Behavior analysis of post-grouted micropiles in clay soils from tension load test results

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ABSTRACT

The design of micropiles is carried out through semi - empirical equations developed from field tests and previous experiences. This design represents an approximation of the real soil - micropile behavior and generates uncertainty since the design involves the ultimate micropile bond strength which is selected as a function of the type of micropile and soil characteristics and presents a broad range of values leading to a wide range of micropile resistances for the same conditions. Therefore, the standards recommend verifying and determining the field capacity of the micropile designed by static load tests, which are real-scale tests that allow knowing the field behavior between the built micropile and the ground. In the present paper, the analysis of the behavior of three different type D post-grouted micropiles was carried out through the results of static tension load tests following the FHWA NHI-05-039 "Micropile Design and Construction" standard, the geotechnical characteristics of the area were considered in the verification of the design and with the results of the load tests an analysis of the acceptance criteria recommended in the aforementioned standard was performed.

Keywords: Deep foundation, micropile, post-grout, load test.

1 INTRODUCTION

The interaction between the soil and a deep foundation has been an uncertainty for the professionals of the area for many years since the calculation methods to determine the theoretical capacity of this element are given by equations developed in a semi-empirical way, these methods are an approximation of the real behavior between the soil and the structure.

Poulos and Davis (1980) indicated that the installation method of a pile will have profound influence on its behavior and the nearby soils and structure. The behavior of a built post-grouted micropile depends on the construction methodology and the stress changes in the surrounding soil induced by the drilling and post-grouted phase that are essential to better understand and predict the performance of the micropile under loads. Consequently, static load tests are executed to determine the real performance of the micropile during the application of loads through the recording of displacements on the head of the micropile that are plotted and evaluated considering acceptance criteria given by standards and, in this way, the assumptions and decisions taken during the design stage are verified.

2 MICROPILES

2.1 Definition

The standard FHWA NHI-05-039 "Micropile Design and Construction" defines micropiles as a structural element similar to piles, but with a small diameter (typically less or equal than 30 centimeters) that have a steel reinforcement that can be several bars or a single tubular steel bar.

2.2 Classification

In 1997, the FHWA published the report FHWA-RD-96-016, -017, -018, and -019; 1997 summarizing the state of the use and execution of micropiles. A classification system was developed which is based on two criteria. The philosophy of its behavior (design) and the method of concreting (construction). The first imposes the micropile design method and the second defines the resistance or capacity that the micropile will have.

According to the concreting method, micropiles can be (Figure 1):

- Type A micropiles are concreted under gravity. The mortar is poured over the entire length of the micropile only by the gravity. This technique is very uncommon.
- Type B micropiles are concreted under pressure, in addition, it uses a temporary casing which is extracted while the micropile is filled with mortar. Pressures from 0.5 to 1 MPa are applied to avoid cracks in the soil around the micropile to maintain the shape of the same while the temporary casing is removed.
- Type C micropiles undergo two processes, concreting and post-grouting. Concreting is carried out under gravity actions such as Type A; and the post-grouted process is applied through valves in a tube inside the micropile. These valves are open at pressures less than 1 MPa.
- Type D micropiles also undergo two processes very similar to Type C. This type of micropiles is concreted under gravity and pressure is exerted during the extraction of the temporary casing. The post-grouted process is accomplished through an internal tube with valves which are open at pressures from 2 to 8 MPa, these valves are located at a certain and known position in order that the micropile can be post-grouted as many times as required.

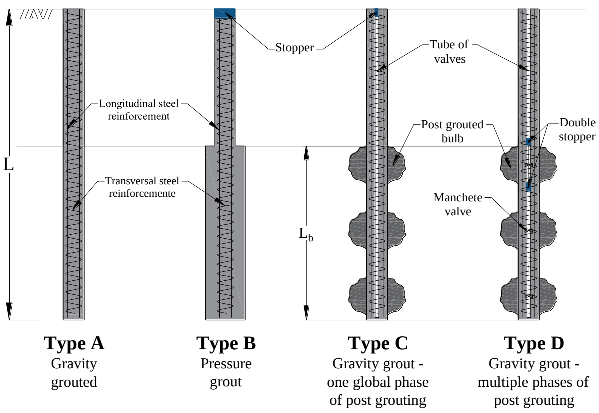

Fig. 1. Classification of micropiles according to the constructive method.

3 COMPRESSION CAPACITY

For post-grouted micropiles, the design is generally controlled by structural considerations. Additionally, the post-grouted process that applies large grout pressures along the micropile generates bulbs that substantially increase the bond or shaft resistance of the micropile.

For the present study, only the shaft capacity was considered for the analysis because the post-grouted micropile represents a small transverse area and this was not founded on rock.

The capacity of the micropiles was obtained from the following equations and tables exposed in AASHTO (2014) LRFD Bridge Design Specification (2014) (Table 1 and Table 2):

$$R_R = \emptyset_{qp} R_p + \emptyset_{qs} R_s \quad (1)$$

$$R_p = q_p A_p \quad (2)$$

$$R_s = q_s A_s \quad (3)$$

Where:

R_R: Capacity of the micropile
R_p: Nominal capacity of the tip
R_s: Nominal capacity of the shaft
$\o_{qp}$: Resistance factor for nominal tip resistance
$\o_{qs}$: Resistance factor for nominal bond resistance (Table 1)
q_p: Unit tip resistance
q_s: Unit bond resistance
A_p: Area of micropile tip
A_s: Area of the bond surface

$$R_s = \alpha_b \pi d_b L_b \quad (4)$$

Where:

α_b: Ultimate micropile bond strength
d_b: Diameter of the micropile
L_b: Micropile bonded length

Table 1. Resistance factors for geotechnical resistance of axially loaded micropiles (AASHTO LRFD Bridge design specifications, 2014)

Limit State	Method / Ground Condition	Resistance factor
Compression resistance of a micropile	Lateral resistance (bond resistance)	0.55
	Tip resistance on rock (O'Neill and Reese 1999)	0.5
	Lateral resistance and tip resistance Load test	Values not greater than 0.70 (1)
Block failure	Clay	0.6
Uplift resistance of single micropile	Presumptive values	0.55
	Tension load test	Values not greater than 0.70 (1)
Group uplift resitance	Sand and clay	0.5

(1) Values in Table 10.5.5.2.3-1 in AASHTO LRFD Bridge design specifications, 2014.

4 METHODOLOGY

The present study began with the collection of information (soil studies, bibliography about the design of micropiles and load tests) about a project that consisted of the construction of deep foundation in the city of Cochabamba, Bolivia. With this information and the data collected, the design of the postgrauted micropiles was carried out.

In January 2018, the construction of post-grouted Type D micropiles of 11 meters length and 30 centimeters in diameter were executed. During the construction of these, tension load tests were performed on three different micropiles according to the FHWA standard NHI 05 - 039, with differences in their characteristics. The data obtained during these load tests were processed and the results were used to verify the design by means of the acceptance criteria mentioned in the standard, moreover, to analyze the behavior of the micropiles considering the design load (500 kN) and the differences of the three tests.

Table 2. Typical α_b values (Grout to ground bond) for micropile design. (FHWA Micropile design and construction, 2014)

Description of soil / rock	Ultimate micropile bond strength (kPa)			
	Type A	Type B	Type C	Type D
Silt and clay (presence of sand) (soft, medium plastic)	35-70	35-95	50-120	50-145
Silt and clay (presence of sand) (stiff, dense to very dense)	50-120	70-190	95-190	95-190
Sand (some silt) (fine, loose-medium dense)	70-145	70-190	95-190	95-240
Sand (some silt, gravel) (fine-coarse, medium to very dense)	95-215	120-360	145-360	145-385
Gravel (some sand) (medium to very dense)	95-265	120-360	145-360	145-385
Glacial till (silt, sand, gravel) (medium-very dense, cemented)	95-190	95-310	120-310	120-335
Soft Shales (fresh-moderate fracturing, little to no weathering)	205-550	N/A	N/A	N/A
Slates and Hard Shales (moderately fresh and fracturing)	515-1380	N/A	N/A	N/A
Limestone (fresh-moderate fracturing, little to no weathering)	1035-2070	N/A	N/A	N/A
Sandstone (fresh-moderate fracturing, little to no weathering)	520-1725	N/A	N/A	N/A
Granite and basalt (fresh-moderate fracturing, little to no weathering)	1380-4200	N/A	N/A	N/A

5 PROJECT FEATURES

5.1 Geotechnical conceptual model

The geotechnical conceptual model is the idealization of the characterization and determination of soil resistance parameters from field tests (SPT) and laboratory tests. In the present project five SPTs were executed up to 20 meters with sample extraction every 1.50 meters. The blown counts for each SPT is shown in Figure 2.

Characterization of the soil, consolidation, specific gravity and triaxial tests were carried out with these samples.

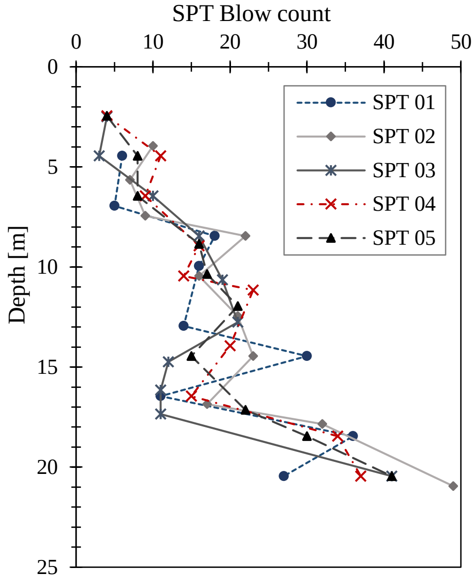

Fig. 2. Geotechnical model of the project area.

The project area was superficially shaped by filling material (gravel and boulders) until 2 meters deep (see Figure 3). The water table was found at 1.5 meters depth. Following this filling layer, the second geotechnical unit was identified, which went from 3 to 8 meters, as lean clay of low plasticity interspersed with thin strata of silt and sand. From the 8 meters to the 15 meters, the lean clay of low plasticity persisted improving its geotechnical characteristics, presenting a consistency that goes from consistent to very consistent. The fourth geotechnical unit was between 15 and 18 meters depth, highlighting the remarkable change in the type and quality of the soil. This stratum was made up of fatty clays (group CH) of high-plasticity and the last geotechnical unit which was from 18 to 21 meters depth presented better geotechnical conditions, silty sands of the SM group predominated interspersed with strata of sandy silts.

5.2 Characteristics of the post-grouted micropiles

The characteristics of the three post-grouted micropiles tested in tension load tests were:

- Type of micropile D
- Diameter of 30 centimeters
- Total length of micropile of 11 meters
- Post-grouted length of 8 meters with a separation of 1 meter between each grout valve

In the grout stage, during the construction of the micropiles, it has been recorded the volume of grout for each micropile that can be seen in Table 3.

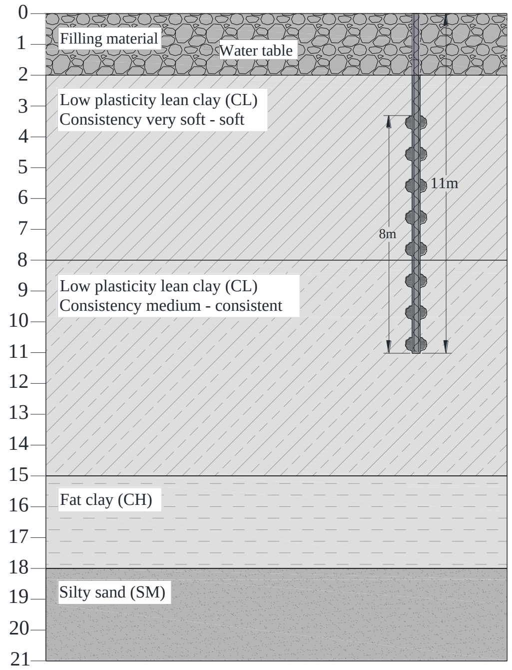

Fig. 3. Geotechnical model of the project area.

Table 3. Volume of grout.

Micropile	Grout volume (m3)
PC1	0.44
C49-1	0.60
C59-1	0.33

5.3 Micropile bond resistance

Applying the equations, considering the type of soil and the dimensions of the micropiles built, the following results were obtained which depends on the ultimate bond resistance (α_b). Results are shown in Table 4.

Table 4. Bond resistance and micropile capacity calculations.

α_b (kPa)	R_s (kN)	R_R (kN)
50	376.99	207.35
73.75	556.06	305.83
97.5	735.13	404.32
121.25	914.21	502.81
145	1093.28	601.30

In Table 4, it can be observed that the length of 11 meters considered in the design satisfies the design load depending on the value of α_b adopted, for certain values of α_b the micropile resistance is major than the design load ($R_R \geq 500$ kN) and for other values of α_b, this condition is not met.

In Figure 4 it can be seen that the values of α_b assumed for RR ≥ 500 kN are values higher than 120 kPa (right side of the red line in Figure 4), otherwise, the capacity of the micropile (RR) will be less than the design load (left side of the red line).

The correct choice of αb is essential to design micropiles. Nevertheless, the ranges of values presented in Table 2 are too large and create uncertainty at the moment of assuming a value of α_b that best represents the type of soil in the project area.

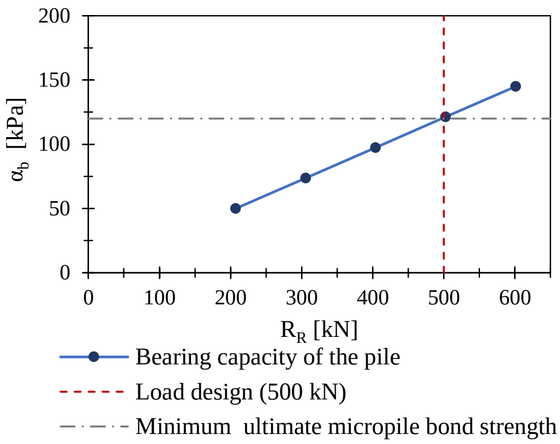

Fig. 4. Micropile capacity as a function of the ultimate bond resistance

6 TENSION LOAD TEST

Fig. 5. Tension load test executed.

The procedure of the static tension load test carried out in this project applied the recommendations of the FHWA NHI-05-039 "Micropile Design and Construction" standard in chapter 7 (Micropile load testing). The type of load test executed was the proof test.

Three load tests were carried out in the post-grouted micropiles PC1, C59-1 and C49-1 (Figure 4), the last two post-grouted micropiles are part of the foundation of the building and the micropile PC1 was built exclusively for load testing. The tension loads were applied to each one of the micropiles though post tension cables that were installed inside the micropiles while they were concreted. Hydraulic jacks were used to apply the required stresses to the head of the micropiles. Figure 5 shows the setup of the load test where it can be seen a reaction steel beam and the hydraulic jack.

During the tension load tests, the displacements were recorded from extensometers that were installed in the head of the micropiles. This data obtained was processed and graphs of deformations as a function of loads applied were plotted (Figure 6).

7 ANALYSIS OF THE RESULTS

It was stablished that the maximum deformation that each micropile must suffer when the design load is applied is 5 mm according to calculations of the engineer responsible for structure design. The deformations obtained when 500 kN were applied in each load test are shown in Table 5.

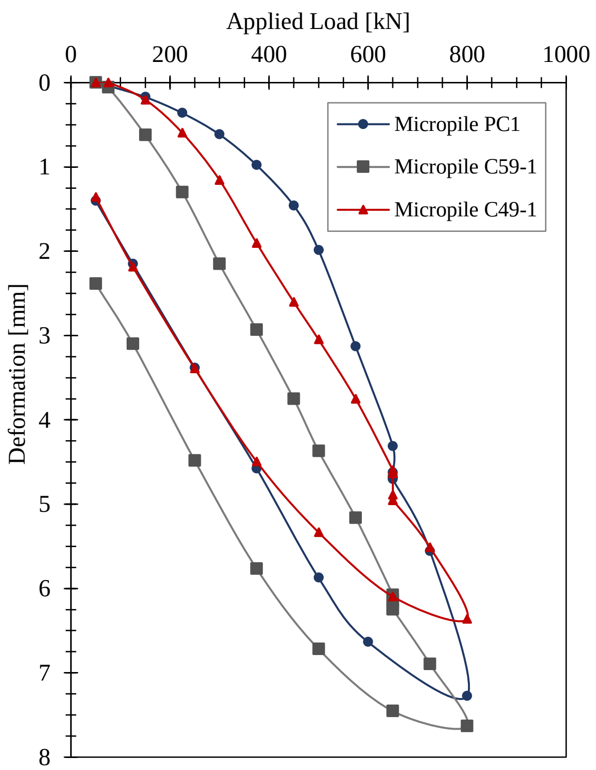

Fig. 6. Results of the load tests.

Table 5. Summary of the deformations for the load design during the load tests.

Post-grouted micropile	Deformation (mm)	Condition
PC1	1.99	Accomplish
C49-1	3.05	Accomplish
C59-1	4.37	Accomplish

All the post-grouted micropiles met the criterion of the total movement of the head of the micropile due to the design load, none in any case exceeding the maximum of 5 mm. The deformations during the creep test must not exceed 1 millimeter, these deformations are shown in Table 6. All the post-grouted micropiles met the criterion of the total movement of the head of the micropile at sustained load, none of them reached the maximum of 1 mm during the application of the sustained load (creep test).

Table 6. Summary of the deformations for the creep test during the load tests.

Post-grouted micropile	Deformation (mm)	Condition
PC1	0.39	Accomplish
C59-1	0.17	Accomplish
C49-1	0.36	Accomplish

The three micropiles tested in load tests accomplish the requirements that the standard demands, therefore, they were accepted, and it was verified that the design made is sufficient for the project design load.

From the graphs of displacements as a function of applied loads (Figure 6) it can be seen that the curves present some differences. The curve of the micropile PC1 presents stiffer behaviour for the first load stages. It can be seen that the curves for micropile C49-1 and micropile C59-1 present similar stiffness during the loading and unloading phase. There are certain differences between the displacements which are lower for the micropile C49-1 at the maximum load of 800kN. This phenome can be related to the fact that this micropile has greater volume of grout.

8 CONCLUSIONS

The design of a post-grouted micropile has been verified starting with the interpretation of the available soil study, in the verification of the design, the capacity of the micropile was obtained in a range of 200kN and 600kN being the design load 500kN. The calculated capacity variation of the micropile is due to the fact that it is sensitive to the ultimate bond resistance (α_b), which is determined from Table 2 and shows large ranges of it. Adopting the value of the ultimate bond resistance generated uncertainty in the design of the post-grouted micropile. To verify the design and, therefore, the selection of the value of α_b it was necessary to realize a static load test.

Three tension load tests were carried out in different post-grouted micropiles meeting all of them the acceptance criteria. However, the results of the load tests shown in the graphs of deformation as a function of load present differences in the behaviour of the micropiles that can be affected for geotechnical aspects as the type of soil where each pile was built and constructions aspects as the amount of concrete and grout of each pile.

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