Foundation Base Material Strength Assessment for Drilled Pipe Piles using Force and Displacement Data

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Abstract

A common type of deep foundation used in Norway to support bridge structures is the drilled pipe piles (piles) filled with concrete reinforcement after installation. The standard installation practice is the use of down-hole hammers. Complex geology and difficult subsoil conditions in Norway causes a high variability of soil and rock layers which in turn make for differences between actual subsurface conditions and those expected from geotechnical exploratory borings. This situation is strongly noted when the foundations are not fully socketed, and the rock layer is sloped. In this particular case, special testing procedures are required to assess the drilled pile base material and evaluate the rock-socket to ensure full contact between the foundation base and the rock surface. The local standard practice to verify the latter condition, consists of coring and visually evaluating the material recovered at the bottom of the drilled pile. This paper presents a case where the coring and visual inspection were not possible and alternatively the geological material encountered at the base of the deep foundations was evaluated using force-displacement measurements. Two 1016-mm (40in) diameter open-end drilled piles identified as P02-04 and P02-05 were tested and evaluated using *in-situ* force-displacement data prior to filling the piles with concrete. Test results showed an average displacement of 7mm (0.28in) corresponding to 35MPa (5.1ksi) stress level for P02-04, and 7.2mm (0.28in) corresponding to a stress level of 38MPa (5.5ksi). Based on testing results, both drilled piles were within the established material assessment criterion presented by the local authorities.

Key Words: Drilled Pipe Piles, Down-Hole Hammers, Rock Socket, Open-End pipe piles, Force-Displacement, Stress levels

INTRODUCTION

This paper presents a case study in Norway where the material encountered at the base of an open-end drilled pipe pile (pile) was evaluated using force-displacement data. In the deep foundation industry in Norway, it is a common practice to install piles to support transportation structures. Once the piles reach the embedment elevation, and the pile base is assessed, these are filled with concrete. In projects where sloping rock is the supporting layer, and all nominal loads are supported by the pile base resistance, assessing the material encountered at the pile base to ensure full contact with the rock becomes critical. The local practice to make this assessment consists of the use of weighted tape, coring, or inspection cameras. However, similar to any other testing and evaluation methods, these come with their own limitations. The variability associated with the use of the weighted tape, accessibility for the coring equipment to complete a coring process, or the conditions at the foundation base such as murky water or thick drilling fluids could significantly impact the photo or video quality taken at the pile base. In such conditions, it is important to consider alternate testing methods to evaluate the material at the foundation base.

Throughout this manuscript, the project and its associated deep foundations properties are introduced followed by a brief description of the site subsurface conditions. Foundation installation methods and local practice for pile base assessment are presented. Finally, the alternate testing device and method is introduced and the testing results are discussed from a qualitative and quantitative approach using the shape and behavior of the force-displacement plots.

It is important to note that in many occasions in the United States, the foundation base assessment has been carried out using *in-situ* testing such as the Standard Penetration Test (SPT) or the Cone Penetration Test (CPT) to evaluate the competency of the foundation base material. Results from such tests are evaluated qualitatively (visual inspection) and quantitatively (by analyzing N-values or Tip resistances) to assess the material encountered at the foundation base. For example, the North Carolina Department of Transportation (NCDOT, 2012) specifies "SPT are generally required for drilled piers with the tip just into rock or not in rock…". Or in the case of Florida Department of Transportation (FLDOT, 2016) the SPT is allowed to be used instead of coring to assess the competency of the foundation base material. The testing method used in the project presented in this paper, could be considered as an alternate or supplement method since force-displacement data can also be evaluated qualitatively and quantitatively.

PROJECT DESCRIPTION

The project described in this paper is related to the foundation system of a vehicular bridge crossing the Seutelva River, located in Fredrikstad, Norway. According to the project information, the proposed bridge will be supported by 15 − 1016-mm (40-inches) and 10 − 813 mm (32-inches) diameter open-end piles which were advanced to the competent rock layer. Each bridge bent consists of five open-end piles which were filled with concrete after reaching the final base elevation, Figure 1. These piles were installed using a down the hole (DTH) hammer system which uses the rotary-percussion drilling method with a button bit with the inner diameter being the same as the pipe pile. The drilling process is completed by using a first pile section with the button driving ring and a button-bit hammer fitted through the pile using drill strings, Figure 2a and 2b.

SUBSURFACE CONDITIONS

According to the available geotechnical information, the subsurface condition for the project site was described as very soft plastic clay extending from the mudline to a depth of 30m (98.4ft) followed by a 6m (20ft) of moraine silt located above the bedrock. The rock formation was encountered to be steeply sloped which made the moraine silt layer thickness varying between 6m (20ft) and 11m (36ft). The rock increasing slope was reported to run from southeast to northwest with several sudden drops and abrupt change in slope.

DRILLED PIPE-PILES BASE ELEVATION

The foundation system for the project presented in this manuscript was designed as end-bearing only where all nominal loads are supported by the foundation’s base. However, due to difficult subsurface conditions and the sloping rock, each drilled pile had to be installed at a different base elevation, Figure 3. The criteria that was followed to decide the final base elevation consisted of several parameters with primary focus on (1) drilling advance rate: 40min/m minimum which corresponded to approximately a limit base resistance of 150MPa (22ksi), and (2) visual inspection with a down-hole camera. Considering uncertainties associated with the rock elevation, the contractor had to continue drilling until encountering a material that took approximately 40 minutes or more to advance 1m (3.28ft). Once the elevation was defined using the drilling rate data, the base of the drilled pile was cleaned using an airlift system, and a down-hole camera was lowered to inspect the bottom of the pipe to ensure full contact with the rock layer.

Figure 1. Proposed Bridge and corresponding Bents

(a) (b)

Figure 2. Down the Hole Hammer System **(a)** First section with Driving ring and **(b)** Hammer

For two piles located on Bent 2, the camera range and the conditions at the bottom of the pile didn’t allow to capture a clear photo or video to confirm the contact between the foundations base and the rock surface. In those locations, a third criterion was established based on rock strength properties where a material with a resistance to penetration of 30 MPa (4.35ksi) with a deformation less than 8 mm (0.32in) was considered as a competent rock to receive the foundation and support the loads. To meet this criterion, it was required to obtain force and displacement data at the base of the foundation to empirically evaluate the material located at the base of the pile. If the force and displacements corresponded to established values (minimum of 30MPa for a maximum displacement of 8mm) then the material was considered competent and the final base elevation was confirmed. Force and displacement plots were determined at the pile base using a testing device known as the shaft quantitative inspection device or the SQUID.

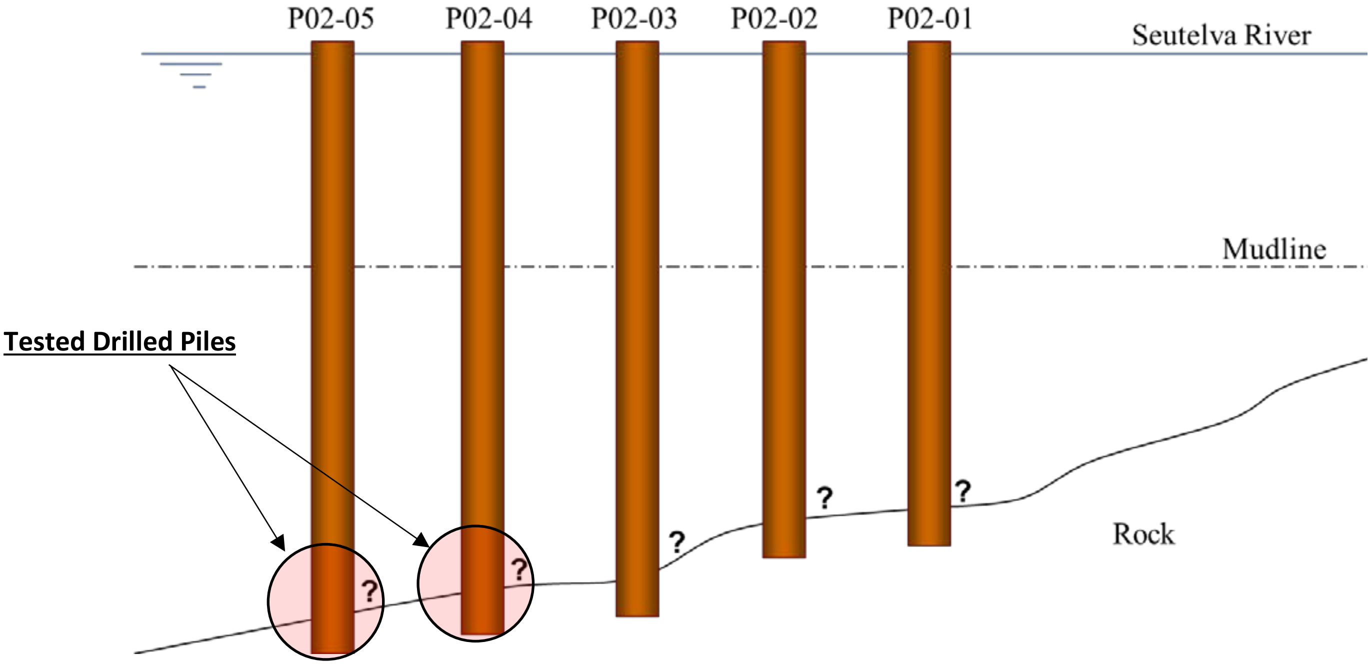

Figure 3. Schematics of base elevations for Bent 2, P02-01 to P02-05

TESTING DEVICE

The SQUID device has an octagonal shape with a maximum diagonal length of 647-mm (25.5-inches) and height of 635-mm (25.0-inches). Three penetrometers and three retractable displacement plates are attached to the device which are used to measure strain and displacements simultaneously. The penetrometers are designed to have conical or flat tips with an average cross-sectional area of 10-cm^2 (1.55-in2) which for purposes of this particular project, conical tips were used.

TESTING PROCEDURE AND RESULTS

The SQUID device was attached to the drilling strings using an American Petroleum Institute (API) adapter located between the swivel plate and the drill string and lowered into the drilled pipe to initiate test runs at the foundation base, Figure 4. Once at the base, axial force was applied using the drill rig crowd and the resistance to penetration was measured by the penetrometers, whereas measured displacements were determined by retractable plates.

 

Figure 4. Testing procedure for Bent 2, Drilled Pile P02-05

Drilled Pile P02-04

A total of 10 runs were completed at the base of the drilled pile P02-04 obtaining force-displacement data. All applied forces were then divided by the penetrometer cross-section area to obtain applied stresses. Stress-displacements plots for the Pile02-04 were plotted individually to observe the criterion established for the material at the foundation base. Results obtained for Pile02-04 showed that all three penetrometers follow a similar trend. However, the nonuniform (i.e., not overlapping) plots behavior indicated that the foundation base was not completely flat. Furthermore, according to the plots, the average stress and displacement for the material at the foundation base were registered to be 35MPa (5.1ksi) and 7mm (0.28in). These values were within the establishes resistance and displacement for the competent material at the foundation base. Figure 5 illustrates the average stress-displacement plot for the runs at the base of pile P02-04. Note that FD1 plot is slightly passing the threshold limit of 8mm (0.32in) with a stress value of 24MPa (3.5ksi) and a maximum stress if 34MPa (5ksi). However, the other two plots are within the established threshold. Another important observation is the shape of the plots from the start or the test up to approximately 10MPa (1.45ksi) where a steady increasing slope is observed. Beyond this point, the plots start to have a more constant and gentler slope with increasing stress which could be indicating an abrupt change of material property going from softer rock to more competent rock. However, a visual inspection using a down-hole camera showed no softer material accumulated nearby the penetrometers. Therefore, the existence of a softer rock versus a more competent rock is more likely to be the case.

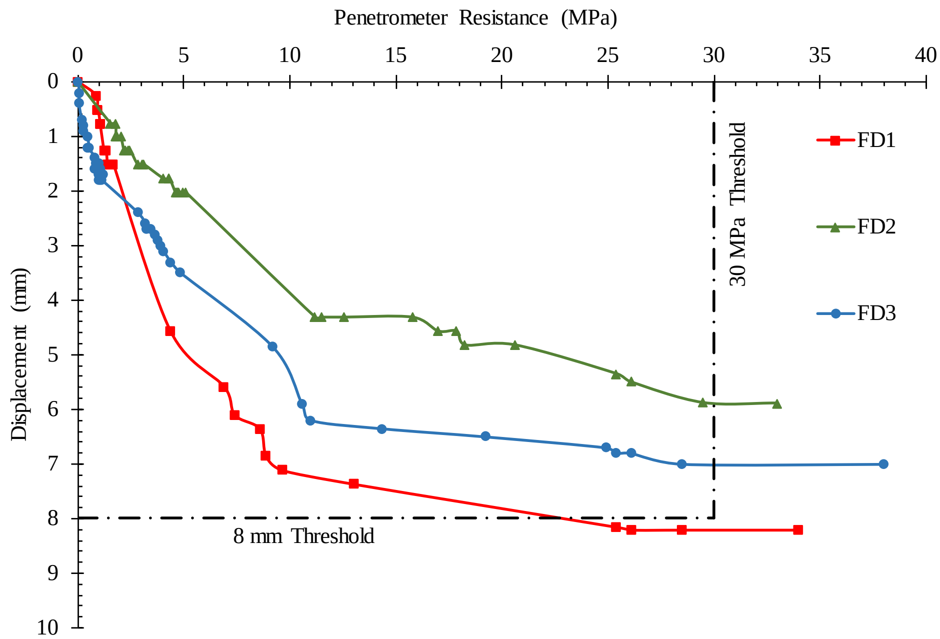

Figure 5. Average stress-displacement at the bottom of the Drilled Pile 02-04

Drilled Pile P02-05

A total of 13 runs were completed at the base of the drilled pile P02-05 and similar to the previous pile, stresses at the foundation base were determined by dividing measured forces by the penetrometers cross-section area. Stress-displacements plots were individually analyzed to observe the criterion established for the foundation base material. Results showed that all three penetrometers follow a similar trend, specially toward the end of the test. Similar to the previous test, a nonuniform foundation base material was detected since the plots are not overlapping. Considering each maximum stress registered by each penetrometer and their corresponding displacements, the average stress and displacement for the material encountered at the foundation base were registered to be 38MPa (5.5ksi) and 7.2mm (0.28in), respectively. These values were within the established resistance and displacement for the competent material at the foundation base. Figure 6 illustrates the average stress-displacement plot for the runs at the base of the pile P02-05. Note that FD2 trend is different compared to the other two plots (i.e., FD1, and FD3). The FD2 plot shows a linear behavior with a constant slope up to approximately 20MPa (2.9ksi) when the abrupt change of slope occurs. From this point forward, the plot turns to an almost zero slope line with increasing stresses and very small change in the displacement. The other two plots on the other hand, follow the same shape and can be divided into three segments: (1) a steep slope from 0 to 1.7MPa (0.25ksi), (2) small slope between 1.7MPa(0.25ksi) and 29MPa (4.20ksi), and (3) zero slope line after 29MPa (4.20ksi). The first portion of these plots could correspond to a very soft material accumulated at the foundation base followed by a material with higher strength (e.g., weak or weathered rock). The third segment is where the abrupt change occurs similar to FD2 and plots corresponding to P02-04 indicating the existence of competent material or rock that meets the established criteria.

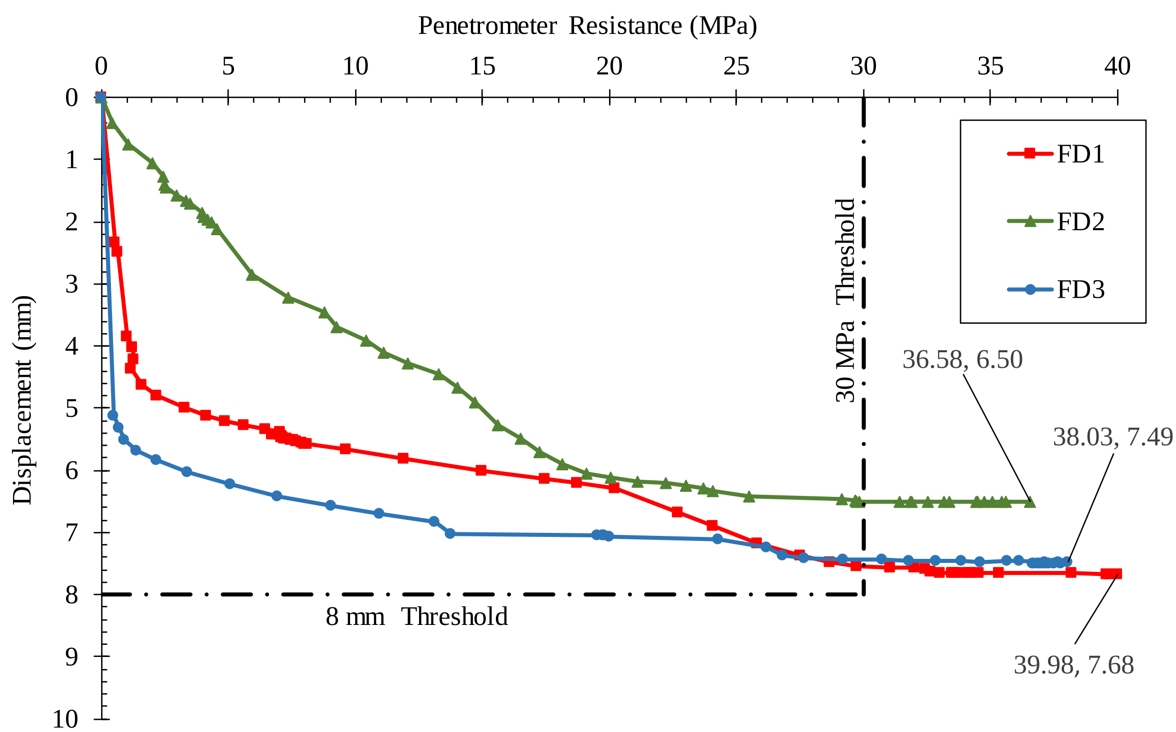

Figure 6. Average stress-displacement at the bottom of the Drilled Pile 02-05

Summary and Conclusions

This paper presented results from SQUID testing two 1016-mm (40-in) diameter open-end drilled piles installed for a vehicular bridge crossing the Seutelva River in Fredrikstad, Norway. These pipes were installed using a down the hole (DTH) hammer system which uses the rotary-percussion drilling method with a button bit and filled with concrete.

The foundation system for the project presented in this paper was designed as end-bearing only where all nominal loads are supported by the foundation's base. However, due to difficult subsurface conditions and the sloping rock, each drilled pile had to be installed at a different base elevation. One of the foundation base material assessment criteria proposed by local authorities was to obtain the material strength and perform the assessment based on the applied stress and measured deformations. In order to obtain such data, the SQUID device and test was selected and completed for two piles identified as P02-04 and P02-05. Results from the SQUID testing showed an average displacement of 7mm (0.28in) corresponding to a 35MPa (5.1ksi) of stress level for P02-04, and 7.2mm (0.28in) corresponding to a stress level of 38MPa (5.5ksi).

The resistance to penetration determined from the SQUID testing is not a correlation to other strength properties defined for soil, intermediate geomaterials, or rock. Therefore, one of the limitations of the SQUID at this time is the lack of correlations with strength parameters determined from laboratory testing such as unconfined compression test. However, in circumstances where access to the pile base is limited and a sampling process is significantly impacting the construction schedule, results such as those obtained from the SQUID could be evaluated qualitatively and quantitatively assessed by qualified geotechnical engineer to further determine the suitability of the tested material.

REFERENCES

FLDOT (2016) *Standard Specifications for Road and Bridge Construction*. Florida Department of Transportation

NCDOT (2012) *Standard Specifications for Road and Structures,* North Carolina Department of Transportation