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Foundation Underpinning Process and Relationship with Groundwater in West-Central Florida

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ABSTRACT

A map of refusal depth for underpinning in West-Central Florida was developed. The purpose of underpinning is to provide support to distressed structures and overcome excessive settlement due to numerous factors, including sinkhole activity. Underpinning expands the existing foundation beneath an existing structure.

Structures that have been affected by sinkhole activity require remediation and underpinning is the ideal solution if the foundation has poor subsurface conditions. Depth and pressure are the factors, which control installation of underpinning piers. Soil profiles at the site determine the depth of the pier. The maximum depth, or refusal depth, is reached when the pier system refuses to be pushed any lower without lifting the structure. Calculating underpinning depth is crucial in determining which underpinning method is suitable for the structure, as well as estimating the required construction materials.

The results of this paper show that the refusal depth increases in areas where water in the Upper Floridian aquifer is low and this may be attributed to the absence of support from groundwater. The results will be useful in predicting installation depths, especially in areas where a few underpinning projects have been taken place.

KEYWORDS: Underpinning, Groundwater, Florida, Sinkhole

INTRODUCTION

Underpinning is the process of reducing or eliminating structural movement using small diameter, high capacity piers, which are attached to the foundation of the structure and driven through the weak soils until competent soils or limestone is reached. The process of underpinning lifts the structure and provides reliable support to prevent settling. For this process to be successful, the underpinning must be correctly planed out and installed.

There are certain circumstances where underpinning is employed. One situation is when structures are on unstable soil and there is the possibility for the building's foundation to move unevenly. Another situation is when the structure is not level, or at sites where cavities have been created. In Florida, the most common reason for the underpinning practice is to stabilize a structure following sinkhole activity.

There are several methods for underpinning a structure including drilling, screwing (helical) or pressing. In the study area that this report concentrates on, pressed steel underpinning is the most common method used and therefore will be the focus of this paper.

Underpinning is accomplished by excavating holes below the foundation and placing hydraulic jacks under the grade beam or footing in order to transfer the loads of the structure to a pile system. Once all pilings are installed, the structure is raised to its desired elevation by lifting and then securing the installed pilings (pipes) onto the grade beam is performed (FRA,2005). The pipes are forced into the ground at each location point either individually or simultaneously. It is important to note that even on a small structure, there is always a difference in pier refusal depth from point to point (Witherspoon, 2006). Refusal is achieved when the driving force exerted on the piers exceeds the load to be supported. It is common for buildings of lighter weight, such as wooden framed structures, to show less resistance than buildings with heavy loads or in multi-level structures. Pushing is terminated when refusal is achieved to prevent damage to the grade beam or overlying structure.

As each individual pier is proof-tested during installation, it is generally perceived that the pier should have no difficulty reaching the required capacity. It is, perhaps, for this reason that so little research has been completed or reported on the development of installation depth.

Installation may also differ with regard to the engineer or contractor. As an example, some contractors use high-pressure water to jet down the holes or around the external diameters to achieve a greater depth. With jetting, however, it has been reported that there is a loss of 50% to 85% axial capacity because of the process (Witherspoon, 2006).

MATERIALS AND METHODS

The underpinning process begins with the estimation of approximate foundation loads, foundation requirements, and obtaining general site information, which may involve a superficial visit to the site. The process may also entail collecting knowledge from previous borings and other underpinning constructions in the site area. This information is useful to avoid installation problems and can be obtained from standard penetration test borings. Depth of limestone is one of the important factors that can be obtained from geo-technical investigations.

Study Area

The study area featured in this report is the area of the northern Tampa Bay region including all or portions of the following counties: Hillsborough, Pasco, Hernando, Citrus, Marion, Levy, Volusia, Sumter, Orange, Seminole, Polk, and Lake (shown in Figure 1). In these locations, the limestone is at or near land surface and the karst features are likely reasons for sinkholes, which have a tendency to open following a tropical storm, especially when the tropical storm occurs after a period of drought (Tihansky et al, 1996). This area does not have a thick clay layer with cohesive sediments to confine the limestone.

Sinkholes in the Study Area

While most of Florida is prone to karst-related problems, sinkholes are more likely to occur in certain portions of the state than in others. Figure 2 shows sinkholes reported in the study area up until March, 2014. It is not, however, inclusive of all sinkholes because the majority of incidents have not been field checked and the cause of subsidence has not yet been verified (FGS, 2014).

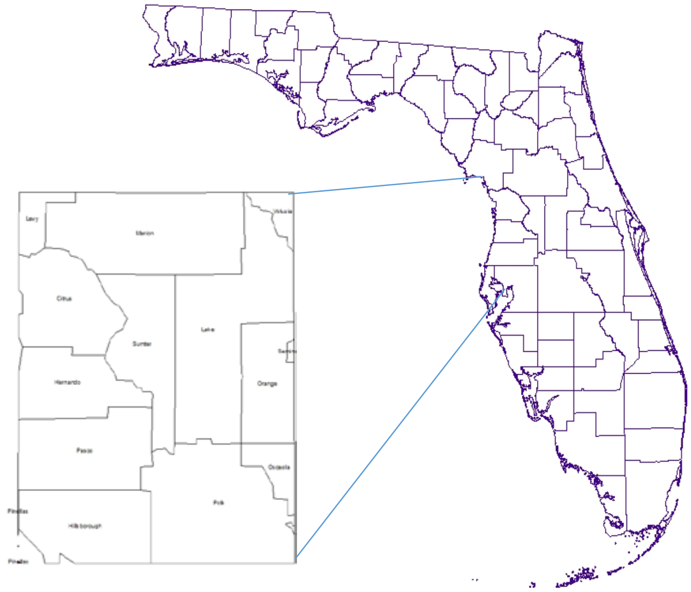

Figure 1: Study Area

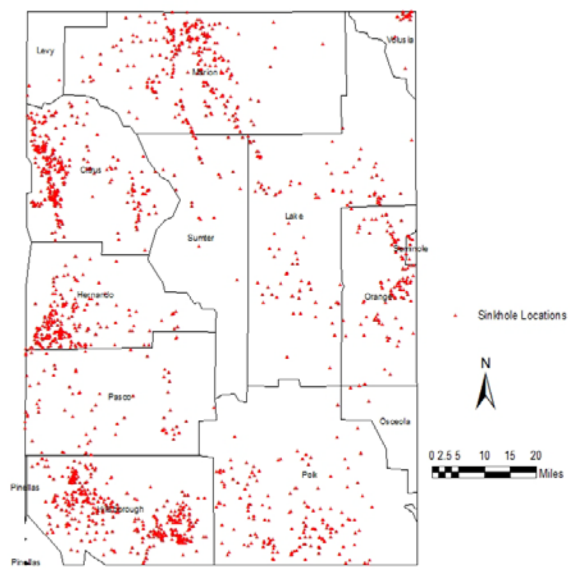

Figure 2: Sinkhole Locations

Potentiometric Surface Map

The aquifer system in west-central Florida consists of three layers, surficial aquifer, intermediate confining clay unit, and Floridan aquifer. In the study area, the intermediate clay unit does not exist, therefore, the surficial aquifer lies directly above the Floridan aquifer system. Groundwater flows from surficial aquifer downward to the Upper Floridan aquifer recharge the Upper Florida aquifer and at the same time erode the unconsolidated sediments in the surficial aquifer and created cavities. The hydraulic gradient, between water in the surficial aquifer and Florida aquifer is the principal force for sinkhole development. As groundwater is high in September and low in May, most of the new sinkholes occur in May when the head difference and the recharge reach its minimum and no support from groundwater that provide cohesion of sediments. The United States Geological Survey (USGS) measures water levels in the Floridan aquifer systems each May and September to map annual potentiometric (POT) surface. The POT is an imaginary surface connecting points of equal altitude to which water will rise in a tightly cased well that taps a confined aquifer system (Lohman, 1979). Figure 3 shows the potentiometric map for May 2010.

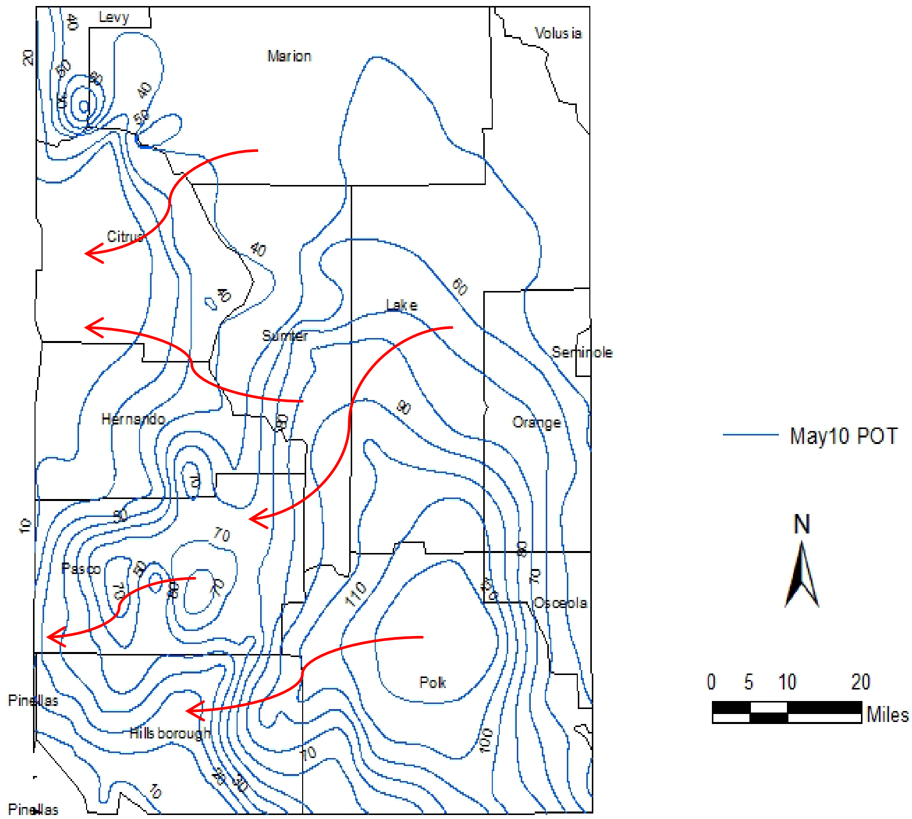

Figure 3: Altitude of potentiometric surface in the Upper Floridan aquifer May 2010

Standard Penetration Test

The Standard Penetration Test (SPT) is a test that performed in situ to find the relative density of the soil. A standard weight hammer of 140 lbs. dropped from a height of 30 inches is used to perform the SPT. The number of blows required to drive the sampler a total distance of 18 inches in 3 increments is recorded. The first 6 inches is called a seating and does not count. The N number is the sum of all blows required to drop the hammer the last two 6-inch increments. It is possible to establish an initial underpinning depth as the depth of limestone or as resistance criteria such as “the depth at minimum SPT resistance of “N” value” equal to 30 or similar criteria. A SPT boring sample is shown in Figure 4.

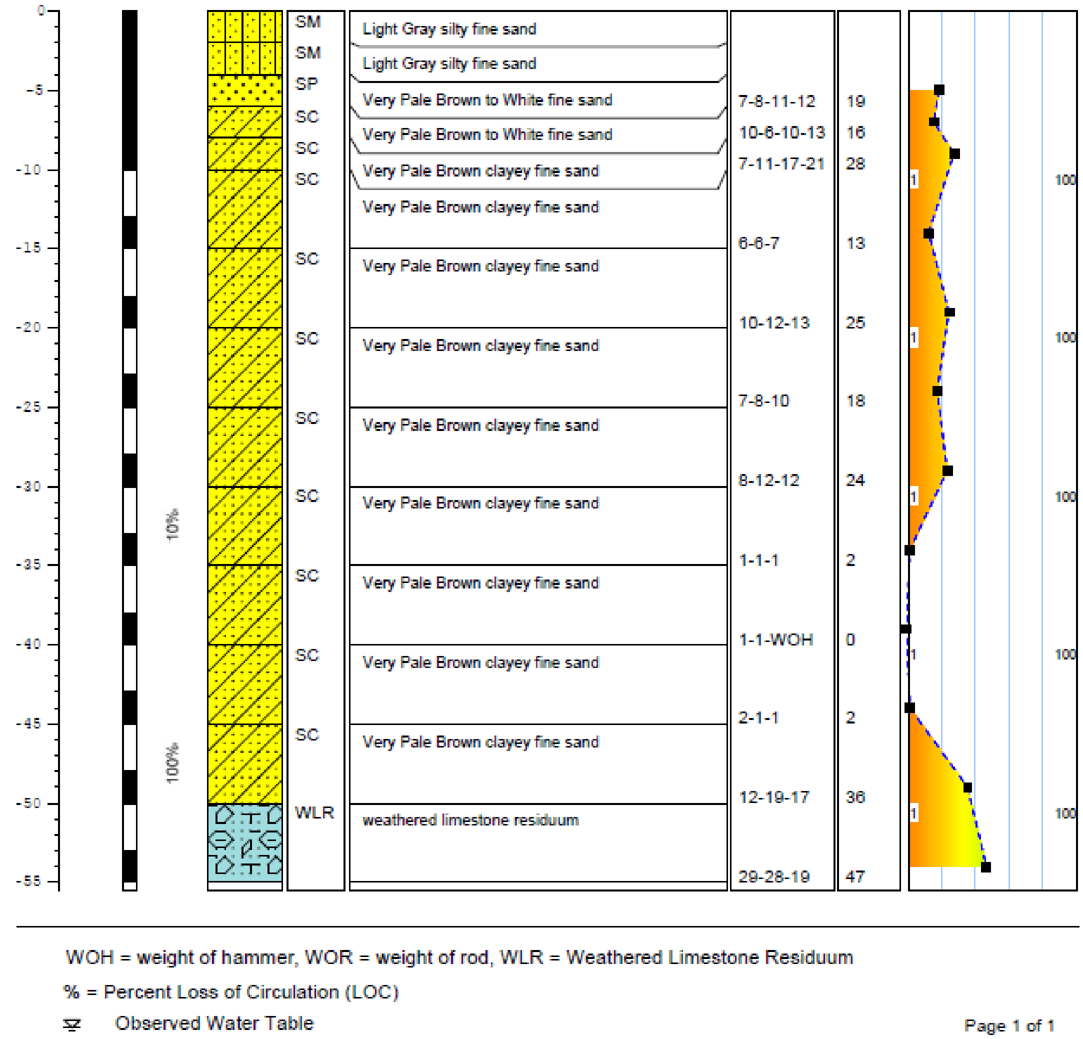

Figure 4: An SPT boring log

Specifications

Steel pipes used for underpinning are specified by grade with reference to ASTM A-252. In this report's study area, black steel and galvanized pipes have been used for underpinning. Galvanized steel allows for a long term strength and corrosion resistance, whereas black steel pipe is usually thicker than the galvanized pipe. Steel piles used for residential projects range in diameter from 200 to 1220mm (7.87 to 48 inches). The most commonly used diameters are approximately 76.2mm (3 inches) or 73mm (2 7/8 inches) and are in 91m (3 ft) long sections. Typical wall thicknesses range from 3 to 25mm (0.118 to 0.98 inches) with a male and female end that fit together to form a fairly rigid, continuous pipe without a tensile connection (Witherspoon, 2006). In the study area contractors used pipes with a thickness of 4.19mm (0.165 inches) for galvanized pies with a yield stress of 3.79 x 10^5 kPa (55 kips) or 5.16 mm (0.203 inches) for black pipes with a yield stress of 4.48 x 10^5 kPa (65 kips). Testing done by the University of South Florida showed the ultimate strength of the pipe section to be 4.48 x 10^5 kPa (65 kips) for galvanized pipes and 4.89 x 10 ^{5} kPa (71 kips) for black pipes.

For unfilled pipe, AASHTO has established the maximum working stress at 0.25 fy (FHWA 1996), which is equivalent to 94,802 kPa (13,750 psi) for galvanized pipe or 112,038 kPa (16,250 psi) for black pipe. Galvanized steel pipe with an area of 903mm² (1.4 in²) would allow 85,628 N (19,250 lbs) of house load support, while black pipe with an area of 1,097mm² (1.7 in²) would allow 122,882 N (27,625 lbs) of house load support. However, house loads calculated at approximately 14,589 N (3,280 lbs) per m (3,28 ft) with a spacing of 2.1 m (7 ft) result in a working load of 31,137 N (7,000 lbs) for a one-story structure and provides a satisfactory factor of safety.

Driving stresses for this type of pile are also set by AASHTO at 0.9 fy which is equivalent to 341,290 kPa (49,500 psi) for galvanized pipe or 403,343 kPa (58,500 psi) for black pipe. This would permit the use of equipment of up to 225,257 N (69,300 lbs) for galvanized pipe or 442,375 N (99,450 lbs) for black pipe. The usual equipment used for underpinning imposes a driving stress of 225,258 N (50,640 lbs) (Witherspoon, 2006) and bending action does not appear to be crucial at this force.

Note: The drive pressure was established at 23,442 kPa (3,400 psi on the gauge and calculated out at 50,640 lbs. of pressure). Because these piles are subject to some bending, they may vary from true vertical as documented (Brown 1999; Brown 2000).

Data Collection

This report contains information taken from over 200 underpinning projects monitored in the study area. Depth and pressure for each underpinning pier was collected and recorded. On any structure there is always a difference in pier refusal depth, therefore, the maximum refusal depth for each project was used as a representation of depth at maximum pressure.

Load Test

Each pier is proof tested during installation so it is generally conceived that piers should have no difficulty in reaching the required capacity. However, according to FHWA-HI-96-033, the failure load of a pile tested under axial compressive load is that load which produces a settlement at failure of the pile head equal to (FHWA, 1996):

$$\boldsymbol{S_f = \frac{QL}{AE} + (4 + 0.008b)}$$

where

S_f = Settlement at failure (mm)
b = pile diameter (mm)
Q = Design axial load (kN)
L = Pile length
A = pile cross sectional area (m^2)
E = modulus of elasticity = 207,000 MPa

For a pile diameter of 2.875 inches, design axial load of 11.24 kN (50 kips), average pile length of 6,096 mm (20 feet), pile cross section of 0.00090322 m² (1.4 in^2) for galvanized pipe or 0.0010968 m² (1.7 in^2) for black pipe:

$$\boldsymbol{S_f = \frac{(11.24)(6{,}096)}{(0.00090322)(207{,}000{,}000)} + (4 + 0.008\,(73.03) = 3.66}$$ mm for galvanized pipe and

$$S_f = \frac{(11.24)(6{,}096)}{(0.0010968)(207{,}000{,}000)} + (4 + 0.008\,(73.03) = 3.02$$ mm for black pipes

While this theory has relevance, it should only be used as a supplementary data tool in conjunction with proven empirical methods that are based on available data. It is also important that foundations be set in homogeneous soil conditions. Those conditions do not exist in this report's study area.

In practice, lifting a structure can be considered a load test, which occurs during the actual underpinning process. After which, the engineer ascertains whether the underpinning is seated securely and the weight of the structure has been fully transferred.

RESULTS AND CONCLUSIONS

The major features, which make underpinning an increasingly popular and powerful technique, include:

1. Relatively small, clean and quiet equipment
2. Installation is possible in very restricted access locations and in any direction
3. Minimum structural disturbance
4. Flexibility for designers to complex problems
5. Excellent, demonstrable performance behavior

As previously explained, the underpinning process commenced when pipes in 3-foot long sections were pushed downward. As the pipes, progressed, additional 3-foot sections were added. There was always some variance in the termination depth. At the time of installation, the initial capacity was established at 50,640 lbs. The drive pressure was established at 3,000 psi (on the gauge it was easier to read but this calculated out at 50,640 lbs in lieu of 50,000 lbs.). At each depth, the pressure was read and recorded on the log sheet. The data collected displayed a trend that is presented in Figure 5. The minimum depth was found in the northeast corner and the maximum depth in the southwest corner of the report study area.

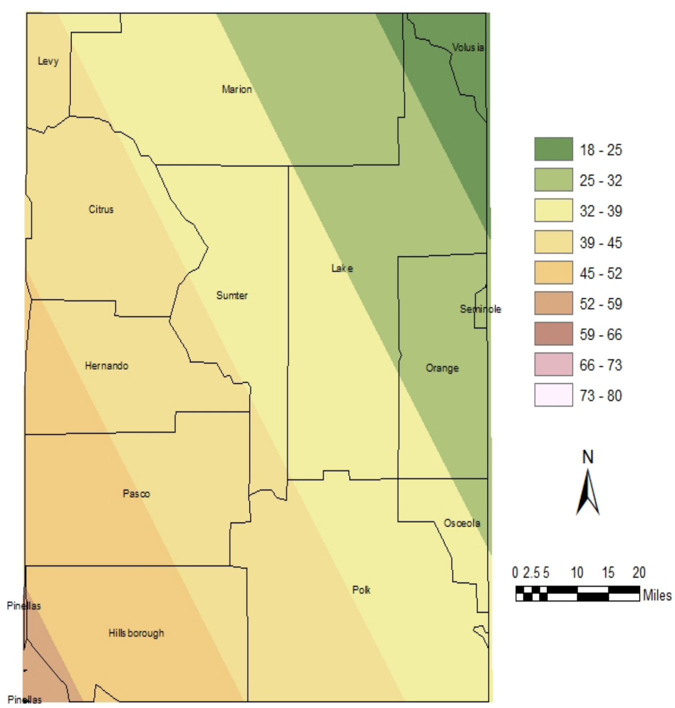

Figure 5: Trend in Depth to Refusal

The actual data showed some exceptions, which are depicted by the use of, contour lines in Figure 6. The circles appear on the figure represent the intense data that used at these areas.

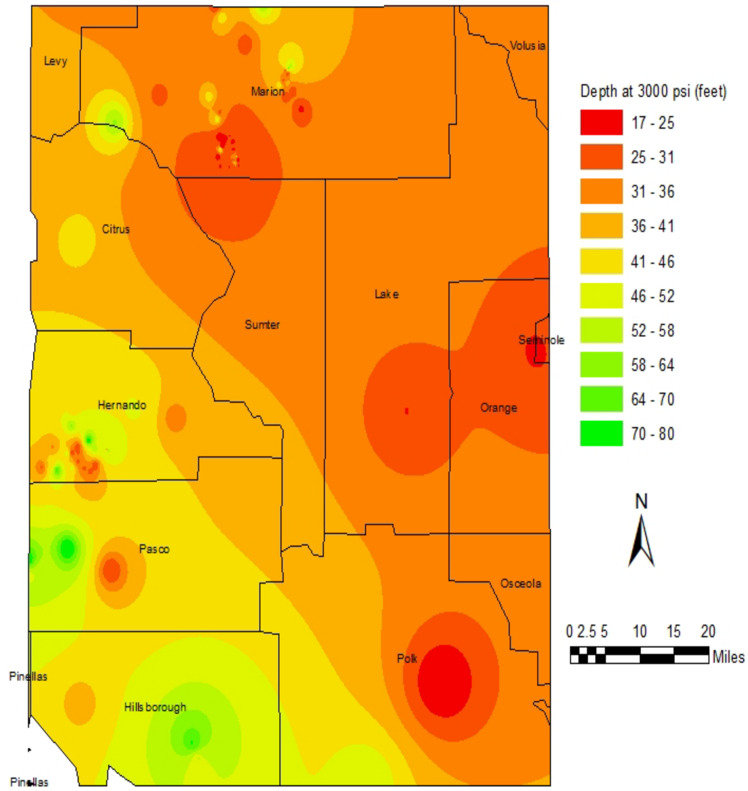

Figure 6: Depth to refusal

The result is consistent with the opposite trend of the potentiometric map. Water in the Upper Florida aquifer moves from recharge areas in the northern and eastern regions to the discharge areas near the coast. At that time, the overlying soils with no support from groundwater transferred to the deeper soils and rocks and unconsolidated sediment move down consequently. In conclusion, as water in the Floridan aquifer goes down, the depth of the 3,000 psi is bigger as shown in Figure 7.

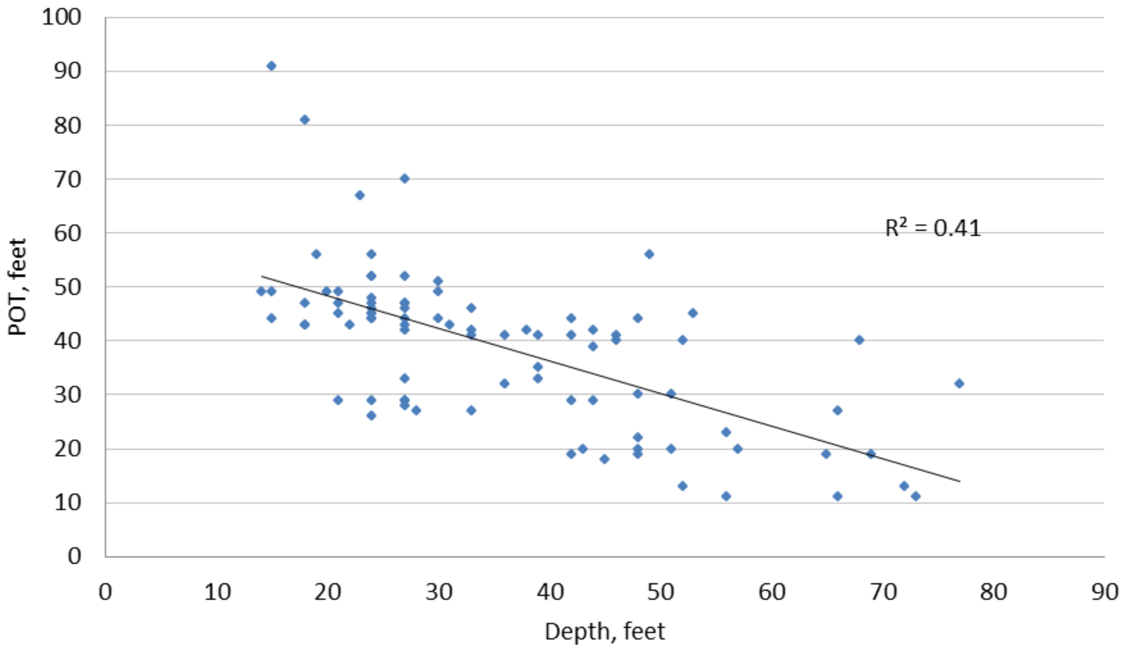

Figure 7: Relationship between POT and depth

The design and installation of underpinning pins is always a challenge for the geotechnical engineer. The preparation of the plan requires the engineer to be aware about the previous investigations findings and recommendations. Design and monitoring are two aspects that are very important considerations throughout the installation process. Not only is the design of piers may be not well developed but it can be also inadequate understanding of the way in which loads are transferred from existing foundations through the piers (Makarchian, 1995). One example of this is that the buckling of the steel stem of piers is a concern when there are long slenderness ratios (Witherspoon, 2006). However, this is only a problem in very soft soil (Davisson 1963). While pressed steel maintains a tighter fit, and thus has a smaller area of disturbance, other piles cause a disturbance area greater than 12 inches, which is possible to create enough soil strength reduction in the lateral soil support to present a problem. As long as the Standard Penetration Count (N) is greater than 4, the soil strength reduction should not be a problem in stiff clay soil (Hoyt et al. 1995).

The results of this study provide estimates for the expected refusal depth. The results are consistent with the hydrologic factors in the study area. The depth at 3,000 psi is generally bigger in the southeast corner of the study area than the northwestern corner and that is the general trends in the potentiometric elevations.

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