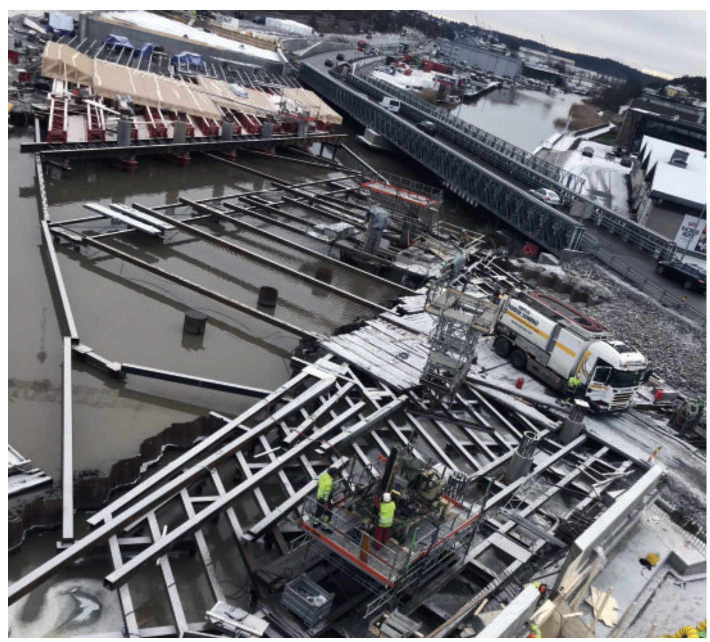
Empirical Assessment of Base Material for a Drilled Pipe Pile

Drilled pipe piles are considered one of the common types of deep foundation used in Norway to support bridge structures. The standard installation practice for these foundation elements is the use of down-the-hole hammers (DTH). Norway's complex geology and difficult subsoil conditions have resulted in a highly variable layering of soil and rock, which, in turn, makes for differences between actual subsurface conditions and those expected from geotechnical exploratory borings. This situation is strongly noted with sloping rock layers. Special testing procedures are required to assess the base material at the tip of drilled piles and to evaluate the rock-foundation contact surface.

Project Description

The project 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 25 ea, 1,016 mm (40 in) diameter open-ended pipe piles advanced to the competent rock layer. Each bridge bent consists of five open-ended pipe piles, which will be filled with concrete after reaching the final base elevation. These piles were installed using a DTH hammer system, which uses the rotary-percussion drilling method with a button bit with its outer diameter being the same as the inner diameter of 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 a drill string.



Aerial view of the project site

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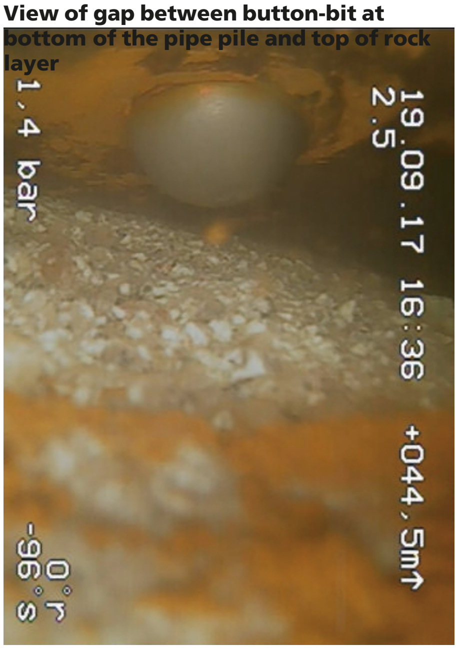
Subsurface Conditions

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 30 m (98.4 ft) followed by 6 m (20 ft) of moraine silt located above the bedrock. The rock formation encountered was sloped, which resulted in a variable thickness moraine silt layer ranging between 6 m (20 ft) and 11 m (36 ft). In general, the reported rock slope increased in steepness from southeast to northwest with several sudden drops and abrupt slope changes.

Drilled Pipe-Piles Base Elevation

The foundation system for the project was designed for end-bearing resistance only, where all of the nominal loads were supported by the base material below the foundations. The following criterion were followed to determine the final base elevation: (1) minimum drilling advance rate of 40 min/m (12.2 min/ft) corresponding to a limit base resistance of approximately 150 MPa (22 ksi) and (2) visual inspection using a down-hole camera to ensure contact between the rock layer and the base of the foundation element. Once the elevation was defined using the drilling rate data, the base of the drilled pile was cleaned using an airlift system, and then a down-hole camera was lowered to inspect the bottom of the pipe to ensure full contact with the rock layer.

View of gap between button-bit at bottom of the pipe pile and top of rock layer



(L) Button driving ring at tip of pipe pile and (R) bottom of a DTH to fit inside pipe pile

For two of the piles located on Bent 2 (piles P02-04 and P02-05), the conditions at the bottom of the pile did not facilitate capturing a clear photo or video to confirm the contact between the base of the foundations 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 (4.35 ksi) with a deformation less than 8 mm (0.32 in) was classified as a competent rock to receive the foundation and to support the loads.

To satisfy this additional criterion, the force and displacement data at the base of the foundation was required to be obtained to evaluate empirically the material located at the base of the pile. If the force and displacements corresponded to agreed upon values (e.g., minimum rock strength of 30 MPa [4.35 ksi] for a maximum displacement of 8 mm [0.32 in]), then the material was considered competent and the final base elevation was confirmed. Force and displacement plots were determined at the base of the pile using a testing device known as the shaft quantitative inspection device (SQUID).

Testing Device and Procedure

A SQUID has an octagonal shape with a maximum diagonal length of 647 mm (25.5 in) and a height of 635 mm (25 in). 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 sq cm (1.55 sq in). For this specific project, conical tips were used with the device.

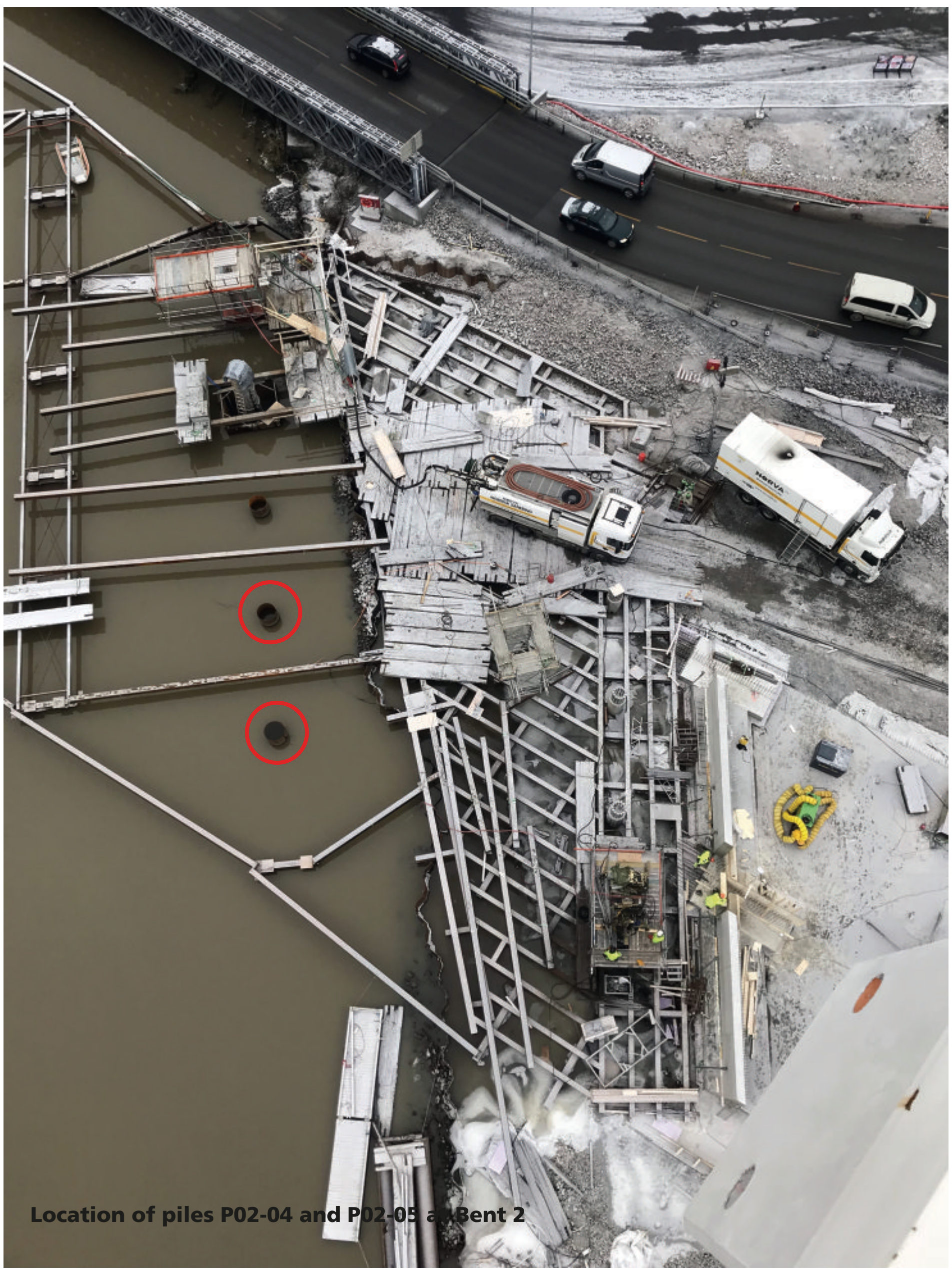
The device was attached to the drill string using an American Petroleum Institute (API) adapter located between the swivel plate and the drill string and was then lowered into the drill pipe to initiate test runs at the base of the foundation. Once the device contacts the base material, an axial force is applied using the crowd (downward thrust) from the drill rig. The resistance to penetration is measured by the penetrometers, while the displacements are measured by the retractable plates.

Drilled Pile P02-04

A total of 10 runs were performed at the base of the pile P02-04 to obtain the data to determine the force-displacement relationship. Each of the applied forces was then divided by the cross-sectional area of the penetrometer to obtain the applied stresses. Stress-displacements plots for pile P02-04 were plotted individually to visualize the force-displacement behavior and to evaluate the criterion established for the material at the base of the foundation. The results obtained for pile P02-04 indicated that each of the three penetrometers follow a similar trend. However, the nonuniform (i.e., not overlapping) plots behavior indicated that the base of the foundation was not completely flat. Furthermore, according to the plotted results, the average stress and displacement for the material at the base of the foundation were determined to be 35 MPa (5.1 ksi) and 7 mm (0.28 in), respectively. These values were within the established resistance and displacement thresholds for the competent material at the base of the foundation.

It is important to note that FD1 plot slightly exceeds the displacement threshold limit of 8 mm (0.32 in) with a stress value of about 24 MPa (3.5 ksi) and a maximum stress of 34 MPa (5 ksi). However, the other two plots (FD2 and FD3) are within the established threshold values. Another important observation is the similarity in the shape of the relationships from the start of the test up to approximately 10 MPa (1.45 ksi) where a steady increasing slope is observed. Beyond this point, the relationships transition to a more constant and gentler slope with increasing stress, which may indicate an abrupt change in material property possibly indicating going from softer rock to more competent rock. However, a visual inspection using a down-hole camera, as discussed above, did not reveal softer material accumulated near the base of the foundation. Therefore, the existence of a softer rock versus a more competent rock is more likely to be the case at this location.

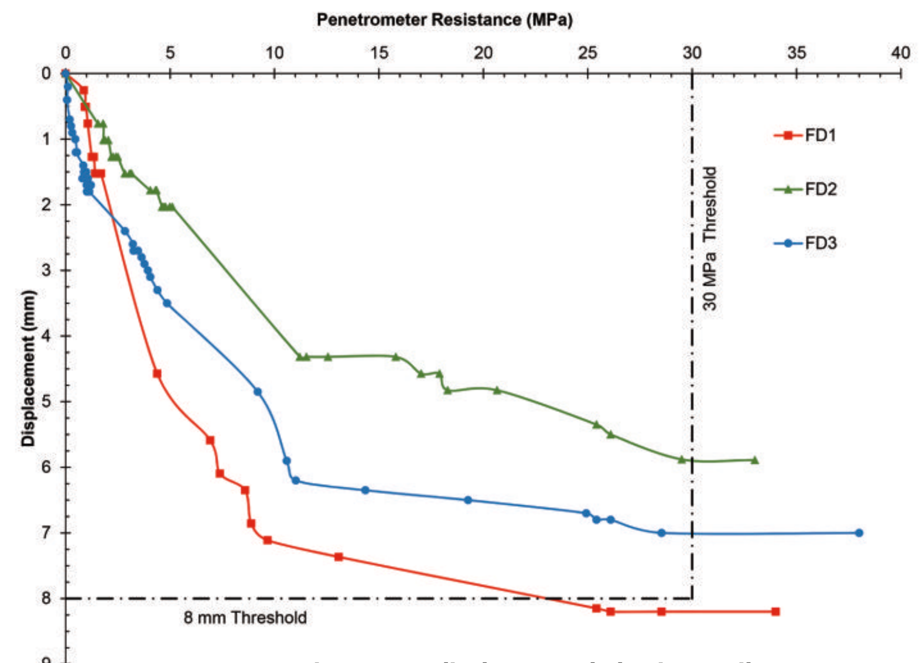
Attachment of the device to the end of a drill string



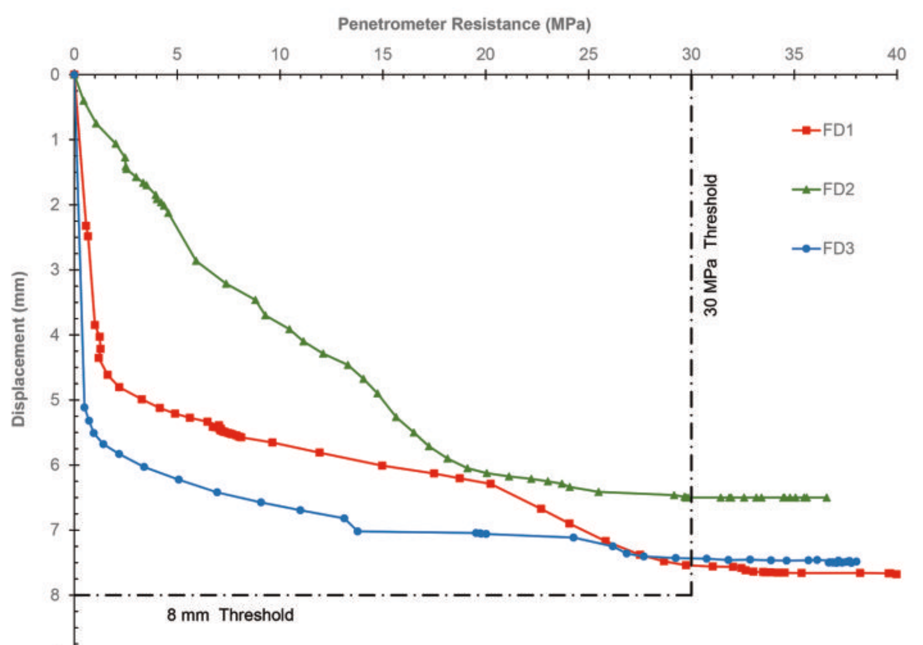
Location of piles P02-04 and P02-05 at Bent 2

Drilled Pile P02-05

Similar to those performed at pile P02-04, a total of 13 runs were performed at the base of pile P02-05 to obtain the data to determine the force-displacement relationships. The graphs of the stress-displacement relationships were analyzed to evaluate the behavior of the material encountered at the base of the foundation. The results indicated that each of the three penetrometers follow a similar trend, especially toward the end of the test. Similar to the tests at pile P02-04, a nonuniform material at the base of the foundation was detected, which was evident from the plots as the individual graphs were not overlapping. Considering the maximum stress measured by each



Penetrometer resistance vs. displacement behavior at pile P02-04



Penetrometer resistance vs. displacement behavior at pile P02-05

penetrometer and the corresponding displacements, the average stress and displacement for the material encountered at the base of the foundation were determined to be about 38 MPa (5.5 ksi) and 7.2 mm (0.28 in), respectively.

It is important to note that trend of FD2 is different compared to FD1 and FD3. The relationship for FD2 indicates a linear behavior with a constant slope up to a stress value of approximately 20 MPa (2.9 ksi) when the abrupt change of slope occurs. From this point forward, the relationship flattens to an almost zero slope with increasing stress along with a very small change in displacement. The relationships for FD1 and FD3, on the other hand, follow a similar shape to each other and can be divided into three segments: (1) a steep slope from a stress of 0 to about 1.7 MPa (0.25 ksi), then (2) a small slope between 1.7 MPa (0.25 ksi) and 29 MPa (4.2 ksi), and then (3) a near zero slope after 29 MPa (4.2 ksi). The first portion of these plots could correspond to a very soft material accumulated at the base of the foundation, which is then 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 the graphical relationship (similar to pile P02-04) indicates the existence of competent material or rock that satisfies the established criteria.

Conclusions

The foundation system for the project was designed for end-bearing resistance only, where all of the nominal loads were to be supported by the foundation's base. However, due to difficult subsurface conditions and sloping rock, each drilled pile was terminated at a different base elevation. One of the assessment criteria for the material at the base of the foundation was to obtain the material strength and perform the assessment based on the applied stress and measured deformations. To obtain such data, the SQUID, along with its associated testing procedure, was utilized to perform penetration tests at two pile locations, P02-04 and P02-05. Results from the testing indicated an average displacement of 7 mm (0.28 in) and 7.2 mm (0.28 in) corresponding to a stress of about 35 MPa (5.1 ksi) and 38 MPa (5.5 ksi) for Piles P02-04 and P02-05, respectively.

The resistance to penetration determined from SQUID testing is not a correlation to other strength properties defined for soil, weak rock or rock. However, in circumstances where access to the pile base is limited and a sampling process significantly impacts the construction schedule, results such as those obtained from this testing device could be qualitatively and quantitatively assessed by a qualified geotechnical engineer to further determine the suitability of the tested material.

Rozbeh B. Moghaddam, P.E., Ph.D., M.B.A., is a senior engineer at GRL Engineers. His academic research and more than 15 years of professional experience have included a significant focus on geotechnical design of deep foundations, retaining structures, excavations and underground structures. He is a member of DFI, ASCE (with active participation in the Geo-Institute's technical committees) and the Mexican Society of Geotechnical Engineers (SMIG).