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AGING AND PROPERTY CHANGES OF CLAY AROUND DRIVEN PILES

A Master of Science Project

Presented by

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MASTER OF SCIENCE IN CIVIL ENGINEERING

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ABSTRACT

The purpose of this research was to determine how soil disturbance caused by the installation of piles (of differing types and geometries) in clay affect the short and long-term capacity of piles.

Several types of piles were installed in lightly overconsolidated clay at three different test sites in Amherst, Massachusetts. Before and after pile installation, an in-situ testing program consisting of field vane shear tests was carried out around piles installed at one of the three testing sites. Undrained shear strength and water content profiles allowed for an approximate determination of changes in the behavior of the clay surrounding some of the piles installed at different aging periods.

The excess pore pressures within the soil surrounding the piles was monitored during and after pile installation by means of collected representative samples located at various depths immediately adjacent to the pile. The changes in pore pressure during pile installation were indicators of the soil deformations caused by the pile installation.

After allowing a recovery period following installation (at all sites), piles with differing geometries were loaded to failure under axial tensile loads.

Load-settlement curves were generated for different piles at different aging times after installation. The Undrained Shear Strength of the clay adjacent to the pile was also monitored at different aging times after installation by performing field vane tests. Disturbed samples were collected after each test to monitor the water content. The determined water content at different aging times was used as an indicator of the distribution of excess pore pressures and distribution of soil deformations caused by pile displacement. The Undrained Shear Strengths and water content were used as principal parameters (controlling factors) for the correlation to the short and long-term capacity of the pile.

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Last but not least, I would like to thank all the people that in some way had a positive impact throughout my graduate studies.

CHAPTER 1

1 INTRODUCTION

1.1 PILES

A pile is a slender, structural member, normally consisting of steel, concrete, timber or plastic. Piles are often used when shallow foundations are not an option to support a structure. Piles are considered deep foundations and their purpose is to transfer the structural loads to soils at deeper depths. The selection of material depends mainly on the magnitude of the design structural loads and soil conditions at the site (Weech, 2002). According to Budhu (2008), pile foundations are typically used when:

- the soil close to the ground surface does not have sufficient capacity to support the structural loads
- the estimated total settlement or the estimated differential settlement exceeds tolerable limits
- the structural loads consist of large horizontal loads, moments or uplift forces
- the excavations to construct a shallow foundation are difficult or expensive.

1.1.1 SOME TYPES OF PILE

The following pile types are most commonly used as structural support for foundations for small and large structures:

- steel pipe piles (i.e. open or closed-ended)
- steel H-piles (i.e. HP, W and S sections)

Steel pipe piles and H-piles are typically driven using a pile hammer. Other pile installation methods include: vibration or jacking into place, or installation in a pre-bored hole. Pile installation by vibration is often limited to granular soils and jacking is limited to fine grained soils. Pile installation in a pre-bored hole is limited to stiff to very stiff fine-grained soils or unsaturated soils in which there is less chance of hole collapse (Bergset, 2015). Piles driven in soft fine-grained soils are usually driven or jacked into place because an open borehole of great length will not stay open long enough (Weech, 2002).

Installation of driven piles causes an outward displacement of soil away from the pile, the volume of which depends on the pile geometry. Steel pipe piles driven with a closed-end, are classified as “displacement” piles, since they cause a large volume of soil displacement. Steel H-piles and open-end pipe piles are usually classified as “low-displacement” piles since soil is allowed to enter the pile. If the bottom of an open-end pipe piles becomes plugged with soil, they will also cause a large volume of soil displacement.

Piles are typically designed to penetrate through layers of weak and/or compressible soils to reach a relatively competent bearing stratum, in which most of their capacity will be mobilized (Weech, 2002). In many cases, shallow soils are not considered suitable for construction of foundation and the only option is to drive piles to deeper soils which consist of suitable material where the pile can develop bearing capacity. In most cases driven piles are not resting on bedrock, but instead are suspended within soil layers. This class of piles is typically referred to as “friction piles”.

Friction piles develop their bearing capacity almost entirely from the shear strength of the disturbed soil surrounding the driven pile. The soil deformations that are induced by the pile installation process alter the total and effective stress states within the soil surrounding the pile and can significantly alter the microstructure of the soil (Burland, 1990). Most natural clays are micro-structured and will exhibit some degradation in strength and stiffness when the natural micro-structure is disturbed (Burland, 1990; Leroueil & Vaughan, 1990). The degree of strength and stiffness degradation will vary from soil to soil and will depend on the intensity of the soil deformations caused by pile installation. Further changes in the stress state and soil fabric, and hence the strength and stiffness, can continue to occur with time after pile installation (Weech, 2002).

1.2 RESEARCH OBJECTIVES

Steel piles are a popular solution to foundation problems in geotechnical engineering practices due to their ease of fabrication, high bearing capacity and durability during driving. The type of foundation depends on the type of soil, elevation of the ground water table, and the type of loads to which a structure will be subjected. The primary function of steel piles is to improve the bearing capacity of a soil by means of side friction and end bearing capacity. The function of piles is to transfer load from the superstructure through weak compressible strata or water onto stiffer or more compact or less compressible soils or rock (Tomlinson, 1995). Piles are also used to transmit uplift loads when supporting structures subjected to overturning forces from wind and waves.

Steel piles are also referred to as “displacement piles” due to their ability to displace a volume of soil equal to the volume of the pile when close-end piles are used. Closed-end pipe piles have the bottom of the pile sealed with a steel plate or cast steel shoe. Pipes piles can also be driven with an open bottom end. In this case, when open-end pipe piles are driven, the soil enters the bottom of the pile creating a seal known as a “(soil) plug”.

The soil displaced by the pile installation creates very high normal and shear forces, which act against the pile wall in the soil-pile interface, that result in an increase in the pore water pressure and, therefore changes in the effective stress. It has also been observed that the pile bearing capacity of driven piles increases with time. This increase in bearing capacity of driven piles is in part developed by the thixotropic behavior of soil around the pile but there are other mechanisms involved. Thixotropic behavior relates time and undrained shear strength. Mitchell (1960) defined thixotropy as the process of softening caused by remolding, followed by a time dependent return to the original harder state at a constant water content and constant porosity.

This research project was geared towards the study of the behavior of driven pipe piles and H-piles over time in sites with similar stratigraphy, mainly clayey soils. The behavior of the soil that surrounds the pile was also studied in order to understand its effects during and after the pile installation. A wide range of steel piles that included steel pipes and H piles of different dimensions and geometry were driven and tested for this research project. These piles were located at three sites in areas adjacent to the University of Massachusetts Amherst campus.

This research included static tension-load tests to failure at different aging periods after installation, repeated tension-load tests until failure, field vane tests adjacent to the pile and at a predetermined distance away from the pile at different time increments, and laboratory experiments to attempt to reproduce and corroborate certain behavior observed in the field tests.

1.3 SCOPE OF RESEARCH

A countless number of piles that included steel pipe piles and H-piles of varying lengths, diameters and wall thicknesses were subjected to uplift static load tests. The piles tested herein were a combination of new piles and piles formerly tested during previous research assignments. The majority of these load tests were single uplift load tests performed at a predetermined aging times of 0 (immediate), 1, 10, 30, 100, 300 and 600 days, respectively. In many cases, various reasons (i.e. favorable weather conditions and time constraints) did not allow load testing piles on the predetermined times previously mentioned. Occasionally, a pile was let to age to be tested at one of the predetermined times previously mentioned or the same pile was tested repeatedly at different predetermined aging times.

The purpose behind these two cases was to compare the increase in bearing capacity when a pile was left undisturbed with increase in bearing capacity of a pile previously tested. Additionally, some of the piles were installed and subjected to repeated uplift load tests at the 10, 11, 12 and 13 days after installation. A series of field vane tests adjacent to the pile wall were performed on two “dummy” piles at determined aging times on the same pile. Dummy piles were almost identical in dimensions or geometry but with different bottoms, in order to observe any change in the undrained shear strength. For both the uplift load tests and field vane tests, the test dates were scheduled beforehand (and occasionally adjusted during the research interval) in order to accurately represent the short and long-term behavior of the piles and surrounding soil, and to avoid any conflict with weather changes due to seasons.

All piles installed and tested were located in three different sites around the University of Massachusetts Amherst campus in Amherst, Massachusetts. Since the goal of this research project was to investigate the role of clayey soils in the increase in bearing capacity, all three sites chosen for this research were based on previously obtained data for the characterization of these sites. Some field and laboratory work was performed to create engineering property profiles such as water content, Atterberg Limits and Undrained Shear Strength profiles. Recent and former data obtained in the field and laboratory were analyzed and compared to find correlations that helped explained the behaviors observed.

Other mechanisms that are believed to increase the bearing capacity are pore water dissipation that causes consolidation of the soil adjacent to the pile and mechanical aging of the soil. Some of these mechanisms where taken into consideration and studied as part of this research. It is known that when piles are driven into ground, the soil displaced consolidates the surrounding soil, resulting in greater friction against the sides of the piles, thus increasing their load bearing capacity. In addition, as driving a pile displaces the soil rather than removes it, pore water pressure dissipates and the earth lateral effective stress lateral increases. For this reason, undrained shear strength and water content profiles were obtained along the length of selected piles at different times.

1.4 ORGANIZATION

Chapter 1 presents the theoretical idea of and practical need for this research project, and has outlined the objectives that were set out for the study. The scope of the study is also mentioned in this chapter.

Chapter 2 presents the background theory, based primarily on published information, which provides the basis for the interpretation of the results obtained during this study. Also presented in this chapter are some of the current design methods.

Chapter 3 presents a description of the test sites used for this study. This includes the location of the test site, the general and regional surficial geology of the area, a characterization of the general subsurface conditions at the test site.

Chapter 4 presents a description of the in-situ and laboratory tests, methods, procedures and equipment used throughout this research project.

Chapter 5 presents the analysis of the pile installation and changes in the soil properties caused by installation disturbance. This chapter also provides a detailed discussion of the capacity behavior after installation with time after pile installation and subsequent tests.

Chapter 6 presents the conclusion drawn from observed pile and soil behavior and the analysis of the results from collected data.

Chapter 7 presents the references used for the preparation of this engineering research report.

CHAPTER 2

2 BACKGROUND THEORY

2.1 SOIL DEFORMATION DURING PILE DRIVING

Flaate (1972) makes reference to observations by Skrede (1967) of downward bending of clay layering next to the surface of a driven timber pile. The downward bending of light and dark bentonite layers due to penetration of a flat-ended model pile was observed by Rourk (1961). Flaate also makes reference to observations by Skaven-Haug (1940) of fluid clay that was squeezed up to the ground surface when a pile was driven into quick clay. Similar observations of fluid clay being squeezed out to the ground surface around the shaft of piles driven into Mexico City clay were reported by Zeevaert (1950). Evidently, the pile driving process can disturbs the soil adjacent to the pile and depending on the degree of disturbance, the soil will experience deformation that at the same time will produce changes in the properties of the soil.

2.2 CHANGES IN SOIL PROPERTIES SURROUNDING DRIVEN PILES IN CLAY

The pile driving process displaces soil predominately around the surface of the shaft along the pile and in some cases, vertical displacement along the pile may also occur, and beneath the toe. Randolph et al. (1979) states that in clay, pile driving can significantly alter the stress in the soil to an approximate distance of 20 pile radii. Yang (1970) indicates that in clay, soil for a distance from the pile of approximately one half of the pile diameter is completely remolded, and for a distance of approximately 1.5 pile diameters exhibits increased compressibility. Massarsch (1976) reported results of model tests in a box filled with artificially manufactured clay and proposed that the zone of soil disturbance extends approximately one pile diameter from the perimeter of the pile. The soil displacement was assumed to be caused by an expanding cylindrical cavity without taking into account soil movements at and below the pile toe. These phenomena occur with “displacement” piles, such as closed-end piles, but it could also occur with “non-displacement” piles, such as H-piles or open-end pipe piles, with an absent soil plug, but to a lesser extent.

Randolph et al. (1979) investigated the deformation pattern around a pile driven into clay using radiographic techniques. Ni et al. (2010) reported results from small-scale model tests in an artificial mixture of clay and oil by particle image velocimetry, from which the soil displacement pattern during pile installation was obtained. Based on the observations of various researchers from these model tests, six zones of disturbance have been identified (Figure 1). Even though, these zones are more marked when driving piles into soft clay, some of them are also found to play a role in medium to stiff clay.

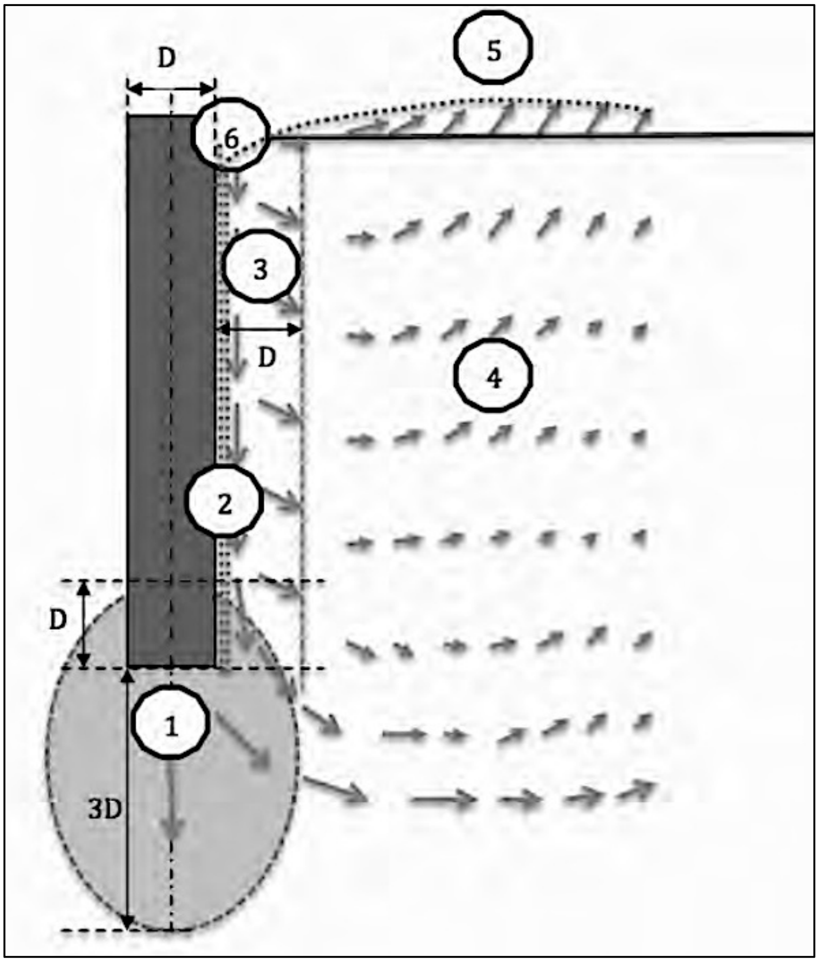

Figure 1. Sketch of the Displacement Field and Zones of Disturbance During Pile Installation (Massarsch & Wersäll, 2013).

Zone of Disturbance below the Pile Toe: This zone is considered the most important zone with regard to ground movement when the pile is driven into the soil. At the pile toe, a high-pressure bulb is developed during driving (Massarsch & Wersäll, 2013). This bulb moves gradually downward as the pile penetrates into the ground. The width of the bulb is approximately three pile diameters. In model studies reported by Randolph et al. (1979) and Ni et al. (2010), the zone of soil disturbance extends approximately one pile diameter from the pile shaft, one pile diameter upward and three pile diameters downward from the pile toe. At the perimeter of the bulb, the soil is displaced primarily in the lateral direction. As the pile toe passes a given level, significant lateral movement occurs, but thereafter only little further movement can be observed (Massarsch & Wersäll, 2013).

Smear Zone along the Pile: The relative movement of the pile wall against the adjacent soil creates this zone. However, model tests show that this zone is small. The structure of the soil is almost completely disturbed but the width of this smear zone is thin. In sensitive clays, this zone width can be of a few millimeters and is almost independent of the diameter of the pile (Massarsch & Wersäll, 2013).

Zone of Disturbance Adjacent to the Pile: This mechanical disturbance occurs within a zone of approximately one pile diameter from the pile wall. This zone of disturbance created behind the pressure bulb, in which the undrained shear strength of the soil is decreased (Massarsch & Wersäll, 2013). Only the progressive downward movement of the pressurized bulb at the pile toe causes this disturbance. At the perimeter of this zone, the soil is displaced primarily in the lateral direction (Massarsch & Wersäll, 2013).

Displacement Pattern Adjacent to the Zone of Disturbance: This zone is subjected to resistance caused by passive earth pressure, during the pile driving, resulting from the expansion of the pressure bulb of zone one (Massarsch & Wersäll, 2013). The displacement pattern in this zone is based on results of finite element analyses (Massarsch, 1976) and confirmed by field measurements (Massarsch, 1976 and Edstam, 2011). The flow pattern from the pile is initially lateral, but gradually rotates toward the ground surface.

Displacement Zone at Ground Surface: In this zone, the heave of the ground surface caused from pile driving is small in the next to the pile and reaches a maximum at a distance of about 0.3 to 1.0 times the pile length (Massarsch & Wersäll, 2013). This means that heave decreases with increasing depth.

Displacement Zone Adjacent to the Driven Pile: In some cases, it is common to find a gap or a small depression between the pile wall and the surrounding soil. This is caused as a result of the downward movement of the pile toe during the initial phase of driving (Massarsch & Wersäll, 2013).

2.3 EFFECTS OF PILE INSTALLATION

Pile installation has a prominent effect on the stresses and strains in the adjacent soil. Sand and clay behave differently, only clay soils are considered herein. When piles are driven into clay, it causes significant shearing and disturbance of the surrounding soil (Bergset, 2015). During installation, the soil fails due to the imposed shear stress at the interface of the pile and soil, and radial compression to the soil mass adjacent to the pile (Budhu, 2008). After pile installation, dissipation of pore water pressures, thixotropy and creep can influence an increase in the shaft friction along a pile by time.

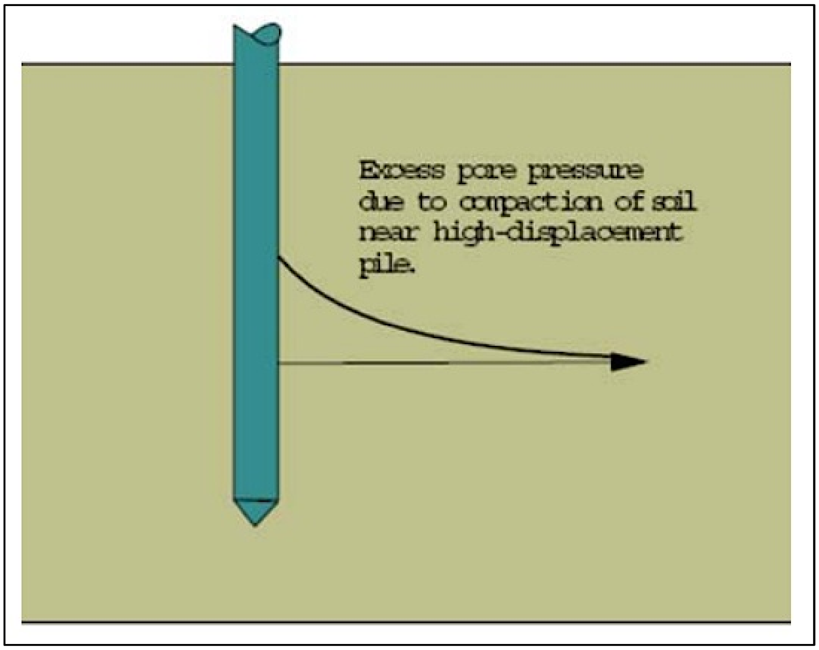

Figure 2. Excess Pore Water Pressure Dissipation After Pile Installation (C.C. Swan,).

As explained formerly, during driving of high-displacement piles, the surrounding soil will experience high compressive stresses that at the same time cause an increase in lateral effective stresses. The shearing experienced by the soil as the pile is driven, tends to dilate the soil generating very high lateral stresses that magnifies the contact between the soil and the pile. These increases in lateral stresses dissipate with time due to soil memory. For this reason, the skin friction capacity of "displacement" piles tends to be quite high. This explains why the majority of the soil disturbance, and the generation and dissipation of excess pore water pressure, happens alongside the pile shaft. Axelsson (2002), Bullock (1999) and Chow et al. (1998) believed that the set up occurs primarily due to an increase in shaft resistance. On the other hand, Fellenius et al. (2000) did not believe that set up occurs due to an increase in shaft resistance but to the stiffening of the soil. Meanwhile, studies carried out after set-up by Seed and Reese (1955) and Randolph, et al. (1979) attributed failure to under axial compressive load to the interface between the soil and the pile. Others, such as Karlsrud and Haugen (1986), Tomlinson (1956) and Yang (1956) believed that failure was caused by a shear zone within the soil.

2.4 PORE WATER PRESSURE (DISSIPATION AFTER PILE DRIVING)

As the soil around and beneath the pile is displaced and disturbed, excess pore water pressures are generated and, with a combination of the soil sensitivity, it causes a short-term decrease of the effective stress of the remolded soil (Massarsch & Wersäll, 2013). Many clay soils tend to be very sensitive to remolding and this leads to significant loss of undrained shear strength in the short term. Soderberg (1961) states that this increase in pore water pressure is constant with depth. Pestana et al. (2002) and Randolph, et al. (1979) agreed that the excess pore water pressure generated could exceed the existing overburden stress within one pile diameter of the pile. Decrease in excess pore water pressure is inversely proportional to the square of the distance from the pile (Pestana et al., 2002). The time the excess pore water pressure takes to dissipate is proportional to the square of the horizontal pile dimension (Holloway and Beddard, 1995; Soderberg, 1961), and inversely proportional to the soil's horizontal coefficient of consolidation (Soderberg, 1961).

Based on Long et al. (1999) and Wang and Reese (1989), piles with larger diameters take longer to set-up than smaller-diameter piles. As the excess pore water pressure dissipates, the surrounding soil consolidates and increases the effective stress of the disturbed soil and the set-up phenomena occurs as a result of this increase in undrained shear strength and increased lateral stress against the pile. In clay soils, with very low hydraulic conductivity, this excess pore water pressure dissipation could take months or even years. As this occurs, the surrounding soil consolidates and increases its strength. The final strength can exceed the initial undisturbed shear strength of the soil. This behavior reflects the thixotropic nature of many clay soils.

There are three phases that identified what happens with piles and the adjacent soil after their installation and up to the point where it reaches its maximum capacity or set-up. These phases could help explain which factors have significant roles and when they come into play. In some cases, these phases occur separately but in other cases, it has been believed that there is likely some overlap between successive phases. Meaning that set-up could be attributed to more than one phase at a specific time. In addition, different soils at different depths will be in different phases of set-up at a specific time.

2.4.1 PHASE I

During this first phase, the set-up rate corresponds to the rate of dissipation, which means that is not constant, linear or uniform with respect to the log of time for some period after driving. Is in this phase that remolded soil experiences an increase in effective and horizontal stress. This soil also consolidates and shows thixotropic behavior by gaining strength. Bullock (1999) was able to demonstrate that in this first phase, set-up accounts for a capacity increase in a matter of minutes after installation. The excess pore water pressure rate is known to be influenced by the soil type, permeability and sensitivity, and also, pile type and size. Low soil permeability and a large amount of soil displaced by the pile will result in longer duration of the dissipation rate.

During the pile installation process in clay soils, it has been observed that horizontal effective stress along the pile surface can be extremely small. But after consolidation, the effective stress ratio (the effective horizontal stress over the effective vertical stress, σ'h/σ'v) has been shown to equal 1.2 with the water content of the remolded soil lower (up to 13 percent) than the original intact clay (Karlsud and Haugen, 1986; Soderberg, 1961)

2.4.2 PHASE II

During this second phase of set-up, set-up rate corresponds to the rate of excess pore water pressure dissipation, and for most soils is also linear with respect to the log of time for some period after driving. In clay soils, logarithmically linear dissipation may continue for several weeks, several months, or even years (Skov and Denver, 1988). Azzouz et al. (1990) indicated that a 15-inch-diameter pile may require 200 to 400 days for complete consolidation. Whittle and Sutabutr (1999) state that for large-diameter open-end pipe piles, the time for dissipation of excess pore water pressure is controlled by the ratio of the pile diameter to wall thickness.

2.4.3 PHASE III

During this third phase, set-up rate is totally independent of effective stress and is related to the phenomenon of aging. Camp et. al. (1993), Long et. al. (1993) and Schmertmann (1991) define the aging phenomenon as a time-dependent change in soil properties at a constant effective stress that has a frictional and mechanical cause, and is attributable to thixotropy, secondary compression particle interference, and clay dispersion. Aging effects increase the soil's shear modulus, stiffness, and dilatancy, and reduce the soil's compressibility (Axelsson, 1998; Schmertmnn, 1981). Aging effects could increase the friction angle at the soil/pile interface (McVay, 1999). Aging effects can improve soils with significant organic content and increased at a rate approximately linear with the log of time (Schmertmann, 1999). Schmertamnn (1991) stated that thixotropic effects occur primarily at very low effective stresses under drained conditions in cohesive soils. In some cases aging may not occur (Schmertmann, 1991).

2.5 THIXOTROPIC BEHAVIOR OF CLAYS

Thixotropy can be defined as the process of softening caused by remolding, followed by a time dependent return to the original harder state at a constant water content and constant porosity (Mitchell 1960). In general, all soils show a decrease in strength when remolded and an increase in strength when left undisturbed, with the exception of insensitive clays and clays with very high water content. This behavior is mainly due to the reorientation of soil particles caused by the remolding action.

Thixotropic effects in remolded natural clays have been studied by Moretto, Skempton and Northey. Schlalek & Szegvari (1923) were the first to observe this phenomenon. They found that aqueous iron oxide gels have the property of becoming completely liquid just by shaking and solidified again after a period of time. Peterfi (1927) created the term “thixotropy” when he published the first paper that properly described this behavior. Freundlich (1935) published a book entirely devoted to this subject called 'Thixotropie'. He also was the first person to officially use this term in the title of a paper when he described the flow properties of aluminum hydroxide gels.

Clay particles can be arranged in two types of structures: flocculated or dispersed. In a flocculated structure, clay particles are in an edge-to-face arrangement (Figure 3). Since clay particles are negatively charged on the face and positively charged on the edge, clay particle’s edges and faces tend to attract themselves. On the other hand, when a clay sample is remolded, its natural structure is destroyed forming a dispersed structure in which clay particles are arranged in parallel. With time, these clay particles will rearrange themselves in a flocculated structure if the sample is not disturbed. The increase in strength will continue if the soil is not remolded, until it reaches an equilibrium state as a flocculated structure. In general, attractive forces caused by positive and negative charges are broken when a clay sample is remolded. In a face-to-face arrangement clay particles repel each other, not allowing contact among them, which results in a relatively weaker clay soil. Studies by, Boswell (1949), Kruyt (1952) and Seed & Chan (1957) suggested that thixotropy may be a common event in clay-water systems. Thixotropic effects can result in a strength increase of up to 100% or more after remolding.

The thixotropic behavior of soils refers to the strength of the soil, which is the maximum or ultimate stress the soil can sustain without failing. This is measured as shear strength; the undrained shear strength of soils is divided into: undisturbed shear strength and remolded shear strength. The undisturbed shear strength is when soils samples are left untouched for an indefinite amount of time. Is in this state that they exhibit the increase in strength with constant water content and volume. Remolded shear strength represents the shear strength of a soil sample measured right after being remolded. At constant water content and volume, it should be constant, namely, independently of aging time.

Thixotropy is the phenomenon that describes the gain in undrained shear strength with time of the soil surrounding the pile after being remolded during pile installation. This thixotropic behavior of the clay is believed to be the main factor in the long-term development of capacity after pile installation. Soil that has been subjected to aging, thixotropic hardening and/or cementation will have a greater strength and stiffness in its intact state than the same soil that has not been subjected to such processes or has had such effects removed due to a break-down of the micro-structure. The effects of consolidation and aging processes on the development of shear strength were described by Leroueil et al. (1979) and by Leroueil and Vaughan (1990).

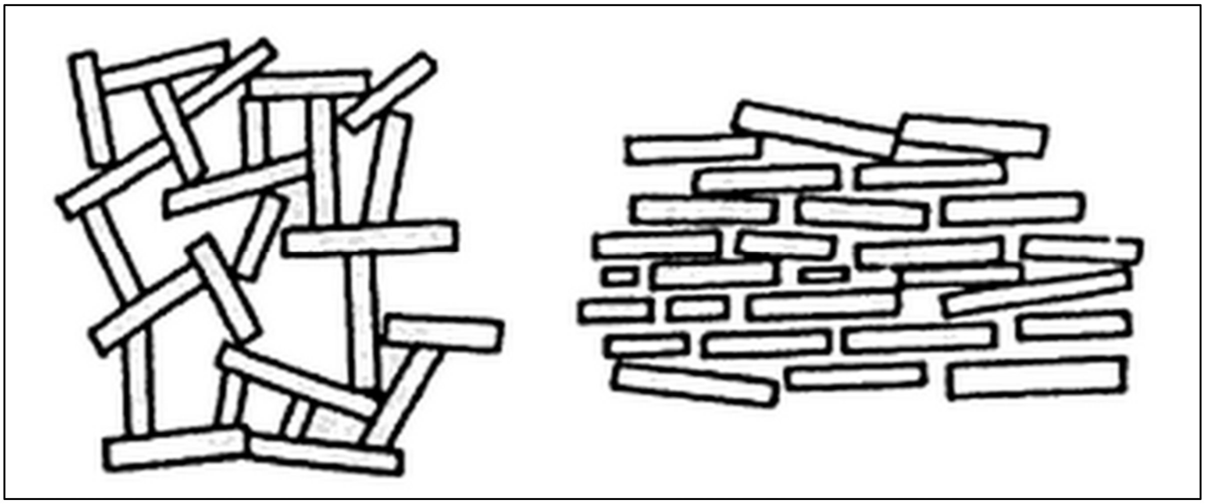

Figure 3. Clay Structures: Flocculated Structure (Left) and Dispersed Structure (Punmia 2005).

The thixotropy effect means that clay may exhibit strength after installation that is higher than the remolded shear strength, even before pore pressure dissipation occurs. It is generally assumed that strength gain from thixotropy and pore pressure dissipation occurs independently of each other (Bergset, 2013). The two processes are not additive, as the interaction between thixotropy and effective stress is unknown (Andersen and Jostad, 2002).

2.6 EFFECT OF SOIL TYPE

In cohesive soils, the undrained shear strength of the disturbed and consolidated soil around the pile has been found to be 50 to 60% higher than the soil’s undisturbed shear strength (Randolph et al., 1979; Seed and Reese, 1955). At distances from the pile, long-term soil strength decreases with the log of the pile radius, until it equals the soil's initial strength at approximately 10 pile radii (Randolph et al., 1979). Limiting values of the shaft resistance have been found to agree closely with shear strength properties of remolded, reconsolidated clay (Karlsrud and Hauger, 1986). Randolph (1979) states that stress changes around a pile after installation in clay are nearly independent of the soil's overconsolidation ratio (OCR). Whittle and Sutabutr (1999) state that reliable set-up predictions for large diameter open-end pipe piles depend on accurate determination of OCR and hydraulic conductivity. Soft clays have been found to set-up more than stiff clays (Long et al., 1999).

2.6.1 RANDOLPH & WROTH METHOD (RANDOLPH & WROTH, 1978)

This method was developed in order to explain the axial load transfer process between pile and soil. In this method, the shaft and base behaviors are studied separately. An imaginary horizontal plane AB at the depth of the pile base separates base and shaft (Figure 4a). Thus, it is considered that above that plane the soil deforms due to the pile shaft only, and that below the plane the soil deforms due to the pile base only (Figure 4b). The deformation above and below the plane is not compatible and that allows for interaction between the upper and lower layers of soil. The soil is considered to be linear elastic. Thus, the effects of installation (residual stresses) are ignored. As explained before, it is also assumed that the parameters of the soil are not affected by the installation of the pile.

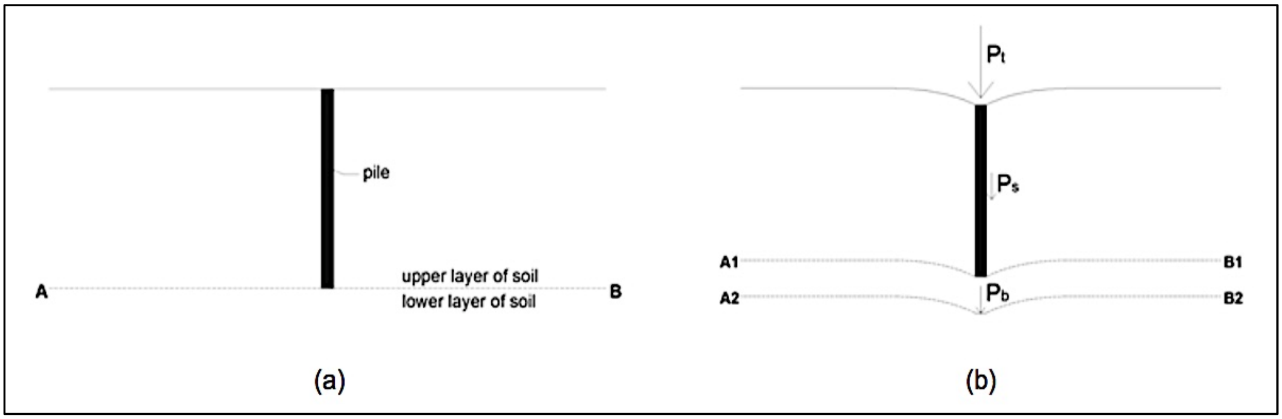

Figure 4. (a) Upper and lower soil layers; (b) independent deformation patters of the upper and lower soil layers (Ribeiro, 2013) and adapted from Randolph & Wroth (978).

2.7 EFFECT OF PILE TYPE

Pipe piles are divided into non-displacement and displacement piles, respectively, depending on the installation method. Driven piles are considered displacement piles that at the same time are subdivided into:

- small displacement and
- large displacement piles

Open-end pipe piles and H-piles are considered small displacement piles and closed-end pipe piles are considered large displacement piles.

Closed-end pipe piles have a plate welded to the lower end of the pile (Figure 5) in order to develop end-bearing capacity. During driving, the closed bottom of a closed-end pipe piles will displace, remold and consolidate a (minimum) volume of soil that will be approximately equal to the embedment volume of the pile. This closed-end pipe piles develop their capacity from the unit-side friction and the toe resistance.

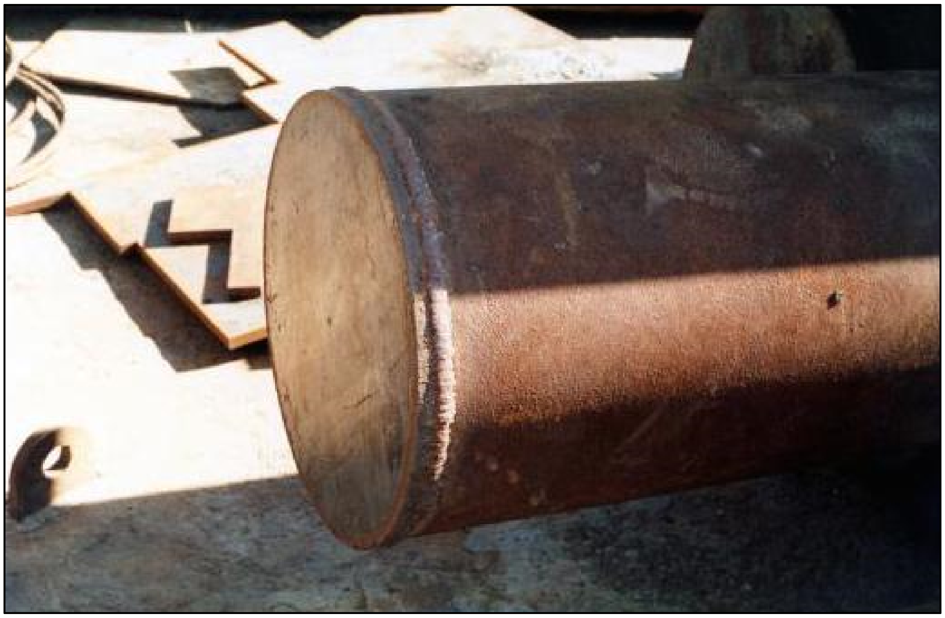

Figure 5. Closed-End Pipe Pile

Open-end pipe piles have an open bottom that allows the soil to enter the pile during driving. When open-ended pipe piles are installed, a limited amount of soil is displaced, remolded and consolidated due to their limited cross section. The volume of soil displaced by an open-end pipe piles depends on the wall thickness (difference between the inner diameter and outer diameter) of the pile. The variation of wall thicknesses can have a substantial effect on pipe piles of the same diameter (Malhotra, 2007). Thicker walled piles tend to form plugs at shallower depths of penetration. Open-end pipe piles rely on unit-side resistance as their main source to develop capacity but they can also develop some capacity from the soil that enters the pile during the initial installation.

When an open-ended pipe pile is driven into the ground, soil enters inside of the pile. If the pile penetration depth is equal to the soil plug length, this behavior is typically referred to as “fully cored” or “fully plugged”. As the pile is driven deeper into the soil, the soil friction on the inside of the pile wall increases until a “soil plug” is formed, which may prevent or partially restrict additional soil from entering the inside of the pipe (Gudavalli, 2013). This behavior is referred to as “plugging”, and the length of soil plug is less than the pile penetration depth. The formation of a soil plug inside the pile will make the open-ended pile behave more like a closed-ended pile during further penetration (Figure 6) . A plugged pile will displace more soil at the bottom just like a close-ended pile. Paik, et. al. (2009) explained that a plug not only benefits the bearing capacity of the pile, but can also increase the unit side resistance (Figure 6). When both types of pipe piles are compared, open-end pipe piles can be installed more easily at the required penetration depth for tension capacity (Figure 7).

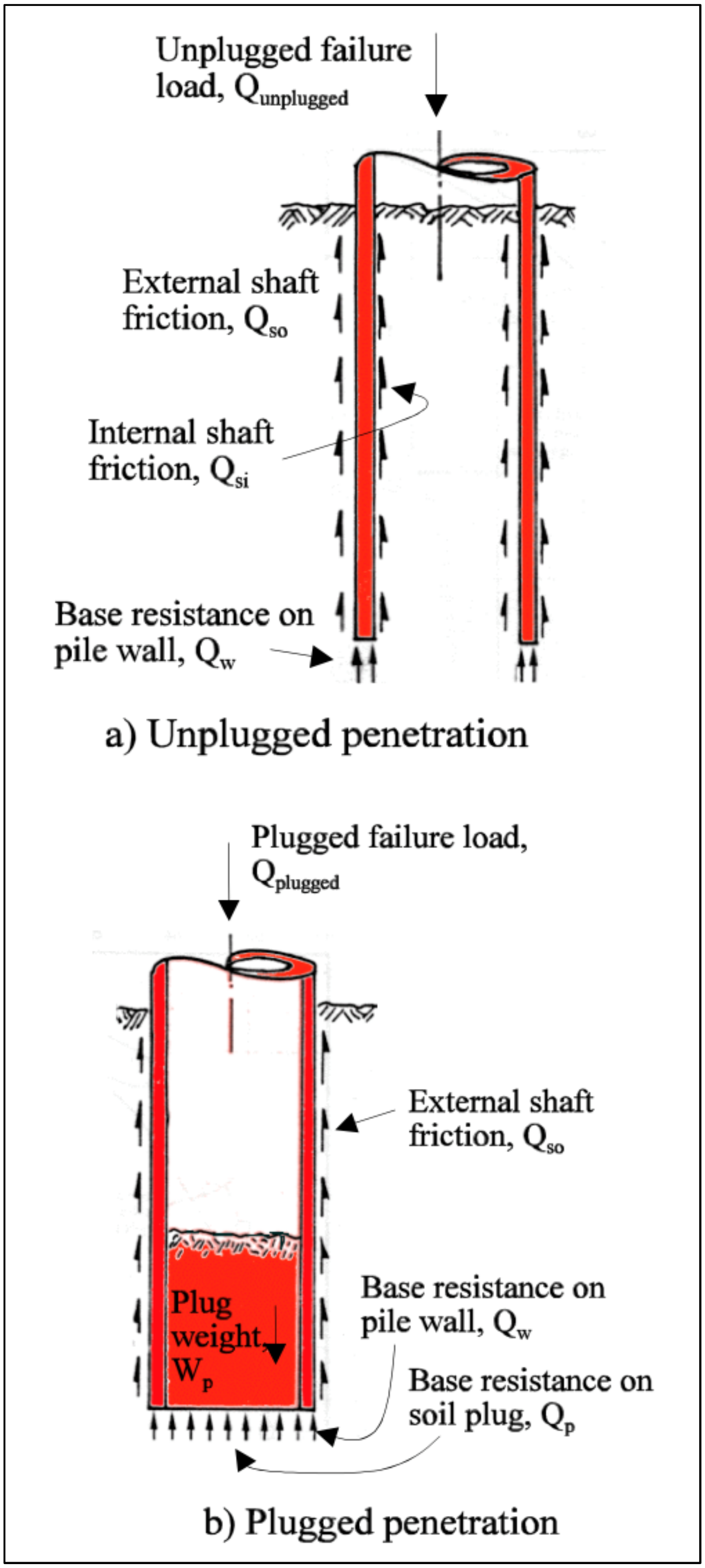

Figure 6. Penetration Mechanisms: (a) Unplugged and (b) Unplugged, and Axial Force Components Under Load (White, 2000).

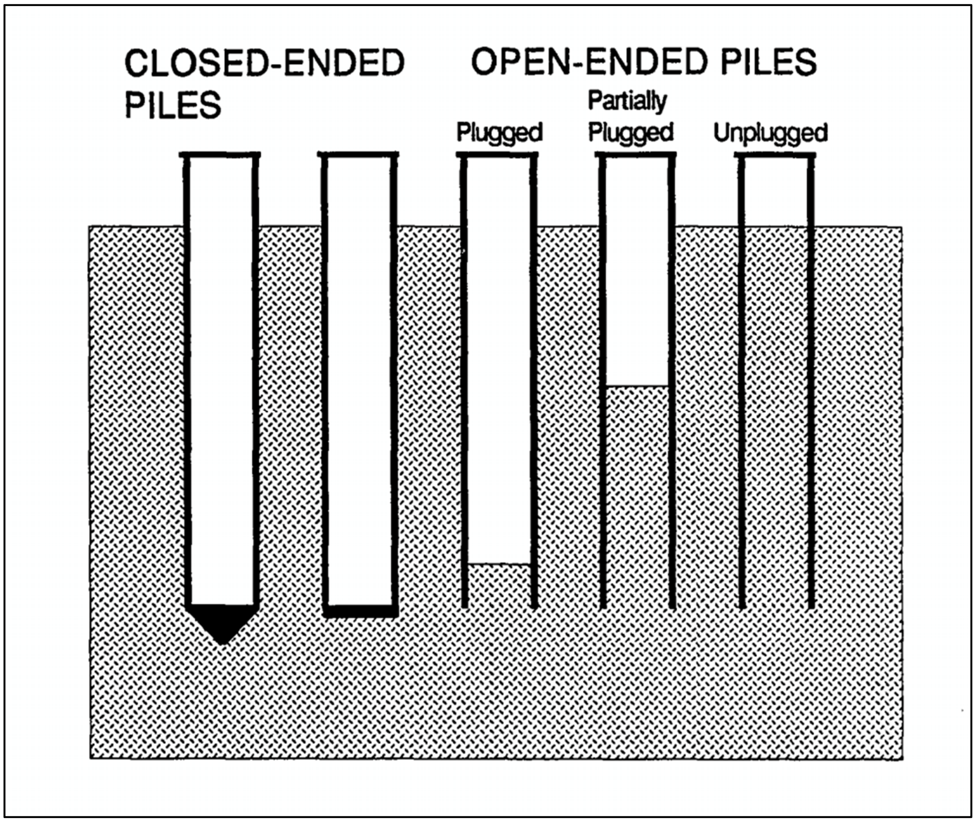

Figure 7. Comparison of Open and Closed-End Pipe Pile Penetration.

Camp and Parmar (1999) reported that the set-up rate decreases as the pile size increases. Long et al. (1999) offered that there is no clear evidence of difference in set-up between small-and large-displacement piles. Finno et al. (1989) found out during installation, pipe piles generated more excess pore water pressures than H-piles, but after a time equal to 43 weeks the unit shaft resistances for both piles was very similar.

2.8 ESTIMATION OF THE CAPACITY OF DRIVEN PILES THROUGH EQUATIONS

Empirical relationships have been used for estimating and predicting set-up capacity. Skov and Denver (1988) presented the most popular equation used today. This relationship models the pile setup as linear with respect to the log of time. They proposed a semi-logarithmic empirical relationship to describe set-up as:

$$Qt/Qo = 1 + A[\log(t/to)]$$ **Equation 1**

where

Qt = axial capacity after driving,

Qo = axial capacity at time to,

A = a constant, depending on soil type, and

to = an empirical value measured in days.

t = time in days.

In this relationship, to (initial time) is the time at which the rate of excess pore water pressure dissipation becomes linear (uniform) with respect to the log of time. In practice, multiple capacity determinations carefully timed are required in order to estimate to. These determinations are not always practical, and for this reason it is back-calculated from field data, or obtained from empirical relationships in the literature. to is a function of soil type, and pile size. Camp and Parmar (1999) stated, the larger the pile diameter, the larger to. Using H-piles, Camp and Parmar (1999) empirically determined to equal to 2 days, but stated that to equal to 1 day seems to be reasonable. Long et al. (1999) recommended using to equal to 0.01 day. Svinkin et al. (1994) used to equal to 1 to 2 days. Bullock (1999), and McVay (1999), recommended standardizing to equal to 1 day.

The A parameter is a function of soil type, pile material, type, size, and capacity (Camp and Parmar, 1999; Svinkin et al., 1994; Svinkin and Skov, 2000), but is independent of depth, and pore water pressure dissipation (Bullock, 1999; McVay, et al., 1999). Just like to, the A parameter is also back-calculated from field data, or obtained from empirical relationships in the literature. Chow (1998) reported that data from 14 researchers indicated values of A ranged from 0.25 to 0.75. Studies by Axelsson (1998) yielded A values ranging from 0.2 to 0.8. Data from studies by Bullock (1999) yielded an average A value of 0.21, and suggests that in the absence of any set-up testing it would be conservative to use an A value of 0.2 for all depths in all soils. It should be noted that determination of A, whether from field data or data in literature, is a function of the value used for to, and visa-versa; these 2 variables are not independent (Bullock, 1999).

Another widely used relationship, but less popular than the one presented by Skov and Denver (1988), is an equation developed by Svinkin et al. (1994):

Qt=1.4QEODt0.1(upper bound) **Equation 2**

Qt=1.025QEODt0.1 (lower bound) **Equation 3** where

Qt = axial capacity at time t measured in days,

QEOD = axial capacity after driving, and

t = any time after driving measured in days.

There are many other equations that have been proposed by several researchers that attempt to predict the capacity of a pile as a function of time after driving. Some of the most common equations are presented in Table 1.

Table 1. Proposed equations to estimate future pile capacity.

Huang (1988), for soft-ground soils of Shanghai: $Qt = QEOD + 0.236(1 + \log(t)(Qmax\text{-}QEOD)$ Qt = at time t measured in days QEOD = axial capacity at time t, measured in days, after driving t = any time after driving measured in days	**Equation 4**
Guang-Yu (1988), soft fine-grained soils: $Q14 = (0.375St + 1)QEOD$ Q14 = axial capacity at 14 days, QEOD = axial capacity after driving St = sensitivity of the fine-grained soil	**Equation 5**
Bogard and Matlock (1990): $Qmax = QEOD\ [(0.2 + 0.8((t/T50)/(1 + t/T50)))]$ Qmax = maximum axial capacity QEOD = axial capacity after driving t = any time after driving measured in days, and T50 = time required to reach 50% of axial capacity	**Equation 6**

Long et al. (1999): $Qt = 1.1QEOD\ t\alpha$ Qt = at time t measured in days QEOD = axial capacity after driving, t = any time after driving measured in days, and α = exponential coefficient (upper bound is 0.18 and lower bound is 0.05	**Equation 7**
Skov and Svinkin (2000): $Ru(t)/REOD - 1 = B[\log10(t) + 1]$ Ru = maximum axial capacity REOD = axial capacity after driving, and t = any time after driving measured in days.	**Equation 8**

2.8.1 DESIGN METHOD TO ESTIMATE UNIT SIDE RESISTANCE

The capacity of driven piles in tension is developed from the unit side resistance, fs. Since there is change in the shear strength of soil adjacent to the pile after the installation of the pile, the unit side resistance will be a function of the resulting remolded shear strength and thixotropic effects of the soil (Vanapalli and Taylan, 2012). The unit side resistance analysis is based on the principle of sliding friction, and is most accurately performed using effective stresses (Coduto, 2001). The side resistance of the piles can be back-calculated from equations used to estimate the ultimate capacity. The unit side resistance is a function of the pile adhesion factor and can be theoretically calculated by multiplying the pile surface area by the capacity:

$Qult = fsAs$ **Equation 9**

where:
Qult = maximum axial capacity
fs = unit side resistance
As = pile surface area

In fine-grained soils, the skin friction, fs along the length of the pile is a key parameter that is required in the estimation of the load bearing capacity of pile foundations. The conventional α, β and λ

methods are used in engineering practice for estimating the ultimate shaft bearing capacity of single piles. Currently, the Beta and Alpha methods are the most common methods to predict the unit side resistance of piles in clays and are based on soil properties.

2.8.1.1 The Beta (β) Method (ESA)

The first methodology use to the estimate the unit side resistance, fs, of piles in clays, called Beta Method, was proposed by Burland (1973). This method is useful to determine the unit side resistance of a pile that is loaded at a relatively slow rate to achieve drained conditions. Because the shear strength of soils associated with cohesion decreases significantly due to the remolding and softening effects during pile installation, the effective cohesion can be neglected along the pile shaft. The Beta Method utilizes the horizontal effective stress and a factor, β that is determined from soil properties (Coduto 2001). The unit side resistance for such conditions can be expressed as follows:

$$fs = \beta\sigma'v$$ **Equation 10**

where:
fs = unit side resistance
β = beta factor
$\sigma'v$ = vertical effective stress along length of the pile

The design β values are obtain by back-calculating them from full-scale static load tests and correlating these values with soil properties and foundation type (Coduto, 2001).

2.8.1.2 The Alpha (α) Method (TSA)

The second methodology to predict the unit side resistance, fs, of piles driven in clay soil, known as the Alpha Method, was proposed by Tomlinson (1957). This method is useful to determine the unit side resistance of a pile that is loaded at a relatively fast rate to achieve undrained conditions. The ultimate shaft resistance can be estimated for these loading conditions extending the TSA (Vanapalli and Taylan, 2012). In other words, the ultimate shaft capacity of a pile is dependent on the undrained shear strength of the soil. The unit side resistance for such conditions can be expressed as follows:

$fs = \alpha Su$ **Equation 11**

where

fs = unit side resistance

α = adhesion factor

Su = Undrained Shear Strength of the Soil Adjacent to the Pile before Driving

This method is the most common approach used, although, is less precise than the Beta Method. The Alpha Method has been used much more widely and thus has the benefit of a more extensive experience base. The formulation of the Alpha Method and the term adhesion factor give the mistaken impression that side-friction resistance is due to a "gluing" effect between the soil and the pile (Coduto, 2001). In this method, the adhesion factor, α, was determined empirically from full-scale load test results, as shown in Figure 8.

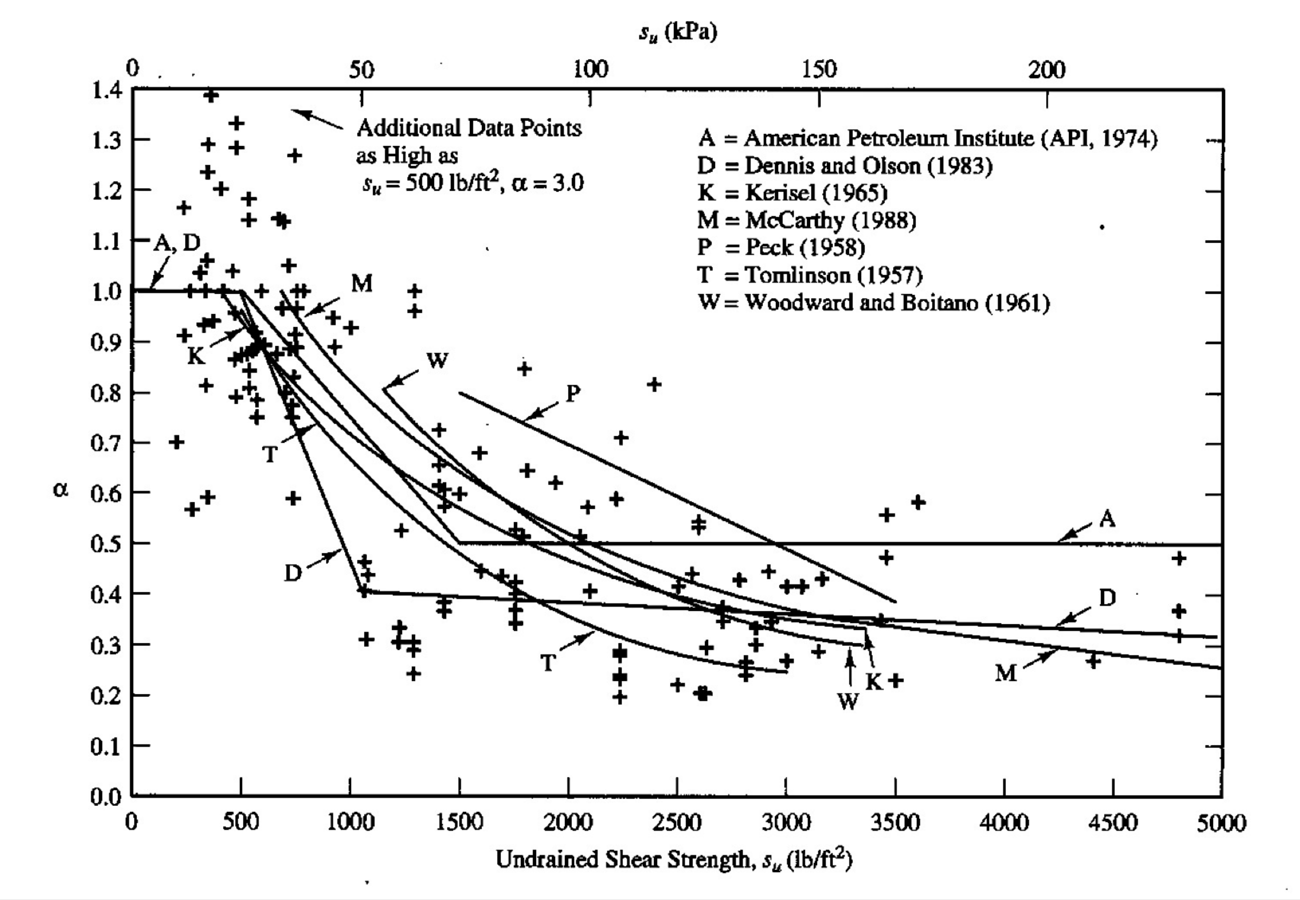

Figure 8. Back-calculated α values from full-scale static load tests, along with several suggested functions (Coduto, 2001).

Although the α- and β-method are two separate methods, they are to some extent correlated through the classical relationship between normalized undrained strength and the overconsolidation ratio (Bergset, 2013).

No clear evidence is found by Karlsrud (2012) regarding any difference in the ultimate shaft friction for closed-ended and open-ended piles. Nor is any difference in resistance found between loading in compression or tension. This is in agreement with most other research carried out in the past. The pile dimensions, including pile length or flexibility, is also found to not affect the local ultimate shaft friction by Karlsrud (2012). However, the length or pile flexibility has a significant effect in several other proposed design methods.

2.9 SOIL PLUG OF OPEN-END PIPE PILES AND H-PILES

Soil plugging in open-ended piles is a complex problem, which depends on many factors relating to pile, soil and even hammer properties. Kishida and Isemoto (1977) and, Klos and Tejchman (1977) recognized that soil-plugging behavior of open-ended pipe piles is concern. Despite this, the efforts to measure the degree of soil plugging have been very rare. The two most widely used equations to measure soil plugging are Plug Length Ratio (PLR): defined as:

$PLR = L / D$ **Equation 12**

where

L = length of soil plug

D = pile penetration depth

Table 2 presents the equations to calculate the Incremental Filling Ratio (IFR) and Final Filling Ratio (FFR).

Table 2. Incremental and Final Filling Ratio

$IFR = dL/dD$: dD = increment of pile penetration depth D = pile penetration depth dL = increment of soil plug length corresponding to an increment of pile penetration depth dD	**Equation 13**

FFR = Average of IFR recorded over the last three diameters of pile penetration	**Equation 14**

By definition, IFR is a first derivative of PLR, meaning that IFR is a slope of curve of plug length versus pile penetration depth plot (Gudavalli, 2013).

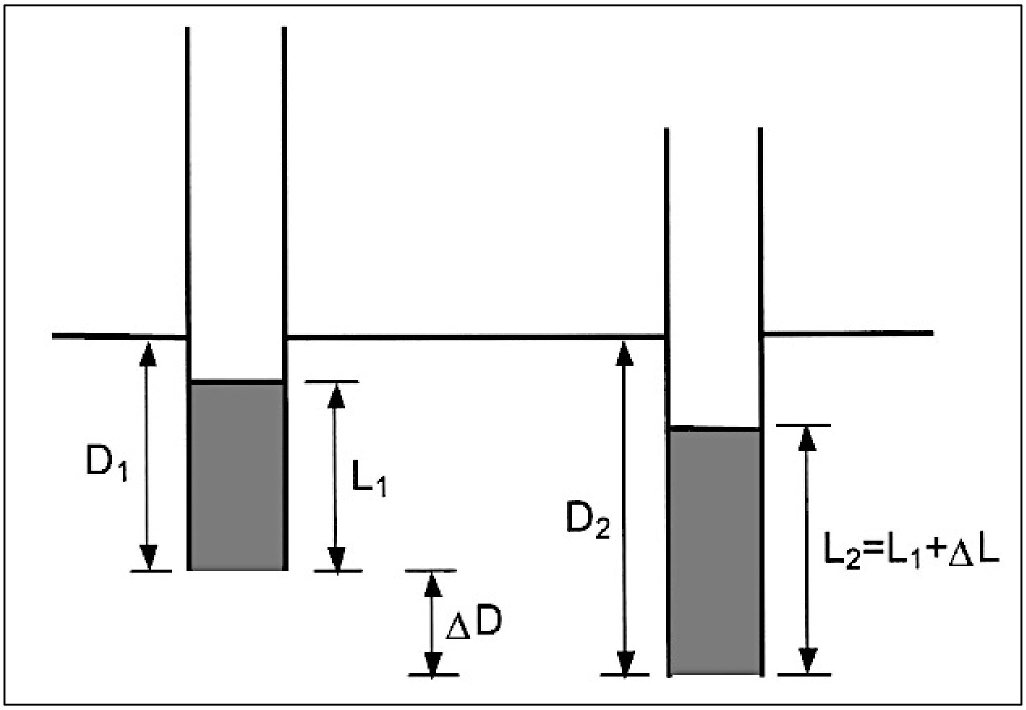

Figure 9. Definition of Incremental Filling Ratio and Plug Length Ratio (Paik and Salgado, 2003).

H-piles are small-displacement piles, and their load response is likely to be in between those of non-displacement and small-displacement piles. The plugging of H-piles is observed more often in coarse-grained soils rather than fine-grained soils. A plug of clay, similar to that of open-ended pipe piles, may be formed within the flanges of H-section piles. Poulos and Davis (1980) stated that capacity of piles may be assumed as the entire surface area of the H-pile where the soil-pile interface contact perimeter, this includes the web and flanges or the outer boundary of the H-pile cross section. Whether or not the soil in the space between the flanges will behave as a plug and therefore become an integral part of the pile depends to a great extent on the soil type (Seo et. al., 2009).

The relation of differing diameters and wall thickness for open-end pipe piles is known as the Area Ratio:

$$\boldsymbol{A_{RP} = 1 - \left(\frac{{D_1}^2}{{D_o}^2}\right)}$$ **Equation 15**

where

$\boldsymbol{A_{RP}}$ = Area Ratio of Pipe Piles

DI = Inner Diameter

DO = Outer Diameter

The relation of differing web depths and wall thickness for H piles is known as the Area Ratio:

$$\boldsymbol{A_{RH} = 1 - \left(\frac{A_P}{A_T}\right)}$$ **Equation 16**

where

$\boldsymbol{A_{RH}}$ = Area Ratio of H Piles

DI = Inner Diameter

DO = Outer Diameter

2.10 INFLUENCE OF REPEATED LOADING OF PILES ON CAPACITY

Karlsrud and Haugen (1985) tested a single pile several times on stiff overconsolidated clay of high plasticity index, but with different times of reconsolidation in between tests. From their investigation, it was observed that the present capacity of a pile is affected by previous loading influences. The difference in the capacity developed by the pile after being tested several times and the expected capacity of the pile is refers as the “pre-shearing effect”. This explains the effect on previous loading on present capacity. The pre-shearing effect is a result of remolding the soil during driving and remolding it again during consecutive load tests (Khalili, 2013). Figure 10 presents the static capacities from these tests as a function of time after pile installation and clearly show the effect of pre-shearing.

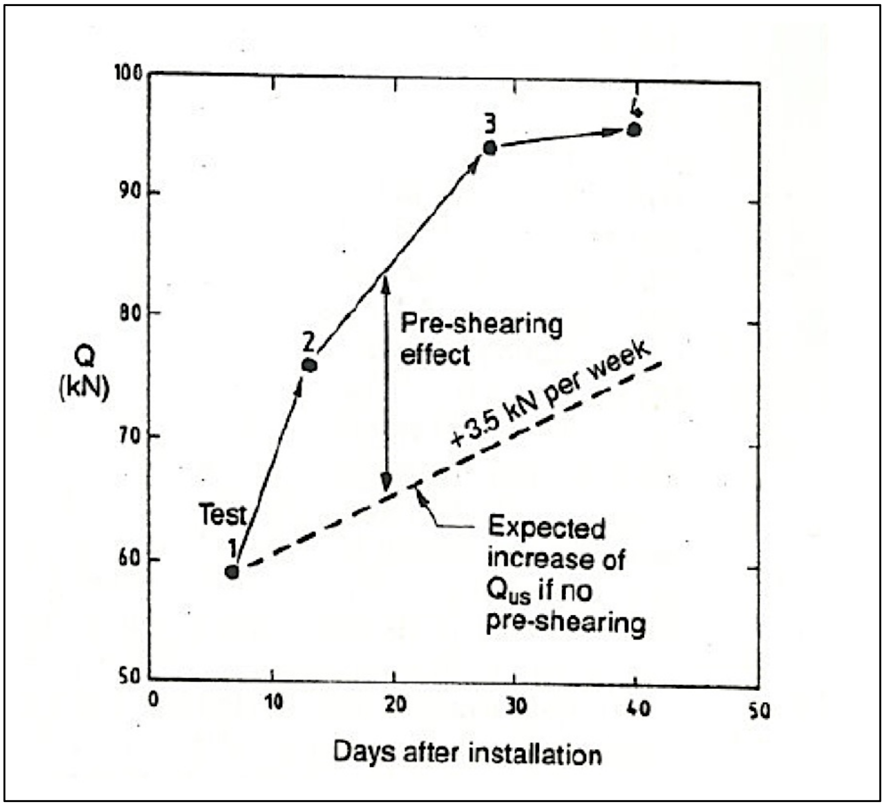

Figure 10. Influence of Static Pre-Shearing on Static Pile Capacity (Karlsrud and Haugen, 1985).

Repeat loadings of piles embedded in clay may cause a progressive deterioration of the soil adjacent to the ground surface. Shearing distortion may cause a reduction in the shear strength and stiffness of clay. If a soil disturbed by a repeated loading is given a rest period, an increase in strength and stiffness may occur, but such an occurrence will depend on the consolidation and thixotropic properties of the clay as for vertical loading (Prakash and Sharma, 1990). Kishida et. al (1988) installed model piles in a normally consolidated soft clay that were load tested in repeated times. They observed that the pile capacity decreased and became close to a constant value and the average excess pore water pressure increases and became close to a constant value with the decrease in the bearing capacity.

Laboratory and field data has shown that repeated loading may cause a reduction in load capacity and an increase in settlement of piles (Poulos, 1980). Piles tested by Bea et. al (1980) showed that the load capacity was reduced between 10% and 20%. These data also showed a trend between the increasing pile head settlement and the increasing number of cycles and level of cyclic load level (Poulos, 1980).

As previously explained, two main mechanisms may be proposed to explain the effects of cyclic loading on piles in clay:

- changes in pore pressure in the soil adjacent to the pile, and
- realignment of the clay particles adjacent to the pile

Puech et. a1 (1980) found no significant changes in pore pressure during cyclic loading of a pile in loose compressible silt, but some reduction in skin friction appears to have occurred. A small-scale field test by Grosch and Reese (1980) on a pile in soft clay showed an overall decrease in pore pressure during cycling, prior to or together with a decrease in skin friction. Fluctuations in pore pressure began immediately on initiation of reduction in skin friction capacity and were greatest during the periods of greatest reduction. Failure was considered to be located entirely in the soil within a zone of about 2mm width and not at the pile-soil interface. The soil in this zone was over-consolidated due to pile insertion and subsequent reconsolidation, and hence was considered to dilate as the clay particles rotate and become realigned. Grosch and Reese considered that the destruction of interparticle bonds and realignment of the soil structure parallel to the direction of shear strain as the primary mechanism of cyclic load-transfer reduction.

2.11 TIME AND LOADING RATE EFFECTS

Bjerrum (1973) and Bea et a1 (1980) have summarized the result: of field tests on piles in clay which clearly indicate that the rate of application (or the time to failure) has a significant effect on pile load capacity. The more rapid the loading rate, the greater the pile capacity, and an approximately linear increase in load capacity with the logarithm of loading rate is observed. Typically, the load capacity increases by between 10 and 20% per decade increase in loading rate. Laboratory tests on model piles in clay also confirm these values (Poulos, 1981a). Similar effects have been noted on pile stiffness by Gallagher and St. John (1980) and Kraft et. a1 (1981) in their field tests.

In cases where rapid cyclic loading is being applied to a pile, the beneficial effects of high loading rate may be offset by the degradation of load capacity due to the cycling of the load, and the ultimate load capacity may be less than or more than the ultimate static capacity. For example, in the tests conducted by Kraft et. a1 (1981), the combined effects of one-way cycling and rapid loading rate resulted in a load capacity which exceeded the static value by up to 20%. Thus, it is necessary to consider both cyclic and rate effects simultaneously in order to assess the ultimate load capacity of piles.

CHAPTER 3

3 SITE GEOLOGY & DESCRIPTION

3.1 INTRODUCTION

All three sites involved in this study are located in the town of Amherst, Massachusetts, on the premises of the University of Massachusetts Amherst campus.. These sites, which are lands owned by the University of Massachusetts Amherst, were named or referenced as Hadley Horse Farm site (HHF), Department of Energy site (DOE) and Taylor Field site. A complete description of these sites will be presented in this chapter. These descriptions will include specific location, geology, stratigraphy and general characteristics. Subsurface explorations were carried out at all three locations by digging out boreholes, and taking samples at 1 foot intervals, using a hand auger in order to obtain a visual description of each site and construct profiles of different profiles of engineering properties.

3.2 GEOLOGIC HISTORY OF MASSACHUSETTS

New England's geology was formed due to ice sheets that once covered this region. Due to retreat of these ice sheets or glaciers, many rivers were formed and the largest one was Lake Hitchcock. Glacial Lake Hitchcock started forming approximately 15,000 calendar years ago due to a natural debris barrier at Rocky Hill, Connecticut (DeGroot and Lutenegger, 2005). The melted water from the Laurentide Ice Sheet formed this river during the Pleistocene period. At one point, Lake Hitchcock extended from Rocky Hill, Connecticut to West Burke, Vermont with an approximately length 200 miles, a width of 20 miles and was 135 feet above sea level (Figure 11). A natural dam formed at Rocky Hill, Connecticut, that was approximately 1 mile wide blocked the water in the valley. When the water level of Lake Hitchcock rose, it flowed over Rocky Hill dam partially draining the glacial lake until water levels stabilized. The water that overflowed the dam created an incision where streams drained the watershed. As a result of these streams, sediments from both the surroundings highlands and the glacier itself got deposited into lake (Daukas, 2007). These deposits consisted of sand and gravel, and finer sediments that once were suspended settled into varved clay layers.

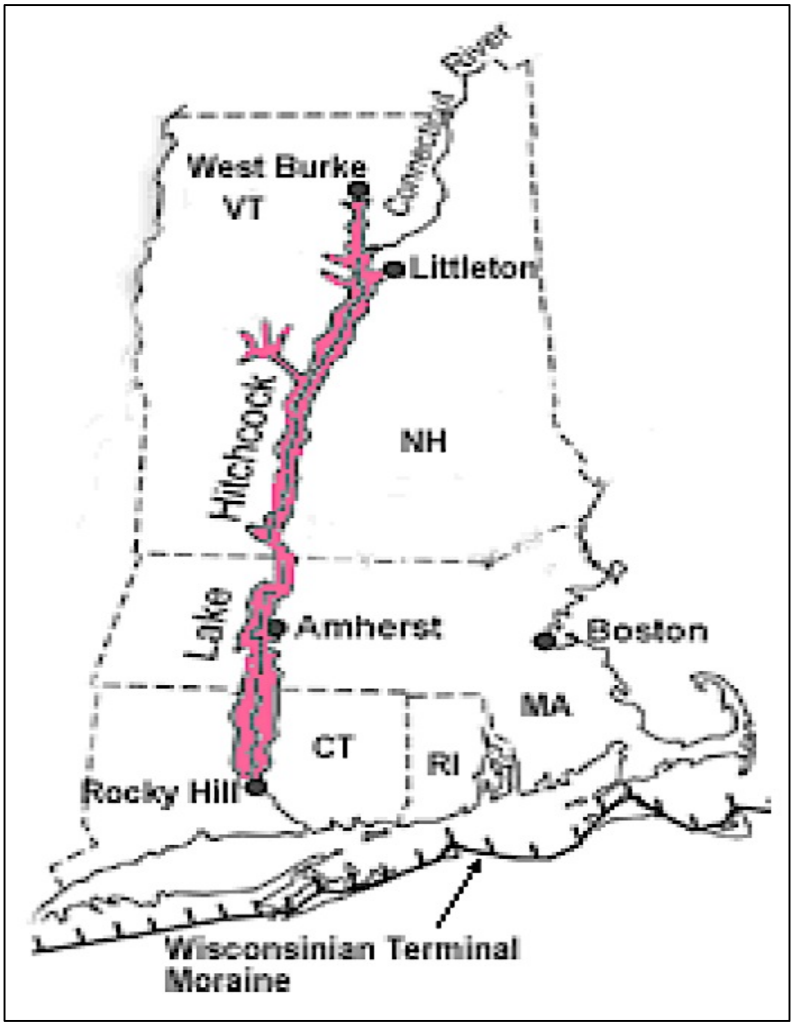

Figure 11. Amherst/Hadley Location with respect to Lake Hitchcock Extension (Daukas, 2007).

3.2.1 CONNECTICUT VALLEY VARVED CLAY (CVVC)

CVVC is a lacustrine soil deposit. The primary bedrock source materials for CVVC were Triassic rocks in the Connecticut River Valley and distant igneous and metamorphic rocks to the north and east (Ladd and Wissa, 1970). When the glacier retreated as far north as the Chicopee and Westfield Rivers, more sediments, from the igneous, uplands was able to flow directly into the glacial lake forming fluvial landforms (Daukas, 2007). Finally, the rest of the Lake Hitchcock was completely drained when the dam at Holyoke Range formed by sediments also failed. Once the Wisconsinian Ice Sheet retreated, the soil on the northern region of the region, once covered by this ice sheet, rebounded. With time melting glacial ice made way into the valley and created the Connecticut River (Daukas, 2007).

During the summer months the combination of active water conditions in the lake and low cation concentration of the cold lake water kept the clay particles in suspension and only the fine sand

and silt particles deposited on the lake bottom. During the winter months the lake surface froze and the calmer water conditions allowed clay particles to settle to the lake bottom (DeGroot and Lutenegger, 2005). The combination of these two annual layers, of a silt-sand layer and a clay layer, formed on the bottom of the lake composes one varve (Figure 12).

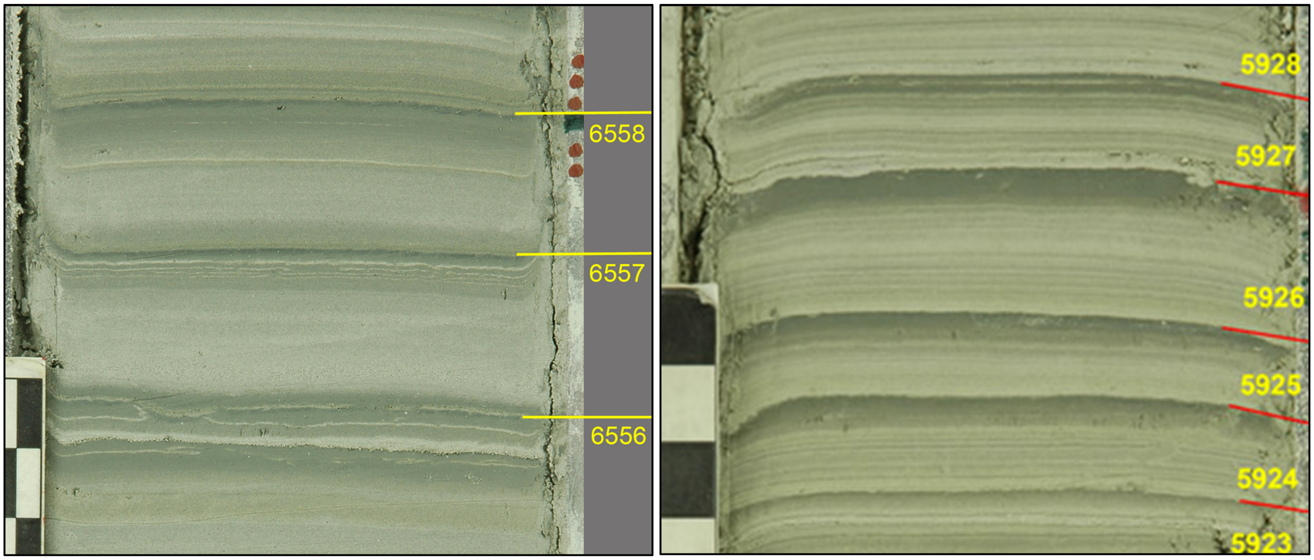

Figure 12. Examples of Connecticut Valley Varved Clays (North American Glacial Varve Project – Tufts University).

DeGroot and Lutenegger (2005) explained that Connecticut Valley Varved Clays:

"…typically rests on top of a relatively thin layer of coarse grained glacial till that covers the underlying bedrock surface. The final thickness of CVVC varies considerably due to large differences in bedrock elevations and variations in postdeposition erosion. In some regions, the deposit is over 50 m thick. The thickness of individual varves ranges from a few millimeters to as thick as 1 m. Close to the ice margin or deltas, large volumes of sediment entering the lake quickly created thick varves, whereas the reduced volume of sediment at locations well away from the ice margin or deltas resulted in thinner varves. The transition from the silt-sand layer to the clay layer is gradual, whereas the transition from the clay layer to the silt-sand layer is abrupt. Typically, most of the variation in thickness of the varves is in the summer silt-sand layer, whereas the winter clay layer changes relatively little in thickness."

3.3 TEST SITE DESCRIPTIONS

3.3.1 HADLEY FARM (HHF) SITE

3.3.1.1 SITE LOCATION

This site is located in Hadley, Massachusetts, adjacent to the Connecticut River. With respect to the University of Massachusetts Amherst campus, this site is located southwest of the campus specifically on 111 North Maple Street (Figure 13). The Hadley Farm is a 131-acre farm that houses horses, sheep, rams, llamas and other farm animals. The testing site was located in the center of a fenced lot used mainly for animals to graze on the north part of the farm. The topography of the site is relatively flat. North Maple Street, North Hadley Road, Rocky Hill Road and Route 116 border the site.

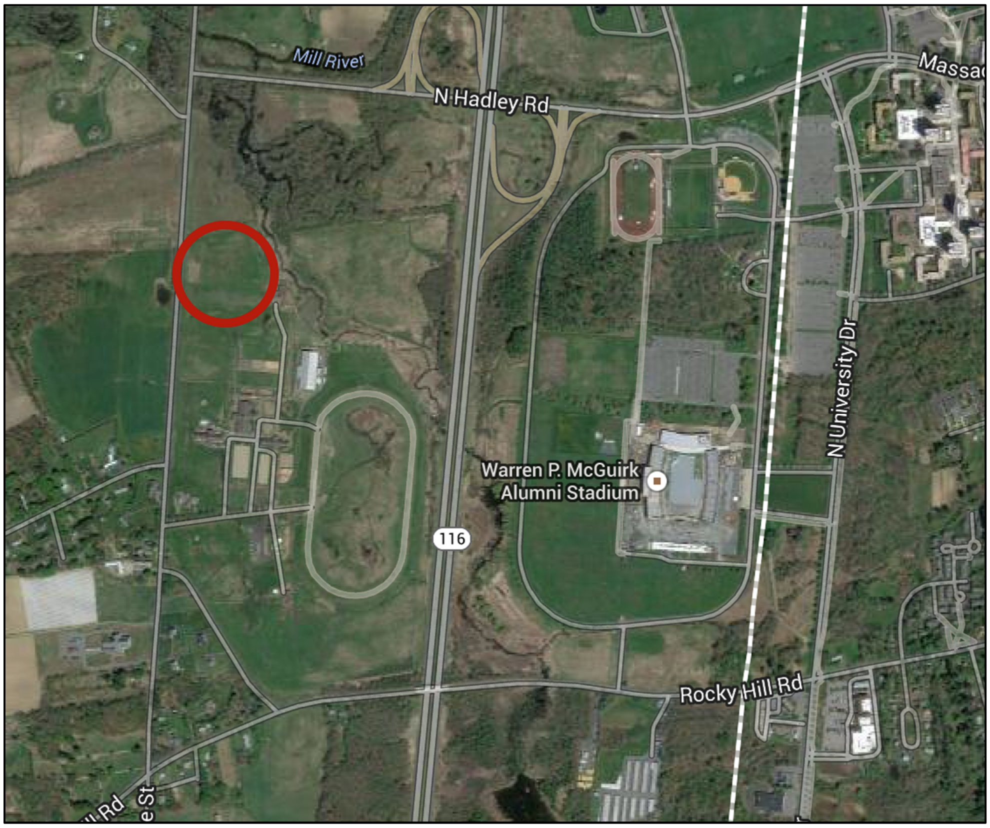

Figure 13. Aerial View of the HHF Site Location (Google Maps).

3.3.1.2 SITE GEOLOGY

This site consists of a silt and clay deposit. This interchanging of silt and clay layers is known as varved clay. Varved clay record the annual freeze-thaw cycle of the glacial lake. More specifically, varve is clay with visible annual layers formed from the summer and winter seasons. This orientation of the layers occurs because during the winter the lake froze and the water barely moves depositing particles suspended in the water and during the summer, the water melts and creates a turbulent flow that only allows for larger particles to be deposited. Samples obtained from this site allowed for visual inspection of the soil, which consisted of an olive-brown. This color could be attributed to a rind or cement formed from iron-rich leachate introduced into the sediment layers.

3.3.1.3 SITE CHARACTERIZATION

In addition to field vane tests, samples were collected using a hand auger in order to perform laboratory testing to characterize the site. The HHF soil deposit is composed of silty clay deposit (Connecticut Valley Varved Clay). The Liquid and Plastic Limit of the CVVC deposit at this location ranges from 22.6% to 35.5% and from 38.8% to 48.6%, respectively. The water content was observed to increase with depth and ranged between 13.7% and 53.8%. The Undrained Shear Strength (determined from Field Vane tests) values of the upper 12 feet were determined to be between 73.5 to 275.6 kPa with a maximum sensitivity value 6.0 (Figure 14).

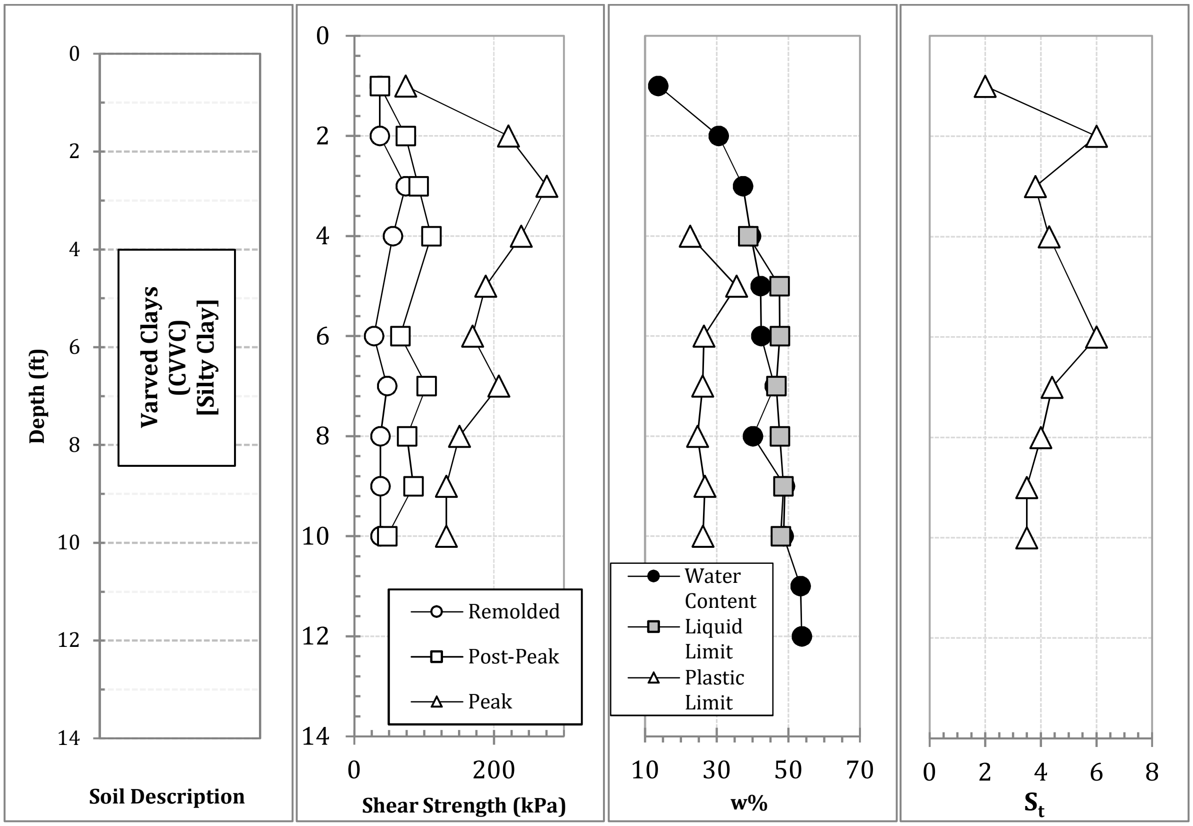

Figure 14. Soil Properties (HHF Site).

3.3.2 DEPARTMENT OF ENERGY (DOE) SITE

3.3.2.1 SITE LOCATION

This site is located in Hadley, Massachusetts, on the corner of North Hadley Road and Mullins Way and south to the Amherst Wastewater Treatment Plant (Figure 15). This site for several years was used for various geotechnical engineering research projects. The topography of the site consists of a flat area covered by grass. The testing area is located to the right side of the gravel driveway of the front part of the site.

Figure 15. Aerial View of the DOE Site Location (Google Maps).

3.3.2.2 SITE GEOLOGY

This site consists mainly of layers of silt and clay deposited over the summer and winter over the years for a long period of time during the glacial period. The first 5 to 6 feet of soil was recently deposited, on top of the native soil. These 5 to 6 feet of soil/fill were excavated from site next to the DOE site when the Wastewater Treatment Plant's aeration and settling tanks were being constructed. This interchanging of silt and clay layers is known as varved clay. Varved clay record the annual freeze-thaw cycle of the glacial lake. More specifically, varve is clay with visible annual layers formed from the summer and winter seasons. This orientation of the layers occurs because during the winter the lake froze and the water barely moves depositing particles suspended in the water and during the summer, the water melts and creates a turbulent flow that only allows for larger particles to be deposited.

3.3.2.3 SITE CHARACTERIZATION

A soil profile is presented in Figure 16. As previously mentioned, the soils at the DOE site consist of Varved Clays with variable Silt and Clay portions that range from Clay and Silt to Silty Clay.

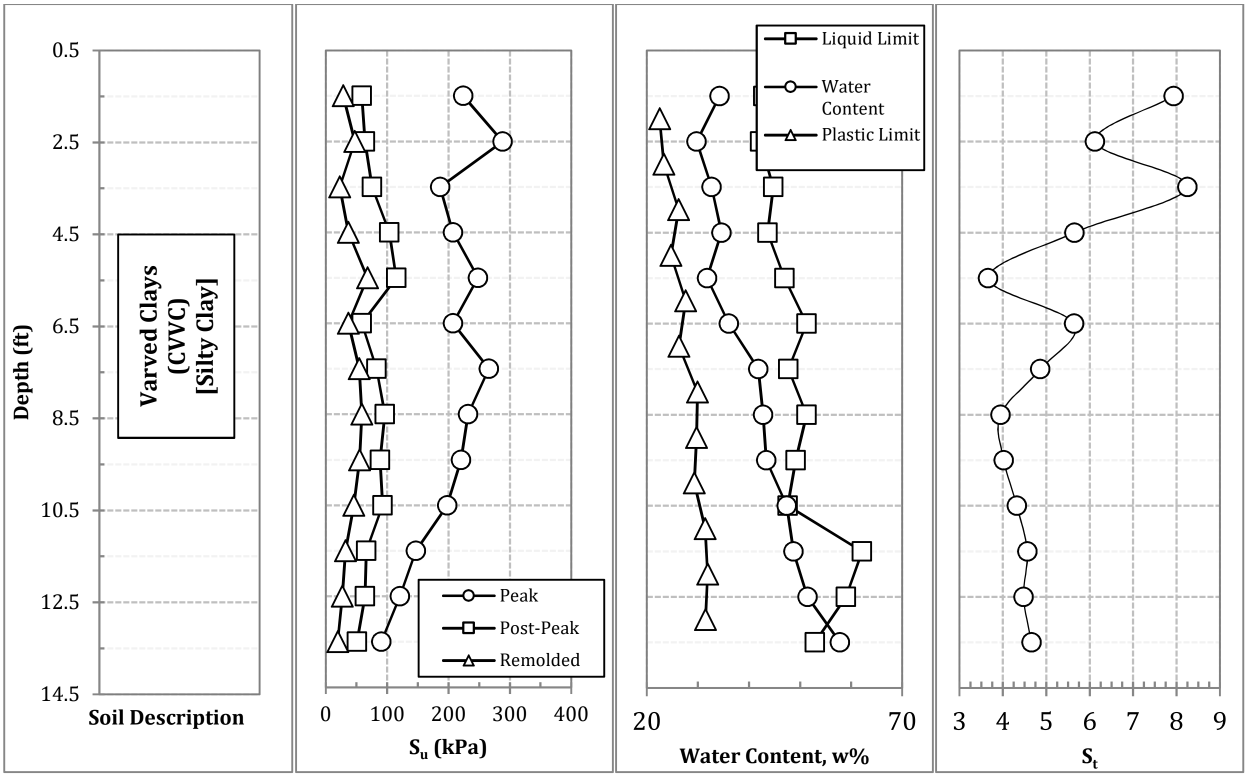

Figure 16. Soil Properties (DOE Site).

The DOE soil deposit is composed of silty clay deposit (Connecticut Valley Varved Clay). The average Liquid Limit of the CVVC deposit at this location is 49.3%. The water content was observed to increase with depth and ranged between 29.7% and 57.8%. The Undrained Shear Strength (determined from Field Vane tests) values of the upper 15 feet were determined to be between 90.4 to 288.2 kPa. The average Post-Peak (Residual) and Remolded Undrained Shear Strength were between

19 and 115 kPa. The sensitivity values ranged from 3.7 to 8.3. The general subsurface profile of the DOE site is presented in Figure 17.

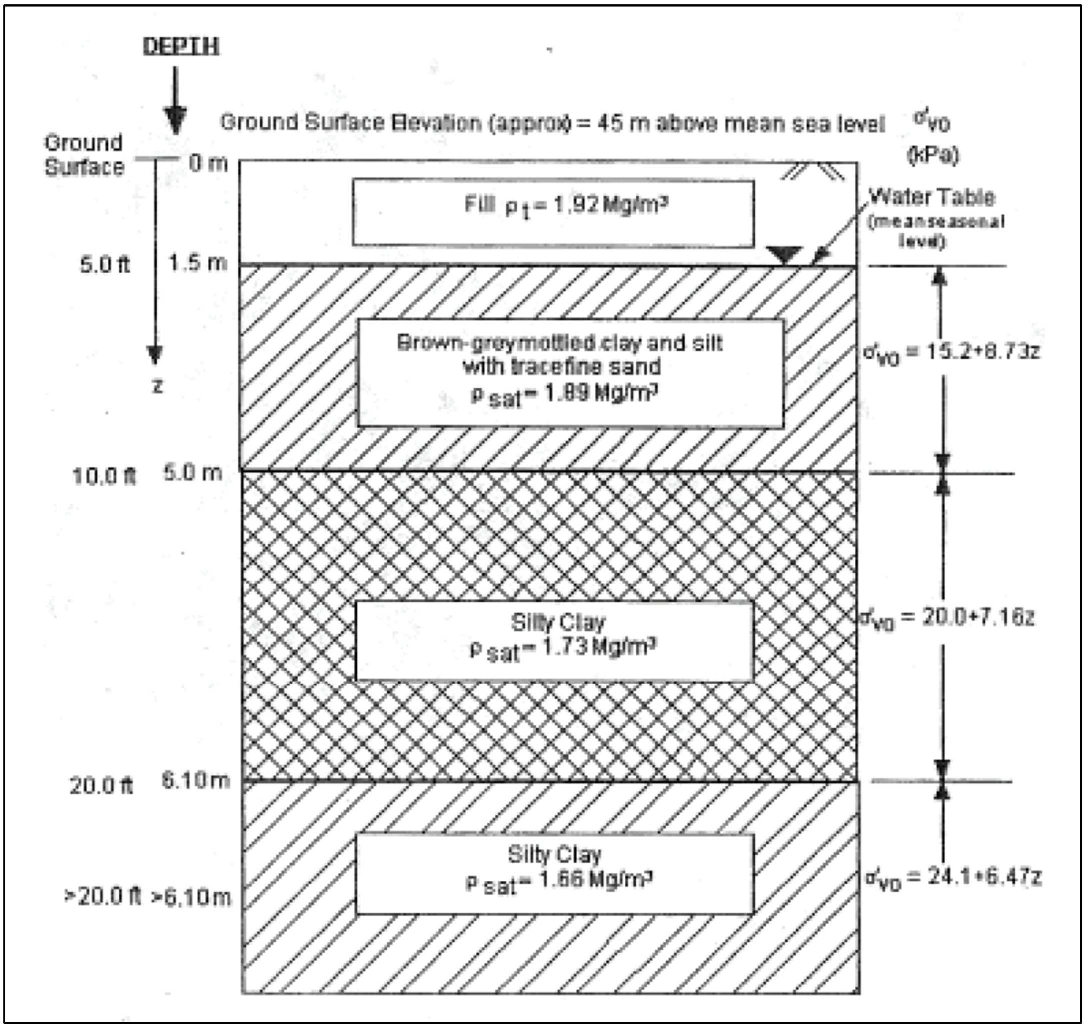

Figure 17. DOE Soil Profile.

3.3.3 TAYLOR FIELD SITE

3.3.3.1 SITE LOCATION

This site is located behind a residential area in Amherst, Massachusetts. The site, located at the end of Valley Lane, is property of the University of Massachusetts Amherst (Figure 18). The topography of the site consists of a flat area covered by grass.

Figure 18. Aerial View of the TF Site Location (Google Maps).

3.3.3.2 SITE GEOLOGY

This site consists of a silt and clay deposit. This interchanging of silt and clay layers is known as varved clay. Varved clay record the annual freeze-thaw cycle of the glacial lake. More specifically, varve is clay with visible annual layers formed from the summer and winter seasons. This orientation of the layers occurs because during the winter the lake froze and the water barely moves depositing particles suspended in the water and during the summer, the water melts and creates a turbulent flow that only allows for larger particles to be deposited.

CHAPTER 4

4 METHODS OF INVESTIGATION

4.1 INTRODUCTION

This chapter presents the methods of investigation used in the laboratory testing and in situ testing programs. Also, the installation and load testing of piles used for this research. The laboratory testing program included water content determination, soil characterization using several methods and, determination and measurement of thixotropic behavior of samples obtained from each of the sites previously mentioned. The in situ testing program consisted of field vane tests and collection of disturbed samples using a hand auger to later be used in the laboratory testing program. All laboratory tests were conducted in the Geotechnical Engineering Laboratories at the University of Massachusetts Amherst and all in situ testing was conducted on the three sites previously mentioned, respectively. In a period of 2 years, the author conducted laboratory and in situ tests and, installed and load test more than 150 piles. Also, tests and data from past students and Dr. Alan J. Lutenegger of the University of Massachusetts Amherst were used for this engineering report.

4.2 IN SITU TESTING PROGRAM

4.2.1 FIELD VANE SHEAR TEST (FVT)

The field vane shear test was performed in general accordance with ASTM 2573 – 94 Standard Test Method for Field Vane Shear Test in Cohesive Soils. Field vanes shear tests were conducted at predetermined distance away from the wall of the pile. Two vanes with a height to width ratio of 2:1 and 1.5:0.75 (units in inches) and a blade thickness of 3 millimeters (approximately 0.1 inch), 2 to 3-foot long steel torque extensions rods (with a 3/8 and 1/2 inch diameters) and a torque reader connected to a socket wrench were used to perform each field vane shear test.

Table 3 and Table 4 showed the dates of the field vane test performed, time of field vane tests after pile driving, dimensions of vane used for each set of tests, profile depth range and approximate distance from pile for each set of field vane tests (Figure 19) shows a sketch of the vane blades used in this research.

Table 3. Field Vane Test Summary

4.5-in. Open-End Pipe Pile (DOE-30)				
Test Date	Time After Pile Driving (Days)	Dimensions of Vane (Horizontal:Vertical)	Profile Depth Range (feet)	Distance from Pile (inches)
	Before Pile Driving	1.5:0.75	1.5 – 13.5	-
13-May-2014	0 (After Pile Driving)	2:1	1.5 -12.5	0.5
14-May-2014	1	2:1	1.5 -12.5	0.5
17-Jun-2014	35	2:1	1.5 -12.5	0.5
27-Oct-2014	167	2:1	1.5 -12.5	0.5

Table 4. Field Vane Test Summary

4.5-in. Open-End Pipe Pile (DOE-30)				
Test Date	Time After Pile Driving (Days)	Dimensions of Vane (Horizontal:Vetical)	Profile Depth Range (ft)	Distance from Pile (inches)
	Before Pile Driving	1.5:0.75	1.5 – 13.5	-
13-May-2014	0 (After Pile Driving)	2:1	1.5 -12.5	0.5
14-May-2014	1	2:1	1.5 -12.5	0.5
17-Jun-2014	35	2:1	1.5 -12.5	0.5
17-Jun-2014	35	1.5:0.75	1.5 -12.5	0.5
27-Oct-2014	167	2:1	1.5 -12.5	0.5

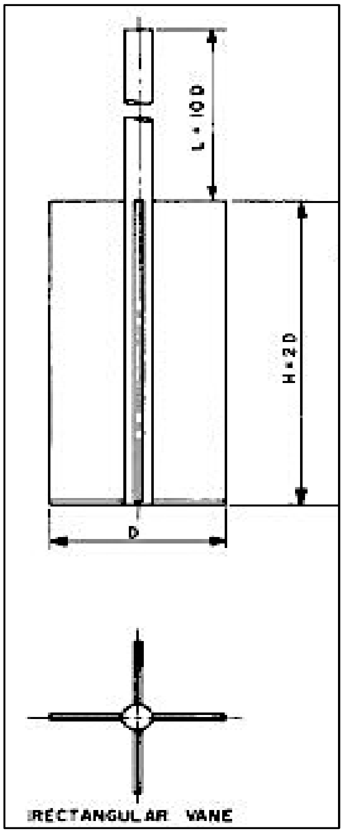

Figure 19. Field Vane Blades Dimensions (http://www.denichsoiltest.com/).

A borehole was dug using a 2-inch hand auger with a spoon for clays and 1 to 3-foot extension rods (Figure 20). Using the hand auger, 6 inches of soil was dug out and the vane, connected to the necessary number of steel torque extensions rods in order to reach the desired depth, was lowered into the hole until it touched the bottom of the borehole. Then, 6 inches from the ground surface were marked using a white chalk and a measuring tape. Subsequently, the vane was carefully pushed six (6) inches into the ground to avoid any excessive disturbance of the soil. The test was runt at each 1-foot depth beginning at a depth of 0.5 or 1 foot (from the existing ground surface). With the vane in the ground, the test was conducted within 1 minute to avoid pore water pressure dissipation. The torque was ran by applying a torque at a rate of no more than 0.1 degrees/sec. Normally, at this rate the soil should failed between 2 and 3 minutes after the star of the test. During the application of the torque, the steel torque rods where held fixed using one hand but making sure that no torque, force in any direction or any friction was applied to the steel torque rods. The torque reader used to measure the torque is shown in Figure 21. The vane was rotated until the soil failed in shear (Figure 22). Failure was observed when there was no further increase in torque. After the peak torque was recorded, the vane was rotated 10 times in the same place in order to the remold the soil. Again, a torque was applied and the same procedure and caution previously explained were followed. When the vane was being rotated for the second time there was a slight increase in shear strength of the vane. When 2 or 3 consecutive remolded torque readings were observed to be the same in a relatively short period of time, the torque was recorded. This torque values were later converted to shear strength values using the following equation:

$$\boldsymbol{S_u = \frac{6T_f}{7\pi d^3}} \qquad \textbf{Equation 17}$$

where

$\boldsymbol{S_u}$ = Undrained Shear Strength (pound per square inch and later pounds per square feet)

$\boldsymbol{T_f}$ = Torque (inch-pounds)

$\boldsymbol{d}$ = diameter of vane (inches).

Field vane tests were performed at 1-foot intervals alongside the pile down to 12 to 13 feet deep in order to obtain a shear strength profile alongside the pile.

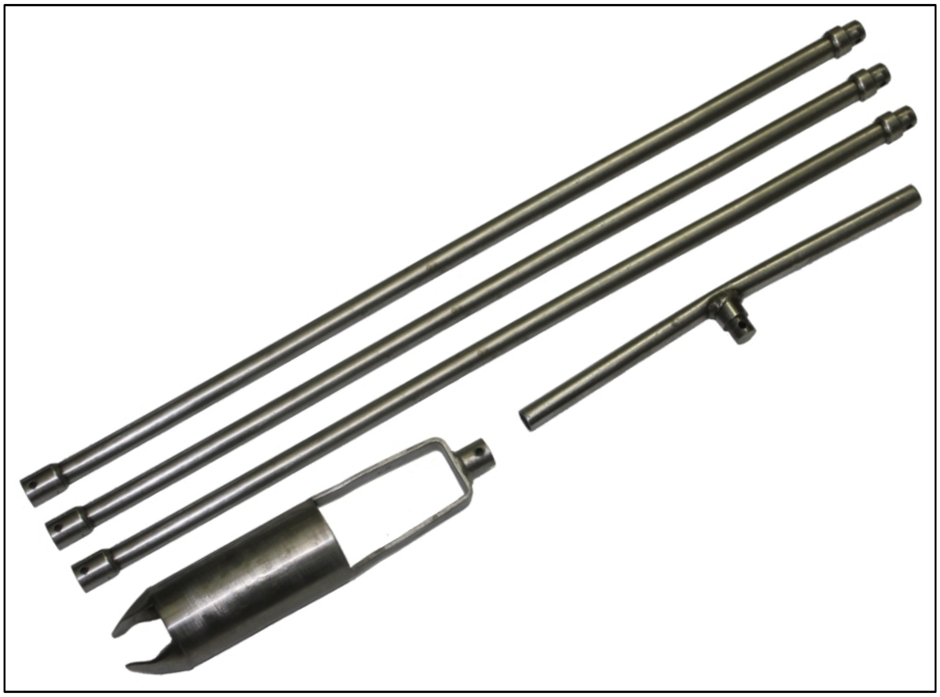

Figure 20. Example of Hand Auger and Extension Rods.

Figure 21. CDI Torque Multitorq Torque Reader.

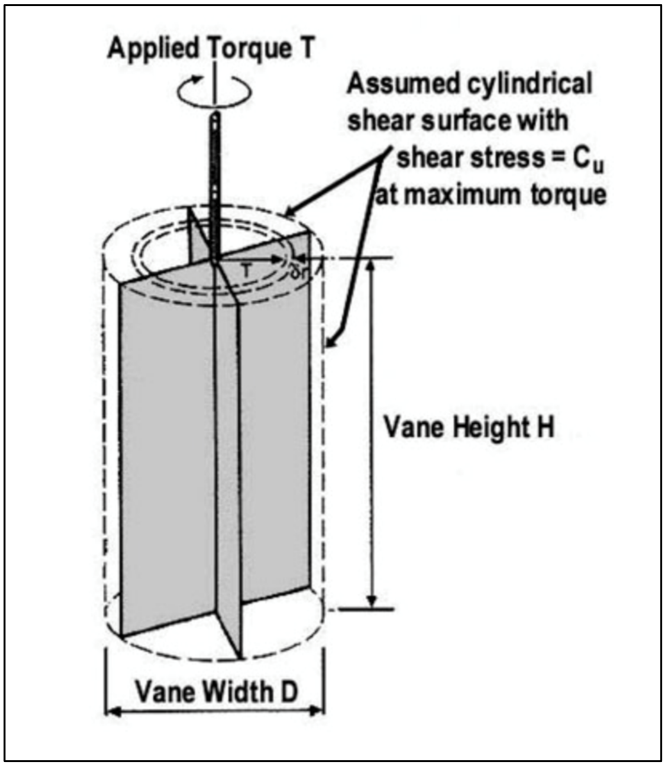

Figure 22. Field Vane Test Assumed Failure Surface (http://www.builtconstructions.in).

4.3 DRIVEN PILE INSTALLATION

4.3.1 PIPE AND H-PILES

All piles were installed using a Kubota M4800 tractor with a King Hitter post ponder attachment with a fabricated steel cap to hold the piles in place and to not drop the weight of the hammer directly on the pile while driving them. Once the piles were aligned vertically using a magnetic level, the fabricated steel cap was lowered to hold the pile in place while the 550 - pound hammer was dropped from a distance of 44 inches. The fabricated steel plate and 550 – hammer can be observed in the photo presented in (Figure 23). In order to ensure the same drop height, 44 – inch chain was used to measure the distance between the steel cap and the bottom of the hammer. The hammer was raised using mechanical pulleys and released to fall under the force of gravity. The distance the pile was embedded in the ground was recorded using a tape measure by measuring distance from the ground surface to the top part of the pile. When opened-end piles were being driven, the soil plug inside the pile was measured every 5 to 7 inches of penetration by measuring the depth inside of the pile, from the surface of the ground inside the pile to the top of the pile. The same equipment and operator was used for the installation of all the piles used for this investigation. Figure 24 shows a photo taken during the installation of a pipe pile.

Figure 23. Steel Plate Fabricated to Hold Piles in Place and 500-lbs Hammer.

Figure 24. Pipe pile Installation at the HHF Site.

4.4 AXIAL UPLIFT LOAD TESTS OF PILES IN TENSION

Uplift load tests were performed in general accordance, following the 'Quick Test' method, with ASTM Standard D3689 – 90 Standard Test Method for Individual Piles Under Static Axial Tensile Load. The purpose of these tests was to measure the axial deflection of a vertical deep foundation when loaded in static axial tension. In this investigation, as explained before, the types of deep foundation tested using this method were pipe piles and H-piles. The axial uplift test consisted of placing two 10 feet long I-beams on top of two sets of 6 inch by 6 inch wood cribbing that ranged in length from 2 to 4 feet. This stacks consisted of 3 to 4 stories depending on the desired height based on the height of the pile section sticking out, and were placed parallel on each side of the pile. In case the ground surface was not leveled, steel plates were used as shims on both wood cribbings. Both reactions

I-beams, that were made out of aluminum in order to facilitate their movement from test to test and site to site, were placed very close to each other and just leaving a 2 to 3 inch gap in between.

A hydraulic jack was placed on top of the two reactions I-beams and centralized with the pile. An adapter connected to a dywidag rod was used to connect the pile to the hydraulic jack. On the top part of the hydraulic jack a load cell sandwiched by two steel plates and were placed and secured using a dywidag threaded hex nut. In order to secure the adapter to the pile, every pile had two drilled holes align. In some cases, a pin connector or a bolt with enough length was used in order to run through the pile.

A 6-foot reference beam was placed perpendicular to the reaction I-beams and was attached to two steel rods, embedded in the ground by means of a sledge hammer, using u-bolts. A displacement gage, Mituyo Corp. Model IDS-10100E, with a precision of 0.0001 inch was attached to the reference beam using c-clamps. The tip of the displacement gage needle was placed on top of a plastic plate clamped to an L-shaped bracket, and this bracket was mounted on the pile by a hose clamp and by c-clamp in case of an H-pile. A sketch of the test setup is shown in Figure 25.

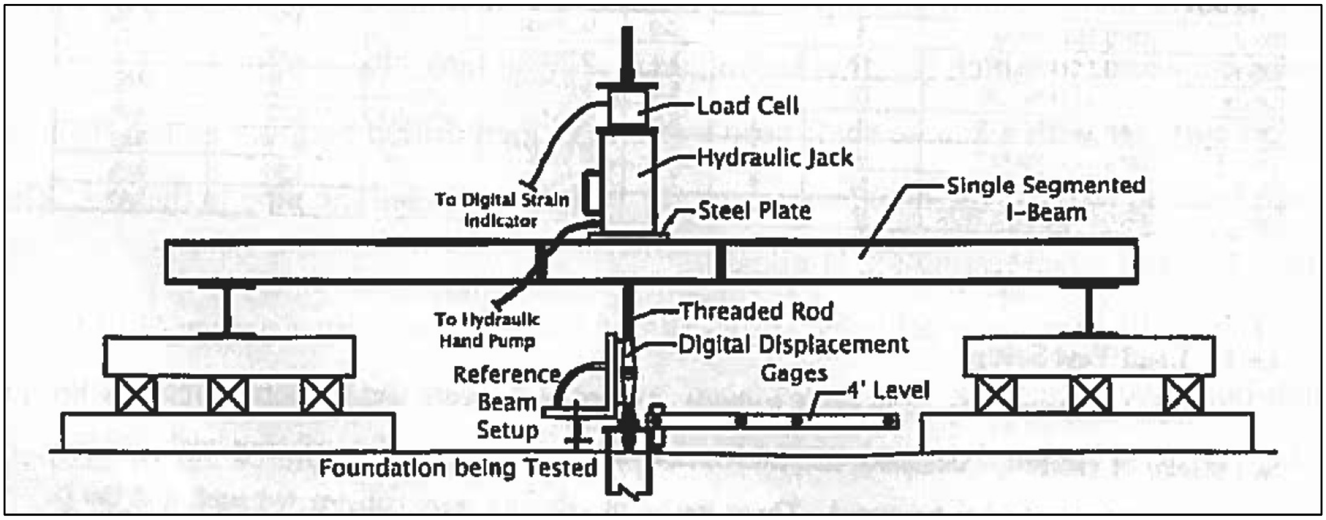

Figure 25. Uplift Load Test Setup Sketch (Tombs 2011).

The axial uplift load test consisted of applying a tension load to the pile for 2.5 minutes. Each test consisted of applying 15 to 20 incremental loads to obtain 1 reading at 30 seconds, 1 and 2.5 minutes per load increment before achieving failure. The load was applied by hand pumping the hydraulic jack. The loads were planned beforehand in order to obtain enough data to construct a displacement curve. A stopwatch was used in order to keep track of the time when the predetermined loads were reached. After 2.5 minutes, the stopwatch was stopped and a new load was applied. After achieving failure, which in this investigation was established to be approximately 1.5 inches of displacement, the load was removed and the pile was left to relaxed. After 5 minutes, a relaxation measurement was recorded. Photos of the load test frame setup at the DOE site are shown in Figure 26 and Figure 27.

Figure 26. Uplift Load Test Frame Set Up at DOE Site.

Figure 27. Hydraulic jack and digital displacement gage.

4.5 LABORATORY TESTING PROGRAM

4.5.1 WATER CONTENT DETERMINATION

The water content values of soil samples, obtained field vane tests, were determined in general accordance with ASTM Standard D2216 Laboratory Determination of Water (Moisture) Content of Soil and Rock by Mass. Samples obtained in the field were placed in Ziploc bags to avoid any moisture lost and to maintain the in situ water content as intact as possible. These bagged samples were also put in an insulated plastic cooler and transported in the trunk of a car.

In the laboratory, a smaller soil sample, around 30 to 40 grams, was taken out of the Ziploc bag and placed in aluminum tare after weighing the aluminum tare alone. After obtaining the weight of the aluminum tare with wet soil sample, the sample was placed in an oven to dry for a period of around 18 to 24 hours. The oven temperature was set at 110 degrees Celsius. After 24 hours in the oven, the aluminum tare with the dry soil sample was weighed. The procedure was followed to determine the water content of all the samples used for this research. In order to determine the water content percentage, it was necessary to subtract the weigh of the aluminum tare to the wet and dry sample weights, and the weight of water was determined to be the difference between the wet soil sample weight and the dry soil sample. Throughout this investigation the same OHAUS Precision Standard balance was used (Figure 28). The water content percent was determined using the following equation:

$$\boldsymbol{w = \frac{W_w}{W_s}(100\%)} \qquad \textbf{Equation 18}$$

where

w = Water Content (%)

ww = Weight of Water (grams)

ws = Weight of Dry Soil (grams)

Figure 28. OHAUS Precision Standard Balance.

4.5.2 ATTERBERG LIMITS

Atterberg Limits determination was performed in general accordance with the ASTM Standard D 4318 "Liquid Limit, Plastic Limit, and Plasticity Index of Soils". The Liquid Limit test was performed using the standard Casagrande cup (Figure 29) calibrated to a drop height of 10 mm or 0.4 in. Using a ceramic bowl, the soil was mixed with enough distilled water to create a paste-like consistency. Then, the uniform soil was spread into the Casagrande cup filling the front half by using a metal spatula. The soil in the cup was then grooved using a grooving tool. The crank of the Casagrande cup was then rotated at a rate of one blow per second until the groove closed over a length of 13 mm or 0.5 in. The number of blows required to achieve this closure was recorded and a small sample for determining the water content was obtained across the groove. The remaining samples was put back in the ceramic bowl with rest and mixed again and let to dry in order to repeat the test at a lower water content.

Figure 29. Casagrande's Cup for Liquid Limit Determination.

This procedure was repeated a total of 5 times at different water contents. The goal was to obtain 5 numbers of blows, one in the following ranges: 5 to 6, 10 to 20, 20 to 30 and 30 to 40, with their respective water content. The water content percent versus the blow counts was plotted and used to determine the Liquid Limit that corresponds to the water content at a blow count of 25 (Figure 30).

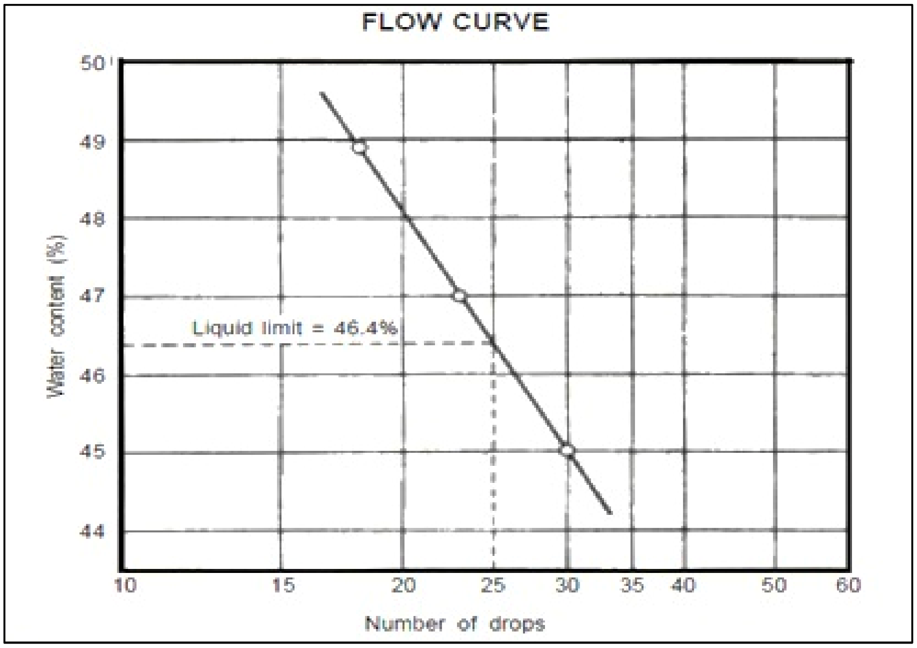

Figure 30. Determination of Liquid Limit Results from Casagrande Cup method.

The Plastic Limit was determined using the thread method by spreading a mixed soil sample over a glass sheet and rolling the sample into a thread until is about to crumble at a diameter of 3.17 mm (0.125 in). A small metal rod with the same diameter was used as a reference. This procedure was repeated two more times and the water contents were determined at each test. The Plastic Limit was determined by averaging all three water content values from each test. The Plasticity Index was determined by subtracting the Plastic Limit from the Liquid Limit.

CHAPTER 5

5 PRESENTATION AND ANALYSIS OF RESULTS

5.1 TYPES OF PILES

An extensive selection of piles were driven and tested at three different sites for this research. Piles used for this research included pipe piles and H-piles. Pipe piles varied in wall thickness, diameter, length and surface coating (Table 5). H piles varied in web thickness, flange width and thickness, end area and surface coating (Table 6). Piles were tested at different time periods in order to study the gain in capacity by separating all the factors that could potentially influence the soil-pile interaction that effect the ultimate pile bearing capacity. Different pile dimensions also allow for the study of certain mechanisms that are known to be related to the capacity development of a pile, such as lateral stress changes, pore water pressure dissipation, consolidation and thixotropic behavior of soil surrounding the pile to be correlated to pile geometry. The use of pipe piles with same geometry at different sites with similar soils (clayey soils) allowed for the comparison of results and the pile's behavior determination, namely, to make the distinction between site-dependent or soil-dependent findings.

5.1.1 PIPE PILES

A great number of piles used for this research investigation consisted mainly of open-end and closed-end pipe piles. Closed-end pipe piles had a cap welded to the bottom of the pile in order to prevent any soil from entering the pile. Contrastingly, open-end pipe piles allow the soil to enter the pile during driving and plugging the pile at a certain depth or height. In general, open and closed-end piles were installed and tested in order to simulate fully or semi plugged pile conditions during driving and the influence of soil plug in the gain in capacity of the piles.

Table 5 Dimensions of Pipe Piles

Outer Diameter (in)	Inner Diameter (in)	Schedule	Wall Thickness (mm)
2.875	2.635	10	0.120
2.875	2.469	40	0.203
4.5	4.260	10	0.120
4.5	4.026	40	0.237
6.625	6.357	10	0.135
6.625	6.065	40	0.280

5.1.2 H-PILES

Several H piles were used in this research investigation. Similarly to pipe piles, a soil plug develops between the flanges of the H pile during driving. H-piles with variations in dimensions (Table 6) were used to determine influencing factors related to pile area, soil plugs and effective stress during driving and over time. The differences in the H-pile depth, web and flange thicknesses, and flange width allowed for the study of soil disturbance due to pile dimension during driving and the soil's thixotropic behavior.

Table 6. Dimensions of H Piles

Pile Name	Depth (in.)	Web Thickness (in.)	Flange Width (in.)	Flange Thickness (in.)
S4 X 7.7	4.00	0.193	2.66	0.293
W6 X 9	5.90	0.170	3.94	0.215
W6 X 12	6.03	0.230	4.00	0.280
W8 X 13	7.99	0.230	4.00	0.255
W8 X 15	8.11	0.245	4.02	0.315

5.2 PILE INSTALLATION

Each pile installation was documented. Information recorded during (pipe or H) pile driving includes site name, pile length, pile dimension (based on pile type) hammer per blows. In the case of open-end pipe piles, the soil plug length was recorded approximately every 6 to 8 inches of penetration.

5.2.1 DOE INSTALLATION ANALYSIS

The study of driven piles at the DOE site was comprised of a total of 20 piles: 9 H-Piles and 11 pipe piles. The parameters supporting the pile driving installation are reported below in Table 7. This section will present and discuss the results of the installation analysis of some of the piles installed at the DOE site. Specifically, driving records and plug length will be studied to observe if there is any correlation with the development of capacity over time

Table 7. Pile Installation Results from DOE Site.

Pile Name	Total Length (ft)	Embedment Depth (ft)	O.D. (in)	Schedule	H-Pile	Area Ratio (%)	Embedded Surface Area (ft2)	Cumulative Blow Count	Avg. Penetrations per Blow	FFR(%)	PLR (%)	Installation Date
DOE-1	9.0	8.0	–	–	W6X12	85.3	18.08	85.0	1.1	-	-	10/12/12
DOE-2	9.0	8.0	–	–	W8X15	86.4	20.88	86.0	1.1	-	-	10/12/12
DOE-3	9.0	8.0	–	–	S4X7.7	78.8	11.36	46.0	2.1	-	-	4/8/13
DOE-6	10.0	9.0	2.9	40.0	–	26.2	7.54	78.0	1.4	-	-	10/12/12
DOE-7	10.0	11.0	4.5	40.0	–	20.0	11.78	114.0	0.8	-	63.7	5/20/13
DOE-9	11.0	10.0	4.5	-	–	100.0	11.78	156.0	0.8	-	-	5/20/13
DOE-10	9.0	8.0	–	–	S3X5.7	76.1	9.28	37.0	2.4	-	-	8/15/13
DOE-11	11.0	10.0	2.9	40.0	–	26.2	7.54	60.0	2.0	-	43.3	8/15/13
DOE-12	11.0	10.0	2.9	-	–	100.0	7.54	72.0	1.7	-	-	8/15/13
DOE-13	11.0	10.0	4.5	40.0	–	20.0	11.78	111.0	1.1	-	61.2	5/20/13
DOE-14	9.0	8.0	–	–	W6X9	88.4	17.84	65.0	1.5	-	-	8/15/13
DOE-15	9.0	8.0	–	–	W6X9	88.4	17.84	78.0	1.2	-	-	8/15/13
DOE-16	11.0	10.0	6.6	40.0	–	16.2	17.34	202.0	0.6	-	73.3	8/15/13
DOE-17	9.0	8.0	–	–	W6X9	88.4	17.84	77.0	1.2	-	-	8/15/13
DOE-18	9.0	8.0	–	–	W6X9	88.4	17.84	87.0	1.1	-	-	9/20/13
DOE-19	11.0	10.0	2.9	-	–	100.0	6.79	80.0	1.5	-	-	9/20/13
DOE-20	11.0	10.0	2.9	-	–	100.0	6.91	75.0	1.6	-	-	9/20/13

DOE-21	11.0	10.0	2.9	-	–	100.0	6.91	90.0	1.3	-	-	9/20/13
DOE-22	11.0	10.0	2.9	-	–	100.0	6.94	83.0	1.4	-	-	9/20/13
DOE-28	9.0	8.0	–	–	W6X9	88.4		81.0	1.2	-	-	5/13/15
DOE-27	11.0	10.0	4.5	-	–	100.0		136.0	0.9	-	-	5/13/14

5.2.2 PIPE PILE INSTALLATION ANALYSIS

Several piles of varying geometries were installed at the DOE site. The pile driving records of these H-piles are presented in Figure 31. Piles DOE-1 and 2 exhibited similar driving behaviors with almost identical cumulative blow counts of 85 and 86, respectively. The pile driving behavior of pile DOE-18 was almost identical to Piles DOE-1 and 2, with the exception occurring between 40 and 80 inches of pile embedment. The area ratio of the W6 x 9, W6 x 12 and W8 x 15 piles (88.4%, 85.3% and 86.4%, respectively) had little influence in the pile installation based on the driving records of each pile. The installation curve for each seems to follow a logarithmic trend. Since all three piles had similar area ratios their driving records indicate that their respective area ratios did not have a significant effect during pile driving due to a small difference of only 1 blow count.

On the other hand, Piles DOE-3 and 10 had smaller area ratios than “W” piles that eased pile driving by yielding lower final cumulative blow counts of 46 and 37, respectively.

In general, the “S” piles required approximately 50% less blow counts than the “W” piles. Correspondingly, the average penetration per blow for the piles with the higher embedded surface areas (DOE -1, DOE-2, and DOE-18) is approximately 50% of those with the smaller embedded surface areas (DOE-3 and DOE-10). The S4 x 7.7 and S3 x 5.7 piles had a penetration rates of 2.1 and 2.4 inches per blow, respectively, as compared to the W6 X 9, W8 X 15 and W6 x 9 piles that exhibited a penetration rate of 1.1 inches per blow. It was observed that the area ratio of the H and S piles played an important role during driving of the first few feet of pile. This can be corroborated by the differences in penetration rates above and below the cumulative blow count of 39 as observed in Figure 32.

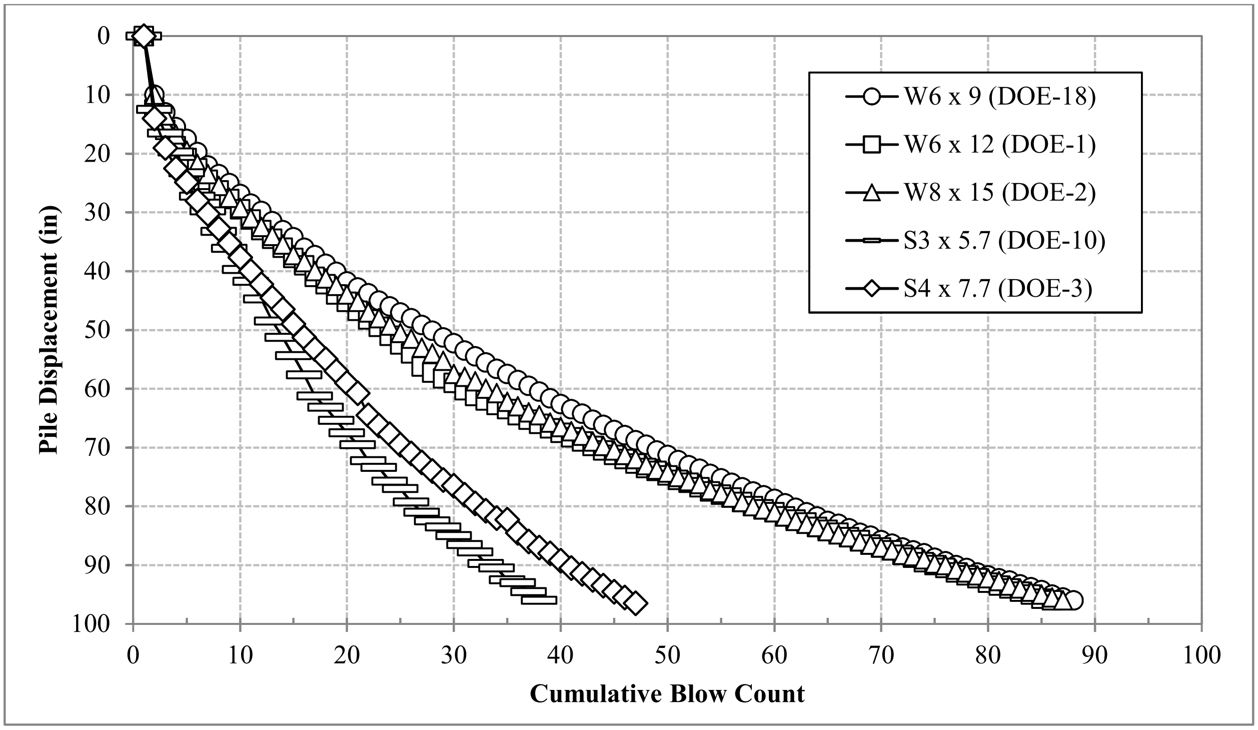

Figure 31. Penetration Analysis of H-Piles with Varying Geometries at DOE Site

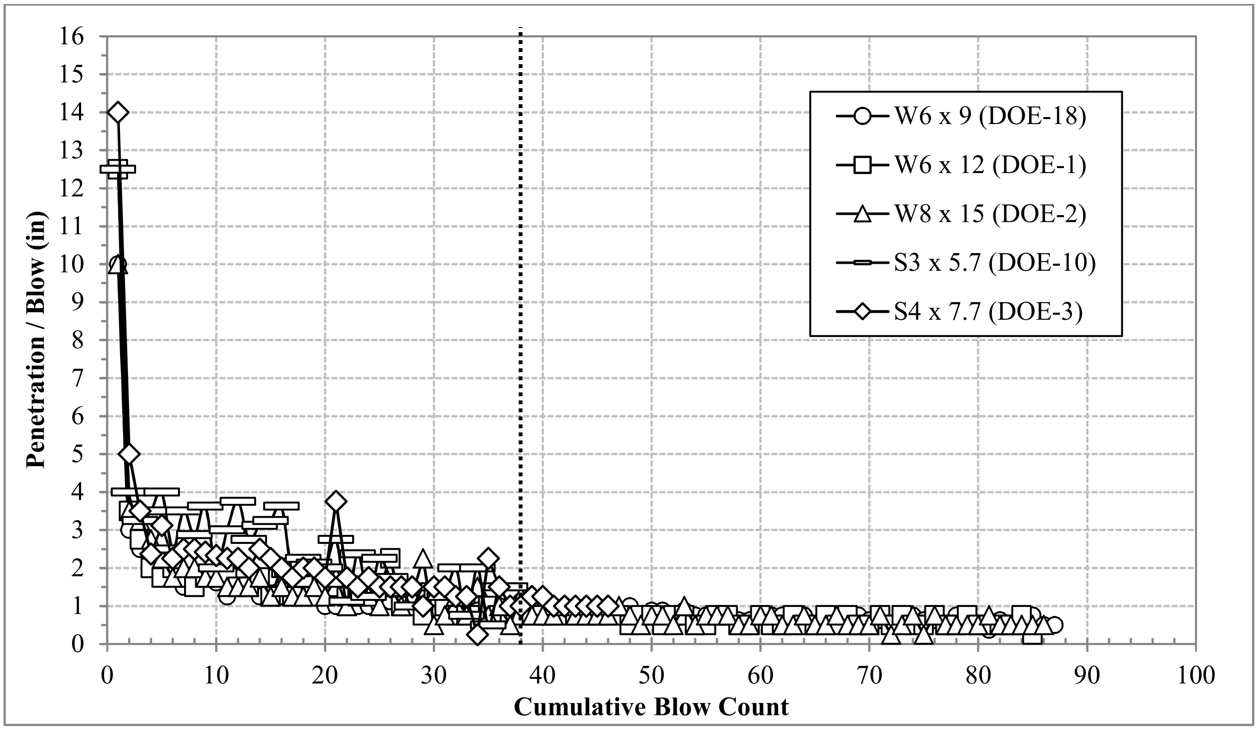

Figure 32. Penetration per Blow Analysis of H-Piles with Varying Geometries at DOE Site.

The driving behavior of pipe piles is directly affected by the development of a plug inside the pipe during driving, in the case of the opened-end pipe piles. Open and closed-end pipe piles with the same diameter behave different depending on its area ratio.

The varying diameter pipe piles compared in Figure 33 show the differences in behavior between open and closed-end pipe piles. In general, the closed-end pipe piles require more blows for the same pile displacement. Specifically, the final cumulative blow count for the 4.5-inch closed and open-end pipe piles were of 156 and 114, respectively. And the final cumulative blow counts for the 2.875-inch closed and open-end pipe piles were of 72 and 60, respectively.

The difference in pile diameter (2.875 to 4.5 inches) of about 63% results in approximately a 90% increase in blow counts for the open-end pipe piles and approximately 118% for the closed-end pipe piles. The average penetration per blows, however, remains consistent at approximately 0.8 inches between the 2.875-inch open and closed-end pipe piles, but reduces approximately 0.3 inches (from 2.0 to 1.7 inches) between the 4.5-inch open and close-end pipe piles (Figure 33). The difference in blow counts during driving increases for open and closed-end pipe piles with same diameters seems to increase as the diameter of the pile increases,. For example, the 4.5-inch closed-end pipe pile required 42 blows more than the same pile with an open-end bottom and, the 2.875-inch closed-end pipe required 12 blows more than the same pile with an open-end bottom. This indicates that as the diameter of the pile increases, the driving resistance also increases and as the area ratio increases the driving resistance increases, as well.

Figure 34 shows that during pile driving, the inches per blow during the first 32 blows ranged from 0 to 4. After 32 blows till end of pile driving, the range of the inches per blow narrowed from 0 to 2. The average penetration per blow is inversely proportional to the diameter sizes, where 2.875-inch pipe pile exhibited an average penetration of 2.0 inches per blow and the larger diameter pipe exhibited an average penetration of 0.6 inches per blow.

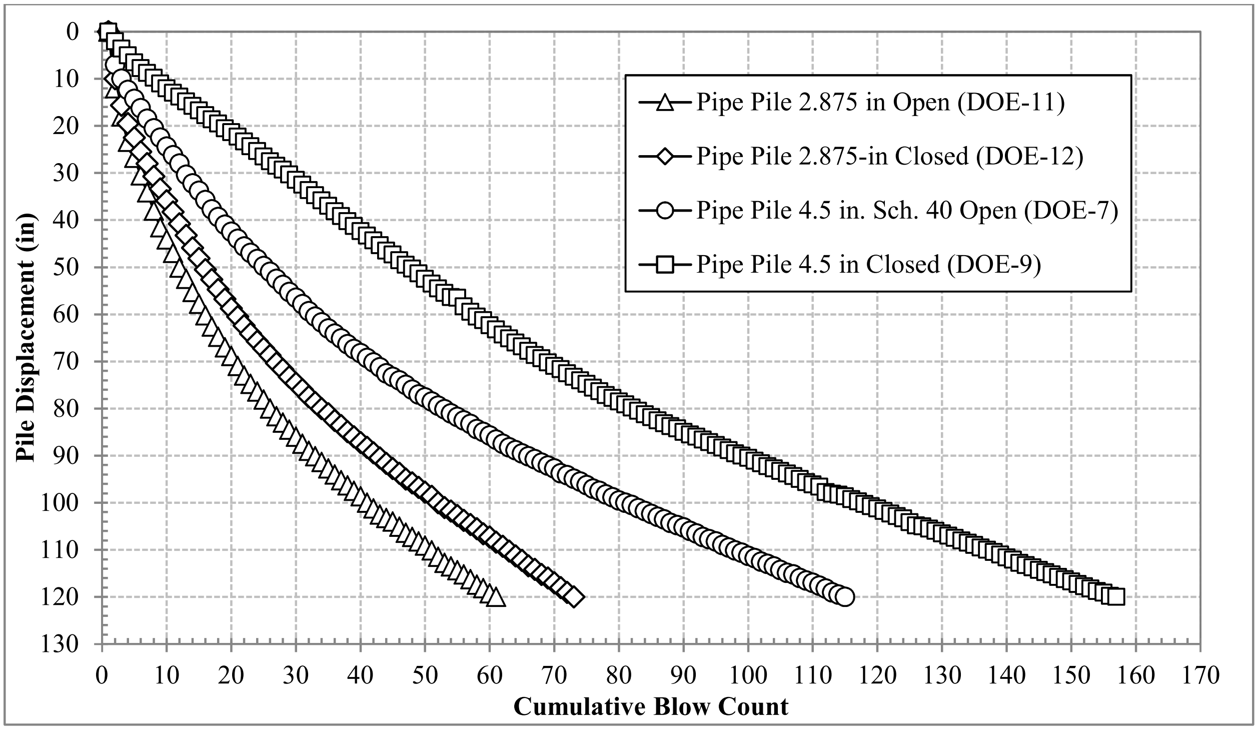

Figure 33. Penetration Analysis of Open and Closed Pipe Piles with Varying Diameters at DOE Site.

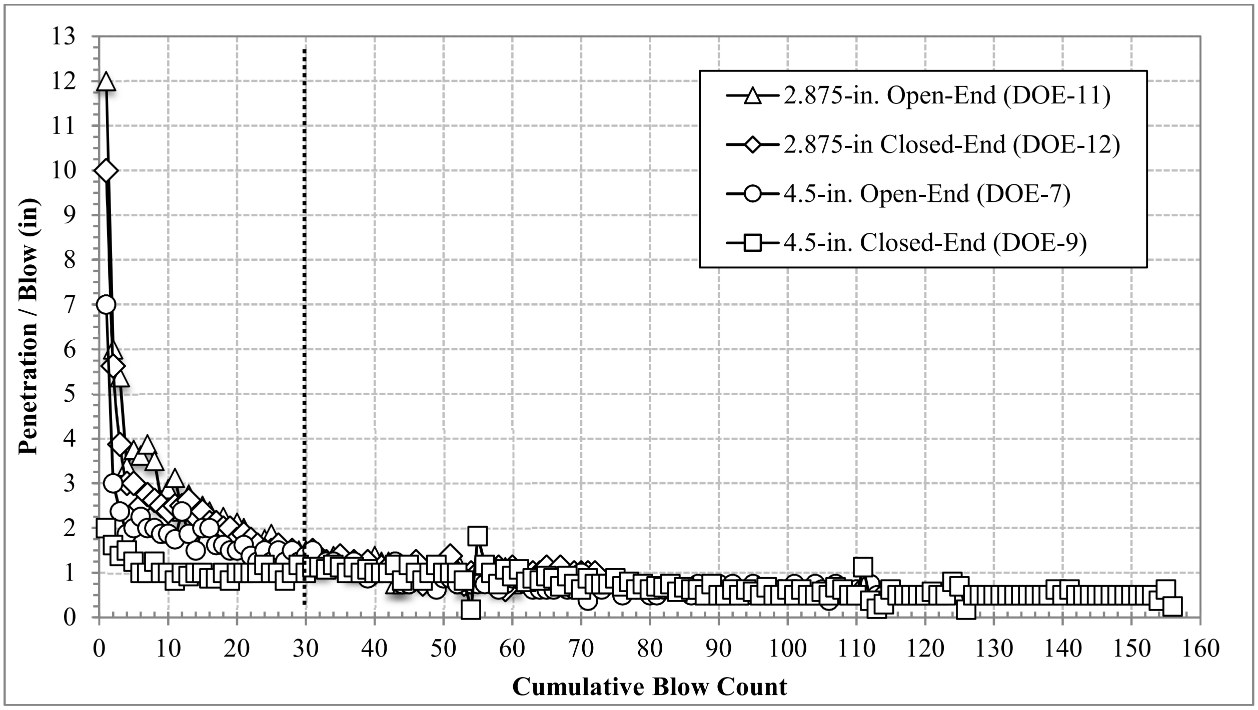

Figure 34. Penetration/Blow Analysis of Open and Closed-End Pipe Piles with Varying Diameters (DOE Site).

The area ratio of the closed-end pipe piles is higher than those of open-end pipe piles and for this reason the installation of closed-end pipe piles requires more energy (higher blow counts) due to the displacement of more soil in the case of closed-end pipe piles. The friction increases as the lateral effective stress increases as soil is displaced during pile driving of the closed-end pipe pile.

Figure 35 presents the plugging relationship among varying diameter pipe piles of the same wall thickness (Schedule 40). Overall, as the diameter of the pile increases, the plug formation increased. The soil plug formation during installation of all three occurred at approximately the same rate during the first 20 inches of penetration, based on the IFR values. Thereafter, the 6.625 and 4.5-inch pipe piles showed similarities between their respective IFR curves to about 70 inches of penetration. At approximately 83 inches of penetration, the IFR values of the 2.875 and 4.5-inch open-end pipe piles were in closer proximity to each other resulting in a difference of 6%. The FFR of the 2.875 and 4.5-inch open-end pipe piles were 53 and 50%, respectively. The IFR for the much larger diameter pile, 6.675-inch open-end pipe pile, exhibited the larger range of FFR, but also converged in proximity to the smaller diameter pipe piles with an FFR of 63%. The PLR of 2.875, 4.5 and 6.675-inch pile were PLR 43.3, 61.2 and 73.3%, respectively. The larger diameter pile were closer to the 1:1 soil plug formation line than the 2.875 and 4.5-inch pipe piles due to their area ratios.

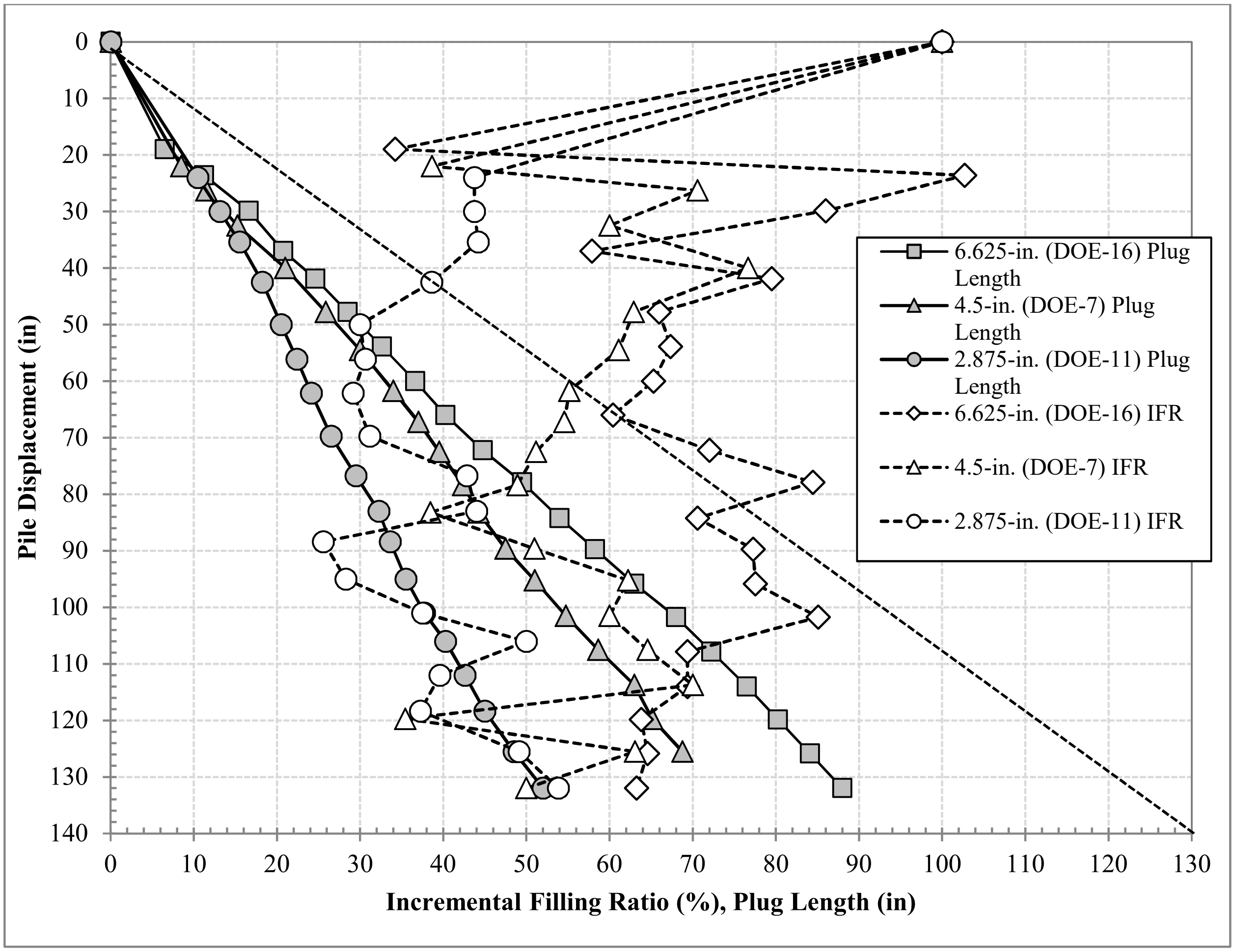

Figure 35. Soil Plug Analysis of Open-End Pipe Piles with Varying Diameters (DOE Site).

Figure 36 presents the driving record of piles DOE-7, 11 and 16. The energy required to install the 2.875, 4.5 and 6.625-inch open-end pipe piles resulted in a final cumulative blow count of 61, 115 and 203, respectively. The percent difference in diameter between piles DOE-7 and DOE-11 (about 44%) resulted in 55% increase in total blow counts. Similarly, the percent difference in diameter between piles DOE-11 and DOE-16 (about 38%) resulted in 55% increase in total blow counts. In general, the pile with the larger diameter required more blows for the same pile displacement.

Each pile exhibited a significant difference in their respective rate of penetration that is dependent on surface area of the piles. Figure 37 shows that during pile driving, the inches per blow during the first 60 blows ranged from 0.75 to 12; the penetration rate after 60-blow mark ranged from 0.25 to 1.75.

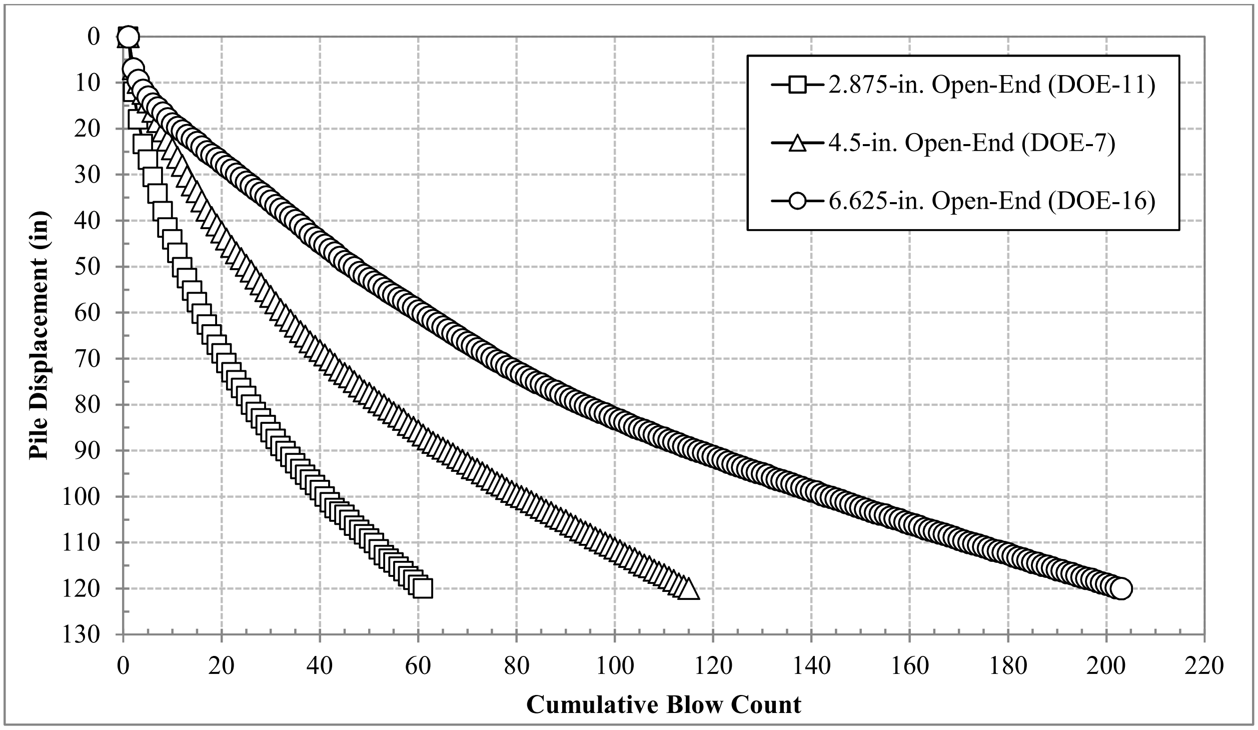

Figure 36. Pile Penetration Analysis of Open Pipe Piles with Varying Diameters at DOE Site.

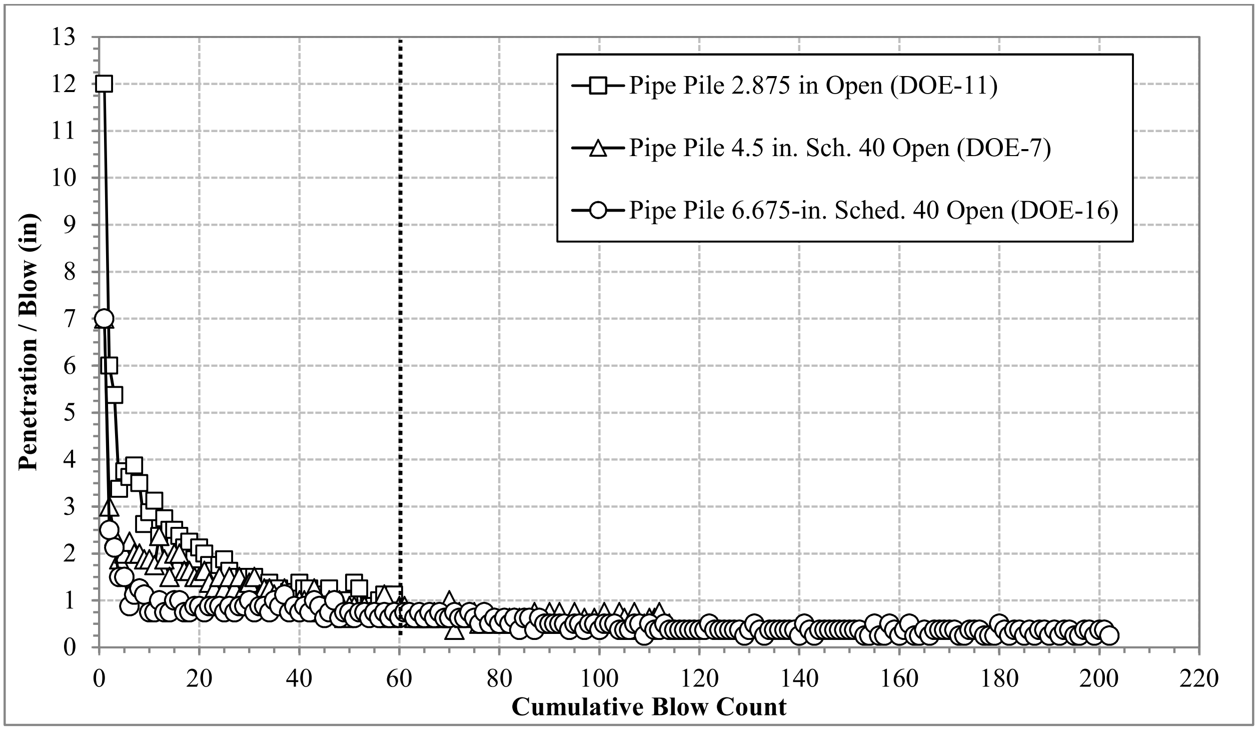

Figure 37. Penetration per Blow Analysis of Open Pipe Piles with Varying Diameters (DOE Site).

The results of the installation of a coated and plain 4.5-inch open-end pipe piles are presented in Figure 38. Overall, the penetration curve for these piles were very similar with a slight difference that occurs mainly between 50 and 90 inches of embedment. It can be observed that open-end pipe plain pile required slightly more energy to be driven than the open-end pipe coated pile based on the total cumulative blow counts. Since driving records were almost identical, the penetration rates were also similar ranging from 0.125 and 9.25 during pile driving.

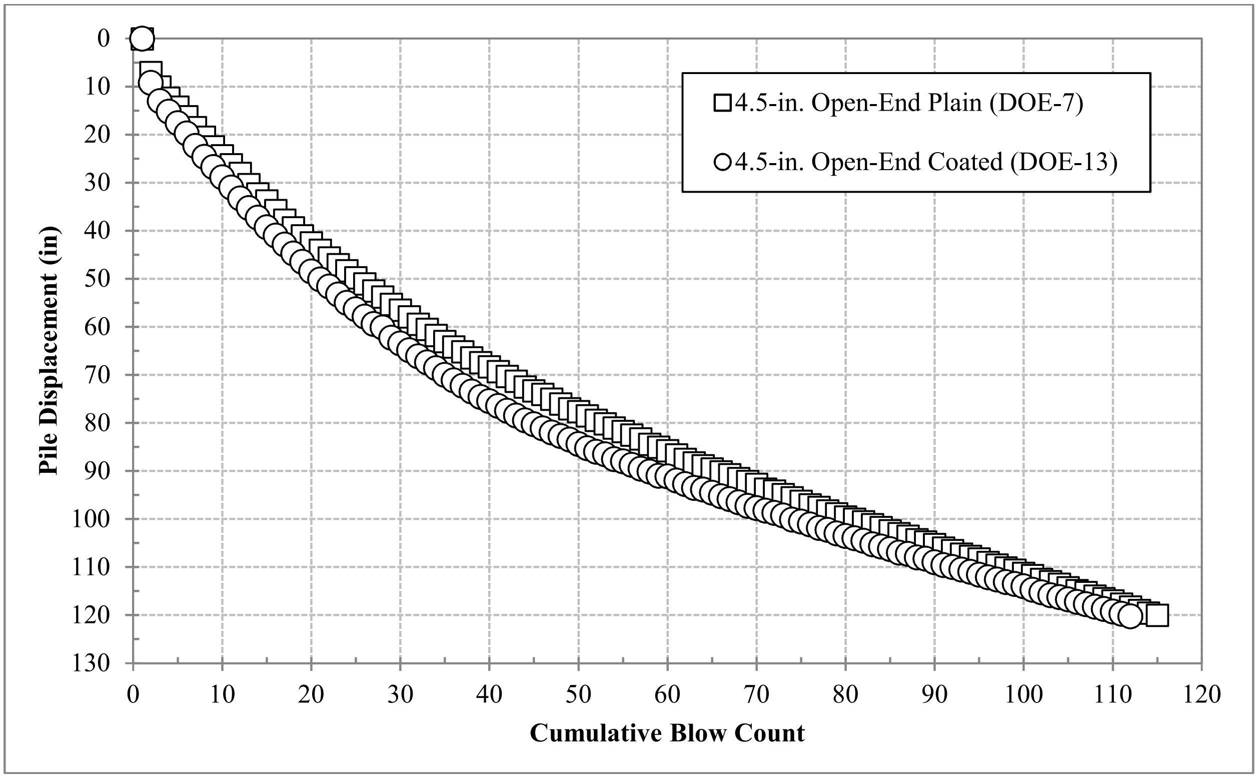

Figure 38. Pile Penetration Analysis of 4.5-inch Open-End Pipe Pile Plain and Coated (DOE Site).

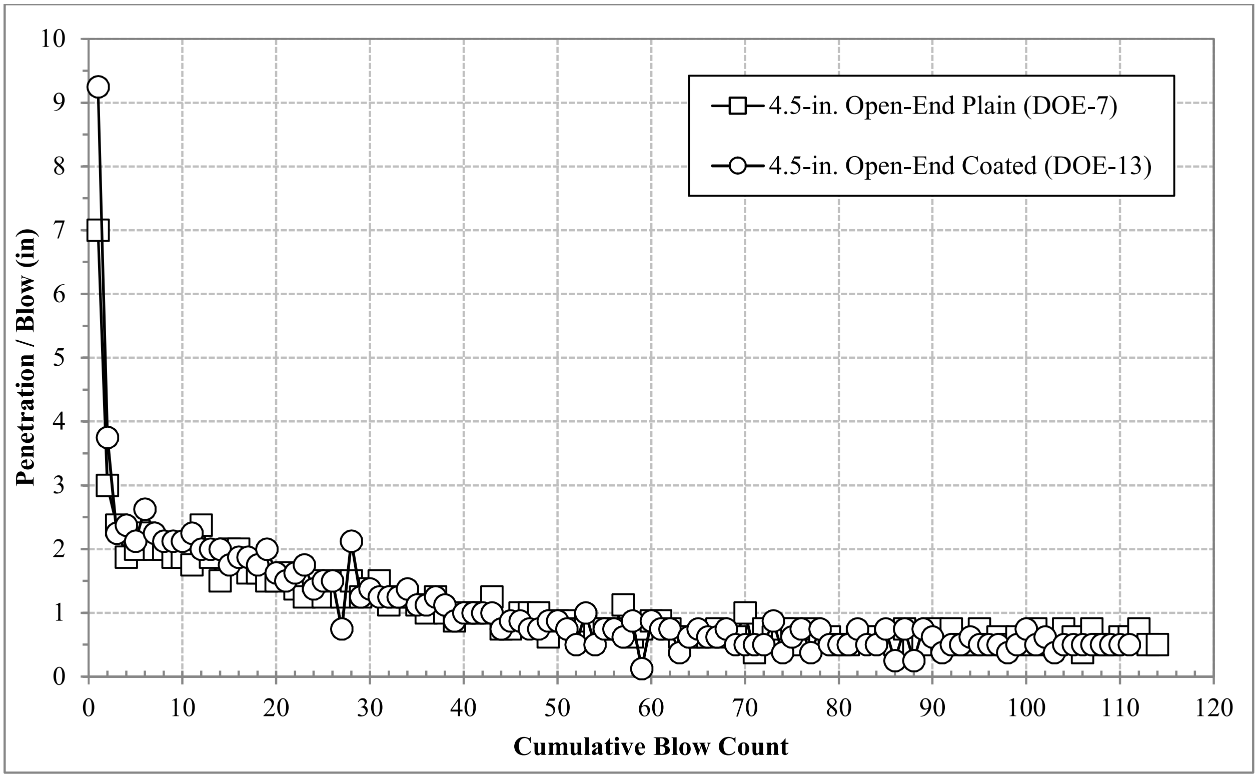

Figure 39. Penetration per Blow Analysis of Open Pipe Piles with Varying Diameters (DOE Site)

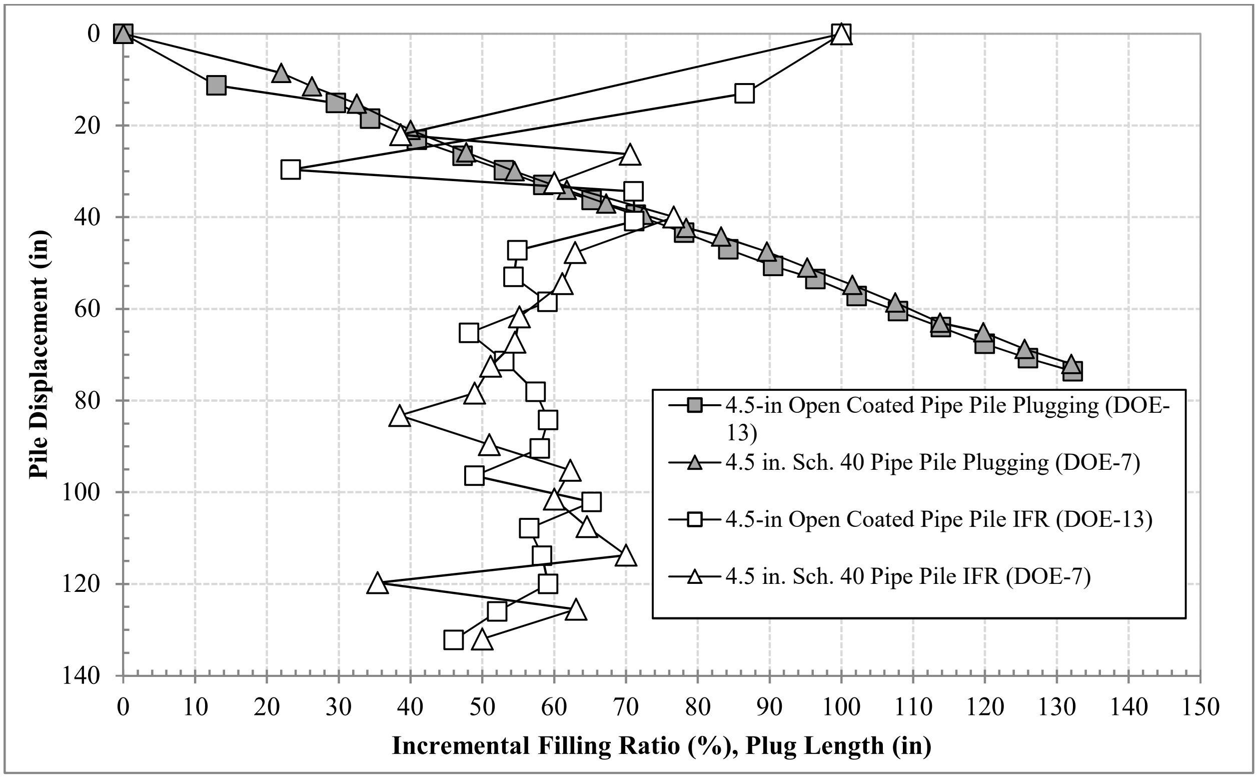

Figure 40. Pile Plugging Analysis of Open Pipe Piles with Varying Diameters (DOE Site).

Figure 40 demonstrates the plugging relationship between a 4.5-inch coated and non-coated pipe piles. The data illustrates that there is a negligible influence on pile driving as a result of pile coating exclusively. The 4.5-inch coated pipe pile exhibited a PLR of 63.7%, while the non-coated pile exhibited a PLR of 61.2%; the IFRs were also similar, exhibiting 46% and 50%, respectively. Similarly, the average penetrations per blow and total cumulative blow counts for the 4.5 inch coated pipe pile were 1.1 and 111, respectively, as compared to the non-coated pipe pile, which were 0.8 and 114, as illustrated formerly in Figure 38 and Figure 39.

5.3 MECHANISMS RELATED TO A GAIN IN (TENSION) CAPACITY OF PILES

Driven piles in many soil profiles may experience an increase in their tension capacity as a function of time. This time-dependent gain in capacity is referred to as "pile setup". This gain in capacity is believed to occur in a diversity of pile types, including H-piles and pipe piles, and in a broad range of soil profiles (e.g. clay and sand). Some of the main mechanisms associated with this increase in the short and long-term capacities of piles in clay profiles have been well established.

The first mechanism is an increase in the effective stress in the soil adjacent to the pile as a result of excess pore water pressure dissipation generated during pile driving and soil disturbance caused by the pile as it is driven. Second, an increase in the Undrained Shear Strength due to the thixotropic behavior of the clay soil following the soil disturbance from pile driving.

Research by Titi and Wathugala (1999) recognized that setup of piles in clay soils is a function of both the increase in the effective stress (due to pore pressure generation and dissipation as a result of pile driving) and also the thixotropic gain of soil strength over time.

5.3.1 PORE WATER PRESSURE DISSIPATION

During pile driving, a volume of clay equal to the volume of the pile will have to be displaced in one way or another (Flaate, 1971). The displacement of the surrounding soil (remolded zone) experiences a degree of consolidation due to remolding of the soil and reduction in water content, thus a reduction in void ratio during the penetration of the pile. Water dissipates in the opposite direction of the pile, causing a reduction in the water content near the pile surface. Since water content is inversely proportional to the shear strength, an increase in the remolded shear strength occurs. The geometry of the pile and the type of soil will determine the amount of displacement, remolding and pore water pressure dissipation. Flaate (1971) stated that the properties of clay are probably the main factor in determining the extent of the remolded zone.

5.3.2 WATER CONTENT BEFORE AND AFTER PILE DRIVING

In order to study the aging behavior of the clay surrounding the pile before and after pile driving, two "dummy" piles, a 4.5-in. closed-end and a 4.5-in. open pipe pile, were installed at the DOE site. These piles were never load tested but their geometry was identical to piles installed at this site that were load tested. A series of field vane tests were performed along the soil immediately adjacent to the pile at 1-foot depth intervals at 0 (immediately after pile driving), 1, 35, and 167 days after pile driving, respectively. At the culmination of each field vane test, a soil sample adjacent to the pile surface was collected for laboratory determination of water content. The soil samples were used to determine water content at the predetermined aging time to create a water content profile with respect to time and possibly determine the extent of the pore water pressure dissipation with respect to time. Samples were collected in order to determine the change in water content of the soil adjacent to each pile with respect to time after pile driving. The samples used for laboratory water content determination were collected alongside the pile wall from within the assumed disturbed zone (Figure 41) since the extent of this disturbed or remolded zone was not accurately known. Overall, the disturbed zone of the closed-end pipe piles is expected to be larger since close-end pipe piles displace more soil during driving. The approximate locations of the series of field vane tests performed in the soil adjacent to the piles are shown in Figure 42.

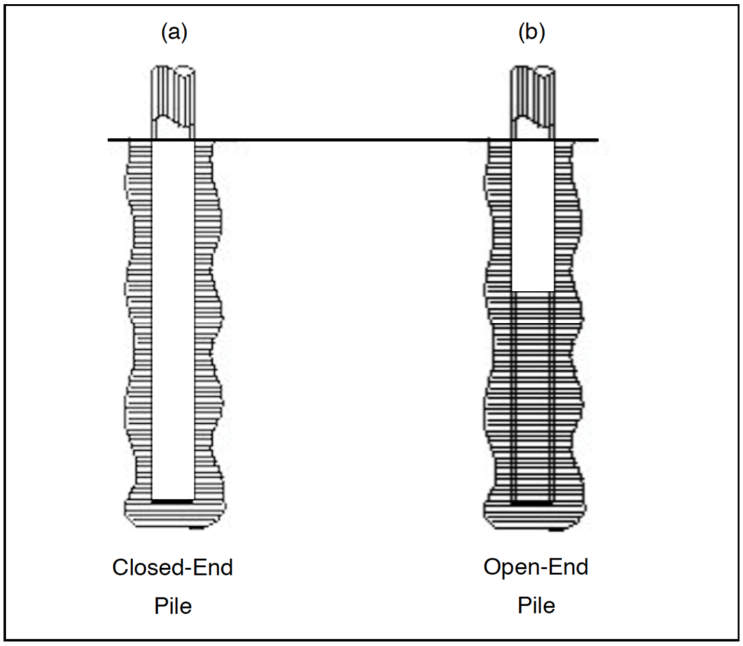

Figure 41. Disturbed or Remolded Zone of (a) Closed and (b) Open-End Pipe Piles (modified from Foundations Course Notes, University of Ljubljana).

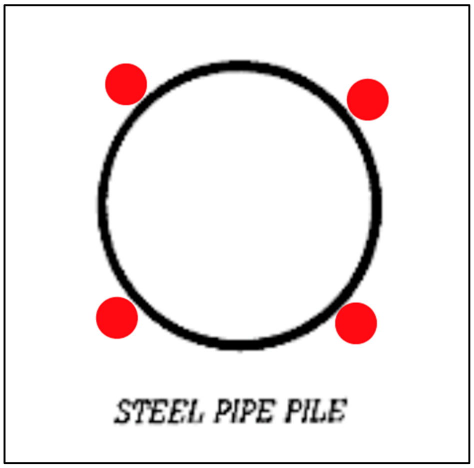

Figure 42. General Cross Section of Pipe Pile with Approximate Locations of Collected Soil Sample Sets (Red Circles) Around the Closed and Open-End Pipe Piles (modified from www.thecivilbuilders.com).

5.3.2.1 CLOSED-END PIPE PILE

Figure 42 shows the changes in the water content of the soil surrounding the 4.5-in. closed-end pipe pile (DOE-29) at 1-foot depth intervals. The water content showed a reduction of 3.1% from “before pile driving” to immediately after “end of pile driving”. After 24 hours, the water content continued to decrease an average of 2.6%, and at 35 days the water content increased an average of 3.2%, which could indicate that most of all the excess pore water pressure dissipated approximately after 1 month. At 167 days, the difference between the average water content at that period of time and the initial or natural water content was merely 1.1%.

In general, the soil surrounding the 4.5-in. closed-end pipe pile (DOE-29) showed an immediate reduction in water content that was later accompanied by an increase in water content along most of the pile length. The maximum increase in water content was observed at approximately 35 days after pile driving. The majority of the samples collected after 35 days, exhibited a decrease. At approximately 125 and 166 days after pile driving, the water content was equal or higher than the natural water content of the site, which indicates complete dissipation of the pore water pressure. In general, the exact duration of the dissipation rate is difficult to determine given the number of days between 35 and 167 days.

5.3.2.2 OPEN-END PIPE PILE

The average water content of the soil surrounding the 4.5-in. open-end pile (DOE-30) showed a reduction of 3.4% from “before pile driving” to immediately after “end of pile driving”. 1 day after end of pile driving, the water content continued to decrease at an average of 1.3%. The increased in water content after 35 days an average of 1.5% could possible indicate that the all the excess pore water pressure dissipated approximately after one month. The average difference between the water content at 167 days and the initial water content was less than 1%. The small differences between the water content at 167 days and the initial water content showed that the water content stabilized after almost 6 months due to hydrostatic conditions. After complete dissipation of the excess pore pressure, any difference in water content could be attributed to groundwater level fluctuations caused by changes in temperature or precipitation or a combination of the two.

In general, the water content of the soil surrounding the 4.5-in open-end pile (DOE-30), which had FFR of 68.5% or a soil plug length of 66.875 inches showed the same trend as the 4.5-in. closed-end pile. From Figure 44, it can be observed that there was an immediate reduction in water content, which in some cases, was later accompanied by an increase in water content. The duration of the dissipation rate was approximately between 125 and 166 days.

The dissipation rate could be influenced mainly by the soil's sensitivity and hydraulic conductivity. Since the pore water pressure dissipation lasted approximately the same time for piles that displace different volumes of soil, the pore water pressure could be soil dependent and not pile dependent.

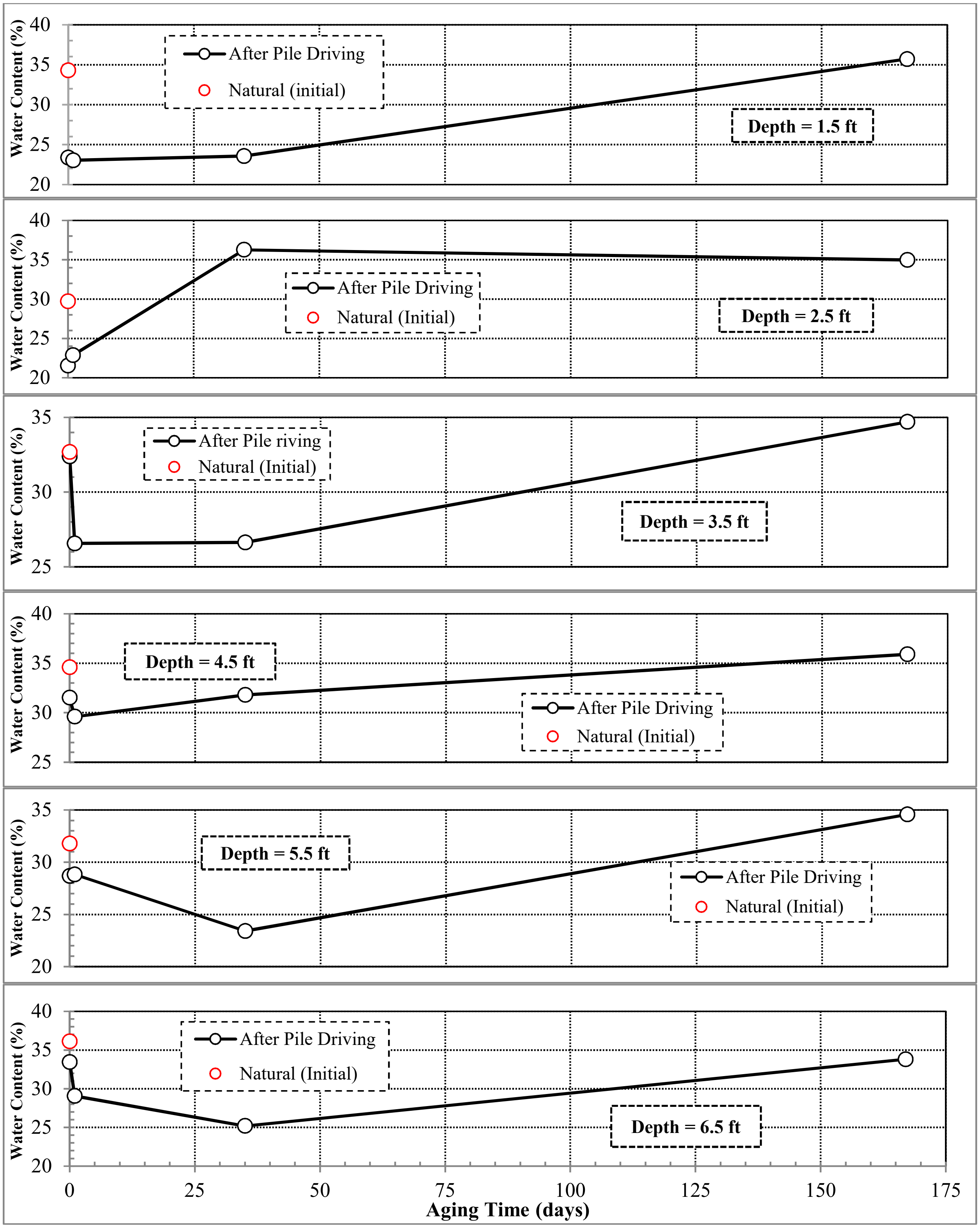

Figure 43. Changes in Water Content between 0 and 6.5 feet Below Ground Surface Before and After Pile Driving with Respect to Aging Time (4.5-in. Closed-End DOE-29) - Continued.

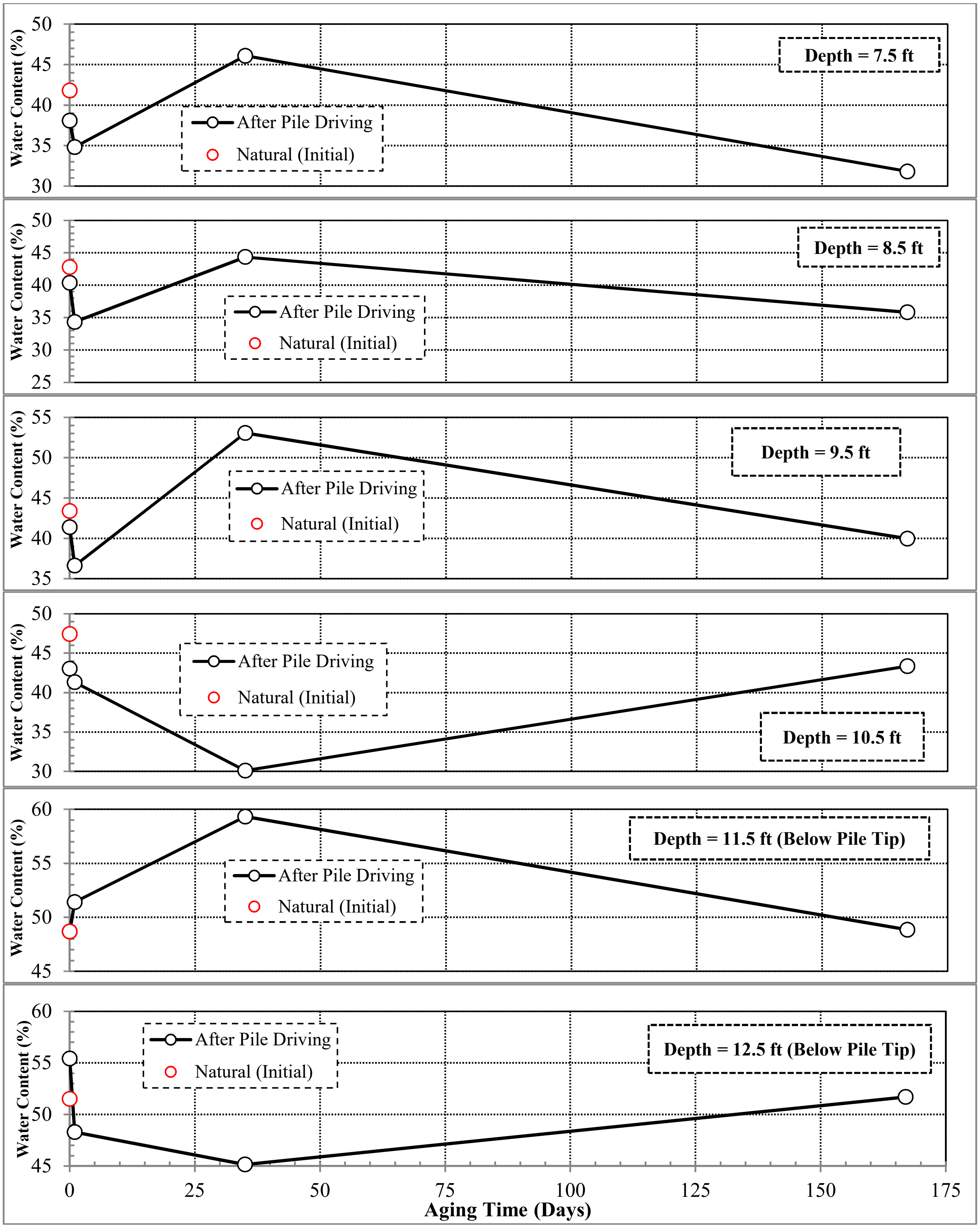

Figure 44. Changes in Water Content between 7.5 and 12.5 feet Below Ground Surface Before and After Pile Driving with Respect to Aging Time (4.5-in. Closed-End DOE-29).

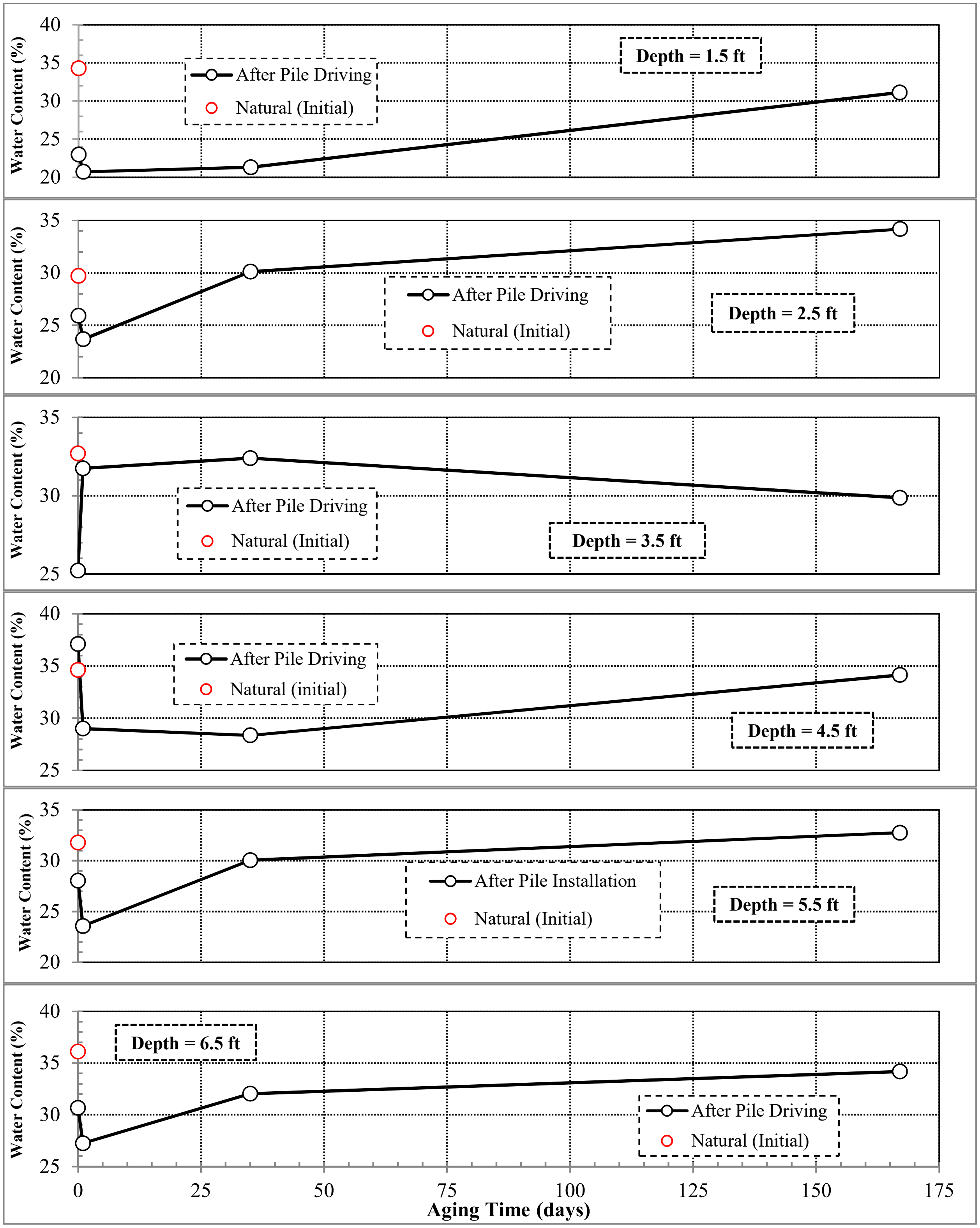

Figure 45. Changes in Water Content between 0 and 6.5 feet Below Ground Surface Before and After Pile Driving with Respect to Aging Time (4.5-in. Open-End DOE-30) - Continued.

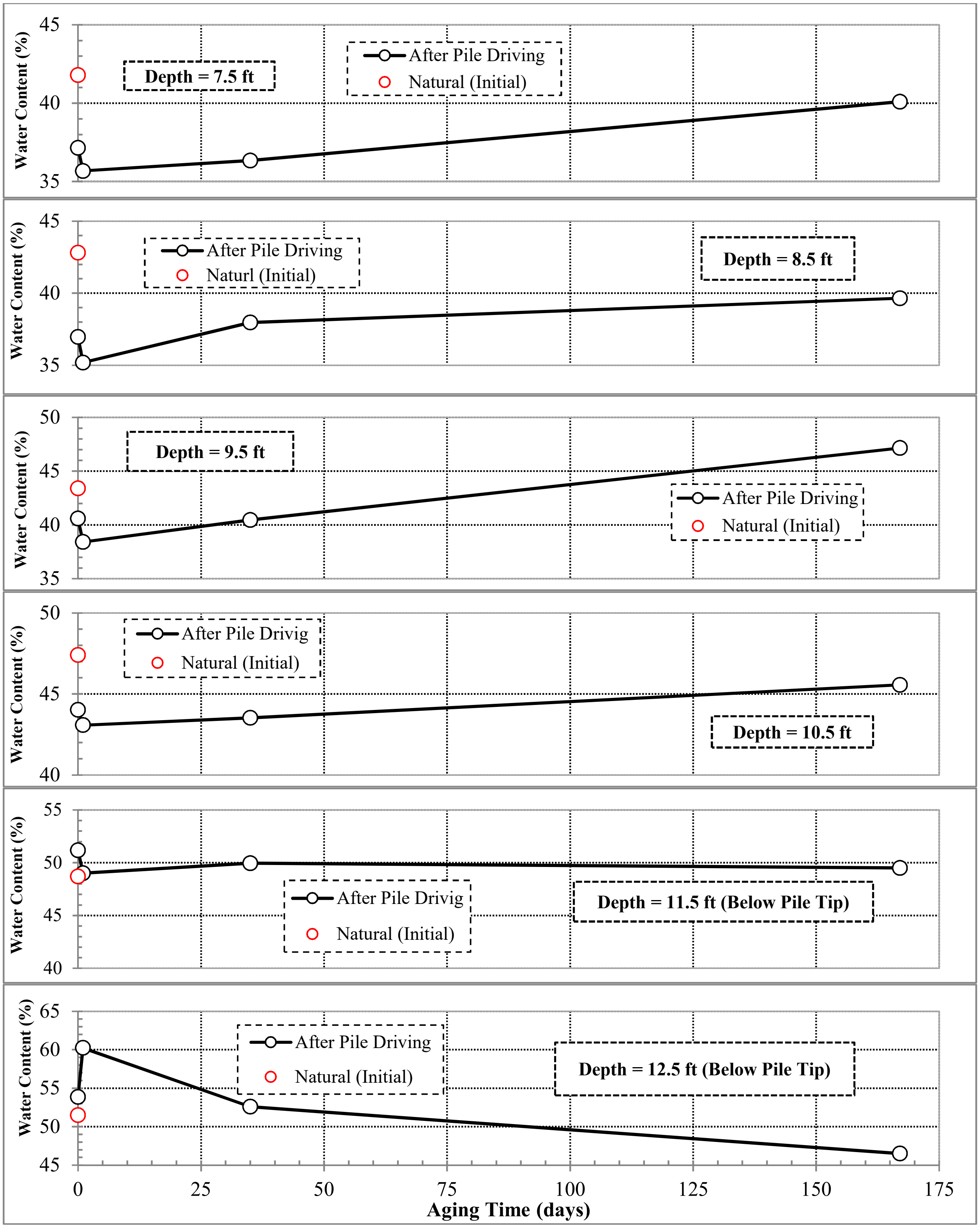

Figure 46. Changes in Water Content between 7.5 and 12.5 feet Below Ground Surface Before and After Pile Driving with Respect to Aging Time (4.5-in. Open-End DOE-30).

Immediately after pile driving, a noticeable water content change was evident. The highest changes in water content happened within the first 8 – 9 feet below ground surface. The rate of pore water pressure dissipation was observed to be constant along most of the pile lengths, but independent to the amount of pore water pressure dissipated. Water content values were more pronounced at shallower depths than at deeper depths. The water content profile showed a proportional trend with respect to depth. On the other hand, water content changes that occurred after pile driving showed an inversely proportional behavior, as the depth increases the percent change in water content decreases (Figure 47 and Figure 48).

Both piles showed the same trend regarding the difference in water content after pile driving but the 4.5-in. closed-end pipe pile (DOE-29) experienced the higher changes in water content close to the ground surface when compared to the 4.5-in. open-end pipe pile (DOE-30), which experienced a decrease in water content change with increased depth. For example, the water content at 1.5 feet ranges from 20.7% to 34.3% and from 49.0% to 50.0% at 11.5 feet, in the area adjacent to the 4.5-in. open-end pipe pile (DOE-30) Also, in the area adjacent to the 4.5-in. closed-end pipe pile (DOE-29), the water content at 1.5 feet ranges 23.6% and 35.7% and at 12.5 the range is from 41.3% and 47.4%.

During pile driving, the soil and pile interaction decreases with depth. Comparably, the soil disturbance decreases with depth, as the pile wall and surrounding soil experience less contact. Any soil section near the ground surface comes in contact with most of the pile as it moves down, but at deeper depths any soil section experiences limited contact since it is closer to the pile tip.

Also, during pile driving, the energy imparted to the pile by the hammer and the vibration caused by hammering the pile dissipates with depth, which could explain part of the higher soil disturbance closer to the ground surface. The behavior of the water content indicates that the soil disturbance is proportional to the change in water content. For this reason, the pile displacing less soil, 4.5-in. open-end pipe pile (DOE-29), generates less pore water pressure and the water content decrease is less compared to the 4.5-in. closed-end pipe pile (DOE-30).

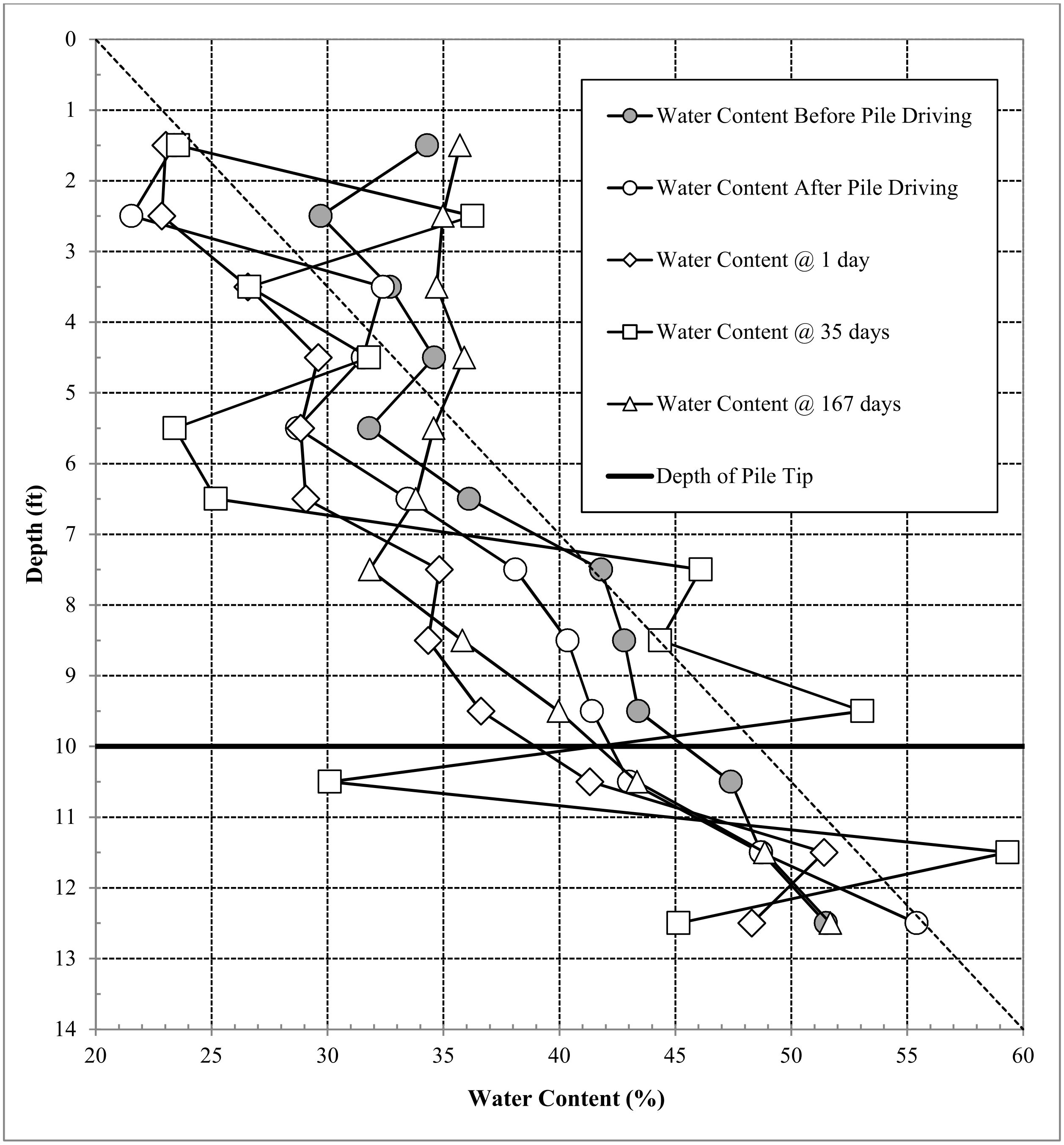

Figure 47. Water Content Variation Range with respect to Depth (4.5-in Closed, DOE-29).

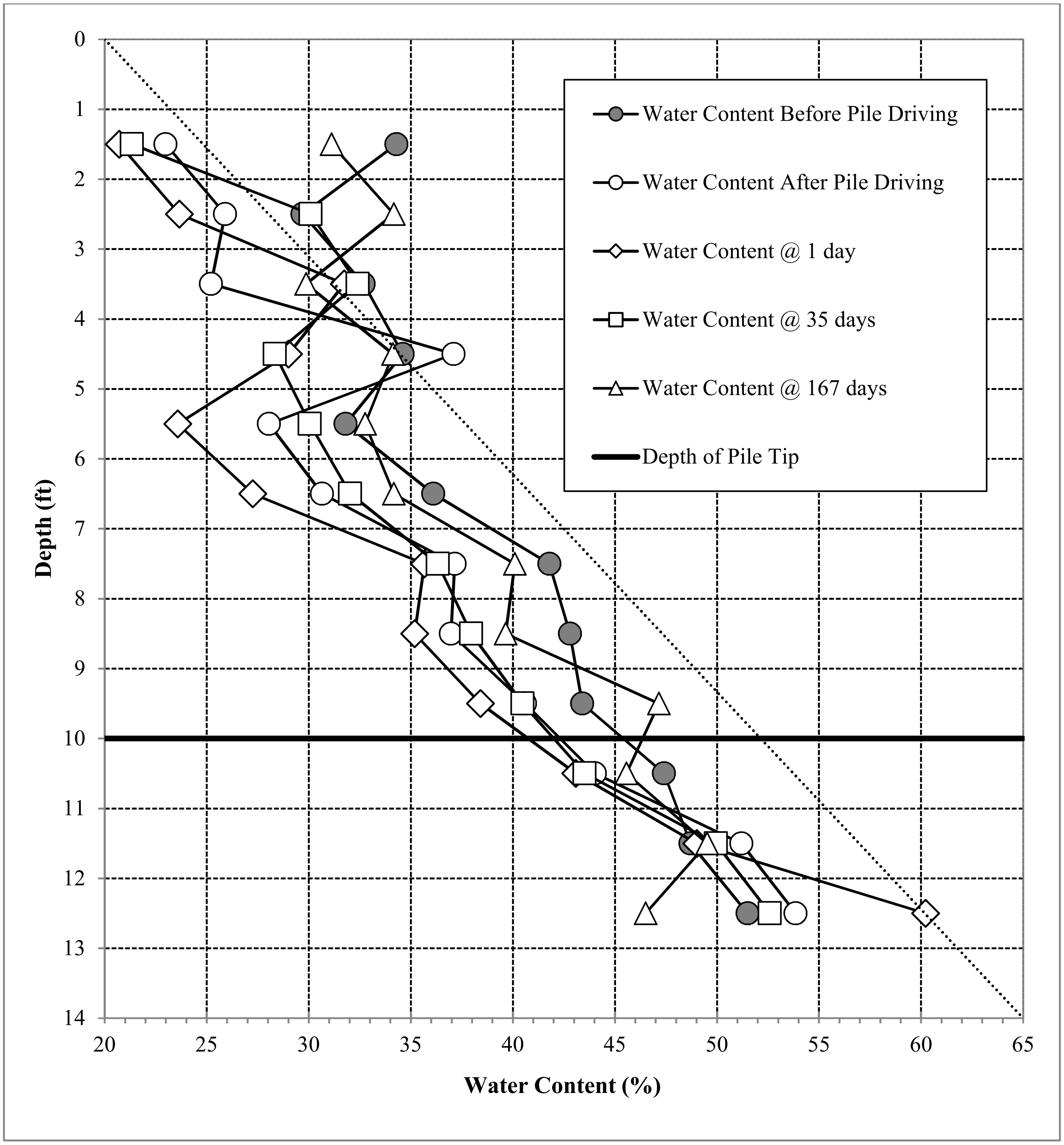

Figure 48. Water Content Variation Range with respect to Depth (4.5-in Open, DOE-30).

The pore water dissipation commences immediately after pile driving, while the consolidation of the soil alongside the pile starts at the end of pile installation (after the disturbance of the soil stops). During pile driving, the Undrained Shear Strength of the soil along the pile decreases due remolding of the soil. After the pore water dissipation, the soil's Undrained Shear Strength increases due to consolidation. Undrained Shear Strength of the soil decreases as the water returns.

This phenomenon is not very noticeable or clear in open-end pile, since the soil displacement and pore water dissipation occurs in all directions due to the geometry of the pile. During the use of closed-end piles, the soil and pore water dissipation occurs in the opposite directions of the pile wall since the pile does not plug.

5.3.3 PORE WATER PRESSURE DISSIPATION IN OVERCONSOLIDATED & NORMALLY CONSOLIDATED SOILS.

As previously mentioned, the generated excess pore pressure field decreases linearly with the logarithm of the radius from the pile. The radial extent of the excess pore pressure field decrease with increasing plasticity index and OCR (Bergset, 2013). As the extent of the generated excess pore pressure is shorter for the overconsolidated soils, shorter consolidation times are predicted for these same soils. Further, the consolidation time tend to increase with increasing plasticity index (Bergset, 2013). Because the extent of the pore water pressure dissipation is shorter for overconsolidated soils than for normally consolidated soils, the duration of pore water dissipation is also expected to last longer due to a lower hydraulic conductivity related to soils with higher OCR values.

Paiwkosky (1993) observed a clear pattern of higher OCR values leading to faster dissipation times for Boston Blue Clay. That same dissipation rate pattern was also observed to be constant between Boston Blue Clay and other soils with OCR between one and two.

Burns and Mayne (1998) proposed a new analytical method that describes the overall form of the response dissipation curve based on piezocone data obtained from sites with clayey soils. Figure 49Figure 50Figure 51 show the normalized dissipation curves estimated for values of internal friction angle (ϕ') equal to 20°, 30°, and 40°. The lower value of internal friction angle (φ') leads to more significant differences in behavior for different values of OCR. Burns and Mayne (1998) explained that this is because the lower value of the friction angle leads to a smaller initial magnitude of pore pressure, and a more rapid decay of the pressures when the values are normalized to the initial value.

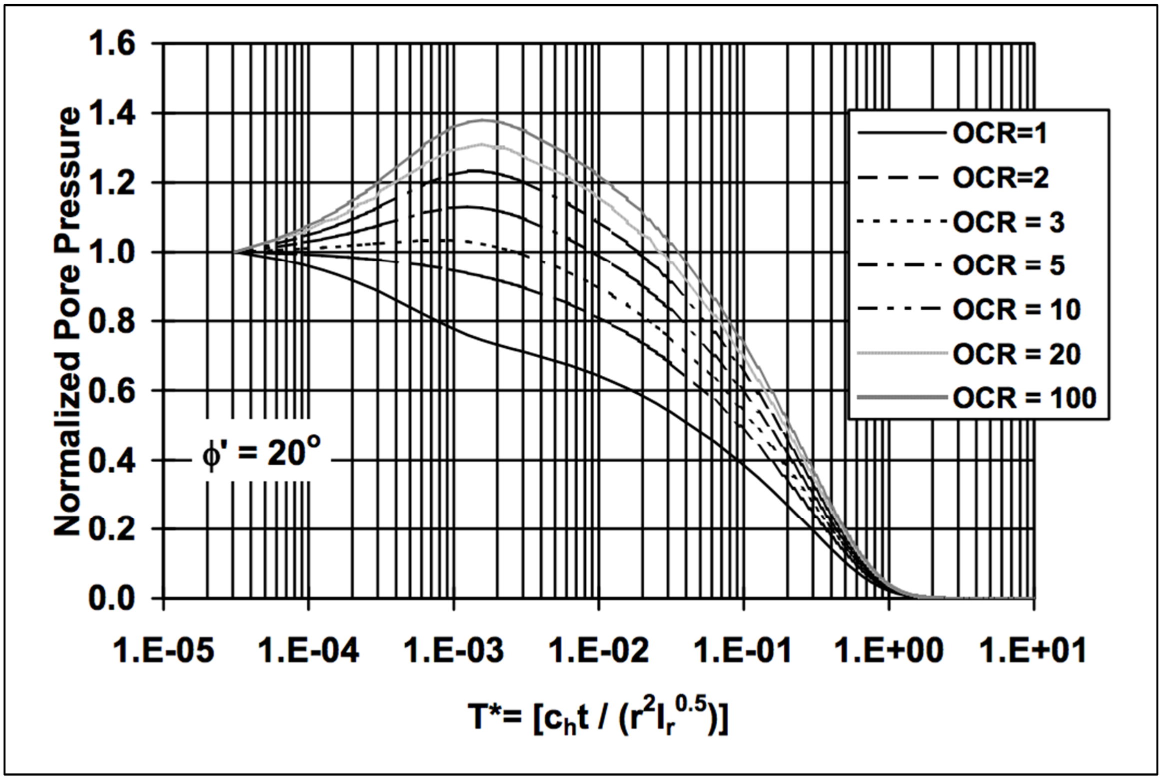

Figure 49. Normalized Dissipation Curves for φ' =20°.

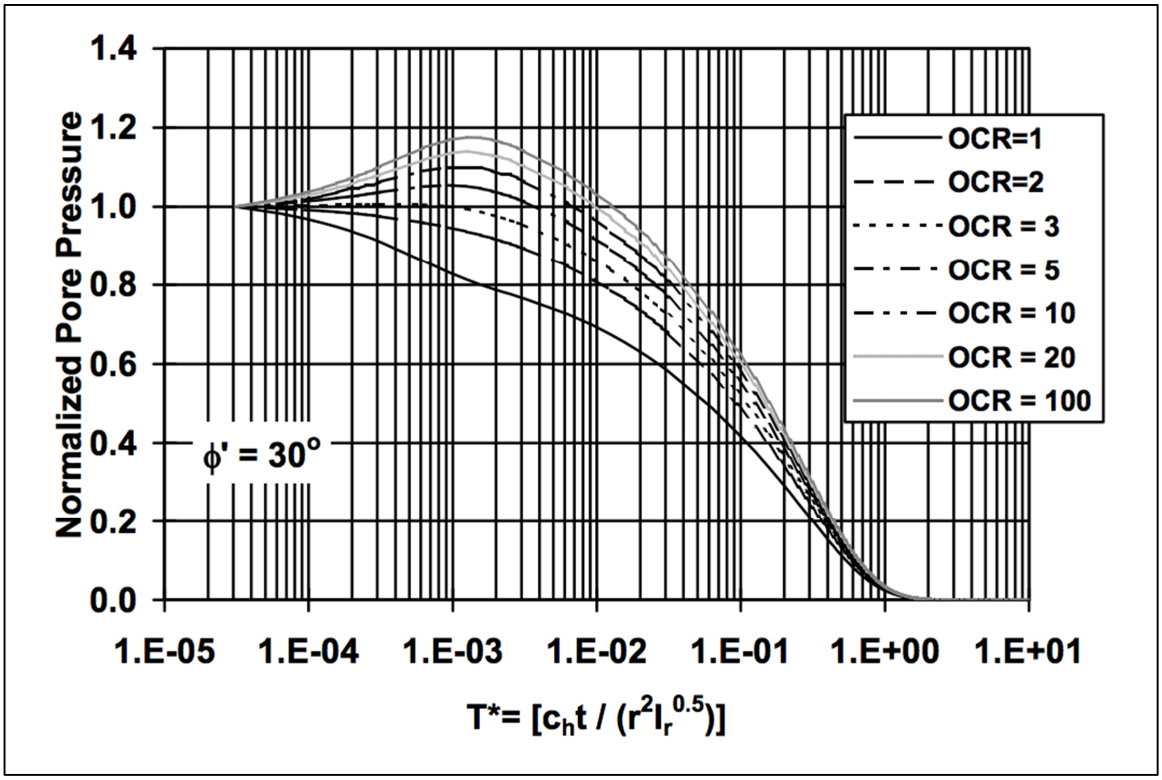

Figure 50. Normalized Dissipation Curves for φ' =30°.

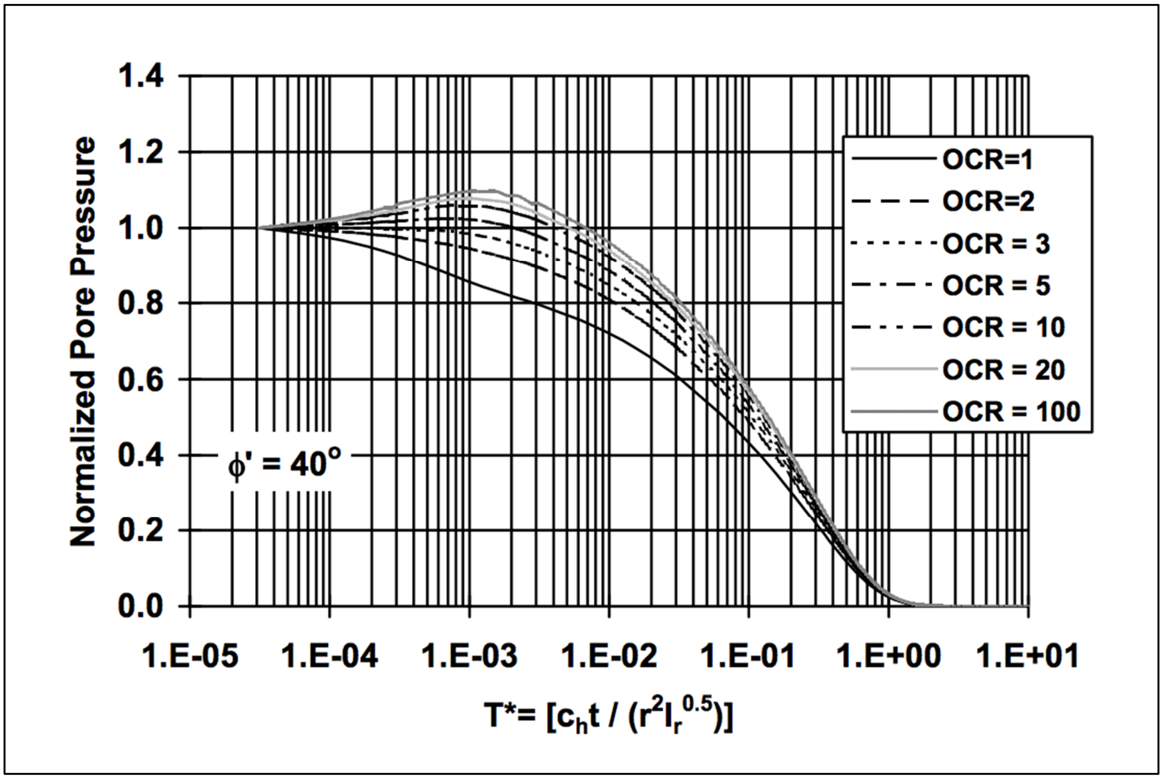

Figure 51. Normalized Dissipation Curves for φ' =40°.

In normally consolidated soil the model gives a monotonic decay of the dissipation curve. In this method, the calculated normalized excess pore pressure increases with overconsolidation but decreases with angle of internal friction and rigidity index (Bałachowski, 2006).

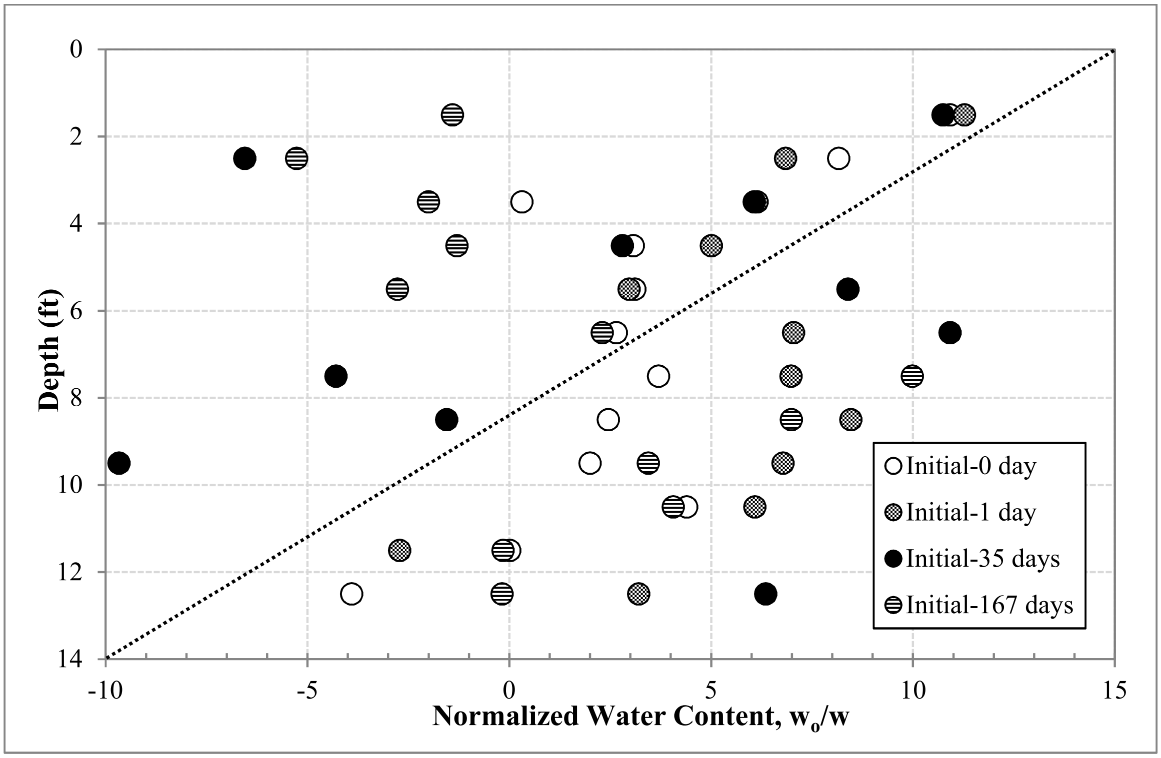

Figure 52. Changes in Normalized Water Content around 4.5-inch Closed End Pipe Pile (DOE Site).

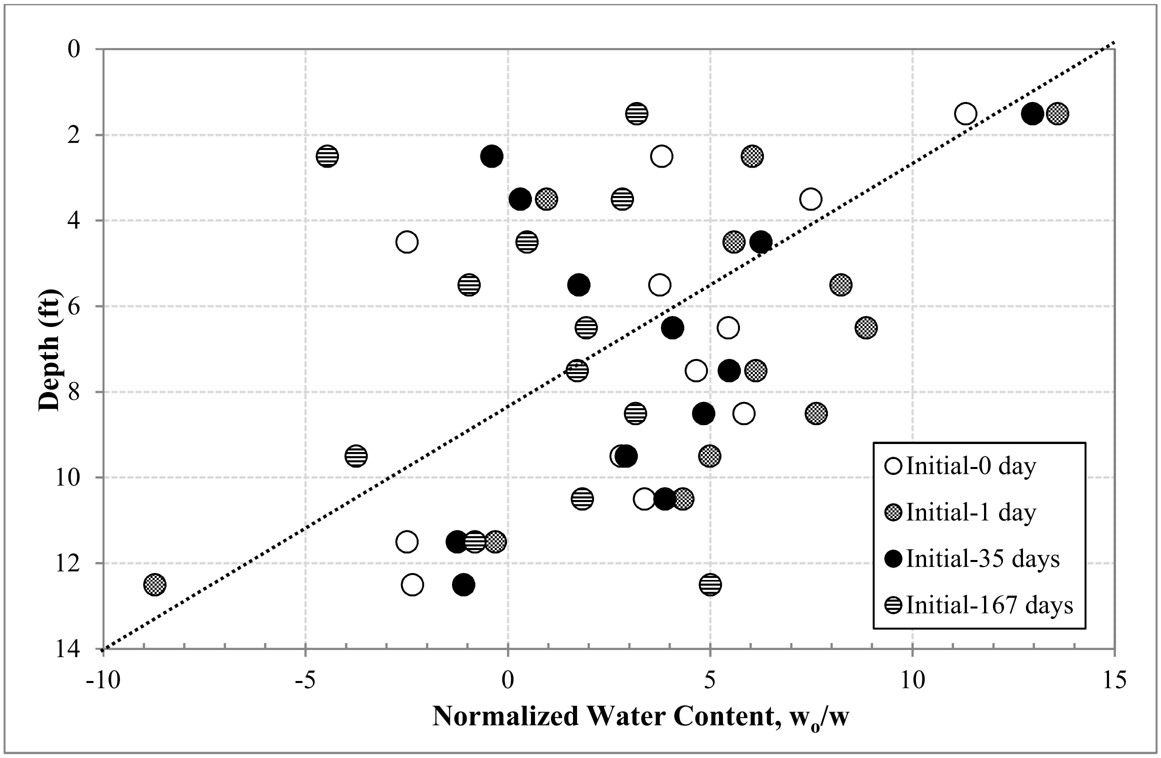

Figure 53. Changes in Normalized Water Content around 4.5-inch Open End Pipe Pile (DOE Site).

The normalized water content of the soil along the pile length was observed to follow the same decrease with depth. The changes in water content were more pronounced along the closed-end pipe pile (Figure 52), based on the scattered data. The wider ranged in normalized water content occurs to due to a higher amount of soil displaced and the dissipation of the pore water pressure opposite to the pile wall.

5.3.4 UNDRAINED SHEAR STRENGTH BEFORE AND AFTER PILE DRIVING

A series of field vane tests along both piles at 1-foot intervals were performed at 0 (immediately after pile driving), 1, 35 and 167 days after pile driving in the soil adjacent (approximately 0.5 inches from pile wall) to the 4.5-in. open-end pipe pile and 4.5-in. closed-end pipe pile in order to study the thixotropic behavior of the soil after pile driving. Table 8 andTable **9** summarize the change in Undrained Shear Strength throughout the testing period. Figure 54 through Figure 59 show the change in Undrained Shear Strength of the soil adjacent to the pile with respect to time after pile driving.

Table 8. Average Change in Undrained Shear Strength after Pile Driving (4.5-in. Closed-End Pipe Pile, DOE-29).

	Avg. Percent Change (%) in Undrained Shear Strength, Su			
	Before – 0 day	Before – 1 day	Before – 35 days	Before – 167 days
Peak	-8.2	-18.6	-32.7	-47.4
Post-Peak	20.9	21.1	-19.0	-38.2

Table 9. Average Change in Undrained Shear Strength after Pile Driving (4.5-in. Open-End Pipe Pile, DOE-30).

	Avg. Percent Change (%) in Undrained Shear Strength, Su			
	Before – 0 day	Before – 1 day	Before – 35 days	Before – 167 days
Peak	-14.3	-19.3	6.5	-33.0
Post-Peak	11.4	9.9	53.1	-20.5

The Undrained Shear Strength of the soil surrounding the 4.5-inch closed-end pipe pile (DOE-29) shows a decrease immediately after pile driving and continued to decrease along most of the pile up to 167 days after pile driving. The peak Undrained Shear Strength values before pile driving ranged from 120 to 288 kPa; after one day, values ranged from 135 to 278 kPa which shows an average difference of 20 kPa. After most of the pore water pressure dissipated (at 35 days), the peak Undrained Shear Strength was observed to be 33% lower than the peak Undrained Shear Strength before pile driving. After approximately one month, the peak Undrained Shear Strength values continued to decrease. The average reduction in peak Shear Strength from before installation and 0, 1, and 167 days after pile driving was of 8, 18 and 47%, respectively. The water content results showed that there was a noticeable reduction with aging time, which would result in an increase in the soil's Undrained Shear Strength. The peak Undrained Shear Strength values of the soil surrounding the 4.5-inch open-end pipe pile (DOE-30) decreased approximately 14% immediately after pile driving and continued to decrease 35 days after pile driving. The peak Undrained Shear Strength before pile driving ranged between 120 and 288 kPa and between 89 and 267 kPa after pile driving with an average difference of 30 kPa. At 35 days after pile driving the peak Undrained Shear Strength was observed to increase

6.5%. The peak Undrained Shear Strength at 167 days was equal to 77% of the Undrained Shear Strength before pile driving.

As previously mentioned, the changes in water content at deeper depths (between 6 and 12 feet below ground surface) were smaller when compared with shallower depths (between 1 and 6 feet below ground surface). Similarly, the changes in Undrained Shear Strength in this zone were smaller than at shallower depths. In general the percent change in Undrained Shear Strength values ranged between 8 and 15% at deeper depths, and from 16 to 31% at shallower depths.

The remolded Shear Strength values after installation, at 1 day, 35 days and 167 days ranged from 2.2 to 66.0 kPa. In general, the remolded Shear Strength values were approximately one-third of the reference shear strength values. The Remolded Shear Strength of the soil surrounding the 4.5-inch open-end pipe pile (DOE-30) seemed to have slightly decreased throughout most of the testing period. Overall, the remolded Undrained Shear Strength values were observed to have decrease between 13 and 23% from the initial remolded Undrained Shear Strength.

Since the soil surrounding the pile experiences the biggest changes in water content closer to the ground, the Undrained Shear Strength of the soil will be higher closer to the ground surface. The open-end pile (DOE-30) displaces less soil (less soil disturbance) during driving and before getting plugged thus resulting in higher Undrained Shear Strength than the closed-end pile (DOE-29).

The remolded Undrained Shear Strength could corroborate any change in water content since the Remolded Undrained Shear Strength does not change unless there is change in water content.

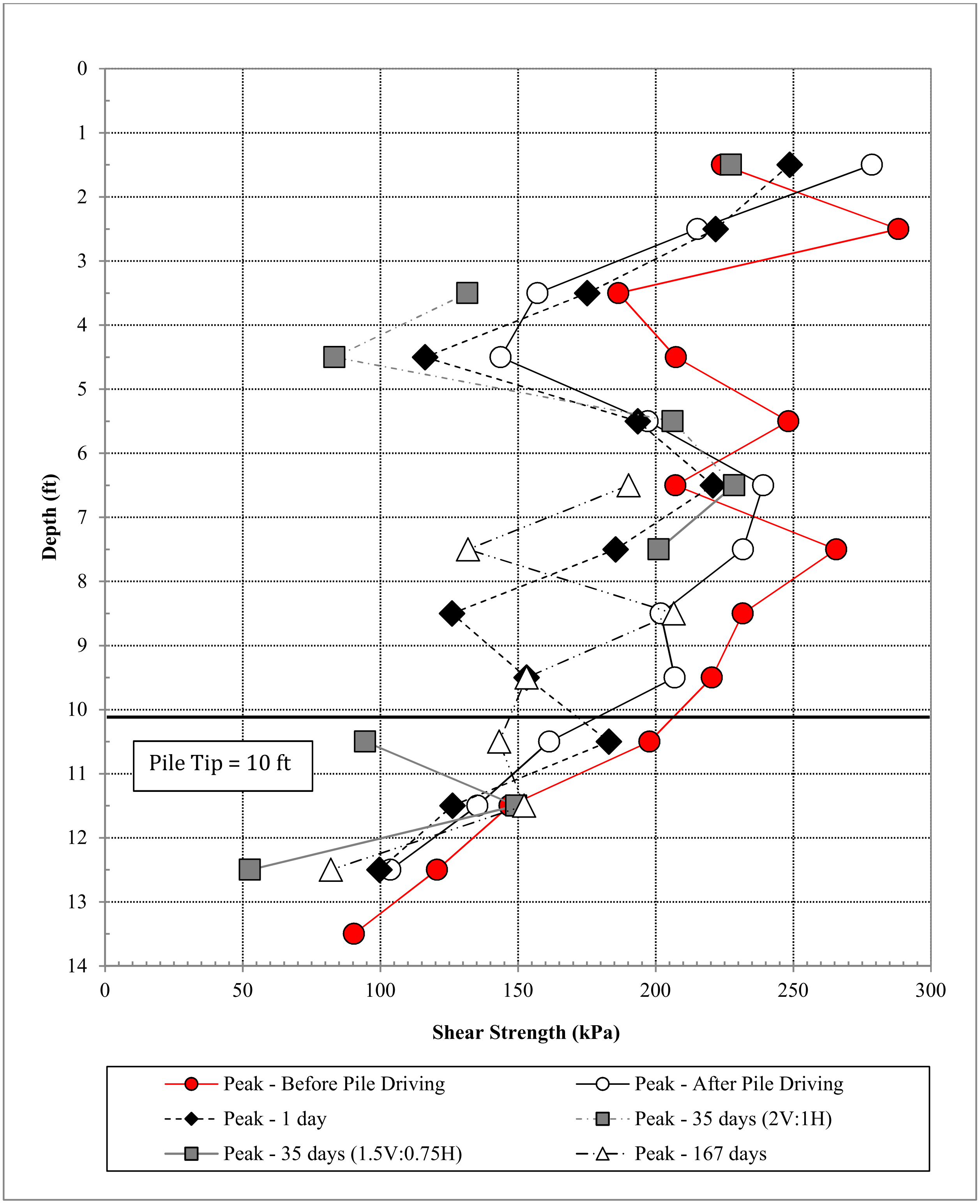

Figure 54. Variation in Peak Undrained Shear Strength with Time (Closed-End Pile, DOE-29).

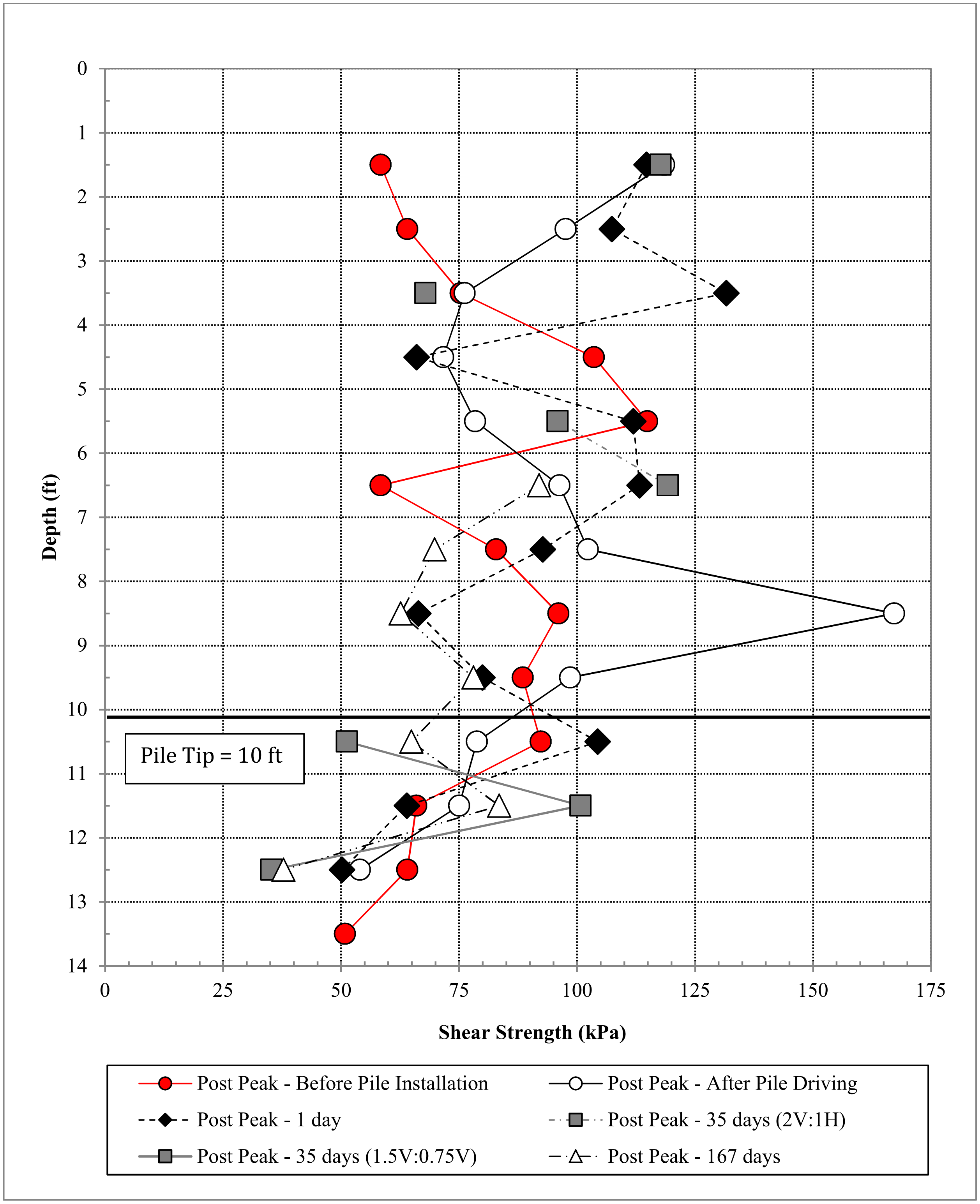

Figure 55. Variation in Post-Peak Undrained Shear Strength with Time (Closed-End Pile, DOE-29).

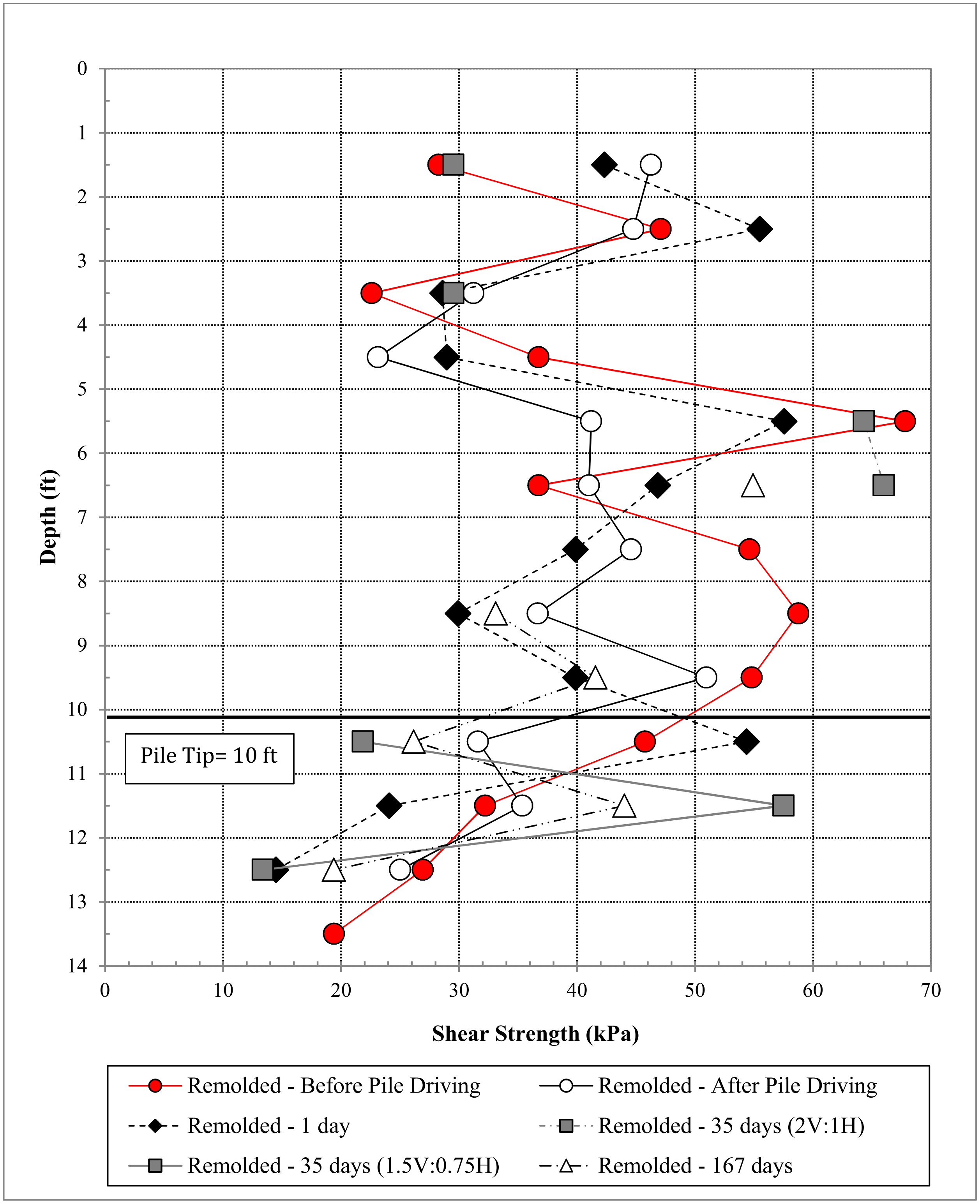

Figure 56. Variation in Remolded Undrained Shear Strength with Time (Closed-End Pile, DOE-29).

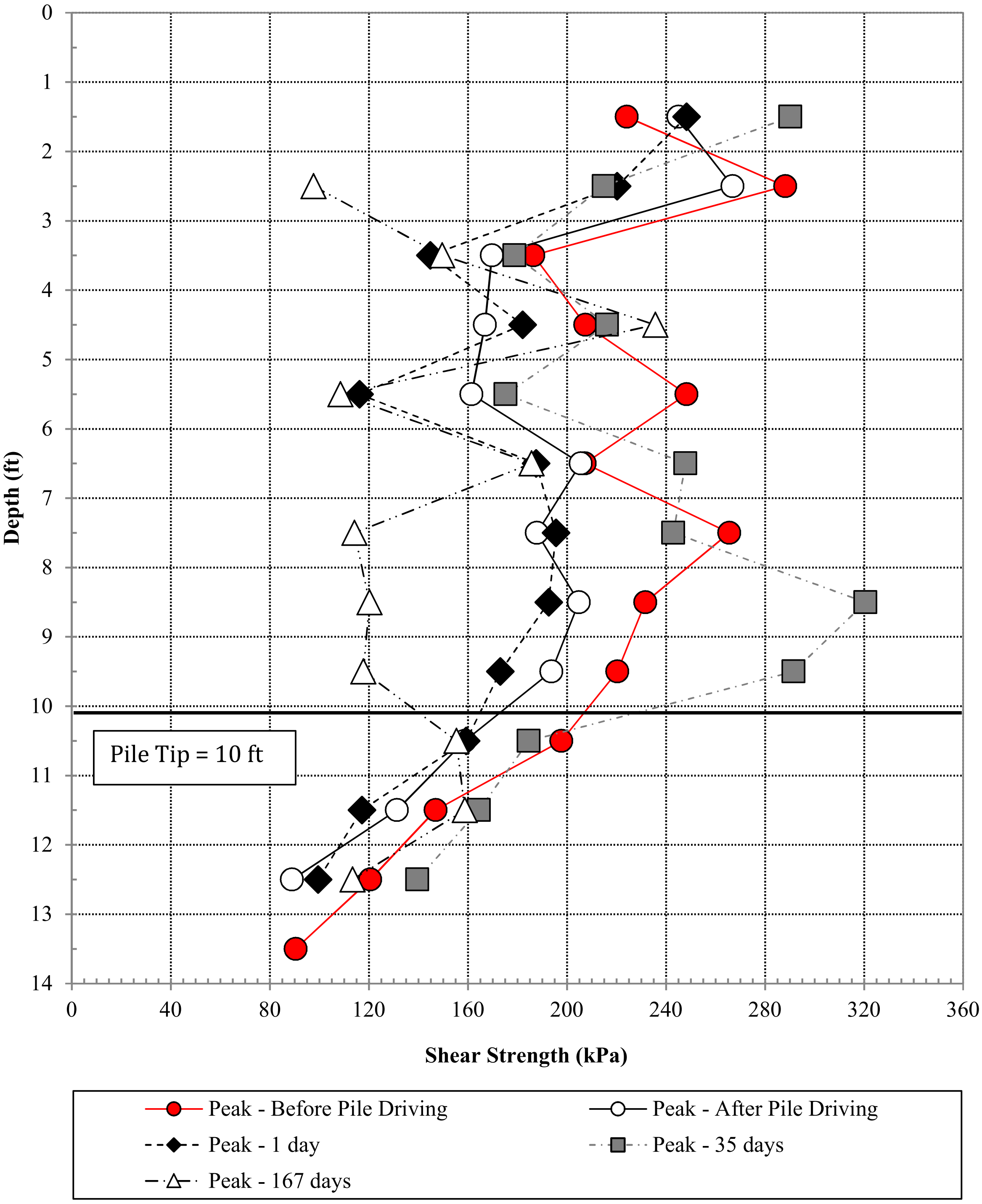

Figure 57. Variation in Peak Undrained Shear Strength with Time (Open-Ended Pile, DOE-30).

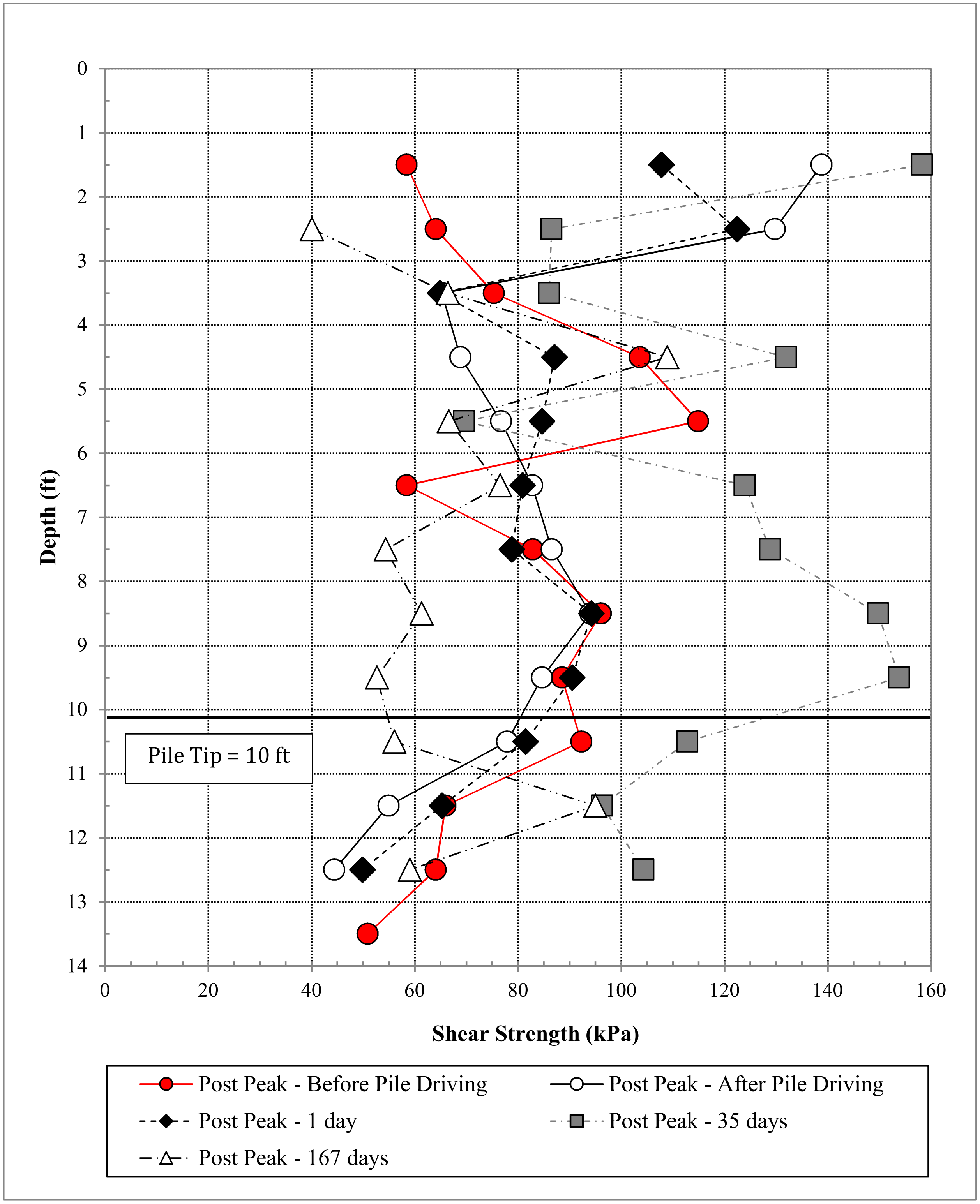

Figure 58. Variation in Post-Peak Undrained Shear Strength with Time (Open-Ended Pile, DOE-30).

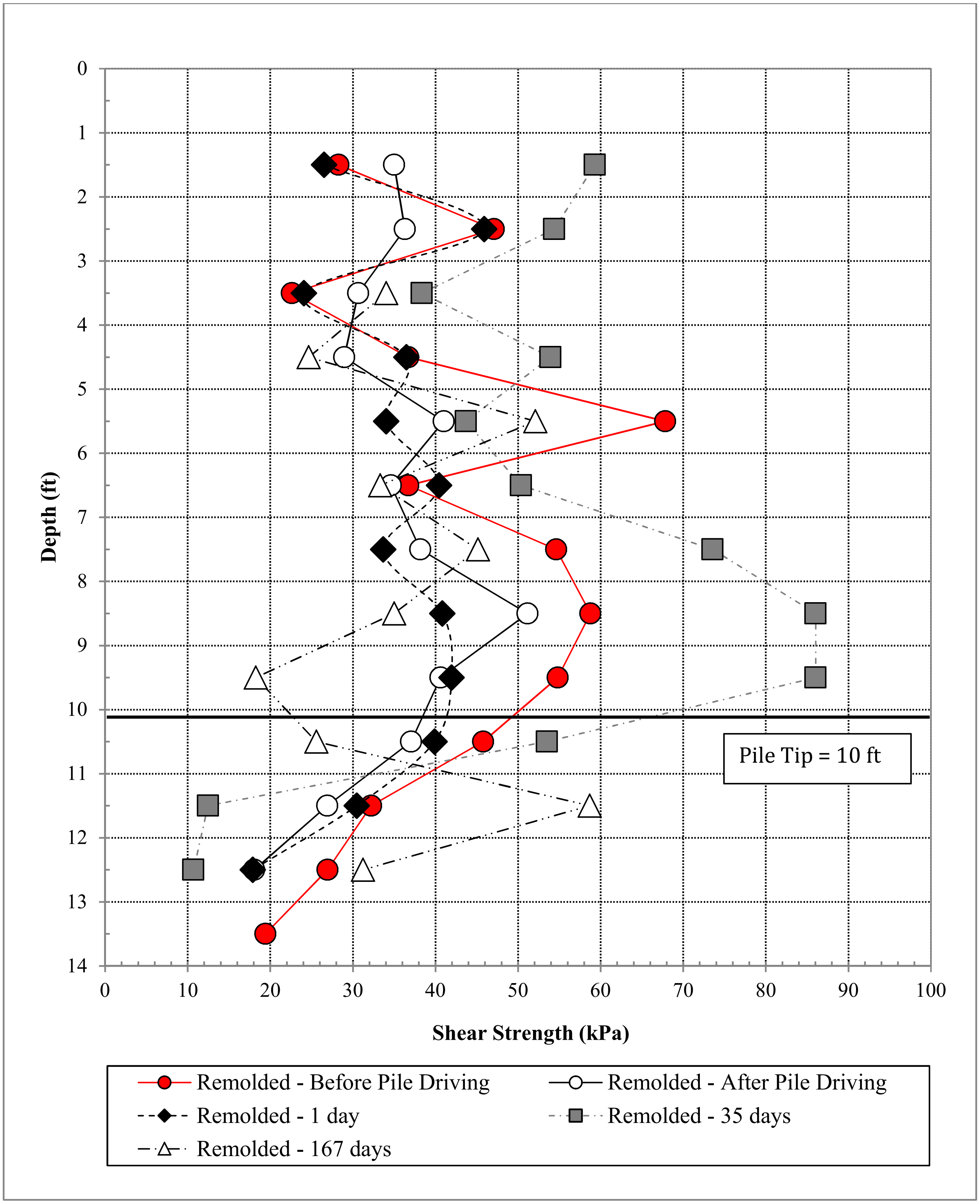

Figure 59. Variation in Post-Peak Undrained Shear Strength with Time (Open-Ended Pile, DOE-30).

Figure 60 presents the Undrained Shear Strength relationship with water content of the clay prior to pile driving. Peak Undrained Shear Strength values follow an exponential trend showing a inversely proportional behavior, as the water content decreases, the Peak Undrained Shear Strength increases. The values of the Peak Undrained Shear Strength at water content of 30 – 35% were of almost 3 times the Remolded Undrained Shear Strength. Post Peak Undrained Shear Strength values were very close to the Remolded Shear Strength values, with both exhibiting a slight increase in Undrained Shear Strength with decreasing water content.

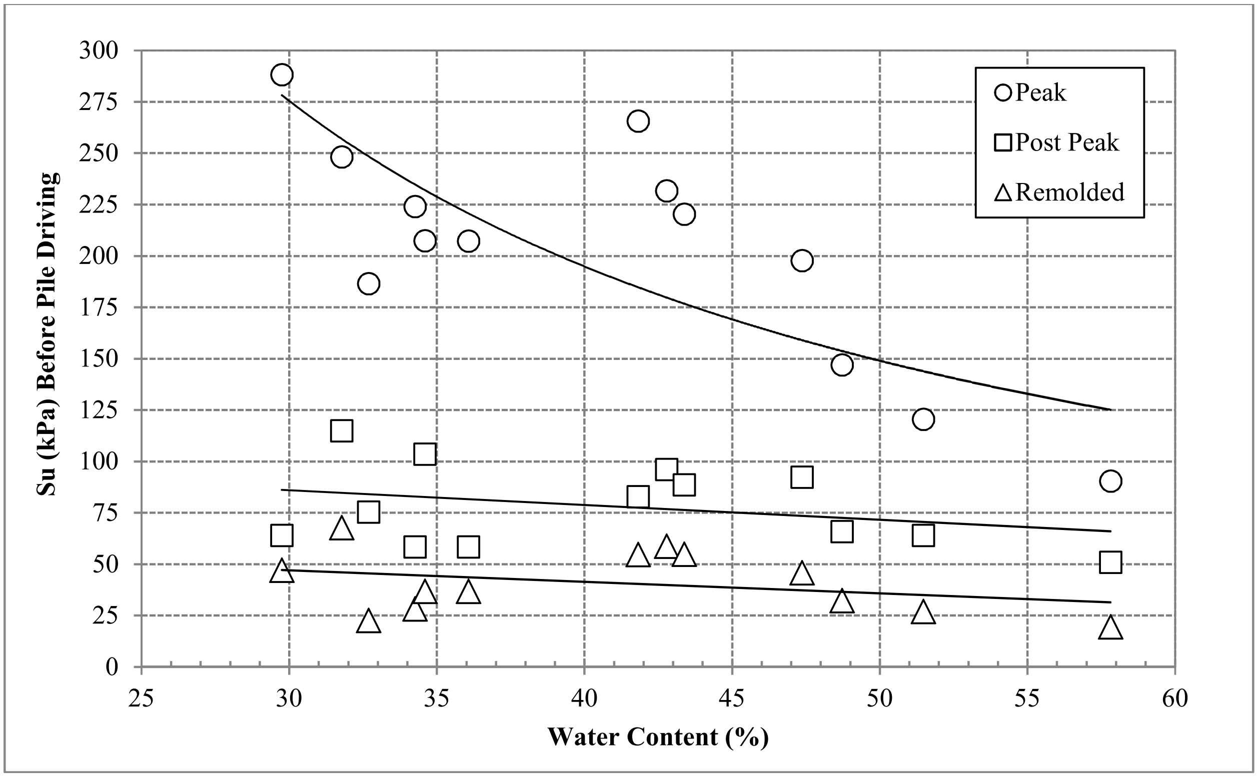

Figure 60. Relationship of Peak Undrained Shear Strength with Water Content Before Pile Driving (DOE Site).

As previously explained, the pile driving generates a build up of pore water pressure that results in pore water pressure dissipation. The soil around the pile consolidates but in a remolded state which will yield lower Undrained Shear Strength values as if it was in an undisturbed state. The geometry of the driven pile will have a direct effect on the degree of soil deformation and thus consolidation.

During primary consolidation, water is being expulsed from within soil particles resulting in lower water content and because the Undrained Shear Strength of the soil depends on its water content, the soil is expected to increase its Undrained Shear Strength. Since the extent of the disturbed zone of the soil surrounding open and closed-end pipe piles are different, different behavior in the Undrained Shear Strength of the soil will occur.

5.3.4.1 CLOSED-END PIPE PILE

After driving the closed-end pipe pile, the Undrained Shear Strength was observed to decrease in a slightly different trend (Figure 61). The range of the Undrained Shear Strength values was observed to be closer to the range of the Post Peak Undrained Shear Strength values. Residual and Remolded Undrained Shear Strength appeared to have change very little.

At 1 day after pile driving, the Peak Undrained Shear Strength appeared to continue to decrease in an almost linear trend with values approaching the range Post Peak Undrained Shear Strength values (

Figure **62**). Post Peak values showed an overall increase below water content of 45%. At this point, the water content values seemed to be shifting left (lower water content values).

35 days after pile driving, the Peak Undrained Shear Strength values at water content between 20 – 25% were observed to decrease in a similar manner to previous days but a sudden drop in the Peak Undrained Shear Strength values between water content of 35 and 55% occurred (

Figure **63**). 167 days after pile driving, the Undrained Shear Strength continued to decrease (

Figure **64**).

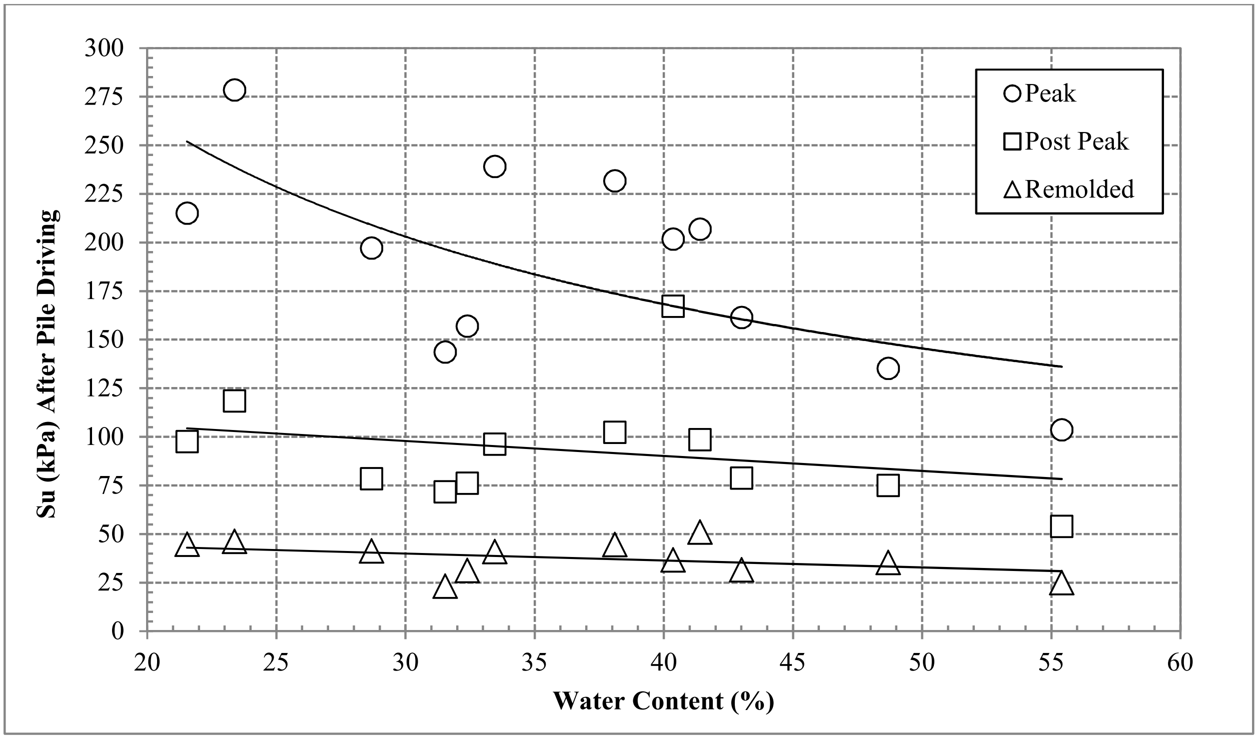

Figure 61. Relationship of S_u with Water Content After Pile Driving.

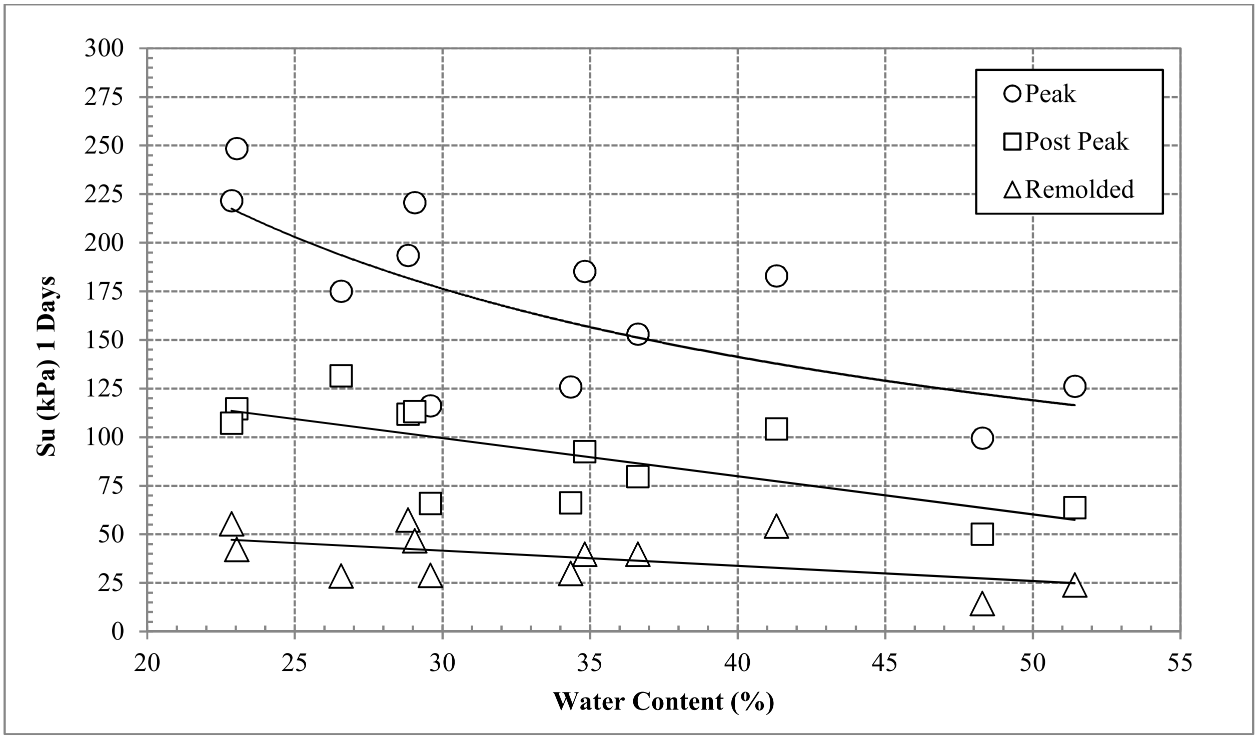

Figure 62. Relationship of S_u with Water Content 1 Day After Pile Driving.

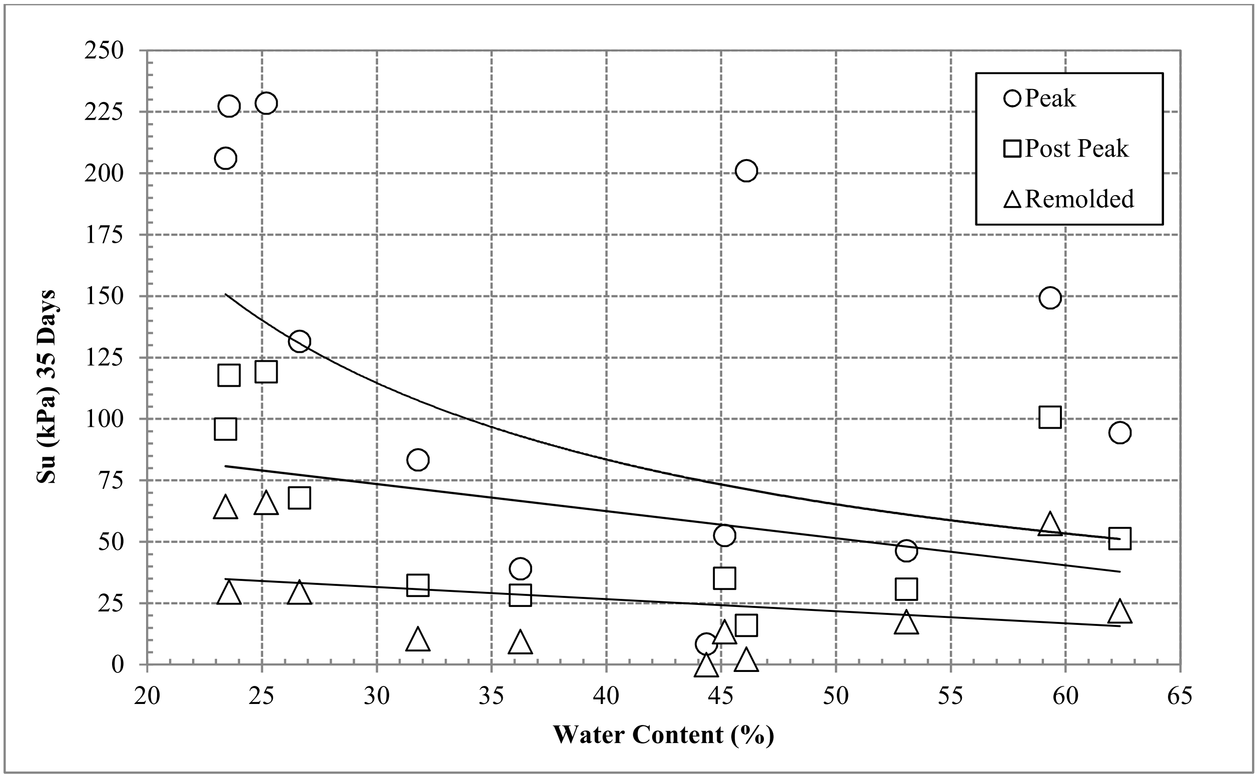

Figure 63. Relationship of S_u with Water Content 35 Days After Pile Driving.

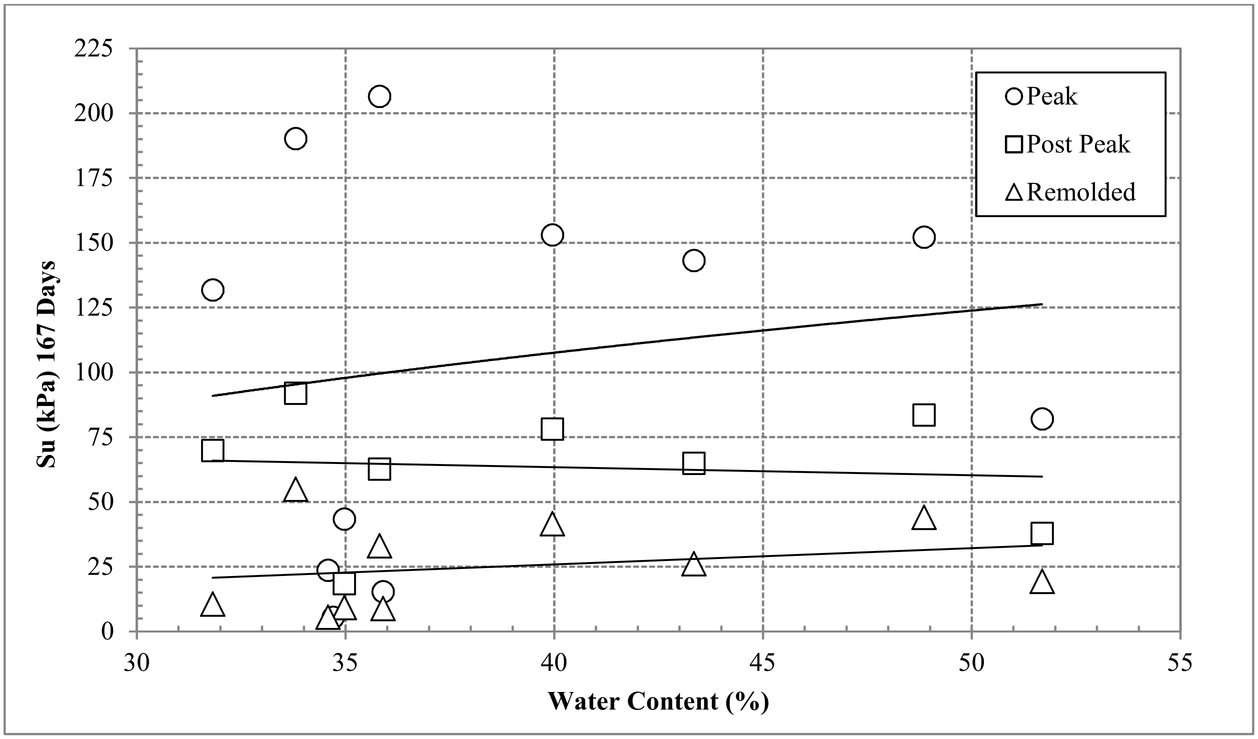

Figure 64. Relationship of S_u with Water Content 167 Days After Pile Driving.

5.3.4.2 OPEN-END PIPE PILE

The Undrained Shear Strength was observed to remain almost constant after pile driving and 1 day (Figure 65 and
Figure **66**). This behavior indicates that soil disturbance did not occur at the same degree as of the soil surrounding the closed-end pipe piles. Also, consolidation could have occurred a lower degree since the extent of the disturbed zone was smaller compared to the disturbed zone surroundin the closed-end pipe piles. The pore water pressure dissipation could have occurred at a lower rate and did not start until some time after 1 day after pile driving.

35 days after pile driving, the Peak Undrained Shear Strength values showed an increase that could be attributed to complete dissipation of the pore water pressure (
Figure **67**). At 167 days, the Undrained Shear Strength was observed to decrease as a result of the stabilization of the pore water pressure (
Figure **68**).

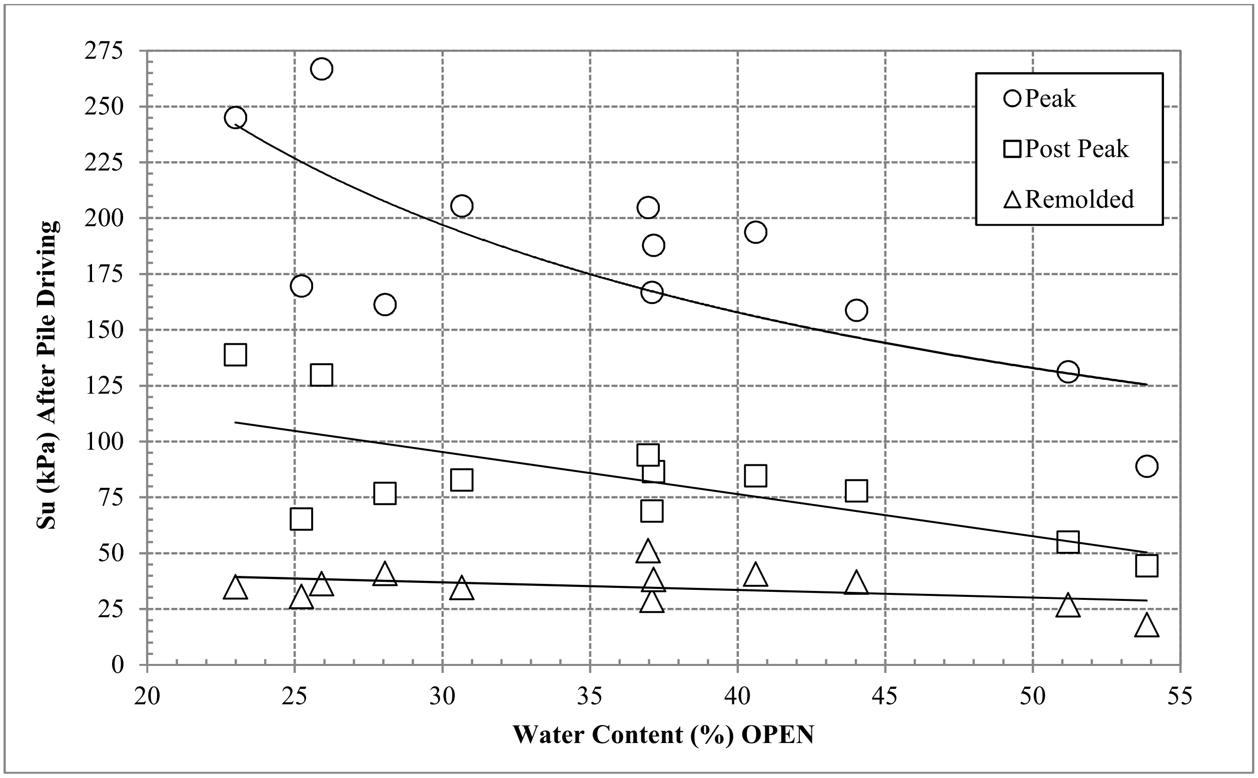

Figure 65. Relationship of S_u with Water Content After Pile Driving.

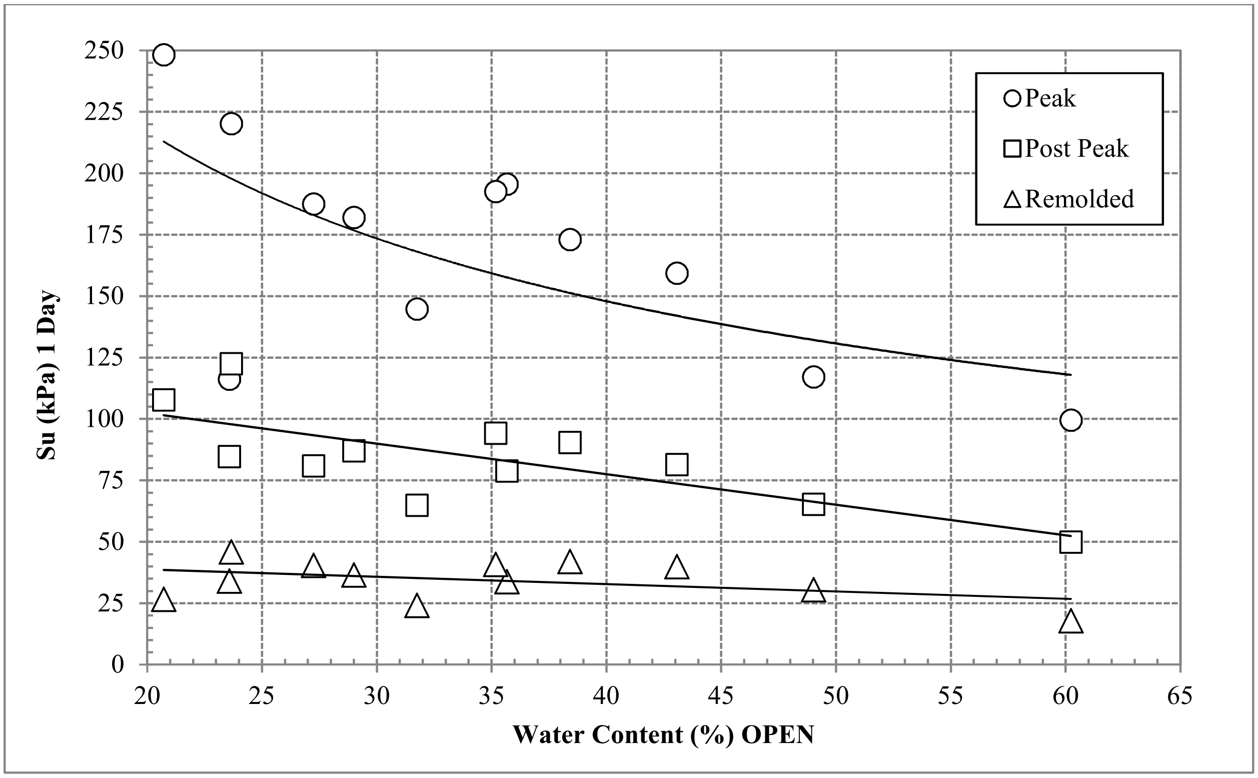

Figure 66. Relationship of S_u with Water Content 1 Day After Pile Driving.

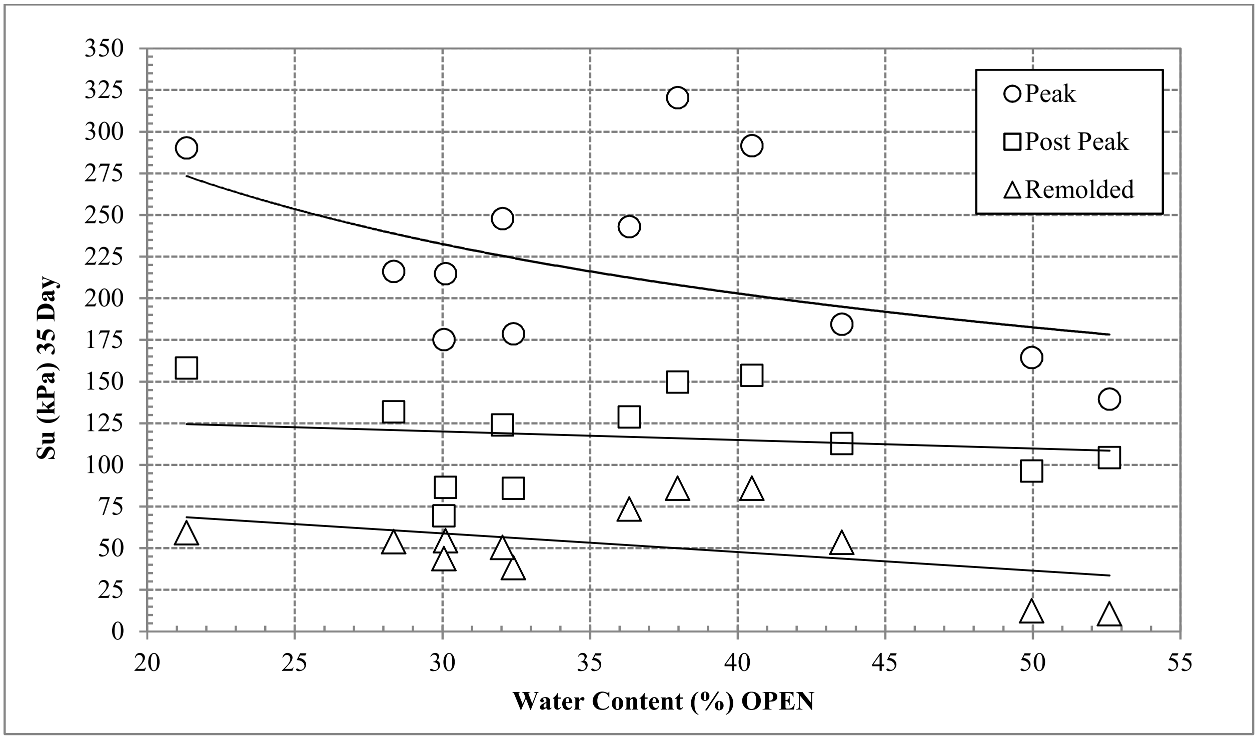

Figure 67. Relationship of S_u with Water Content 35 Days After Pile Driving.

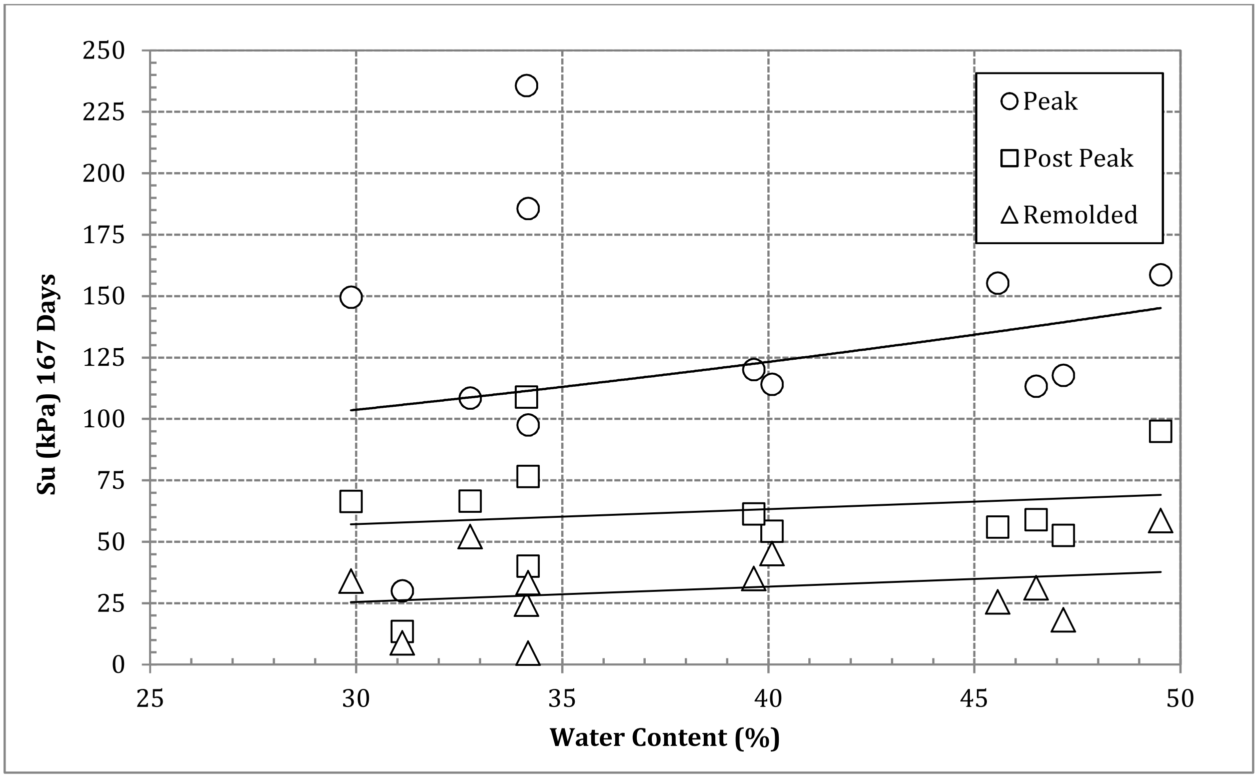

Figure 68. Relationship of S_u with Water Content 167 Days After Pile Driving.

5.4 INCREASE IN PILE CAPACITY WITH TIME

Time-dependent increase in capacity of the pile depends on many factors. Soil-pile setup is predominately associated with an increase in pile friction. As a pile is driven, the installation induces a major displacement or shear strains on shaft (Ng et al, 2010). Such displacement causes the pore water pressure in the soil surrounding the pile to increase.

Ng et al, 2010 explained that:

"In cohesive soil, the soil at the pile toe is pushed laterally to a location at or beyond the pile radius, which will lead to shear failure of the soil. The soil in the immediate vicinity of the pile is significantly remolded by the driving process. This generates excess pore water pressure and subsequently causes re-consolidation as the excess pore water pressure dissipates. Pile penetration into clay induced an excess pore water pressure that can be much larger than the initial effective overburden stress. After the completion of pile driving and the dissipation of excess pore water pressure, the soil reconsolidates resulting in the increase of effective stress."

Komurka et al. (2003) divided the soil/pile set-up mechanisms into the following three phases:

logarithmically nonlinear rate of excess pore water pressure dissipation (phase I), logarithmically linear rate of excess pore water pressure dissipation (phase II) and independent of effective stress (phase III).

During the initial phase, I, the rate of pore water pressure dissipation is not constant with respect to the log of time for some periods. The duration of nonlinear dissipation is a function of soil and pile Komurka et al. (2003). The greater the amount of soil displaced during driving, the longer the duration of the pore water pressure in this phase.

In phase II, the rate of dissipation becomes constant with respect to log time. The displaced soil will experience an increase in effective vertical and horizontal stresses leading to consolidation and increase in shear strength (Komurka et al. (2003). Since the hydraulic conductivity is smaller in cohesive soils than in non-cohesive soils, full dissipation will require a longer time (several weeks, months or even years).

The third phase of set-up is known as independent stage of effective stress or aging. The dissipation of excess pore water pressure becomes very low and infinite time may be required for the completion of set-up mechanisms (Komurka et al. (2003). In this phase, set-up rate is independent of effective stress and related to the phenomenon of aging (Komurka et al. (2003).

These three phases of set-up might overlap and more than one phase may simultaneously contribute to the development of an increase in capacity or pile set-up (Komurka et al. (2003). Mechanisms of set-up are shown in Figure 69.

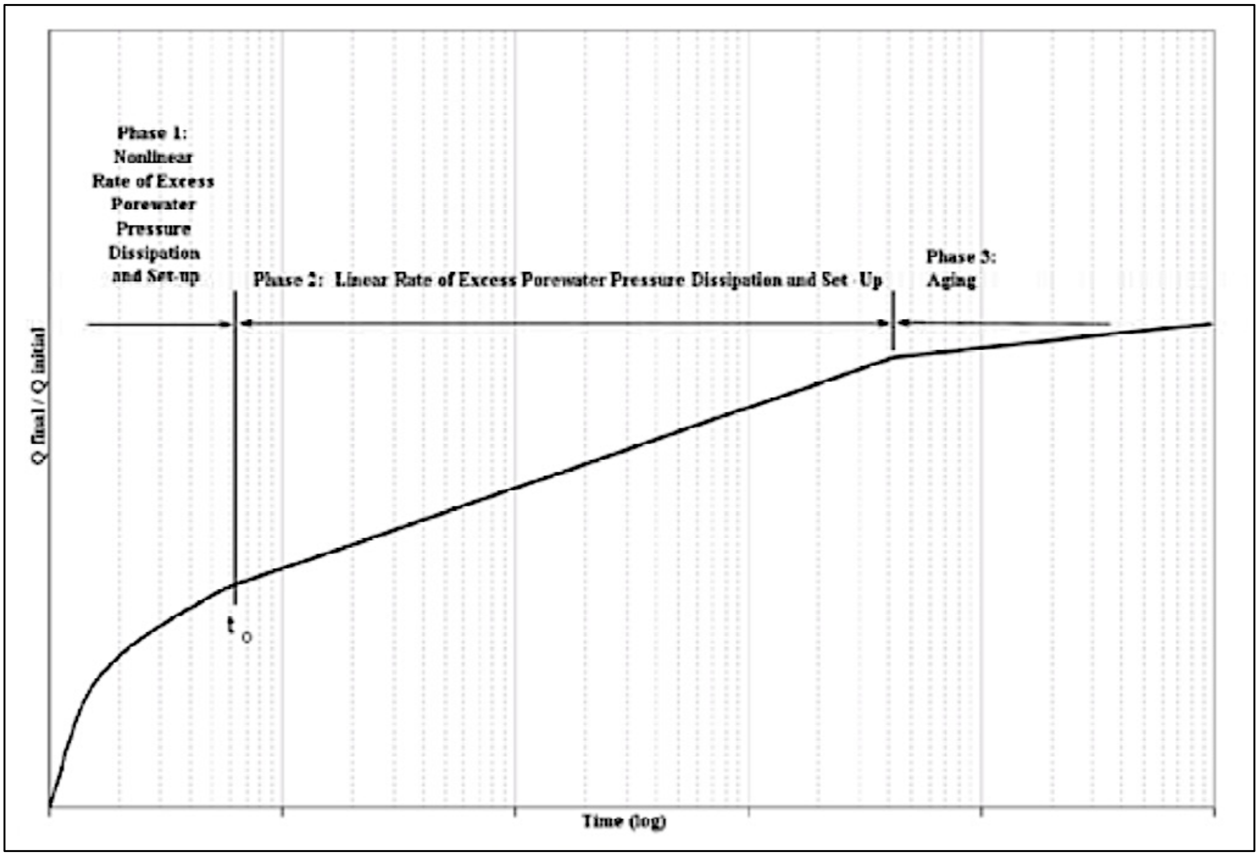

Figure 69. Mechanisms of Pile Capacity (Komurka et al, 2003).

There is strong evidence that the increase in effective stress along the pile shaft during the reconsolidation process controls the increase in soil shear strength and the resulting capacity of friction piles (Weech, 2002).

5.4.1 SHORT-TERM BEHAVIOR OF THE SOIL SURROUNDING DRIVEN PILES

Several piles with varying diameters, closed or open ends, and varying geometries were installed and static load tested at the DOE, HHF and Taylor Field sites, respectively, at different aging times to study their short and long-term capacity-related behavior and the possible mechanisms involved. Piles S4 x 7.7 and W6 x 12 (Figure 70 through Figure 73) showed the same behavior trend in which a consecutive increase occurred followed by a reduction in capacity. The capacity of the S4 x 7.7 at 7, 148 and 597 days after installation was 6357, 7824 and 7335, respectively. The increase in capacity from 7 to 148 days (about 1467 lbs more) could be due to an increase in radial stresses after reconsolidation. At 597, the capacity was observed to be approximately 6% lower than after the previous static load test. During loading at 148, the soil was disturbed or remolded thus causing a reduction in the capacity. Since enough time was allowed between tests at 148 and 597 days, a gain in capacity attributed to the thixotropic behavior occurred. After 449 days from the most recent static load test, the gain in capacity resulted in a difference of approximately 489 lbs. The capacity of the W6 x 12 at 10, 168 and 619 days was 8500, 9000 and 7700 lbs, respectively. The capacity at 168 days was 14% higher than at 616 days and 6% higher than at 10 days. It is possible that remolding of the soil around the pile during loading caused this reduction in capacity.

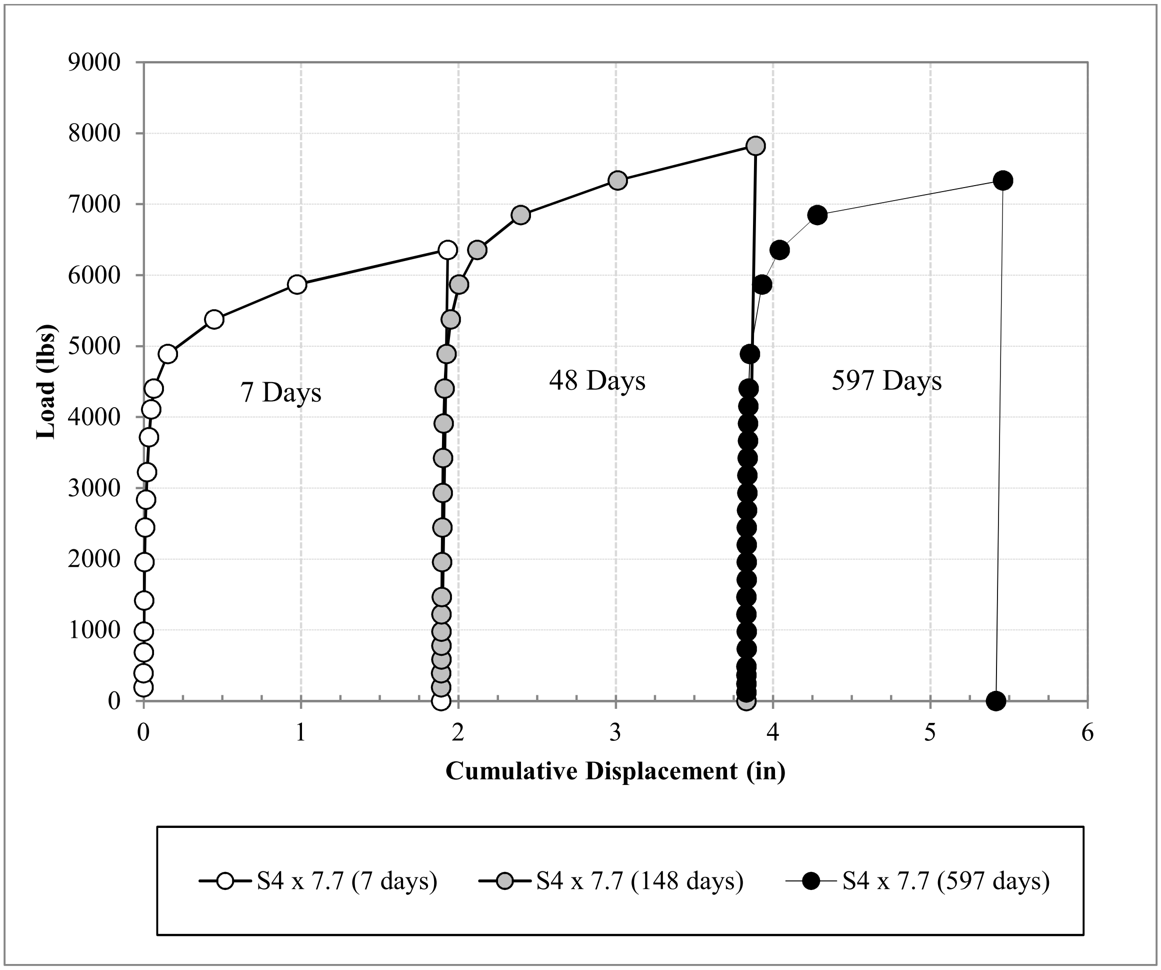

Figure 70. Load-Displacement Curve – S4 x 7.7 Pile (HHF-8).

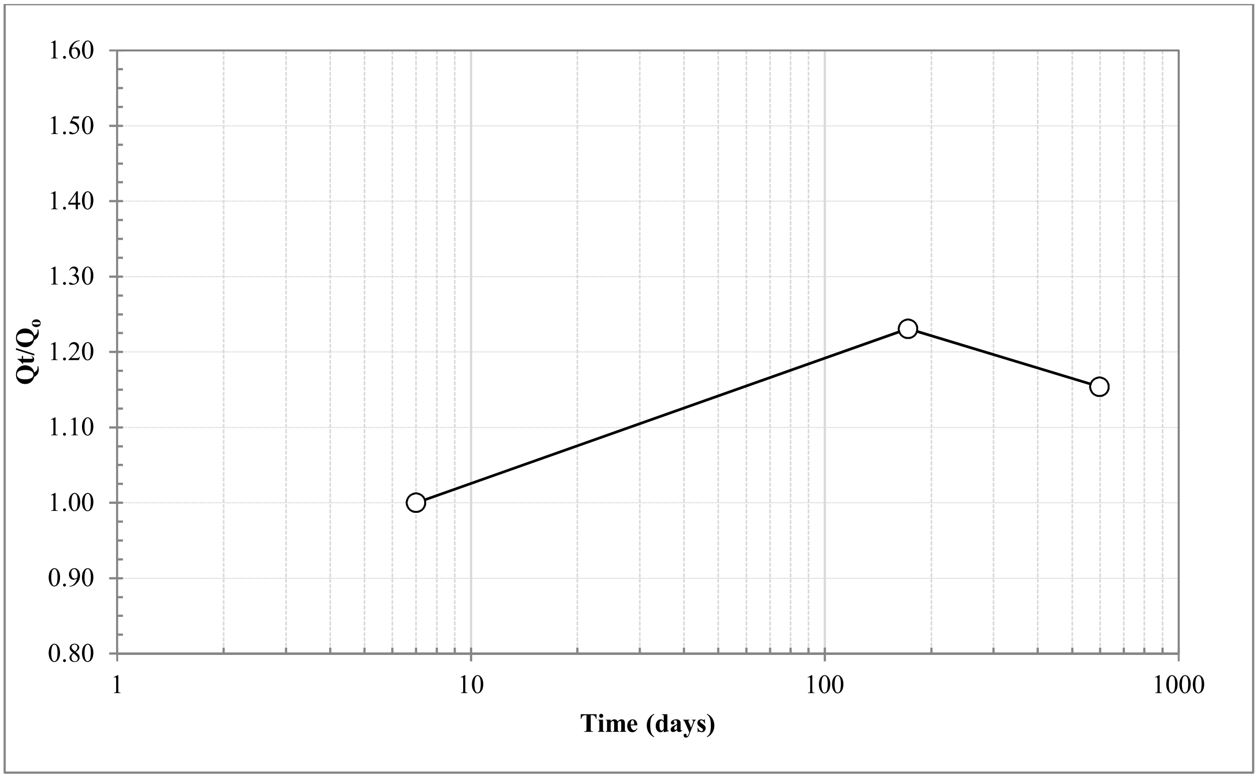

Figure 71. Normalized Ultimate Capacity with Respect to Aging Time - S4 x 7.7 Pile (HHF-8).

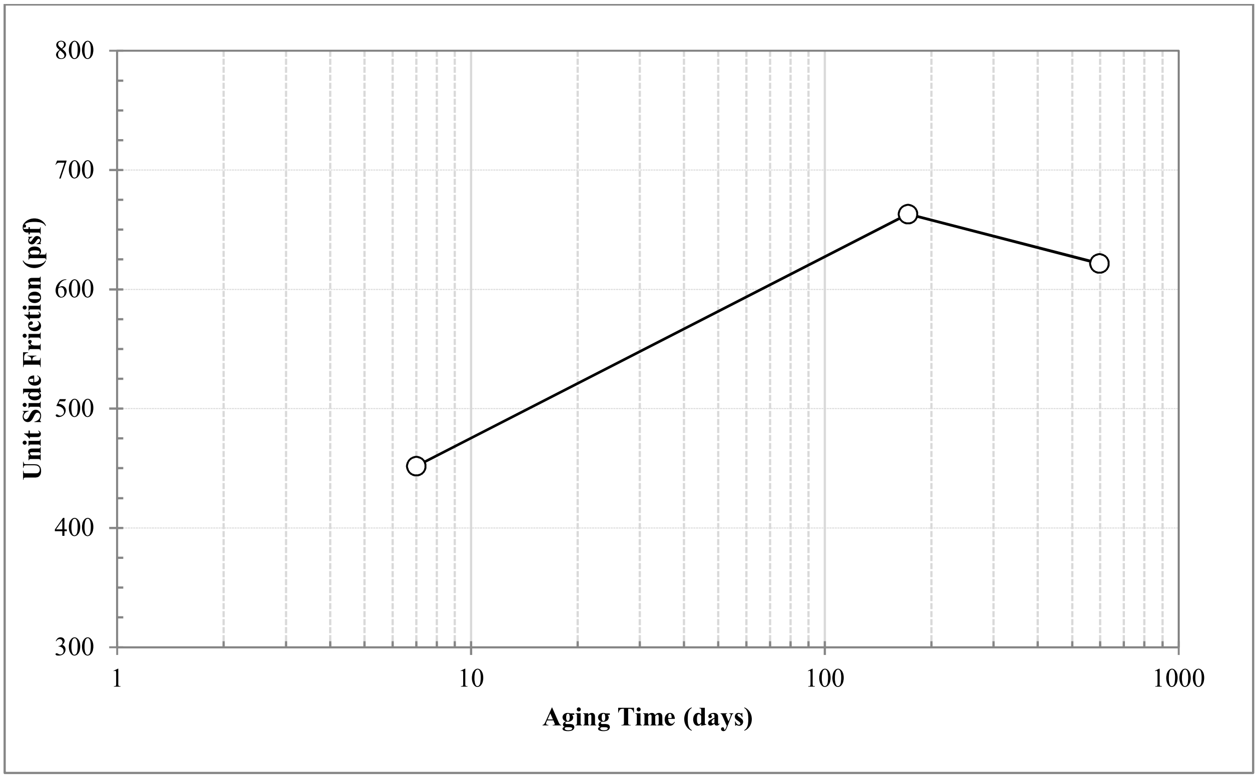

Figure 72. Unit Side Resistance with Respect to Aging Time - S4 x 7.7 Pile (HHF-8).

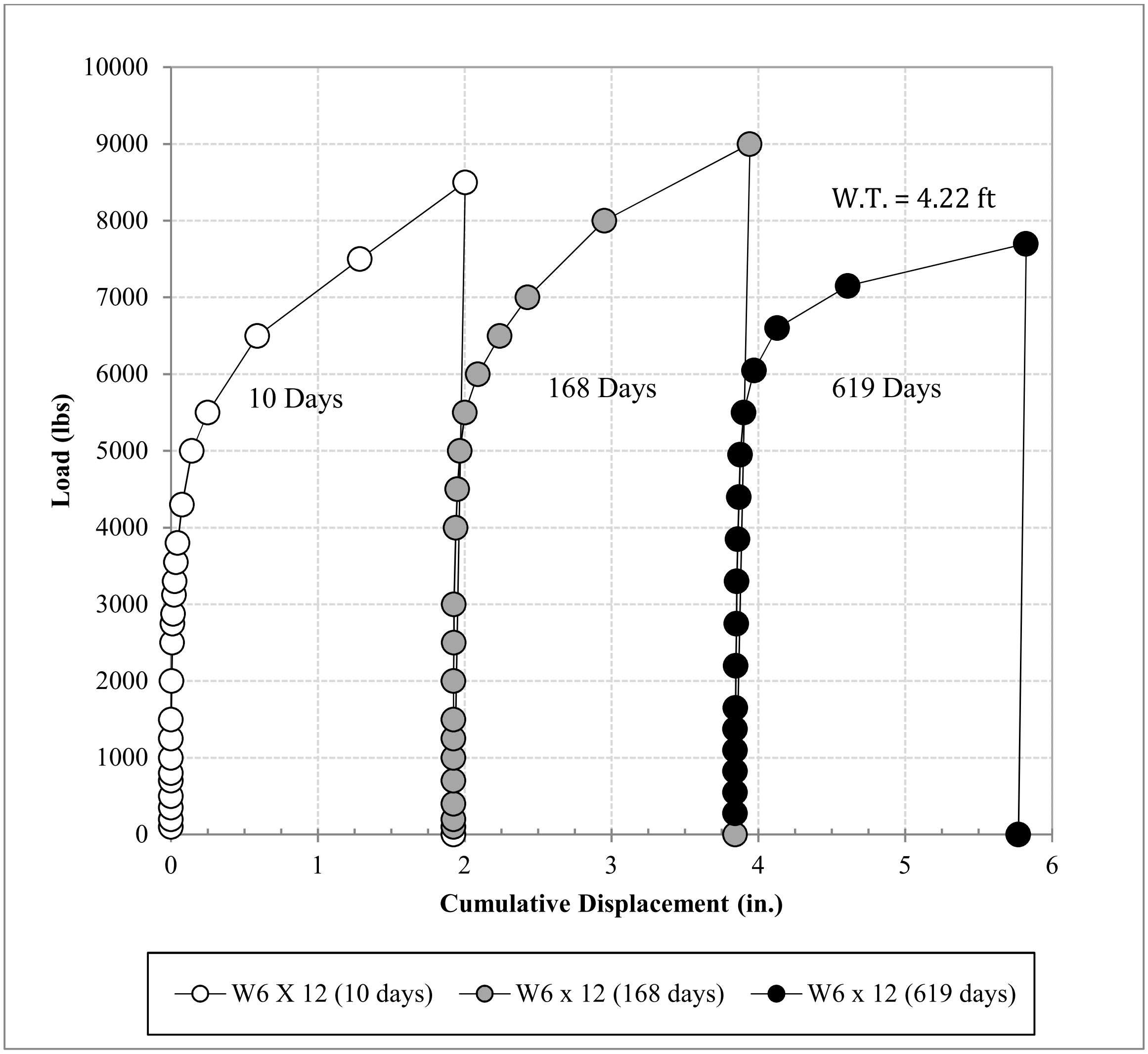

Figure 73. Load-Displacement Curve – W6 x 12 Pile (DOE-1).

Both H-piles, S4 x 7.7 and W6 x 12, exhibited gradual failure modes that could be related to the formation of a soil plug between the flanges. A change in the curve slope section immediately after the soil's yield point (plastic region) was evident.

Similar to the W6 x 12, the capacity of the W6 x 9 (Figure 74) was observed to increase throughout the first two tests. The second and third static load test had equal capacities with gradual lower capacities thereafter. The capacity of the second test was 21% higher than the first test. The third and fourth were 16% and 21% lower than the capacity of the second test (peak ultimate capacity), respectively. The capacities of the first and fifth static load tests were equal, 7,500 lbs.

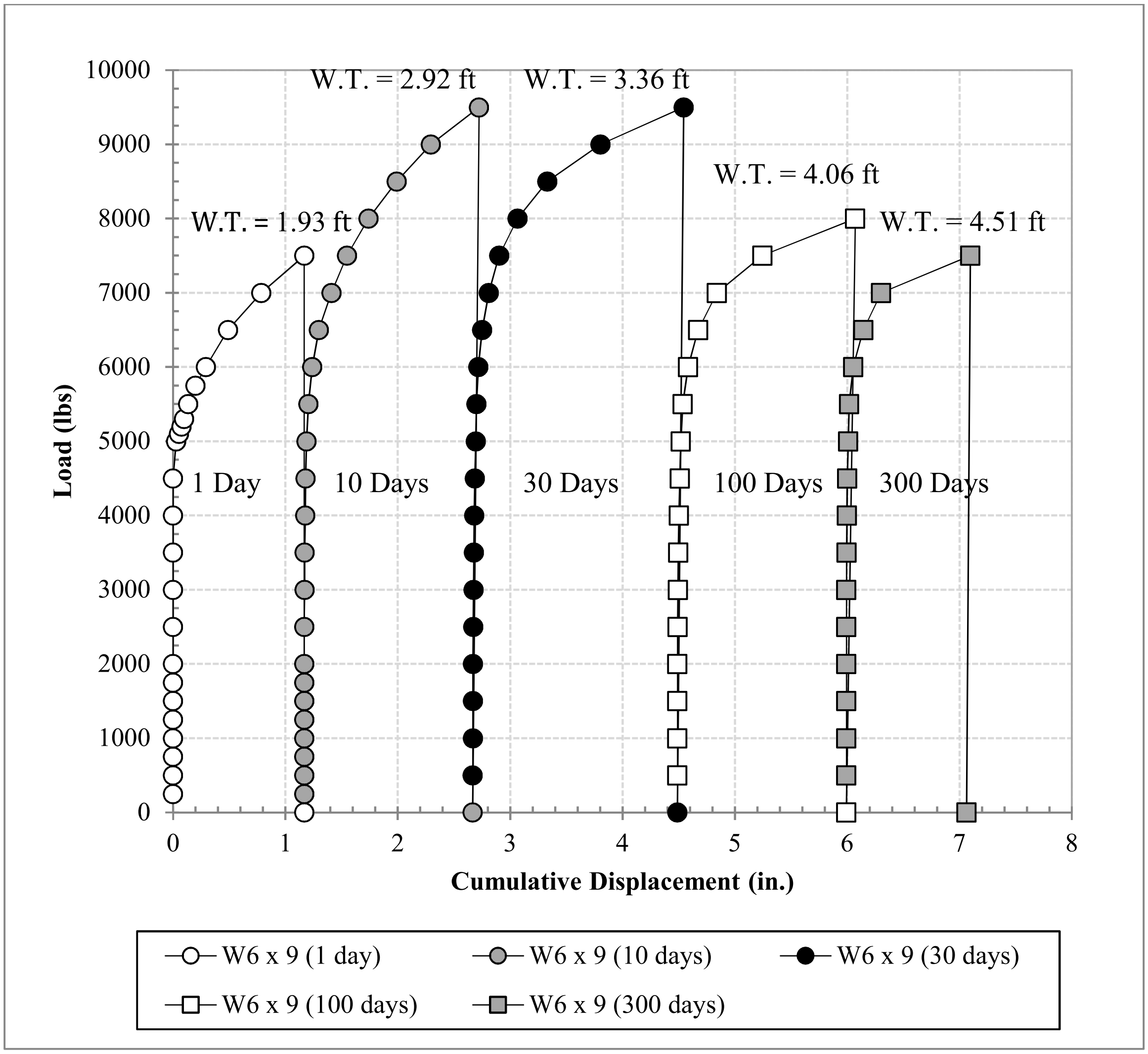

Figure 74. Short and Long-Term Capacity of W6 x 9 Pile (DOE-15).

An increase in capacity as a result of shaft friction was evident on piles installed at all three sites previously described, but it was also observed that many other factors (e.g. pile geometry and coating) influenced this gain in capacity.

Figure 75 showed the differences in the short-term capacity gain due to varying pile thicknesses. Both 6.625-inch pipe piles were static-load-tested after 7 days of pile driving to observe the influence of pile wall thickness on the short-term gain in capacity. It can be observed that the pile with the highest area ratio value developed approximately 22% more capacity mainly because it displaced more soil, in addition to the fact that the extent of the disturbed zone was larger. As a consequence of soil disturbance, it could be assumed that the duration of the pore water pressure dissipation lasted longer and reconsolidation occurred at a higher degree thus, increasing the radial stresses acting against the pile.

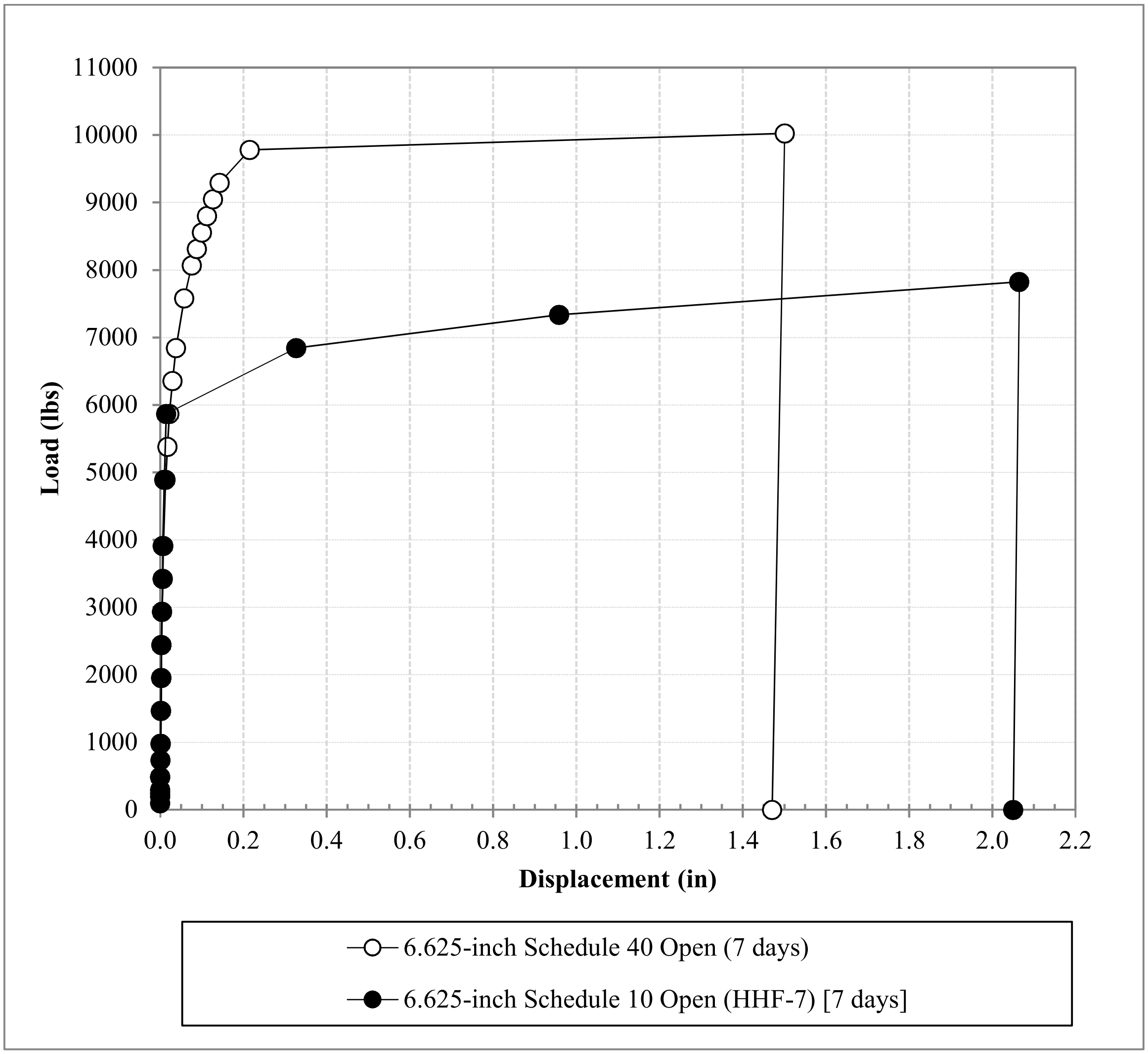

Figure 75. Influence of Pile Wall Thickness (Area Ratio) on Short-Term Capacity of a 6.625-inch Open-End Pipe Pile (Schedule 10 and 40) (HHF-7 and HHF-10) at 7 days.

In a similar manner, two 2.875-inch pipe piles (one closed-end and one open-end) were installed at the DOE site. The load-displacement curve of both piles tested 7 days after pile driving are shown in Figure 76. The 2.875-inch closed-end pipe pile developed a slightly higher capacity (10% higher) than the open-end pile and this was attributed to a higher degree of reconsolidation as a result of a larger disturbed zone (or more soil displaced) during installation.

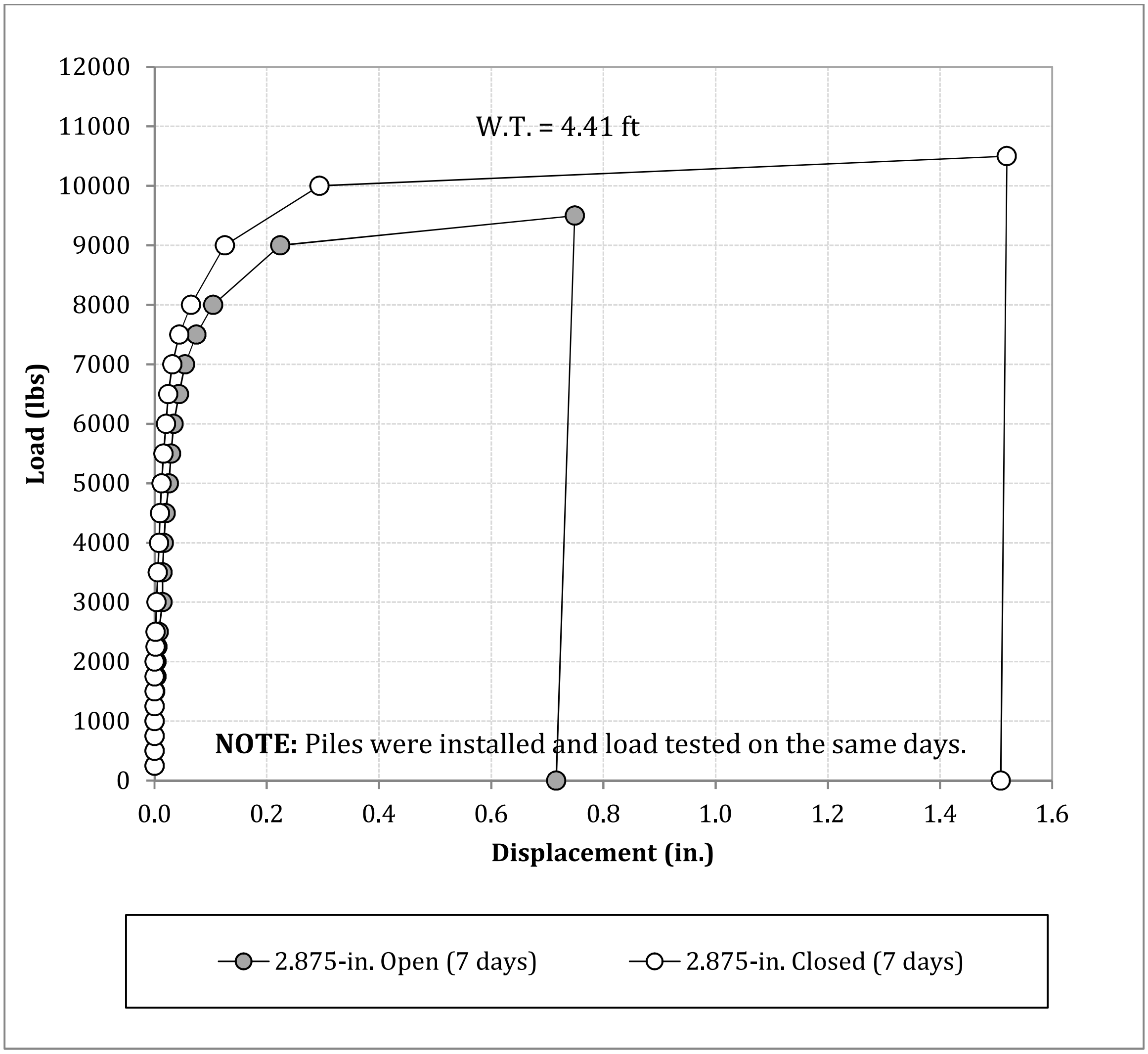

Figure 76. Short-Term Capacity of 2.875-inch Open and Closed-End Pipe Piles (DOE-11 and DOE-12).

Fearon and Coop (2000) analyzed the effect of the work done in remolding the soil on the behavior of the reconstituted soil. They showed that soils that have been reconstituted using high and low-energy methods, respectively, might have different characteristics. A reconstituted soil is made by remolding a natural soil to break down particle structure, destroy shear planes, eliminate large pores and produce a more homogenous fabric at a macro scale. After installation, the soil within the disturbed zone adjacent to the pile gets reconstituted and after each subsequent test the clay gets remolded again.

This could explain some of the complicated load histories of some piles. Based on this, it could be assumed that the ultimate capacity will be related to the initial state of the soil and degree of remolding during driving (due to installation method and area ratio of the pile). Since both open and closed-end pipe piles were installed using the same method, the number of total blows will be an indication of the differences in energy required during installation/driving and thus resulting in differences in capacities for the same pile.

The main controlling mechanism of the short-term gain in capacity of pipe piles could be attributed to the degree of deformation or remolding during pile driving, based on the observations that the 6.625-inch schedule 40 pipe pile developed a higher capacity than the same pile with a schedule 10 at 7 days, and the 2.875-inch closed-end pipe pile also developed a higher capacity than the same pile with an open-end. Overall, the piles that displaced more soil (due to higher area ratios or closed end) showed higher short-term capacities.

5.4.2 SHORT AND LONG-TERM BEHAVIOR OF SOIL SUROUNDING DRIVEN PILES

Figure 77 shows the pile load displacement curves for the 2.875-inch schedule 10 open-end pipe pile and 2.875-inch schedule 40 open-end pipe pile. Each pile was tested 1 day after installation, 172 and 602 days after installation, respectively, to observe soil disturbance effects on the long-term capacity of the piles using the same pile but with different pile wall thicknesses. Both piles presented similar behaviors over the same period of time; a trend of increased capacity with time is observed. The 2.875-inch schedule 10 open-end pipe pile had a higher capacity 1 day after installation than the 2.875-inch schedule 40 open-end pipe pile that could be attributed to a lower degree of soil disturbance during installation due to a thinner pile wall. During installation of both piles, not only soil disturbance occurred at different degrees, but also plugging. A smaller area ratio (2.875-inch schedule 10 open-end pipe pile) will result in a higher PLR value that will also contribute to the gain in capacity of the pile. Immediately after installation, the pile with the smaller area ratio value developed a higher immediate capacity mainly due to soil disturbance during installation. The pile with the higher area ratio value (similar to piles HHF-7 and HHF-10) disturbed the soil to a higher degree thus reducing the Undrained Shear Strength of the soil adjacent to the pile and at 1 day after driving, there is not enough time for complete dissipation of pore water pressure. After all the pore water pressure dissipates, other mechanisms come into play and this can be observed at 172 days after pile driving, where the 2.875-inch schedule 40 open-end pipe pile showed a higher capacity than the

2.875-inch schedule 10 open-end pipe pile, for example, mainly due to the thixotropic behavior of the clay. This behavior will be more prominent in the soil (surrounding the pile) that was subjected to higher deformation during pile driving. This is more evident at 602 days after pile driving, where the 2.875-inch schedule 10 open-end pipe pile exhibited an ultimate capacity 25% higher than the capacity of the 2.875-inch schedule 40 open-end pipe pile due to higher radial stresses possibly related to a higher plug formation. Overall the 2.875-inch schedule 10 open-end pipe pile increased 40% and the 2.875-inch schedule 40 open-end pipe pile increased 20% over the same period, 602 days (Figure 77). The 2.875-inch schedule 10 open-end pipe appeared to have shown a pile capacity increase faster based on the trend of its normalized capacity curve and unit side resistance (Figure 78Figure 79). The unit site resistance trend of both the 2.875-inch schedule 10 open-end and the 2.875-inch schedule 40 open-end pipe piles follows an exponential trend. The determined unit side resistance values for the 2.875-inch open-end pipe piles, schedule 10 and 40, were 782 and 587 psf, respectively.

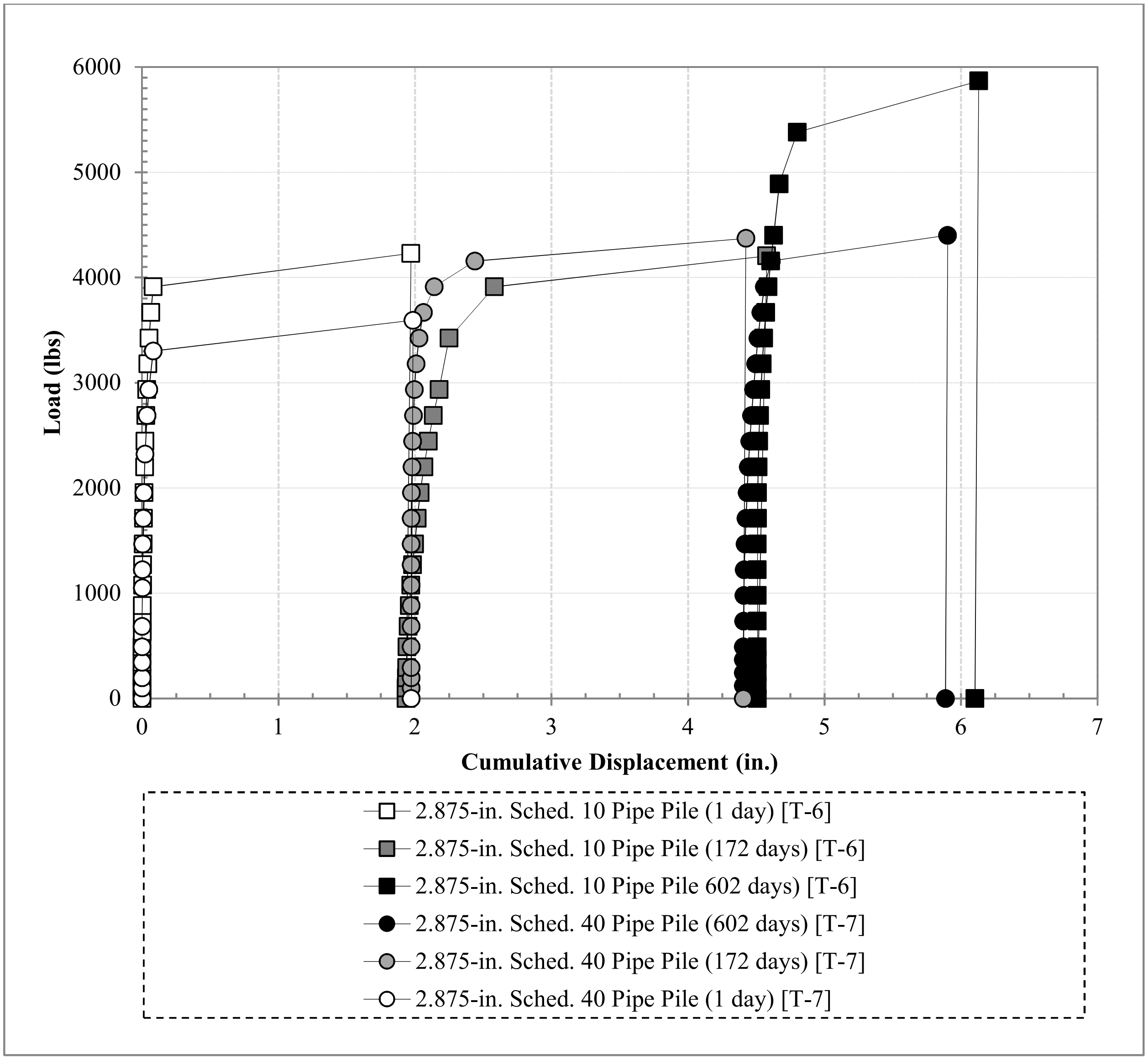

Figure 77. Load-Displacement Curves - 2.875-inch Schedule 10 Open-End Pipe Pile (TF-6) and 2.875-inch Schedule 40 Open-End Pipe Pile (TF-7).

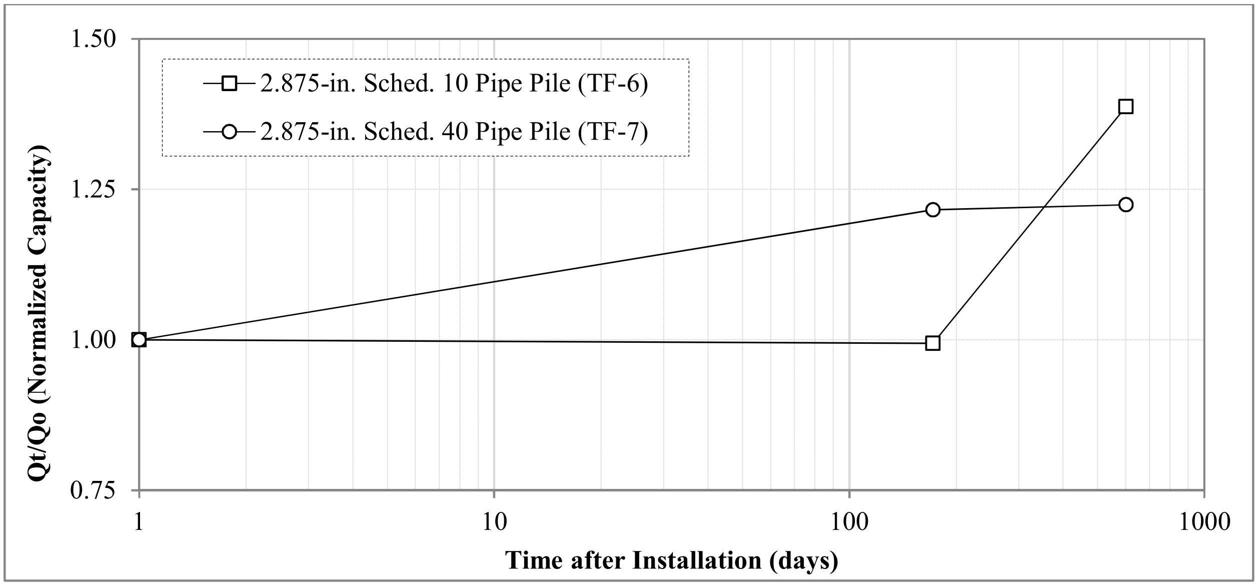

Figure 78. Normalized Capacity - 2.875-inch Schedule 10 Open-End Pipe Pile (TF-6) and 2.875-inch Schedule 40 Open-End Pipe Pile (TF-7).

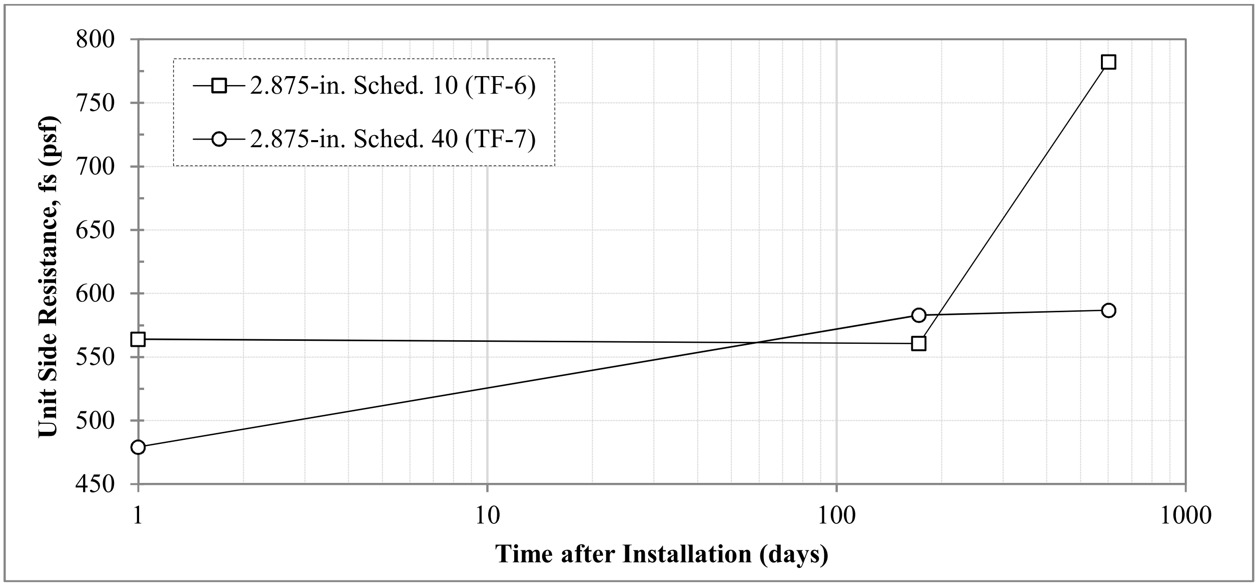

Figure 79. Unit Side Resistance - 2.875-inch Schedule 10 Open-End Pipe Pile (TF-6) and 2.875-inch Schedule 40 Open-End Pipe Pile (TF-7).

Similarly to the 2.875-inch closed-end pipe piles, two 4.5-inch open-end pipe piles, schedule 10 and 40, were installed with the same purpose of studying how soil disturbance caused by pile driving (due to pile geometry and wall thickness). The load-displacement curves are presented in Figure 80. The capacity of the 4.5-inch schedule 10 open-end pipe pile, 5330 lbs, was slightly higher the capacity of the 4.5-inch schedule 40 open-end pipe pile, 5232 lbs. This could be attributed to a lower degree of disturbance during pile driving. The 4.5-inch schedule 40 open-end pipe pile exhibited a complicated load history. The pile showed a 4% decrease in capacity at 172 days followed by a 13% increase. This increase is associated with the thixotropic behavior of the clay.

In general, the capacity of the 4.5-inch schedule 40 open-end pipe pile was observed to decrease constantly with time. Specifically, the capacity of the 4.5-inch schedule 10 open-end pipe pile at 176 days and 602 days after pile driving were almost 7% and 5% lower than the ultimate capacity at 1 day. The behavior of the normalized ultimate capacity of the 4.5-inch schedule 10 open-end pipe pile is presented in Figure 81. The unit site resistance values of the 4.5-inch open-end pipe piles, schedule 10 and 40, were 497 and 394 psf, respectively (
Figure 82).

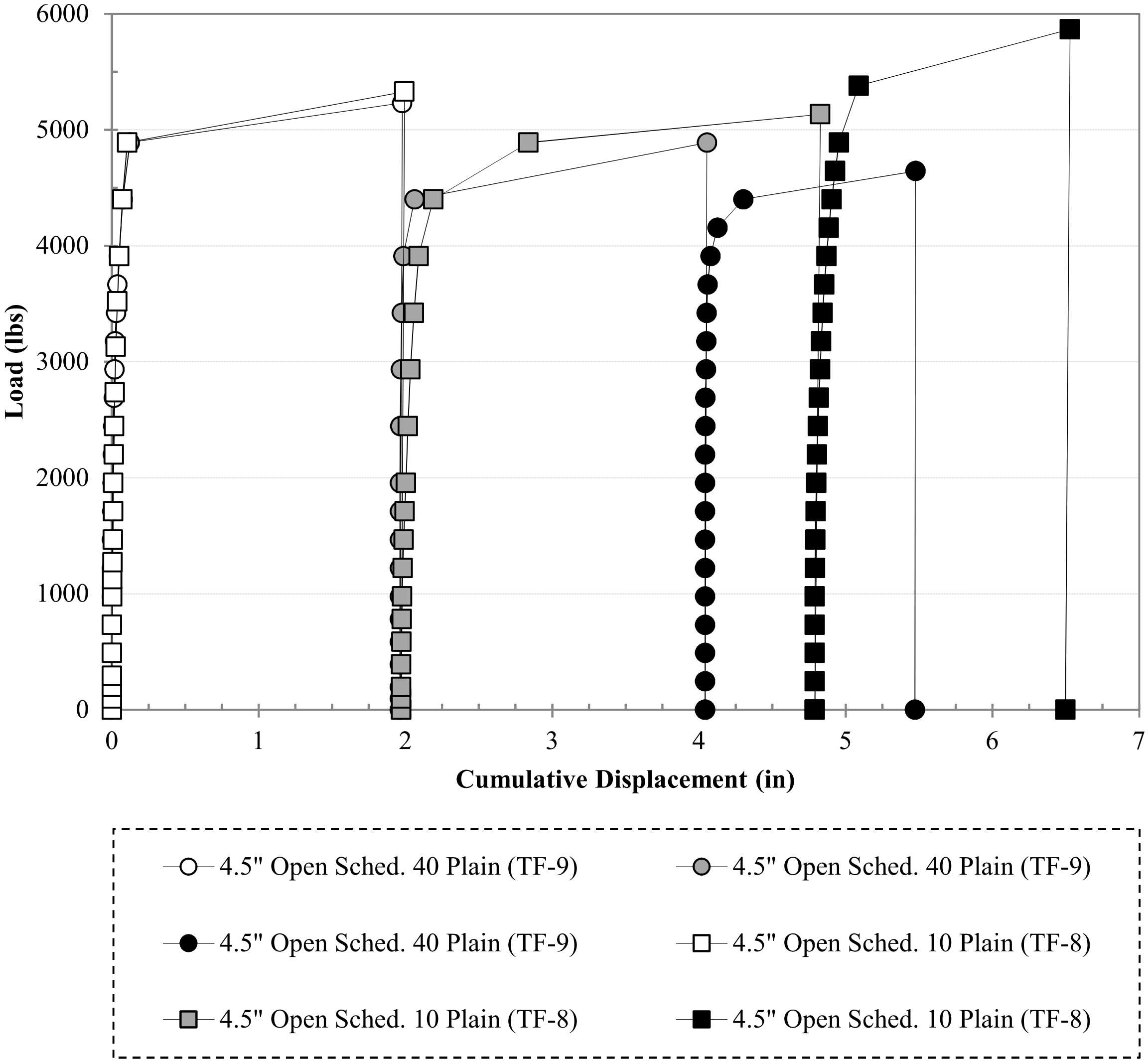

Figure 80. Load-Displacement Curves – 4.5-inch Schedule 10 Open-End Pipe Pile (TF-8) and 4.5-inch Schedule 40 Open-End Pipe Pile (TF-9).

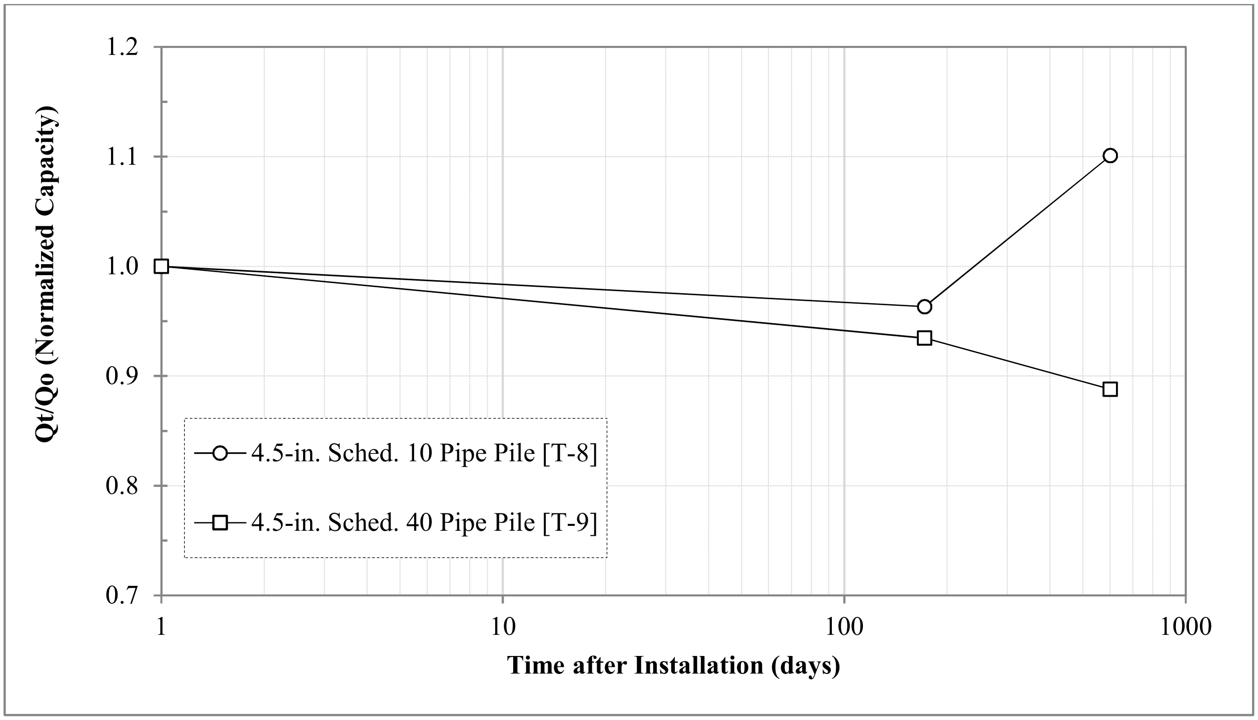

Figure 81. Normalized Capacity – 4.5-inch Schedule 10 Open-End Pipe Pile (TF-8) and 4.5-inch Schedule 40 Open-End Pipe Pile (TF-9).

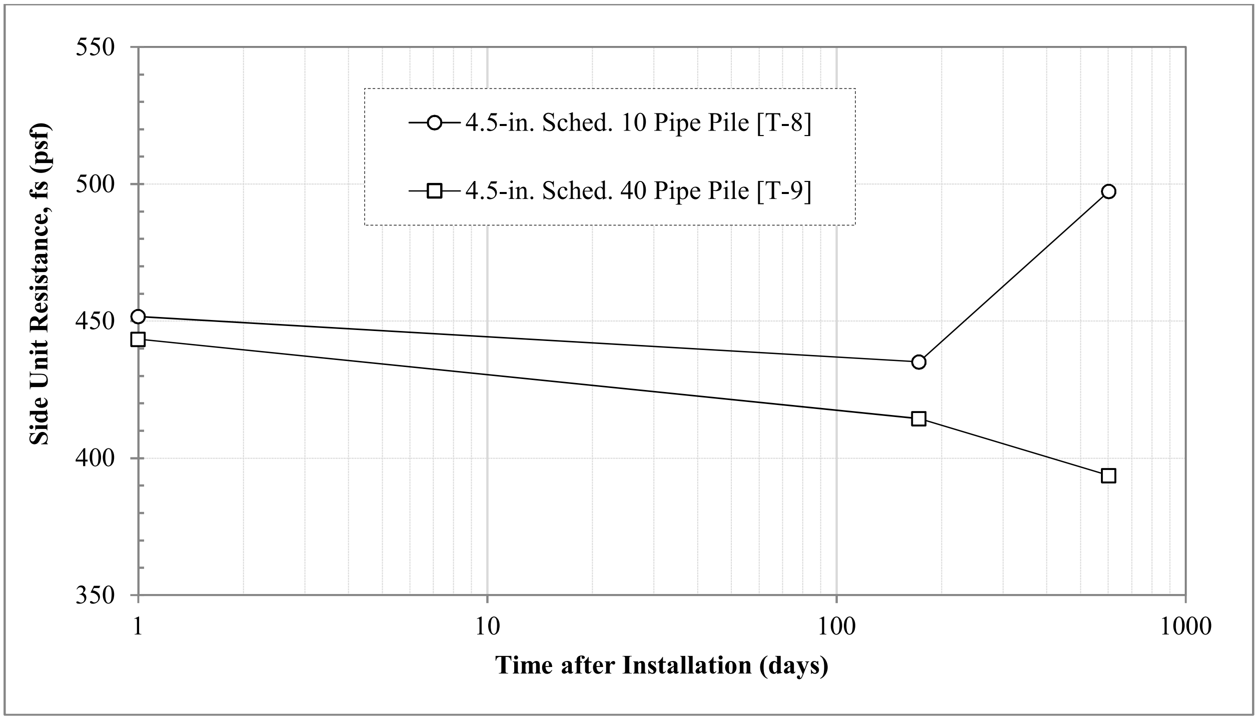

Figure 82. Unit Side Resistance – 4.5-inch Schedule 10 Open-End Pipe Pile (TF-8) and 4.5-inch Schedule 40 Open-End Pipe Pile (TF-9).

Three H-piles (two coated and one plain) of the same geometry were installed at the DOE site with the purpose of studying the short and long-term capacity of these piles due to the use of coatings. The coating (Blue, Regular, and Normal) does not corrode and is manufactured to induce slippage of the soil along the pile surface in freeze-thaw processes in the winter months (Khalili, 2013).

The short-term capacity of the W6 x 9 pile was observed to be affected by the use of coating. Specifically, the short-term capacity of the W6 x 9 pile (with blue coat) at 7 days after pile driving was almost 60% lower than the W6 x 9 plain pile (Figure 83). The use of coatings against corrosion does not let the formation of a soil plug within the flanges of the H-pile, which explains the significant reduction in capacity. The coated H-pile failed along the pile-soil interface based on the slippage failure mode, whereas the plain H-pile failed in a more gradual way, which could suggest the pile failed along a soil-soil plane with a higher friction angle.

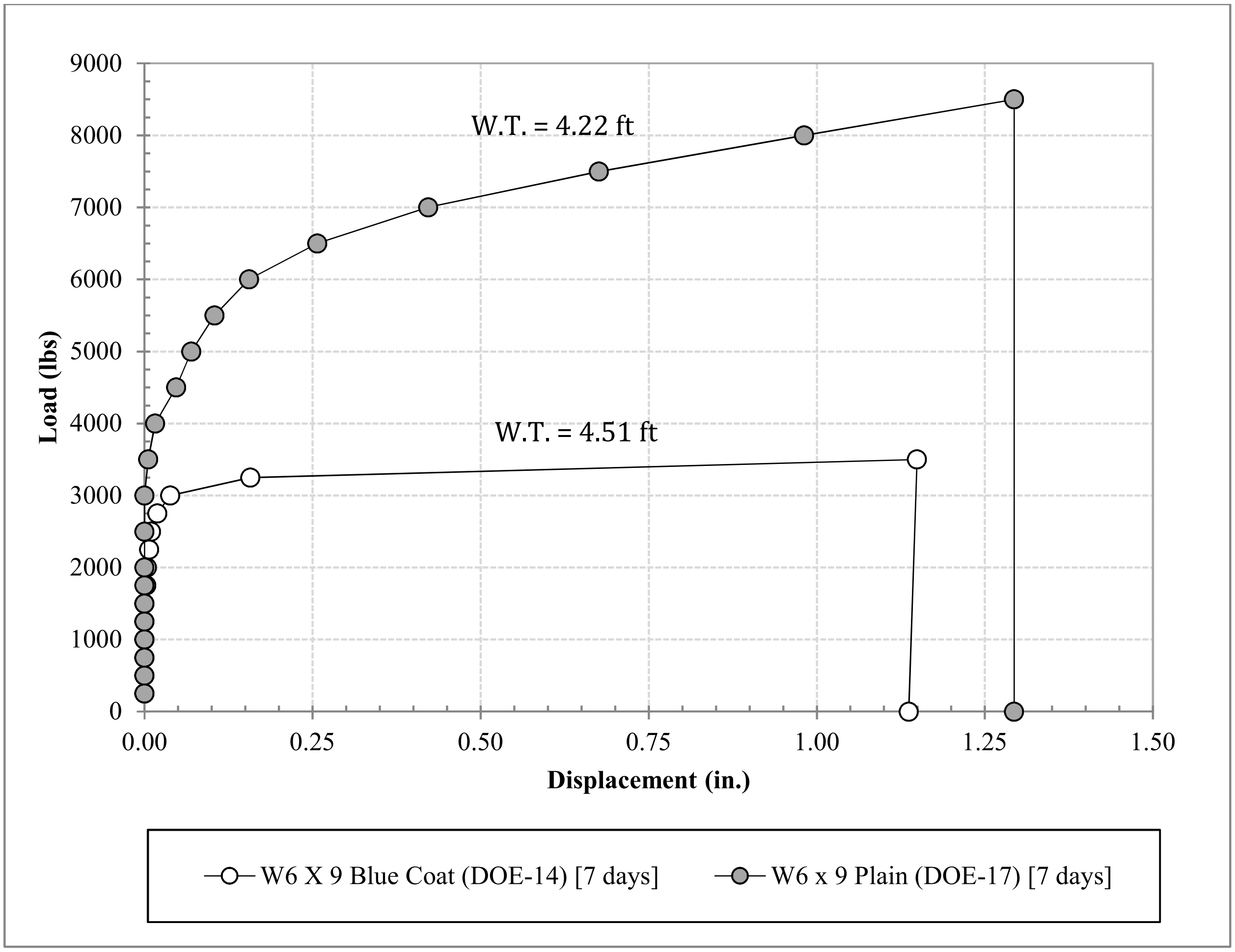

Figure 83. Short-Term Capacity of Coated Vs Non-Coated W6 x 9 Piles (DOE-14 and DOE-17).

From Figure 84, it can be inferred that the two coated H-pile failed along the pile-soil interface based on the slippage failure mode. The plain H-pile was observed to failed gradually, which could suggest the formation of a soil plug between the flanges. Due to this, a failure plane occurred along a soil-soil interface on the outside of the flanges. Lutenegger and Khalili (2005) pointed out that it is possible that two different failure mechanisms took place during static loading of some of their test piles (including piles installed at the DOE, HHF and Taylor Field).

The two different coatings used on the two W6 x 9 reduce the capacity of its respective pile significantly. Overall, the capacity of the W6 x 9 plain H-pile was approximately 60% higher than the capacity of the W6 x 9 Regular Coat and W6 x 9 Blue Coat H-piles 8 days after pile driving. Similarly, the capacity W6 x 9 plain H-pile was 65% higher than both coated H-piles and at 175 after pile driving. In general, the surface coating does not let any interaction take place between the soil particles and the pile wall. In other words, the formation of a plug could have shifted the location of the of the failure plane from the soil-pile interface (within the flanges of the H-pile) to some soil-soil plane (outside the H-pile) where the friction angle could be higher.

Despite the significant gain in capacity of the W6 x 9 plain pile throughout the first 8 days after pile driving, the capacity stopped its increased at 176 days. Later, a reduction in capacity took place some time between 176 and 602 days that resulted in a difference of almost 40% from its initial capacity when loaded at 602 days after pile driving. This capacity reduction could possibly be attributed to a remolding of soil, surrounding the pile, during loading past the yield point of the soil. The gradual failure mode seems to decrease with the number of tests. This could indicate that the W6 x 9 plain pile failed along the same failure plane throughout the three static load tests. The same behavior was observed with the two coated H-piles. Both H-piles were also observed to decrease with time. Unlike the W6 x 9 plain pile, the two coated failed along the same failure plane due to the use of the surface coatings, as previously explained.

The normalized ultimate capacity of the W6 x 9 piles are shown in Figure 85. The capacity of the W6 x 9 piles is observed to remained constant throughout the first 176 days after pile driving and decreases at 602 days. Similarly, the two coated piles were observed to decrease with time with the exception of the W6 x 9 Regular Coat pile that showed a slight increase (about 4%) in its capacity at 602 days. From the two coated H-piles, the W6 x 9 Regular Coat pile reached higher ultimate capacity values. The approximate unit side resistance developed along each pile is presented in Figure 86. Overall, the unit side resistance behavior seems to follow the same trend as the Qt/Qinitial.

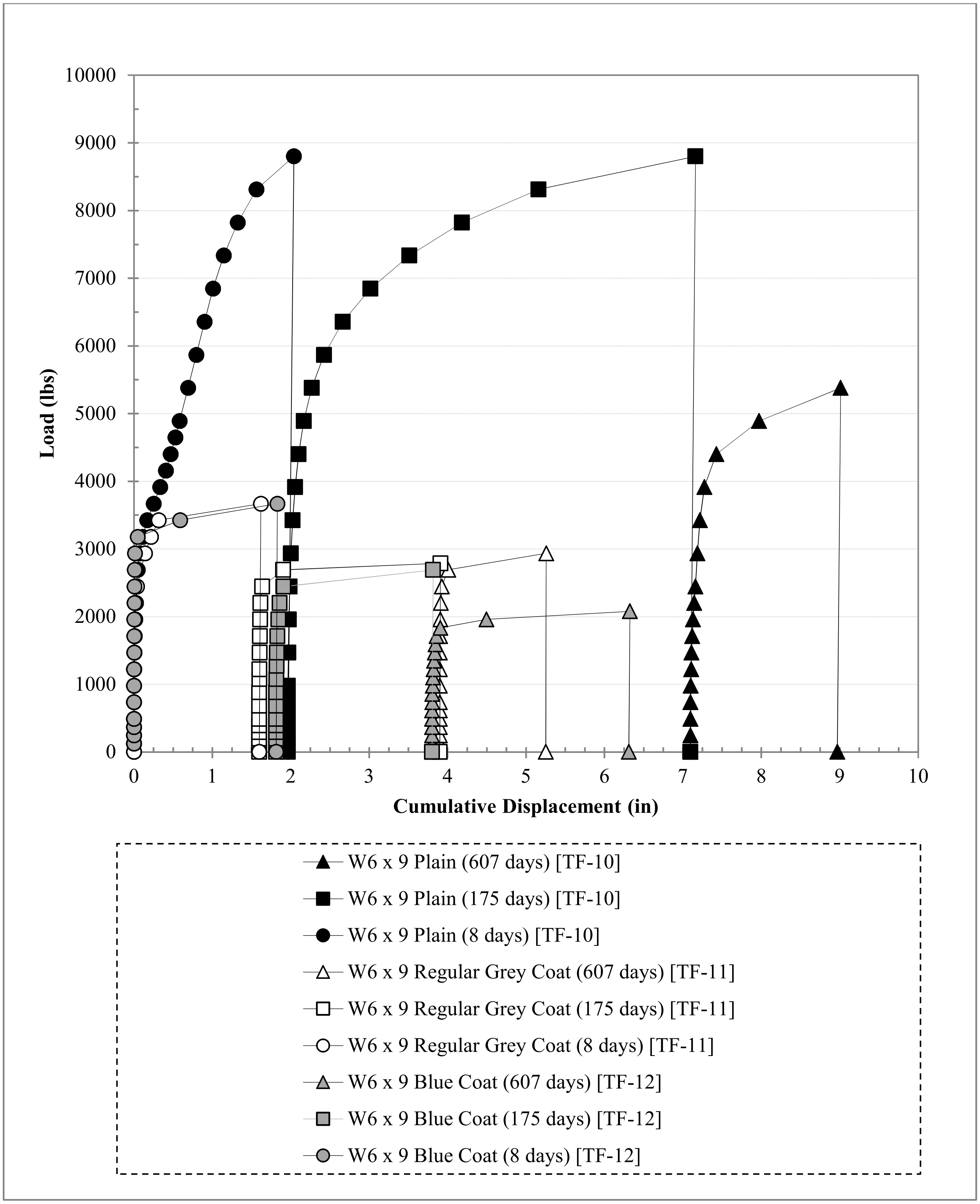

Figure 84. Load-Displacement Curves – W6 x 9 Plain Pile (TF-10), W6 x 9 Regular Coat Pile (TF-11) and W6 x 9 Blue Coat Pile (TF-12).

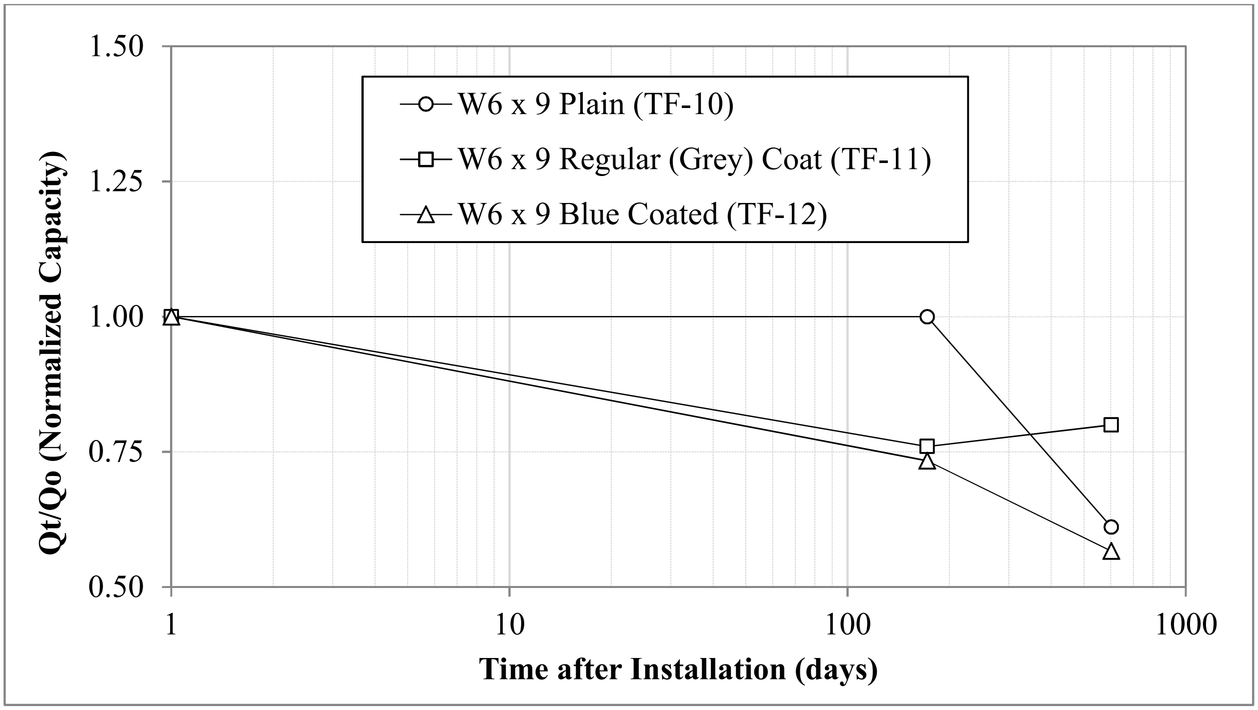

Figure 85. Normalized Capacity – W6 x 9 Plain Pile (TF-10), W6 x 9 Regular Coat Pile (TF-11) and W6 x 9 Blue Coat Pile (TF-12).

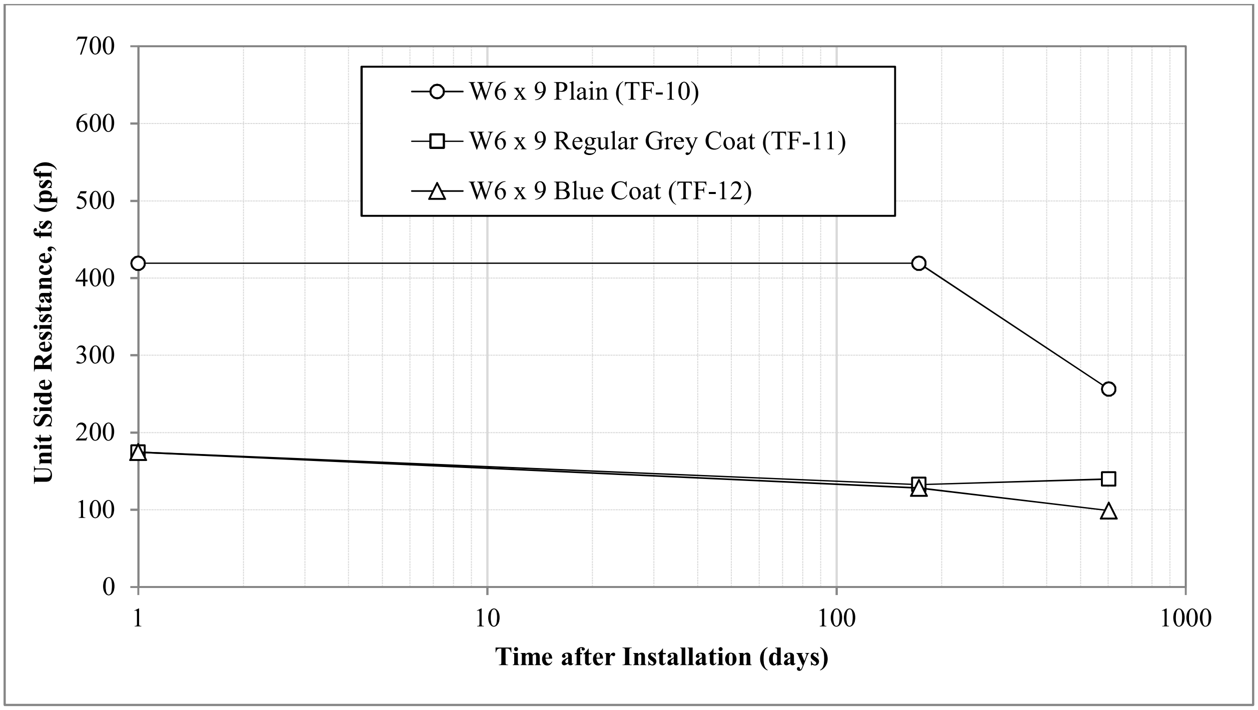

Figure 86. Normalized Capacity – W6 x 9 Plain Pile (TF-10), W6 x 9 Regular Coat Pile (TF-11) and W6 x 9 Blue Coat Pile (TF-12).

As previously mentioned, several piles showed a reduction in capacity with aging time. It is possibly that some of the piles that showed a reduction in capacity after initial test, experienced friction fatigue effects after each subsequent test since ground heave was observed, especially with H-piles, after, after static load tests. The behavior of the unit side resistance showed how the friction decreases with aging time after each static load test.

5.5 FRICTION FATIGUE

"Friction fatigue" is a term first introduced by Heerema (1980) to describe the reduction in mobilized shear stress developed in a given soil horizon during driving, as L/D increased. Heerema attributed this term to the two-way plastic shearing cycles undergone by the clay adjacent to the pile shaft.

Heerema (1980) proposed that the radial effective stress around the pile should be assumed to vary exponentially along the pile, from a maximum value near the tip of the pile to a minimum value near the ground surface. The maximum value is an empirical function of the shear strength of the clay at the level, and the penetration of the pile. Heerema's approach also assumes that the shaft friction at a given level appears to decrease as the pile is driven to deeper depths.

Many researchers (Bond and Jardine, 1991; Lehan & Jardine, 1994a and 1994b) observed evidence of the effect of friction fatigue at their respective test sites during installation of piles into clay and glacial till. Chow (1997) considered many possible mechanisms which could contribute to friction fatigue including:

- heave – with upward soil displacements resulting from pile installation causing a reduction in radial stress;
- pile whip – in which lateral movement of the pile head results in loss of contact between the pile wall and the surrounding soil;
- stress concentration at the pile tip caused by the large end bearing resistance generated during pile installation; and
- the effects of extreme cyclic loading.

White & Lehane (2004) demonstrated that the radial stress and base resistance was also affected by the number of load cycles experienced by the soil. Gavin et al (2010) pointed out that it is likely that friction fatigue effects would depend on the initial soil state. Kraft et al. (1981) and Randolph (1983) suggested that progressive failure, which occurs in strain softening soil, was a possible mechanism controlling friction fatigue.

Randolph (2003) noted that strain-softening soils, progressive failure at the pile-soil interface could occur, leading to the mobilized of the residual interface friction angle near the top of the pile and peak interface friction angle near the toe.

The load-displacement curve of the 4.5-inch schedule 40 open-end pipe pile (HHF-9) is shown in Figure 87. The capacity of the pile was observed to decrease after the first static load test due to possible friction fatigue mechanisms. Reconsolidation of the soil after the second test caused an increased in the capacity of the pile and continues to increase (up to 262 days). The highest capacity (approximately 13,692 lbs) was achieved at 262 days after pile installation. The load-displacement curve during the first and second test showed an abrupt failure mode and becomes more gradual during the third and fourth test. This gradual failure mode is an indication of an increase in radial stresses acting against the pile. The immediate reduction in the capacity of the pile after the first test, from 9,536 lbs to 8,313 lbs, and later accompanied increases its capacity by about 29% 77 days after the second test. The capacity of the pile was observed to continue to increase (14%) after the fourth test, reaching its maximum capacity, 13,692 lbs. During loading of the pile (test no. 4), the soil particles were rearranged causing a soil disturbance past its elastic behavior. The capacity of the pile after the fifth consecutive test showed a reduction of almost 11% at 300 days. The 4.5-inch schedule 40 open-end pipe showed a short-time decrease in its capacity followed by an increase around the time where pore water pressure fully dissipated (around 30+ days) and continued to increase its capacity up to 262 days. The normalized capacity of the pipe pile shows the behavior of the ultimate capacity for each static load test (Figure 88). During each loading cycle (static load tests), the soil is subjected to a deformation caused by the upward movement of the pile and friction of the pile acting against the movement of the pile. The friction fatigue effects were evident after the first test and by a sudden drop in the unit side resistance after the fourth static load test (Figure 89). This deformation appears to be cumulative to the point where the deformation of the soil causes a change in the soil structure making it behave plastically, thus affecting the radial stresses.

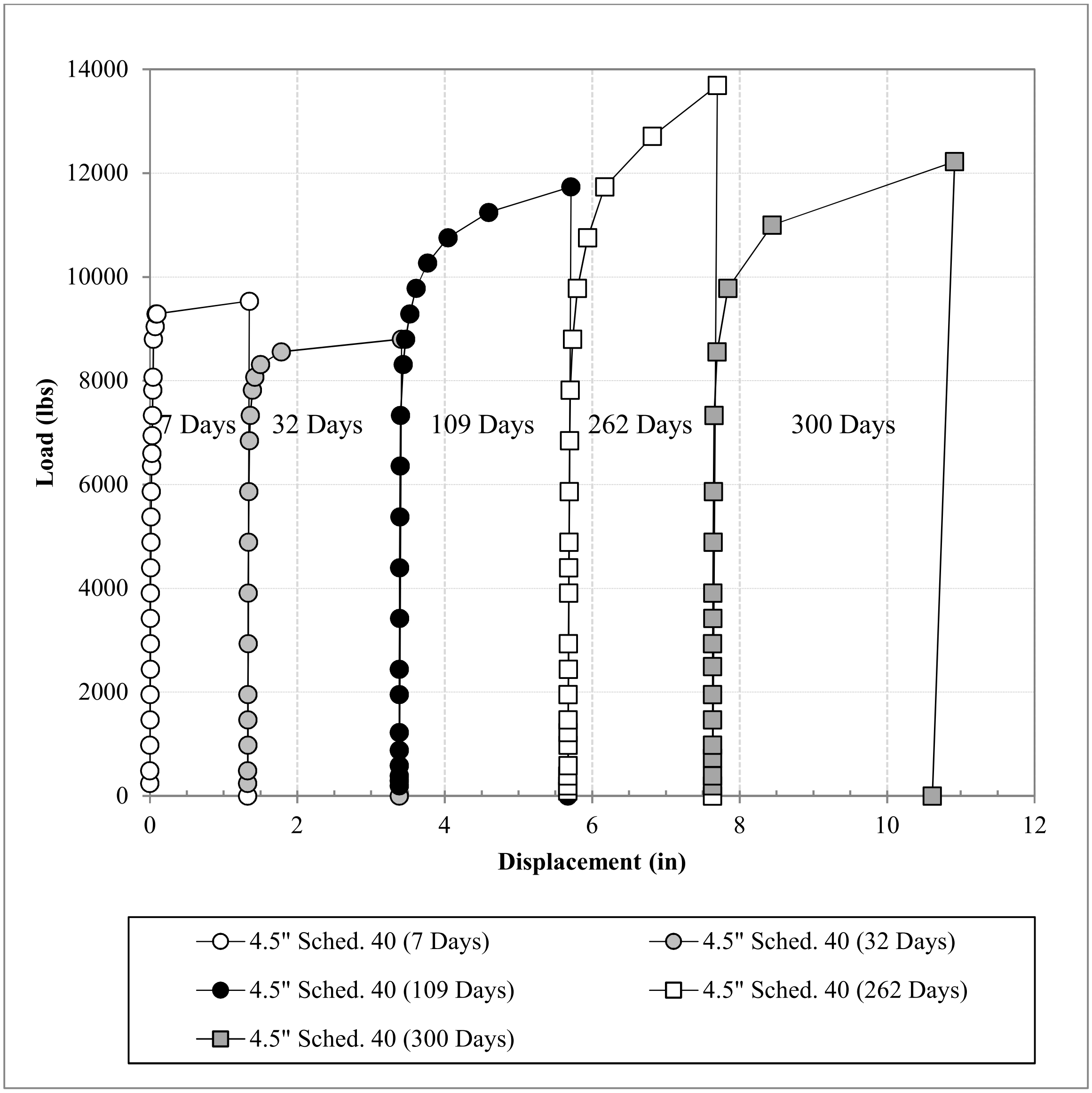

Figure 87. Load-Displacement Curve – 4.5-inch Schedule 40 Open-End Pipe Pile (HHF-9).

Figure 88. Normalized Capacity – 4.5-inch Schedule 40 Open-End Pipe Pile (HHF-9).

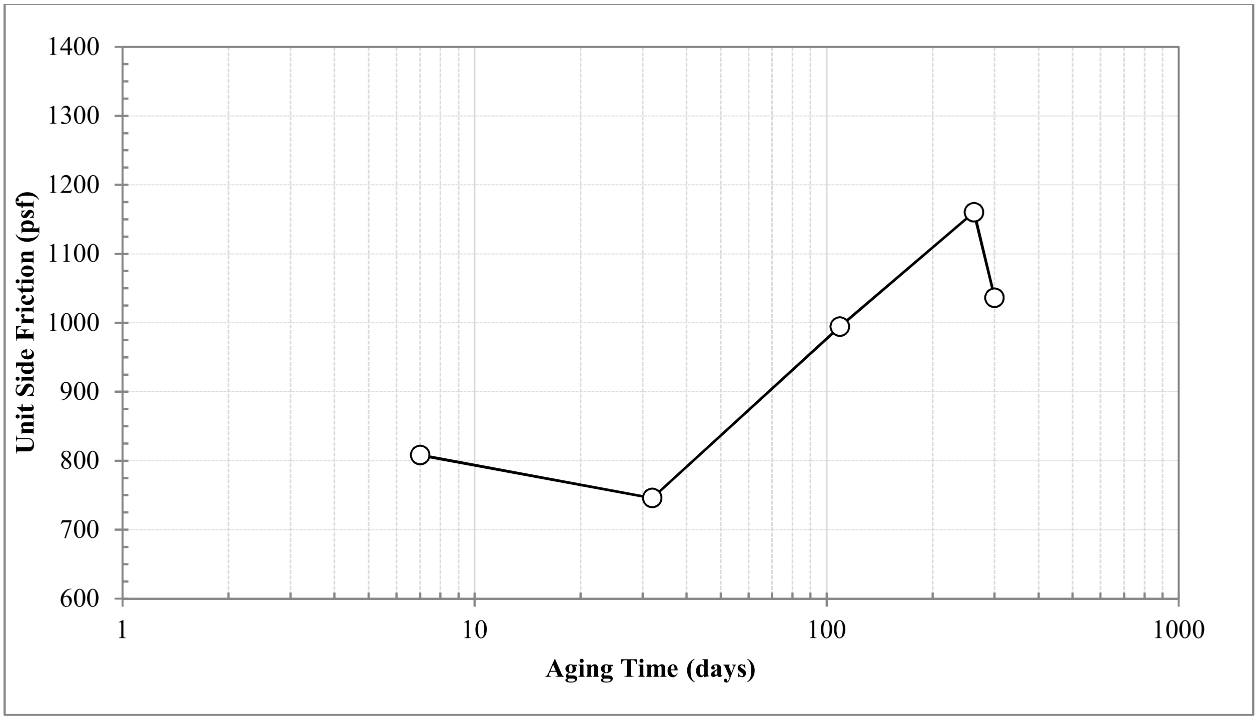

Figure 89. Normalized Capacity – 4.5-inch Schedule 40 Open-End Pipe Pile (HHF-9).

The 6.625-inch schedule 40 open-end pipe pile was load tested at 7, 115, 262 and 300 days (Figure 90). Overall, the pile capacity was observed to increase reaching a peak ultimate capacity of 13,692 lbs at 115 days. The capacity of the pile was 27% higher than the capacity at 7 days. The reduction after the second and third test was of about 17% and 18%, respectively. After the second test, the time allowed between the second test and third was enough to let the soil recover some of its capacity, which was higher than the capacity at 7 days that at the same it could be assume that is higher than the capacity immediately after installation (Undrained Shear Strength of the soil at this point is equal to the remolded shear strength of the soil).

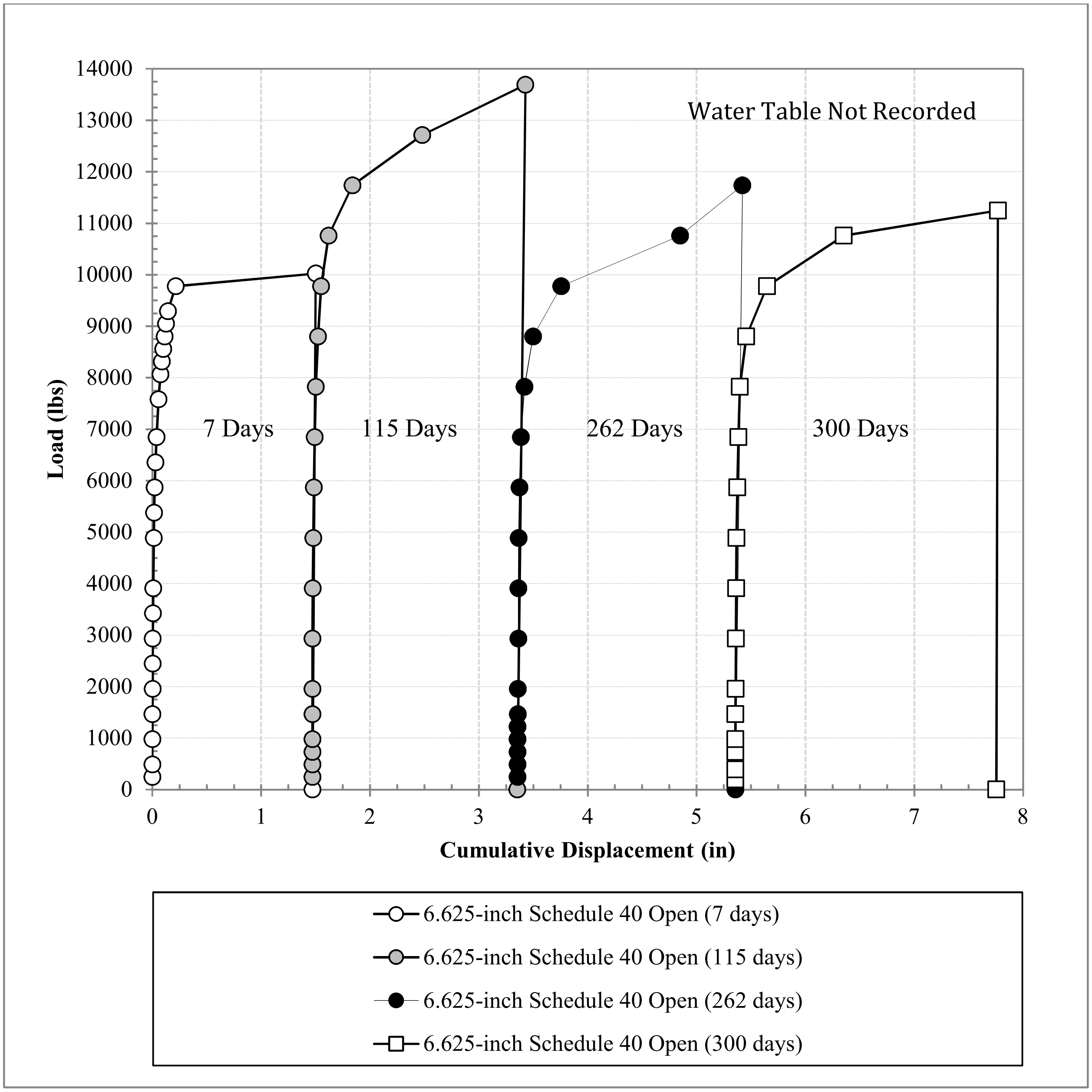

Figure 90. Load-Displacement Curve – 6.625-inch Schedule 40 Open-End Pipe Pile (HHF-10).

A 2.875-inch schedule 40 closed-end pipe pile was tested consecutively up to 100+ days. The load-displacement curve of the 2.875-inch pipe pile is shown in Figure 91. The ultimate capacity of the pile at 1 day after pile driving was 5,995 lbs with a slight decrease of almost 13% (5,225 lbs) after the second test. At 30 days after pile driving (20 days after the second test), the capacity of the pile increases to 6,600 lbs. The peak ultimate capacity of 11,550 lbs was achieved at 104 days (fourth test). Overall, the peak capacity of the pile was approximately two times the initial capacity of the pile at 1 day after pile driving. Friction fatigue could have caused the slight decrease in the pile friction and after reconsolidation after the second test and complete pore water pressure dissipation at 30 days the soil recovered and increase the radial stresses acting against the pile and thus increasing the capacity of the pile. Because the soil adjacent to the pile was not completely deformed past its elastic region, the soil recovered through its thixotropic behavior resulting in significant increase in its capacity.

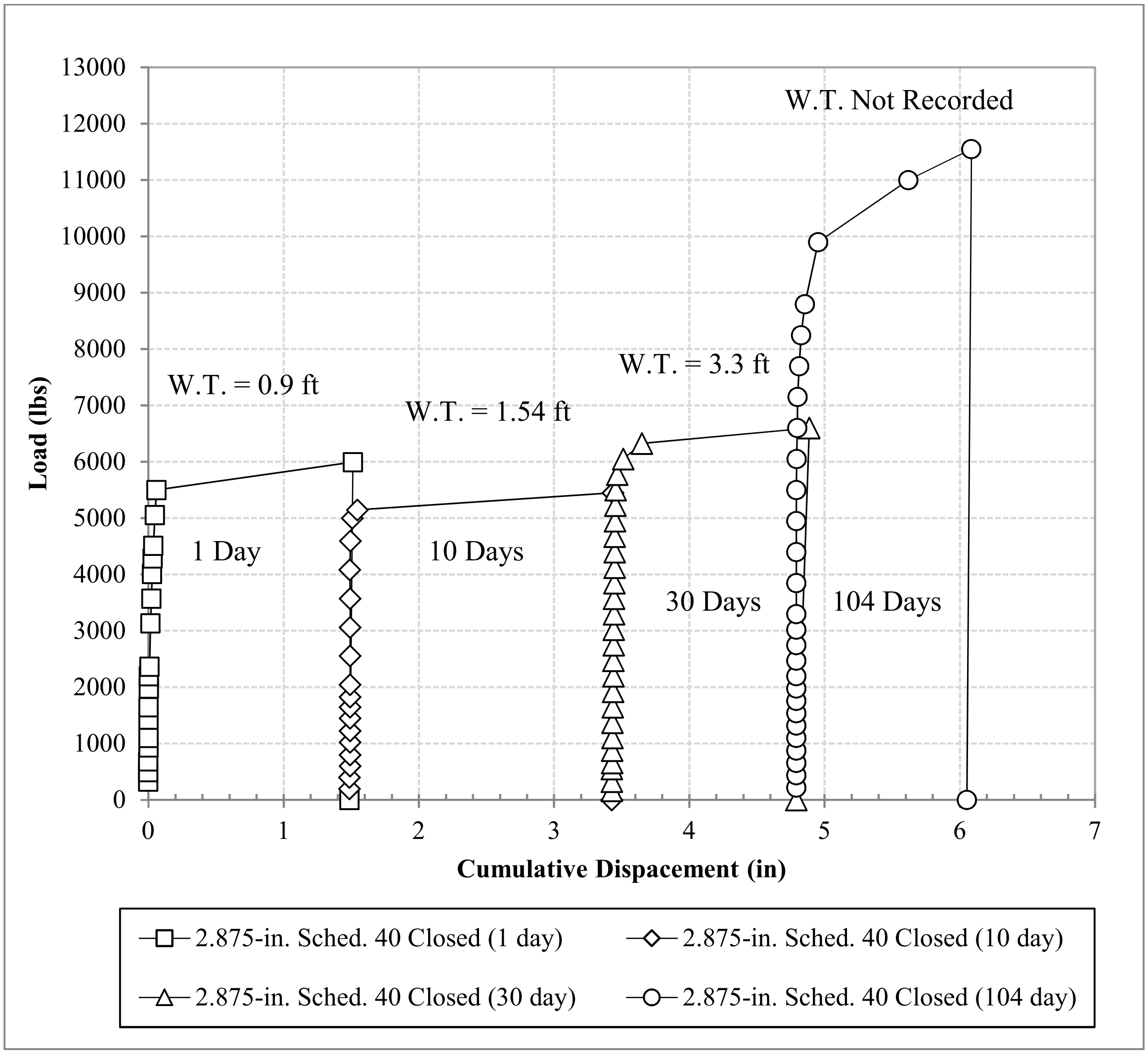

Figure 91. Short and Long-Term Capacity of 2.875-inch Closed-End Pipe Pile (DOE-6).

The load-displacement curve of H-pile W6 x 9 (DOE-15) is showed in Figure 92. A continuous gain capacity after the first two static load tests (up to 10 days) is followed by a halt in the capacity gain. The capacity (about 9,500 lbs) at 30 days was equal to that at 10 days, with the exception that the load-displacement curve shows a less gradual deformation which could be an indication that during this loading stage the soil was subjected to stresses that were breaking down the current structure of the clay past its elastic behavior. The capacity of the pile showed a reduction of almost 16% at 100 days and 21% at 300 days from its peak ultimate capacity achieved at 10 days after pile installation. In general, the W6 x 9 pile showed a short-time increase in capacity followed by continuous decrease in capacity probably due to constant remolding of the clay during each test after the soil adjacent to the pile was loaded past its yield point (during static load test at 10 days).

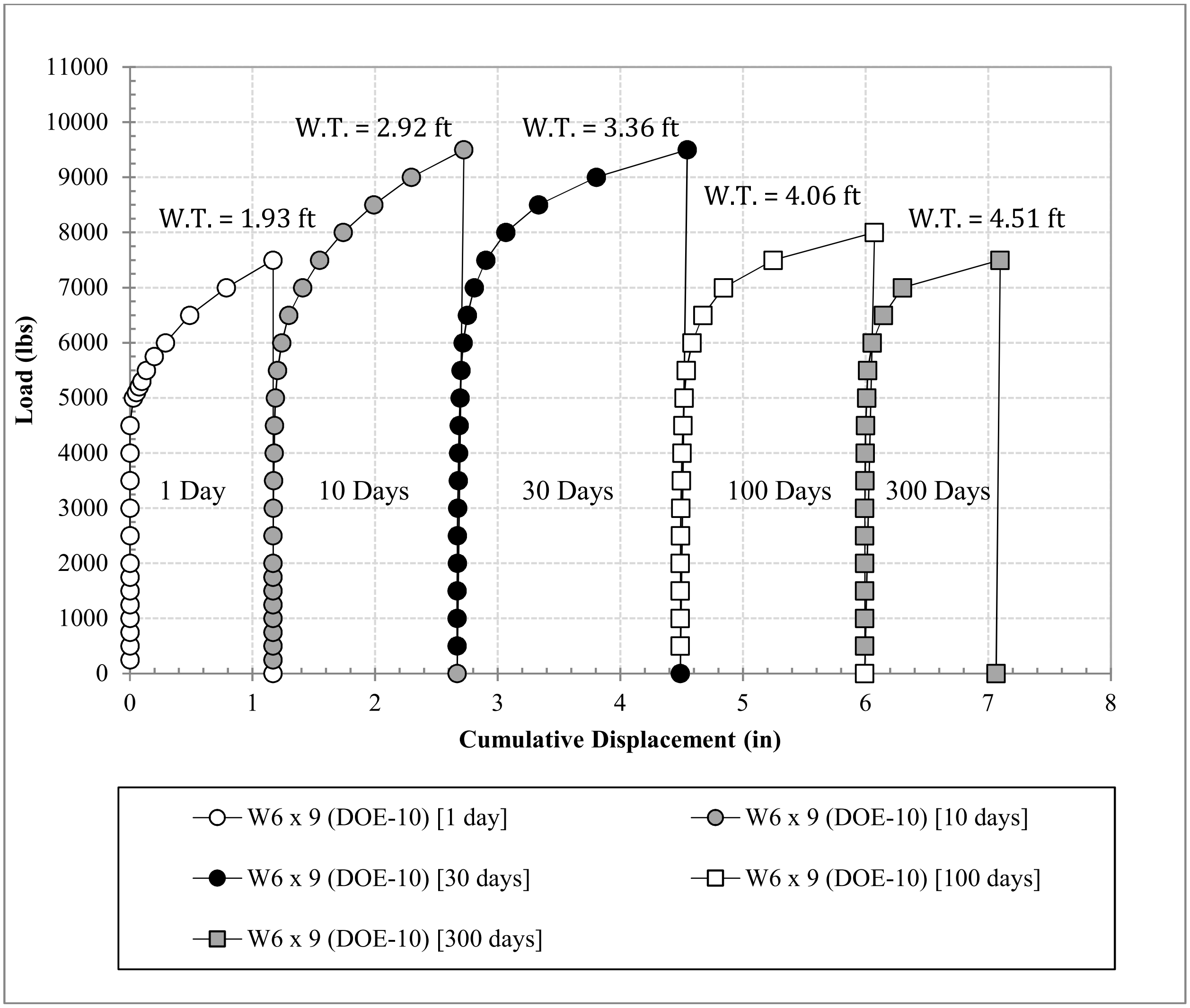

Figure 92. Short and Long-Term Capacity of W6 x 9 Pile (DOE-15).

The normalized ultimate capacity of the 4.5-inch and 6.625-inch open-end pipe piles with respect to aging time is shown in Figure 93. After the 6.625-inch schedule 40 open-end pipe pile was initially tested, it remolded the soil to the point where it affected the long-term behavior of the pile. At approximately 112 days (average) after pile driving, the capacity of the 6.625-inch schedule 40 open-end pipe pile exhibited at higher capacity than the 4.5-inch schedule 40 open-end pipe pile possibly because the soil around the pile gets deformed less times during loading. The difference in capacity of both piles was of 20% at 100+ days.

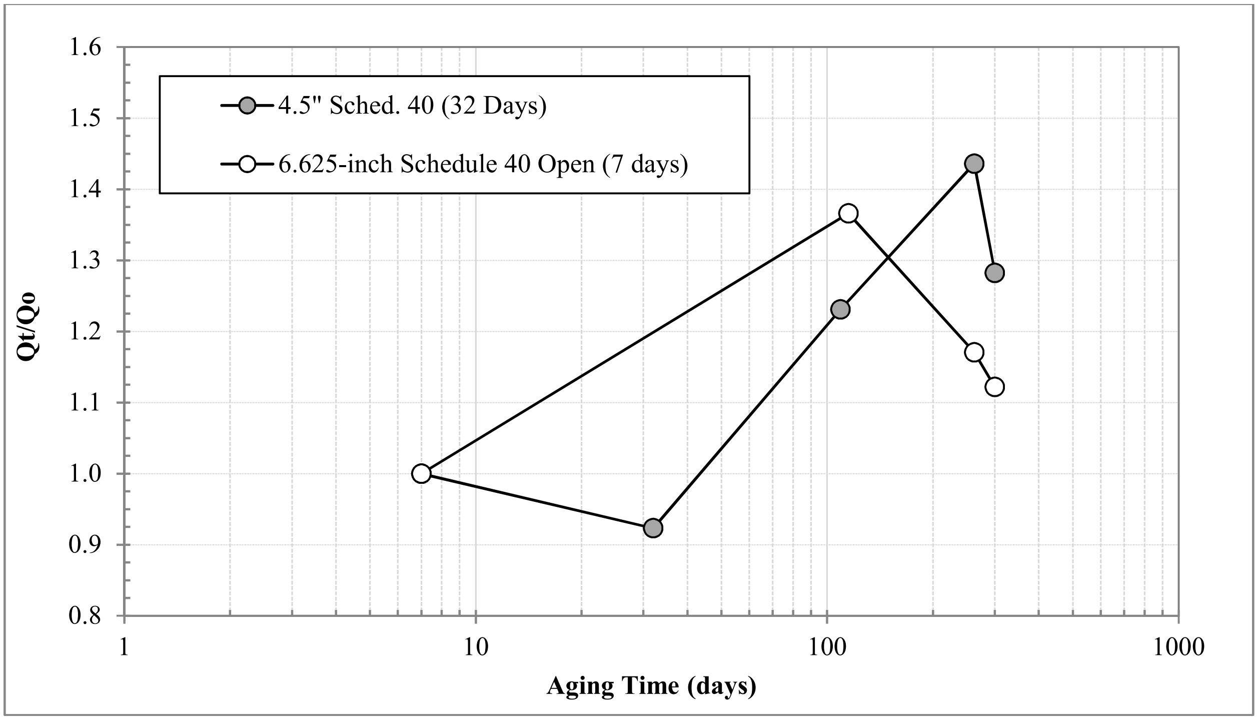

Figure 93. Normalized Capacity –4.5” Open Schedule 40 (HHF-9) and 6.625” Open Schedule 40 (HHF-10)

5.6 CYCLIC TENSION LOADS (REPEATED LOAD TESTS)

Karlsrud and Haugen (1985) subjected a steel pipe pile to a series of static load tests and observed that the previous loading influenced the future capacity of the pile. They attributed this behavior to preshearing, which results as a consequence of remolding of the clay during driving and allowing it to consolidate. This behavior, mainly in clayey soils, occurs because of thixotropic effects. Two piles were driven at the DOE site with the purpose of retesting them consecutively. Each pile was subjected to five immediate repeat static tensile load tests in succession 10 days after pile driving to allow the piles to gain some capacity over that period of time. After the initial static tensile load test, each consecutive static tensile load test was performed approximately 24 hours after the previous one. A W6 x 9 and a 4.5-inch closed-end pipe pile were tested after 10 days to allow for some pore water pressure dissipation and soil consolidation of the soil around the pile to consolidate. The results of both series of static load test for each pile are shown in Figures 94 and 95.

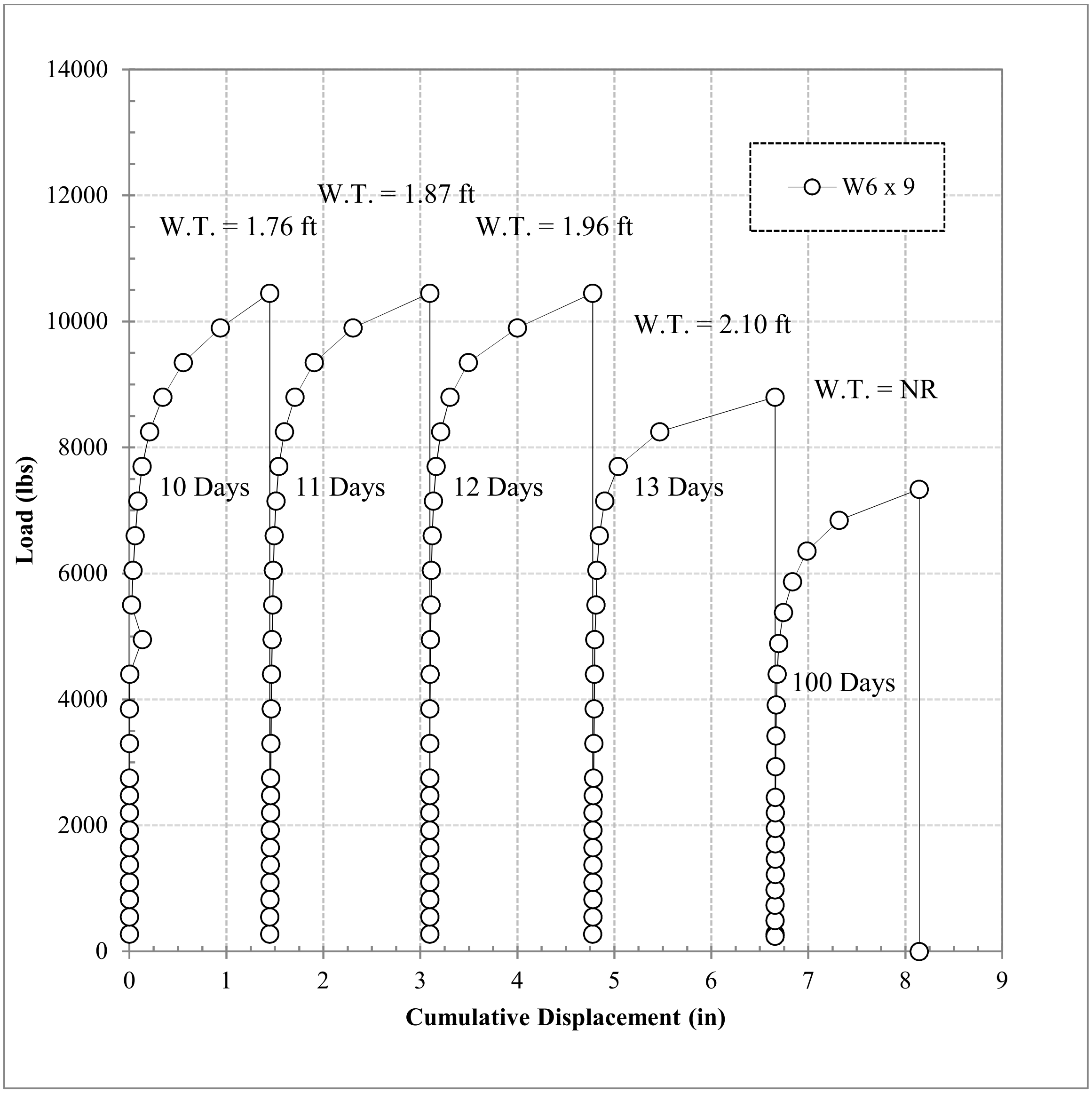

Figure 94. Repeated Load Test Results performed on W6 x 9 Pile (HHF-31).

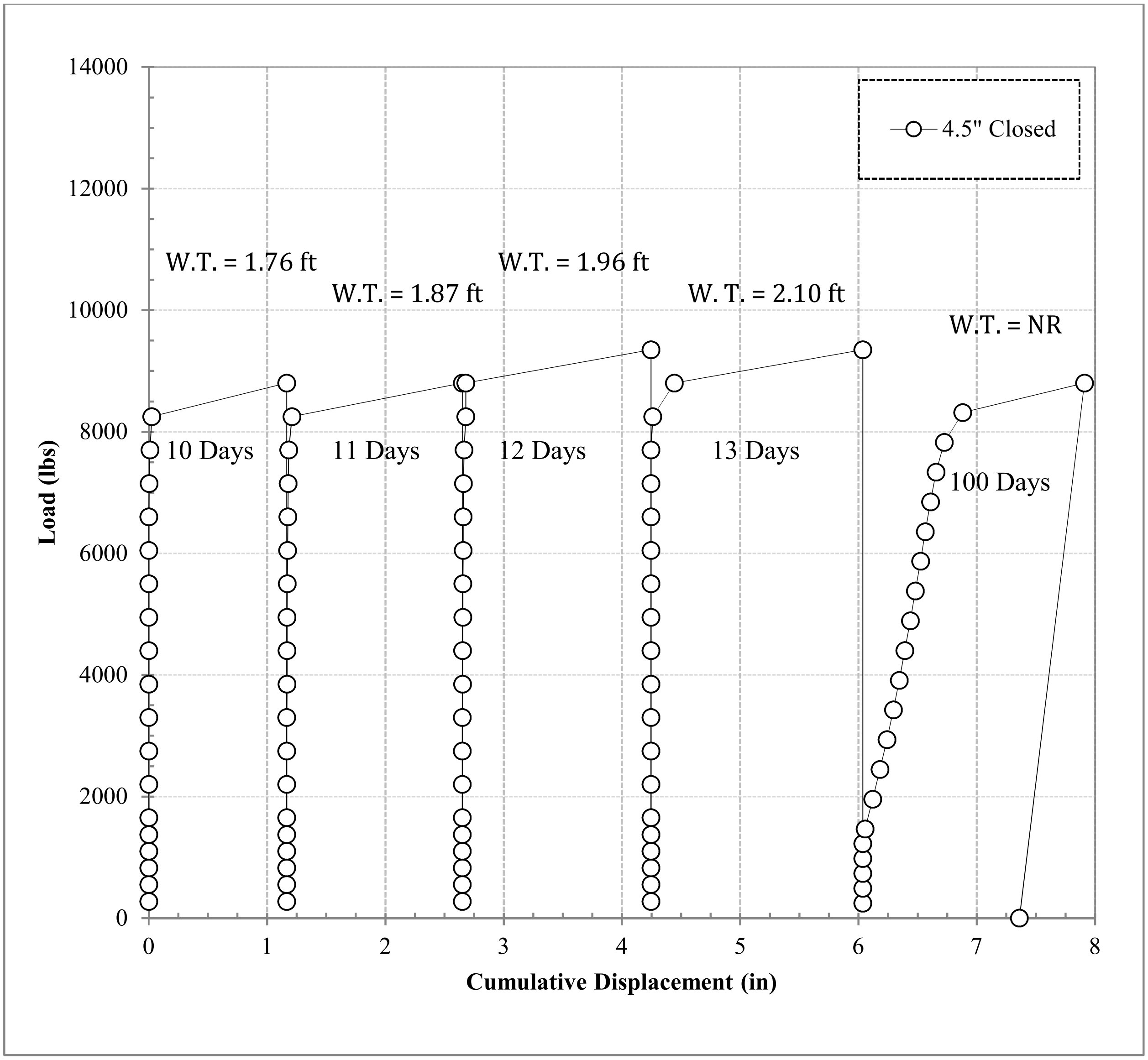

Figure 95. Repeated Load Test Results performed on a 4.5-inch closed-end pipe pile (HHF-32).

The first three repeated successive static load tests on the W6 x 9 pile (HHF-31) showed the same capacity, 10,450 lbs. But after the third consecutive repeated static load test, the capacity of the pile decreased to about 8,800 lbs, approximately 16%. In each test, the pile showed a gradual failure mode that can be attributed to failure along the same plane located at the soil-pile interface. After each successive repeated static load test, the clay was deformed to some degree within the elastic region of the soil's stress-strain curve where the soil still maintains its memory. The same pile was load tested after 100 days and showed a decrease in capacity, approximately 16% lower than the capacity at 13 days.

When testing a 4.5-inch closed-end pipe pile a slightly different behavior was observed. The capacity of the pile remained constant throughout the first two tests and then increased and remained constant during tests number three and four. This increase in capacity is a direct result of preshearing of the clay as pointed out by Karlsrud (1985). After the end of test, the soil surrounding the 4.5-inch closed-end pipe pile was remolded to some degree that resulted in some pore water pressure dissipation and thus reconsolidation of the clay. This consolidation of the soil surrounding the pile reduced the water content and voids within the soil along the pile that resulted in an increase in Undrained Shear Strength. The capacity of the pile was observed to increase from 8,800 lbs to 9,350 lbs (after the 4th consecutive load test), approximately 6% more. The failure mode indicates a friction angle located at the soil-pile interface. During loading of a pile in tension, the surrounding soil was not disturbed or deformed past the soil's yielding point allowing the soil to recover. The gain in capacity could be attributed to preshearing of the clay. The capacity of the pile at 100 days was about 5% lower than the capacity after 13 days.

In general, the increase in capacity over time for the W6 x 9 pile was less than the increase of the 4.5-inch open-end pipe pile. Since both piles were installed at the same site and both piles were the same length the mode of failure and increase in capacity could be attributed to the pile geometry. At 100 days, the capacity of the pipe pile was approximately 15% higher than the H-pile.

Another W6 x 9 pile (TF-17), same as W6 x 9 (TF-16), was installed and only load tested 405 days after pile driving (Figure 96). The ultimate capacity of the pile was 8,800 lbs, approximately 25% higher than the W6 x 9 pile (TF-17) also tested at 405 days (and previously tested 5 consecutive times after pile driving). This gain in capacity demonstrated how the load history of a pile influences and affect the long-term ultimate capacity of the pile. Specifically, if a pile is not left loaded in the short-term, it will develop a higher long-term capacity than piles loaded in the short-term. These results are site dependent (thixotropic behavior of the clay) and in this case, remolding the soil around the piles installed at the Taylor Field would affect the pile's capacity in the short and long-term.

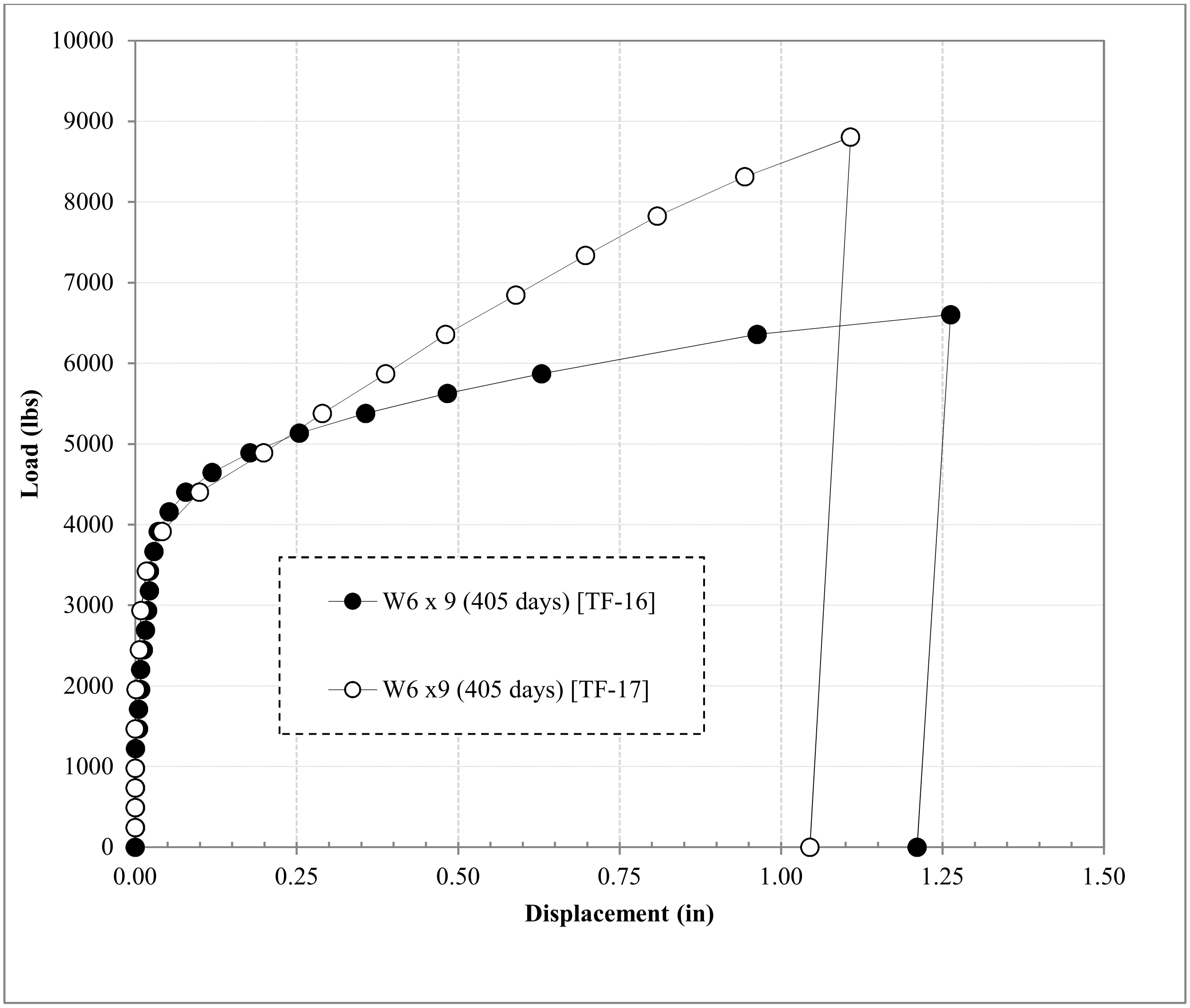

Figure 96. Long-Term Capacity of previously tested versus non- tested Piles (TF-16 and 17).

The 5 consecutive tests performed on the W6 x 9 pile (Figure 97), showed that after the first two consecutive tests, the soil surrounding the pile was not remolded to the point where it reduced the soils Undrained Shear Strength, which could indicate that soil recovered after the 1 test. During the first two tests, the deformation of the soil due to pile displacement was within the soil's elastic region in the stress-strain curve. Inside this region, the soil maintains its memory. After the first two initial consecutive tests, each subsequent test resulted in a decrease in the pile's capacity due to the deformation of the soil surpassing its yield limit within the plastic limit of the soil and thus creating a failure plane. The third, fourth and fifth repeat tests yielded consecutive decreases in capacity due to remolding of the clay already within the plastic zone and failing when it reached the end of its plastic deformation. For this reason, every successive test failed at a lower load. The ultimate capacity of each test (during the first five repeat load tests) may indicate the clay's ultimate stress at failure along the stress-strain curve (for this soil). The failure occurs at some soil-soil plane outside the flanges due to formation of a plug within the flanges. Additionally, some capacity gain can be attributed to interlocking of the sand particles (Figure 98) every time the pile deforms the surrounding soils when axially loaded. For this reason, the ultimate capacity of each test models the stress-strain curve of the clay (Figure 99) and sand, (surrounding the pile) working together through their own independent mechanisms related to the pile's gain in capacity. Based on the stress-strain curve formed by using the pile's ultimate capacity at each test, it could be assumed that the capacity of the pile was governed by the sand layer.

A sixth load test was performed on the W6 x 9 pile at approximately 392 days after pile driving (Figure 100). At this aging time, the pile showed an increase in the pile's long-term ultimate capacity attributed to the clay's thixotropic behavior and bonding of sand particles with the pile wall as a result of corrosion. At 392 days, the capacity of W6 x 9 pile (TF-16) was 25% more than the last (5th) successive repeat test. Also, a gradual mode of failure was observed, it can be assumed that the pile did not fail along the same plane as the third, fourth and fifth test.

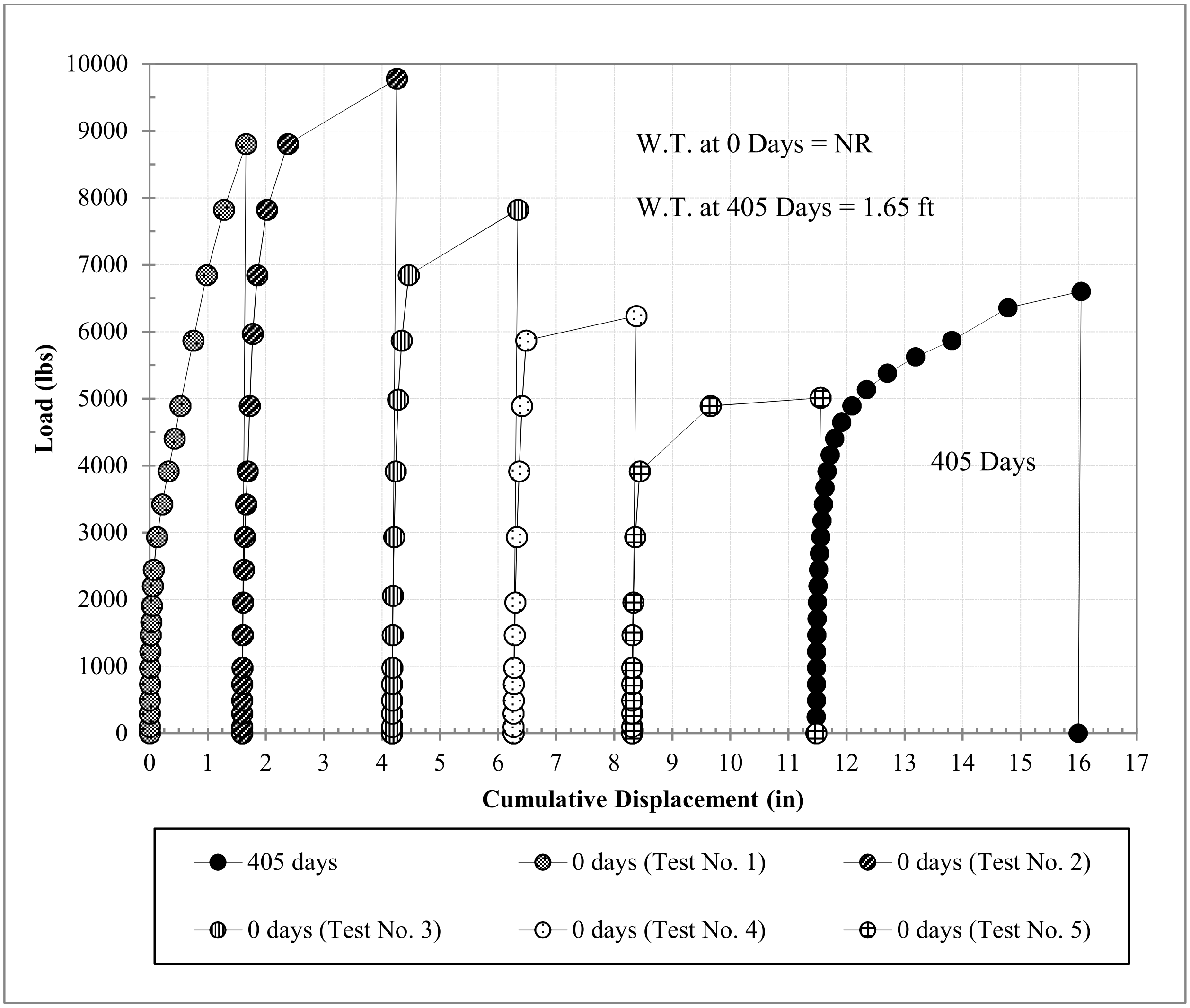

Figure 97. Long-Term Load Test Performed After a Series of Short-Term Repeated Successive Load Tests Performed on a W6 x 9 H-Pile (TF-16).

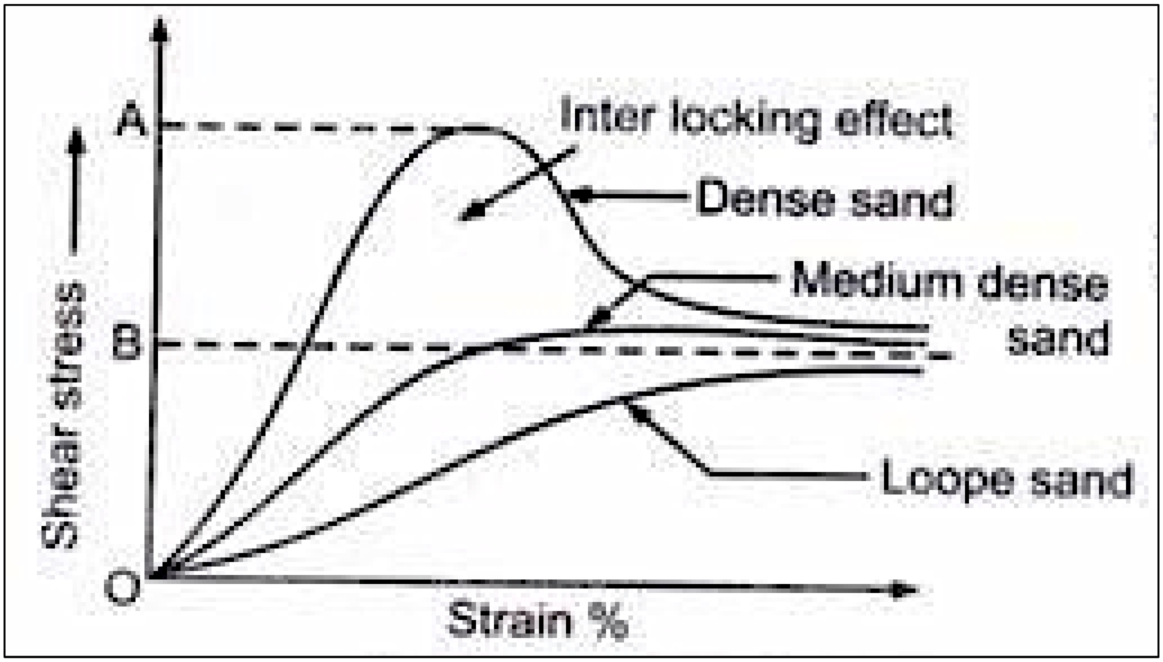

Figure 98. Typical Stress-Strain Curve for Dense, Medium Dense and Loose Sands.

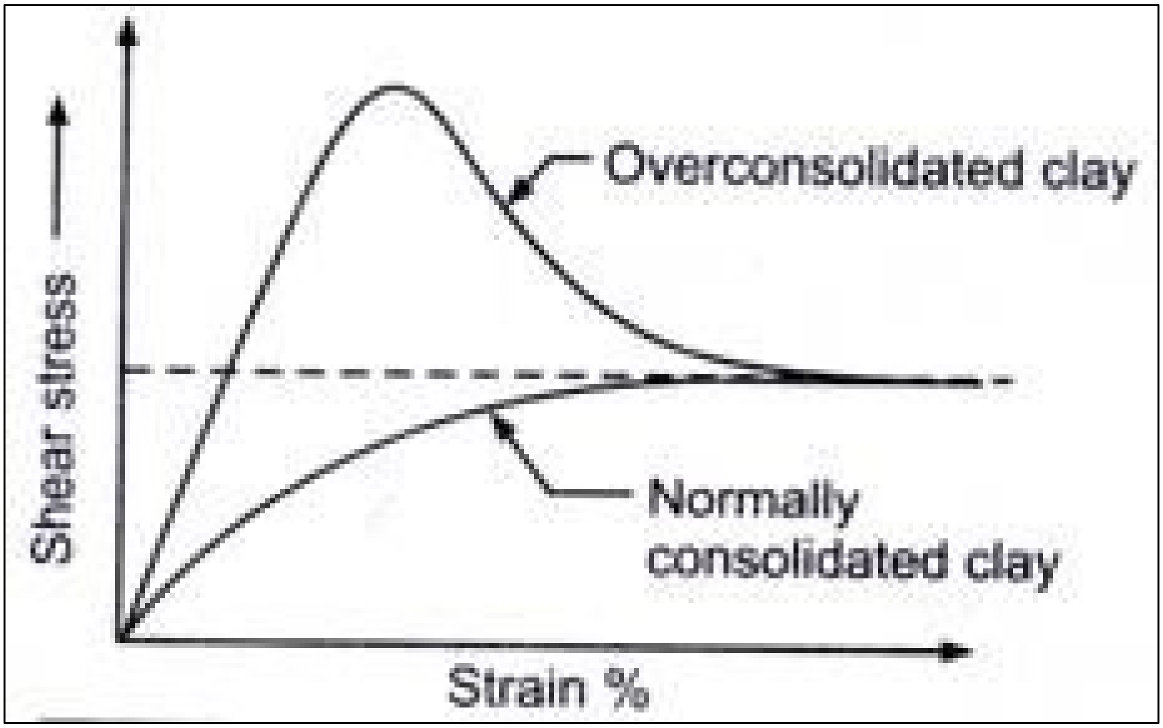

Figure 99. Typical Stress-Strain Curve for Normally Consolidated and Overconsolidated Clays.

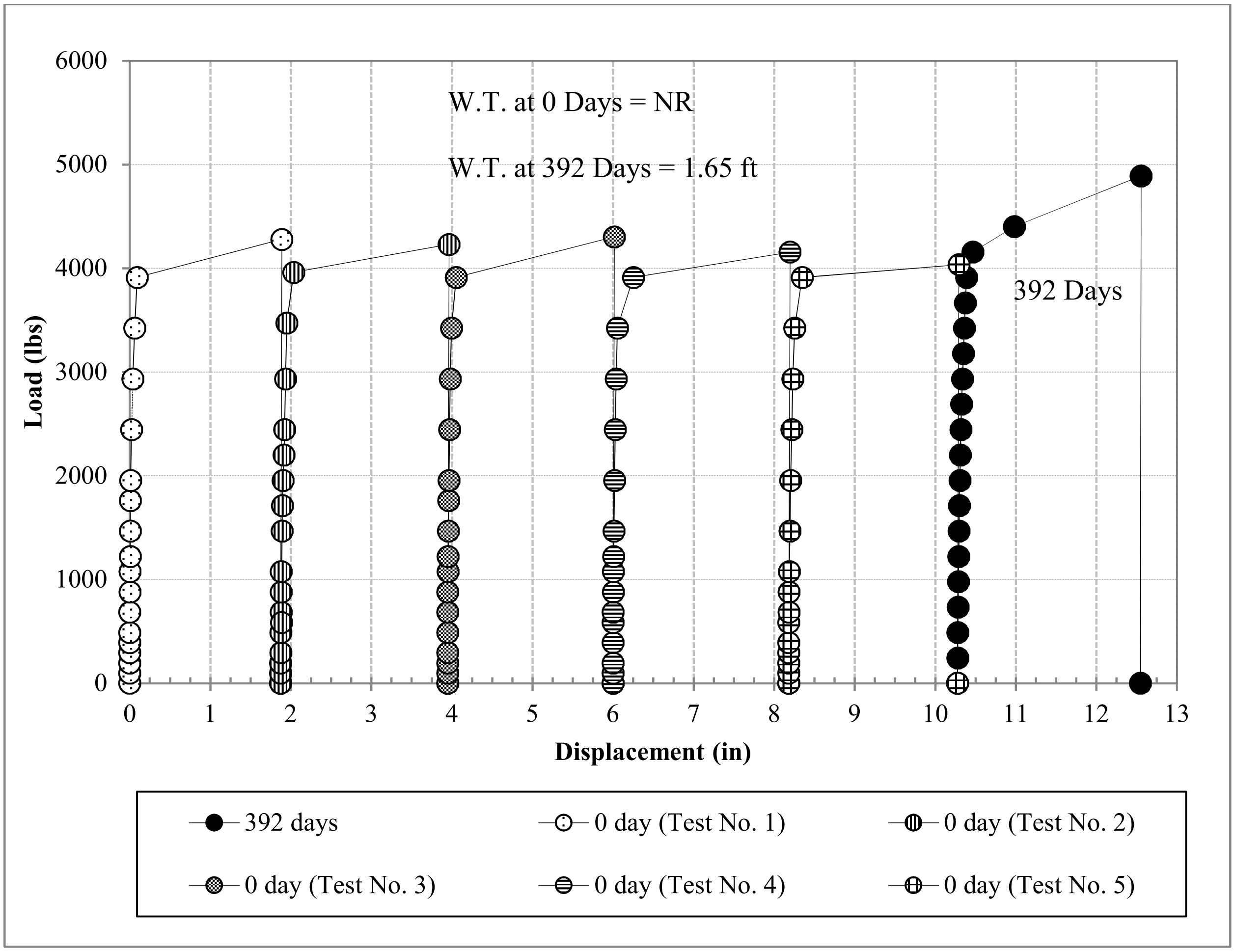

Figure 100. Long-Term Load Test Performed After a Series of Short-Term Repeated Load Tests – (TF-18).

The location of the failure surface on which the shear resistance develops during pile loading will depend on the interface roughness, and at least for steel piles, some consideration of the interface friction angle, which controls the shear resistance at the soil-pile interface (Doherty & Gavin, 2011).

Similarly, a sixth load test was performed on the 4.5-in. Schedule 40 Open-End pipe pile 392 days after pile driving, allowing for enough time for aging-related effects such as the pore water pressure dissipation and creep to occur. The slippage failure mode shows that no bonding of the clay particles and the pile surface occur and that the gain in capacity could be only attributed to the thixotropic behavior of the clay. Also, since the same failure mode was observed throughout each test, it can be assumed that the pile failed along the same plane located at soil-pile interface. At 392 days, the capacity of the 4.5-in. Schedule 40 pipe pile (TF-18) was almost 18% than the average capacity throughout the five repeated tests.

At the end of pile driving, an excess pore pressure field will exist around the pile. The excess pore pressure is primarily due to increase in total stress as the soil is pushed outwards (Bergset, 2015). The behavior of the soil surrounding the pile is governed by the effective stresses acting against the pile wall and a complicated stress-strain changes that occur during the installation of pile driving (Doherty & Gavin, 2011).

Also, when installing or driving a pile into clay under undrained conditions, large excess pore pressures are generated close to the pile (Doherty & Gavin, 2011). Pile installation is recognized to significantly disturb the surrounding clay and cause changes in total and effective stresses around the pile (Bergset, 2015). This affected area around the pile is referred to as the disturbed zone. During installation, the soil fails due to the imposed shear stress at the interface of the pile and soil, and radial compression to the soil mass adjacent to the pile (Budhu, 2008).

5.7 RATE OF LOAD APPLICATION

5.7.1 BACKGROUND

Soils like many other materials, exhibit strong time dependent behavior, which can be translated in term of creep, relaxation or strain-rate effect (Charue, 2004). The degree of this rheological behavior varies with the type of soil (sand and the opposite, clay), the type of structure, the soil stress history (Mitchell, 1976). The behavior of clays tends to be very sensitive to the rate of loading. Many researchers (Richardson & Whitman, 1963; Berre & Bjerrum, 1973) agreed that there is an increase in rate of deformation results in an increase of the Undrained Shear Strength.

Loading rates have also affected the axial capacity of piles. Kraft et al. (1981) reported that the ultimate bearing capacity of piles embedded in clay increases by about 40% to 75% when the loading rate is increased by about three orders of magnitude. Whitaker (1963) developed a Constant Rate of Penetration Test, CRPT, and showed that the rate of penetration enhances pile shaft resistance in clay soils (Whitaker and Cooke, 1966; Burland et al, 1988). Lyndon (1994) performed Constant Rate of Penetration (CPR) tests on different piles of the same nominal diameter (400 mm) installed in clay and noticed that a gradual loading rate increase exhibits a variation of peak resistance (Figure 101). For this reason, the ultimate capacity is a function of the rate of load application.

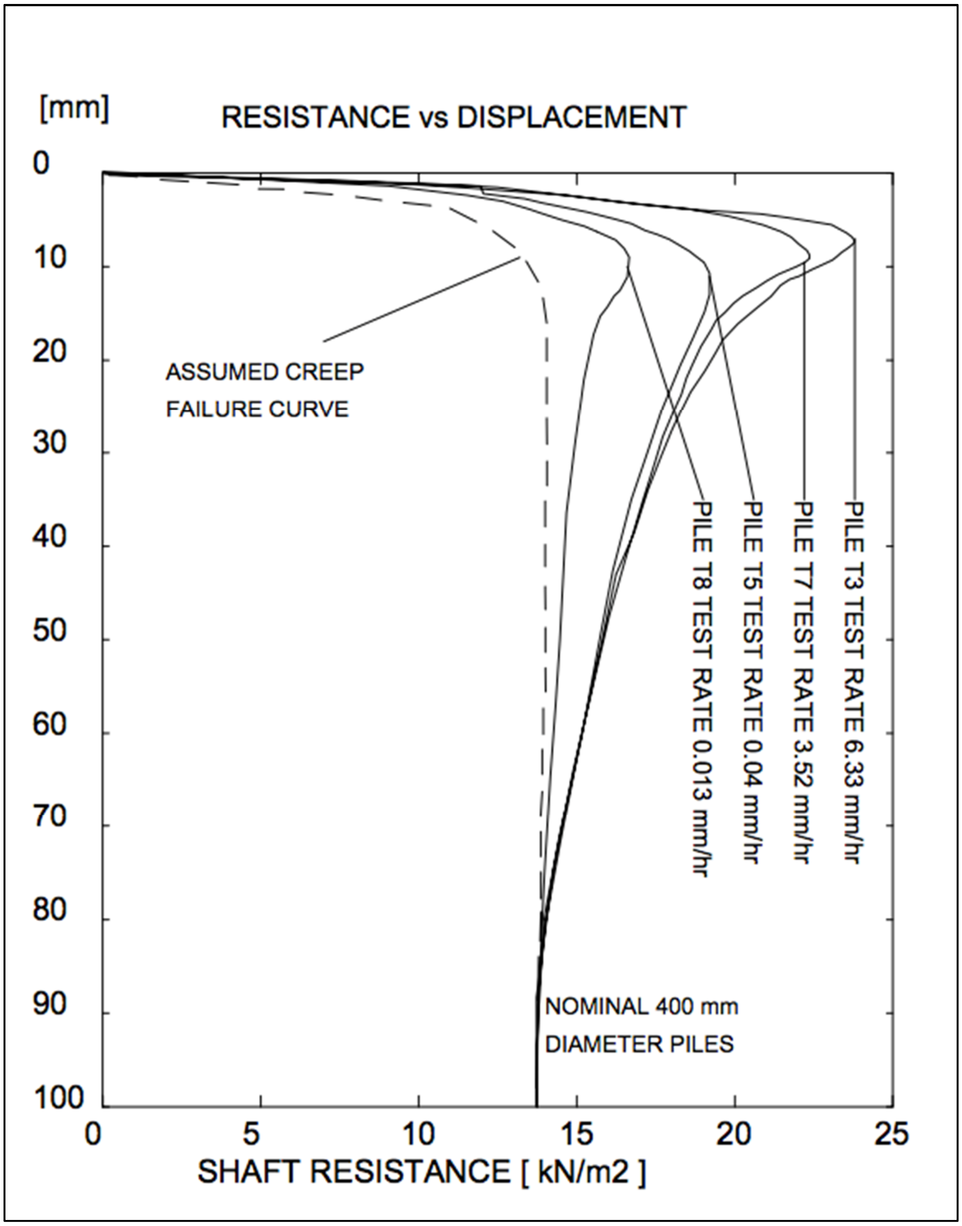

Figure 101. Shaft friction determined from different CRP tests (Lyndon et al., 1994).

5.7.2 INFLUENCE OF SHEARING RATE IN THE CAPACITY OF THE PILE

As the rate of load application increases (or the strain rate increases), the Undrained Shear Strength of clay also increases, due to viscous properties of clay (Briaud and Garland, 1985; Leroueil & Marques, 1996). This is an important phenomenon that must be addressed in any pile test where capacity is derived from clays. Clays have consistently been shown to exhibit significant “rate effects” (Garner, 2007). Leroueil and Marques (1996) found that due to viscosity in clays, the Undrained Shear Strength increases by about 10% per log cycle increase in load rate but decreases about 10% for each 120 °C increase in temperature. Other factors that influence rate effects include, but are not limited to: plasticity index, overconsolidation ratio (OCR), soil structure, water content and aging. Though all of these factors have been shown to affect strain rate phenomenon, little research has been done to quantify their effects (Garner, 2007).

Briaud and Garland (1985) explained the physical reasons for rate-dependent properties of clays and attributed rate dependent properties to pore water, particle contacts and water/soil interaction. Water in pores is more viscous than clay particles.

Garner (2007) explained that because water is Newtonian fluid, when the shearing rate doubles, the shear strength will double and therefore the higher the water content of the clay, the higher the viscosity of the clay. Viscosity plays a major role in particle contact of the clay because these contacts consist of a mineral particle and its absorbed water layer penetrating into the absorbed water layer of another mineral particle. He also stated that the viscosity of the absorbed water layer is greater than the viscosity of the free water in pores and for this reason if the overlap of absorbed water layer becomes greater, then the viscosity of the clay will be greater. Garner (2007) also explained that the overlap of layers is greater in overconsolidated clays because they are forced closer together. Also, higher viscosity can be seen if the absorbed layers are thicker, such as with clays having high plasticity indexes.

The shear strength due to water/soil interaction varies with the rate of the shear in the soil because the path of least resistance is found when the shear is low but with faster rates, the soil structure does not have time to deform and find the path of least resistance (Garner, 2007). This explains why the shear strength goes up with increased rate of strain that will result in negative pore water pressure and as a result, the shear strength of the soil increases (Garner, 2007). Permeability therefore affects the strain rate effects because with lower permeability, pore pressure does not dissipate when soil is sheared quickly, but it will dissipate if load is applied slowly enough (Garner, 2007).

During static load tests, the loads are applied to piles at a slow pace slowly that the viscous component of response is negligible (Airhart, 1967). The ultimate capacity determined from static load tests is a function of the friction between the soil and pile. The analysis of factors influencing the static load response is in effect an analysis of factors influencing: soil particle contacts (Airhart, 1967). The most important factor influencing the development of soil particle contacts associated with a denser soil structure is the excess pore water pressure. The ultimate load bearing capacity, which a friction pile will develop, is usually measured by load test only after excess pore water pressures have dissipated and the soil has attained its final consolidated structure. The load bearing capacity attained by a friction pile then becomes a function of the shear strength of the disturbed and reconsolidated soil along the length of the pile and of any point load developed. The application of a load at a slower rate will result in a less extensive shear failure mechanism than at a fast rate (Figure 102).

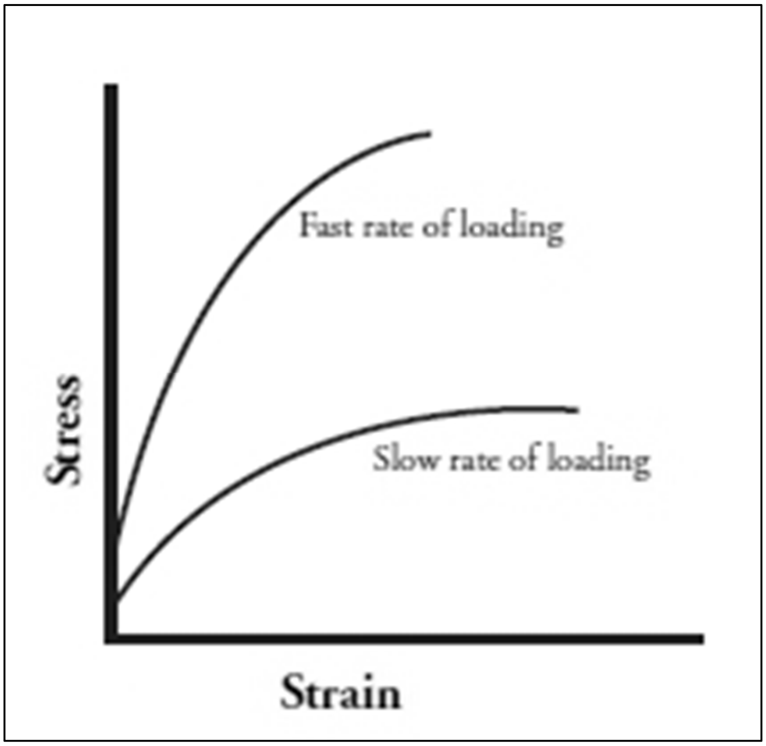

Figure 102. Stress-Strain Behavior of Piles Subjected to Different Loading Rate Conditions.

As the rate at which load is applied to a test pile increases, the capacity also increases, particularly in clay. Strain rate effects can vary widely and may be influenced by many factors including plasticity index, structure, aging, overconsolidation ratio, temperature, etc.

Figure 103 shows the load-displacement curve for a series of tests performed on two different piles with same geometry. Each piles was load tested at different loading rates in order to study how this how the rate of load application influences the ultimate capacity of a pile. Two 2.875-inch closed-end pipe piles were load tested at the same aging period to observe how the ultimate capacities compared. The results of two static load test (quick and fast) that were performed 300 days after pile driving showed that the capacity of the pile used for the “fast” static load test was approximately 18% higher than the “quick” load test. Not only the 2.875-inch closed-end pipe pile exhibited a higher capacity but it also showed a smaller degree of deformation since failure occurred after a displacement of 1 inch.

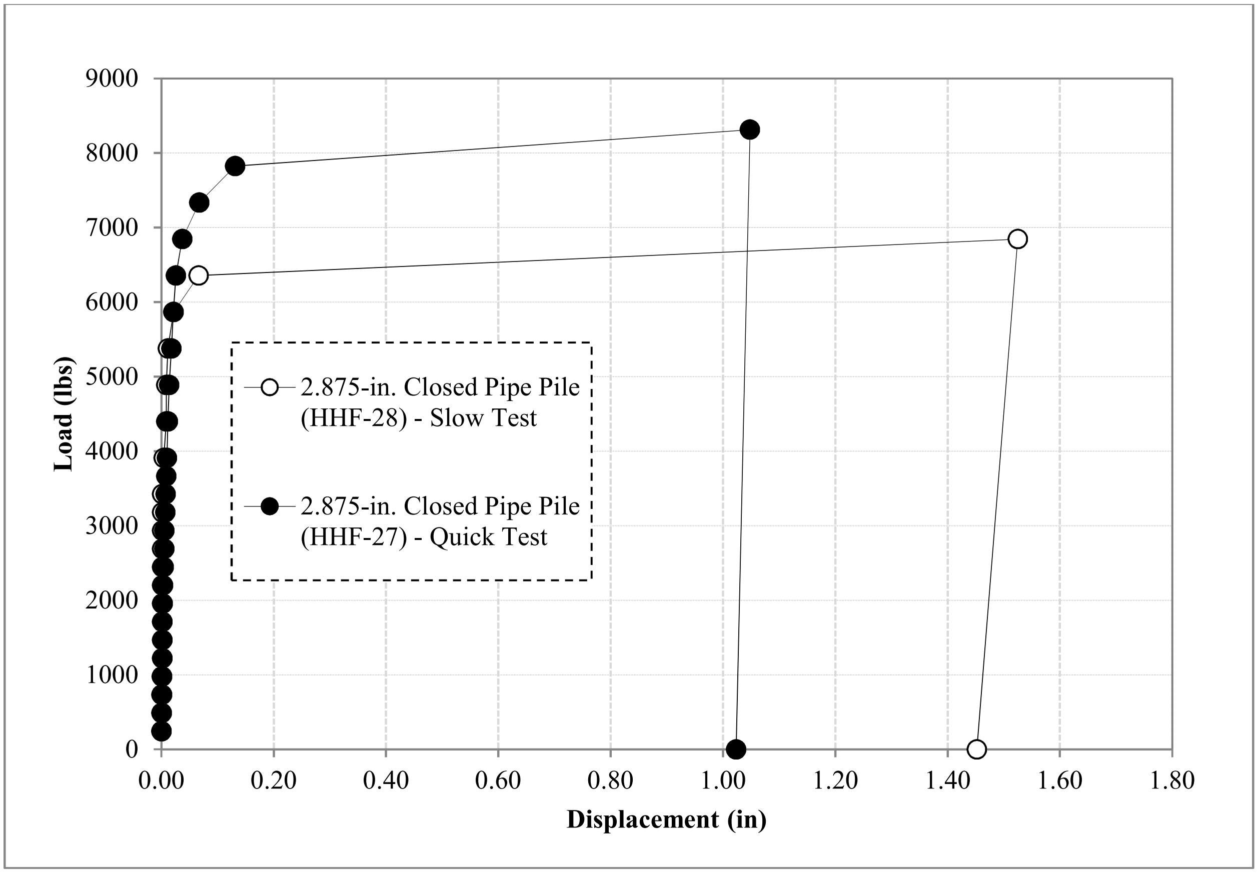

Figure 103. Load Rate Effects on Long-Term Behavior of a 2.875-inch Closed Pipe Pile (HHF-27 and HHF-28).

5.8 ULTIMATE SHAFT FRICTION

5.8.1 THE ALPHA (α) METHOD

Karlsrud (2012) propose two new procedures for predicting the ultimate shaft friction, respectively the α- and β-approach. These procedures were developed using a database of results from numerous instrumented pile load tests. Instrumentation of the piles includes measurement of the pore pressure, earth pressure and shaft friction along the pile shafts. In-situ and laboratory testing have generally been carried out together with the fully instrumented load tests. On this basis, the two procedures tie the local ultimate shaft friction along a pile to the undisturbed in-situ Undrained Shear Strength as determined from Direct Simple Shear Tests, the in-situ vertical effective stress, the overconsolidation ratio, and the plasticity index of the clay. During axial pile loading, the mode of shearing along the pile shaft resembles the Direct Simple Shear (DSS) mode of failure. Thus, Karlsrud (2012) chose to use Sud as reference strength in his study.

For the α-method, the ultimate shaft friction can be determined from Figure 104 or estimated using the following equation:

$$\boldsymbol{\tau_{us} = \alpha S_u}$$

The α-value is determined on the basis of the normalized undrained strength, Sud/σ'vo, and the plasticity index, Ip, of the clay. The ultimate shaft friction is lower than the in-situ Undrained Shear Strength due to the impact of the severe disturbance caused by pile installation on the stress-strain and strength properties of the soil (Karlsrud, 2012).

Although the α- and β-method are two separate methods, they are to some extent correlated through the classical relationship between normalized Undrained Shear Strength and the overconsolidation ratio.

The total stress method is still the most popular method used to estimate the shaft capacity of piles in clay:

$$\boldsymbol{\tau_{av} = \alpha S_u}$$

where

$\boldsymbol{\tau_{av}}$ = average shaft resistance

$\boldsymbol{\alpha}$ = adhesion factor (alpha value)

$\boldsymbol{S_u}$ = average Undrained Shear Strength

Tomlinson (1957) noted that the relationship between τ_{av} and S_u was non-linear, with backclaculated α values decreasing as the Undrained Shear Strength of the soil increased. This correlation was developed from static load tests on un-instrumented piles driven through multiple soil strata with variable Undrained Shear Strengths. Early alpha correlations developed from load test databases are presented in Figure 104.

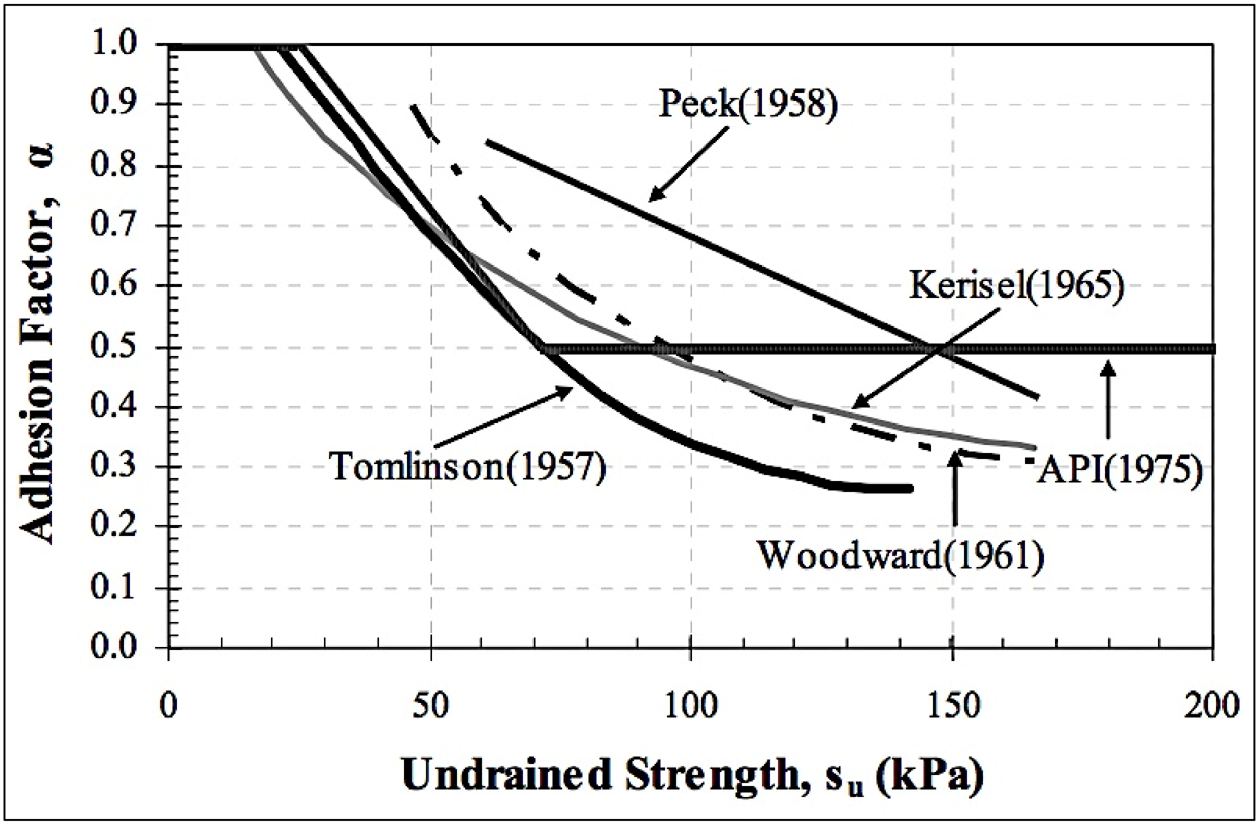

Figure 104. Alpha Value Correlation developed from Load Test Database.

From the data obtained from the 4.5-inch closed-end and 4.5-inch open-end pipe piles installed at the DOE, the α were backcalculated using the Undrained Shear Strength values obtained at different aging times. Since the 4.5-inch pipe piles were installed with the purpose of studying the behavior of the soil surrounding the pile with aging time and were not load tested, the α values were estimated using the design method developed by Karlsrud et al (2005) known as NGI-99:

$$\propto = \mathbf{0.32}\ (\boldsymbol{PI} - \mathbf{10})^{0.3}, \boldsymbol{for}\ {}^{S_u}\!/_{\sigma'_{v0}} < \mathbf{0.25}$$ **Equation 19**

$$\propto = \mathbf{0.5}\ ({}^{S_u}\!/_{\sigma'_{v0}})^{-0.3}, \boldsymbol{for}\ {}^{S_u}\!/_{\sigma'_{v0}} > \mathbf{1.0}$$ **Equation 20**

where:

$\propto$ = adhesion factor (alpha values)

PI = Plasticity Index

$\boldsymbol{S_u}$ = Undrained Shear Strength

The approach shown graphically in Figure 105 assumes a constant alpha value which depends on PI for ${}^{S_u}\!/_{\sigma'_{v0}}$ < 0.25, a log-linear variation for ${}^{S_u}\!/_{\sigma'_{v0}}$ up to 1, while for higher ${}^{S_u}\!/_{\sigma'_{v0}}$ > 1.

The results of the estimated adhesion factor, Undrained Shear Strength, Plasticity Index and Undrained Shear Strength – Effective Stress Ratio along the pile shaft of 4.5-in. Close and Open-End pipe piles (DOE-29 and 30) are presented in Table 10 through 16.

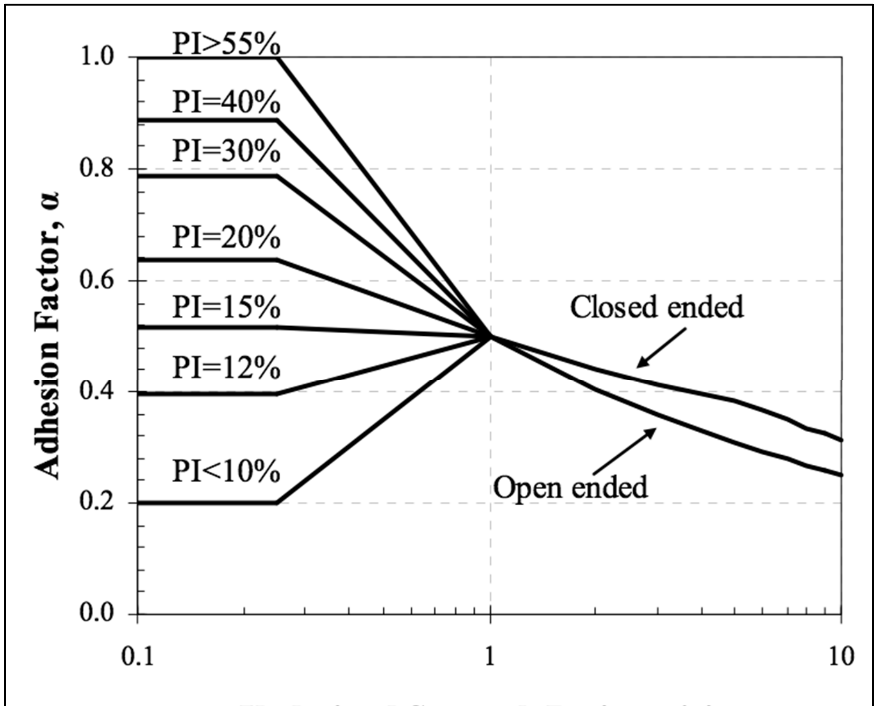

Figure 105. NGI-99 Pile Design Method showing Influence of Soil Plasticity (Karlsrud et al, 2005).

5.8.1.1 4.5-INCH CLOSED OPEN-END PIPE PILES (DOE SITE)

The behavior of the Undrained Shear Strength of the soil surrounding the 4.5-inch Closed and Open-End pipe pile with respect to aging time is presented in Table 10 and 14. Liquidity Index values calculated with the changes in water content due to pore water pressure dissipation at different aging times are presented in Tables 11 and 15.

The Strength Ratio values determined the results of the several Field Vane tests performed along the soil-pile interface are presented in Tables 12. The calculated adhesion factor values are presented in Tables 13 and 16.

The average determined alpha values for the closed-end pipe pile before pile driving, immediately, 1 day, 35 and 167 days after pile driving were 0.36, 0.45, 0.57, 0.55 and 0.65, and 0.55, 0.53, 0.60, 0.46 and 0.59, respectively. This trend demonstrated an increase in the radial stresses acting against the pile wall following pore water pressure dissipation for both piles. Since the pore water pressure dissipation, as previously mentioned, could have lasted approximately 30 days and no test was performed within this time range, the highest alpha values observed at 1 day could not represent the actual highest alpha values achieved during this period.

Table 10. Undrained Shear Strength (Peak Values) with Respect to Aging Time (4.5-in. Closed-End Pipe Pile, DOE-29).

	Before Pile Driving	After Pile Driving - 0 day	After Pile Driving - 1 day	After Pile Driving - 35 day	After Pile Driving - 167 day
Depth (ft)	Peak Su (kPa)				
1.5	224	279	249	227	-
2.5	288	215	222	39	43
3.5	187	157	175	132	6
4.5	207	144	116	83	15
5.5	248	197	194	206	24
6.5	207	239	221	229	190
7.5	265	232	185	201	132
8.5	232	202	126	9	207
9.5	220	207	153	46	153
10.5	198	161	183	95	143
11.5	147	135	126	149	152
12.5	121	104	100	53	82

Table 11. Liquidity Index Change with respect to Aging Time (4.5-in. Closed-End Pipe Pile, DOE-29).

	Before Pile Driving	After Pile Driving - 0 day	After Pile Driving - 1 day	After Pile Driving - 35 day	After Pile Driving - 167 day
Depth (ft)	Liquidity Index				
1.5	0.6	0.0	0.0	0.1	0.7
2.5	0.3	0.0	0.0	0.7	0.6
3.5	0.4	0.3	0.0	0.0	0.5
4.5	0.5	0.4	0.3	0.4	0.6
5.5	0.2	0.1	0.1	0.0	0.4
6.5	0.4	0.3	0.1	0.0	0.3
7.5	0.7	0.5	0.3	0.9	0.1
8.5	0.6	0.5	0.2	0.7	0.3
9.5	0.7	0.6	0.4	1.2	0.5
10.5	1.0	0.7	0.6	1.9	0.7
11.5	0.6	0.6	0.6	0.9	0.6
12.5	0.7	0.9	0.6	0.5	0.7
Average	0.6	0.4	0.3	0.6	0.5

Table 12. Normalized Undrained Shear Strength with respect to Aging Time (4.5-in. Closed-End Pipe Pile, DOE-29).

	Before Pile Driving	After Pile Driving - 0 day	After Pile Driving - 1 day	After Pile Driving - 35 day	After Pile Driving - 167 day
Depth (ft)	S_u / σ'_{v0}				
1.5	1.25	1.55	1.38	1.26	-
2.5	0.96	0.72	0.74	0.13	0.14
3.5	0.44	0.37	0.42	0.31	0.01
4.5	0.38	0.27	0.22	0.15	0.03
5.5	0.38	0.30	0.29	0.31	0.04
6.5	0.27	0.31	0.28	0.29	0.24
7.5	0.30	0.26	0.21	0.22	0.15
8.5	0.23	0.20	0.12	0.01	0.20
9.5	0.19	0.18	0.14	0.04	0.14
10.5	0.16	0.13	0.15	0.08	0.11
11.5	0.11	0.10	0.09	0.11	0.11
12.5	0.08	0.07	0.07	0.04	0.06
Average	0.40	0.37	0.34	0.25	0.11

Table 13. Back-calculated Adhesion Factor with respect to Aging Time (4.5-in. Closed-End Pipe Pile, DOE-29).

	Before Pile Driving	After Pile Driving - 0 day	After Pile Driving - 1 day	After Pile Driving - 35 day	After Pile Driving - 167 day
Depth (ft)	∝				
1.5	0.47	0.44	0.45	0.47	0.64
2.5	0.96	0.72	0.74	0.62	0.62
3.5	0.44	0.37	0.42	0.31	0.61
4.5	0.38	0.27	0.62	0.62	0.62
5.5	0.38	0.30	0.29	0.31	0.63
6.5	0.27	0.31	0.28	0.29	0.72
7.5	0.30	0.26	0.59	0.59	0.59
8.5	0.23	0.67	0.67	0.67	0.67
9.5	0.19	0.64	0.64	0.64	0.64
10.5	0.16	0.55	0.55	0.55	0.55
11.5	0.46	0.10	0.79	0.79	0.79
12.5	0.08	0.76	0.76	0.76	0.76
Average	0.36	0.45	0.57	0.55	0.65

Table 14. Undrained Shear Strength (Peak Values) with Respect to Aging Time (4.5-in. Open-End Pipe Pile, DOE-30).

	Before Pile Driving	After Pile Driving - 0 day	After Pile Driving - 1 day	After Pile Driving - 35 day	After Pile Driving - 167 day
Depth (ft)	Peak Su (kPa)				
1.5	224	245	248	290	30
2.5	288	267	220	215	98
3.5	187	170	145	179	150
4.5	207	167	182	216	236
5.5	248	161	116	175	109
6.5	207	206	188	248	186
7.5	266	188	196	243	114
8.5	232	205	193	321	120
9.5	220	194	173	292	118
10.5	198	158	159	185	155
11.5	147	131	117	165	159
12.5	121	89	100	140	113

Table 15. Liquidity Index Change with respect to Aging Time (4.5-in. 40 Open-End Pipe Pile, DOE-30).

	Before Pile Driving	After Pile Driving - 0 day	After Pile Driving - 1 day	After Pile Driving - 35 day	After Pile Driving - 167 day
Depth (ft)	Liquidity Index				
1.5	0.3	0.0	0.0	-0.1	0.4
2.5	0.1	-0.3	-0.2	0.2	0.5
3.5	0.2	0.4	0.1	0.4	0.3
4.5	0.2	0.2	0.1	0.0	0.4
5.5	0.1	0.1	0.1	0.2	0.3
6.5	0.1	0.2	0.0	0.1	0.2
7.5	0.3	0.5	0.3	0.4	0.6
8.5	0.3	0.5	0.2	0.4	0.5
9.5	0.2	0.6	0.3	0.5	0.9
10.5	0.3	0.7	0.6	0.7	0.9
11.5	0.3	0.6	0.7	0.6	0.6
12.5	0.9	0.9	0.8	0.9	0.8
Average	0.3	0.4	0.2	0.4	0.5

Table 16. Back-calculated Adhesion Factor with respect to Aging Time (4.5-in. Open-End Pipe Pile, DOE-30).

	Before Pile Driving	After Pile Driving - 0 day	After Pile Driving - 1 day	After Pile Driving - 35 day	After Pile Driving - 167 day
Depth (ft)	∝				
1.5	0.47	0.46	0.45	0.43	0.64
2.5	0.96	0.89	0.73	0.72	0.33
3.5	0.44	0.40	0.35	0.43	0.36
4.5	0.38	0.31	0.62	0.40	0.44
5.5	0.38	0.25	0.31	0.27	0.63
6.5	0.27	0.26	0.72	0.32	0.72
7.5	0.30	0.59	0.59	0.27	0.59
8.5	0.67	0.31	0.67	0.32	0.67
9.5	0.64	0.64	0.64	0.26	0.64
10.5	0.55	0.55	0.55	0.55	0.55
11.5	0.79	0.79	0.79	0.79	0.79
12.5	0.76	0.76	0.76	0.76	0.76
Average	0.55	0.52	0.60	0.46	0.59

Table 17. Normalized Undrained Shear Strength with respect to Aging Time (4.5-in. Closed-End Pipe Pile, DOE-29).

	Before Pile Driving	After Pile Driving - 0 day	After Pile Driving - 1 day	After Pile Driving - 35 day	After Pile Driving - 167 day
Depth (ft)	S_u / σ'_{v0}				
1.5	1.25	1.36	1.38	1.61	0.17
2.5	0.96	0.89	0.73	0.72	0.33
3.5	0.44	0.40	0.35	0.43	0.36
4.5	0.38	0.31	0.34	0.40	0.44
5.5	0.38	0.25	0.18	0.27	0.16
6.5	0.27	0.26	0.24	0.32	0.24
7.5	0.30	0.21	0.22	0.27	0.13
8.5	0.23	0.20	0.19	0.32	0.12
9.5	0.19	0.17	0.15	0.26	0.10
10.5	0.16	0.13	0.13	0.15	0.12
11.5	0.11	0.10	0.09	0.12	0.12
12.5	0.08	0.06	0.07	0.09	0.08
Average	0.40	0.36	0.34	0.41	0.20

Overall, the back-calculated adhesion factor values along the 4.5-inch closed-end pipe pile ranged between 0.36 and 0.65, and along the 4.5-inch open-end pipe pile ranged from 0.46 and 0.60. The average results of the calculated parameters are presented in Table 18.

The adhesion factor ($\propto$) values were observed to slightly increased as with increase in Undrained Shear Strength and Strength Ratio (Figure 106 through Figure 108). The differences in adhesion factor values between the closed-end and open-end pipe piles are presented in Table 19. The differences in the average adhesion factor values between the open and closed-end pipe piles before pile driving, at 0, 1, 35 and 167 days after pile driving were 0.19, 0.07, 0.03, 0.09 and 0.06, respectively.

Table 18. Average Results along each Pipe Pile.

	OPEN			CLOSED		
Aging Time (Days)	Avg. Su (kPa)	Avg. α	Su/σ'v	Avg. Su	Avg. α	Su/σ'v
Before Pile Driving	212	0.55	0.40	212	0.36	0.40
0	182	0.52	0.36	189	0.45	0.37
1	170	0.60	0.34	171	0.57	0.34
35	222	0.46	0.41	122	0.55	0.25
167	132	0.59	0.20	104	0.65	0.11

Table 19. Differences in Back-calculated Adhesion Factor Values between Open-End (DOE-30) and Closed-End (DOE-29) Pipe Piles.

	Before Pile Driving	**After Pile Driving - 0 day**	**After Pile Driving - 1 day**	**After Pile Driving - 35 day**	**After Pile Driving - 167 day**
Depth (ft)	Differences in ∝ Values				
1.5	0.00	0.02	0.00	-0.04	0.00
2.5	0.00	0.17	-0.01	0.10	-0.29
3.5	0.00	0.03	-0.07	0.12	-0.25
4.5	0.00	0.04	0.00	-0.22	-0.18
5.5	0.00	-0.05	0.02	-0.04	0.00
6.5	0.00	-0.05	0.44	0.03	0.00
7.5	0.00	0.33	0.00	-0.32	0.00
8.5	0.44	0.00	0.00	-0.35	0.00
9.5	0.45	0.00	0.00	-0.38	0.00
10.5	0.39	0.00	0.00	0.00	0.00
11.5	0.33	0.69	0.00	0.00	0.00
12.5	0.68	0.00	0.00	0.00	0.00

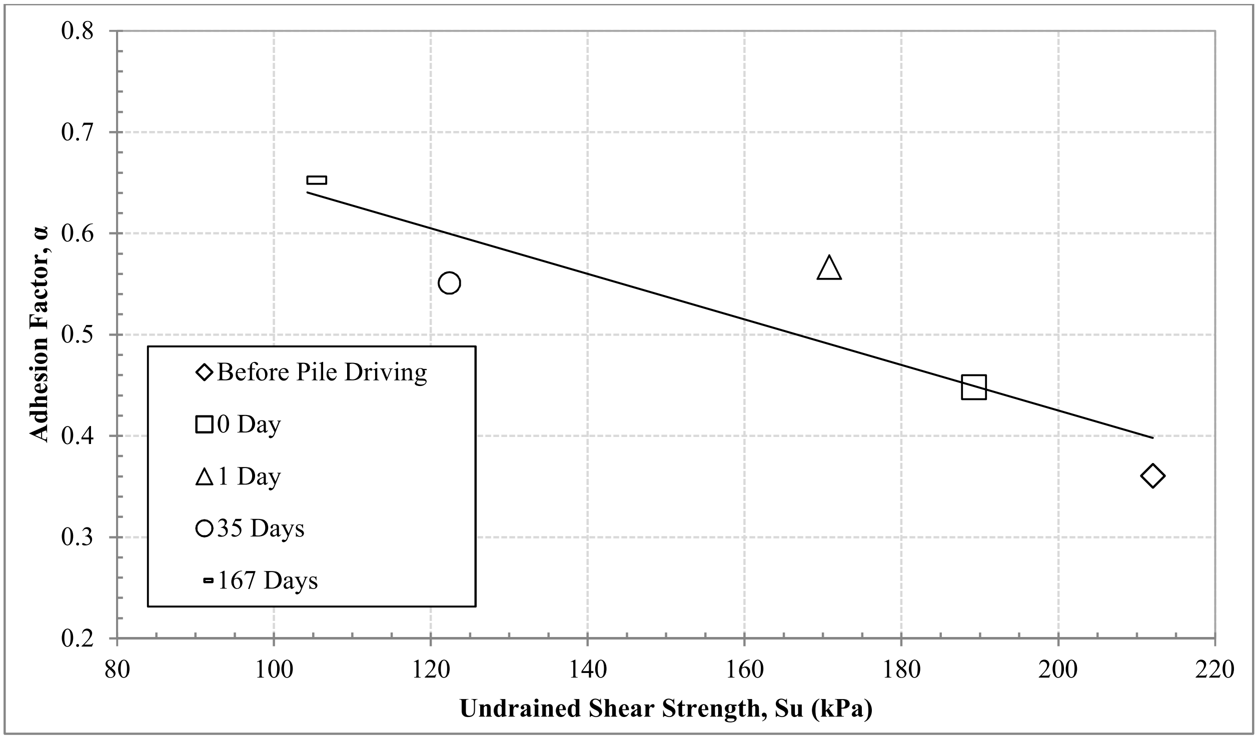

Figure 106. Adhesion as a Function of Undrained Shear Strength – 4.5-inch Closed-End Pipe Pile (DOE-29).

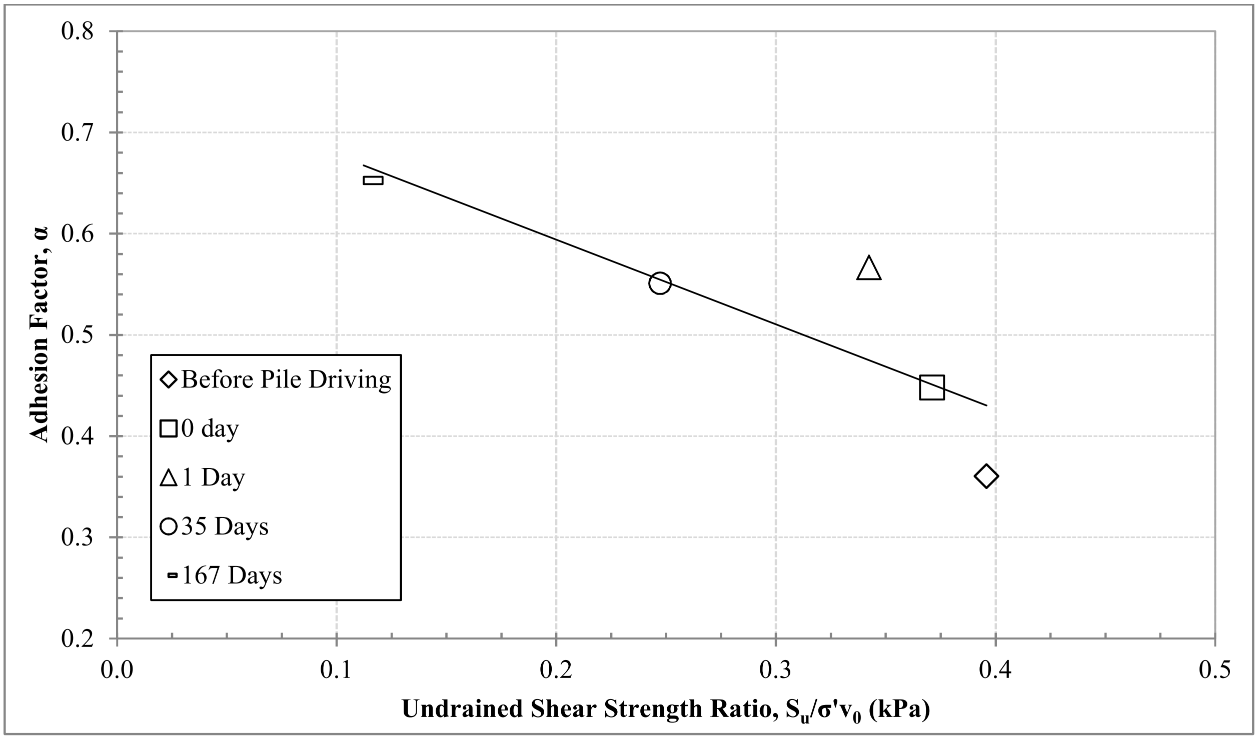

Figure 107. Adhesion as a Function of Strength Ratio – 4.5-inch Open-End Pipe Pile (DOE-30).

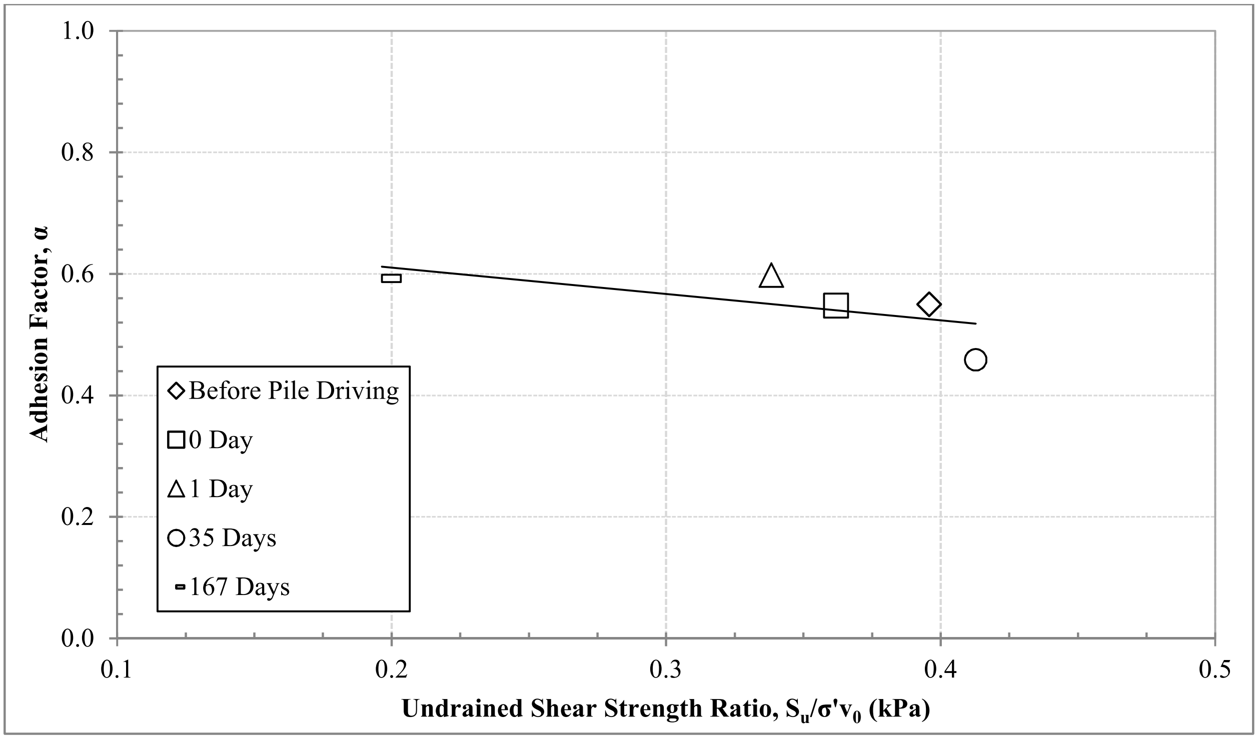

Figure 108. Adhesion as a Function of Strength Ratio – 4.5-inch Open-End Pipe Pile (DOE-29).

5.8.1.2 FIN PILES

A series of piles that consisted of five fin piles and one plain open-end pipe pile with no fins were tested in order to compare their tension behavior. In general, fin piles are open-end piles with fins welded to the outside bottom of the pile to increase their capacity. As fin piles are driven into the ground, their fin causes some degree of disturbance that depends on the size and number of fins.

Based on the results presented in Figure 109, the number of fins is directly related to their capacity development with time. It can be observed that number of fins is directly proportional to an increase in capacity but only up to 4 fins. The pile with 4 fins reached a maximum capacity of 16,626 lbs. The piles with 4 short fins and 6 fins showed a capacity lower than the pile with 4 fins. The results could indicate that piles might have a limited number of fins that could be installed on and after this limited number of fins is exceeded the capacity would only be affected negatively (. As more fins are installed on a pile, the degree of disturbance would be greater thus, a regain of capacity will require more time.

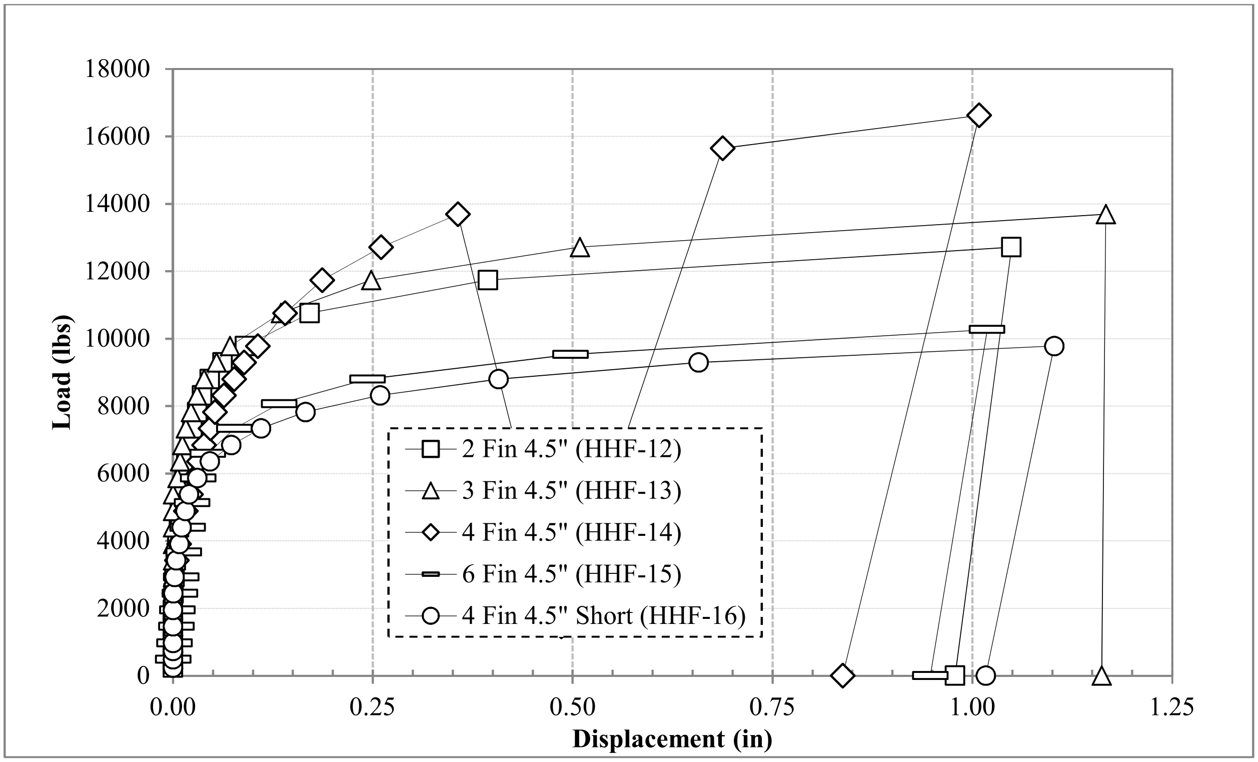

Figure 109. Load Displacement Curves for Fin Piles

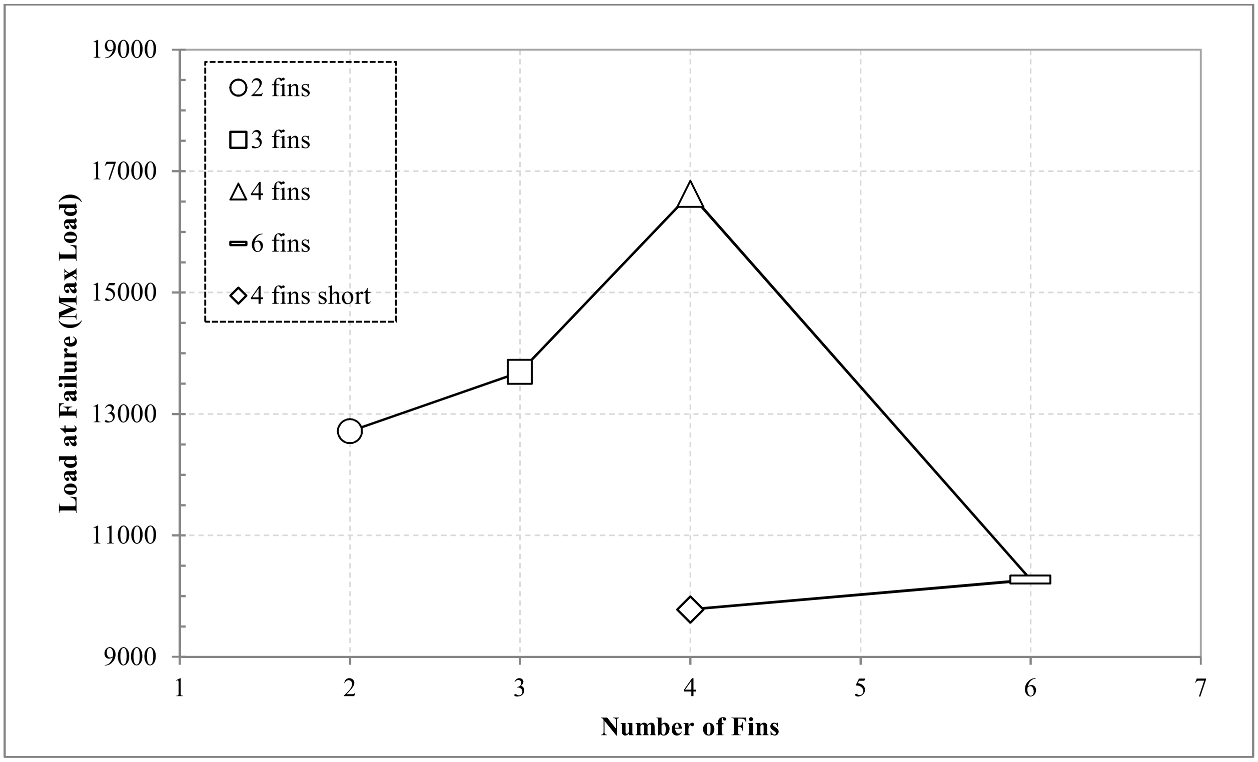

Figure 110. Pile Capacity with Respect to Number of Fins on a Pile

CHAPTER 6

6 CONCLUSION

Easiness of pile penetration depends on the pipe pile diameter. As the pile diameter decreases, the number of cumulative blow counts decreases. Plug formation was observed to develop faster in piles with smaller diameter.

Closed-end pipe piles required more energy during driving due to displacement of more soil than open-end pipe piles.

Easiness of pile penetration depends on the area ratio of the H-pile. As the H-pile area ratio decreases, the number of cumulative blow counts decreases.

The water content of the soil adjacent to the pile exhibited an immediate decreased after pile installation. In some cases, the water content continued to decrease up to 35 days and after 167 days and was observed to be equal to the water content prior to pile installation.

The duration of the pore water pressure lasted approximately 30-35 days after pile driving for the close and open-end pipe pile. During and immediately after driving, the changes in water content were observed to decrease with depth.

The geometry of the pile had a direct influence on the disturbance of the soil surrounding the pile and thus the Undrained Shear Strength of the soil.

The changes in water content were observed to decrease with depth and aging time. The pore water pressure dissipation in the soil surrounding the closed and open-end pipe piles lasted approximately the same, 30-35 days and could be attributed to the homogenous and normally consolidated deposit of the DOE site. Overall, the pore water pressure dissipation is OCR dependent and not pile geometry dependent. The pore water pressure dissipation time was observed to last approximately the same time for the both piles (4.5-inch closed and open-end pipe pile) which could indicate that the pore water dissipation is independent of the pile geometry.

Piles in clay, along with preshearing, leads to an increase in capacity with respect to time. Piles subjected to multiple static load tests exhibited complicated load histories mainly due to remolding of the clay past its yield point. Also, friction fatigue could have affected the gain in capacity of some piles.

Piles, with corrosion resistant coatings, experienced a capacity decrease with aging time due to a progressive failure along the same plane located at the pile-soil interface. Coated piles subjected to more than one test showed a lower capacity after each successive test due to failure along the same plane. Pile coating showed a negligible influence on pile driving.

The ultimate capacity of piles is sensitive to the rate of load application. As the rate at which load is applied to a pile increases, the capacity will also increase.

The 4.5-inch closed-end pipe pile developed higher adhesion factor values than the open-end pipe pile probably due to a higher amount of soil displaced during installation.

CHAPTER 7

7 BIBLIOGRAPHY

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CHAPTER 8

8 APPENDIX

8.1 DEPARTMENT OF ENERGY (DOE)

8.1.1 INSTALLATION LOGS

Technicians	JK, AJL & NW
Pile Type	W6 x 12 Plain
Pile Name	DOE-1
Hammer Weight (lbs)	550
Drop Height (in)	48
Rig Type	Tractor
Location	DOE
Installation Date	06/16/14

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)
1	12.5	12.5	83.5
2	3.5	16	80
3	2.75	18.75	77.25
4	2	20.75	75.25
5	1.75	22.5	73.5
6	2	24.5	71.5
7	1.75	26.25	69.75
8	1.5	27.75	68.25
9	1.75	29.5	66.5
10	1.75	31.25	64.75
11	1.75	33	63
12	1.5	34.5	61.5
13	1.5	36	60
14	1.75	37.75	58.25
15	1.25	39	57
16	2	41	55
17	1.25	42.25	53.75
18	1.75	44	52
19	1.25	45.25	50.75
20	1.5	46.75	49.25
21	1.5	48.25	47.75
22	1.25	49.5	46.5
23	1.5	51	45
24	1.5	52.5	43.5
25	1.5	54	42

26	2.25	56.25	39.75
27	1	57.25	38.75
28	1	58.25	37.75
29	0.75	59	37
30	1.25	60.25	35.75
31	1	61.25	34.75
32	0.75	62	34
33	0.75	62.75	33.25
34	0.75	63.5	32.5
35	1	64.5	31.5
36	0.75	65.25	30.75
37	0.75	66	30
38	0.75	66.75	29.25
39	0.75	67.5	28.5
40	0.75	68.25	27.75
41	0.75	69	27
42	0.75	69.75	26.25
43	0.75	70.5	25.5
44	0.75	71.25	24.75
45	0.75	72	24
46	0.75	72.75	23.25
47	0.75	73.5	22.5
48	0.5	74	22
49	0.75	74.75	21.25
50	0.75	75.5	20.5
51	0.5	76	20
52	0.75	76.75	19.25
53	0.75	77.5	18.5
54	0.5	78	18
55	0.5	78.5	17.5
56	0.75	79.25	16.75
57	0.75	80	16
58	0.5	80.5	15.5
59	0.5	81	15
60	0.75	81.75	14.25
61	0.5	82.25	13.75
62	0.5	82.75	13.25
63	0.75	83.5	12.5
64	0.5	84	12
65	0.5	84.5	11.5
66	0.75	85.25	10.75
67	0.5	85.75	10.25
68	0.75	86.5	9.5
69	0.5	87	9
70	0.5	87.5	8.5

71	0.75	88.25	7.75
72	0.5	88.75	7.25
73	0.75	89.5	6.5
74	0.5	90	6
75	0.5	90.5	5.5
76	0.75	91.25	4.75
77	0.5	91.75	4.25
78	0.5	92.25	3.75
79	0.75	93	3
80	0.5	93.5	2.5
81	0.5	94	2
82	0.5	94.5	1.5
83	0.5	95	1
84	0.75	95.75	0.25
85	0.25	96	0

Technicians	JK, AJL & NW
Pile Type	W8 x 15 Plain
Pile Name	DOE-2
Hammer Weight (lbs)	550
Drop Height (in)	48
Rig Type	Tractor
Location	DOE
Date	10/12/12

Cumulative Blow Count	**Penetration per Blow (in)**	**Cumulative Penetration (in)**	**Pile Penetration (in)**
1	10	10	86
2	3.5	13.5	82.5
3	3.25	16.75	79.25
4	2.75	19.5	76.5
5	2.25	21.75	74.25
6	1.75	23.5	72.5
7	2	25.5	70.5
8	2	27.5	68.5
9	1.75	29.25	66.75
10	1.75	31	65
11	1.5	32.5	63.5
12	1.5	34	62
13	1.5	35.5	60.5
14	1.75	37.25	58.75
15	1.25	38.5	57.5
16	1.5	40	56
17	1.25	41.25	54.75
18	1.25	42.5	53.5
19	1.5	44	52
20	1.25	45.25	50.75
21	1.75	47	49
22	1	48	48
23	1.25	49.25	46.75
24	1.25	50.5	45.5
25	1	51.5	44.5
26	1.5	53	43
27	1	54	42
28	1.25	55.25	40.75
29	2.25	57.5	38.5
30	0.5	58	38
31	0.75	58.75	37.25
32	1.25	60	36
33	0.75	60.75	35.25

34	1.5	62.25	33.75
35	0.75	63	33
36	1	64	32
37	0.5	64.5	31.5
38	1.25	65.75	30.25
39	0.75	66.5	29.5
40	0.75	67.25	28.75
41	0.75	68	28
42	1	69	27
43	0.75	69.75	26.25
44	0.75	70.5	25.5
45	0.75	71.25	24.75
46	0.75	72	24
47	1	73	23
48	0.75	73.75	22.25
49	0.5	74.25	21.75
50	0.75	75	21
51	0.75	75.75	20.25
52	0.5	76.25	19.75
53	1	77.25	18.75
54	0.5	77.75	18.25
55	0.75	78.5	17.5
56	0.75	79.25	16.75
57	0.75	80	16
58	0.5	80.5	15.5
59	0.5	81	15
60	0.75	81.75	14.25
61	0.75	82.5	13.5
62	0.5	83	13
63	0.5	83.5	12.5
64	0.75	84.25	11.75
65	0.5	84.75	11.25
66	0.5	85.25	10.75
67	0.75	86	10
68	0.5	86.5	9.5
69	0.5	87	9
70	0.5	87.5	8.5
71	0.75	88.25	7.75
72	0.25	88.5	7.5
73	0.5	89	7
74	0.75	89.75	6.25
75	0.25	90	6
76	0.75	90.75	5.25
77	0.5	91.25	4.75
78	0.5	91.75	4.25

79	0.5	92.25	3.75
80	0.5	92.75	3.25
81	0.75	93.5	2.5
82	0.5	94	2
83	0.5	94.5	1.5
84	0.5	95	1
85	0.5	95.5	0.5
86	0.5	96	0

Technicians	JK, NW
Pile Type	S4 x 7.7 Plain
Pile Name	DOE-3
Hammer Weight (lbs)	550
Drop Height (in)	48
Rig Type	Tractor
Location	DOE
Date	4/8/13

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)
1	14	14	82
2	5	19	77
3	3.5	22.5	73.5
4	2.375	24.875	71.125
5	3.125	28	68
6	2.25	30.25	65.75
7	2.5	32.75	63.25
8	2.5	35.25	60.75
9	2.425	37.675	58.325
10	2.325	40	56
11	2.25	42.25	53.75
12	2.25	44.5	51.5
13	2	46.5	49.5
14	2.5	49	47
15	2.25	51.25	44.75
16	2	53.25	42.75
17	1.75	55	41
18	2	57	39
19	2	59	37
20	1.75	60.75	35.25
21	3.75	64.5	31.5
22	1.75	66.25	29.75
23	1.5	67.75	28.25
24	1.75	69.5	26.5
25	1.5	71	25
26	1.5	72.5	23.5
27	1.5	74	22
28	1.5	75.5	20.5
29	1	76.5	19.5
30	1.5	78	18

31	1.5	79.5	16.5
32	1.25	80.75	15.25
33	1.25	82	14
34	0.25	82.25	13.75
35	2.25	84.5	11.5
36	1.5	86	10
37	1	87	9
38	1	88	8
39	1.25	89.25	6.75
40	1.25	90.5	5.5
41	1	91.5	4.5
42	1	92.5	3.5
43	1	93.5	2.5
44	1	94.5	1.5
45	1	95.5	0.5
46	1	96.5	-0.5

Technicians:	JK, NW, JE, DG, PP & KL
Pile Type:	2.875-in Sch. 40 Closed
Pile Name	DOE-6
Pile I.D.	2.635
Pile O.D.	2.875
Hammer Weight (lbs):	550
Drop Height (in)	44
Rig Type:	Tractor
Location:	DOE
Date:	4/16/13

Cumulative Blow Count	**Penetration per Blow (in)**	**Cumulative Penetration (in)**	**Pile Penetration (in)**
1	4.25	4.25	105.75
2	3.5	7.75	102.25
3	3.375	11.125	98.875
4	2.875	14	96
5	2.875	16.875	93.125
6	3.125	20	90
7	3.25	23.25	86.75
8	3	26.25	83.75
9	2.75	29	81
10	2.5	31.5	78.5
11	2.5	34	76
12	2.25	36.25	73.75
13	2.25	38.5	71.5
14	2	40.5	69.5
15	2.25	42.75	67.25
16	1.5	44.25	65.75
17	1.75	46	64
18	1.75	47.75	62.25
19	1.75	49.5	60.5
20	1.375	50.875	59.125
21	1.625	52.5	57.5
22	1.5	54	56
23	1.5	55.5	54.5
24	1.25	56.75	53.25
25	1.625	58.375	51.625
26	1.25	59.625	50.375
27	1.5	61.125	48.875
28	1.375	62.5	47.5
29	1.25	63.75	46.25
30	1.25	65	45
31	1.25	66.25	43.75

32	1.25	67.5	42.5
33	1.125	68.625	41.375
34	1.25	69.875	40.125
35	1	70.875	39.125
36	1	71.875	38.125
37	1.125	73	37
38	1	74	36
39	1	75	35
40	1.175	76.175	33.825
41	0.95	77.125	32.875
42	0.875	78	32
43	1	79	31
44	1	80	30
45	1.125	81.125	28.875
46	0.875	82	28
47	1	83	27
48	1	84	26
49	0.75	84.75	25.25
50	1.125	85.875	24.125
51	0.875	86.75	23.25
52	0.75	87.5	22.5
53	1.25	88.75	21.25
54	1	89.75	20.25
55	0.875	90.625	19.375
56	1	91.625	18.375
57	0.875	92.5	17.5
58	1	93.5	16.5
59	0.875	94.375	15.625
60	1	95.375	14.625
61	0.875	96.25	13.75
62	1	97.25	12.75
63	0.75	98	12
64	1	99	11
65	1.125	100.125	9.875
66	0.875	101	9
67	1	102	8
68	0.875	102.875	7.125
69	1.125	104	6
70	0.875	104.875	5.125
71	0.875	105.75	4.25
72	1	106.75	3.25
73	1	107.75	2.25
74	1	108.75	1.25

75	1	109.75	0.25
76	0.625	110.375	-0.375
77	0.875	111.25	-1.25
78	0.75	112	-2

Technicians	AJL, JL, NW and HZ
Pile Type	4.5 in Sch. 40 Open
Pile Name	DOE-7
Pile I.D.	4.03
Pile O.D.	4.5
Hammer Weight (lbs)	550
Drop Height (in)	48
Rig Type	Tractor
Location	DOE
Date	5/20/13

Cumulative Blow Count	**Penetration per Blow (in)**	**Cumulative Penetration (in)**	**Pile Penetration (in)**	**Plug (in)**
1	3	3	113	
2	3	6	110	123.5
3	2.375	8.375	107.625	
4	1.875	10.25	105.75	120.5
5	2	12.25	103.75	
6	2.25	14.5	101.5	
7	2	16.5	99.5	116.75
8	2	18.5	97.5	
9	1.875	20.375	95.625	
10	1.875	22.25	93.75	
11	1.75	24	92	111
12	2.375	26.375	89.625	
13	1.875	28.25	87.75	
14	1.5	29.75	86.25	
15	2	31.75	84.25	106.175
16	2	33.75	82.25	
17	1.625	35.375	80.625	
18	1.625	37	79	
19	1.5	38.5	77.5	102
20	1.5	40	76	
21	1.625	41.625	74.375	
22	1.375	43	73	
23	1.25	44.25	71.75	
24	1.5	45.75	70.25	98
25	1.25	47	69	
26	1.5	48.5	67.5	
27	1.25	49.75	66.25	
28	1.5	51.25	64.75	
29	1.25	52.5	63.5	
30	1.375	53.875	62.125	
31	1.5	55.375	60.625	

32	1.125	56.5	59.5	92.5
33	1.25	57.75	58.25	
34	1.25	59	57	
35	1.125	60.125	55.875	
36	1	61.125	54.875	
37	1.25	62.375	53.625	89.625
38	1.25	63.625	52.375	
39	0.625	64.25	51.75	
40	1	65.25	50.75	
41	1	66.25	49.75	
42	1	67.25	48.75	87.75
43	1.25	68.5	47.5	
44	0.75	69.25	46.75	
45	1.75	71	46	
46	1	72	45	
47	1	73	44	
48	-0.375	72.625	43	
49	1.875	74.5	43.375	84.5
50	1.875	76.375	41.5	
51	0.875	77.25	40.625	
52	0.8	78.05	39.825	
53	0.825	78.875	39	
54	0.75	79.625	38.25	
55	0.75	80.375	37.5	
56	0.75	81.125	36.75	81
57	1.125	82.25	35.625	
58	0.625	82.875	35	
59	1.625	84.5	34.25	
60	0.875	85.375	33.375	
61	0.75	86.125	32.5	
62	0.625	86.75	31.75	
63	0.625	87.375	31.125	
64	0.625	88	30.5	77.25
65	0.675	88.675	29.825	
66	0.575	89.25	29.25	
67	0.75	90	28.5	
68	0.675	90.675	27.825	
69	0.575	91.25	27.25	
70	1	92.25	26.25	
71	0.375	92.625	25.875	
72	0.7	93.325	25.175	
73	1.425	94.75	24.5	73.375
74	0.75	95.5	23.75	
75	0.5	96	23	
76	0.75	96.75	22.5	

77	0.75	97.5	21.75	
78	0.57	98.075	21.175	
79	0.675	98.75	20.5	
80	0.5	99.25	20	
81	0.5	99.75	19.5	
82	0.625	100.375	18.875	
83	0.625	101	18.25	69
84	0.575	101.575	17.675	
85	0.675	102.25	17	
86	0.5	102.75	16.5	
87	0.75	103.5	15.75	
88	0.5	104	15.25	
89	0.5	104.5	14.75	
90	0.75	105.25	14	
91	0.5	105.75	13.5	
92	0.75	106.5	12.75	
93	0.5	107	12.25	66.875
94	0.5	107.5	11.75	
95	0.75	108.25	11	
96	0.5	108.75	10.5	
97	0.625	109.375	9.875	
98	0.25	109.625	9.625	
99	0.875	110.5	8.75	
100	0.5	111	8.25	
101	0.75	111.75	7.5	
102	0.5	112.25	7	
103	0.5	112.75	6.5	63.25
104	0.75	113.5	5.75	
105	0.625	114.125	5.125	
106	0.375	114.5	4.75	
107	0.75	115.25	4	
108	0.5	115.75	3.5	
109	0.5	116.25	3	
110	0.625	116.875	2.375	
111	0.625	117.5	1.75	
112	0.75	118.25	1	
113	0.5	118.75	0.5	
114	0.5	119.25	0	60

Technicians:	JK, NW, JE, DG, PP & KL
Pile Type:	4.5 in Closed
Pile Name	DOE-9
Hammer Weight (lbs):	550
Drop Height (in)	48
Rig Type:	Tractor
Location:	DOE
Date:	5/20/13

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)
1	4	4	118
2	1.63	5.63	116.38
3	1.38	7	115
4	1.5	8.5	113.5
5	1.25	9.75	112.25
6	1	10.75	111.25
7	1	11.75	110.25
8	1.25	13	109
9	1	14	108
10	1	15	107
11	0.83	15.83	106.18
12	1	16.83	105.18
13	0.92	17.75	104.25
14	1	18.75	103.25
15	1	19.75	102.25
16	0.88	20.63	101.38
17	0.88	21.5	100.5
18	1	22.5	99.5
19	0.83	23.33	98.68
20	1	24.33	97.68
21	1	25.33	96.68
22	1	26.33	95.68
23	1	27.33	94.68
24	1.18	28.5	93.5
25	1	29.5	92.5
26	1	30.5	91.5
27	0.83	31.33	90.68
28	1	32.33	89.68
29	1.18	33.5	88.5
30	1	34.5	87.5
31	1.13	35.63	86.38
32	1.13	36.75	85.25
33	1.08	37.83	84.18

34	1.18	39	83.
35	1.13	40.13	81.88
36	1	41.13	80.88
37	1.13	42.25	79.75
38	1	43.25	78.75
39	1.08	44.33	77.68
40	1	45.33	76.68
41	1	46.33	75.68
42	1	47.33	74.68
43	1.18	48.5	73.5
44	0.83	49.33	72.68
45	1.18	50.5	71.5
46	1	51.5	70.5
47	0.83	52.33	69.68
48	1	53.33	68.68
49	1.18	54.5	67.5
50	1	55.5	66.5
51	1	56.5	65.5
52	1	57.5	64.5
53	0.83	58.33	63.68
54	0.17	58.5	63.5
55	1.83	60.33	61.68
56	1.18	61.5	60.5
57	1	62.5	59.5
58	2.75	65.25	56.75
59	-0.92	64.33	57.68
60	0.92	65.25	56.75
61	1.08	66.33	55.68
62	0.8	67.13	54.88
63	0.88	68	54
64	0.83	68.83	53.18
65	0.92	69.75	52.25
66	0.88	70.63	51.38
67	0.7	71.33	50.68
68	0.92	72.25	49.75
69	0.75	73	49
70	0.63	73.63	48.38
71	0.88	74.5	47.5
72	0.75	75.25	46.75
73	0.75	76	46
74	0.75	76.75	45.25
75	0.88	77.63	44.38
76	0.7	78.33	43.68
77	0.8	79.13	42.88
78	0.63	79.75	42.25

79	0.75	80.5	41.5
80	0.63	81.13	40.88
81	0.7	81.83	40.18
82	0.67	82.5	39.5
83	0.75	83.25	38.75
84	0.58	83.83	38.18
85	0.67	84.5	37.5
86	0.63	85.13	36.88
87	0.63	85.75	36.25
88	0.5	86.25	35.75
89	0.75	87	35
90	0.5	87.5	34.5
91	0.5	88	34
92	0.63	88.63	33.38
93	0.5	89.13	32.88
94	0.63	89.75	32.25
95	0.57	90.33	31.68
96	0.5	90.83	31.18
97	0.68	91.5	30.5
98	0.5	92	30
99	0.5	92.5	29.5
100	0.63	93.13	28.88
101	0.5	93.63	28.38
102	0.63	94.25	27.75
103	0.5	94.75	27.25
104	0.5	95.25	26.75
105	0.57	95.83	26.18
106	0.5	96.33	25.68
107	0.68	97	25
108	0.63	97.63	24.38
109	0.5	98.13	23.88
110	0.5	98.63	23.38
111	1.13	99.75	22.25
112	0.38	100.13	21.88
113	0.2	100.33	21.68
114	0.3	100.63	21.38
115	0.63	101.25	20.75
116	0.5	101.75	20.25
117	0.5	102.25	19.75
118	0.5	102.75	19.25
119	0.5	103.25	18.75
120	0.5	103.75	18.25
121	0.57	104.33	17.68
122	0.5	104.83	17.18
123	0.5	105.33	16.68

124	0.8	106.13	15.88
125	0.7	106.83	15.18
126	0.18	107	15
127	0.5	107.5	14.5
128	0.5	108	14
129	0.5	108.5	13.5
130	0.5	109	13
131	0.5	109.5	12.5
132	0.5	110	12
133	0.5	110.5	11.5
134	0.5	111	11
135	0.5	111.5	10.5
136	0.5	112	10
137	0.5	112.5	9.5
138	0.5	113	9
139	0.63	113.63	8.38
140	0.5	114.13	7.88
141	0.63	114.75	7.25
142	0.5	115.25	6.75
143	0.5	115.75	6.25
144	0.5	116.25	5.75
145	0.5	116.75	5.25
146	0.5	117.25	4.75
147	0.5	117.75	4.25
148	0.5	118.25	3.75
149	0.5	118.75	3.25
150	0.5	119.25	2.75
151	0.5	119.75	2.25
152	0.5	120.25	1.75
153	0.5	120.75	1.25
154	0.38	121.13	0.88
155	0.63	121.75	0.25
156	0.25	122	0

Technicians:	JL and JE
Pile Type:	S3 x 5.7
Pile Name	DOE-10
Hammer Weight (lbs):	550
Drop Height (in)	48
Rig Type:	Tractor
Location:	DOE
Date:	8/15/13

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)
1	14	14	83.5
2	5	19	79.5
3	3.5	22.5	76.25
4	2.38	24.88	72.25
5	3.13	28	68.75
6	2.25	30.25	66.25
7	2.5	32.75	62.75
8	2.5	35.25	59.88
9	2.43	37.68	56.25
10	2.33	40	54.25
11	2.25	42.25	51.25
12	2.25	44.5	47.5
13	2	46.5	44.75
14	2.5	49	41.63
15	2.25	51.25	38.38
16	2	53.25	34.75
17	1.75	55	32.88
18	2	57	30.63
19	2	59	28.5
20	1.75	60.75	26.5
21	3.75	64.5	23.75
22	1.75	66.25	22.68
23	1.5	67.75	20.25
24	1.75	69.5	19
25	1.5	71	16.75
26	1.5	72.5	15
27	1.5	74	13.5
28	1.5	75.5	12.5
29	1	76.5	11
30	1.5	78	9.5

31	1.5	79.5	8.25
32	1.25	80.75	6.25
33	1.25	82	5.5
34	0.25	82.25	3.5
35	2.25	84.5	3
36	1.5	86	1.5
37	1	87	0

Technicians:	JL and JE
Pile Type:	2.875-in Open
Pile Name	DOE-11
Pile I.D.	2.635
Pile O.D.	2.875
Hammer Weight (lbs):	550
Drop Height (in)	48
Rig Type:	Tractor
Location:	DOE
Date:	8/15/13

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)	Plug (in)
1	0	0	108	121.5
2	6	6	102	118.875
3	5.38	11.38	96.63	116.5
4	3.38	14.75	93.25	
5	3.75	18.5	89.5	113.75
6	3.63	22.13	85.88	
7	3.88	26	82	111.5
8	3.5	29.5	78.5	
9	2.63	32.13	75.88	109.625
10	2.88	35	73	
11	3.13	38.13	69.88	107.875
12	2.38	40.5	67.5	
13	2.75	43.25	64.75	
14	2.5	45.75	62.25	105.5
15	2.5	48.25	59.75	
16	2.38	50.63	57.38	
17	2.13	52.75	55.25	102.5
18	2.25	55.	53	
19	1.88	56.88	51.13	
20	2.13	59	49	99.75
21	2	61	47	
22	1.75	62.75	45.25	
23	1.63	64.38	43.63	98.375
24	1.75	66.13	41.88	
25	1.88	68	40	
26	1.63	69.63	38.38	
27	1.38	71	37	96.5
28	1.5	72.5	35.5	

29	1.5	74	34	
30	1.5	75.5	32.5	
31	1.5	77	31	94.25
32	1.13	78.13	29.88	
33	1.25	79.38	28.63	
34	1.38	80.75	27.25	
35	1.25	82	26	91.75
36	1.25	83.25	24.75	
37	1.08	84.33	23.68	
38	1.18	85.5	22.5	
39	1.13	86.63	21.38	
40	1.38	88	20	89.375
41	1.25	89.25	18.75	
42	1.25	90.5	17.5	
43	0.75	91.25	16.75	
44	0.75	92	16	
45	1.13	93.13	14.88	
46	1.25	94.38	13.63	87
47	0.88	95.25	12.75	
48	1	96.25	11.75	
49	0.88	97.13	10.88	
50	1	98.13	9.88	
51	1.38	99.5	8.5	
52	1.25	100.75	7.25	
53	0.75	101.5	6.5	83.5
54	0.88	102.38	5.63	
55	0.88	103.25	4.75	
56	1	104.25	3.75	
57	1.13	105.38	2.63	
58	0.75	106.13	1.88	
59	1.13	107.25	0.75	
60	0.75	108	0	80

Technicians:	JL and JE
Pile Type:	2.875-in Closed
Pile Name	DOE-12
Hammer Weight (lbs):	550
Drop Height (in)	48
Rig Type:	Tractor
Location:	DOE
Date:	8/15/13

Cumulative Blow Count	**Penetration per Blow (in)**	**Cumulative Penetration (in)**	**Pile Penetration (in)**
1	10	10	110
2	5.63	15.63	104.38
3	3.88	19.5	100.5
4	3	22.5	97.5
5	3	25.5	94.5
6	2.5	28	92
7	2.75	30.75	89.25
8	2.63	33.38	86.63
9	2.5	35.88	84.13
10	2.38	38.25	81.75
11	2.5	40.75	79.25
12	2.5	43.25	76.75
13	2.63	45.88	74.13
14	2.25	48.13	71.88
15	2.38	50.5	69.5
16	2.13	52.63	67.38
17	2.13	54.75	65.25
18	2	56.75	63.25
19	2	58.75	61.25
20	1.75	60.5	59.5
21	1.88	62.38	57.63
22	1.75	64.13	55.88
23	1.63	65.75	54.25
24	1.5	67.25	52.75
25	1.5	68.75	51.25
26	1.63	70.38	49.63
27	1.38	71.75	48.25
28	1.5	73.25	46.75
29	1.38	74.63	45.38
30	1.38	76	44
31	1.5	77.5	42.5
32	1.25	78.75	41.25
33	1.25	80	40

34	1.13	81.13	38.88
35	1.38	82.5	37.5
36	1.13	83.63	36.38
37	1.25	84.88	35.13
38	1.13	86	34
39	1.25	87.25	32.75
40	1	88.25	31.75
41	1.13	89.38	30.63
42	1.13	90.5	29.5
43	1.13	91.63	28.38
44	1.13	92.75	27.25
45	1	93.75	26.25
46	1.25	95	25
47	0.75	95.75	24.25
48	1	96.75	23.25
49	1	97.75	22.25
50	0.88	98.63	21.38
51	1.38	100	20
52	1	101	19
53	0.75	101.75	18.25
54	1	102.75	17.25
55	1	103.75	16.25
56	0.88	104.63	15.38
57	0.88	105.5	14.5
58	1.13	106.63	13.38
59	0.63	107.25	12.75
60	1.13	108.38	11.63
61	0.88	109.25	10.75
62	1	110.25	9.75
63	1	111.25	8.75
64	1	112.25	7.75
65	1.13	113.38	6.63
66	0.75	114.13	5.88
67	1.13	115.25	4.75
68	0.75	116	4
69	1	117	3
70	1	118	2
71	1	119	1
72	1	120	0

Technicians:	JL and JE
Pile Type:	4.5 in Open Coated
Pile Name	DOE-13
Pile I.D.	4.03
Pile O.D.	4.5
Hammer Weight (lbs):	550
Drop Height (in)	48
Rig Type:	Tractor
Location:	DOE
Date:	8/15/13

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)	Plug (in)
1	9.25	9.25	110.75	123.75
2	3.75	13	107	120.75
3	2.25	15.25	104.75	
4	2.375	17.625	102.375	116.875
5	2.125	19.75	100.25	
6	2.625	22.375	97.625	113.5
7	2.25	24.625	95.375	
8	2.125	26.75	93.25	
9	2.125	28.875	91.125	108.875
10	2.125	31	89	
11	2.25	33.25	86.75	
12	2	35.25	84.75	105.375
13	2	37.25	82.75	
14	2	39.25	80.75	
15	1.75	41	79	102.25
16	1.875	42.875	77.125	
17	1.875	44.75	75.25	
18	1.75	46.5	73.5	99
19	2	48.	71.5	
20	1.625	50.125	69.875	
21	1.5	51.625	68.375	
22	1.625	53.25	66.75	95.75
23	1.75	55	65	
24	1.375	56.375	63.625	
25	1.5	57.875	62.125	
26	1.5	59.375	60.625	92.5
27	0.75	60.125	59.875	
28	2.125	62.25	57.75	

29	1.25	63.5	56.5	
30	1.375	64.875	55.125	
31	1.25	66.125	53.875	88.625
32	1.25	67.375	52.625	
33	1.25	68.625	51.375	
34	1.375	70	50	
35	1.125	71.125	48.875	
36	1.125	72.25	47.75	85
37	1.25	73.5	46.5	
38	1.125	74.625	45.375	
39	0.875	75.5	44.5	
40	1	76.5	43.5	
41	1	77.5	42.5	
42	1	78.5	41.5	81.375
43	1	79.5	40.5	
44	0.75	80.25	39.75	
45	0.875	81.125	38.875	
46	0.875	82	38	
47	0.75	82.75	37.25	
48	0.75	83.5	36.5	
49	0.875	84.375	35.625	78.5
50	0.875	85.25	34.75	
51	0.75	86	34	
52	0.5	86.5	33.5	
53	1	87.5	32.5	
54	0.5	88	32	
55	0.75	88.75	31.25	
56	0.75	89.5	30.5	
57	0.625	90.125	29.875	74.75
58	0.875	91	29	
59	0.125	91.125	28.875	
60	0.875	92	28	
61	0.75	92.75	27.25	
62	0.75	93.5	26.5	
63	0.375	93.875	26.125	
64	0.625	94.5	25.5	
65	0.75	95.25	24.75	
66	0.625	95.875	24.125	71.5
67	0.625	96.5	23.5	
68	0.75	97.25	22.75	
69	0.5	97.75	22.25	

70	0.5	98.25	21.75	
71	0.5	98.75	21.25	
72	0.5	99.25	20.75	
73	0.875	100.125	19.875	
74	0.375	100.5	19.5	
75	0.625	101.125	18.875	
76	0.75	101.875	18.125	68
77	0.375	102.25	17.75	
78	0.75	103	17	
79	0.5	103.5	16.5	
80	0.5	104	16	
81	0.5	104.5	15.5	
82	0.75	105.25	14.75	
83	0.5	105.75	14.25	
84	0.5	106.25	13.75	
85	0.75	107	13	
86	0.25	107.25	12.75	
87	0.75	108	12	64.375
88	0.25	108.25	11.75	
89	0.75	109	11	
90	0.625	109.625	10.375	
91	0.375	110	10	
92	0.5	110.5	9.5	
93	0.5	111	9	
94	0.625	111.625	8.375	
95	0.5	112.125	7.875	
96	0.5	112.625	7.375	
97	0.5	113.125	6.875	
98	0.375	113.5	6	
99	0.5	114	6	61.25
100	0.75	114.75	5.25	
101	0.5	115.25	4.75	
102	0.625	115.875	4.125	
103	0.375	116.25	3.75	
104	0.5	116.75	3.25	
105	0.5	117.25	2.75	
106	0.5	117.75	2.25	
107	0.5	118.25	1.75	
108	0.5	118.75	1.25	
109	0.5	119.25	0.75	
110	0.500	119.750	0.250	

111	0.500	120.250	-0.250	58.375

Technicians:	JL and JE
Pile Type:	W6 x 9 Coated
Pile Name	DOE-14
Hammer Weight (lbs):	550
Drop Height (in)	48
Rig Type:	Tractor
Location:	DOE
Date:	8/15/13

Cumulative Blow Count	**Penetration per Blow (in)**	**Cumulative Penetration (in)**	**Pile Penetration (in)**
1	11.25	11.25	84.75
2	4.75	16	80
3	3.5	19.5	76.5
4	2.75	22.25	73.75
5	2	24.25	71.75
6	2.75	27	69
7	2.125	29.125	66.875
8	2.375	31.5	64.5
9	2.75	34.25	61.75
10	2.25	36.5	59.5
11	2.25	38.75	57.25
12	2.125	40.875	55.125
13	2.125	43	53
14	2	45	51
15	2	47	49
16	1.75	48.75	47.25
17	1.875	50.625	45.375
18	1.75	52.375	43.625
19	1.75	54.125	41.875
20	1.625	55.75	40.25
21	1.75	57.5	38.5
22	1.75	59.25	36.75
23	1.25	60.5	35.5
24	1.25	61.75	34.25
25	1.5	63.25	32.75
26	1.375	64.625	31.375
27	1.375	66	30
28	1.125	67.125	28.875
29	1.125	68.25	27.75

30	1.125	69.375	26.625
31	1.25	70.625	25.375
32	0.875	71.5	24.5
33	1	72.5	23.5
34	1	73.5	22.5
35	1.125	74.625	21.375
36	1	75.625	20.375
37	0.875	76.5	19.5
38	1	77.5	18.5
39	0.875	78.375	17.625
40	0.875	79.25	16.75
41	0.75	80	16
42	0.75	80.75	15.25
43	0.875	81.625	14.375
44	0.75	82.375	13.625
45	0.75	83.125	12.875
46	0.625	83.75	12.25
47	0.75	84.5	11.5
48	0.75	85.25	10.75
49	0.75	86	10
50	0.625	86.625	9.375
51	0.75	87.375	8.625
52	0.625	88	8
53	0.625	88.625	7.375
54	0.625	89.25	6.75
55	0.625	89.875	6.125
56	0.75	90.625	5.375
57	0.625	91.25	4.75
58	0.625	91.875	4.125
59	0.375	92.25	3.75
60	0.875	93.125	2.875
61	0.625	93.75	2.25
62	0.5	94.25	1.75
63	0.5	94.75	1.25
64	0.75	95.5	0.5
65	0.5	96	0

Technicians:	JL and JE
Pile Type:	W6 x 9
Pile Name	DOE-15
Hammer Weight (lbs):	550
Drop Height (in)	48
Rig Type:	Tractor
Location:	DOE
Date:	8/15/13

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)
1	12	12	84
2	2	14	82
3	2.75	16.75	79.25
4	1.375	18.125	77.875
5	2.5	20.625	75.375
6	1.625	22.25	73.75
7	2	24.25	71.75
8	2.75	27	69
9	2.375	29.375	66.625
10	1.125	30.5	65.5
11	1.5	32	64
12	1.75	33.75	62.25
13	1.25	35	61
14	1.625	36.625	59.375
15	1.5	38.125	57.875
16	1.5	39.625	56.375
17	1	40.625	55.375
18	2.375	43	53
19	1.375	44.375	51.625
20	1.375	45.75	50.25
21	1.375	47.125	48.875
22	0.625	47.75	48.25
23	1.25	49	47
24	2	51	45
25	2	53	43
26	0.25	53.25	42.75
27	1	54.25	41.75
28	1.375	55.625	40.375
29	1.125	56.75	39.25
30	1.25	58	38
31	1.25	59.25	36.75
32	1.25	60.5	35.5

33	1	61.5	34.5
34	0.75	62.25	33.75
35	1.125	63.375	32.625
36	1.5	64.875	31.125
37	0.625	65.5	30.5
38	1	66.5	29.5
39	1.75	68.25	27.75
40	1	69.25	26.75
41	0.25	69.5	26.5
42	0.5	70	26
43	0.875	70.875	25.125
44	0.875	71.75	24.25
45	1	72.75	23.25
46	0.5	73.25	22.75
47	1	74.25	21.75
48	0.75	75	21
49	0.75	75.75	20.25
50	0.75	76.5	19.5
51	0.75	77.25	18.75
52	0.875	78.125	17.875
53	0.75	78.875	17.125
54	0.75	79.625	16.375
55	1.125	80.75	15.25
56	0.25	81	15
57	0.875	81.875	14.125
58	1.125	83	13
59	0.5	83.5	12.5
60	0.75	84.25	11.75
61	0.625	84.875	11.125
62	0.375	85.25	10.75
63	0.75	86	10
64	0.5	86.5	9.5
65	1	87.5	8.5
66	0.625	88.125	7.875
67	0.75	88.875	7.125
68	0.625	89.5	6.5
69	0.5	90	6
70	0.625	90.625	5.375
71	0.625	91.25	4.75
72	1	92.25	3.75
73	0.25	92.5	3.5
74	0.75	93.25	2.75
75	0.75	94	2
76	0.5	94.5	1.5

77	1	95.5	0.5
78	0.5	96	0

Technicians:	JL and JE
Pile Type:	6.675-in Sched. 40 Open
Pile Name	DOE-16
Pile I.D.	6.065
Pile O.D.	6.625
Hammer Weight (lbs):	550
Drop Height (in)	48
Rig Type:	Tractor
Location:	DOE
Date:	8/15/13

Cumulative Blow Count	**Penetration per Blow (in)**	**Cumulative Penetration (in)**	**Pile Penetration (in)**	**Plug (in)**
1	7	7	113	125.5
2	2.5	9.5	110.5	
3	2.13	11.63	108.38	120.75
4	1.5	13.13	106.88	
5	1.5	14.63	105.38	
6	0.88	15.5	104.5	
7	1.13	16.63	103.38	
8	1.25	17.88	102.13	115.375
9	1.13	19	101	
10	0.75	19.75	100.25	
11	0.75	20.5	99.5	
12	1	21.5	98.5	
13	0.75	22.25	97.75	
14	0.75	23	97	
15	1	24	96	
16	1	25	95	111.25
17	0.75	25.75	94.25	
18	0.75	26.5	93.5	
19	0.88	27.38	92.63	
20	0.88	28.25	91.75	
21	0.75	29	91	
22	0.88	29.88	90.13	107.375
23	0.88	30.75	89.25	
24	0.88	31.63	88.38	
25	0.75	32.38	87.63	
26	0.88	33.25	86.75	
27	0.75	34	86	
28	0.88	34.88	85.13	
29	0.88	35.75	84.25	103.5
30	1	36.75	83.25	
31	0.75	37.5	82.5	

32	0.88	38.38	81.63	
33	0.88	39.25	80.75	
34	0.75	40	80	
35	1	41	79	
36	0.88	41.88	78.13	99.375
37	1.13	43	77	
38	0.75	43.75	76.25	
39	0.88	44.63	75.38	
40	0.75	45.38	74.63	
41	0.88	46.25	73.75	
42	0.75	47	73	
43	1	48	72	95.375
44	0.88	48.88	71.13	
45	0.63	49.5	70.5	
46	0.75	50.25	69.75	
47	1	51.25	68.75	
48	0.63	51.88	68.13	
49	0.75	52.63	67.38	
50	0.75	53.38	66.63	
51	0.63	54	66	91.75
52	0.75	54.75	65.25	
53	0.75	55.5	64.5	
54	0.63	56.13	63.88	
55	0.75	56.88	63.13	
56	0.63	57.5	62.5	
57	0.75	58.25	61.75	
58	0.63	58.88	61.13	
59	0.75	59.63	60.38	
60	0.63	60.25	59.75	87.25
61	0.75	61	59	
62	0.75	61.75	58.25	
63	0.63	62.38	57.63	
64	0.75	63.13	56.88	
65	0.63	63.75	56.25	
66	0.75	64.5	55.5	
67	0.63	65.13	54.88	
68	0.75	65.88	54.13	82.5
69	0.63	66.5	53.5	
70	0.63	67.13	52.88	
71	0.75	67.88	52.13	
72	0.63	68.5	51.5	
73	0.63	69.13	50.88	
74	0.75	69.88	50.13	
75	0.63	70.5	49.5	
76	0.5	71	49	

77	0.75	71.75	48.25	
78	0.5	72.25	47.75	78
79	0.63	72.88	47.13	
80	0.5	73.38	46.63	
81	0.63	74	46	
82	0.5	74.5	45.5	
83	0.63	75.13	44.88	
84	0.38	75.5	44.5	
85	0.63	76.13	43.88	
86	0.63	76.75	43.25	
87	0.38	77.13	42.88	
88	0.63	77.75	42.25	73.75
89	0.5	78.25	41.75	
90	0.5	78.75	41.25	
91	0.5	79.25	40.75	
92	0.5	79.75	40.25	
93	0.5	80.25	39.75	
94	0.38	80.63	39.38	
95	0.5	81.13	38.88	
96	0.5	81.63	38.38	
97	0.38	82	38	
98	0.5	82.5	37.5	
99	0.5	83	37	
100	0.38	83.38	36.63	
101	0.5	83.88	36.13	69
102	0.5	84.38	35.63	
103	0.5	84.88	35.13	
104	0.38	85.25	34.75	
105	0.38	85.63	34.38	
106	0.38	86	34	
107	0.5	86.5	33.5	
108	0.5	87	33	
109	0.25	87.25	32.75	
110	0.5	87.75	32.25	
111	0.38	88.13	31.88	
112	0.38	88.5	31.5	
113	0.5	89	31	
114	0.38	89.38	30.63	
115	0.38	89.75	30.25	64
116	0.38	90.13	29.88	
117	0.38	90.5	29.5	
118	0.38	90.88	29.13	
119	0.38	91.25	28.75	
120	0.38	91.63	28.38	
121	0.38	92	28	

122	0.5	92.5	27.5	
123	0.38	92.88	27.13	
124	0.38	93.25	26.75	
125	0.38	93.63	26.38	
126	0.38	94	26	
127	0.38	94.38	25.63	
128	0.38	94.75	25.25	
129	0.25	95	25	
130	0.38	95.38	24.63	
131	0.5	95.88	24.13	59.75
132	0.38	96.25	23.75	
133	0.25	96.5	23.5	
134	0.38	96.88	23.13	
135	0.38	97.25	22.75	
136	0.38	97.63	22.38	
137	0.38	98	22	
138	0.38	98.38	21.63	
139	0.38	98.75	21.25	
140	0.25	99	21	
141	0.5	99.5	20.5	
142	0.38	99.88	20.13	
143	0.25	100.13	19.88	
144	0.38	100.5	19.5	
145	0.38	100.88	19.13	
146	0.38	101.25	18.75	
147	0.38	101.63	18.38	
148	0.38	102	18	55.5
149	0.38	102.38	17.63	
150	0.38	102.75	17.25	
151	0.38	103.13	16.88	
152	0.38	103.5	16.5	
153	0.25	103.75	16.25	
154	0.25	104	16	
155	0.5	104.5	15.5	
156	0.25	104.75	15.25	
157	0.25	105	15	
158	0.5	105.5	14.5	
159	0.38	105.88	14.13	
160	0.25	106.13	13.88	
161	0.38	106.5	13.5	
162	0.5	107	13	
163	0.25	107.25	12.75	
164	0.25	107.5	12.5	
165	0.38	107.88	12.13	51.75
166	0.25	108.13	11.88	

167	0.38	108.5	11.5	
168	0.38	108.88	11.13	
169	0.38	109.25	10.75	
170	0.38	109.63	10.38	
171	0.38	110	10	
172	0.25	110.25	9.75	
173	0.25	110.5	9.5	
174	0.38	110.88	9.13	
175	0.38	111.25	8.75	
176	0.38	111.63	8.38	
177	0.25	111.88	8.13	
178	0.25	112.13	7.88	
179	0.25	112.38	7.63	
180	0.5	112.88	7.13	
181	0.38	113.25	6.75	
182	0.25	113.5	6.5	
183	0.38	113.88	6.13	47.875
184	0.38	114.25	5.75	
185	0.25	114.5	5.5	
186	0.38	114.88	5.13	
187	0.25	115.13	4.88	
188	0.38	115.5	4.5	
189	0.38	115.88	4.13	
190	0.25	116.13	3.88	
191	0.38	116.5	3.5	
192	0.25	116.75	3.25	
193	0.38	117.13	2.88	
194	0.38	117.5	2.5	
195	0.25	117.75	2.25	
196	0.25	118	2	
197	0.38	118.38	1.63	
198	0.38	118.75	1.25	
199	0.25	119	1	
200	0.38	119.38	0.63	
201	0.38	119.75	0.25	
202	0.25	120	0	44

Technicians:	JL and JE
Pile Type:	W6 x 9
Pile Name	DOE-17
Hammer Weight (lbs):	550
Drop Height (in)	48
Rig Type:	Tractor
Location:	DOE
Date:	8/15/13

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)
1	11.75	11.75	84.25
2	3.25	15	81
3	2.5	17.5	78.5
4	2	19.5	76.5
5	2	21.5	74.5
6	1.875	23.375	72.625
7	1.625	25	71
8	1.625	26.625	69.375
9	1.625	28.25	67.75
10	1.625	29.875	66.125
11	1.5	31.375	64.625
12	1.375	32.75	63.25
13	1.625	34.375	61.625
14	1.375	35.75	60.25
15	1.75	37.5	58.5
16	1.5	39	57
17	1.625	40.625	55.375
18	1.625	42.25	53.75
19	1.5	43.75	52.25
20	1.5	45.25	50.75
21	1.5	46.75	49.25
22	1.375	48.125	47.875
23	1.5	49.625	46.375
24	1.375	51	45
25	1.5	52.5	43.5
26	1.25	53.75	42.25
27	1.5	55.25	40.75
28	1.25	56.5	39.5
29	1.25	57.75	38.25
30	1.25	59	37
31	1.125	60.125	35.875
32	1.125	61.25	34.75
33	1.125	62.375	33.625

34	1.25	63.625	32
35	0.875	64.5	31.5
36	1	65.5	30.5
37	1.125	66.625	29.375
38	0.875	67.5	28.5
39	0.875	68.375	27.625
40	1	69.375	26.625
41	1	70.375	25.625
42	0.875	71.25	24.75
43	1	72.25	23.75
44	0.75	73	23
45	1	74	22
46	0.5	74.5	21.5
47	1	75.5	20.5
48	0.75	76.25	19.75
49	0.75	77	19
50	0.75	77.75	18.25
51	1.125	78.875	17.125
52	0.375	79.25	16.75
53	0.5	79.75	16.25
54	1	80.75	15.25
55	0.75	81.5	14.5
56	0.75	82.25	13.75
57	1.125	83.375	12.625
58	0.625	84	12
59	0.75	84.75	11.25
60	0.75	85.5	10.5
61	0.625	86.125	9.875
62	0.75	86.875	9.125
63	0.625	87.5	8.5
64	0.625	88.125	7.875
65	0.875	89	7
66	0.5	89.5	6.5
67	0.5	90	6
68	0.75	90.75	5.25
69	0.625	91.375	4.625
70	0.625	92	4
71	0.25	92.25	3.75
72	0.75	93	3
73	0.25	93.25	2.75
74	1.25	94.5	1.5
75	0.5	95	1
76	0.75	95.75	0.25
77	0.25	96	0

Technicians:	AJL
Pile Type:	W6 x 9
Pile Name	DOE-18
Hammer Weight (lbs):	550
Drop Height (in)	48
Rig Type:	Tractor
Location:	DOE
Date:	9/20/13

Cumulative Blow Count	**Penetration per Blow (in)**	**Cumulative Penetration (in)**	**Pile Penetration (in)**
1	10	10	86
2	3	13	83
3	2.5	15.5	80.5
4	2	17.5	78.5
5	2.25	19.75	76.25
6	2.25	22	74
7	1.5	23.5	72.5
8	1.5	25	71
9	1.875	26.875	69.125
10	1.625	28.5	67.5
11	1.25	29.75	66.25
12	1.75	31.5	64.5
13	1.5	33	63
14	1.25	34.25	61.75
15	1.75	36	60
16	1.25	37.25	58.75
17	1.5	38.75	57.25
18	1.375	40.125	55.875
19	1.625	41.75	54.25
20	1	42.75	53.25
21	1	43.75	52.25
22	1.25	45	51
23	1	46	50
24	1	47	49
25	1	48	48
26	1.125	49.125	46.875
27	1	50.125	45.875
28	1.125	51.25	44.75
29	1	52.25	43.75
30	1.25	53.5	42.5
31	1	54.5	41.5
32	1	55.5	40.5
33	1.125	56.625	39.375

34	0.875	57.5	39
35	1	58.5	37.5
36	1	59.5	36.5
37	1	60.5	35.5
38	1.125	61.625	34.375
39	1	62.625	33.375
40	0.875	63.5	32.5
41	0.75	64.25	31.75
42	1	65.25	30.75
43	0.875	66.125	29.875
44	0.875	67	29
45	0.875	67.875	28.125
46	0.875	68.75	27.25
47	0.75	69.5	26.5
48	1	70.5	25.5
49	0.75	71.25	24.75
50	0.875	72.125	23.875
51	0.875	73	23
52	0.625	73.625	22.375
53	0.875	74.5	21.5
54	0.75	75.25	20.75
55	0.75	76	20
56	0.75	76.75	19.25
57	0.75	77.5	18.5
58	0.625	78.125	17.875
59	0.625	78.75	17.25
60	0.75	79.5	16.5
61	0.75	80.25	15.75
62	0.75	81	15
63	0.75	81.75	14.25
64	0.75	82.5	13.5
65	0.5	83	13
66	0.75	83.75	12.25
67	0.75	84.5	11.5
68	0.5	85	11
69	0.75	85.75	10.25
70	0.625	86.375	9.625
71	0.625	87	9
72	0.5	87.5	8.5
73	0.5	88	8
74	0.75	88.75	7.25
75	0.625	89.375	6.625
76	0.625	90	6
77	0.5	90.5	5.5
78	0.75	91.25	4.75

79	0.5	91.75	4.25
80	0.5	92.25	3.75
81	0.375	92.625	3.375
82	0.625	93.25	2.75
83	0.5	93.75	2.25
84	0.5	94.25	1.75
85	0.75	95	1
86	0.5	95.5	0.5
87	0.5	96	0

Technicians:	AJL
Pile Type:	2.875-in Closed
Pile Name	DOE-19
Hammer Weight (lbs):	550
Drop Height (in)	48
Rig Type:	Tractor
Location:	DOE
Date:	9/20/13

Cumulative Blow Count	**Penetration per Blow (in)**	**Cumulative Penetration (in)**	**Pile Penetration (in)**
1	11.5	11.5	108.5
2	4	15.5	104.5
3	3.63	19.13	100.88
4	2.75	21.88	98.13
5	3.38	25.25	94.75
6	3	28.25	91.75
7	2.75	31	89
8	2.5	33.5	86.5
9	2.5	36	84
10	2.25	38.25	81.75
11	2	40.25	79.75
12	2	42.25	77.75
13	1.88	44.13	75.88
14	1.88	46	74
15	2	48	72
16	2	50	70
17	1.75	51.75	68.25
18	1.75	53.5	66.5
19	1.75	55.25	64.75
20	2	57.25	62.75
21	1.75	59	61
22	1.5	60.5	59.5
23	1.5	62	58
24	1.75	63.75	56.25
25	1.25	65	55
26	1.5	66.5	53.5
27	1.5	68	52
28	1.25	69.25	50.75
29	1.25	70.5	49.5
30	1.38	71.88	48.13
31	1.13	73	47
32	1.25	74.25	45.75

33	1.25	75.5	44.5
34	1.25	76.75	43.25
35	0.38	77.13	42.88
36	1.88	79	41
37	1	80	40
38	1	81	39
39	1.13	82.13	37.88
40	1.13	83.25	36.75
41	1	84.25	35.75
42	1	85.25	34.75
43	1	86.25	33.75
44	1	87.25	32.75
45	1	88.25	31.75
46	1	89.25	30.75
47	1	90.25	29.75
48	1	91.25	28.75
49	1	92.25	27.75
50	1	93.25	26.75
51	1	94.25	25.75
52	0.75	95	25
53	1.	96	24
54	1	97	23
55	1	98	22
56	-0.25	97.75	22.25
57	1.88	99.63	20.38
58	1.13	100.75	19.25
59	0.88	101.63	18.38
60	0.88	102.5	17.5
61	1	103.5	16.5
62	-0.13	103.38	16.63
63	0.88	104.25	15.75
64	2	106.25	13.75
65	0.88	107.13	12.88
66	0.88	108	12
67	1	109	11
68	0.75	109.75	10.25
69	0.63	110.38	9.63
70	1	111.38	8.63
71	1.13	112.5	7.5
72	0.88	113.38	6.63
73	1	114.38	5.63
74	0.88	115.25	4.75
75	0.88	116.13	3.88
76	0.88	117	3

77	0.88	117.88	2.13
78	0.63	118.5	1.5
79	1	119.5	0.5
80	0.5	120	0

Technicians:	AJL and HZ
Pile Type:	2.875-in Closed
Pile Name	DOE-20
Hammer Weight (lbs):	550
Drop Height (in)	48
Rig Type:	Tractor
Location:	DOE
Date:	9/20/13

Cumulative Blow Count	**Penetration per Blow (in)**	**Cumulative Penetration (in)**	**Pile Penetration (in)**
1	10	10	110
2	3.5	13.5	106.5
3	2.88	16.38	103.625
4	2.63	19	101
5	2.88	21.88	98.125
6	2	23.88	96.125
7	2.38	26.25	93.75
8	2.25	28.5	91.5
9	2.25	30.75	89.25
10	2.25	33	87
11	2.13	35.13	84.875
12	2.38	37.5	82.5
13	2.5	40	80
14	2.63	42.63	77.375
15	1.88	44.5	75.5
16	2.13	46.63	73.375
17	1.5	48.13	71.875
18	2.63	50.75	69.25
19	2.25	53	67
20	1.75	54.75	65.25
21	1.88	56.63	63.375
22	1.88	58.5	61.5
23	1.63	60.13	59.875
24	1.88	62	58
25	1.75	63.75	56.25
26	1.5	65.25	54.75
27	1.75	67	53
28	1.5	68.5	51.5
29	1.25	69.75	50.25
30	1.25	71	49

31	1.5	72.5	47.5
32	1	73.5	46.5
33	1.5	75	45
34	1.25	76.25	43.75
35	1.25	77.5	42.5
36	1.25	78.75	41.25
37	1.25	80	40
38	1.25	81.25	38.75
39	1.25	82.5	37.5
40	1.13	83.63	36.375
41	1.13	84.75	35.25
42	1	85.75	34.25
43	1	86.75	33.25
44	1.25	88	32
45	1.25	89.25	30.75
46	1	90.25	29.75
47	1.13	91.38	28.625
48	1.13	92.5	27.5
49	1	93.5	26.5
50	1.13	94.63	25.375
51	1.13	95.75	24.25
52	1	96.75	23.25
53	0.75	97.5	22.5
54	1.38	98.88	21.125
55	1.13	100	20
56	1	101	19
57	1	102	18
58	1	103	17
59	1.13	104.13	15.875
60	1	105.13	14.875
61	1	106.13	13.875
62	1	107.13	12.875
63	1.13	108.25	11.75
64	1	109.25	10.75
65	1	110.25	9.75
66	1	111.25	8.75
67	1	112.25	7.75
68	0.88	113.13	6.875
69	0.88	114	6
70	1	115	5
71	1	116	4

72	1	117	3
73	1	118	2
74	1	119	1
75	1	120	0

Technicians:	AJL
Pile Type:	2.875-in Closed
Pile Name	DOE-21
Hammer Weight (lbs):	550
Drop Height (in)	48
Rig Type:	Tractor
Location:	DOE
Date:	9/20/13

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)
1	10	10	110
2	3.75	13.75	106.25
3	2.25	16	104
4	2.25	18.25	101.75
5	2.25	20.5	99.5
6	2.5	23	97
7	2.5	25.5	94.5
8	2.63	28.13	91.88
9	2.13	30.25	89.75
10	2.5	32.75	87.25
11	2	34.75	85.25
12	2.25	37	83
13	2	39	81
14	2.25	41.25	78.75
15	1.75	43	77
16	1.75	44.75	75.25
17	2	46.75	73.25
18	1.5	48.25	71.75
19	1.75	50	70
20	0.75	50.75	69.25
21	1.38	52.13	67.88
22	1	53.13	66.88
23	1.88	55	65
24	1.38	56.38	63.63
25	2	58.38	61.63
26	1.25	59.63	60.38
27	0.88	60.5	59.5
28	2.25	62.75	57.25
29	1.38	64.13	55.88
30	1.63	65.75	54.25
31	1.25	67	53
32	1.25	68.25	51.75
33	1	69.25	50.75

34	1.25	70.5	49.5
35	1	71.5	48.5
36	1.5	73	47
37	1	74	46
38	1.25	75.25	44.75
39	1	76.25	43.75
40	1.25	77.5	42.5
41	1.13	78.63	41.38
42	1	79.63	40.38
43	1	80.63	39.38
44	1.13	81.75	38.25
45	0.88	82.63	37.38
46	1	83.63	36.38
47	0.88	84.5	35.5
48	1	85.5	34.5
49	1	86.5	33.5
50	0.88	87.38	32.63
51	0.88	88.25	31.75
52	0.88	89.13	30.88
53	0.88	90	30
54	0.88	90.88	29.13
55	0.88	91.75	28.25
56	0.88	92.63	27.38
57	0.88	93.5	26.5
58	0.75	94.25	25.75
59	1	95.25	24.75
60	0.75	96	24
61	0.88	96.88	23.13
62	0.88	97.75	22.25
63	0.75	98.5	21.5
64	0.75	99.25	20.75
65	1	100.25	19.75
66	0.75	101	19
67	1	102	18
68	0.63	102.63	17.38
69	0.75	103.38	16.63
70	0.88	104.25	15.75
71	1	105.25	14.75
72	0.75	106	14
73	1	107	13
74	0.65	107.65	12.35
75	0.6	108.25	11.75
76	0.75	109	11
77	0.88	109.88	10.13
78	0.63	110.5	9.5

79	0.88	111.38	8.63
80	0.63	112	8
81	0.88	112.88	7.13
82	0.63	113.5	6.5
83	1	114.5	5.5
84	0.75	115.25	4.75
85	0.75	116	4
86	0.75	116.75	3.25
87	0.63	117.38	2.63
88	0.88	118.25	1.75
89	0.75	119	1
90	1	120	0

Technicians:	AJL
Pile Type:	2.875-in Closed
Pile Name	DOE-22
Total Length (ft)	10
Hammer Weight (lbs):	550
Drop Height (in)	48
Rig Type:	Tractor
Location:	DOE
Date:	9/20/13

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)
1	9.5	9.5	110.5
2	3.75	13.25	106.75
3	2.75	16	104
4	2.5	18.5	101.5
5	2.5	21	99
6	2.25	23.25	96.75
7	3	26.25	93.75
8	2.5	28.75	91.25
9	2.63	31.38	88.63
10	2.38	33.75	86.25
11	2.5	36.25	83.75
12	2.13	38.38	81.63
13	1.88	40.25	79.75
14	2	42.25	77.75
15	1.75	44	76
16	1.75	45.75	74.25
17	1.88	47.63	72.38
18	1.75	49.38	70.63
19	1.88	51.25	68.75
20	1.5	52.75	67.25
21	1.5	54.25	65.75
22	1.5	55.75	64.25
23	1.63	57.38	62.63
24	1.38	58.75	61.25
25	1.63	60.38	59.63
26	1.63	62	58
27	1.5	63.5	56.5
28	1.38	64.88	55.13
29	1.5	66.38	53.63
30	1	67.38	52.63
31	1.63	69	51
32	1.25	70.25	49.75

33	1.25	71.5	48.5
34	1.25	72.75	47.25
35	1.25	74	46
36	1.13	75.13	44.88
37	1.13	76.25	43.75
38	1.5	77.75	42.25
39	1	78.75	41.25
40	1	79.75	40.25
41	1	80.75	39.25
42	1	81.75	38.25
43	1	82.75	37.25
44	1	83.75	36.25
45	1	84.75	35.25
46	1	85.75	34.25
47	1	86.75	33.25
48	0.88	87.63	32.38
49	0.88	88.5	31.5
50	1.13	89.63	30.38
51	0.88	90.5	29.5
52	1	91.5	28.5
53	0.88	92.38	27.63
54	0.88	93.25	26.75
55	1	94.25	25.75
56	1	95.25	24.75
57	1	96.25	23.75
58	1	97.25	22.75
59	1	98.25	21.75
60	0.88	99.13	20.88
61	0.88	100	20
62	1	101	19
63	1	102	18
64	1	103	17
65	1.13	104.13	15.88
66	0.88	105	15
67	1	106	14
68	0.75	106.75	13.25
69	0.88	107.63	12.38
70	0.75	108.38	11.63
71	1.13	109.5	10.5
72	1	110.5	9.5
73	0.88	111.38	8.63
74	1	112.38	7.63
75	0.88	113.25	6.75
76	0.88	114.13	5.88
77	0.88	115	5

78	1	116	4
79	0.88	116.88	3.13
80	0.63	117.5	2.5
81	0.88	118.38	1.63
82	0.88	119.25	0.75
83	0.75	120	0

8.1.2 LOAD TEST SCHEDULE

Pile	Pile Length (ft)	Pile No.	Installation Date	Test Date (Days)							
				0	1	7	10	30	100	300	600
W6 x 12	**8**	**DOE-1**	10/12/12				10/22/12		3/29/13 (168)		6/23/14 (619)
W8 x 15		**DOE-2**	6/17/14			6/24/14					6/24/14 (619)
S4 x 7.7 Plain		**DOE-3**	4/8/13								
2.875-in Closed Sched. 40	**10**	**DOE-6**	4/16/13		4/17/13		4/26/13 (10)	5/25/13	7/29/13 (104)		
4.5-in. Open Sched. 40		**DOE-7**	5/20/13								
4.5-in. Closed Sched. 40	**12**	**DOE-9**	5/20/13								
S3 x 5.7	**8**	**DOE-10**	4/10/13			4/17/13					
2.875-in. Open		**DOE-11**	6/17/14			6/24/14					
2.875-in Closed		**DOE-12**	6/17/14			6/24/14					
2.875-in Closed		**DOE-13**	6/18/14			6/25/14					
W6 x 9	**9 (8)**	**DOE-14**	6/18/14			6/25/14					
W6 x 9	**9 (8)**	**DOE-15**	8/15/13		8/16/13		8/26/13	9/14/13	11/23/13	6/15/14	
6.625-in. Open Sched. 40	**11 (10)**	**DOE-16**	6/18/14			6/25/14			11/11/14 (170)		
W6 x 9	**9**	**DOE-17**	8/15/13			8/26/13				6/25/14	
W6 x 9	**8**	**DOE-18**	9/20/13							7/15/14	
2.875-in. Closed Sched. 10	**10**	**DOE-19**	9/20/13				9/30/13			7/15/14	
2.875-in. Closed Sched. 10	**10**	**DOE-20**	9/20/13	9/20/13						7/15/14	
2.875-in. Closed Sched. 10	**10**	**DOE-21**	7/10/14			7/17/14					

2.875-in. Closed Sched. 10	**10**	**DOE-22**	9/20/13				9/30/13			7/18/14	
6.625-in. Open Sched. 40	**10**	**DOE-26**	11/4/14			11/11/14					
4.5-in. Closed		**DOE-27**	5/13/14						8/27/14 (105)		
W6 x 9		**DOE-28**	5/13/14						8/27/14 (105)		

8.1.3 LOAD TEST RESULTS

Technician(s)	HZ
Pile Type	W6 x 12
Pile Name	DOE-1
Location	DOE
Date	6/23/14
Age	619
Installation Date	10/12/12

Digital Reading	Load (lbs)	Displacement (in.)
50	275	0.0000
100	550	0.0000
150	825	0.0000
200	1100	0.0000
250	1375	0.0000
300	1650	0.0020
400	2200	0.0045
500	2750	0.0075
600	3300	0.0105
700	3850	0.0165
800	4400	0.0245
900	4950	0.0345
1000	5500	0.0570
1100	6050	0.1280
1200	6600	0.2850
1300	7150	0.7675
1400	7700	1.9800

Final Displacement (in.)	1.9830
Rebound (in.)	1.9270

Technician(s)	HZ
Pile Type	W8 x 15
Pile Name	DOE-2
Location	DOE
Date	6/24/14
Age	742 days
Installation Date	6/17/12

Digital Reading	Load (lbs)	Displacement (in.)
100	550	0.0000
200	1100	0.0000
300	1650	0.0000
400	2200	0.0000
500	2750	0.0010
600	3300	0.0030
700	3850	0.0040
800	4400	0.0045
900	4950	0.0065
1000	5500	0.0100
1200	6600	0.0180
1400	7700	0.0285
1600	8800	0.0465
1800	9900	0.0965
2000	11000	0.2110
2200	12100	0.4990
2400	13200	1.4760

Final Displacement (in.)	1.5260
Rebound (in.)	1.4390

Technicians:	HZ
Pile Type:	2.875 in. Closed
Pile Name	DOE-6
Location:	DOE
Date:	4/17/13
Age	1 day
Installation Date	4/16/13

Digital Reading	Load (lbs)	Displacement (in.)
60	330	0.0000
90	495	0.0000
125	687.5	0.0005
170	935	0.0010
200	1100	0.0020
260	1430	0.0020
300	1650	0.0025
360	1980	0.0035
400	2200	0.0050
430	2365	0.0095
570	3135	0.0160
650	3575	0.0220
730	4015	0.0270
780	4290	0.0325
820	4510	0.0380
920	5060	0.0495
1000	5500	0.0600
1090	5995	1.5130

Final Displacement (in.)	1.513
Rebound (in.)	1.4865

Technicians:	NVW
Pile Type:	2.875 in. Closed
Pile Name	DOE-6
Location:	DOE
Date:	4/26/13
Age	10 days
Installation Date	4/16/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
40	200	0.0005
80	400	0.0015
120	600	0.0055
160	800	0.0055
205	1025	0.0055
245	1225	0.0055
290	1450	0.0055
330	1650	0.0055
365	1825	0.0055
409	2045	0.0055
511	2555	0.0055
613	3065	0.0055
715	3575	0.0055
817	4085	0.0035
919	4595	0.0225
1021	5105	1.0000
1000	5000	0.0600
1090	5450	1.9500

Final Displacement (in.)	1.9500
Rebound (in.)	1.9410

Technicians:	HZ
Pile Type:	2.875 in. Closed
Pile Name	DOE-6
Location:	DOE
Date:	5/25/13
Age	30 days
Installation Date	4/16/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
30	165	0.0000
60	330	0.0000
100	550	0.0005
120	660	0.0010
160	880	0.0025
200	1100	0.0040
250	1375	0.0050
300	1650	0.0070
350	1925	0.0090
400	2200	0.0105
450	2475	0.0110
500	2750	0.0125
550	3025	0.0140
600	3300	0.0150
650	3575	0.0165
700	3850	0.0180
750	4125	0.0195
800	4400	0.0210
850	4675	0.0215
900	4950	0.0235
950	5225	0.0250
1000	5500	0.0285
1050	5775	0.0400
1100	6050	0.0835
1150	6325	0.2225
1200	6600	1.4595

Final Displacement (in.)	1.4595
Rebound (in.)	1.6635

Technicians:	HZ
Pile Type:	2.875 in. Closed
Pile Name	DOE-6
Location:	DOE
Date:	7/29/13
Age	104 days
Installation Date	7/29/13

Digital Reading	Load (lbs)	Displacement (in.)
40	220	0.0000
80	440	0.0000
120	660	0.0000
160	880	0.0000
200	1100	0.0000
240	1320	0.0000
280	1540	-0.0005
320	1760	-0.0005
360	1980	-0.0005
400	2200	-0.0005
450	2475	-0.0005
500	2750	-0.0005
550	3025	0.0000
600	3300	0.0000
700	3850	0.0000
800	4400	0.0000
900	4950	0.0000
1000	5500	0.0000
1100	6050	0.0030
1200	6600	0.0070
1300	7150	0.0100
1400	7700	0.0210
1500	8250	0.3400
1600	8800	0.0635
1800	9900	0.1615
2000	11000	0.8285
2100	11550	1.2950

Final Displacement (in.)	1.2950
Rebound (in.)	1.2610

Technician(s)	HZ
Pile Type	2.875 in. Open
Pile Name	DOE-11
Location	DOE
Date	6/24/14
Age	7 days
Installation Date	6/17/14

Digital Reading	Load	Displacement (in.)
50	250	0.0000
100	500	0.0000
150	750	0.0000
200	1000	0.0000
250	1250	0.0005
300	1500	0.0015
350	1750	0.0035
400	2000	0.0035
450	2250	0.0055
500	2500	0.0075
600	3000	0.0145
700	3500	0.0145
800	4000	0.0165
900	4500	0.0200
1000	5000	0.0255
1100	5500	0.0295
1200	6000	0.0340
1300	6500	0.0435
1400	7000	0.0545
1500	7500	0.0745
1600	8000	0.1045
1800	9000	0.2240
1900	9500	0.7490

Final Displacement (in.)	1.0320
Rebound (in.)	0.0999

Technicians:	HZ
Pile Type:	2.875 in. Closed
Pile Name	DOE-12
Location:	DOE
Date:	6/24/14
Age	7 days
Installation Date	6/17/14

Digital Reading	Load (lbs)	Displacement (in.)
50	250	0.0000
100	500	0.0000
150	750	0.0000
200	1000	0.0000
250	1250	0.0000
300	1500	0.0000
350	1750	0.0000
400	2000	0.0000
450	2250	0.0020
500	2500	0.0020
600	3000	0.0035
700	3500	0.0060
800	4000	0.0080
900	4500	0.0100
1000	5000	0.0125
1100	5500	0.0160
1200	6000	0.0205
1300	6500	0.0245
1400	7000	0.0320
1500	7500	0.0445
1600	8000	0.0650
1800	9000	0.1255
2000	10000	0.2940
2100	10500	1.519

Final Displacement (in.)	1.5460
Rebound (in.)	1.5080

Technicians:	HZ
Pile Type:	2.875 in. Closed
Pile Name	DOE-13
Location:	DOE
Date:	6/25/14
Age	7 days
Installation Date	6/18/14

Digital Reading	**Load (lbs)**	**Displacement (in.)**
50	250	0.0000
100	500	0.0000
150	750	0.0000
200	1000	0.0000
250	1250	0.0000
300	1500	0.0000
350	1750	0.0010
400	2000	0.0020
450	2250	0.0035
500	2500	0.0035
550	2750	0.0035
600	3000	0.0060
650	3250	0.0075
700	3500	0.0090
800	4000	0.0120
900	4500	1.0450

Final Displacement (in.)	1.0825
Rebound (in.)	1.0760

Technicians:	HZ
Pile Type:	W6 x 9
Pile Name	DOE-14
Location:	DOE
Date:	6/25/14
Age	7 days
Installation Date	6/18/14

Digital Reading	Load	Displacement (in.)
50	250	0.0000
100	500	0.0000
150	750	0.0000
200	1000	0.0000
250	1250	0.0000
300	1500	0.0000
350	1750	0.0025
400	2000	0.0035
450	2250	0.0070
500	2500	0.0095
550	2750	0.0190
600	3000	0.0380
650	3250	0.1575
700	3500	1.0705

Final Displacement (in.)	1.1490
Rebound (in.)	1.1365

Technicians:	HZ
Pile Type:	W6 x 9
Pile Name	DOE-15
Location:	DOE
Date:	8/16/13
Age	1 day
Installation Date	8/15/13

Digital Reading	Load (lbs)	Displacement (in.)
50	250	0.0000
100	500	0.0000
150	750	0.0000
200	1000	0.0000
250	1250	0.0000
300	1500	0.0000
350	1750	0.0000
400	2000	0.0000
500	2500	0.0000
600	3000	0.0000
700	3500	0.0000
800	4000	0.0000
900	4500	0.0000
1000	5000	0.0275
1020	5100	0.052
1040	5200	0.0755
1060	5300	0.0975
1100	5500	0.1345
1150	5750	0.1985
1200	6000	0.2905
1300	6500	0.4885
1400	7000	0.7855
1500	7500	1.1675

Final Displacement (in.)	1.1675
Rebound (in.)	1.1275

Technicians:	HZ
Pile Type:	W6 x 9
Pile Name	DOE-15
Location:	DOE
Date:	8/26/13
Age	10 days
Installation Date	8/15/13

Digital Reading	**Load (lbs)**	**Displacement (in.)**
50	250	0.0000
100	500	0.0000
150	750	0.0000
200	1000	0.0000
250	1250	0.0000
300	1500	0.0000
350	1750	0.0000
400	2000	0.0000
500	2500	0.0000
600	3000	0.0025
700	3500	0.0040
800	4000	0.0080
900	4500	0.0120
1000	5000	0.0190
1100	5500	0.0355
1200	6000	0.0705
1300	6500	0.1285
1400	7000	0.2425
1500	7500	0.3795
1600	8000	0.5725
1700	8500	0.822
1800	9000	1.128
1900	9500	1.556

Final Displacement (in.)	1.5560
Rebound (in.)	1.5000

Technicians:	HZ
Pile Type:	W6 x 9
Pile Name	DOE-15
Location:	DOE
Date:	9/14/13
Age	30 days
Installation Date	8/15/13

Digital Reading	**Load (lbs)**	**Displacement (in.)**
100	500	0.0000
200	1000	0.0005
300	1500	0.0010
400	2000	0.0020
500	2500	0.0030
600	3000	0.0060
700	3500	0.0100
800	4000	0.0135
900	4500	0.0190
1000	5000	0.0255
1100	5500	0.0330
1200	6000	0.0505
1300	6500	0.0835
1400	7000	0.1410
1500	7500	0.235
1600	8000	0.3995
1700	8500	0.6645
1800	9000	1.1375
1900	9500	1.8775

Final Displacement (in.)	1.5560
Rebound (in.)	1.5000

Technicians:	HZ
Pile Type:	W6 x 9
Pile Name	DOE-15
Location:	DOE
Date:	11/23/13
Age	100 days
Installation Date	8/15/13

Digital Reading	Load (lbs)	Displacement (in.)
100	500	0.0000
200	1000	0.0000
300	1500	0.0000
400	2000	0.0000
500	2500	0.0025
600	3000	0.0050
700	3500	0.0080
800	4000	0.0140
900	4500	0.0220
1000	5000	0.0310
1100	5500	0.0485
1200	6000	0.0965
1300	6500	0.0186
1400	7000	0.0353
1500	7500	0.7575
1600	8000	1.583

Final Displacement (in.)	1.9850
Rebound (in.)	1.9060

Technicians:	HZ
Pile Type:	W6 x 9
Pile Name	DOE-15
Location:	DOE
Date:	6/25/14
Age	300 days
Installation Date	8/15/13

Digital Reading	**Load (lbs)**	**Displacement (in.)**
100	500	0.0000
200	1000	0.0000
300	1500	0.0000
400	2000	0.0000
500	2500	0.0000
600	3000	0.0000
700	3500	0.0025
800	4000	0.0045
900	4500	0.0075
1000	5000	0.0165
1100	5500	0.0250
1200	6000	0.0615
1300	6500	0.1515
1400	7000	0.3090
1500	7500	1.1035

Final Displacement (in.)	1.1520
Rebound (in.)	1.1185

Technicians:	HZ
Pile Type:	6.625 in. Open
Pile Name	DOE-16
Location:	DOE
Date:	6/25/14
Age	7 days
Installation Date	6/18/14

Digital Reading	**Load (lbs)**	**Displacement (in.)**
100	500	0.0000
200	1000	0.0000
300	1500	0.0000
400	2000	0.0000
600	3000	0.0000
800	4000	0.0000
1000	5000	0.0050
1200	6000	0.0070
1400	7000	0.0090
1600	8000	0.0130
1800	9000	0.0175
2000	10000	0.0235
2200	11000	0.0265
2400	12000	0.0335
2600	13000	0.0510
2800	14000	0.1065
3000	15000	0.2760
3200	16000	0.8615
3300	16500	1.7310

Final Displacement (in.)	1.7955
Rebound (in.)	1.7425

Technicians:	JL
Pile Type:	W6 x 9
Pile Name	DOE-17
Location:	DOE
Date:	8/26/13
Age	11 days
Installation Date	8/15/13

Digital Reading	**Load (lbs)**	**Displacement (in.)**
50	250	0.0000
100	500	0.0000
150	750	0.0000
200	1000	0.0000
250	1250	0.0000
300	1500	0.0000
350	1750	0.0000
400	2000	0.0000
500	2500	0.0000
600	3000	0.0000
700	3500	0.0055
800	4000	0.0155
900	4500	0.4700
1000	5000	0.0695
1100	5500	0.1040
1200	6000	0.1555
1300	6500	0.2570
1400	7000	0.4220
1500	7500	0.6760
1600	8000	0.9810
1700	8500	1.2935

Final Displacement (in.)	1.2935
Rebound (in.)	1.2420

Technicians:	HZ
Pile Type:	W6 x 9
Pile Name	DOE-17
Location:	DOE
Date:	6/25/14
Age	300 days
Installation Date	8/15/13

Digital Reading	**Load (lbs)**	**Displacement (in.)**
50	250	0.0000
100	500	0.0000
150	750	0.0000
200	1000	0.0000
250	1250	0.0010
300	1500	0.0025
350	1750	0.0025
400	2000	0.0035
500	2500	0.0055
600	3000	0.0070
700	3500	0.0115
800	4000	0.0145
900	4500	0.0165
1000	5000	0.0210
1100	5500	0.0240
1200	6000	0.0295
1300	6500	0.0365
1400	7000	0.0480
1500	7500	0.0675
1600	8000	0.0960
1800	9000	0.18300
2000	10000	0.37950
2100	10500	0.61100
2200	11000	1.01650

Final Displacement (in.)	1.0520
Rebound (in.)	0.9820

Technicians:	HZ
Pile Type:	2.875” Closed
Pile Name	DOE-19
Location:	DOE
Date:	9/30/13
Age	10 days
Installation Date	9/20/13

Digital Reading	**Load (lbs)**	**Displacement (in.)**
50	250	0.0000
100	500	0.0000
150	750	0.0015
200	1000	0.0015
250	1250	0.0020
300	1500	0.0020
350	1750	0.0045
400	2000	0.0045
450	2250	0.0045
500	2500	0.0070
550	2750	0.0070
600	3000	0.0070
650	3250	0.0105
700	3500	0.0145
750	3750	0.0180
800	4000	0.0175
850	4250	0.0210
900	4500	0.0260
950	4750	0.0285
1000	5000	0.0350
1100	5500	0.0470
1200	6000	0.0835
1300	6500	0.431

Final Displacement (in.)	0.589
Rebound (in.)	0.565

Technicians:	HZ
Pile Type:	2.875” Closed
Pile Name	DOE-20
Location:	DOE
Date:	9/20/13
Age	0 day
Installation Date	9/20/13

Digital Reading	**Load (lbs)**	**Displacement (in.)**
50	250	0.0000
100	500	0.0005
150	750	0.0005
200	1000	0.0005
250	1250	0.0005
300	1500	0.0000
350	1750	0.0010
400	2000	0.0010
450	2250	0.0010
500	2500	0.0015
550	2750	0.0015
600	3000	0.0020
650	3250	0.0030
700	3500	0.0050
750	3750	0.0080
800	4000	0.0100
850	4250	0.0135
900	4500	0.0160
950	4750	0.0205
1000	5000	0.0235
1100	5500	0.0330
1200	6000	0.0485

Final Displacement (in.)	0.3750
Rebound (in.)	0.3575

Technicians:	HZ
Pile Type:	2.875” Closed
Pile Name	DOE-21
Location:	DOE
Date:	7/17/14
Age	7 days
Installation Date	7/10/14

Digital Reading	**Load (lbs)**	**Displacement (in.)**
50	250	0.0000
100	500	0.0000
150	750	0.0005
200	1000	0.0005
250	1250	0.0005
300	1500	0.0005
400	2000	0.0030
500	2500	0.0055
600	3000	0.0060
700	3500	0.0090
800	4000	0.0095
900	4500	0.0115
1000	5000	0.0175
1200	6000	0.0265
1400	7000	0.0510
1600	8000	0.0810
1800	9000	0.1210
2000	10000	0.2115
2300	11500	1.9595

Final Displacement (in.)	1.9840
Rebound (in.)	1.9170

Technicians:	HZ
Pile Type:	2.875 Closed
Pile Name	DOE-22
Location:	DOE
Date:	9/30/13
Age	10 days
Installation Date	9/20/13

Digital Reading	Load (lbs)	Displacement (in.)
50	250	-0.0020
100	500	-0.0040
150	750	-0.0065
200	1000	-0.0065
250	1250	-0.0060
300	1500	-0.0060
350	1750	-0.0065
400	2000	-0.0010
450	2250	-0.0010
500	2500	0.0005
550	2750	0.0025
600	3000	0.0050
650	3250	0.0070
700	3500	0.0095
750	3750	0.0130
800	4000	0.0180
850	4250	0.0215
900	4500	0.0235
950	4750	0.0265
1000	5000	0.0295
1100	5500	0.0370
1200	6000	0.0425
1300	6500	0.0615
1400	7000	0.0910

Final Displacement (in.)	0.1600
Rebound (in.)	0.1420

Technicians:	HZ
Pile Type:	2.875 Closed
Pile Name	DOE-22
Location:	DOE
Date:	7/18/14
Age	300 days
Installation Date	9/20/13

Digital Reading	**Load (lbs)**	**Displacement (in.)**
50	250	0.0000
100	500	0.0010
150	750	0.0020
200	1000	0.0025
250	1250	0.0025
300	1500	0.0025
400	2000	0.0030
500	2500	0.0030
600	3000	0.0040
700	3500	0.0075
800	4000	0.0075
900	4500	0.0105
1000	5000	0.0105
1200	6000	0.0150
1400	7000	0.0215
1600	8000	0.0990
1800	9000	1.7070

Final Displacement (in.)	1.7750
Rebound (in.)	1.7500

Technicians:	HZ
Pile Type:	6.625" Open
Pile Name	DOE-26
Location:	DOE
Date:	11/11/14
Age	7 days
Installation Date	11/4/14

Digital Reading	**Load (lbs)**	**Displacement (in.)**
100	500	0.0000
200	1000	0.0000
300	1500	0.0000
400	2000	0.0000
600	3000	0.0020
800	4000	0.0040
1000	5000	0.0065
1200	6000	0.0085
1400	7000	0.0135
1600	8000	0.0200
1800	9000	0.0270
2000	10000	0.0395
2200	11000	0.0525
2400	12000	0.0665
2600	13000	0.0875
2800	14000	0.1140
3000	15000	0.1445
3200	16000	0.1860
3400	17000	0.2400
3600	18000	0.3125
3800	19000	0.4150
4000	20000	0.7295
4200	21000	1.5445

Final Displacement (in.)	1.8520
Rebound (in.)	1.7575

Technicians:	HZ
Pile Type:	4.5" Closed
Pile Name	DOE-27
Location:	DOE
Date:	8/27/14
Age	105 days
Installation Date	5/13/14

Digital Reading	Load (lbs)	Displacement (in.)
50	250	0.0000
100	500	0.0000
150	750	0.0000
200	1000	0.0000
250	1250	0.0020
300	1500	0.0020
400	2000	0.0050
500	2500	0.0075
600	3000	0.0125
700	3500	0.0145
800	4000	0.0165
900	4500	0.0195
1000	5000	0.0220
1100	5500	0.0250
1200	6000	0.0300
1300	6500	0.0470
1400	7000	0.1055
1500	7500	0.1815
1600	8000	1.4385

Final Displacement (in.)	1.5070
Rebound (in.)	1.4830

Technician(s)	HZ
Pile Type	W6 x 9
Pile Name	DOE-28
Location	DOE
Date	8/27/14
Age	105 days
Installation Date	5/13/14

Digital Reading	**Load (lbs)**	**Displacement (in.)**
50	250	0.0000
100	500	0.0000
150	750	0.0000
200	1000	0.0000
250	1250	0.0000
300	1500	0.0000
350	1750	0.0000
400	2000	0.0000
450	2250	0.0000
500	2500	0.0000
600	3000	0.0015
700	3500	0.0060
800	4000	0.0110
900	4500	0.0175
1000	5000	0.0300
1100	5500	0.0520
1200	6000	0.1120
1300	6500	0.2400
1400	7000	0.4615
1500	7500	1.0160

Final Displacement (in.)	1.0680
Rebound (in.)	1.0160

8.1.4 FIELD VANE TEST RESULTS

Pile	4.5-in Closed
Pile Number	DOE-29
Aging	Immediate (0 day)
Date	13/May/2014

Depth (ft)	**Peak Torque (in-lb)**	**Post Peak Torque (in-lb)**	**Remolded Torque (in-lb)**
1.5	148.1	63.0	24.6
2.5	114.4	51.9	23.8
3.5	83.5	40.5	16.6
4.5	76.4	38.1	12.3
5.5	104.8	41.7	21.9
6.5	127.1	51.2	21.8
7.5	123.2	54.4	23.7
8.5	107.3	88.9	19.5
9.5	110	52.4	27.1
10.5	85.8	41.9	16.8
11.5	71.9	39.9	18.8
12.5	55.1	28.7	13.3

Pile	4.5-in Closed
Pile Number	DOE-29
Aging	1 day
Date	14/May/2014

Depth (ft)	**Peak Torque (in-lb)**	**Post Peak Torque (in-lb)**	**Remolded Torque (in-lb)**
1.5	132.2	61.0	22.5
2.5	117.9	57.1	29.5
3.5	93.1	70.0	15.2
4.5	61.8	35.1	15.4
5.5	102.9	59.5	30.6
6.5	117.4	60.2	24.9
7.5	98.6	49.3	21.2
8.5	67.0	35.3	15.9
9.5	81.4	42.5	21.2
10.5	97.3	55.5	28.9
11.5	67.1	34	12.8
12.5	53.0	26.7	7.7

Pile	4.5-in Closed
Pile Number	DOE-29
Aging	35 day
Date	19/June/2014

Depth (ft)	**Peak Torque (in-lb)**	**Post Peak Torque (in-lb)**	**Remolded Torque (in-lb)**
1.5	120.9	62.6	15.7
2.5	20.8	15	5
3.5	70	36.1	15.7
4.5	44.3	17.2	5.6
5.5	109.6	51	34.2
6.5	121.5	63.4	35.1
7.5*	45.1	3.6	0.5
8.5*	1.9	-	-
9.5*	10.4	6.9	3.9
10.5*	21.2	11.5	4.9
11.5*	33.5	22.6	12.9
12.5*	11.8	7.9	3.0

Pile	4.5-in Closed
Pile Number	DOE-29
Aging	167 day
Date	25/October/2014

Depth (ft)	**Peak Torque (in-lb)**	**Post Peak Torque (in-lb)**	**Remolded Torque (in-lb)**
1.5	-	-	-
2.5	23.1	9.8	4.9
3.5	2.9	-	-
4.5	8.2	-	4.7
5.5	12.6	-	2.9
6.5	101.1	48.9	29.2
7.5	70.1	37.1	5.6
8.5	109.8	33.3	17.6
9.5	81.4	41.5	22.1
10.5	76.1	34.5	13.9
11.5	80.9	44.4	23.4
12.5	43.6	20.1	10.3

Pile	4.5-in Open
Pile Number	DOE-30
Aging	Immediate (0 day)
Date	13/May/2014

Depth (ft)	**Peak Torque (in-lb)**	**Post Peak Torque (in-lb)**	**Remolded Torque (in-lb)**
1.5	130.3	73.8	18.6
2.5	141.9	69.0	19.3
3.5	90.2	34.7	16.3
4.5	88.7	36.6	15.4
5.5	85.8	40.8	21.8
6.5	109.3	44.0	18.4
7.5	99.9	46.0	20.3
8.5	108.9	50.0	27.2
9.5	103.0	45.0	21.6
10.5	84.4	41.4	19.7
11.5	69.8	29.2	14.3
12.5	47.3	23.6	9.6

Pile	4.5-in Open
Pile Number	DOE-30
Aging	1 day
Date	14/May/2014

Depth (ft)	**Peak Torque (in-lb)**	**Post Peak Torque (in-lb)**	**Remolded Torque (in-lb)**
1.5	132	57.3	14.1
2.5	117.1	65.1	24.4
3.5	77.0	34.5	12.8
4.5	96.8	46.3	19.4
5.5	61.8	45.0	18.1
6.5	99.7	43.0	21.5
7.5	104.0	41.9	17.9
8.5	102.4	50.1	21.7
9.5	92.0	48.1	22.3
10.5	84.7	43.3	21.2
11.5	62.3	34.7	16.2
12.5	52.9	26.5	9.5

Pile	4.5-in Open
Pile Number	DOE-30
Aging	35 days
Date	19/June/2014

Depth (ft)	**Peak Torque (in-lb)**	**Post Peak Torque (in-lb)**	**Remolded Torque (in-lb)**
1.5	65.1	35.5	13.3
2.5	48.2	19.4	12.2
3.5	40.1	19.3	8.6
4.5	48.5	29.6	12.1
5.5	39.3	15.6	9.8
6.5	55.6	27.8	11.3
7.5	54.5	28.9	16.5
8.5	171.9	33.6	19.3
9.5	65.4	34.5	19.3
10.5	41.4	25.3	12
11.5	36.9	21.6	2.8
12.5	31.3	23.4	2.4

Pile	4.5-in Open
Pile Number	DOE-30
Aging	167 days
Date	25/October/2014

Depth (ft)	**Peak Torque (in-lb)**	**Post Peak Torque (in-lb)**	**Remolded Torque (in-lb)**
1.5	16.0	7.2	4.7
2.5	51.9	21.3	2.5
3.5	79.5	35.3	18.1
4.5	125.3	57.9	13.1
5.5	57.7	35.4	27.7
6.5	98.7	40.7	17.7
7.5	60.7	28.9	24.0
8.5	63.9	32.6	18.6
9.5	62.6	28.0	9.7
10.5	82.6	29.8	13.6
11.5	84.4	50.5	31.2
12.5	60.3	31.4	16.6

8.1.5 WATER CONTENT

Pile	4.5-in Closed
Pile Number	DOE-29

	Natural (initial)	**Day(s)**			
Depth (ft)	**Water Content (%)**	**0**	**1**	**35**	**167**
1.5	34.3	23.4	23.0	23.6	35.7
2.5	29.7	21.5	22.9	36.3	35.0
3.5	32.7	32.4	26.6	26.6	34.7
4.5	34.6	31.5	29.6	31.8	35.9
5.5	31.8	28.7	28.8	23.4	34.6
6.5	36.1	33.5	29.1	25.2	33.8
7.5	41.8	38.1	34.8	46.1	31.8
8.5	42.8	40.4	34.3	44.3	35.8
9.5	43.4	41.4	36.6	53.1	40.0
10.5	47.4	43.0	41.3	30.1	43.3
11.5	48.7	48.7	51.4	59.3	48.9
12.5	51.5	55.4	48.3	45.1	51.7

Pile	4.5-in Open
Pile Number	DOE-30

	Natural (initial) Water Content (%)	**Day(s)**			
Depth (ft)		**0**	**1**	**35**	**167**
1.5	34.3	23.0	20.7	21.3	31.1
2.5	29.7	25.9	23.7	30.1	34.2
3.5	32.7	25.2	31.7	32.4	29.9
4.5	34.6	37.1	29.0	28.3	34.1
5.5	31.8	28.1	23.6	30.0	32.8
6.5	36.1	30.7	27.2	32.0	34.2
7.5	41.8	37.1	35.7	36.3	40.1
8.5	42.8	37.0	35.2	38.0	39.6
9.5	43.4	40.6	38.4	40.5	47.2
10.5	47.4	44.0	43.1	43.5	45.6
11.5	48.7	51.2	49.0	50.0	49.5
12.5	51.5	53.9	60.2	52.6	46.5

8.2 TAYLOR FIELD (TF)

8.2.1 INSTALLATION LOGS

Technicians	JK, AJL, NW
Pile Type	2.875" Sched. 10 Plain
Pile Name	TF-6
Pile I.D.	2.635
Pile O.D.	2.875
Hammer Weight (lbs)	550
Drop Height (in)	48
Rig Type	Tractor
Location	TF
Installation Date	10/16/2012

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)	Distance to Plug (in.)	Plug (in)
1	13.25	13.25	106.75	120.75	11.25
2	10.5	23.75	96.25	117	15
3	5.75	29.5	90.5		
4	2.92	32.42	87.58	111.15	20.85
5	2.58	35	85		
6	2	37	83		
7	1.5	38.5	81.5	107.27	24.73
8	1.5	40	80		
9	1.5	41.5	78.5		
10	1.5	43	77		
11	1.5	44.5	75.5		
12	1.5	46	74	104.5	27.5
13	1.5	47.5	72.5		
14	1.5	49	71		
15	1.5	50.5	69.5		
16	2	52.5	67.5		
17	1	53.5	66.5	102.75	29.25
18	1.5	55	65		
19	1.5	56.5	63.5		
20	1.5	58	62		
21	1.75	59.75	60.25		
22	1.25	61	59	101	31
23	1.5	62.5	57.5		
24	1.75	64.25	55.75		

25	2	66.25	53.75		
26	2.5	68.75	51.25	99.25	32.75
27	3.25	72	48	99	33
28	4	76	44		
29	3.75	79.75	40.25	98	34
30	3.5	83.25	36.75		
31	3.25	86.5	33.5	96.5	35.5
32	3	89.5	30.5	96	36
33	2.5	92	28		
34	2.5	94.5	25.5		
35	2	96.5	23.5	94.25	37.75
36	2.25	98.75	21.25		
37	2	100.75	19.25		
38	2.25	103	17	92.75	39.25
39	2	105	15		
40	2.25	107.25	12.75	91.75	40.25
41	2	109.25	10.75		
42	1.75	111	9		
43	2.25	113.25	6.75	90	42
44	1.75	115	5		
45	2	117	3		
46	2	119	1		
47	2.25	121.25	-1.25	87.5	44.5

Technicians	JK, AJL, NW
Pile Type	2.875" Sched. 40 Plain
Pile Name	TF-7
Pile I.D.	2.469
Pile O.D.	2.875
Hammer Weight (lbs)	550
Drop Height (in)	48
Rig Type	Tractor
Location	TF
Installation Date	10/16/2012

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)	Distance to Plug (in.)	Plug (in)
1	14.75	14.75	105.25	119.75	12.25
2	15.25	30	90	118	14
3	6.25	36.25	83.75	115.5	16.5
4	4	40.25	79.75		
5	2.75	43	77	111	21
6	2.5	45.5	74.5		
7	2	47.5	72.5		
8	1.75	49.25	70.75	106.5	25.5
9	1.75	51	69		
10	1.5	52.5	67.5		
11	1.5	54	66	103.5	28.5
12	1.5	55.5	64.5		
13	1	56.5	63.5		
14	1.5	58	62		
15	1.25	59.25	60.75		
16	1.25	60.5	59.5	101.5	30.5
17	1.5	62	58		
18	1.75	63.75	56.25		
19	1.5	65.25	54.75	100.5	31.5
20	2.25	67.5	52.5		
21	2.75	70.25	49.75		
22	3.5	73.75	46.25	99.5	32.5
23	2.75	76.5	43.5		
24	2.5	79	41	98.75	33.25
25	2.5	81.5	38.5		
26	3	84.5	35.5	98	34
27	3	87.5	32.5		
28	3.75	91.25	28.75	97	35
29	3.25	94.5	25.5		
30	3	97.5	22.5	95.75	36.25
31	2.5	100	20		

32	2.5	102.5	17.5	94.25	37.75
33	2.25	104.75	15.25		
34	2.25	107	13	93.25	38.75
35	2	109	11		
36	2.25	111.25	8.75		
37	2.25	113.5	6.5	91.5	40.5
38	1.75	115.25	4.75		
39	2	117.25	2.75		
40	1.75	119	1		
41	2.5	121.5	-1.5	88.75	43.25

Technicians	JK, AJL, NW
Pile Type	4.5" Open Sched. 40 Plain
Pile Name	TF-8
Pile I.D.	4.26
Pile O.D.	4.50
Hammer Weight (lbs)	550
Drop Height (in)	48
Rig Type	Tractor
Location	TF
Installation Date	10/12/12

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)	Distance to Plug (in.)	Plug (in)
1	10.5	10.5	109.5	122	10
2	5.75	16.25	103.75	117.5	14.5
3	5.25	21.5	98.5		
4	3	24.5	95.5	110.5	21.5
5	2.25	26.75	93.25		
6	2	28.75	91.25		
7	2	30.75	89.25		
8	1.75	32.5	87.5	103.5	28.5
9	1.75	34.25	85.75		
10	1.5	35.75	84.25		
11	1.25	37	83		
12	1.25	38.25	81.75	100	32
13	1.25	39.5	80.5		
14	1.5	41	79		
15	1	42	78		
16	1.25	43.25	76.75	97.5	34.5
17	1.25	44.5	75.5		
18	1	45.5	74.5		
19	1.5	47	73		
20	1	48	72		
21	1.25	49.25	70.75	94.5	37.5
22	1.25	50.5	69.5		
23	1.125	51.625	68.375		
24	1.125	52.75	67.25		
25	1	53.75	66.25		
26	1.25	55	65	91.25	40.75
27	1	56	64		
28	1	57	63		
29	1	58	62		
30	1	59	61		
31	1	60	60	88.25	43.75

32	1	61	59		
33	1.25	62.25	57.75		
34	1.25	63.5	56.5		
35	1.75	65.25	54.75		
36	1.875	67.125	52.875	84.625	47.375
37	2.125	69.25	50.75		
38	2.25	71.5	48.5		
39	2.75	74.25	45.75		
40	2.5	76.75	43.25	81.25	50.75
41	2.25	79	41		
42	2.25	81.25	38.75		
43	1.75	83	37		
44	1.625	84.625	35.375		
45	1.625	86.25	33.75	78	54
46	1.25	87.5	32.5		
47	1.5	89	31		
48	1.5	90.5	29.5		
49	1.25	91.75	28.25		
50	1.25	93	27	75.5	56.5
51	1	94	26		
52	1.25	95.25	24.75		
53	1.25	96.5	23.5		
54	1	97.5	22.5		
55	1.25	98.75	21.25	73.375	58.625
56	1	99.75	20.25		
57	1.25	101	19		
58	1.25	102.25	17.75		
59	1	103.25	16.75		
60	1.25	104.5	15.5		
61	1	105.5	14.5	71	61
62	1	106.5	13.5		
63	1.5	108	12		
64	1	109	11		
65	1.125	110.125	9.875		
66	1.125	111.25	8.75	68.75	63.25
67	1	112.25	7.75		
68	1.25	113.5	6.5		
69	1	114.5	5.5		
70	1.125	115.625	4.375	67.25	64.75
71	1.125	116.75	3.25		
72	0.75	117.5	2.5		
73	1	118.5	1.5		
74	1.25	119.75	0.25		
75	0.75	120.5	-0.5	65.5	66.5

Technicians	JK, AJL, NW
Pile Type	4.5" Open Sched. 40 Plain
Pile Name	TF-9
Pile I.D.	4.026
Pile O.D.	4.5
Hammer Weight (lbs)	550
Drop Height (in)	48
Rig Type	Tractor
Location	TF
Installation Date	10/12/12

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)	Distance to Plug (in.)	Plug (in)
1	10.75	10.75	109.25	116.5	15.5
2	5.5	16.25	103.75		
3	3.5	19.75	100.25	109.5	22.5
4	2.5	22.25	97.75		
5	2	24.25	95.75		
6	1.75	26	94	104.5	27.5
7	1.5	27.5	92.5		
8	1.25	28.75	91.25		
9	1.25	30	90	101.75	30.25
10	1	31	89		
11	1.25	32.25	87.75		
12	1.25	33.5	86.5		
13	1	34.5	85.5		
14	1.25	35.75	84.25	98.5	33.5
15	1.25	37	83		
16	1	38	82		
17	1.25	39.25	80.75		
18	0.75	40	80		
19	1.25	41.25	78.75	95.5	36.5
20	1.25	42.5	77.5		
21	1.25	43.75	76.25		
22	1	44.75	75.25		
23	1	45.75	74.25	93.25	38.75
24	1.25	47	73		
25	1	48	72		
26	1.25	49.25	70.75		
27	0.75	50	70		
28	1	51	69	91.25	40.75
29	1	52	68		
30	1	53	67		
31	1	54	66		

32	1	55	65	89.75	42.25
33	1	56	64		
34	0.75	56.75	63.25		
35	1	57.75	62.25		
36	0.75	58.5	61.5		
37	1	59.5	60.5	87.5	44.5
38	1	60.5	59.5		
39	1	61.5	58.5		
40	0.75	62.25	57.75		
41	1.125	63.375	56.625		
42	1.125	64.5	55.5		
43	1.25	65.75	54.25	85	47
44	1.25	67	53		
45	1.5	68.5	51.5		
46	1.5	70	50		
47	1.75	71.75	48.25		
48	1.75	73.5	46.5	83	49
49	1.625	75.125	44.875		
50	1.875	77	43		
51	1.75	78.75	41.25		
52	1.75	80.5	39.5	81.75	50.25
53	1.75	82.25	37.75		
54	1.5	83.75	36.25		
55	1.75	85.5	34.5		
56	1.25	86.75	33.25		
57	1.5	88.25	31.75		
58	1.375	89.625	30.375	79	53
59	1.125	90.75	29.25		
60	1.25	92	28		
61	1.25	93.25	26.75		
62	1.25	94.5	25.5		
63	1	95.5	24.5	76.75	55.25
64	1	96.5	23.5		
65	1.25	97.75	22.25		
66	1.25	99	21		
67	1	100	20		
68	1.125	101.125	18.875	74.25	57.75
69	1.375	102.5	17.5		
70	1	103.5	16.5		
71	1	104.5	15.5		
72	1.125	105.625	14.375		
73	1.125	106.75	13.25	72	60
74	1.25	108	12		
75	1	109	11		
76	1	110	10		

77	1.125	111.125	8.875	70	62
78	1.125	112.25	7.75		
79	1.125	113.375	6.625		
80	1.125	114.5	5.5		
81	1	115.5	4.5		
82	1.25	116.75	3.25	67	65
83	0.75	117.5	2.5		
84	1.25	118.75	1.25		
85	1	119.75	0.25	65.25	66.75
86	0.25	120	0		
87	0.75	120.75	-0.75	65	67

Technicians	AJL and NW
Pile Type	W6 x 9 Plain
Pile Name	TF-10
Hammer Weight (lbs)	550
Drop Height (in)	48
Rig Type	Tractor
Location	TF
Installation Date	10/12/12

Cumulative Blow Count	**Penetration per Blow (in)**	**Cumulative Penetration (in)**	**Pile Penetration (in)**
1	11	11	109
2	6.25	17.25	102.75
3	5.5	22.75	97.25
4	3.25	26	94
5	2	28	92
6	1.75	29.75	90.25
7	1.5	31.25	88.75
8	1.25	32.5	87.5
9	1.5	34	86
10	1.5	35.5	84.5
11	1.75	37.25	82.75
12	1.5	38.75	81.25
13	1.25	40	80
14	1.25	41.25	78.75
15	1.25	42.5	77.5
16	1.25	43.75	76.25
17	1.25	45	75
18	1.25	46.25	73.75
19	1.25	47.5	72.5
20	1.25	48.75	71.25
21	0	48.75	71.25
22	2.25	51	69
23	1.25	52.25	67.75
24	1	53.25	66.75
25	1.25	54.5	65.5
26	1.25	55.75	64.25
27	1	56.75	63.25
28	1	57.75	62.25
29	1.25	59	61
30	1	60	60
31	1.25	61.25	58.75
32	1	62.25	57.75
33	1.25	63.5	56.5

34	1	64.5	55.5
35	1	65.5	54.5
36	1	66.5	53.5
37	1	67.5	52.5
38	1	68.5	51.5
39	1.25	69.75	50.25
40	1.25	71	49
41	1.25	72.25	47.75
42	1.25	73.5	46.5
43	1.25	74.75	45.25
44	1.5	76.25	43.75
45	1.25	77.5	42.5
46	1.25	78.75	41.25
47	1.25	80	40
48	1.25	81.25	38.75
49	1.25	82.5	37.5
50	1.25	83.75	36.25
51	1	84.75	35.25
52	1.25	86	34
53	1.25	87.25	32.75
54	1	88.25	31.75
55	1	89.25	30.75
56	1	90.25	29.75
57	1	91.25	28.75
58	1	92.25	27.75
59	1	93.25	26.75
60	1	94.25	25.75
61	1	95.25	24.75
62	1	96.25	23.75
63	1	97.25	22.75
64	0.75	98	22
65	1	99	21
66	1	100	20
67	1	101	19
68	1	102	18
69	0.75	102.75	17.25
70	1	103.75	16.25
71	1	104.75	15.25
72	1	105.75	14.25
73	1	106.75	13.25
74	0.75	107.5	12.5
75	1	108.5	11.5
76	0.75	109.25	10.75
77	1	110.25	9.75
78	0.75	111	9

79	1.25	112.25	7.75
80	0.75	113	7
81	0.75	113.75	6.25
82	0.75	114.5	5.5
83	1	115.5	4.5
84	0.75	116.25	3.75
85	1	117.25	2.75
86	1	118.25	1.75
87	1	119.25	0.75
88	0.5	119.75	0.25

Technicians	JK, AJL, NW
Pile Type	W6 x 9 Regular (Grey) Coat
Pile Name	TF-11
Hammer Weight (lbs)	550
Drop Height (in)	48
Rig Type	Tractor
Location	TF
Installation Date	10/12/12

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)
1	12	12	108
2	6.25	18.25	101.75
3	6.5	24.75	95.25
4	3.75	28.5	91.5
5	3.25	31.75	88.25
6	2.75	34.5	85.5
7	2.25	36.75	83.25
8	2.25	39	81
9	1.5	40.5	79.5
10	1.5	42	78
11	1.25	43.25	76.75
12	1.25	44.5	75.5
13	1	45.5	74.5
14	1	46.5	73.5
15	1	47.5	72.5
16	1.25	48.75	71.25
17	1	49.75	70.25
18	1	50.75	69.25
19	1	51.75	68.25
20	0.75	52.5	67.5
21	1.25	53.75	66.25
22	1	54.75	65.25
23	1	55.75	64.25
24	0.75	56.5	63.5
25	1.25	57.75	62.25
26	0.875	58.625	61.375
27	1.125	59.75	60.25
28	1	60.75	59.25
29	1	61.75	58.25
30	1	62.75	57.25
31	0.75	63.5	56.5
32	1	64.5	55.5
33	0.75	65.25	54.75

34	1	66.25	53.75
35	1.25	67.5	52.5
36	1	68.5	51.5
37	1.25	69.75	50.25
38	0.75	70.5	49.5
39	1	71.5	48.5
40	1.5	73	47
41	1.25	74.25	45.75
42	1.375	75.625	44.375
43	1.625	77.25	42.75
44	1.5	78.75	41.25
45	1.25	80	40
46	1.5	81.5	38.5
47	1	82.5	37.5
48	1.25	83.75	36.25
49	1.075	84.825	35.175
50	1.175	86	34
51	1	87	33
52	1.25	88.25	31.75
53	0.75	89	31
54	1	90	30
55	1	91	29
56	1	92	28
57	1	93	27
58	1.125	94.125	25.875
59	0.875	95	25
60	1	96	24
61	0.75	96.75	23.25
62	0.75	97.5	22.5
63	1	98.5	21.5
64	0.75	99.25	20.75
65	0.75	100	20
66	0.825	100.825	19.175
67	0.925	101.75	18.25
68	0.75	102.5	17.5
69	1	103.5	16.5
70	0.625	104.125	15.875
71	0.875	105	15
72	0.75	105.75	14.25
73	0.75	106.5	13.5
74	1	107.5	12.5
75	0.75	108.25	11.75
76	0.75	109	11
77	0.75	109.75	10.25
78	0.75	110.5	9.5

79	0.75	111.25	8.75
80	0.75	112	8
81	1	113	7
82	0.75	113.75	6.25
83	0.75	114.5	5.5
84	0.75	115.25	4.75
85	0.75	116	4
86	0.75	116.75	3.25
87	0.875	117.625	2.375
88	0.625	118.25	1.75
89	0.75	119	1
90	0.75	119.75	0.25
91	0.25	120	0

Technicians	JK, AJL, NW
Pile Type	W6 x 9 Blue Coat
Pile Name	TF-12
Hammer Weight (lbs)	550
Drop Height (in)	48
Rig Type	Tractor
Location	TF
Installation Date	10/12/12

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)
1	8	8	112
2	5.25	13.25	106.75
3	4.5	17.75	102.25
4	4.75	22.5	97.5
5	4	26.5	93.5
6	3.75	30.25	89.75
7	1.75	32	88
8	2	34	86
9	2	36	84
10	1.5	37.5	82.5
11	2.25	39.75	80.25
12	0.75	40.5	79.5
13	1.5	42	78
14	1.25	43.25	76.75
15	1.5	44.75	75.25
16	1.25	46	74
17	1.25	47.25	72.75
18	1	48.25	71.75
19	1.25	49.5	70.5
20	1.125	50.625	69.375
21	1.375	52	68
22	1	53	67
23	1.25	54.25	65.75
24	1	55.25	64.75
25	1.25	56.5	63.5
26	1	57.5	62.5
27	1	58.5	61.5
28	1	59.5	60.5
29	1	60.5	59.5
30	0.75	61.25	58.75
31	1	62.25	57.75
32	1	63.25	56.75
33	1	64.25	55.75

34	1	65.25	54.75
35	1.25	66.5	53.5
36	0.75	67.25	52.75
37	1	68.25	51.75
38	2.25	70.5	49.5
39	1.25	71.75	48.25
40	1.25	73	47
41	1	74	46
42	1.25	75.25	44.75
43	1.25	76.5	43.5
44	1.25	77.75	42.25
45	1	78.75	41.25
46	1.25	80	40
47	1	81	39
48	1.25	82.25	37.75
49	1.25	83.5	36.5
50	1	84.5	35.5
51	1	85.5	34.5
52	1.125	86.625	33.375
53	1.125	87.75	32.25
54	1	88.75	31.25
55	1.25	90	30
56	1.25	91.25	28.75
57	1.25	92.5	27.5
58	1.25	93.75	26.25
59	1	94.75	25.25
60	1.25	96	24
61	1.25	97.25	22.75
62	1	98.25	21.75
63	1	99.25	20.75
64	1	100.25	19.75
65	1	101.25	18.75
66	0.875	102.125	17.875
67	0.875	103	17
68	0.875	103.875	16.125
69	0.625	104.5	15.5
70	0.5	105	15
71	1	106	14
72	0.875	106.875	13.125
73	0.875	107.75	12.25
74	0.75	108.5	11.5
75	0.75	109.25	10.75
76	1	110.25	9.75
77	0.75	111	9
78	0.875	111.875	8.125

79	0.75	112.625	7.375
80	0.875	113.5	6.5
81	0.75	114.25	5.75
82	0.75	115	5
83	0.875	115.875	4.125
84	0.75	116.625	3.375
85	0.875	117.5	2.5
86	0.75	118.25	1.75
87	0.75	119	1
88	0.625	119.625	0.375
89	0.375	120	0

Technicians	JK, NW

Pile Type	W8 x 15
Pile Name	TF-13
Hammer Weight (lbs)	550
Drop Height (in)	48
Rig Type	Tractor
Location	TF
Installation Date	10/16/12

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)
1	9.25	9.25	110.75
2	4.25	13.5	106.5
3	3.5	17	103
4	4.5	21.5	98.5
5	4	25.5	94.5
6	3.75	29.25	90.75
7	3.25	32.5	87.5
8	2.5	35	85
9	3	38	82
10	2.25	40.25	79.75
11	1.5	41.75	78.25
12	1.25	43	77
13	1	44	76
14	1	45	75
15	1.5	46.5	73.5
16	1	47.5	72.5
17	1	48.5	71.5
18	0.75	49.25	70.75
19	1.25	50.5	69.5
20	1	51.5	68.5
21	0.75	52.25	67.75
22	1	53.25	66.75
23	0.75	54	66
24	0.75	54.75	65.25
25	0.75	55.5	64.5
26	1	56.5	63.5
27	0.75	57.25	62.75
28	0.75	58	62
29	0.75	58.75	61.25
30	0.75	59.5	60.5
31	0.75	60.25	59.75
32	0.75	61	59
33	0.75	61.75	58.25
34	0.5	62.25	57.75

35	1	63.25	56.75
36	0.75	64	56
37	0.75	64.75	55.25
38	0.75	65.5	54.5
39	0.75	66.25	53.75
40	0.75	67	53
41	0.75	67.75	52.25
42	0.75	68.5	51.5
43	1	69.5	50.5
44	0.75	70.25	49.75
45	0.75	71	49
46	1	72	48
47	1	73	47
48	1	74	46
49	0.75	74.75	45.25
50	1	75.75	44.25
51	1.25	77	43
52	1	78	42
53	1	79	41
54	1	80	40
55	1	81	39
56	1	82	38
57	0.5	82.5	37.5
58	1	83.5	36.5
59	0.75	84.25	35.75
60	0.75	85	35
61	1	86	34
62	0.75	86.75	33.25
63	0.75	87.5	32.5
64	1	88.5	31.5
65	0.75	89.25	30.75
66	0.75	90	30
67	0.5	90.5	29.5
68	0.75	91.25	28.75
69	0.75	92	28
70	0.5	92.5	27.5
71	1	93.5	26.5
72	0.5	94	26
73	0.75	94.75	25.25
74	0.75	95.5	24.5
75	1	96.5	23.5
76	0.5	97	23
77	0.75	97.75	22.25
78	0.75	98.5	21.5
79	0.75	99.25	20.75

80	0.75	100	20
81	0.5	100.5	19.5
82	1	101.5	18.5
83	0.75	102.25	17.75
84	0.5	102.75	17.25
85	0.75	103.5	16.5
86	0.75	104.25	15.75
87	0.75	105	15
88	0.75	105.75	14.25
89	0.5	106.25	13.75
90	0.75	107	13
91	0.75	107.75	12.25
92	0.75	108.5	11.5
93	0.5	109	11
94	1	110	10
95	0.5	110.5	9.5
96	0.5	111	9
97	0.5	111.5	8.5
98	1	112.5	7.5
99	0.5	113	7
100	1	114	6
101	0.5	114.5	5.5
102	0.5	115	5
103	0.75	115.75	4.25
104	0.75	116.5	3.5
105	0.5	117	3
106	0.75	117.75	2.25
107	0.75	118.5	1.5
108	1	119.5	0.5
109	0.5	120	0

Technicians	JK, NW
Pile Type	S4 x 7.7 Plain
Pile Name	TF-14
Hammer Weight (lbs)	550
Drop Height (in)	48
Rig Type	Tractor
Location	TF
Installation Date	11/5/12

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)
1	13.75	13.75	106.25
2	11	24.75	95.25
3	7.25	32	88
4	2.625	34.625	85.375
5	2.375	37	83
6	2.5	39.5	80.5
7	2	41.5	78.5
8	2.125	43.625	76.375
9	2.375	46	74
10	2	48	72
11	1.875	49.875	70.125
12	1.875	51.75	68.25
13	2.25	54	66
14	1.875	55.875	64.125
15	1.625	57.5	62.5
16	1.75	59.25	60.75
17	2	61.25	58.75
18	1.5	62.75	57.25
19	2	64.75	55.25
20	1.625	66.375	53.625
21	1.625	68	52
22	1.25	69.25	50.75
23	2.625	71.875	48.125
24	1.125	73	47
25	2.25	75.25	44.75
26	2.875	78.125	41.875
27	2.375	80.5	39.5
28	2	82.5	37.5
29	1.625	84.125	35.875
30	1.75	85.875	34.125
31	2	87.875	32.125
32	1.875	89.75	30.25
33	2.25	92	28

34	1.75	93.75	26.25
35	1.75	95.5	24.5
36	1.5	97	23
37	1.625	98.625	21.375
38	1.5	100.125	19.875
39	1.375	101.5	18.5
40	1.5	103	17
41	1.5	104.5	15.5
42	1.75	106.25	13.75
43	1.5	107.75	12.25
44	1.25	109	11
45	1.5	110.5	9.5
46	1.5	112	8
47	1.5	113.5	6.5
48	1.5	115	5
49	1.25	116.25	3.75
50	1.25	117.5	2.5
51	1.5	119	1
52	1	120	0

Technicians	JK, NW
Pile Type	W6 x 9 Plain
Pile Name	TF-16
Hammer Weight (lbs)	550
Drop Height (in)	48
Rig Type	Tractor
Location	TF
Installation Date	4/30/13

Cumulative Blow Count	**Penetration per Blow (in)**	**Cumulative Penetration (in)**	**Pile Penetration (in)**
1	13	13	107
2	8.5	21.5	98.5
3	5.25	26.75	93.25
4	2.75	29.5	90.5
5	2.5	32	88
6	2	34	86
7	1.5	35.5	84.5
8	1.75	37.25	82.75
9	1.75	39	81
10	1.75	40.75	79.25
11	1.75	42.5	77.5
12	1	43.5	76.5
13	1.75	45.25	74.75
14	1.25	46.5	73.5
15	1.5	48	72
16	1.5	49.5	70.5
17	1.25	50.75	69.25
18	1.25	52	68
19	1.25	53.25	66.75
20	1.25	54.5	65.5
21	1.25	55.75	64.25
22	1.25	57	63
23	1.25	58.25	61.75
24	1	59.25	60.75
25	1.25	60.5	59.5
26	1.25	61.75	58.25
27	1.25	63	57
28	1	64	56
29	2.25	66.25	53.75
30	1.25	67.5	52.5
31	0.75	68.25	51.75
32	1	69.25	50.75
33	1.25	70.5	49.5

34	0.75	71.25	48.75
35	1.25	72.5	47.5
36	1.25	73.75	46.25
37	1.25	75	45
38	1.75	76.75	43.25
39	1.75	78.5	41.5
40	1.75	80.25	39.75
41	1.25	81.5	38.5
42	1.5	83	37
43	1	84	36
44	1.5	85.5	34.5
45	1.25	86.75	33.25
46	1.25	88	32
47	1	89	31
48	1	90	30
49	1.25	91.25	28.75
50	1	92.25	27.75
51	0.75	93	27
52	1.25	94.25	25.75
53	1	95.25	24.75
54	0.75	96	24
55	1.25	97.25	22.75
56	0.75	98	22
57	1	99	21
58	1	100	20
59	1	101	19
60	1	102	18
61	0.75	102.75	17.25
62	0.75	103.5	16.5
63	1	104.5	15.5
64	0.75	105.25	14.75
65	1.25	106.5	13.5
66	0.75	107.25	12.75
67	1	108.25	11.75
68	1	109.25	10.75
69	0.75	110	10
70	1	111	9
71	0.75	111.75	8.25
72	1.25	113	7
73	1	114	6
74	1	115	5
75	1	116	4
76	1	117	3
77	1	118	2
78	1	119	1

79	1	120	0
80	1	121	-1
81	1	122	-2
82	1	123	-3

Technicians	JK, NW
Pile Type	W6 x 9 Plain
Pile Name	TF-17
Hammer Weight (lbs)	550
Drop Height (in)	48
Rig Type	Tractor
Location	TF
Installation Date	4/30/13

Cumulative Blow Count	**Penetration per Blow (in)**	**Cumulative Penetration (in)**	**Pile Penetration (in)**
1	13	13	107
2	6.5	19.5	100.5
3	4.5	24	96
4	3	27	93
5	2.5	29.5	90.5
6	2.5	32	88
7	2.5	34.5	85.5
8	2	36.5	83.5
9	2.25	38.75	81.25
10	1.75	40.5	79.5
11	1.5	42	78
12	1.75	43.75	76.25
13	2	45.75	74.25
14	1.25	47	73
15	1.5	48.5	71.5
16	1.5	50	70
17	1.5	51.5	68.5
18	1.25	52.75	67.25
19	1.25	54	66
20	1.25	55.25	64.75
21	1.25	56.5	63.5
22	1.25	57.75	62.25
23	1.25	59	61
24	1.25	60.25	59.75
25	1.25	61.5	58.5
26	1	62.5	57.5
27	1	63.5	56.5
28	1	64.5	55.5
29	1	65.5	54.5
30	1	66.5	53.5
31	1	67.5	52.5
32	1	68.5	51.5
33	1	69.5	50.5

34	1	70.5	49.5
35	1	71.5	48.5
36	1.25	72.75	47.25
37	1	73.75	46.25
38	1.25	75	45
39	1.25	76.25	43.75
40	1.5	77.75	42.25
41	1	78.75	41.25
42	1.5	80.25	39.75
43	1	81.25	38.75
44	1.25	82.5	37.5
45	0.75	83.25	36.75
46	1.5	84.75	35.25
47	1	85.75	34.25
48	1	86.75	33.25
49	0.75	87.5	32.5
50	1.25	88.75	31.25
51	1	89.75	30.25
52	1	90.75	29.25
53	0.75	91.5	28.5
54	1	92.5	27.5
55	1	93.5	26.5
56	1	94.5	25.5
57	1	95.5	24.5
58	1	96.5	23.5
59	0.75	97.25	22.75
60	0.75	98	22
61	1	99	21
62	0.5	99.5	20.5
63	1	100.5	19.5
64	0.75	101.25	18.75
65	0.75	102	18
66	0.75	102.75	17.25
67	0.75	103.5	16.5
68	0.75	104.25	15.75
69	0.75	105	15
70	0.75	105.75	14.25
71	0.75	106.5	13.5
72	0.75	107.25	12.75
73	0.75	108	12
74	0.75	108.75	11.25
75	0.75	109.5	10.5
76	0.75	110.25	9.75
77	0.75	111	9
78	0.75	111.75	8.25

79	0.75	112.5	7.5
80	0.75	113.25	6.75
81	0.75	114	6
82	1	115	5
83	0.75	115.75	4.25
84	0.75	116.5	3.5
85	1	117.5	2.5
86	0.75	118.25	1.75
87	0.75	119	1
88	1	120	0

Technicians	JK, HZ, NW
Pile Type	4.5" Open Sched. 40 Plain
Pile Name	HHF-8
Pile I.D.	4.03
Pile O.D.	4.5
Hammer Weight (lbs)	550
Drop Height (in)	48
Rig Type	Tractor
Location	TF
Installation Date	5/13/13

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)
1	10.25	10.25	109.75
2	4.75	15	105
3	3.5	18.5	101.5
4	2.25	20.75	99.25
5	2.25	23	97
6	2	25	95
7	1.5	26.5	93.5
8	1.25	27.75	92.25
9	1.5	29.25	90.75
10	1.25	30.5	89.5
11	1.5	32	88
12	1	33	87
13	1	34	86
14	1.5	35.5	84.5
15	1	36.5	83.5
16	1.25	37.75	82.25
17	1	38.75	81.25
18	1.25	40	80
19	0.75	40.75	79.25
20	1.25	42	78
21	1	43	77
22	1	44	76
23	1	45	75
24	1	46	74
25	1	47	73
26	1	48	72
27	1	49	71
28	0.75	49.75	70.25
29	1	50.75	69.25
30	1	51.75	68.25
31	0.75	52.5	67.5

32	1	53.5	66.5
33	1.5	55	65
34	0.5	55.5	64.5
35	1	56.5	63.5
36	0.75	57.25	62.75
37	0.75	58	62
38	1	59	61
39	1	60	60
40	0.75	60.75	59.25
41	0.75	61.5	58.5
42	1	62.5	57.5
43	1	63.5	56.5
44	0.75	64.25	55.75
45	1	65.25	54.75
46	0.75	66	54
47	1	67	53
48	1	68	52
49	1	69	51
50	1.25	70.25	49.75
51	1.75	72	48
52	0.5	72.5	47.5
53	1.5	74	46
54	1	75	45
55	1.5	76.5	43.5
56	1.5	78	42
57	1.75	79.75	40.25
58	1.75	81.5	38.5
59	2	83.5	36.5
60	1.75	85.25	34.75
61	2	87.25	32.75
62	1.75	89	31
63	1.75	90.75	29.25
64	1.5	92.25	27.75
65	1.75	94	26
66	1.25	95.25	24.75
67	1.25	96.5	23.5
68	1.25	97.75	22.25
69	1.25	99	21
70	1	100	20
71	1	101	19
72	1.25	102.25	17.75
73	1	103.25	16.75
74	1.25	104.5	15.5
75	1	105.5	14.5
76	1	106.5	13.5

77	1.25	107.75	12.25
78	1	108.75	11.25
79	1	109.75	10.25
80	1	110.75	9.25
81	1.25	112	8
82	1	113	7
83	1	114	6
84	1	115	5
85	1	116	4
86	1.25	117.25	2.75
87	1	118.25	1.75
88	1.25	119.5	0.5
89	0.5	120	0

Technicians	JK, HZ, NW
Pile Type	W6 x 9 Plain
Pile Name	TF-19
Hammer Weight (lbs)	550
Drop Height (in)	48
Rig Type	Tractor
Location	TF
Installation Date	5/13/13

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)
1	11	11	109
2	6.25	17.25	102.75
3	5	22.25	97.75
4	2.25	24.5	95.5
5	1.5	26	94
6	1.5	27.5	92.5
7	1.25	28.75	91.25
8	1.5	30.25	89.75
9	1.5	31.75	88.25
10	1.25	33	87
11	1.5	34.5	85.5
12	1.25	35.75	84.25
13	1.25	37	83
14	1.25	38.25	81.75
15	1.25	39.5	80.5
16	1.5	41	79
17	1.25	42.25	77.75
18	1.25	43.5	76.5
19	1.5	45	75
20	1.5	46.5	73.5
21	1	47.5	72.5
22	1	48.5	71.5
23	1	49.5	70.5
24	1.5	51	69
25	1.25	52.25	67.75
26	1.25	53.5	66.5
27	1	54.5	65.5
28	1.25	55.75	64.25
29	1.25	57	63
30	1	58	62
31	1.25	59.25	60.75
32	1	60.25	59.75
33	1.25	61.5	58.5

34	1	62.5	57.5
35	1	63.5	56.5
36	1	64.5	55.5
37	1.25	65.75	54.25
38	1	66.75	53.25
39	1	67.75	52.25
40	1	68.75	51.25
41	1.25	70	50
42	1	71	49
43	1.5	72.5	47.5
44	1.25	73.75	46.25
45	1.5	75.25	44.75
46	1.75	77	43
47	1.5	78.5	41.5
48	1.5	80	40
49	1.25	81.25	38.75
50	1.5	82.75	37.25
51	1.25	84	36
52	1	85	35
53	1.25	86.25	33.75
54	1.25	87.5	32.5
55	1	88.5	31.5
56	1	89.5	30.5
57	1	90.5	29.5
58	1	91.5	28.5
59	1	92.5	27.5
60	0.75	93.25	26.75
61	1	94.25	25.75
62	0.75	95	25
63	1	96	24
64	0.75	96.75	23.25
65	0.75	97.5	22.5
66	1	98.5	21.5
67	1	99.5	20.5
68	0.75	100.25	19.75
69	0.75	101	19
70	1	102	18
71	0.5	102.5	17.5
72	1	103.5	16.5
73	0.75	104.25	15.75
74	0.75	105	15
75	0.75	105.75	14.25
76	0.75	106.5	13.5
77	1	107.5	12.5
78	0.75	108.25	11.75

79	0.75	109	11
80	0.75	109.75	10.25
81	0.75	110.5	9.5
82	1	111.5	8.5
83	0.75	112.25	7.75
84	0.75	113	7
85	1	114	6
86	0.75	114.75	5.25
87	0.75	115.5	4.5
88	1	116.5	3.5
89	0.75	117.25	2.75
90	1	118.25	1.75
91	0.75	119	1
92	0.75	119.75	0.25
93	1.25	121	-1
94	1	122	-2

Technicians	JK, HZ, NW
Pile Type	4.5" Open Sched. 40 Plain
Pile Name	TF-20
Pile I.D.	4.03
Pile O.D.	4.5
Hammer Weight (lbs)	550
Drop Height (in)	48
Rig Type	Tractor
Location	TF
Installation Date	5/13/13

Cumulative Blow Count	**Penetration per Blow (in)**	**Cumulative Penetration (in)**	**Pile Penetration (in)**	**Distance to Plug (in.)**	**Plug (in)**
1	11.5	11.50	108.5	120.75	11.25
2	5.5	17	103.00	116.5	15.5
3	4.5	21.50	98.5	113.25	18.75
4	3.5	25	95		
5	2	27.000	93	108.25	23.75
6	2	29.00	91		
7	1	30.00	90		
8	1.5	31.5	88.50		
9	1.25	32.750	87.25		
10	1.25	34.000	86	102.5	29.5
11	1.5	35.500	84.5		
12	1.5	37.00	83		
13	1	38	82		
14	1	39.000	81		
15	1.75	40.750	79.25		
16	0.75	42	78.5	97.5	34.5
17	0.5	42.00	78		
18	1.25	43.3	76.75		
19	1.25	44.50	75.5		
20	0.75	45	74.75		
21	1	46.25	73.75		
22	1	47.25	72.75		
23	1	48.250	71.75		
24	0.75	49.00	71	92.75	39.25
25	1	50	70		
26	1	51.000	69.00		
27	1	52.00	68		
28	1	53.000	67		
29	1	53.500	66.5		
30	1	54.5	65.5		
31	1	55.3	64.75	89.25	42.75

32	1	56.0	64.00		
33	1	57.0	63		
34	1	57.8	62.25		
35	0.75	58.500	61.5		
36	1	59.50	60.5		
37	0.75	60.250	59.75		
38	0.75	61	59.00		
39	1	62.000	58	85	47
40	1	63.00	57		
41	1	64.0	56		
42	1	65.000	55		
43	0.75	65.750	54.25		
44	1	66.750	53.25		
45	1	67.75	52.25		
46	1.25	69.0	51	82	50
47	1	70.00	50		
48	1.25	71	48.75		
49	0.75	72.000	48		
50	1.5	73.500	46.50		
51	1	74.5	45.5		
52	1.25	75.75	44.25		
53	1.5	77	42.75		
54	1.25	78.500	41.5	78.75	53.25
55	1	79.500	40.5		
56	1.25	80.8	39.25		
57	1.25	82.000	38		
58	1	83.000	37		
59	1.25	84.25	35.75		
60	1.25	85.5	34.5	75.25	56.75
61	1	86.500	33.5		
62	1.25	88	32.25		
63	1.25	89.000	31		
64	1	90.000	30		
65	1	91.0	29		
66	1.25	92.250	27.75	72.25	59.75
67	1.25	93.500	26.5		
68	1	94.500	25.50		
69	1.25	95.750	24.25		
70	1.25	97	23		
71	1	98.000	22		
72	1.25	99.250	20.75	69.5	62.5
73	1.25	100.500	19.5		
74	1.25	102	18.25		
75	0.75	102.500	17.5		
76	1.5	104.000	16		

77	1	105.000	15		
78	1	106	14		
79	1	107.000	13		
80	1	108.000	12.00	65	67
81	1.25	109.250	10.75		
82	1.25	111	9.5		
83	1	111.500	8.5		
84	1	112.500	7.5		
85	1.25	113.750	6.25	62.25	69.75
86	1	115	5.25		
87	1.25	116.000	4		
88	1	117.000	3		
89	1	118.000	2		
90	1	119	1		
91	1	120	0	58.75	73.25

Technicians	JK, HZ, NW
Pile Type	4.5" Closed Sched. 40 Plain
Pile Name	TF-21
Pile I.D.	4.03
Pile O.D.	4.5
Hammer Weight (lbs)	550
Drop Height (in)	48
Rig Type	Tractor
Location	TF
Installation Date	5/13/13

Cumulative Blow Count	**Penetration per Blow (in)**	**Cumulative Penetration (in)**	**Pile Penetration (in)**	**Distance to Plug (in.)**	**Plug (in)**
1	11.5	11.5	108.5	120.5	11.5
2	6.25	18	102.25	115.5	16.5
3	3.75	22	98.5		
4	3	24.5	95.5	110.75	21.25
5	2.25	26.75	93.25		
6	2.25	29	91		
7	2	31	89		
8	1.75	32.75	87.25	104.5	27.5
9	1.75	34.5	85.5		
10	1	35.5	84.5		
11	1.75	37.25	82.75		
12	1.25	38.5	81.5		
13	1.5	40	80	98.75	33.25
14	1.5	41.5	78.5		
15	1	42.5	77.5		
16	1	43.5	76.5		
17	1.25	44.75	75.25		
18	1.25	46	74		
19	1.25	47.25	72.75		
20	1	48.25	71.75	93.5	38.5
21	1.25	49.5	70.5		
22	1.25	50.75	69.25		
23	1.25	52	68		
24	0.75	52.75	67.25		
25	0.75	53.5	66.5		
26	1.25	54.75	65.25	90	42
27	1	55.75	64.25		
28	1	56.75	63.25		
29	0.75	57.5	62.5		
30	1	58.5	61.5		
31	1	59.5	60.5		

32	1	60.5	59.5	86.5	45.5
33	1.25	61.75	58.25		
34	1.25	63	57		
35	1	64	56		
36	1.25	65.25	54.75		
37	1.5	66.75	53.25	83	49
38	1.5	68.25	51.75		
39	1.75	70	50		
40	2	72	48		
41	2	74	46		
42	2	76	44	80.5	51.5
43	1.5	77.5	42.5		
44	1.5	79	41		
45	1.5	80.5	39.5		
46	1.5	82	38	78.25	53.75
47	1.75	83.75	36.25		
48	1.5	85.25	34.75		
49	1.5	86.75	33.25		
50	1.5	88.25	31.75		
51	1.25	89.5	30.5	73.5	58.5
52	1.5	91	29		
53	1.25	92.25	27.75		
54	1.25	93.5	26.5		
55	1	94.5	25.5		
56	1.25	95.75	24.25	70	62
57	1.25	97	23		
58	1	98	22		
59	1	99	21		
60	1	100	20		
61	1	101	19		
62	1.25	102.25	17.75		
63	1.25	103.5	16.5		
64	1	104.5	15.5	64.75	67.25
65	1.25	105.75	14.25		
66	1	106.75	13.25		
67	1.25	108	12	63	69
68	1	109	11		
69	1	110	10		
70	1.000	111	9		
71	1.250	112.25	7.75		
72	1	113.25	6.75	60	72
73	1.25	114.5	5.5		
74	1	115.5	4.5		
75	1	116.5	3.5		
76	1.25	117.75	2.25		

77	1	118.75	1.25		
78	1.250	120	0	56	76

8.2.2 LOAD TEST SCHEDULE

Pile	Pile Length (ft)	Pile No.	Installation Date	Test Date (Days)							
				Immediate	**1**	**7**	**10**	**30**	**100**	**300**	**600**
2.875" Sched. 10	**10**	**TF - 6**	10/16/12		10/17/12					4/6/13 (172)	6/10/14 (602)
2.875" Sched. 40	**10**	**TF-7**	10/16/12		10/17/12					4/6/13 (172)	6/10/14 (602)
4.5" Sched. 10	**10**	**TF-8**	10/12/12		10/13/12					4/6/13 (176)	6/11/14 (607)
4.5" Sched. 40	**10**	**TF - 9**	10/12/12		10/13/12					4/6/13 (176)	6/11/14 (607)
W6 x 9 Plain	**10**	**TF-10**	10/12/12			10/20/12 (8)				4/5/13 (175)	6/11/14 (607)
W6 x 9 – Reg. (Grey) Coat	**10**	**TF-11**	10/12/12			10/20/12 (8)				4/5/13 (175)	6/11/14 (607)
W6 x 9 - Blue Coat	**10**	**TF-12**	10/12/12			10/20/12 (8)				4/5/13 (175)	6/11/14 (607)
W8 x 15 Plain	**10**	**TF-13**	10/16/12			10/24/12 (8)				4/6/13 (172)	6/9/14 (605)
S4 x 7.7	**10**	**TF-14**	11/5/12			11/12/12				4/6/13 (152)	6/12/14 (605)
W6 x 9 Plain	**10**	**TF-16**	4/30/12	4/30/12							6/9/14 (405)
W6 x 9 Plain	**10**	**TF-17**	4/30/12	4/30/12							6/9/14 (405)
4.5" Sched. 40	**10**	**TF-18**	5/13/13								6/9/14 (392)
4.5" Sched. 40	**10**	**TF-21**	5/13/13								6/10/14 (393)

8.2.3 LOAD TES RESULTS

Technician(s)	JK
Pile Type	2.875" Sched. 10
Pile Name	TF-6
Location	TF
Date	10/17/12
Age	1 day
Installation Date	10/16/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
20	97.8	0.0000
40	195.6	0.0000
70	342.3	0.0000
100	489.0	0.0010
130	635.7	0.0020
150	733.5	0.0020
180	880.2	0.0030
220	1075.8	0.0045
260	1271.4	0.0060
300	1467.0	0.0085
350	1711.5	0.0115
400	1956.0	0.0155
450	2200.5	0.0190
500	2445.0	0.0225
550	2689.5	0.0285
600	2934.0	0.0345
650	3178.5	0.0425
700	3423.0	0.0520
750	3667.5	0.0655
800	3912.0	0.0810
865	4229.9	1.9700
0	0	1.9360

Final Displacement (in.)	1.9360
Rebound (in.)	-

Technician(s)	JK
Pile Type	2.875" Sched. 10
Pile Name	TF-6
Location	TF
Date	4/6/13
Age	172 days
Installation Date	10/16/12

Digital Reading	Load (lbs)	Displacement (in.)
20	97.8	0.0000
40	195.6	0.0010
60	293.4	0.0020
100	489.0	0.0035
140	684.6	0.0070
180	880.2	0.0085
220	1075.8	0.0105
260	1271.4	0.0135
300	1467.0	0.0155
350	1711.5	0.0185
400	1956.0	0.0220
450	2200.5	0.0270
500	2445.0	0.0325
550	2689.5	0.0375
600	2934.0	0.0425
700	3423.0	0.0725
800	3912.0	0.3325
860	4205.4	1.9945
0	0	1.9255

Final Displacement (in.)	1.9255
Rebound (in.)	-

Technician(s)	HZ
Pile Type	2.875" Sched. 10
Pile Name	TF-6
Location	TF
Date	6/10/14
Age	602 days
Installation Date	10/16/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
25	122.25	0.0000
50	244.5	0.0000
75	366.75	0.0000
100	489	0.0000
150	733.5	0.0000
200	978	0.0000
250	1222.5	0.0000
300	1467	0.0000
350	1711.5	0.0010
400	1956	0.0010
450	2200.5	0.0040
500	2445	0.0040
550	2689.5	0.0065
600	2934	0.0090
650	3178.5	0.0110
700	3423	0.0110
750	3667.5	0.0135
800	3912	0.0175
850	4156.5	0.0195
900	4401	0.0225
1000	4890	0.0395
1100	5379	0.1335
1200	5868	1.3275
0	0	1.3010

Final Displacement (in.)	1.3475
Rebound (in.)	1.3210

Technician(s)	JK
Pile Type	2.875" Sched. 40
Pile Name	TF-7
Location	TF
Date	10/17/12
Age	1 day
Installation Date	10/16/12

Digital Reading	Load (lbs)	Displacement (in.)
20	97.8	0.0000
40	195.6	0.0000
70	342.3	0.0000
100	489.0	0.0000
140	684.6	0.0000
215	1051.4	0.0020
250	1222.5	0.0025
300	1467.0	0.0050
350	1711.5	0.0085
400	1956.0	0.0130
475	2322.8	0.0220
550	2689.5	0.0375
600	2934.0	0.0495
675	3300.8	0.0830
735	3594.2	1.9850
0	0	1.9720

Final Displacement (in.)	1.9850
Rebound (in.)	1.9270

Technician(s)	JK
Pile Type	2.875" Sched. 40
Pile Name	TF-7
Location	TF
Date	4/6/13
Age	172 days
Installation Date	10/16/12

Digital Reading	Load (lbs)	Displacement (in.)
20	97.80	0.0000
40	195.6	0.0000
60	293.40	0.0000
100	489	0.0000
140	684.6	0.0000
180	880	0.0000
220	1075.8	0.0000
260	1271	0.0005
300	1467.0	0.0000
350	1712	0.0000
400	1956.0	0.0015
450	2201	0.0035
500	2445.0	0.0045
550	2690	0.0060
600	2934.0	0.0080
650	3179	0.0115
700	3423.0	0.0220
750	3668	0.0330
800	3912.0	0.0775
850	4157	0.2980
894	4372	1.9860
0	0	1.9670

Final Displacement (in.)	1.9860
Rebound (in.)	1.9670

Technician(s)	HZ
Pile Type	2.875" Sched. 40
Pile Name	TF-7
Location	TF
Date	6/10/14
Age	602 days
Installation Date	10/16/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
25	122.25	0.0000
50	244.5	0.0000
75	366.75	0.0000
100	489	0.0005
150	733.5	0.0010
200	978	0.0020
250	1222.5	0.0035
300	1467	0.0050
350	1711.5	0.0065
400	1956	0.0085
450	2200.5	0.0095
500	2445	0.0110
550	2689.5	0.0125
600	2934	0.0140
650	3178.5	0.0155
700	3423	0.0180
750	3667.5	0.0205
800	3912	0.0255
850	4156.5	0.0530
900	4401	1.2900
0	0	1.2735

Final Displacement (in.)	1.3350
Rebound (in.)	1.3185

Technician(s)	JK
Pile Type	4.5" Sched. 10
Pile Name	TF-8
Location	TF
Date	10/13/12
Age	1 day
Installation Date	10/12/12

Digital Reading	Load (lbs)	Displacement (in.)
20	97.80	0.0000
40	195.6	0.0000
60	293.40	0.0000
100	489	0.0000
150	733.5	0.0005
200	978	0.0020
230	1124.7	0.0030
260	1271	0.0040
300	1467.0	0.0060
350	1712	0.0080
400	1956.0	0.0095
450	2201	0.0125
500	2445.0	0.0155
560	2738	0.0195
640	3129.6	0.0255
720	3521	0.0365
800	3912.0	0.0490
900	4401	0.0710
1000	4890.0	0.1050
1090	5330	1.9930
0	0	1.9700

Final Displacement (in.)	1.9930
Rebound (in.)	1.9700

Technician(s)	JK
Pile Type	4.5" Sched. 10
Pile Name	TF-8
Location	TF
Date	4/6/13
Age	176 days
Installation Date	10/12/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
20	97.80	0.0000
40	195.6	0.0000
80	391.20	0.0005
120	587	0.0020
160	782.4	0.0020
200	978	0.0035
250	1222.5	0.0040
300	1467	0.0055
350	1711.5	0.0070
400	1956	0.0095
500	2445.0	0.0135
600	2934	0.0175
700	3423.0	0.0235
800	3912	0.0330
900	4401.0	0.0995
1000	4890	0.6475
1050	5134.5	1.9890
0	0	1.9515

Final Displacement (in.)	1.9890
Rebound (in.)	1.9515

Technician(s)	HZ
Pile Type	4.5" Sched. 10
Pile Name	TF-8
Location	TF
Date	6/11/14
Age	607 days
Installation Date	10/12/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
50	244.50	0.0000
100	489.0	0.0000
150	733.50	0.0000
200	978	0.0000
250	1222.5	0.0015
300	1467	0.0015
350	1711.5	0.0035
400	1956	0.0035
450	2200.5	0.0055
500	2445	0.0055
550	2689.5	0.0075
600	2934	0.0075
650	3178.5	0.0075
700	3423	0.0110
750	3667.5	0.0110
800	3912	0.0140
850	4156.5	0.0165
900	4401	0.0195
950	4645.5	0.0225
1000	4890	0.0270
1100	5379.0	0.1340
1200	5868	1.4400
0	0	1.4090

Final Displacement (in.)	1.4570
Rebound (in.)	1.4260

Technician(s)	JK
Pile Type	4.5" Open Sched. 40 Plain
Pile Name	TF-9
Location	TF
Date	10/13/12
Age	1 day
Installation Date	10/12/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
30	146.7	0.0000
60	293.4	0.0000
100	489.0	0.0000
150	733.5	0.0000
200	978.0	0.0000
250	1222.5	0.0005
300	1467.0	0.0010
350	1711.5	0.0025
400	1956.0	0.0040
450	2200.5	0.0060
500	2445.0	0.0090
550	2689.5	0.0130
600	2934.0	0.0170
650	3178.5	0.0225
700	3423.0	0.0290
750	3667.5	0.0380
800	3912.0	0.0475
900	4401.0	0.0745
1000	4890.0	0.1215
1070	5232.3	1.9780
0	0	1.9615

Final Displacement (in.)	1.9780
Rebound (in.)	1.9615

Technician(s)	JK
Pile Type	4.5" Open Sched. 40 Plain
Pile Name	TF-9
Location	TF
Date	4/6/13
Age	175 days
Installation Date	10/12/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
20	97.8	0.0000
40	195.6	0.0000
80	391.2	0.0000
120	586.8	0.0000
160	782.4	0.0000
200	978.0	0.0000
250	1222.5	0.0000
300	1467.0	0.0000
350	1711.5	0.0000
400	1956.0	0.0015
500	2445.0	0.0020
600	2934.0	0.0035
700	3423.0	0.0065
800	3912.0	0.0105
900	4401.0	0.0775
1000	4890.0	1.9915
0	0	1.9790

Final Displacement (in.)	1.9915
Rebound (in.)	1.9790

Technician(s)	HZ
Pile Type	4.5" Open Sched. 40 Plain
Pile Name	TF-9
Location	TF
Date	6/11/14
Age	607 days
Installation Date	10/12/12

Digital Reading	Load (lbs)	Displacement (in.)
50	244.50	0.0000
100	489.0	0.0000
150	733.50	0.0000
200	978	0.0000
250	1222.5	0.0000
300	1467	0.0000
350	1711.5	0.0000
400	1956	0.0000
450	2200.5	0.0010
500	2445	0.0010
550	2689.5	0.0010
600	2934	0.0025
650	3178.5	0.0025
700	3423	0.0025
750	3667.5	0.0060
800	3912	0.0205
850	4156.5	0.0480
900	4401	0.1760
950	4645.5	1.1730
0	0	1.1680

Final Displacement (in.)	1.1990
Rebound (in.)	1.1940

Technician(s)	AJL
Pile Type	W6 x 9 Plain
Pile Name	TF-10
Location	TF
Date	10/20/13
Age	8 days
Installation Date	10/12/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
25	122.3	0.0000
50	244.5	0.0000
75	366.8	0.0005
100	489.0	0.0010
150	733.5	0.0015
200	978.0	0.0020
250	1222.5	0.0035
300	1467.0	0.0045
350	1711.5	0.0080
400	1956.0	0.0130
500	2445.0	0.0315
550	2689.5	0.0485
600	2934.0	0.0730
650	3178.5	0.1140
700	3423.0	0.1700
750	3667.5	0.2515
800	3912.0	0.3345
850	4156.5	0.4075
900	4401.0	0.4700
950	4645.5	0.5305
1000	4890.0	0.5845
1100	5379.0	0.6900
1200	5868.0	0.7965
1300	6357.0	0.9000
1400	6846.0	1.0085
1500	7335.0	1.1455
1600	7824.0	1.3240
1700	8313.0	1.5640
1800	8802.0	2.0400
0	0.0	1.9630

Final Displacement (in.)	2.0400
Rebound (in.)	1.9630

Technician(s)	JK
Pile Type	W6 x 9 Plain
Pile Name	TF-10
Location	TF
Date	6/11/14
Age	175 days
Installation Date	10/12/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
20	97.8	0.0000
40	195.6	0.0000
80	391.2	0.0000
120	586.8	0.0000
160	782.4	0.0000
200	978.0	0.0020
300	1467.0	0.0045
400	1956.0	0.0075
500	2445.0	0.0100
600	2934.0	0.0150
700	3423.0	0.0225
800	3912.0	0.0315
900	4401.0	0.0455
1000	4890.0	0.0670
1100	5379.0	0.1010
1200	5868.0	0.1550
1300	6357.0	0.2370
1400	6846.0	0.3540
1500	7335.0	0.4960
1600	7824.0	0.6725
1700	8313.0	0.9765
1800	8802.0	1.9995
0	0.0	1.9345

Final Displacement (in.)	1.9995
Rebound (in.)	1.9345

Technician(s)	HZ
Pile Type	W6 x 9 Plain
Pile Name	TF-10
Location	TF
Date	6/11/14
Age	607 days
Installation Date	10/12/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
50	244.50	0.0000
100	489.0	0.0005
150	733.50	0.0020
200	978	0.0030
250	1222.5	0.0040
300	1467	0.0055
350	1711.5	0.0085
400	1956	0.0105
450	2200.5	0.0140
500	2445.0	0.0165
600	2934	0.0245
700	3423.0	0.0335
800	3912	0.0555
900	4401.0	0.1545
1000	4890.0	0.5435
1100	5379	1.0405
0	0.0	0.9980

Final Displacement (in.)	1.0670
Rebound (in.)	1.0245

Technician(s)	AJL
Pile Type	W6 x 9 Regular (Grey) Coat
Pile Name	TF-11
Location	TF
Date	10/10/12
Age	8 days
Installation Date	10/12/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
25	122.3	0.0000
50	244.5	0.0000
75	366.8	0.0005
100	489.0	0.0005
150	733.5	0.0005
200	978.0	0.0015
250	1222.5	0.0025
300	1467.0	0.0075
350	1711.5	0.0115
400	1956.0	0.0185
450	2200.5	0.0265
500	2445.0	0.0405
600	2934.0	0.1425
650	3178.5	0.2180
700	3423.0	0.3170
750	3667.5	1.6190
0	0.0	1.5965

Final Displacement (in.)	1.6190
Rebound (in.)	1.5965

Technician(s)	HZ
Pile Type	W6 x 9 Reg. Grey Coat
Pile Name	TF-11
Location	TF
Date	6/11/14
Age	175 days
Installation Date	10/12/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
20	97.8	0.0000
40	195.6	0.0000
60	293.4	0.0000
80	391.2	0.0005
100	489.0	0.0005
140	684.6	0.0005
180	880.2	0.0005
220	1075.8	0.0015
250	1222.5	0.0015
300	1467.0	0.0025
350	1711.5	0.0025
400	1956.0	0.0035
450	2200.5	0.0050
500	2445.0	0.0215
550	2689.5	0.2650
570	2787.3	2.0070
0	0.0	1.9985

Final Displacement (in.)	2.0070
Rebound (in.)	1.9985

Technician(s)	HZ
Pile Type	W6 x 9 Reg. Grey Coat
Pile Name	TF-11
Location	TF
Date	6/11/14
Age	607 days
Installation Date	10/12/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
25	122.25	0.0000
50	244.5	0.0000
75	366.75	0.0000
100	489	0.0000
125	611.3	0.0000
150	734	0.0000
200	978.0	0.0000
250	1223	0.0000
300	1467.0	0.0000
350	1711.5	0.0025
400	1956	0.0050
450	2200.5	0.0065
500	2445	0.0125
550	2689.5	0.0830
600	2934.0	1.2475
0	0.0	1.2415

Final Displacement (in.)	1.2925
Rebound (in.)	1.2865

Technician(s)	AJL
Pile Type	W6 x 9 Blue Coat
Pile Name	TF-12
Location	TF
Date	10/20/12
Age	8 days
Installation Date	10/12/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
25	122.25	0.0000
50	244.5	0.0000
75	366.75	0.0000
100	489	0.0005
150	733.5	0.0005
200	978	0.0015
250	1222.5	0.0020
300	1467	0.0035
350	1711.5	0.0045
400	1956.0	0.0055
450	2201	0.0070
500	2445.0	0.0085
550	2690	0.0105
600	2934.0	0.0130
650	3178.5	0.0485
700	3423.0	0.5885
750	3668	1.8285
0	0.0	1.8145

Final Displacement (in.)	1.8360
Rebound (in.)	1.8220

Technician(s)	JK
Pile Type	W6 x 9 Blue Coat
Pile Name	TF-12
Location	TF
Date	4/5/13
Age	175 days
Installation Date	10/12/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
20	97.8	0.0000
40	195.6	0.0000
60	293.4	0.0000
80	391.2	0.0000
100	489.0	0.0000
140	684.6	0.0000
180	880.2	0.0000
220	1075.8	0.0015
260	1271.4	0.0035
300	1467.0	0.0045
350	1711.5	0.0070
400	1956.0	0.0115
450	2200.5	0.0155
500	2445.0	0.0485
550	2689.5	1.9080
0	0.0	1.8950

Final Displacement (in.)	1.9080
Rebound (in.)	1.8950

Technician(s)	HZ
Pile Type	W6 x 9 Blue Coat
Pile Name	TF-12
Location	TF
Date	6/11/14
Age	607 days
Installation Date	10/12/12

Digital Reading	Load (lbs)	Displacement (in.)
25	122.25	0.0000
50	244.5	0.0000
75	366.75	0.0000
100	489	0.0005
125	611.3	0.0005
150	734	0.0015
175	855.8	0.0020
200	978	0.0035
225	1100.3	0.0045
250	1222.5	0.0055
275	1345	0.0070
300	1467.0	0.0085
325	1589	0.0105
350	1711.5	0.0130
375	1833.8	0.0485
400	1956.0	0.5885
425	2078	1.8285
0	0.0	1.8145

Final Displacement (in.)	1.8360
Rebound (in.)	1.8220

Technician(s)	JK
Pile Type	W8 x 15 Plain
Pile Name	TF-13
Location	TF
Date	10/24/12
Age	8 days
Installation Date	10/16/12

Digital Reading	Load (lbs)	Displacement (in.)
30	146.70	0.0000
60	293.4	0.0000
100	489.00	0.0000
200	978	0.0000
300	1467.0	0.0015
400	1956	0.0075
475	2322.8	0.0120
575	2812	0.0210
650	3178.5	0.0310
725	3545.3	0.0470
800	3912	0.0705
875	4278.8	0.1060
950	4646	0.1560
1000	4890.0	0.2015
1100	5379.0	0.3070
1200	5868.0	0.4290
1300	6357	0.5525
1400	6846.0	0.6830
1500	7335.0	0.8110
1600	7824	0.9515
1700	8313.0	1.1265
1850	9047	1.4125
2000	9780.0	1.8780
0	0.0	1.8075

Final Displacement (in.)	1.8780
Rebound (in.)	1.8075

Technician(s)	HZ
Pile Type	W8 x 15 Plain
Pile Name	TF-13
Location	TF
Date	4/6/12
Age	172 days
Installation Date	10/16/12

Digital Reading	Load (lbs)	Displacement (in.)
20	97.80	0.0000
40	195.6	0.0000
60	293.40	0.0000
100	489	0.0000
140	684.6	0.0010
180	880	0.0020
220	1075.8	0.0035
260	1271	0.0045
300	1467.0	0.0055
400	1956.0	0.0115
500	2445	0.0175
600	2934.0	0.0235
700	3423	0.0315
800	3912.0	0.0420
900	4401.0	0.0520
1000	4890.0	0.0660
1100	5379	0.0840
1200	5868.0	0.1070
1300	6357.0	0.2230
1400	6846	0.4855
1600	7824.0	1.0100
1800	8802	1.9850
0	0.0	1.8880

Final Displacement (in.)	1.0530
Rebound (in.)	0.9895

Technician(s)	HZ
Pile Type	W8 x 15 Plain
Pile Name	TF-13
Location	TF
Date	6/12/14
Age	604 days
Installation Date	10/16/12

Digital Reading	Load (lbs)	Displacement (in.)
50	244.50	0.0000
100	489.0	0.0000
150	733.50	0.0000
200	978	0.0000
250	1222.5	0.0000
300	1467	0.0000
350	1711.5	0.0010
400	1956	0.0015
450	2200.5	0.0035
500	2445.0	0.0050
600	2934	0.0095
700	3423.0	0.0130
800	3912	0.0175
900	4401.0	0.0215
1000	4890.0	0.0280
1100	5379.0	0.0315
1200	5868	0.0385
1300	6357.0	0.0480
1400	6846.0	0.0700
1500	7335	0.1220
1600	7824.0	0.2200
1700	8313	0.3495
1800	8802.0	0.5625
1900	9291.0	1.0295
0	0.0	0.9660

Final Displacement (in.)	1.0530
Rebound (in.)	0.9895

Technician(s)	HZ
Pile Type	S4 x 7.7
Pile Name	TF-14
Location	TF
Date	11/12/12
Age	7 days
Installation Date	11/5/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
20	97.8	0.0000
40	195.6	0.0005
50	244.5	0.0015
70	342.3	0.0025
90	440.1	0.0035
110	537.9	0.0040
140	684.6	0.0050
180	880.2	0.0070
220	1075.8	0.0090
260	1271.4	0.0125
310	1515.9	0.0200
360	1760.4	0.0310
400	1956.0	0.0450
440	2151.6	0.0685
480	2347.2	0.1025
520	2542.8	0.1615
580	2836.2	0.2845
640	3129.6	0.3690
700	3423.0	0.4460
800	3912.0	0.5575
900	4401.0	0.6615
1100	5379.0	0.8550
1300	6357.0	1.0960
1500	7335.0	1.6835
0	0	1.6115

Final Displacement (in.)	1.2065
Rebound (in.)	1.1665

Technician(s)	HZ
Pile Type	S4 x 7.7
Pile Name	TF-14
Location	TF
Date	4/6/13
Age	152 days
Installation Date	11/5/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
20	97.8	0.0000
40	195.6	0.0010
80	391.2	0.0010
120	586.8	0.0025
160	782.4	0.0040
200	978.0	0.0070
300	1467.0	0.0115
400	1956.0	0.0175
500	2445.0	0.0235
600	2934.0	0.0315
700	3423.0	0.0405
800	3912.0	0.0545
900	4401.0	0.0860
1000	4890.0	0.1740
1100	5379.0	0.4215
1200	5868.0	1.3395
1215	5941.4	2.0145
0	0.0	1.9470

Final Displacement (in.)	2.0145
Rebound (in.)	1.9470

Technician(s)	HZ
Pile Type	S4 x 7.7
Pile Name	TF-14
Location	TF
Date	6/11/14
Age	583 days
Installation Date	11/5/12

Digital Reading	Load (lbs)	Displacement (in.)
50	244.50	0.0000
100	489.0	0.0000
150	733.50	0.0005
200	978	0.0025
250	1222.5	0.0035
300	1467	0.0050
350	1711.5	0.0080
400	1956	0.0100
450	2200.5	0.0140
500	2445.0	0.0155
550	2690	0.0205
600	2934.0	0.0235
650	3179	0.0290
700	3423.0	0.0345
750	3667.5	0.0435
800	3912.0	0.0545
850	4157	0.0775
900	4401.0	0.1300
950	4645.5	0.2990
1000	4890	1.1999
0	0.0	1.1599

Final Displacement (in.)	1.2065
Rebound (in.)	1.1665

Technician(s)	HZ
Pile Type	W6 x 9 Plain
Pile Name	TF-16
Location	TF
Date	4/30/13
Age	0 days (Test No. 1)
Installation Date	4/30/13

Digital Reading	**Load (lbs)**	**Displacement (in.)**
20	97.8	0.0000
60	293.4	0.0000
100	489.0	0.0010
150	734.0	0.0035
200	978.0	0.0075
250	1223.0	0.0125
300	1467.0	0.0180
340	1663.0	0.0260
390	1907.1	0.0355
450	2200.5	0.0525
500	2445	0.0695
600	2934.0	0.1265
700	3423.0	0.2145
800	3912.0	0.3215
900	4401.0	0.4260
1000	4890.0	0.5265
1200	5868.0	0.7500
1400	6846.0	0.9825
1600	7824.0	1.2790
1800	8802.0	1.6580
0	0.0	1.5910

Final Displacement (in.)	1.6580
Rebound (in.)	1.5910

Technician(s)	HZ
Pile Type	W6 x 9 Plain
Pile Name	TF-16
Location	TF
Date	4/30/13
Age	0 days (Test No. 2)
Installation Date	4/30/13

Digital Reading	Load (lbs)	Displacement (in.)
20	97.80	0.0000
60	293.4	0.0000
100	489.00	0.0000
150	734	0.0010
200	978.0	0.0035
300	1467	0.0050
400	1956.0	0.0080
500	2445	0.0115
600	2934.0	0.0160
700	3423.0	0.0210
800	3912	0.0260
1000	4890.0	0.0365
1220	5966	0.0540
1400	6846.0	0.0805
1600	7824.0	0.1645
1800	8802.0	0.3620
2000	9780	1.8740
0	0.0	1.7925

Final Displacement (in.)	1.8740
Rebound (in.)	1.7925

Technician(s)	HZ
Pile Type	W6 x 9 Plain
Pile Name	TF-16
Location	TF
Date	4/30/13
Age	0 days (Test No. 3)
Installation Date	4/30/13

Digital Reading	**Load (lbs)**	**Displacement (in.)**
20	97.8	0.0000
60	293.4	0.0000
100	489.0	0.0000
150	733.5	0.0010
200	978.0	0.0020
300	1467.0	0.0050
420	2053.8	0.0085
600	2934.0	0.0180
800	3912.0	0.0285
1020	4987.8	0.0430
1200	5868.0	0.0605
1400	6846.0	0.1225
1600	7824.0	1.8780
0	0.0	1.8045

Final Displacement (in.)	1.8780
Rebound (in.)	1.8045

Technician(s)	HZ
Pile Type	W6 x 9 Plain
Pile Name	TF-16
Location	TF
Date	4/30/13
Age	0 days (Test No. 4)
Installation Date	4/30/13

Digital Reading	**Load (lbs)**	**Displacement (in.)**
20	97.8	0.0000
60	293.4	0.0000
100	489.0	0.0025
150	733.5	0.0025
200	978.0	0.0045
300	1467.0	0.0085
400	1956.0	0.0130
600	2934.0	0.0255
800	3912.0	0.0410
1000	4890.0	0.0445
1200	5868.0	0.0740
1275	6234.8	1.8990
0	0.0	1.8240

Final Displacement (in.)	1.8990
Rebound (in.)	1.8240

Technician(s)	HZ
Pile Type	W6 x 9 Plain
Pile Name	TF-16
Location	TF
Date	4/30/13
Age	0 days (Test No. 5)
Installation Date	4/30/13

Digital Reading	**Load (lbs)**	**Displacement (in.)**
20	97.8	0.0000
60	293.4	0.0000
100	489.0	0.0000
150	733.5	0.0000
200	978.0	0.0020
300	1467.0	0.0080
400	1956.0	0.0140
600	2934.0	0.0325
800	3912.0	0.0760
1000	4890.0	1.2185
1025	5012.3	1.8960
0	0.0	1.8240

Final Displacement (in.)	1.8960
Rebound (in.)	1.8240

Technician(s)	HZ
Pile Type	W6 x 9 Plain
Pile Name	TF-16
Location	TF
Date	6/9/14
Age	405 days
Installation Date	4/30/13

Digital Reading	**Load (lbs)**	**Displacement (in.)**
50	244.50	0.0005
100	489.0	0.0005
150	733.50	0.0005
200	978	0.0005
250	1222.5	0.0005
300	1467	0.0050
350	1711.5	0.0050
400	1956	0.0085
450	2200.5	0.0085
500	2445.0	0.0125
550	2690	0.0160
600	2934.0	0.0190
650	3179	0.0220
700	3423.0	0.0220
750	3667.5	0.0290
800	3912.0	0.0355
850	4157	0.0525
900	4401.0	0.0780
950	4645.5	0.1190
1000	4890	0.1775
1050	5134.50	0.2540
1100	5379.0	0.3565
1150	5623.50	0.4835
1200	5868	0.6290
1300	6357.0	0.9630
1350	6602	1.2625
0	0.0	1.2105

Final Displacement (in.)	1.2935
Rebound (in.)	1.2415

Technician(s)	HZ
Pile Type	W6 x 9 Plain
Pile Name	TF-17
Location	TF
Date	6/9/14
Age	405 days
Installation Date	4/30/13

Digital Reading	**Load (lbs)**	**Displacement (in.)**
50	244.50	0.0000
100	489.00	0.0000
150	733.50	0.0000
200	978.00	0.0000
300	1467.00	0.0000
400	1956.00	0.0015
500	2445.00	0.0065
600	2934.00	0.0090
700	3423.00	0.0170
800	3912.00	0.0415
900	4401.00	0.0995
1000	4890.00	0.1985
1100	5379.00	0.2895
1200	5868.00	0.3875
1300	6357.00	0.4805
1400	6846.00	0.5895
1500	7335.00	0.6970
1600	7824.0	0.8085
1700	8313.00	0.9440
1800	8802	1.1075
0	0.0	1.0445

Final Displacement (in.)	1.1430
Rebound (in.)	1.0800

Technician(s)	JK
Pile Type	4.5" Sched. 40
Pile Name	TF-18
Location	TF
Date	5/13/13
Age	0 day (Test No. 1)
Installation Date	5/13/13

Digital Reading	**Load (lbs)**	**Displacement (in.)**
20	97.80	0.0000
40	195.60	0.0000
60	293.40	0.0000
80	391.20	0.0000
100	489.00	0.0000
140	684.60	0.0000
180	880.20	0.0015
220	1075.80	0.0030
250	1222.50	0.0045
300	1467.00	0.0045
360	1760.40	0.0075
400	1956.00	0.0120
500	2445.00	0.0230
600	2934.00	0.0385
700	3423.00	0.0590
800	3912.00	0.0910
875	4278.75	1.8875
0	0.0	1.8710

Final Displacement (in.)	1.8875
Rebound (in.)	1.8710

Technician(s)	JK
Pile Type	4.5" Sched. 40
Pile Name	TF-18
Location	TF
Date	5/13/13
Age	0 day (Test No. 2)
Installation Date	5/13/13

Digital Reading	**Load (lbs)**	**Displacement (in.)**
20	97.80	0.0000
40	195.60	0.0015
60	293.40	0.0020
100	489.00	0.0025
140	684.60	0.0010
180	880.20	0.0005
220	1075.80	0.0015
120	586.80	0.0040
300	1467.00	0.0055
350	1711.50	0.0065
400	1956.00	0.0080
450	2200.50	0.0095
500	2445.00	0.0095
600	2934.00	0.0120
710	3471.90	0.0160
810	3960.90	0.0830
865	4229.85	1.9290
0	0.0	1.9120

Final Displacement (in.)	1.9290
Rebound (in.)	1.9120

Technician(s)	JK
Pile Type	4.5" Sched. 40
Pile Name	TF-18
Location	TF
Date	5/13/13
Age	0 day (Test No. 3)
Installation Date	5/13/13

Digital Reading	**Load (lbs)**	**Displacement (in.)**
20	97.80	0.0000
40	195.60	0.0000
60	293.40	0.0000
100	489.00	0.0000
140	684.60	0.0005
180	880.20	0.0010
220	1075.80	0.0015
250	1222.50	0.0020
300	1467.00	0.0030
360	1760.40	0.0035
400	1956.00	0.0045
500	2445.00	0.0075
600	2934.00	0.0100
700	3423.00	0.0135
800	3912.00	0.0590
880	4303.20	1.9640
0	0.0	1.9455

Final Displacement (in.)	1.9640
Rebound (in.)	1.9455

Technician(s)	JK
Pile Type	4.5" Sched. 40
Pile Name	TF-18
Location	TF
Date	5/13/13
Age	0 day (Test No. 4)
Installation Date	5/13/13

Digital Reading	**Load (lbs)**	**Displacement (in.)**
20	97.80	0.0000
40	195.60	0.0000
80	391.20	0.0000
120	586.80	0.0010
140	684.60	0.0010
180	880.20	0.0015
220	1075.80	0.0025
250	1222.50	0.0035
300	1467.00	0.0040
400	1956.00	0.0060
500	2445.00	0.0095
600	2934.00	0.0120
700	3423.00	0.0160
800	3912.00	0.1995
850	4156.50	1.9425
0	0.0	1.9260

Final Displacement (in.)	1.9425
Rebound (in.)	1.9260

Technician(s)	JK
Pile Type	4.5" Sched. 40
Pile Name	TF-18
Location	TF
Date	5/13/13
Age	0 day (Test No. 5)
Installation Date	5/13/13

Digital Reading	**Load (lbs)**	**Displacement (in.)**
20	97.80	0.0000
40	195.60	0.0000
60	293.40	0.0000
80	391.20	0.0000
120	586.80	0.0000
140	684.60	0.0020
180	880.20	0.0030
220	1075.80	0.0040
300	1467.00	0.0065
400	1956.00	0.0090
500	2445.00	0.0125
600	2934.00	0.0155
700	3423.00	0.0200
800	3912.00	0.0969
825	4034.25	1.9440
0	0.0	1.9270

Final Displacement (in.)	1.9440
Rebound (in.)	1.9270

Technician(s)	HZ
Pile Type	4.5" Sched. 40
Pile Name	TF-18
Location	TF
Date	6/9/14
Age	392 days
Installation Date	5/13/13

Digital Reading	**Load (lbs)**	**Displacement (in.)**
50	244.50	0.0015
100	489.00	0.0015
150	733.50	0.0025
200	978.00	0.0030
250	1222.50	0.0040
300	1467.00	0.0040
350	1711.50	0.0050
400	1956.00	0.0065
450	2200.50	0.0065
500	2445.00	0.0075
550	2689.50	0.0090
600	2934.00	0.0100
650	3178.50	0.0110
700	3423.00	0.0110
750	3667.50	0.0130
800	3912.00	0.0150
850	4156.50	0.0795
900	4401.00	0.5125
1000	4890.00	1.5760
0	0.0	1.5675

Final Displacement (in.)	1.6200
Rebound (in.)	1.6115

8.3 HADLEY HORSE FARM (HHF)

8.3.1 INSTALLATION LOGS

Technicians	AJL, NW
Pile Type	2.875" Open
Pile Name	HHF-3
Pile I.D. (in)	2.469
Pile O.D. (in)	2.875
Hammer Weight (lbs)	550
Drop Height (in)	48
Rig Type	Tractor
Location	HHF
Date	10/24/12

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)	Distance to Plug (in.)	Plug (in)
1	17.75	17.75	78.25	92.125	15.875
2	10	27.75	68.25	85	23
3	5.25	33	63		
4	3.5	36.5	59.5	80.75	27.25
5	3.25	39.75	56.25		
6	2.75	42.5	53.5	79	29
7	2.5	45	51		
8	2.5	47.5	48.5		
9	2	49.5	46.5	76.125	31.875
10	2	51.5	44.5		
11	**2**	53.42	42.58		
12	**2**	55.5	40.5	73.5	34.5
13	2	57.5	38.5		
14	2	59.5	36.5		
15	1.75	61.25	34.75	71.125	36.875
16	1.875	63.125	32.875		
17	1.375	64.5	31.5		
18	1.75	66.25	29.75	69	39
19	1.5	67.75	28.25		
20	1.5	69.25	26.75		
21	1.75	71	25	66.6125	41.3875
22	1.5	72.5	23.5		
23	1.5	74	22		
24	1.5	75.5	20.5	64.5	43.5
25	1.375	76.875	19.125		
26	1.5	78.375	17.625		

27	1.25	79.625	16.375	63	45
28	1.375	81	15		
29	1.375	82.375	13.625		
30	1.375	83.75	12.25	61.125	46.875
31	1.25	85	11		
32	1.5	86.5	9.5		
33	1.25	87.75	8.25	59.5	48.5
34	1.625	89.375	6.625		
35	1.125	90.5	5.5		
36	1.25	91.75	4.25	58.125	49.875
37	1.25	93	3		
38	1.5	94.5	1.5		
39	1.5	96	0	56.75	51.25

Technicians	AJL, NW
Pile Type	2.875" Open
Pile Name	HHF-4
Pile I.D. (in)	2.469
Pile O.D. (in)	2.875
Hammer Weight (lbs)	550
Drop Height (in)	48
Rig Type	Tractor
Location	HHF
Date	10/24/12

Cumulative Blow Count	**Penetration per Blow (in)**	**Cumulative Penetration (in)**	**Pile Penetration (in)**	**Distance to Plug (in.)**	**Plug (in)**
1	20.5	20.5	99.5	115	17
2	7	27.5	92.5	110.125	21.875
3	5.875	33.375	86.625		
4	4.25	37.625	82.375	106	26
5	3.375	41	79		
6	3	44	76		
7	2.875	46.875	73.125	102.625	29.375
8	3.125	50	70		
9	2.875	52.875	67.125		
10	2.875	55.75	64.25	99.5	32.5
11	2.5	58.25	61.75		
12	2.25	60.5	59.5		
13	2.25	62.75	57.25	96.25	35.75
14	2.25	65	55		
15	2.25	67.25	52.75		
16	2	69.25	50.75	93.5	38.5
17	1.75	71	49		
18	2.125	73.125	46.875		
19	1.625	74.75	45.25	90.5	41.5
20	1.75	76.5	43.5		
21	1.875	78.375	41.625		
22	1.875	80.25	39.75	88	44
23	1.625	81.875	38.125		
24	1.625	83.5	36.5		
25	1.75	85.25	34.75	85.75	46.25
26	1.5	86.75	33.25		
27	1.625	88.375	31.625		
28	1.625	90	30	84.125	47.875

29	1.25	91.25	28.75		
30	2	93.25	26.75		
31	1.375	94.625	25.375	82.75	49.25
32	1.625	96.25	23.75		
33	1.375	97.625	22.375		
34	1.625	99.25	20.75	81	51
35	1.375	100.625	19.375		
36	1.625	102.25	17.75		
37	1.375	103.625	16.375	79.75	52.25
38	1.375	105	15		
39	1.375	106.375	13.625		
40	1.625	108	12	78.5	53.5
41	1.25	109.25	10.75		
42	1.25	110.5	9.5		
43	1.5	112	8	77.58	54.42
44	1.5	113.5	6.5		
45	1.25	114.75	5.25		
46	1.5	116.25	3.75	76.125	55.875
47	1.5	117.75	2.25		
48	1.25	119	1		
49	1	120	0	74.125	57.875

Technicians	AJL and NW
Pile Type	2.875" Closed
Pile Name	HHF-5
Hammer Weight (lbs)	550
Drop Height (in)	48
Rig Type	Tractor
Location	HHF
Date	10/24/12

Cumulative Blow Count	**Penetration per Blow (in)**	**Cumulative Penetration (in)**	**Pile Penetration (in)**
1	16	16	104
2	6.25	22.25	97.75
3	5.625	27.875	92.125
4	3.625	31.5	88.5
5	2.375	33.875	86.125
6	3.375	37.25	82.75
7	2.125	39.375	80.625
8	2.875	42.25	77.75
9	2.25	44.5	75.5
10	2.375	46.875	73.125
11	2.25	49.125	70.875
12	2.25	51.375	68.625
13	2.125	53.5	66.5
14	1.875	55.375	64.625
15	2.25	57.625	62.375
16	1.875	59.5	60.5
17	1.5	61	59
18	2.375	63.375	56.625
19	1.625	65	55
20	2	67	53
21	1.875	68.875	51.125
22	1.875	70.75	49.25
23	2	72.75	47.25
24	1.625	74.375	45.625
25	1.75	76.125	43.875
26	1.75	77.875	42.125
27	1.75	79.625	40.375
28	1.625	81.25	38.75
29	1.75	83	37
30	1.625	84.625	35.375
31	1.375	86	34
32	1.875	87.875	32.125
33	1.5	89.375	30.625

34	1.625	91	29
35	1	92	28
36	1.75	93.75	26.25
37	2	95.75	24.25
38	1.75	97.5	22.5
39	1.5	99	21
40	1.875	100.875	19.125
41	1	101.875	18.125
42	1.875	103.75	16.25
43	1.75	105.5	14.5
44	1.375	106.875	13.125
45	1.625	108.5	11.5
46	1.875	110.375	9.625
47	1.25	111.625	8.375
48	1.625	113.25	6.75
49	1.75	115	5
50	1.5	116.5	3.5
51	1.5	118	2
52	1.5	119.5	0.5
53	0.5	120	0

Technicians	AJL and NW
Pile Type	2.875" Open
Pile Name	HHF-6
Pile I.D. (in)	2.635
Pile O.D. (in)	2.875
Hammer Weight (lbs)	550
Drop Height (in)	44
Rig Type	Tractor
Location	HHF
Date	11/2/12

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)	Distance to Plug (in.)	Plug (in)
1	22	22	74	89.375	18.625
2	5	27	69		
3	3.25	30.25	65.75	86.58	21.42
4	2.875	33.125	62.875		
5	2.625	35.75	60.25		
6	2.5	38.25	57.75	84	24
7	2.25	40.5	55.5		
8	2.25	42.75	53.25		
9	2.25	45	51	81.75	26.25
10	2	47	49		
11	2	49	47		
12	2.25	51.25	44.75	80	28
13	2.25	53.5	42.5		
14	2	55.5	40.5		
15	2	57.5	38.5	78	30
16	1.75	59.25	36.75		
17	1.875	61.125	34.875		
18	1.875	63	33	76.25	31.75
19	1.75	64.75	31.25		
20	1.75	66.5	29.5		
21	1.75	68.25	27.75	74.5	33.5
22	1.75	70	26		
23	2	72	24		
24	1.5	73.5	22.5	72.5	35.5
25	1.625	75.125	20.875		
26	1.375	76.5	19.5		
27	1.75	78.25	17.75	70.5	37.5
28	1.75	80	16		
29	1.5	81.5	14.5		
30	1.25	82.75	13.25	69.125	38.875
31	1.5	84.25	11.75		

32	1.25	85.5	10.5		
33	2	87.5	8.5	67.5	40.5
34	1	88.5	7.5		
35	1.5	90	6		
36	1	91	5	66.25	41.75
37	1.5	92.5	3.5		
38	1.5	94	2		
39	1.25	95.25	0.75		
40	0.75	96	0	64.5	43.5

Technicians	AJL, NW
Pile Type	2.875" Open
Pile Name	HHF-7
Pile I.D. (in)	2.635
Pile O.D. (in)	2.875
Hammer Weight (lbs)	550
Drop Height (in)	44
Rig Type	Tractor
Location	HHF
Date	11/2/12

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)	Distance to Plug (in.)	Plug (in)
1	14.75	14.75	81.25	93.5	14.5
2	5.75	20.5	75.5	88.5	19.5
3	3	23.5	72.5		
4	2.5	26	70	83	25
5	2	28	68		
6	1.75	29.75	66.25		
7	1.25	31	65	80	28
8	1.25	32.25	63.75		
9	1.375	33.625	62.375	76.875	31.125
10	1.125	34.75	61.25		
11	1.25	36	60		
12	1.375	37.375	58.625	74	34
13	0.875	38.25	57.75		
14	1	39.25	56.75		
15	1	40.25	55.75	71.75	36.25
16	1	41.25	54.75		
17	0.875	42.125	53.875		
18	1	43.125	52.875	69	39
19	0.875	44	52		
20	0.9875	44.9875	51.0125		
21	0.7625	45.75	50.25	67	41
22	0.75	46.5	49.5		
23	0.75	47.25	48.75	66.5	41.5
24	0.75	48	48		
25	1	49	47		
26	0.5	49.5	46.5	64.25	43.75
27	1	50.5	45.5		
28	0.75	51.25	44.75		
29	0.75	52	44	62.75	45.25
30	0.75	52.75	43.25		
31	0.75	53.5	42.5		

32	0.75	54.25	41.75	61.25	46.75
33	0.75	55	41		
34	0.5	55.5	40.5		
35	0.75	56.25	39.75	59.5	48.5
36	1	57.25	38.75		
37	0.25	57.5	38.5		
38	1	58.5	37.5	58.125	49.875
39	0.75	59.25	36.75		
40	0.75	60	36		
41	0.625	60.625	35.375	56.5	51.5
42	0.625	61.25	34.75		
43	0.75	62	34		
44	0.5	62.5	33.5	55.375	52.625
45	1	63.5	32.5		
46	0.5	64	32		
47	0.5	64.5	31.5	53.75	54.25
48	0.75	65.25	30.75		
49	0.75	66	30		
50	0.75	66.75	29.25	52.5	55.5
51	0.5	67.25	28.75		
52	0.75	68	28		
53	0.5	68.5	27.5	51	57
54	0.75	69.25	26.75		
55	0.625	69.875	26.125		
56	0.625	70.5	25.5	49.75	58.25
57	0.5	71	25		
58	0.5	71.5	24.5		
59	1	72.5	23.5	48	60
60	0.5	73	23		
61	0.5	73.5	22.5		
62	0.75	74.25	21.75	47	61
63	0.625	74.875	21.125		
64	0.625	75.5	20.5		
65	0.5	76	20	45.5	62.5
66	0.75	76.75	19.25		
67	0.5	77.25	18.75		
68	0.75	78	18	44.5	63.5
69	0.375	78.375	17.625		
70	0.625	79	17		
71	0.75	79.75	16.25	43	65
72	0.5	80.25	15.75		
73	0.75	81	15		
74	0.5	81.5	14.5	41.75	66.25
75	0.5	82	14		
76	0.5	82.5	13.5		

77	0.875	83.375	12.625	40.5	67.5
78	0.625	84	12		
79	0.5	84.5	11.5		
80	0.625	85.125	10.875	39.75	68.25
81	0.75	85.875	10.125		
82	0.5	86.375	9.625		
83	0.625	87	9	38.5	69.5
84	0.5	87.5	8.5		
85	0.5	88	8		
86	0.75	88.75	7.25	37	71
87	0.5	89.25	6.75		
88	0.75	90	6		
89	0.5	90.5	5.5	36.25	71.75
90	0.75	91.25	4.75		
91	0.5	91.75	4.25		
92	0.75	92.5	3.5	35	73
93	0.375	92.875	3.125		
94	0.5	93.375	2.625		
95	0.75	94.125	1.875	34	74
96	0.625	94.75	1.25		
97	0.375	95.125	0.875		
98	0.625	95.75	0.25	32.75	75.25
99	0.25	96	0	32.5	75.5

Technicians	JK, NW
Pile Type	S4 x 7.7 Plain
Pile Name	HHF-8
Hammer Weight (lbs)	550
Drop Height (in)	44
Rig Type	Tractor
Location	HHF
Date	11/2/12

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)
1	19.75	19.75	76.25
2	5.75	25.5	70.5
3	3.5	29	67
4	2.75	31.75	64.25
5	2.375	34.125	61.875
6	2	36	60
7	2	38	58
8	1.875	39.875	56.125
9	2	41.875	54.125
10	1.875	43.75	52.25
11	1.5	45.25	50.75
12	1.75	47	49
13	1.5	48.5	47.5
14	1.5	50	46
15	1.5	51.5	44.5
16	1.75	53.25	42.75
17	1.5	54.75	41.25
18	1.375	56.125	39.875
19	1.625	57.75	38.25
20	1.25	59	37
21	1.5	60.5	35.5
22	1.25	61.75	34.25
23	1.25	63	33
24	1.25	64.25	31.75
25	1.375	65.625	30.375
26	1.5	67.125	28.875
27	1.125	68.25	27.75
28	1.5	69.75	26.25
29	1.25	71	25
30	1.25	72.25	23.75
31	1.25	73.5	22.5
32	1.25	74.75	21.25
33	1.25	76	20

34	1.125	77.125	18.875
35	1.125	78.25	17.75
36	1	79.25	16.75
37	1.25	80.5	15.5
38	1	81.5	14.5
39	1.125	82.625	13.375
40	1	83.625	12.375
41	1.125	84.75	11.25
42	1.125	85.875	10.125
43	1	86.875	9.125
44	1	87.875	8.125
45	1	88.875	7.125
46	1	89.875	6.125
47	1	90.875	5.125
48	1.125	92	4
49	1.125	93.125	2.875
50	1	94.125	1.875
51	0.75	94.875	1.125
52	1	95.875	0.125

Technicians	TO, JK, NW
Pile Type	4.5" Plain Open
Pile Name	HHF-9
Pile I.D. (in)	4.5
Pile O.D. (in)	4.026
Hammer Weight (lbs)	550
Drop Height (in)	60
Rig Type	Tractor
Location	HHF
Date	7/11/12

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)	Distance to Plug (in.)	Plug (in)
1	8	8	112	125.5	6.5
2	3	11	109	123.5	8.5
3	2.5	13.5	106.5	123	9
4	2	15.5	104.5		
5	2.5	18	102		
6	2.25	20.25	99.75	120	12
7	2.75	23	97		
8	2.25	25.25	94.75		
9	2.25	27.5	92.5	117.5	14.5
10	2	29.5	90.5		
11	1.75	31.25	88.75		
12	1.75	33	87		
13	1.5	34.5	85.5		
14	1.75	36.25	83.75	113.5	18.5
15	1.25	37.5	82.5		
16	1	38.5	81.5		
17	1.25	39.75	80.25		
18	1.25	41	79		
19	2	43	77	111	21
20	0.5	43.5	76.5		
21	1.5	45	75		
22	1	46	74		
23	1.5	47.5	72.5	108	24
24	0.75	48.25	71.75		
25	1.25	49.5	70.5		
26	1	50.5	69.5		
27	1	51.5	68.5		
28	1	52.5	67.5		
29	1	53.5	66.5	105.5	26.5
30	1.5	55	65		
31	0.5	55.5	64.5		

32	1.25	56.75	63.25		
33	0.67	57.42	62.58		
34	1.33	58.75	61.25		
35	1.25	60	60	102.5	29.5
36	0.75	60.75	59.25		
37	1.25	62	58		
38	1.25	63.25	56.75		
39	0.75	64	56		
40	1.25	65.25	54.75		
41	0.75	66	54	100.5	31.5
42	1.25	67.25	52.75		
43	0.75	68	52		
44	1	69	51		
45	1	70	50		
46	1	71	49		
47	1	72	48	96.5	35.5
48	0.5	72.5	47.5		
49	1.25	73.75	46.25		
50	0.75	74.5	45.5		
51	1	75.5	44.5		
52	1	76.5	43.5		
53	0.75	77.25	42.75	94	38
54	0.75	78	42		
55	1	79	41		
56	0.5	79.5	40.5		
57	0.75	80.25	39.75		
58	1	81.25	38.75		
59	0.75	82	38		
60	0.5	82.5	37.5		
61	0.75	83.25	36.75	91	41
62	1	84.25	35.75		
63	0.75	85	35		
64	0.75	85.75	34.25		
65	0.75	86.5	33.5		
66	0.5	87	33		
67	1	88	32		
68	0.75	88.75	31.25		
69	0.75	89.5	30.5	88	44
70	0.75	90.25	29.75		
71	0.75	91	29		
72	1	92	28		
73	0.5	92.5	27.5		
74	0.75	93.25	26.75		
75	0.75	94	26		
76	0.75	94.75	25.25		

77	0.75	95.5	24.5	85.75	46.25
78	0.75	96.25	23.75		
79	0.75	97	23		
80	0.5	97.5	22.5		
81	1	98.5	21.5		
82	0.5	99	21		
83	0.75	99.75	20.25		
84	0.75	100.5	19.5		
85	0.75	101.25	18.75		
86	1	102.25	17.75	83.5	48.5
87	0.75	103	17		
88	0.5	103.5	16.5		
89	1	104.5	15.5		
90	0.5	105	15		
91	0.5	105.5	14.5		
92	0.75	106.25	13.75		
93	0.75	107	13		
94	0.5	107.5	12.5	81.25	50.75
95	0.75	108.25	11.75		
96	1	109.25	10.75		
97	0.75	110	10		
98	0.5	110.5	9.5		
99	1.75	112.25	7.75		
100	0.5	112.75	7.25		
101	0.75	113.5	6.5		
102	0.75	114.25	5.75		
103	0.75	115	5	79	53
104	0.5	115.5	4.5		
105	0.75	116.25	3.75		
106	0.75	117	3		
107	0.5	117.5	2.5		
108	0.5	118	2		
109	0.5	118.5	1.5		
110	0.5	119	1		
111	0.5	119.5	0.5		
112	0.75	120.25	-0.25		
113	0.75	121	-1	77	55

Technicians	AJL, NW
Pile Type	6.625" Sched. 40 Open
Pile Name	HHF-10
Pile I.D. (in)	6.625
Pile O.D. (in)	6.065
Hammer Weight (lbs)	550
Drop Height (in)	48
Rig Type	Tractor
Location	HHF
Date	7/11/12

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)	Distance to Plug (in.)	Plug (in)
1	7.5	7.5	88.5	100.5	7.5
2	5	12.5	83.5	96	12
3	2.5	15	81		
4	2	17	79		
5	2	19	77	90.25	17.75
6	2.75	21.75	74.25		
7	1.75	23.5	72.5	86	22
8	2	25.5	70.5		
9	2	27.5	68.5		
10	1.5	29	67		
11	1.25	30.25	65.75	79.75	28.25
12	1.75	32	64		
13	1	33	63		
14	1	34	62		
15	0.5	34.5	61.5		
16	1	35.5	60.5	75	33
17	1	36.5	59.5		
18	1	37.5	58.5		
19	1	38.5	57.5		
20	1	39.5	56.5		
21	0.75	40.25	55.75		
22	1	41.25	54.75		
23	0.75	42	54	70	38
24	1.25	43.25	52.75		
25	0.75	44	52		
26	0.5	44.5	51.5		
27	1.25	45.75	50.25		
28	1	46.75	49.25		
29	1	47.75	48.25	66	42
30	0.25	48	48		
31	1	49	47		

32	0.75	49.75	46.25		
33	0.75	50.5	45.5		
34	0.75	51.25	44.75		
35	0.75	52	44		
36	0.75	52.75	43.25		
37	0.75	53.5	42.5		
38	0.75	54.25	41.75	60.5	47.5
39	0.25	54.5	41.5		
40	1	55.5	40.5		
41	0.5	56	40		
42	0.75	56.75	39.25		
43	0.75	57.5	38.5		
44	0.5	58	38		
45	0.75	58.75	37.25		
46	0.75	59.5	36.5		
47	0.75	60.25	35.75	55.5	52.5
48	0.25	60.5	35.5		
49	0.5	61	35		
50	0.75	61.75	34.25		
51	0.75	62.5	33.5		
52	0.5	63	33		
53	0.5	63.5	32.5		
54	0.75	64.25	31.75		
55	0.5	64.75	31.25		
56	0.75	65.5	30.5		
57	0.5	66	30	51	57
58	0.5	66.5	29.5		
59	0.75	67.25	28.75		
60	0.5	67.75	28.25		
61	0.5	68.25	27.75		
62	0.75	69	27		
63	0.5	69.5	26.5		
64	0.5	70	26		
65	0.5	70.5	25.5		
66	0.5	71	25		
67	0.5	71.5	24.5		
68	0.75	72.25	23.75	46	62
69	0.75	73	23		
70	0.5	73.5	22.5		
71	0.5	74	22		
72	0.5	74.5	21.5		
73	0.5	75	21		
74	0.5	75.5	20.5		
75	0.75	76.25	19.75		
76	0.25	76.5	19.5		

77	0.75	77.25	18.75		
78	0.75	78	18	42	66
79	0.25	78.25	17.75		
80	0.25	78.5	17.5		
81	0.75	79.25	16.75		
82	0.5	79.75	16.25		
83	0.25	80	16		
84	0.5	80.5	15.5		
85	0.5	81	15		
86	0.5	81.5	14.5		
87	0.5	82	14		
88	0.5	82.5	13.5		
89	0.5	83	13		
90	0.25	83.25	12.75		
91	0.5	83.75	12.25	38.25	69.75
92	0.5	84.25	11.75		
93	0.5	84.75	11.25		
94	0.5	85.25	10.75		
95	0.5	85.75	10.25		
96	0.5	86.25	9.75		
97	0.25	86.5	9.5		
98	0.5	87	9		
99	0.5	87.5	8.5		
100	0.5	88	8		
101	0.5	88.5	7.5		
102	0.5	89	7		
103	0.25	89.25	6.75		
104	0.75	90	6		
105	0.5	90.5	5.5		
106	0.5	91	5	34.5	73.5
107	0.5	91.5	4.5		
108	0.5	92	4		
109	0.5	92.5	3.5		
110	0.5	93	3		
111	0.5	93.5	2.5		
112	0.5	94	2		
113	0.25	94.25	1.75		
114	0.5	94.75	1.25		
115	0.5	95.25	0.75		
116	0.75	96	0	31	77

Technicians	TO, JK
Pile Type	W8 x 13 Plain
Pile Name	HHF-11
Hammer Weight (lbs)	550
Drop Height (in)	48
Rig Type	Tractor
Location	HHF
Date	7/11/12

Cumulative Blow Count	**Penetration per Blow (in)**	**Cumulative Penetration (in)**	**Pile Penetration (in)**
1	9	9	87
2	4.5	13.5	82.5
3	3.75	17.25	78.75
4	4.25	21.5	74.5
5	2	23.5	72.5
6	2	25.5	70.5
7	2	27.5	68.5
8	2	29.5	66.5
9	1.25	30.75	65.25
10	1.5	32.25	63.75
11	1.25	33.5	62.5
12	1.25	34.75	61.25
13	1.25	36	60
14	1.25	37.25	58.75
15	1.25	38.5	57.5
16	1	39.5	56.5
17	1.25	40.75	55.25
18	1.25	42	54
19	1	43	53
20	1	44	52
21	1.25	45.25	50.75
22	1.25	46.5	49.5
23	1	47.5	48.5
24	1	48.5	47.5
25	1	49.5	46.5
26	0.75	50.25	45.75
27	1	51.25	44.75
28	1	52.25	43.75
29	0.75	53	43
30	1	54	42
31	1	55	41
32	1	56	40
33	1	57	39

34	0.5	57.5	38.5
35	1	58.5	37.5
36	0.75	59.25	36.75
37	0.75	60	36
38	1	61	35
39	0.75	61.75	34.25
40	0.75	62.5	33.5
41	1	63.5	32.5
42	0.75	64.25	31.75
43	0.75	65	31
44	1	66	30
45	0.75	66.75	29.25
46	0.75	67.5	28.5
47	0.75	68.25	27.75
48	0.75	69	27
49	1	70	26
50	0.75	70.75	25.25
51	0.75	71.5	24.5
52	1	72.5	23.5
53	0.5	73	23
54	1	74	22
55	0.75	74.75	21.25
56	0.75	75.5	20.5
57	0.5	76	20
58	1	77	19
59	0.5	77.5	18.5
60	1	78.5	17.5
61	0.5	79	17
62	1	80	16
63	0.5	80.5	15.5
64	0.75	81.25	14.75
65	0.75	82	14
66	0.75	82.75	13.25
67	0.75	83.5	12.5
68	0.75	84.25	11.75
69	0.75	85	11
70	0.75	85.75	10.25
71	0.75	86.5	9.5
72	0.5	87	9
73	0.75	87.75	8.25
74	0.75	88.5	7.5
75	0.75	89.25	6.75
76	0.75	90	6
77	0.5	90.5	5.5
78	1	91.5	4.5

79	0.5	92	4
80	1	93	3
81	0.5	93.5	2.5
82	0.5	94	2
83	1	95	1
84	0.5	95.5	0.5
85	0.5	96	0

Technicians	TO, JK
Pile Type	W6 x 9 Plain
Pile Name	HHF-18
Hammer Weight (lbs)	550
Drop Height (in)	48
Rig Type	Tractor
Location	HHF
Date	7/11/12

Cumulative Blow Count	Penetration per Blow (in)	Cumulative Penetration (in)	Pile Penetration (in)
1	10.5	10.5	85.5
2	5.25	15.75	80.25
3	3.25	19	77
4	3	22	74
5	3.75	25.75	70.25
6	3	28.5	67.5
7	3	31.5	64.5
8	2	33.5	62.5
9	2	35.5	60.5
10	1.75	37.25	58.75
11	1.75	39	57
12	1.5	40.5	55.5
13	1.5	42	54
14	1.75	43.75	52.25
15	1	44.75	51.25
16	1.25	46	50
17	1	47	49
18	1.5	48.5	47.5
19	1	49.5	46.5
20	1.25	50.75	45.25
21	1.25	52	44
22	1	53	43
23	1	54	42
24	1.25	55.25	40.75
25	1	56.25	39.75
26	1.25	57.5	38.5
27	1	58.5	37.5
28	0.75	59.25	36.75
29	1.25	60.5	35.5
30	1	61.5	34.5
31	1	62.5	33.5
32	1.25	63.75	32.25
33	1	64.75	31.25

34	1	65.75	30.25
35	0.75	66.5	29.5
36	1.25	67.75	28.25
37	1	68.75	27.25
38	1	69.75	26.25
39	0.75	70.5	25.5
40	1	71.5	24.5
41	1.25	72.75	23.25
42	0.75	73.5	22.5
43	0.75	74.25	21.75
44	1	75.25	20.75
45	1	76.25	19.75
46	0.75	77	19
47	1	78	18
48	0.75	78.75	17.25
49	0.75	79.5	16.5
50	1	80.5	15.5
51	0.75	81.25	14.75
52	1	82.25	13.75
53	0.75	83	13
54	1	84	12
55	0.75	84.75	11.25
56	0.75	85.5	10.5
57	0.75	86.25	9.75
58	1	87.25	8.75
59	0.75	88	8
60	0.75	88.75	7.25
61	0.75	89.5	6.5
62	1	90.5	5.5
63	0.75	91.25	4.75
64	0.75	92	4
65	1	93	3
66	0.75	93.75	2.25
67	0.75	94.5	1.5
68	0.75	95.25	0.75
69	0.75	96	0

8.3.2 LOAD TEST SCHEDULE

Pile	**Pile Length (ft)**	**Pile No.**	**Installation Date**	**Test Date (Days)**							
				0	**1**	**7**	**10**	**30**	**100**	**300**	**600**
2.875" Plain	**8**	**H-3**	10/24/12			11/1/12 (8)				8/20/13	
2.875" Plain	**10**	**H-4**	10/24/12			11/1/12 (8)				8/20/13	
2.875" Closed End	**10**	**H-5**	10/24/12			11/1/12 (8)				8/20/13	
2.875" Sched. 10	**8**	**H-6**	11/2/12			11/9/12				8/29/13	
6.625" Sched. 10	**8**	**H-7**	11/2/12			11/9/12			3/30/13 (148)	8/29/13	
S4 x 7.7	**8**	**H-8**	11/2/12			11/9/12			3/30/13 (148)	8/29/13	
4.5" Plain	**10**	**H-9**	7/11/12			7/18/12		8/12/2012 (32)	10/28/12 (109)	5/7/13	
6.625" Plain	**8**	**H-10**	7/11/12			7/18/12		8/12/2012 (32)	11/3/12 (115)	5/7/13	
W8 x 11 Plain	**8**	**H-11**	7/11/12			7/18/12			11/13/12 (115)	5/7/13	6/18/14
2-Fin (Long) 4.5" Plain	**10**	**H-12**	7/19/12			7/26/12			11/2/12 (106)	5/15/13	
3-Fin (Long) 4.5" Plain	**10**	**H-13**	7/20/12			7/26/12			11/2/12 (106)	5/15/13	
4-Fin (Long) 4.5" Plain	**10**	**H-14**	7/21/12			7/26/12			10/28/12 (101)	5/15/13	
4-Fin (Long) 4.5" Plain	**10**	**H-15**	7/22/12			7/26/12			10/28/12 (101)	5/15/13	
6-Fin (Long) 4.5" Plain	**10**	**H-16**	7/23/12			7/26/12			11/3/12 (107)	5/15/13	
4-Fin (Long) 4.5" Plain	**10**	**H-17**	7/24/12			7/26/12			11/3/2012 (107)	5/15/13	

W6 x 9 Plain (Ripped)	**8**	**H-18**	7/11/12			7/18/12					
4.5" Sched. 10	**8**	**H-19**	7/11/12			7/18/12					

8.3.3 LOAD TEST RESULTS

Technician(s)	JK
Pile Type	2.875" Plain Sched. 40
Pile Name	HHF-3
Location	HHF
Date	11/1/12
Age (days)	8
Installation Date	10/24/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
20	97.80	0.0000
40	195.6	0.0005
80	391.2	0.0015
100	489	0.0020
150	733.5	0.0040
200	978	0.0055
250	1222.5	0.0070
300	1467	0.0080
375	1833.8	0.0100
450	2201	0.0120
525	2567.3	0.0165
600	2934	0.0240
675	3300.8	0.0330
750	3668	0.0455
800	3912	0.0580
900	4401	1.9930
0	0	1.9780

Final Displacement (in.)	1.9930
Rebound (in.)	1.9780

Technician(s)	JK
Pile Type	2.875" Plain Sched. 40
Pile Name	HHF-4
Location	HHF
Date	11/1/12
Age (days)	8
Installation Date	10/24/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
20	97.80	0.0000
60	293.4	0.0005
75	366.75	0.0005
100	489	0.0010
150	733.5	0.0015
200	978	0.0020
250	1222.5	0.0035
300	1467	0.0040
400	1956.0	0.0060
475	2323	0.0075
550	2689.5	0.0110
625	3056	0.0150
700	3423.0	0.0205
775	3790	0.0275
850	4156.5	0.0370
925	4523	0.0540
980	4792	2.0135
0	0	1.9965

Final Displacement (in.)	2.0135
Rebound (in.)	1.9965

Technician(s)	JK
Pile Type	2.875" Closed-End Plain Sched. 40
Pile Name	HHF-5
Location	HHF
Date	11/1/12
Age (days)	8
Installation Date	10/24/12

Digital Reading	Load (lbs)	Displacement (in.)
20	97.80	0.0000
40	195.6	0.0000
60	293.40	0.0000
100	489	0.0010
150	733.5	0.0015
200	978	0.0025
250	1222.5	0.0025
325	1589	0.0035
400	1956.0	0.0045
475	2323	0.0055
550	2689.5	0.0070
625	3056	0.0085
700	3423.0	0.0110
800	3912	0.0155
900	4401.0	0.0220
1000	4890	0.0320
1090	5330	2.0410
0	0	2.0310

Final Displacement (in.)	2.0410
Rebound (in.)	2.0310

Technician(s)	JK
Pile Type	2.875" Plain Sched. 10
Pile Name	HHF-6
Location	HHF
Date	11/9/12
Age (days)	7
Installation Date	11/2/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
30	146.70	0.0000
60	293.4	0.0010
100	489.00	0.0020
150	734	0.0020
200	978.0	0.0035
260	1271	0.0050
340	1662.6	0.0070
400	1956	0.0090
460	2249.4	0.0110
540	2641	0.0140
600	2934.0	0.0175
660	3227	0.0210
740	3618.6	0.0275
800	3912	0.0350
840	4107.6	0.0410
860	4205	1.8100
0	0	1.8050

Final Displacement (in.)	1.8100
Rebound (in.)	1.8050

Technician(s)	JK
Pile Type	6.625" Plain Sched. 10
Pile Name	HH-7
Location	HHF
Date	11/9/12
Age (days)	7 days
Installation Date	11/2/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
20	97.80	0.0000
40	195.6	0.0000
60	293.40	0.0000
100	489	0.0000
150	733.5	0.0005
200	978	0.0010
300	1467.0	0.0020
400	1956	0.0025
500	2445.0	0.0030
600	2934	0.0045
700	3423.0	0.0055
800	3912	0.0060
1000	4890.0	0.0095
1200	5868	0.0140
1400	6846.0	0.3265
1500	7335	0.9590
1600	7824	2.0650
0	0	2.0505

Final Displacement (in.)	2.0650
Rebound (in.)	2.0505

Technician(s)	JK
Pile Type	6.625" Plain Sched. 10
Pile Name	HH-7
Location	HHF
Date	3/30/13
Age (days)	148 days
Installation Date	11/2/12

Digital Reading	Load (lbs)	Displacement (in.)
20	97.80	0.0000
40	195.6	0.0005
80	391.20	0.0010
120	587	0.0010
200	978.0	0.0020
300	1467	0.0070
400	1956.0	0.0120
500	2445	0.0195
600	2934.0	0.0235
800	3912	0.0355
1000	4890.0	0.0635
1100	5379	0.0890
1200	5868.0	0.1110
1300	6357	0.1470
1400	6846.0	0.3705
1500	7335	1.8760
0	0	1.7455

Final Displacement (in.)	1.8760
Rebound (in.)	1.7455

Technician(s)	HZ
Pile Type	S4 x 7.7
Pile Name	HHF-8
Location	HHF
Date	11/9/12
Age (days)	7 days
Installation Date	11/2/12

Digital Reading	Load (lbs)	Displacement (in.)
40	195.60	0.0000
80	391.2	0.0005
140	684.60	0.0015
200	978	0.0025
290	1418.1	0.0035
400	1956	0.0060
500	2445.0	0.0100
580	2836	0.0150
660	3227.4	0.0220
760	3716	0.0345
840	4107.6	0.0485
900	4401	0.0645
1000	4890.0	0.1535
1100	5379	0.4495
1200	5868.0	0.9755
1300	6357	1.9330
0	0	1.8905

Final Displacement (in.)	1.9330
Rebound (in.)	1.8905

Technician(s)	HZ
Pile Type	S4 x 7.7
Pile Name	HHF-8
Location	HHF
Date	3/30/13
Age (days)	148 days
Installation Date	11/2/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
40	195.60	0.0000
80	391.2	0.0010
120	586.80	0.0020
160	782	0.0020
200	978.0	0.0025
250	1223	0.0030
300	1467.0	0.0040
400	1956	0.0070
500	2445.0	0.0080
600	2934	0.0095
700	3423.0	0.0125
800	3912	0.0160
900	4401.0	0.0225
1000	4890	0.0340
1100	5379.0	0.0605
1200	5868	0.1140
1300	6357.0	0.2290
1400	6846	0.5060
1500	7335.0	1.1225
1600	7824	1.9990
0	0	1.9410

Final Displacement (in.)	1.9990
Rebound (in.)	1.9410

Technician(s)	HZ
Pile Type	S4 x 7.7
Pile Name	HHF-8
Location	HHF
Date	6/22/14
Age (days)	
Installation Date	11/2/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
25	122.25	0.0000
50	244.5	0.0000
75	366.75	0.0000
100	489	0.0000
150	733.5	0.0005
200	978	0.0005
250	1222.5	0.0000
300	1467	0.0000
350	1711.5	0.0005
400	1956	0.0010
450	2200.5	0.0020
500	2445	0.0020
550	2689.5	0.0040
600	2934	0.0060
650	3178.5	0.0060
700	3423	0.0080
750	3667.5	0.0100
800	3912	0.0100
850	4156.5	0.0115
900	4401	0.0125
1000	4890	0.0220
1200	5868	0.0980
1300	6357	0.2110
1400	6846	0.4505
1500	7335	1.6290
0	0	1.5860

Final Displacement (in.)	1.6590
Rebound (in.)	1.6160

Technician(s)	TJO
Pile Type	4.5" Plain Sched. 40
Pile Name	HHF-9
Location	HHF
Date	7/18/12
Age (days)	7 days
Installation Date	7/11/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
50	244.5	0.0000
100	489.0	0.0000
200	978.0	0.0000
300	1467.0	0.0025
400	1956.0	0.0025
500	2445.0	0.0050
600	2934.0	0.0055
700	3423.0	0.0070
800	3912.0	0.0080
900	4401.0	0.0095
1000	4890.0	0.0125
1100	5379.0	0.0135
1200	5868.0	0.0175
1300	6357.0	0.0230
1350	6601.5	0.0250
1420	6943.8	0.0290
1500	7335.0	0.033
1550	7824.0	0.0385
1600	8068.5	0.0425
1650	8802.0	0.048
1800	9046.5	0.0725
1850	9291.0	0.082
1900	9291.0	0.0965
1950	9535.5	1.3480
0	0.0	1.3265

Final Displacement (in.)	1.3480
Rebound (in.)	1.3265

Technician(s)	TJO
Pile Type	4.5" Plain Sched. 40
Pile Name	HHF-9
Location	HHF
Date	8/12/12
Age (days)	32 days
Installation Date	7/11/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
50	244.50	0.0005
100	489.0	0.0005
200	978.00	0.0010
300	1467	0.0020
400	1956.0	0.0035
600	2934	0.0060
800	3912.0	0.0085
1000	4890	0.0115
1200	5868.0	0.0160
1400	6846	0.0230
1500	7335.0	0.0360
1600	7824	0.0630
1650	8068.5	0.0985
1700	8313	0.1730
1750	8557.5	0.4570
1800	8802	2.0860
0	0	2.0545

Final Displacement (in.)	2.0860
Rebound (in.)	2.0545

Technician(s)	JK
Pile Type	4.5" Plain Sched. 40
Pile Name	HHF-9
Location	HHF
Date	10/28/12
Age (days)	109 days
Installation Date	7/11/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
40	195.60	0.0000
60	293.4	0.0000
80	391.20	0.0000
120	587	0.0000
180	880.2	0.0000
250	1223	0.0005
400	1956.0	0.0020
500	2445	0.0030
700	3423.0	0.0060
900	4401	0.0075
1100	5379.0	0.0105
1300	6357	0.0140
1500	7335.0	0.0195
1700	8313	0.0540
1800	8802.0	0.0880
1900	9291	0.1435
2000	9780.0	0.2300
2100	10269	0.3840
2200	10758.0	0.6615
2300	11247	1.2150
2400	11736	2.3310
0	0	2.2890

Final Displacement (in.)	2.3310
Rebound (in.)	2.2890

Technician(s)	JK
Pile Type	4.5" Plain Sched. 40
Pile Name	HHF-9
Location	HHF
Date	3/30/12
Age (days)	262 days
Installation Date	7/11/12

Digital Reading	Load (lbs)	Displacement (in.)
20	97.80	0.0000
40	195.6	0.0005
80	391.20	0.0010
120	587	0.0020
200	978.0	0.0030
250	1223	0.0035
300	1467.0	0.0035
400	1956	0.0050
500	2445.0	0.0065
600	2934	0.0075
800	3912.0	0.0100
900	4401	0.0125
1000	4890.0	0.0145
1200	5868	0.0185
1400	6846.0	0.0235
1600	7824	0.0330
1800	8802.0	0.0665
2000	9780	0.1320
2200	10758.0	0.2675
2400	11736	0.5020
2600	12714	1.1465
2800	13692	2.0285
0	0	1.9620

Final Displacement (in.)	2.0285
Rebound (in.)	1.9620

Technician(s)	HZ
Pile Type	4.5" Plain Sched. 40
Pile Name	HHF-9
Location	HHF
Date	5/7/13
Age (days)	300 days
Installation Date	7/11/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
40	195.60	0.0000
80	391.2	0.0005
150	733.50	0.0010
200	978	0.0010
300	1467.0	0.0005
400	1956	0.0005
510	2493.9	0.0025
600	2934	0.0035
700	3423.0	0.0040
800	3912	0.0055
1000	4890.0	0.0085
1200	5868	0.0120
1500	7335.0	0.0235
1750	8558	0.0620
2000	9780.0	0.2115
2250	11003	0.8095
2500	12225.0	3.2850
0	0	2.9840

Final Displacement (in.)	1.6590
Rebound (in.)	1.6160

Technician(s)	TJO
Pile Type	W8 x 13 (HHF-11)
Pile Name	HHF-11
Location	HHF
Date	7/18/12
Age (days)	7 days
Installation Date	7/11/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
50	244.5	0.0000
100	489	0.0000
200	978	0.0000
400	1956	0.0020
600	2934	0.0065
800	3912	0.0155
1000	4890	0.0250
1100	5379	0.0410
1250	6112.5	0.0655
1400	6846	0.0990
1500	7335	0.1350
1600	7824	0.1850
1700	8313	0.2715
1800	8802	0.4155
1900	9291	0.6020
2000	9780	0.8450
2100	10269	1.1085
2150	10513.5	1.3065
2200	10758	1.5015
2250	11002.5	1.7145
2300	11247	1.9290
2350	11491.5	2.1910
2400	11736	2.4950
0	0	2.4840

Final Displacement (in.)	2.4950
Rebound (in.)	2.4840

Technician(s)	TJO
Pile Type	W8 x 13 (HHF-11)
Pile Name	HHF-11
Location	HHF
Date	8/12/12
Age (days)	32 days
Installation Date	7/11/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
50	244.5	0.0000
100	489	0.0000
200	978	0.0000
400	1956	0.0000
600	2934	0.0020
800	3912	0.0060
1000	4890	0.0120
1200	5868	0.0185
1400	6846	0.0305
1600	7824	0.0455
1800	8802	0.0735
2000	9780	0.1185
2200	10758	0.2075
2400	11736	0.3690
2600	12714	0.6760
2700	13203	1.0855
2800	13692	2.0490
0	0	1.9565

Final Displacement (in.)	2.0490
Rebound (in.)	1.9565

Technician(s)	TJO
Pile Type	6.625" Plain Sched. 40
Pile Name	HHF-10
Location	HHF
Date	7/18/12
Age (days)	7 days
Installation Date	7/11/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
50	244.5	0.0000
100	489.0	0.0000
200	978.0	0.0005
300	1467.0	0.0010
400	1956.0	0.0020
500	2445.0	0.0030
600	2934.0	0.0040
700	3423.0	0.0055
800	3912.0	0.0070
1000	#REF!	0.0125
1100	4890.0	0.0170
1200	5379.0	0.0220
1300	5868.0	0.0290
1400	6357.0	0.0380
1550	6846.0	0.0575
1650	7579.5	0.0755
1700	8068.5	0.0880
1750	8557.5	0.1000
1800	8802.0	0.1125
1850	9046.5	0.1265
1900	9291.0	0.1430
2000	10024.5	0.2150
2050	10024.5	1.5010
0	0.0	1.4705

Final Displacement (in.)	1.5010
Rebound (in.)	1.4705

Technician(s)	TJO
Pile Type	6.625" Plain Sched. 40
Pile Name	HHF-10
Location	HHF
Date	11/3/12
Age (days)	115 days
Installation Date	7/11/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
50	244.5	0.0000
100	489.0	0.0000
150	733.5	0.0000
200	978.0	0.0000
300	1467.0	0.0000
400	1956.0	0.0000
600	2934.0	0.0010
800	3912.0	0.0040
1000	4890.0	0.0085
1200	5868.0	0.0125
1400	6846.0	0.0200
1600	7824.0	0.0300
1800	8802.0	0.0505
2000	9780.0	0.0790
2200	10758.0	0.1495
2400	11736.0	0.3690
2600	12714.0	1.0090
2800	13692.0	1.9570
0	0.0	1.8825

Final Displacement (in.)	1.9570
Rebound (in.)	1.8825

Technician(s)	JK
Pile Type	6.625" Plain Sched. 40
Pile Name	HHF-10
Location	HHF
Date	3/30/13
Age (days)	262 days
Installation Date	7/11/12

Digital Reading	Load (lbs)	Displacement (in.)
50	244.5	0.0015
100	489.0	0.0025
150	733.5	0.0030
200	978.0	0.0030
250	1222.5	0.0035
300	1467.0	0.0040
400	1956.0	0.0050
600	2934.0	0.0090
800	3912.0	0.0100
1000	4890.0	0.0135
1200	5868.0	0.0205
1400	6846.0	0.0335
1600	7824.0	0.0650
1800	8802.0	0.1450
2000	9780.0	0.4025
2200	10758.0	1.4970
2400	11736.0	2.0680
0	0.0	2.0040

Final Displacement (in.)	2.0680
Rebound (in.)	2.0040

Technician(s)	JK
Pile Type	6.625" Plain Sched. 40
Pile Name	HHF-10
Location	HHF
Date	5/7/13
Age (days)	300 days
Installation Date	7/11/12

Digital Reading	Load (lbs)	Displacement (in.)
40	195.60	0.0000
80	391.2	0.0000
150	733.50	0.0000
200	978	0.0000
300	1467.0	0.0005
400	1956	0.0025
600	2934.0	0.0045
800	3912	0.0075
1000	4890.0	0.0105
1200	5868	0.0190
1400	6846.0	0.0275
1600	7824	0.0415
1800	8802.0	0.1005
2000	9780	0.2920
2200	10758.0	0.9965
2300	11247	2.4120
0	0	2.3960

Final Displacement (in.)	2.4120
Rebound (in.)	2.3960

Technician(s)	JK
Pile Type	W8 x 13
Pile Name	HHF-11
Location	HHF
Date	7/18/12
Age (days)	7 days
Installation Date	7/11/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
50	244.5	0.0000
100	489	0.0000
200	978	0.0000
400	1956	0.0020
600	2934	0.0065
800	3912	0.0155
1000	4890	0.0250
1100	5379	0.0410
1250	6112.5	0.0655
1400	6846	0.0990
1500	7335	0.1350
1600	7824	0.1850
1700	8313	0.2715
1800	8802	0.4155
1900	9291	0.6020
2000	9780	0.8450
2100	10269	1.1085
2150	10513.5	1.3065
2200	10758	1.5015
2250	11002.5	1.7145
2300	11247	1.9290
2350	11491.5	2.1910
2400	11736	2.4950
0	0	2.4840

Final Displacement (in.)	2.4950
Rebound (in.)	2.4840

Technician(s)	JK
Pile Type	W8 x 13
Pile Name	HHF-11
Location	HHF
Date	8/12/12
Age (days)	32 days
Installation Date	7/11/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
50	244.5	0.0000
100	489	0.0000
200	978	0.0000
400	1956	0.0000
600	2934	0.0020
800	3912	0.0060
1000	4890	0.0120
1200	5868	0.0185
1400	6846	0.0305
1600	7824	0.0455
1800	8802	0.0735
2000	9780	0.1185
2200	10758	0.2075
2400	11736	0.3690
2600	12714	0.6760
2700	13203	1.0855
2800	13692	2.0490
0	0	1.9565

Final Displacement (in.)	2.0490
Rebound (in.)	1.9565

Technician(s)	JK
Pile Type	W8 x 13
Pile Name	HHF-11
Location	HHF
Date	11/3/12
Age (days)	115 days
Installation Date	7/11/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
50	244.5	0.0000
100	489	0.0000
150	733.5	0.0005
200	978	0.0010
400	1222.5	0.0035
600	1467	0.0070
800	1711.5	0.0130
1000	1956	0.0220
1200	2200.5	0.0370
1400	2445	0.0620
1600	2689.5	0.1075
1800	2934	0.1850
2000	3178.5	0.3385
2200	3423	0.6800
2400	3667.5	1.6180
2500	3912	1.9850
0	0	1.8770

Final Displacement (in.)	1.9850
Rebound (in.)	1.0405

Technician(s)	JK
Pile Type	W8 x 13
Pile Name	HHF-11
Location	HHF
Date	3/30/13
Age (days)	262 days
Installation Date	7/11/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
20	97.8	0.0000
50	244.5	0.0020
75	366.75	0.0025
100	489	0.0025
200	978	0.0040
300	1467	0.0070
400	1956	0.0950
500	2445	0.0100
600	2934	0.0135
800	3912	0.0230
900	4401	0.0295
1000	4890	0.0390
1200	5868	0.0740
1400	6846	0.1460
1500	7335	0.2275
1600	7824	0.3490
1700	8313	0.5530
1800	8802	0.8920
1900	9291	1.4595
2000	9780	2.0165
0	0	1.9115

Final Displacement (in.)	2.0165
Rebound (in.)	1.9115

Technician(s)	HZ
Pile Type	W8 x 13
Pile Name	HHF-11
Location	HHF
Date	5/7/13
Age (days)	300 days
Installation Date	7/11/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
40	195.6	0.0000
80	391.2	0.0000
150	733.5	0.0000
200	978	0.0005
300	1467	0.0005
400	1956	0.0025
600	2934	0.0085
800	3912	0.0205
1000	4890	0.0515
1200	5868	0.1325
1400	6846	0.4035
1600	7824	1.0645
1800	8802	2.5570
0	0	2.5485

Final Displacement (in.)	2.5570
Rebound (in.)	2.5485

Technician(s)	HZ
Pile Type	W8 x 13
Pile Name	HHF-11
Location	HHF
Date	6/18/14
Age (days)	707 days
Installation Date	7/11/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
50	244.5	0.0000
100	489	0.0000
150	733.5	0.0000
200	978	0.0000
250	1222.5	0.0000
300	1467	0.0005
350	1711.5	0.0005
400	1956	0.0020
450	2200.5	0.0055
500	2445	0.0080
550	2689.5	0.0090
600	2934	0.0120
650	3178.5	0.0145
700	3423	0.0170
750	3667.5	0.0225
800	3912	0.0335
900	4401	0.0850
1000	4890	0.1990
1100	5379	0.4490
1200	5868	1.0300
0	0	0.9820

Final Displacement (in.)	1.0885
Rebound (in.)	1.0405

Technician(s)	HZ
Pile Type	2 Fin 4.5" Plain
Pile Name	HHF-12
Location	HHF
Date	6/21/14
Age (days)	702 days
Installation Date	7/19/12

Digital Reading	Load (lbs)	Displacement (in.)
50	244.5	0.0000
100	489	0.0000
150	733.5	0.0000
200	978	0.0000
300	1467	0.0000
400	1956	0.0000
500	2445	0.0010
600	2934	0.0020
700	3423	0.0035
800	3912	0.0055
900	4401	0.0075
1000	4890	0.0090
1100	5379	0.0115
1200	5868	0.0145
1300	6357	0.0170
1400	6846	0.0210
1500	7335	0.0245
1600	7824	0.0305
1700	8313	0.0365
1800	8802	0.0460
1900	9291	0.0620
2000	9780	0.0900
2200	10758	0.1710
2400	11736	0.3940
2600	12714	1.0490
0	0	0.9785

Final Displacement (in.)	1.1160
Rebound (in.)	1.0455

Technician(s)	HZ
Pile Type	3 Fin 4.5" Plain
Pile Name	HHF-13
Location	HHF
Date	6/17/14
Age (days)	698 days
Installation Date	7/19/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
100	489	0.0000
200	978	0.0000
300	1467	0.0000
400	1956	0.0000
500	2445	0.0000
600	2934	0.0000
700	3423	0.0000
800	3912	0.0000
900	4401	0.0000
1000	4890	0.0000
1100	5379	0.0000
1200	5868	0.0055
1300	6357	0.0090
1400	6846	0.0115
1500	7335	0.0160
1600	7824	0.0225
1700	8313	0.0300
1800	8802	0.0390
1900	9291	0.0545
2000	9780	0.0715
2200	10758	0.1350
2400	11736	0.2480
2600	12714	0.5090
2800	13692	1.1670
0	0	1.1620

Final Displacement (in.)	1.2045
Rebound (in.)	1.1995

Technician(s)	HZ
Pile Type	4 Fin 4.5" Plain
Pile Name	HHF-14
Location	HHF
Date	6/18/14
Age (days)	699 days
Installation Date	7/19/12

Digital Reading	Load (lbs)	Displacement (in.)
100	489	0.0000
200	978	0.0000
300	1467	0.0005
400	1956	0.0005
500	2445	0.0015
600	2934	0.0035
700	3423	0.0050
800	3912	0.0075
900	4401	0.0115
1000	4890	0.0160
1100	5379	0.0225
1200	5868	0.0265
1300	6357	0.0325
1400	6846	0.0390
1500	7335	0.0470
1600	7824	0.0525
1700	8313	0.0635
1800	8802	0.0765
1900	9291	0.0890
2000	9780	0.1060
2200	10758	0.1400
2400	11736	0.1865
2600	12714	0.2605
2800	13692	0.3565
3000	14670	0.4860
3200	15648	0.6875
3400	16626	1.0085
0	0	0.8380

Final Displacement (in.)	1.0350
Rebound (in.)	0.8645

Technician(s)	HZ
Pile Type	6 Fin 4.5" (HHF-15)
Pile Name	HHF-15
Location	HHF
Date	6/21/14
Age (days)	702 days
Installation Date	7/19/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
100	489	0.0005
200	978	0.0020
300	1467	0.0045
400	1956	0.0055
500	2445	0.0090
600	2934	0.0105
750	3667.5	0.0135
900	4401	0.0185
1050	5134.5	0.0240
1200	5868	0.0315
1350	6601.5	0.0435
1500	7335	0.0770
1650	8068.5	0.1330
1800	8802	0.2435
1950	9535.5	0.4975
2100	10269	1.0185
0	0	0.9475

Final Displacement (in.)	1.0720
Rebound (in.)	1.0010

Technician(s)	HZ
Pile Type	4 Fin 4.5" Short
Pile Name	HHF-16
Location	HHF
Date	6/18/14
Age (days)	699 days
Installation Date	7/19/12

Digital Reading	**Load (lbs)**	**Displacement (in.)**
50	244.5	0.0000
100	489	0.0000
150	733.5	0.0000
200	978	0.0000
300	1467	0.0000
400	1956	0.0000
500	2445	0.0005
600	2934	0.0020
700	3423	0.0040
800	3912	0.0080
900	4401	0.0110
1000	4890	0.0155
1100	5379	0.0200
1200	5868	0.0305
1300	6357	0.0460
1400	6846	0.0730
1500	7335	0.1100
1600	7824	0.1660
1700	8313	0.2590
1800	8802	0.4075
1900	9291	0.6575
2000	9780	1.1025
0	0	1.0170

Final Displacement (in.)	1.1640
Rebound (in.)	1.0785