconds/L}	28 – 45 {30 – 48}	28 – 45 {30 – 48}	Marsh Cone
pH	8 – 11	8 – 11	pH paper, pH meter
Sand Content Percent by Volume	N/A	N/A	N/A

* Increase by 2 lb/ft^3 (30 kg/m^3) in salt water.

a. Tests should be performed when slurry temperature is above 41°F (5°C).

b. If desanding is required, sand content shall not exceed 4% (by volume) at any point in the borehole as determined by the American Petroleum Institute sand content test.

Polymer Slurry Specifications

<table>
<tr><th>Property (Units)</th><th>At Time of Slurry Introduction</th><th>In Hole at Time of Concreting</th><th>Test Method</th></tr>
<tr><td>Density lb/ft^3 {kg/m^3}</td><td colspan="3" rowspan="3">Mineral slurries shall be employed when slurry is used in the drilling process, unless other drilling fluids are approved in writing by the Engineer. No Polymer Specification Available.</td></tr>
<tr><td>Viscosity Seconds/qt {Seconds/L}</td></tr>
<tr><td>pH</td></tr>
</table>

Source:United States. Mississippi Department of Transportation. *Special Provision No. 907-803-18M, Deep Foundations*. 2007.
http://mdot.ms.gov/portal/construction.aspx

Table B.25. Missouri slurry specifications (MODOT, 2013).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 {kg/m^3}	63.5 – 66.8 {1017 – 1129}	63.5 – 70.5 {1017 – 1129}	Density Balance
Viscosity Seconds/qt {Seconds/L}	32 – 60 {34 – 60}	32 – 60 {34 – 60}	Marsh Funnel
pH	8 – 10	8 – 11	pH paper, pH meter
Sand Content Percent by Volume	<4	<10	API Sand Content Kit
Maximum Contact Time* Hours	N/A	4	N/A

a. All values without agitation and sidewall cleaning.
b. Higher viscosities may be required to maintain excavation stability in loose or gravelly sand deposits.
c. All values for freshwater without additives.

Polymer Slurry Specifications

Emulsified Polymer			
Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 {kg/m^3}	< 63 {1009}	< 63 {1009}	Density Balance
Viscosity Seconds/qt {Seconds/L}	33 – 43* {35 – 45}*	33 – 43* {35 – 45}*	Marsh Funnel
pH	8 - 11	8 - 11	pH Paper or pH Meter
Sand Content Percent by Volume	< 1	< 1	API Sand Content Kit
Maximum Contact Time Without Agitation and Sidewall Cleaning	72 hrs		

*Higher viscosities may be required to maintain excavation stability in loose or gravelly sand deposits.

Table B.25. continued

Dry Polymer			
Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 {kg/m^3}	< 63 {1009}	< 63 {1009}	Density Balance
Viscosity Seconds/qt {Seconds/L}	50 – 80* {53 – 85}*	50 – 80* {53 – 85}*	Marsh Funnel
pH	7 - 11	7 - 11	pH Paper or pH Meter
Sand Content Percent by Volume	< 1	< 1	API Sand Content Kit
Maximum Contact Time Without Agitation and Sidewall Cleaning	72 hrs		

*Higher viscosities may be required to maintain excavation stability in loose or gravelly sand deposits.

a. All values for freshwater without additives.

Source:United States. Missouri Department of Transportation. *Supplemental Specifications to 2013 Missouri Standard Specifications for Highway Construction.* 2013. http://www.modot.org/business/standards_and_specs/highwayspecs.htm

Table B.26. Montana slurry specifications (MDT,2011).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density kg/m^3	Mineral slurry use not permitted.		
Viscosity Seconds/L			
pH			
Sand Content Percent by Volume			

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density kg/m^3	Slurry must be in conformance with Manufacturer's recommendations		
Viscosity Seconds/L			
pH			
Sand Content Percent by Volume			

The following synthetic slurries are approved as slurry systems:

Product	*Manufacturer*
Novagel	Geo-Tech Services, LLC 220 North Zapata Highway, Suite 11A Laredo, TX 78043-4464
ShorePac GCV	CETCO 1500 West Shure Drive Arlington Heights IL, 60004
SlurryPro CDP	KB International, LLC Suite 216, 735 Broad Street Chattanooga, TN 37402-1855
Super Mud*	PDS Company 8140 East Rosecrans Ave. Paramount, CA 90723-2754

*Approval as a product applies to the liquid product only.

Submit other proposed synthetic slurry products for approval. Submit proposed additives for approval.

Source: United States. Montana Department of Transportation. *Special Provisions: Synthetic Slurry for Drilled Shafts*. 2011.
http://www.mdt.mt.gov/business/contracting/standard_specs.shtml

Table B.27. Nebraska slurry specifications (Larsen, 2013).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	Mineral slurry not allowed without engineer approval.		
Viscosity Seconds/qt			
pH			
Sand Content Percent by Volume			

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	Manufacturer specifications required upon engineer approval.		
Viscosity Seconds/qt			
pH			
Sand Content Percent by Volume			

Source: Jordan Larsen (Nebraska Department of Roads Bridge Foundation Engineer) in discussion with author, August 2013
http://www.transportation.nebraska.gov/ref-man/specbook-2007.pdf

Table B.28. Nevada slurry specifications (NDOT, 2001).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 $\{kN/m^3\}$	64.0-68.8 {10.1-10.8}	64.0-74.6 {10.1-11.8}	Density Method API 13B-1 Section 1
Viscosity* Seconds/qt	28 – 45	28 – 45	Marsh Funnel and Cup API 13B-1 Section 2.2
pH	8 – 11	8 – 11	pH paper, Glass Electrode pH meter
Sand Content Percent by Volume	4 MAX	4 MAX	N/A

* The Marsh Funnel Test is conducted using one quart of fluid, not one liter.

a. Testing shall be performed when the slurry temperature is above 40°F (4°C).

b. The sand content shall not exceed 4% (by volume) at any point in the bore hole as determined by the American Petroleum Institute sand content test.

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 $\{kN/m^3\}$	No specifications pertaining to slurry parameters available at time of study.		
Viscosity* Seconds/qt			
pH			

Source:United States. Nevada Department of Transportation. *Standard Specifications for Road and Bridge Construction*. 2001. http://www.nevadadot.com/uploadedFiles/NDOT/About_NDOT/NDOT_Divisions/Engineering/Specifications/2001StandardSpecifications.pdf

Table B.29. New Hampshire slurry specifications (NHDOT, 2010).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 {kN/m^3}	64.3 – 69.1* {410 – 440*}	64.3 – 75.0* {410 – 478*}	Density Balance
Viscosity Seconds/qt {Seconds/0.945L}	28 – 45 {28 – 45}	28 – 45 {28 – 45}	Marsh Funnel
pH	8 – 11	8 – 11	pH paper, pH meter
Sand Content Percent by Volume	N/A	N/A	N/A

* Upper limit assumes that the slurry is being reused after having been treated. Initial mixing of mineral powder and fresh water should be no higher than 65.5 lb/ft^3 (717 kN/m^3) unless additional density is obtained with weighting agents. Increase by 2 lb/ft^3 (12.5 kN/m^3) in salt water.

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 {kN/m^3}	64.3 – 69.1* {410 – 440*}	64.3 – 75.0* {410 – 478*}	Density Balance
Viscosity Seconds/qt {Seconds/0.945L}	28 – 45 {28 – 45}	28 – 45 {28 – 45}	Marsh Funnel
pH	8 – 11	8 – 11	pH paper, pH meter

* Upper limit assumes that the slurry is being reused after having been treated. Initial mixing of mineral powder and fresh water should be no higher than 65.5 lb/ft^3 (717 kN/m^3) unless additional density is obtained with weighting agents. Increase by 2 lb/ft^3 (12.5 kN/m^3) in salt water.

Source: United States. New Hampshire Department of Transportation. *Standard Specifications.* 2010.
http://www.nh.gov/dot/org/projectdevelopment/highwaydesign/specifications/index.htm

Table B.30. New Jersey slurry specifications (NJDOT, 2007).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	64.3 – 69.1*	64.3 – 75.0*	Mud Balance API 13B ASTM D 4380
Viscosity Seconds/qt	28 – 45*	28 – 45*	Marsh Funnel and Cup API 13B Section 2
pH	8 – 11	8 – 11	pH paper, Glass-Electrode pH meter API 13B Section 6
Sand Content Percent by Volume	4 MAX	4 MAX	Sand Screen Set API 13B Section 4 ASTM D 4381

* Increase by 2 lb/ft^3 in salt water.

a. Perform tests when slurry temperature is above 40°F.

b. Ensure that the sand content does not exceed 4% (by volume) at any point in the borehole as determined by the API sand content test when the slurry is introduced.

c. Perform tests to determine density, viscosity and pH value during the shaft excavation to establish a consistent working pattern. Perform a minimum of 4 sets of tests during the first 8 hours of slurry use. When the results show consistent behavior, the Contractor may decrease the testing frequency to 1 set per every 4 hours of slurry use.

d. One sec/qt = 1.06 sec/L.

Table B.30. continued

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 {kg/m^3}	No specifications pertaining to slurry parameters available.		API 13B-1, Section 1
Viscosity Seconds/qt {Seconds/L}			(Marsh funnel and cup, API 13B-1), Section 2.2 or approved viscometer
pH			pH meter, pH paper
Sand Content Percent by Volume			API sand content kit, API 13B-1, Section 5

Provide a slurry management plan to the RE that includes a set of the slurry manufacturer's written recommendations and results of the following tests, as a minimum:

1. Density Test (API 13B-1, Section 1).
2. Viscosity Test (Marsh funnel and cup, API 13B-1), Section 2.2 or approved viscometer.
3. pH Test (pH meter, pH paper).
4. Sand Content Test (API sand content kit, API 13B-1, Section 5).

Also include the tests to be performed, the frequency of those tests, the test methods, and the maximum and minimum property requirements that must be met to ensure that the slurry meets its intended functions. Ensure that all test reports are signed, and provide them to the RE on completion of each drilled shaft.

Source: United States. New Jersey Department of Transportation. *Standard Specifications for Road and Bridge Construction*. 2007.
http://www.state.nj.us/transportation/eng/specs/
http://www.state.nj.us/transportation/eng/specs/2007/spec500.shtm#s503

Table B.31. New Mexico slurry specifications (NMDOT, 2007).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	N/A	64.0 – 75.0	Density Balance
Viscosity Seconds/qt	28 – 45	N/A	Marsh Cone
pH	8 – 10	8 – 10	pH paper
Sand Content Percent by Volume	N/A	0 – 4	API Method

a. Perform tests when the slurry temperature is above 40 °F.
b. Premix the slurry according to the manufacturer's directions. Prevent the slurry from "setting up" in the shaft. Dispose of the slurry offsite in accordance with Section 107.14.8, "Disposal of Other Materials and Debris."

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	62.4 - 64	62.4 - 64	Density Balance
Viscosity Seconds/qt	50-120	50-120	Marsh Cone
pH	8 – 11.7	8 – 11.7	pH paper
Sand Content Percent by Volume	0-1	0 – 1	API Method

a. Premix the slurry according to the manufacturer's directions. Prevent the slurry from "setting up" in the shaft. Dispose of the slurry offsite in accordance with Section 107.14.8, "Disposal of Other Materials and Debris."
b. Perform tests when the slurry temperature is above 40 °F.
c. Table pertains to Emulsified or Dry Phpa Polymer

Source: United States. New Mexico State Department of Transportation. *Standard Specifications for Highway and Bridge Construction.* 2007.
http://www.dot.state.nm.us/en/Standards.html
http://www.dot.state.nm.us/content/dam/nmdot/Plans_Specs_Estimates/2007_Specs_for_Highway_and_Bridge_Construction.pdf

Table B.32. New York slurry specifications (NYSDOT, 2008).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density kg/m^3	1030 – 1106	1030 – 1200	Density Balance
Viscosity Seconds/L	29 – 48	29 – 48	Marsh Cone
pH	8 – 11	8 – 11	pH paper, pH meter
Sand Content Percent by Volume	N/A	N/A	N/A

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density kg/m^3	**Polymer Slurry.** Provide a polymer slurry with sufficient viscosity and gel characteristics to hold the hole open, and transport excavated material to a suitable screening system. Polymer slurry may be made from PHPA (emulsified), vinyl (dry), or natural polymers. Desand the polymer slurry so that the sand content is less than 1 percent (by volume) prior to concrete placement, as determined by the American Petroleum Institute sand content test.		
Viscosity Seconds/L			
pH			

Source: United States. New York State Department of Transportation. Standard Specifications. 2008.
https://www.dot.ny.gov/main/business-center/engineering/specifications/updated-standard-specifications-us

Table B.33. North Carolina slurry specifications (NCDOT, 2012).

Define “slurry” as bentonite or polymer slurry. Mix bentonite clay or synthetic polymer with water to form bentonite or polymer slurry.

Bentonite Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	64.3 – 72	64.3 – 72	Mud Weight API RP[b]13B-1 Section 4
Viscosity Seconds/qt	28 – 50	28 – 50	Marsh Funnel and Cup API RP[b]13B-1 Section 6.2
pH	8 – 11	8 – 11	Glass Electrode pH meter API RP[b] 13B-1 Section 9
Sand Content Percent by Volume	Vol≤4	Vol≤2	Sand API RP[b] 13B-1 Section 9

a. Slurry temperature of at least 40°F (4.4°C) required.
b. American National Standards Institute/ American Petroleum Institute Recommended Practice
c. Increase density requirements by 2 lb/ft^3 in salt water
d. pH paper is also acceptable for measuring pH.

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	≤64	≤64	Mud Weight API RP[b] 13B-1 Section 4
Viscosity Seconds/qt	32 – 135	32 - 135	Marsh Funnel and Cup API RP[b] 13B-1 Section 6.2
pH	8 – 11.5	8 – 11.5	Glass Electrode pH meter API RP[b] Section 11
Sand Content Percent by Volume	≤0.5	≤0.5	Sand API RP[b] 13B-1 Section 9

a. Slurry temperature of at least 40°F (4.4°C) required.
b. American National Standards Institute/ American Petroleum Institute Recommended Practice

Table B.33. continued

c. Increase density requirements by 2 lb/ft^3 in salt water
d. pH paper is also acceptable for measuring pH.

The following polymer slurries are approved for use:

Product	**Manufacturer**
Shore Pac	CETCO Construction Drilling Products 2870 Forbs Avenue Hoffman Estates, IL 60192 (800) 527-9948
https://connect.ncdot.gov/resources/Geological/Lists/GEOTechApprvlList/Attachments/2/SHORE%20PAC%20Technical%20Data.pdf	
Terragel	Geo-Tech Services, LLC 220 North Zapata Highway Suite 11A-449A Laredo, TX 78043 (210) 259-6386
https://connect.ncdot.gov/resources/Geological/Lists/GEOTechApprvlList/Attachments/32/Terragel%20Technical%20Data.pdf	
SlurryPro CDP	KB International, LLC 735 Broad Street Suite 209 Chattanooga, TN 37402 (423) 266-6964
https://connect.ncdot.gov/resources/Geological/Lists/GEOTechApprvlList/Attachments/3/SlurryPro%20CDP%20Technical%20Data.pdf	
Super Mud	PDS Co., Inc. 105 West Sharp Street El Dorado, AR 71731 (800) 243-4755
https://connect.ncdot.gov/resources/Geological/Lists/GEOTechApprvlList/Attachments/4/Super%20Mud%20Technical%20Data.pdf	
Super Mud Dry	PDS Co., Inc. 105 West Sharp Street El Dorado, AR 71731 (800) 243-475
https://connect.ncdot.gov/resources/Geological/Lists/GEOTechApprvlList/Attachments/5/Super%20Mud%20Dry%20Technical%20Data.pdf	

Source: United States. North Carolina Department of Transportation. *Standard Specifications*. 2012.

Table B.34. North Dakota slurry specifications (NDDOT,2010).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density kg/m^3	No specifications pertaining to slurry parameters available at time of study.		
Viscosity Seconds/L			
pH			
Sand Content Percent by Volume			

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density kg/m^3	No specifications pertaining to slurry parameters available at time of study.		
Viscosity Seconds/L			
pH			
Sand Content Percent by Volume			

http://www.dot.nd.gov/dotnet/supplspecs/StandardSpecs.aspx

Table B.35. Ohio slurry specifications **(**ODOT, 2013).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 {kg/m^3}	64.3 – 69.1 {1030 – 1107}	64.3 – 75.0 {1030 – 1201}	Density Balance
Viscosity Seconds/qt {Seconds/L}	28 – 45 {30 – 48}	28 – 45 {30 – 48}	Marsh Cone
pH	8 – 11	8 – 11	pH paper, pH meter
Sand Content Percent by Volume	N/A	N/A	N/A

a. Range of values for 68°F.

Polymer Slurry Specifications

<table>
<tr><th>Property
(Units)</th><th>At Time of Slurry Introduction</th><th>In Hole at Time of Concreting</th><th>Test Method</th></tr>
<tr><td>Density
lb/ft^3
{kg/m^3}</td><td colspan="3" rowspan="3">Only use polymer slurry after demonstrating to the Engineer that the stability of the hole perimeter can be maintained while advancing the excavation to its final depth by excavating a trial hole of the same diameter and depth as that of the production shafts. Use the same polymer slurry in the trial hole as proposed for the production shafts. If using different sizes of the shafts at the project, use the same size trial hole as that of the largest diameter shaft, except the depth of the trial hole need not be more than 40 feet (12 meters). Only one trial hole per project is required. Do not use the trial hole excavation for a production shaft. After completing the trial hole excavation, fill the hole with sand. The acceptance of the polymer slurry does not relieve the Contractor of responsibility to maintain the stability of the excavation. Polymer slurry shall conform to the manufacturer‟s requirements.</td></tr>
<tr><td>Viscosity
Seconds/qt
{Seconds/L}</td></tr>
<tr><td>pH</td></tr>
</table>

Source: Ohio Department of Transportation. *Construction and Material Specifications.* 2013. http://www.dot.state.oh.us/Divisions/ConstructionMgt/OnlineDocs/Specifications/2013CMS/2013_CMS_11142012_FINAL.PDF

Table B.36. Oklahoma slurry specifications (ODOT, 2009).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 {kg/m^3}	64.3 – 69.1 {1030 – 1107}	64.3 – 75.0 {1030 – 1200}	Density Balance
Viscosity Seconds/qt {Seconds/L}	28 – 45 {30 – 48}	28 – 45 {30 – 48}	Marsh Cone
pH	8 – 11	8 – 11	pH paper, pH meter
Sand Content Percent by Volume	N/A	N/A	N/A

a. Perform tests when slurry temperature is above 40°F [4°C]

b. Density values are for fresh water. Increase density values 2.0 lb/ft^3 [32 kg/m^3] for salt water

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 {kg/m^3}	62.4 – 63 {1000 – 1010}	62.4 – 63.5 {1000 – 1017}	Density Balance
Viscosity Seconds/qt {Seconds/L}	30 – 40 {32 – 42}	30 – 40 {32 – 42}	Marsh Cone
pH	9 – 11	9 – 11	pH paper, pH meter
Sand Content Percent by Volume	< 1	< 1	N/A

a. Perform tests when slurry temperature is above 40°F [4°C]

b. Density values are for fresh water. Increase density values 2.0 lb/ft^3 [32 kg/m^3] for salt water

Source: United States. Oklahoma Department of Transportation. *Standard Specifications Book.* 2009.
http://www.okladot.state.ok.us/c_manuals/specbook/oe_ss_2009.pdf

Table B.37. Oregon slurry specifications (ODOT, 2008).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	64 – 75	64 – 75	Mud Density API 13B-1 Section 1
Viscosity Seconds/qt	26 – 50	26 – 50	Marsh Funnel and Cup API 13B-1 Section 2.2
pH	8 – 11	8 – 11	pH paper, pH meter, Glass Electrode
Sand Content Percent by Volume	4 MAX	4 MAX	Sand API 13B-1 Section 5

a. Maintain slurry temperature at 40°F or more during testing.

Polymer Slurry Specifications

<table>
<tr><th>Property
(Units)</th><th>At Time of Slurry
Introduction</th><th>In Hole at Time of
Concreting</th><th>Test
Method</th></tr>
<tr><td>Density
lb/ft^3</td><td colspan="3" rowspan="3">(b) Synthetic Slurries - Select synthetic slurries from the QPL. Use synthetic slurries according to the manufacturer's recommendations and the Contractor's quality control plan. The sand content of synthetic slurry shall be less than 2.0 percent (API 13B-1, Section 5) prior to final cleaning and immediately prior to concrete placement.</td></tr>
<tr><td>Viscosity
Seconds/qt</td></tr>
<tr><td>pH</td></tr>
<tr><td>Sand Content
Percent by Volume</td><td><2</td><td><2</td><td>Sand
API 13B-1
Section 5</td></tr>
</table>

a. Maintain slurry temperature at 40°F or more during testing.

Water may be used as slurry when casing is used for the entire length of the drilled shaft. Use of water slurry without full-length casing will only be allowed with the Engineer's approval.

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	70 MAX	70 MAX	Mud Density API 13B-1 Section 1
Sand Content Percent by Volume	2 MAX	2 MAX	Sand API 13B-1 Section 5

a. Do not use blended slurries.

Source: United States. Oregon Department of Transportation. *Standard Specifications*. 2008. http://www.oregon.gov/ODOT/HWY/SPECS/docs/08book/08_00500.pdf

Table B.38. Pennsylvania slurry specifications.

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 $\{kg/m^3\}$	No specifications pertaining to slurry parameters available at time of study.		
Viscosity Seconds/qt {Seconds/L}			
pH			
Sand Content Percent by Volume			

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 $\{kg/m^3\}$	No specifications pertaining to slurry parameters available at time of study.		
Viscosity Seconds/qt {Seconds/L}			
pH			
Sand Content Percent by Volume			

ftp://ftp.dot.state.pa.us/public/bureaus/design/Pub408/pdf%20for%20printing%202011%206/408%202011%20Change%206.pdf

Table B.39. Rhode Island slurry specifications 2010.

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	No specifications pertaining to slurry parameters available at time of study.		
Viscosity Seconds/qt			
pH			
Sand Content Percent by Volume			

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	No specifications pertaining to slurry parameters available at time of study.		
Viscosity Seconds/qt			
pH			
Sand Content Percent by Volume			

http://www.dot.ri.gov/documents/engineering/BlueBook/Bluebook_2010.pdf

Table B.40. South Carolina slurry specifications (SCDOT, 2007).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	64.3 – 69.1	64.3 – 75.0	Density Balance API 13B-1 Section 1
Viscosity Seconds/qt	28 – 45	28 – 45	Marsh Cone API 13B-1 Section 2.2
pH	8 – 11	8 – 11	pH paper, pH meter
Sand Content Percent by Volume	N/A	N/A	N/A

a. Perform tests when the slurry temperature is above 40° F.
b. If desanding is required, do not allow sand content to exceed 4% (by volume) at any point in the borehole as determined by the American Petroleum Institute Sand Content Test (API 13B-1, Section 5).

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	64.3 – 69.1	64.3 – 75.0	Density Balance API 13B-1 Section 1
Viscosity Seconds/qt	28 – 45	28 – 45	Marsh Cone API 13B-1 Section 2.2
pH	8 – 11	8 – 11	pH paper, pH meter

Source: United States. South Carolina Department of Transportation. *Standard Specifications for Highway Construction*. 2007.
http://www.scdot.org/doing/construction_standardspec.aspx

Table B.41. South Dakota slurry specifications.

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density kg/m^3	Drilled shafts permitted but no specifications pertaining to slurry parameters available.		
Viscosity Seconds/L			
pH			
Sand Content Percent by Volume			

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density kg/m^3	Drilled shafts permitted but no specifications pertaining to slurry parameters available.		
Viscosity Seconds/L			
pH			
Sand Content Percent by Volume			

Source: United States. South Dakota Department of Transportation. *Standard Specifications*. 2004.
http://www.sddot.com/business/contractors/specs/Default.aspx

Table B.42. Tennessee slurry specifications (TDOT, 2006).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	63.5 – 66.8	63.5 – 70.5	Density Balance
Viscosity Seconds/qt	32 – 60	32 – 60	Marsh Funnel
pH	8 – 10	8 – 10	pH paper, pH meter
Sand Content Percent by Volume	Vol<4	Vol<10	API Sand Content Kit
Maximum Contact Time Hours	N/A	N/A	N/A

Polymer Slurry Specifications

Emulsified Polymer			
Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 $\{kg/m^3\}$	< 63	< 63	Density Balance
Viscosity Seconds/qt {Seconds/L}	33-43*	33-43*	Marsh Funnel
pH	8 - 11	8 - 11	pH paper or meter
Sand Content Percent by Volume	< 1	< 1	API Sand Content Kit
Maximum Contact Time Without Agitation or Sidewall Cleaning	72 hrs	72 hrs	

*Higher viscosities may be required to maintain excavation stability in loose or gravelly sand deposits.

Table B.42. continued

Dry Polymer			
Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 $\{kg/m^3\}$	< 63	< 63	Density Balance
Viscosity Seconds/qt {Seconds/L}	50 – 80*	50 – 80*	Marsh Funnel
pH	7 - 11	7 - 11	pH paper or meter
Sand Content Percent by Volume	< 1	< 1	API Sand Content Kit
Maximum Contact Time Without Agitation or Sidewall Cleaning	72 hrs	72 hrs	

*Higher viscosities may be required to maintain excavation stability in loose or gravelly sand deposits.
Source: United States. Tennessee Department of Transportation. *Special Provisions Item 625: Drill Shaft Specifications.* 2006.
http://www.tdot.state.tn.us/construction/specs.htm

Table B.43. Texas slurry specifications (TxDOT, 2004).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Specific Gravity	≤1.10	≤1.15	
Viscosity Seconds/qt {Seconds/L}	N/A	≤45	
pH			
Sand Content Percent by Volume	Vol≤1	Vol≤6	

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Specific Gravity	"Do not use PHPA (partially hydrolyzed polyacrylamide) polymeric slurry or any other fluid composed primarily of a polymer solution."		
Viscosity Seconds/qt {Seconds/L}			
pH			
Sand Content Percent by Volume			

Source: United States. Texas Department of Transportation. *Standard Specifications*. 2004. http://www.dot.state.tx.us/business/specifications.htm

Table B.44. Utah slurry specifications.

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density kg/m^3	Slurry drilling is not permitted.		
Viscosity Seconds/L			
pH			
Sand Content Percent by Volume			

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density kg/m^3	Slurry drilling is not permitted.		
Viscosity Seconds/L			
pH			
Sand Content Percent by Volume			

Source: United States. Utah Department of Transportation. *Standard Specifications*. 2012. http://vtransengineering.vermont.gov/publications

Table B.45. Vermont slurry specifications (AOT, 2009).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 {kg/m^3}	64.3 – 69.1 {1030 – 1107}	64.3 – 75.0 {1030 – 1201}	Density Balance API 13B-1 Section 1
Viscosity Seconds/qt {Seconds/L}	28 – 45 {30 – 47}	28 – 45 {30 – 47}	Marsh Cone API 13B-1 Section 2.2
pH	7 – 11	7 – 11	pH paper, pH meter
Sand Content Percent by Volume	N/A	≤4	Sand API 13B-1 Section 5

a. These tests shall be done per the American Petroleum Institute RP 13B-1 Standard Procedure for field testing Water Based Drilling Fluids.

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3 {kg/m^3}	63 – 64 {1009 – 1025}	63 – 64 {1009 – 1025}	Density Balance API 13B-1 Section 1
Viscosity Seconds/qt {Seconds/L}	45 min {48 min}	45 min {48 min}	Marsh Cone API 13B-1 Section 2.2
pH	7 – 11	7 – 11	pH paper, pH meter
Sand Content Percent by Volume	N/A	< 1	Sand API 13B-1 Section 5

a. These tests shall be done per the American Petroleum Institute RP 13B-1 Standard Procedure for field testing Water Based Drilling Fluids.
b. Range of values for polymer slurry at 68° F [20° C]
c. The use of a blended mineral-polymer slurry is not permitted.
d. Polymer slurry (vinyl (dry) or natural polymers) shall be made from Partially-Hydrolyzed Polyacrylamide Polymer (PHPA) (emulsified). The polymer slurry product must be approved for use by the Agency.

Source: United States. Vermont Agency of Transportation. *Bennington AC NH 019-1(51) Construction Special Provisions*. 2009. http://vtransengineering.vermont.gov/publications

Table B.46. Virginia slurry specifications (VDOT, 2010).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	63 – 65	65 – 67	Mud Balance API 13B-1 Section 1
Viscosity Seconds/qt	50 max.	50 max.	Marsh Cone Method API 13B-1 Section 2.2
pH	8 – 10	8 – 10	pH paper, pH meter
Sand Content Percent by Volume	0.3% max	1% max	API 13B -1

a. Density values shall be increased by two pounds per cubic foot (lb/ft^3) in salt water.
b. At time of concreting, sand content at any point in the drilled shaft excavation shall not exceed 1% (by volume); test for sand content as determined by the American Petroleum Institute.
c. Minimum mixing time shall be 15 minutes.
d. Storage time to allow for hydration shall be minimum of 4 hours.

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	63 – 65	65 – 67	Mud Balance API 13B-1 Section 1
Viscosity Seconds/qt	50 max.	50 max.	Marsh Cone Method API 13B-1 Section 2.2
pH	8 – 10	8 – 10	pH paper, pH meter
Sand Content Percent by Volume	0.3% max	1% max	API 13B -1

(a) Density values shall be increased by two pounds per cubic foot (lb/ft^3) in salt water.
(b) At time of concreting, sand content at any point in the drilled shaft excavation shall not exceed 1% (by volume); test for sand content as determined by the American Petroleum Institute.
(c) Minimum mixing time shall be 15 minutes.
(d) Storage time to allow for hydration shall be minimum of 4 hours.

Source: United States. Virginia Department of Transportation. *Special Provisions for Drilled Shafts*. 2010. http://www.virginiadot.org/business/const/spec-default.asp

Table B.47. Washington slurry specifications (WSDOT, 2014).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	63 – 75	63 – 75	Mud Weight API 13B-1 Section 1
Viscosity Seconds/qt	26 – 50	26 – 50	Marsh Funnel and Cup API 13B-1 Section 2.2
pH	8 – 11	8 – 11	Glass electrode, pH paper, pH meter
Sand Content Percent by Volume	4 MAX	4 MAX	Sand API 13B-1 Section 5

a. Use of mineral slurry in salt water installations will not be allowed.
b. Slurry temperature shall be at least 40 F when tested.

Water Slurry Specifications

Water without site soils may be used as slurry when casing is used for the entire length of the drilled hole. Water slurry without full length casing may only be used with the approval of the Engineer.

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	65 MAX	65 MAX	Mud Weight (Density)API 13B-1 Section 1
Sand Content Percent by Volume	1 MAX	1 MAX	Sand API 13B-1 Section 5

Use of water slurry in salt water installations will not be allowed.

Slurry temperature shall be at least 40ºF when tested.

Table B.47. continued.

Synthetic Slurry Specifications

Synthetic slurries shall be used in conformance with the manufacturer's recommendations and shall conform to the quality control plan specified in Section 6-19.3(2)B, item 4. The synthetic slurry shall conform to the following requirements:

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	64 MAX	64 MAX	Mud Weight API 13B-1 Section 1
Viscosity Seconds/qt	32-135	32-135	Marsh Funnel and Cup API 13B-1 Section 2.2
pH	6 -11.5	6 -11.5	Glass electrode, pH paper, pH meter
Sand Content Percent by Volume	1 MAX	1 MAX	Sand API 13B-1 Sec 5

Source: United States. Washington State Department of Transportation. *Bridge Special Provisions.* 2014.
http://www.wsdot.wa.gov/biz/mats/qpl/QPLProductsGrid.cfm

Table B.48. West Virginia slurry specifications (WVDOT, 2000).

Mineral Slurry Specifications

<table>
<tr><th>Property
(Units)</th><th>At Time of Slurry
Introduction</th><th>In Hole at Time of
Concreting</th><th>Test
Method</th></tr>
<tr><td>Density
kg/m³</td><td colspan="3" rowspan="4">When the use of slurry is anticipated, details of the methods to mix, circulate, and de-sand slurry. Any request to use a slurry displacement method for the construction of caissons shall also provide information for the Engineer's approval as follows:
1. Detailed description of proposed construction method.
2. Concrete mix, as modified for use with the slurry displacement method.
3. Components and proportions in proposed slurry mixture.
4. Tests proving slurry mixture will not degrade rock or interfere with bond.
5. Methods to agitate slurry mixture prior to concrete placement.
6. Methods to clean slurry mixture for re-use.
7. Disposal methods for used slurry.</td></tr>
<tr><td>Viscosity
Seconds/L</td></tr>
<tr><td>pH</td></tr>
<tr><td>Sand Content
Percent by Volume</td></tr>
</table>

Polymer Slurry Specifications

<table>
<tr><th>Property
(Units)</th><th>At Time of Slurry
Introduction</th><th>In Hole at Time of
Concreting</th><th>Test
Method</th></tr>
<tr><td>Density
kg/m³</td><td colspan="3" rowspan="4">No specific polymer slurry specifications</td></tr>
<tr><td>Viscosity
Seconds/L</td></tr>
<tr><td>pH</td></tr>
<tr><td>Sand Content
Percent by Volume</td></tr>
</table>

Source: United States. West Virginia Department of Transportation. *West Virginia Division of Highways: Supplemental Specifications.* 2000.

Table B.49. Wisconsin slurry specifications (WDOT, 2013).

Mineral Slurry Specifications

Property at 68°F Units	At the Time of Slurry Introduction into the Drilled Shaft	Before Concrete Placement in the Drilled Shaft	Test Method
Density in Fresh Water (lb/ft^3) (a)	64 to 69	64 to 75	Density Balance
Viscosity (seconds per quart)	28 to 45	28 to 45	Marsh Funnel
pH	7 to 11	7 to 11	pH paper or meter
Sand Content (%) (b)	4 maximum	10 maximum	200 Sieve Retain

Polymer Slurry Specifications

Property at 68°F Units	At the Time of Slurry Introduction into the Drilled Shaft	Before Concrete Placement in the Drilled Shaft	Test Method
Density in Fresh Water (lb/ft^3) (a)	63 or less	63 or less	Density Balance
Viscosity (seconds per quart)	50 minimum	50 minimum	Marsh Funnel
pH	8 to 11	8 to 11	pH paper or meter
Sand Content (%)	2 maximum	10 maximum	200 Sieve Retain

Source : United States. Wisconsin Department of Transportation. Standard Specification, 2013.

Table B.50. Wyoming slurry specifications.

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density kg/m^3	Drilled shafts permitted but no specifications pertaining to slurry parameters available.		
Viscosity Seconds/L			
pH			
Sand Content Percent by Volume			

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density kg/m^3	Drilled shafts permitted but no specifications pertaining to slurry parameters available.		
Viscosity Seconds/L			
pH			
Sand Content Percent by Volume			

Source: United States. State of Wyoming Department of Transportation. *Standard Specifications*. 2010.

Table B.51. Federal Highway Administration slurry specifications (FHWA, 2010).

Mineral Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	64.3 – 72	N/A	Mud Weight Density Balance (API 13B-1)
Viscosity Seconds/L	28 – 50	N/A	Marsh Funnel and Cup (API 13B-1)
pH	8 – 11	N/A	pH paper, pH meter
Sand Content Percent by Volume	4 MAX	N/A	Sand Content API 13B-1

Note: Density values shown are for fresh water. Increase density values 2 pounds per cubic foot for saltwater. Perform tests when slurry temperature is above 40 °F. If desanding is required, sand content shall not exceed 4 percent by volume at any point in the bore hole according to the American Petroleum Institute sand content test.

Polymer Slurry Specifications

Property (Units)	At Time of Slurry Introduction	In Hole at Time of Concreting	Test Method
Density lb/ft^3	≤64	N/A	Mud Weight Density Balance (API 13B-1)
Viscosity Seconds/L	32 to 135	N/A	Marsh Funnel and Cup (API 13B-1)
pH	8 – 11.5	N/A	pH paper, pH meter
Sand Content Percent by Volume	≤ 1.0	N/A	Sand Content API 13B-1

Source: United States. United States Department of Transportation Federal Highway Administration. *Drilled Shafts: Construction Procedures and LRFD Design Methods*. 2010.

APPENDIX C: CONCRETE INFORMATION

CEMEX

Brooksville South Plant
10311 CEMENT PLANT ROAD
Brooksville, Fl 34601
Phone (352) 799-7881 / FAX (352) 799-6088

CEMENT MILL TEST REPORT

Cement Identified as: **AASHTO M85, Type I, Type II and Type II (MH) , C-150**

Date of Report: 01/04/12

Production Period:
Beginning: 1-Dec-12
Ending: 31-Dec-12

Silo 1,2,4,5,13,15

CHEMICAL REQUIRMENTS ASTM C114 and AASHTO M 85	Test Results	Specifications	AASHTO M 85, ASTM C 150			ASTM C-1157
			Type I	TYPE II	TYPE II (MH)	GU
Silicon Dioxide (SiO2) %	20.1	Minimum	----	----	---	----
Aluminum Oxide (Al2O3) %	4.9	Maximum	----	6.0	6.0	----
Ferric Oxide (Fe2O3) %	3.9	Maximum	----	6.0	6.0	----
Calcium Oxide (CaO) %	64.5		----	----	----	----
Magnesium Oxide (MgO) %	0.7	Maximum	6.0	6.0	6.0	----
Sulfur Trioxide (SO3) % [A]	2.8	Maximum	3.5	3.0	3.0	----
Loss on Ignition (LOI) %	2.4	Maximum	3	3	3.0	----
Insoluble Residue (IR) %	0.50	Maximum	0.75	0.75	0.75	----
Alkalies (Na2O equivalent) %	0.41	Optional Max	0.60	0.60	0.60	----
Carbon Dioxide in cement (CO2) %	1.10					
Limestone % in cement (ASTM C150 A1)	2.7	Maximum	5	5	5	----
CaCO3 in limestone % (2.274 x %CO2 LS)	86	Minimum	70	70	70	----
Inorganic Processing Addition (Kiln dust) (%)	3.0	Maximum	5	5	5	----
Potential Phase composition [D]						
Tricalcium Silicate (C3S) %	61		----	----	----	----
Dicalcium Silicate (C2S) %	10		----	----	----	----
Tricalcium Aluminate (C3A) %	6	Maximum	----	8	8	----
Tetracalcium Aluminoferrite (C4AF) %	12		----	----	----	
(C3S + 4.75 C3A)	90	Maximum	----	----	100	----
(C4AF + 2C3A) or (C4AF + C2F) %	24	Maximum	----	----	----	----
PHYSICAL REQUIRMENTS						
(ASTM C204) Blaine Fineness, cm2/g	3972	Minimum	2600	2600	2600	----
(ASTM C204) Blaine Fineness, cm2/g	3972	Maximum	----	----	4300 [B]	----
(ASTM C430) -325 Mesh %	95.8		----	----	----	----
(ASTM C191) Time of Setting (Vicat) Initial Set, minutes	105	Min / Max	45 / 375	45 / 375	45 / 375	45 / 420
(ASTM C185) Air Content of Mortar %	5.2	Maximum	12	12	12	----
(ASTM C151) Autoclave Expansion %	-0.020	Maximum	0.80	0.80	0.80	0.80
(ASTM C187) Normal Consistency %	25.0		----	----	----	----
(ASTM C1038) Expansion in Water % *	0.011	Maximum	0.020	0.020	0.020	0.020
(ASTM C186) 7 day Heat of Hydration cal/g [C]	76	Informational				
(ASTM C109) Compressive Strength, psi (Mpa)						
1 Day	2266 (15.6)		----	----	----	----
3 Days	4148 (28.6)	Minimum	1740 (12.0)	1450 (10.0)	1450 (10.0)	1890 (13.0)
7 Days	5236 (36.1)	Minimum	2760 (19.0)	2470 (17.0)	2470 (17.0)	2900 (20.0)
28 Days [C]	6324 (43.7)	Minimum	----	----	----	4060 (28.0)

A As per note D of table 1. SO3 limit may be exceeded demonstrating expansion according to ASTM C 1038 <= 0.020
B Blaine limits does not apply if Sum of C3S + 4.75* C3A <= 90
C Test results for this period not available. Most recent test result provided.
D Adjusted per A 1.6
* Required only if SO3 exceeds limit of table 1.
This Cement contains Limestone.

Physical Testing completed by: KW, ES
Chemical Testing completed by : KW, ES, RP

Cemex hereby certifies that this cement meets or exceeds the chemical and physical specifications of :
x AASHTO M 85 Type I and Type II and ASTM C150 Type I and Type II
x AASHTO M 85 Type II (MH) and ASTM C150 Type II (MH)
x ASTM C-1157 GU
x Florida Spec 921

Oliver Sohn
Oliver Sohn
Quality Control Manager

We certify that the above described data represents the materials used in the cement manufactured during the production period indicated.
Cemex is not responsible for the improper use or workmanship that may be associated with the use of this cement.

Figure C.1. Page 1 of cement mill certificate.

CEMEX

Brooksville South Plant
10311 CEMENT PLANT ROAD
Brooksville, Fl 34601
Phone (352) 799-7881 / FAX (352) 799-6088

CEMENT MILL TEST REPORT

Cement Identified as: AASHTO M85, Type I, Type II and Type II (MH) , C-150

Date of Report: 01/04/12

Production Period:
Beginning: 1-Dec-12
Ending: 31-Dec-12

Silo 1,2,4,5,13,15

ADDITIONAL DATA

Inorganic Processing Addition

Type	Baghouse Dust
Amount (%)	3.0
SiO2 (%)	18.77
Al2O3 (%)	7.38
Fe2O3 (%)	2.8
CaO (%)	71.71
SO3 (%)	0.24

Base Cement Phase Composition

C3S (%)	63
C2S (%)	10
C3A (%)	6
C4AF (%)	12

Figure C.2. Page 2 of cement mill certificate.

Preferred
MATERIALS, INC.

Delivery Ticket for Structural Concrete

Financial Project Number	N/A	Serial #	7526992
DOT Plant Number	10-410	Date	May 8, 2013
Concrete Supplier	Oldcastle Southern Group / Preferred Materials, Inc.	Delivered to	USF/DANNY WINTERS
		Phone #	
Phone Number	800-331-3375	Address;	LAUREL & HOLLEY
Address	1811 N. 57th Street		USF
	Tampa, FL 33619		

84097010

Truck # 4195	DOT class CL IV DS 4000 EQUL		DOT mix ID		Cubic yards this load 4	
allowable jobsite Water 13.58		Time loaded 8:44 AM	Mixing revolutions 78		Cubic yards total today 4	
Chloride Test Results:			Chloride Test Date:			
Cement			Flyash / Slag			
American	TYPEI/ II	2075	ProAsh	F		1020
source	Type	amount-lbs	source	Type		amount-lbs
Coarse agg			Air admixture			
87-089	2.90	6400	Euclid	AEA-92S		12
Pit num.	%moisture	amount-lbs	source	brand	Type	amount-oz.
Fine agg.			Admixture			
16-659	3.20	4500	Euclid	WR	D	216
Pit num.	% moisture	amount-lbs	source	brand	Type	amount-oz.
		0.00				
ICE	Lbs.	Gal.	Admixture			
Batch water			Euclid	Viscstol	F	
Amount	799.0	96	source	brand	Type	amount
	Lbs.	Gal.				

Issuance of this ticket constitutes certification that the concrete batched was produced and information recorded in compliance with Department specifications for Structural Concrete

W363-620-53-391-0
CTQP Technician Identification number

Signature of batch plant operator

Arrival on jobsite		Number of revolutions upon arrival at job site	
Water added at job site(gal or lbs)		Additional mixing revs. With added water	
Time concrete completely discharged		Total number of revolutions	
Initial slump	Initial air	Initial concrete temp	Initial W/C ratio
Accept. Slump	Accept. Air	Accept. Concrete temp	Accept W/C ratio

Issuance of this ticket constitutes certification that the maximum specified water cementitious ratio was not exceeded and the batch was delivered and plaved in compliance with Department specification requirements

CTQP Technician Identification number

Signature of contractors representative

Figure C.3. FDOT batch ticket for placement 1.

Preferred
MATERIALS, INC.

Delivery Ticket for Structural Concrete

Financial Project Number	N/A	Serial #	7528042
DOT Plant Number	10-410	Date	June 5, 2013
Concrete Supplier	Oldcastle Southern Group / Preferred Materials, Inc.	Delivered to	KEVIN JOHNSON
		Phone #	
Phone Number	800-331-3375	Address;	HOLLEY & PLUM DR
Address	1811 N. 57th Street Tampa, FL 33619		USF

Truck # 4282	DOT class CL IV DS 4000			DOT mix ID 01-1031-01		Cubic yards this load 6	
allowable jobsite Water 20.52		Time loaded 8:11 AM		Mixing revolutions 78		Cubic yards total today 6	
Chloride Test Results:				Chloride Test Date:			
Cement				Flyash / Slag			
American	TYPEI/ II	3120		ProAsh	F		1525
source	Type	amount-lbs		source	Type		amount-lbs
Coarse agg				Air admixture			
87-089	3.00	9680		Euclid	AEA-92S		18
Pit num.	%moisture	amount-lbs		source	brand	Type	amount-oz.
Fine agg.				Admixture			
16-659	4.10	6680		Euclid	WR	D	372
Pit num.	% moisture	amount-lbs		source	brand	Type	amount-oz.
		0.00					
ICE	Lbs.	Gal.		Admixture			
Batch water				Euclid	Viscstol	F	
Amount	1132.0	136		source	brand	Type	amount
	Lbs.	Gal.					

Issuance of this ticket constitutes certification that the concrete batched was produced and information recorded in compliance with Department specifications for Structural Concrete

W363-620-53-391-0
CTQP Technician Identification number

Signature of batch plant operator

Arrival on jobsite		Number of revolutions upon arrival at job site	
Water added at job site(gal or lbs)		Additional mixing revs. With added water	
Time concrete completely discharged		Total number of revolutions	
Initial slump	Initial air	Initial concreti temp	Initial W/C ratio
Accept. Slump	Accept. Air	Accept. Concrete temp	Accept W/C ratio

Issuance of this ticket constitutes certification that the maximum specified water cementitious ratio was not exceeded and the batch was delivered and plaved in compliance with Department specification requirements

CTQP Technician Identification number

Signature of contractors representative

Figure C.4. FDOT batch ticket for placement 2.

Preferred
MATERIALS, INC.

Delivery Ticket for Structural Concrete

Financial Project Number	N/A	Serial #	7528554
DOT Plant Number	10-410	Date	June 18, 2013
Concrete Supplier	Oldcastle Southern Group / Preferred Materials, Inc.	Delivered to	KEVIN JOHNSON
		Phone #	
Phone Number	800-331-3375	Address;	HOLLEY & PLUM
Address	1811 N. 57th Street Tampa, FL 33619		TAMPA

Truck # 4202	DOT class CL IV DS 4000			DOT mix ID 01-1031-01		Cubic yards this load 6	
allowable jobsite Water 7.42		Time loaded 9:45 AM		Mixing revolutions 78		Cubic yards total today 6	
Chloride Test Results:				Chloride Test Date:			
Cement				Flyash / Slag			
American	TYPEI/ II	3090		ProAsh	F		1520
source	Type	amount-lbs		source	Type		amount-lbs
Coarse agg				Air admixture			
87-089	3.40	9840		Euclid	AEA-92S		24
Pit num.	%moisture	amount-lbs		source	brand	Type	amount-oz.
Fine agg.				Admixture			
16-659	3.40	6740		Euclid	WR	D	464
Pit num.	% moisture	amount-lbs		source	brand	Type	amount-oz.
		0.00					
ICE	Lbs.	Gal.		Admixture			
Batch water				Euclid	Viscstol	F	
Amount	1241.0	149		source	brand	Type	amount
	Lbs.	Gal.					

Issuance of this ticket constitutes certification that the concrete batched was produced and information recorded in compliance with Department specifications for Structural Concrete

W363-620-57-391-0
CTQP Technician Identification number

[signature]
Signature of batch plant operator

Arrival on jobsite		Number of revolutions upon arrival at job site	
Water added at job site(gal or lbs)		Additional mixing revs. With added water	
Time concrete completely discharged		Total number of revolutions	
Initial slump	Initial air	Initial concrete temp	Initial W/C ratio
Accept. Slump	Accept. Air	Accept. Concrete temp	Accept W/C ratio

20 Revs

Issuance of this ticket constitutes certification that the maximum specified water cementitious ratio was not exceeded and the batch was delivered and plaved in compliance with Department specification requirements

CTQP Technician Identification number

Signature of contractors representative

Figure C.5. FDOT batch ticket for placement 3.

Preferred
MATERIALS, INC.

Delivery Ticket for Structural Concrete

Financial Project Number	N/A	Serial #	7531916
DOT Plant Number	10-410	Date	September 20, 2013
Concrete Supplier	Oldcastle Southern Group / Preferred Materials, Inc.	Delivered to	KEVIN JOHNSON
		Phone #	
Phone Number	800-331-3375	Address;	4202 E FOWLER AVE
Address	1811 N. 57th Street Tampa, FL 33619		TAMPA

Truck # 3972	DOT class CL IV DS 4000	DOT mix ID 01-1031-01	Cubic yards this load 5
allowable jobsite Water 30.41	Time loaded 8:00 AM	Mixing revolutions 78	Cubic yards total today 5
Chloride Test Results:		Chloride Test Date:	

Cement			Flyash / Slag			
American	TYPEI/ II	2565	ProAsh	F		1255
source	Type	amount-lbs	source	Type		amount-lbs
Coarse agg			Air admixture			
87-089	2.50	8040	Euclid	AEA-92S		17
Pit num.	%moisture	amount-lbs	source	brand	Type	amount-oz.
Fine agg.			Admixture			
16-659	3.10	5540	Euclid	WR	D	387
Pit num.	% moisture	amount-lbs	source	brand	Type	amount-oz.
		0.00				
ICE	Lbs.	Gal.	Admixture			
Batch water			Euclid	Viscstol	F	
Amount	924.0	111	source	brand	Type	amount
	Lbs.	Gal.				

Issuance of this ticket constitutes certification that the concrete batched was produced and information recorded in compliance with Department specifications for Structural Concrete

4363-620-53-391-0
CTQP Technician Identification number

[signature]
Signature of batch plant operator

Arrival on jobsite 845		Number of revolutions upon arrival at job site 115	
Water added at job site(gal or lbs)		Additional mixing revs. With added water	
Time concrete completely discharged		Total number of revolutions	
Initial slump	Initial air	Initial concret temp	Initial W/C ratio
Accept. Slump	Accept. Air	Accept. Concrete temp	Accept W/C ratio

Issuance of this ticket constitutes certification that the maximum specified water cementitious ratio was not exceeded and the batch was delivered and plaved in compliance with Department specification requirements

CTQP Technician Identification number

Signature of contractors representative

Figure C.6. FDOT batch ticket for placement 4.