LATERAL PERFORMANCE OF HOLLOW BAR MICROPILE IN COHESIONLESS SOIL

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Hollow bar micropiles are increasingly used to support a variety of structures due to their fast installation and effective load transfer due to associated ground improvement. However, their lateral capacity is relatively small due to their small cross – sectional area. In this study, a full–scale micropile was installed in cohesionless soil and was subjected to monotonic lateral load test. The micropile was 115 mm in diameter and 6m in length. The soil at the test site was medium dense to dense sand. The test results are presented and discussed in terms of load – displacement curve. In addition, the micropile behavior during the test was analyzed numerically utilizing the program LPILE and the results are compared to the load-horizontal displacement curve obtained from the full-scale load test.

Keywords: Hollow bar micropile; Lateral loading; Cohesionless soil.

INTRODUCTION

Micropiles are increasingly used as a preferred foundation option in different civil projects to carry a considerable axial load but moderate lateral load. Federal Highway Administration (FHWA 2005) classifies micropiles into four main categories according to their grouting technique: Type A, the grout is placed under gravity; Type B, the grout is installed under pressure ranging from 0.5 to 1 MPa; Type C, initial grout is poured under gravity and then similar grout is pressurized before the hardening of the initial grout; and Type D, where initial grout is placed under gravity then before hardening of the initial grout, additional grout is pressurized at 2 to 9 MPa through sleeved pipe by using packers.

Recently, hollow bar micropiles were introduced as an efficient micropile construction technique where drilling and grouting are done in one step, eliminating the need for casing. The construction of hollow bar micropile starts with advancing a threaded hollow bar utilizing a drilling bit and drilling grout to the predetermine level and then the grout is pressurized through the nozzles of the drill bit.

Richards and Rothbauer (2004) compared the results of lateral load tests performed on micropiles installed as part of eight different projects to the predictions of the methods recommended by NAVFAC and CLM as well as that predicted from LPILE analysis. They concluded that the LPILE results compared well with the measured responses while the deflections obtained from CLM or NAVFAC methods were significantly less than the measured values. They indicated that the soil properties along the top 2 to 5 m controlled the response of the micropile.

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Long et al. (2005) reported the results of lateral load tests on micropiles installed in medium-strength clay overlying sand. The micropiles were installed to 15.2 m depth and reinforced with a high-strength threaded bar. The upper 9 m was stiffened by steel casing with 224 mm outer diameter and 13.8 mm thickness. The measured horizontal displacements were compared to the predicated values obtained from LPILE software. They concluded that the measured and predicated load-displacement curves agreed well with difference less than 10 percent. Abd Elaziz and El Naggar (2015) studied the performance of hollow bar micropiles under monotonic and cyclic lateral loads installed in stiff silty clay. The load test results were employed to calibrate a numerical model that was used to perform a parametric study. They concluded that the properties of soil along a depth of 10 times the pile diameter govern the load-displacement curve. They demonstrated the ability of hollow bar micropiles to carry moderate lateral loads with appropriate reinforcement configuration and pile head fixity.

SITE INVESTIGATION

An extensive site investigation was performed that included both in-situ and laboratory testing. Three mechanical boreholes were drilled to various depths using hollow stem auger of 130mm, followed by standard penetration test (SPT). Samples were extracted using split spoon sampling method and transported to the laboratory for further testing. Four CPT soundings were performed across the site. Figure 1 shows the SPT results for BH1 and BH2, including N values and water content for different soil layers. The first 400 mm consists of granular fill with some gravel and recycled asphalt overlaying a layer of very dense sand up to 11m below ground surface. Seams of silt and silty clay were observed at different levels. The ground water table was observed between 9.5 to 10.5m below ground surface. The average cone resistance corrected for pore water pressure (q_t) ranged from 10 to 30 MPa in the upper 6.5m and 30 to 45 MPa from 6.5m to 8m followed by a decrease in (q_t) with an average of 20 MPa.

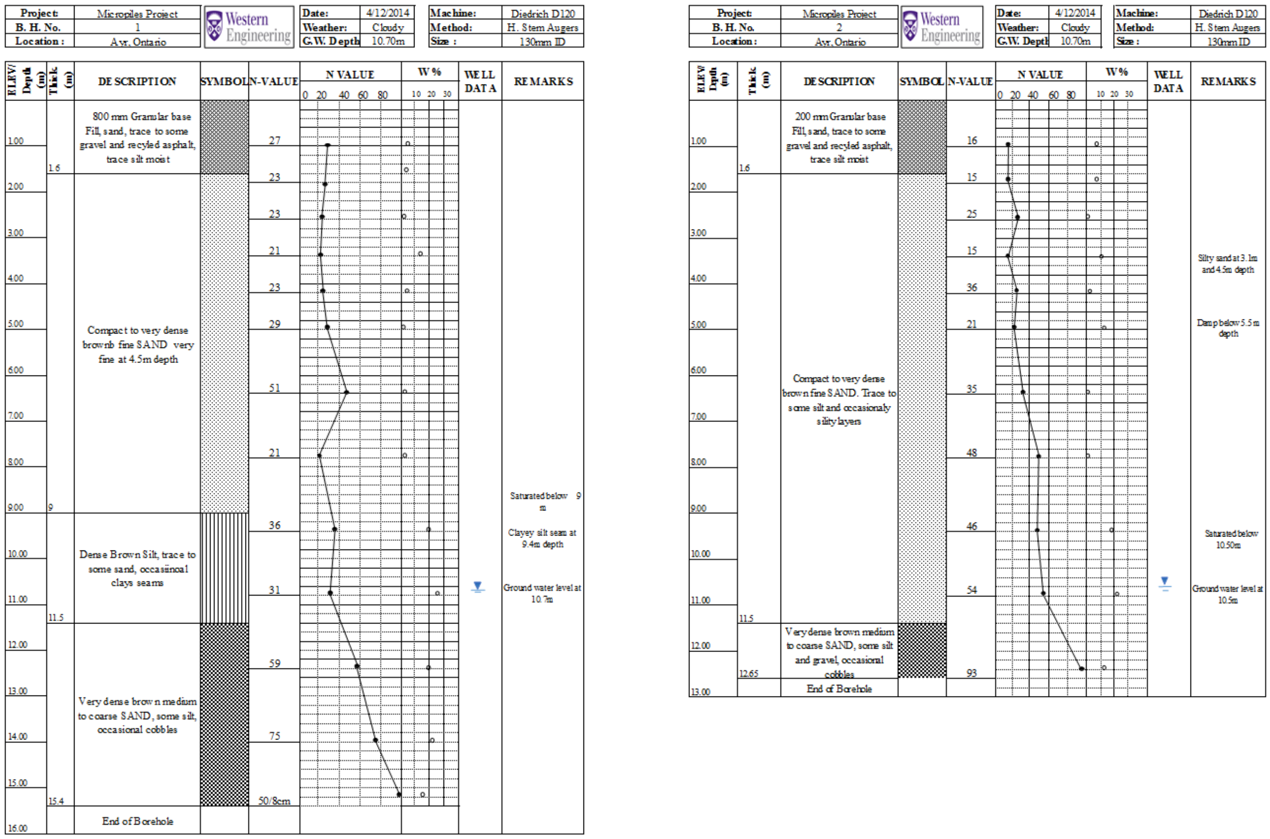

Fig 1. Boreholes 1 & 2, SPT N Value and water content.

MICROPILE MATERIALS AND INSTALLATION.

Six self-drilling hollow bar micropiles R51N were installed using an Ingersoll Rand ECM-350 drill rig. The outer diameter of the hollow bar was 51 mm and the inner diameter was 33 mm. A Tungsten carbide cross cut drill bit was used as an excellent choice for granular soils. Figure 2 presents a plan view of the micropiles locations in the test site. Six micropiles were constructed and tested. In this paper, the test results of only one micropile, denoted MP4 is presented. MP4 was installed using drill bit with 115 mm diameter. The diameter ratio of drill bit/ hollow bar (D_b/D_h) is 2.25. The total length of the micropiles is 6m with 5.75m embedded length.

The drill bit attached to the hollow bar was positioned in the predetermined location. The verticality of hollow bar was ensured by attaching a 1m-long magnetic water level to the hollow bar. Rotary percussive drilling was employed simultaneously with grout flushing technique. A Nonstructural grout with specific gravity between 1.4 and 1.5 was employed as drilling fluid to drill the hole to the required depth. Once the first segment of the hollow bar was installed, coupler was attached to allow the second segment to be installed. Upon completion the drilling, structural grout with specific gravity between 1.80 and 1.95 was injected at a pressure of 0.8 to 1 MPa. Grout cylinders were collected during the installation and were transported to a control room with a relative humidity of 100% and constant temperature of 23ºC. The average compressive strength after 28 days of the grout cylinders was 40 MPa and the average spilt tensile strength was 3.97 MPa. The compressive strength was determined according to ASTM C39 and the tensile strength was obtained in according to ASTM C496. The compressive strength meets the minimum requirement (28 MPa) set by FHWA (2005).

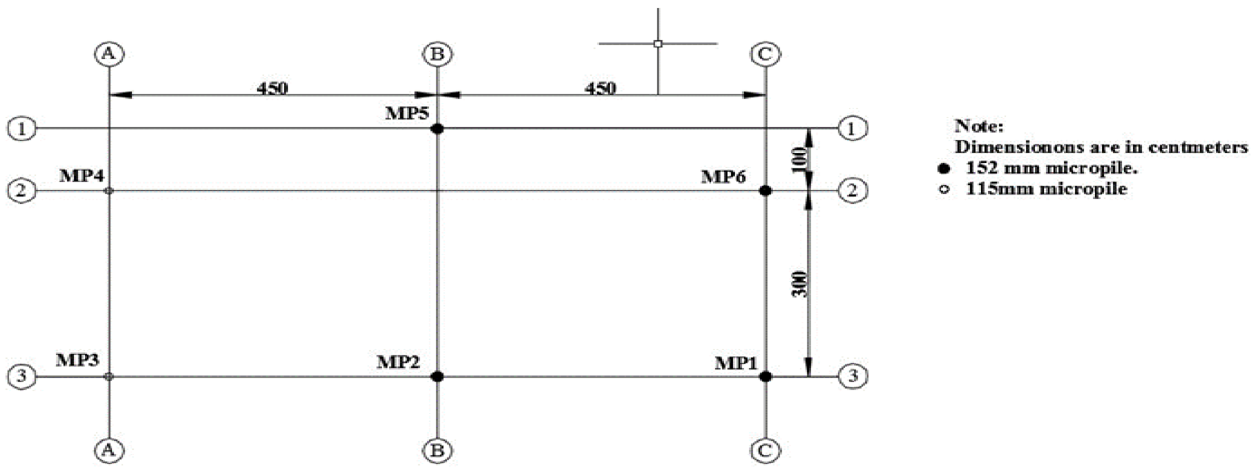

Fig 2. Plan view of micropiles locations.

TEST SETUP AND PROCEDURES.

A special loading system was designed and fabricated to apply the lateral loading to the micropile head. It consisted of a steel rod connecting the hydraulic jack to the micropile head; the steel rod was hinged to the pile head to ensure a free head condition. The load applied by the hydraulic jack was measured using a load cell that was connected to the loading system. Four HLP 190 linear potentiometers were employed to record the horizontal pile head movement and their average value was taken. The HLP 190 has 100 mm stroke and an accuracy of 0.01 mm. The potentiometers were attached to the loading steel plate in a square arrangement and clamped to an independent reference heavy steel beam.

The load was applied monotonically to the micropile head in increments of 3 kN. The load was maintained for 5 minutes for each loading increment. The load was increased until excessive settlement was observed.

TEST RESULTS AND ANALYSIS.

The load – displacement curve for MP4 is presented in Figure 3. The lateral response of the micropile exhibited two main regions: linear elastic response until about 3.5 mm displacement, which corresponds to about 3 % of the micropile diameter; and a non-linear behaviour extended to the test termination.

Two different mechanisms can define the pile failure: failure due to yielding of surrounding soil along the pile length, which is also called short pile behavior; or failure due to yielding of the pile materials when the maximum applied moment reaches the moment capacity of the pile, which is known as long pile behavior. Bierschwale et al (1981) used the slenderness ratio to define the pile rigidity and hence potential failure mechanism. The pile is short if its slenderness ratio is less than 6, while the long pile has slenderness ratio greater than 20. According to this criteria, MP4 is considered a long pile as it has a slenderness ratio of 44.

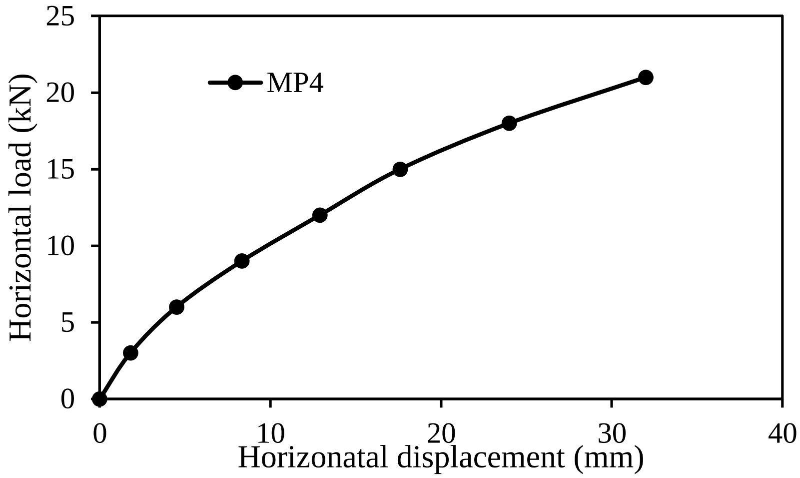

Fig. 3. Load – horizontal displacement curve for MP4.

Several interpretation criteria of ultimate lateral capacity of piles are presented in the literature. Five methods are compared in this paper: three are based on displacement limits, including McNulty (1956), Walker and Cox (1966), New York City (1981); and two are based on the displacement as function of pile diameter, i.e., Pyke (1984) and Briaud (1984). Table 1 summarizes the ultimate capacity according to these methods. It should be noted that the micropile diameter increased by 12.8 % over the drill bit diameter and is taken as 132 mm based on the real measurement of exhumed micropile diameter adjacent to MP4 and the top 2 m of MP3.

Table 1. Interpreted lateral failure loads for MP4

Method	Definition of failure load	Failure load (kN)
McNulty (1956)	Load at 6.25 mm head displacement	7.30
Walker and Cox (1966)	Load at 13.0 mm head displacement	12.10
New York City (1981)	Load at 25.0 mm head displacement	18.40
Pyke (1984)	Load at 5% the shaft diameter	7.50
Briaud (1984)	Load at 10 % the shaft diameter	12.10

Lpile computer software (Ensoft, 2006) was used to simulate the lateral response of hollow bar micropile installed in sand. Lpile utilizes the p-y curves approach assuming the pile acts as beam-column, representing the soil by nonlinear Winkler springs. The load-horizontal displacement curve obtained using Lpile software was calibrated using the load-horizontal displacement curve obtained from the field data. The hollow bar micropile was modeled in Lpile as round shaft with permanent casing and core. As the hollow bar micropile was installed without casing, the casing wall thickness in Lpile was set to zero. As the micropile was installed in cohesionless soil, sand model (Reese et al 1974) was utilized. The soil and pile properties were obtained from the results of the site investigation and the laboratory tests on grout cylinders. Figure 4 compares the results obtained from the calibrated Lpile model with the field test results. As it can be noticed from Fig. 4, there is a good agreement between the measured and calculated responses. Lpile results show a stiffer response for the first two load increments. However, the measured response was slightly stiffer than the calculated response at higher loads.

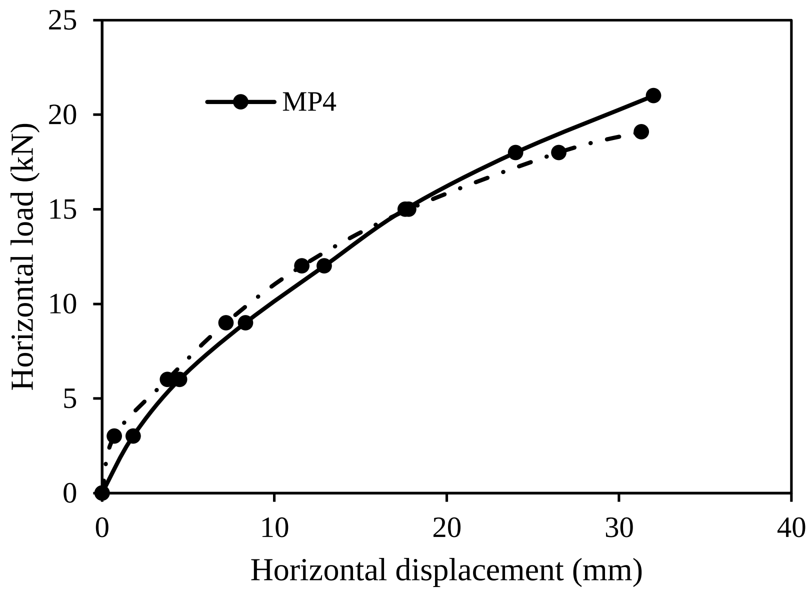

Fig. 4. Comparison between the field data and LPILE results.

Lpile can be utilized to calculate the deflection, bending moment and shear along the entire pile depth. Figure 5 (a and b) shows the micropile deflection and bending moment results obtained from Lpile model along the depth of the micropile. Figure 5 (a) indicates that the micropile behaves as long flexible pile and the top 1.0 m (about 8 micropile diameters) experienced lateral deflection, which indicated that the properties of the soil along the top 8 micropile diameter have an important influence on the lateral behavior of the hollow bar micropile installed in cohesionless soil. Lpile model was calibrated using the filed load test results and the maximum moment was about 8.9 kN.m. The analysis shows that the plastic hinge was developed at about 5 times the micropile diameter depth.

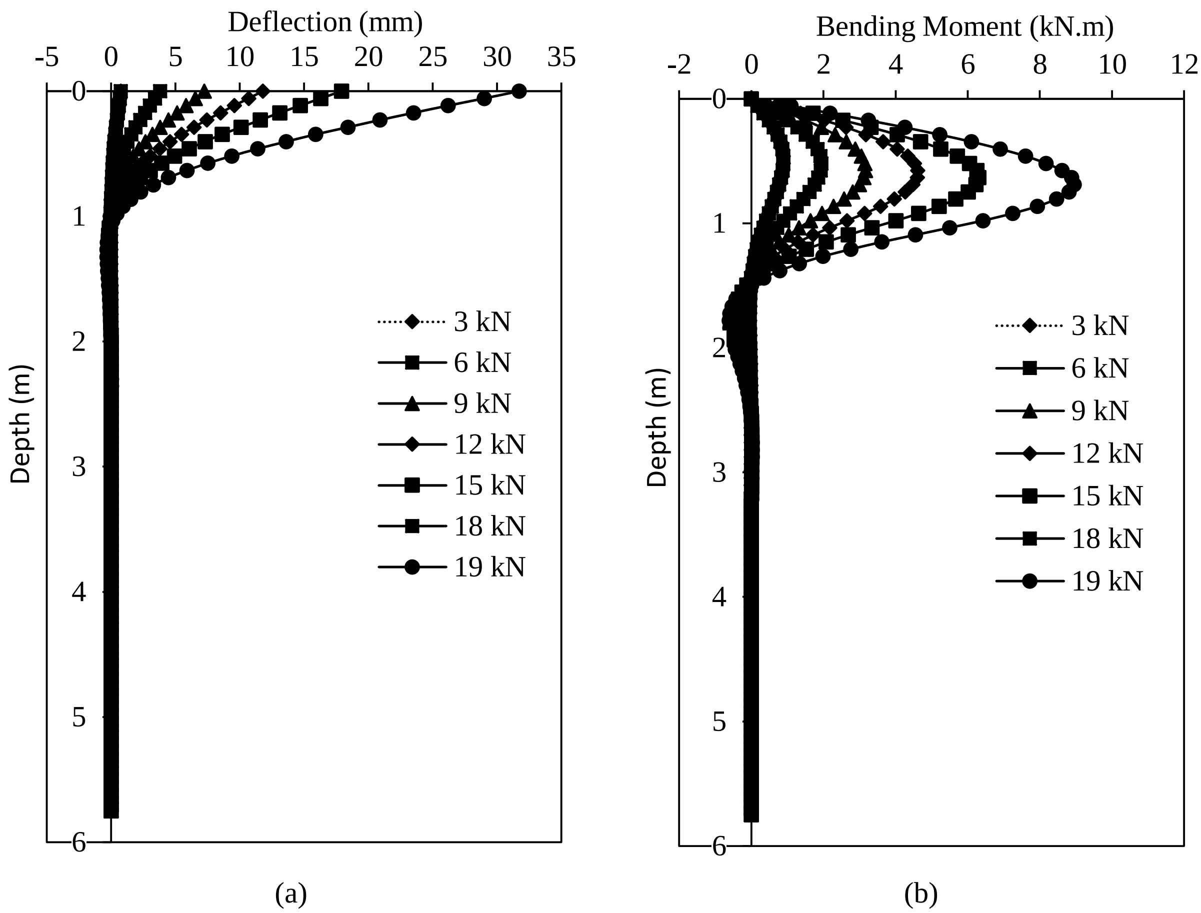

Fig. 8. Deflection and bending moment along the micropile depth.

SUMMARY AND CONCLUSIONS

A full-scale lateral test was conducted on a hollow bar micropile with D_b/D_h ratio of 2.25. The OD of the hollow bar was 51 mm and the ID was 33 mm. The drill bit diameter was 115 mm. The behavior of hollow bar micropile under lateral load was investigated and a numerical model using Lpile software was developed. The ultimate interpreted capacity was calculated using different methods and was compared with the predictions from LPILE analysis. The micropile did not show any sign of failure up to lateral deflection of 25 mm. Accordingly, the ultimate lateral capacity can be taken as the load corresponding to 25 mm lateral displacement with a factor of safety of 2 for the design purpose. Similar observations were made from testing the other micropiles

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