Instrumented micropiles load tests at future Bridge El Salvador - Guatemala: some insights.

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Abstract

The government of El Salvador is currently building a new bridge to connect the frontier between El Salvador and Guatemala in the Hachadura / Pedro de Alvarado sector. Due to ground conditions principally gravel and boulders, micropile foundations were designed to carry the loads of two abutments and two piers along the bridge. The micropiles consisted of cement slurry reinforced with a steel pipe. The micropiles have an overall diameter of 24-26 cm and depths from 19 to 24 m. Two static load tests (SLT) were executed at each margin of the river on non-definitive locations to an ultimate load of 3 MN. The piles were instrumented with LVDTs and dial gauges to measure the head and toe settlement, and with strain gauges for account for the load distribution at several levels. In this paper, the results of these tests will be presented, including a discussion of challenges for them, which lead to different insights and learning experiences for this kind of elements.

Keywords: bridge, micropile, static load test, load transfer, value engineering.

1 Introduction

The government of El Salvador is currently building a new bridge with a total length of 243 m over the Paz River, to connect the frontier between El Salvador and Guatemala in the Hachadura / Pedro de Alvarado sector.

The foundation design from the contractor called for abutments and piers over an arrangement of several micropiles. This decision was driven due to the presence of coarse alluvial material on both margins, principally blocks and boulders. This hamper the installation of drilled shafts, so they were substituted by more micropiles of easer construction on these conditions.

These micropiles have an overall diameter of 24-26 cm and depths from 19 to 24 m, the longer on the El Salvador side. They are reinforced with a 160 diameter x 10 mm thick high-capacity (550 MPa yield stress) steel pipe.

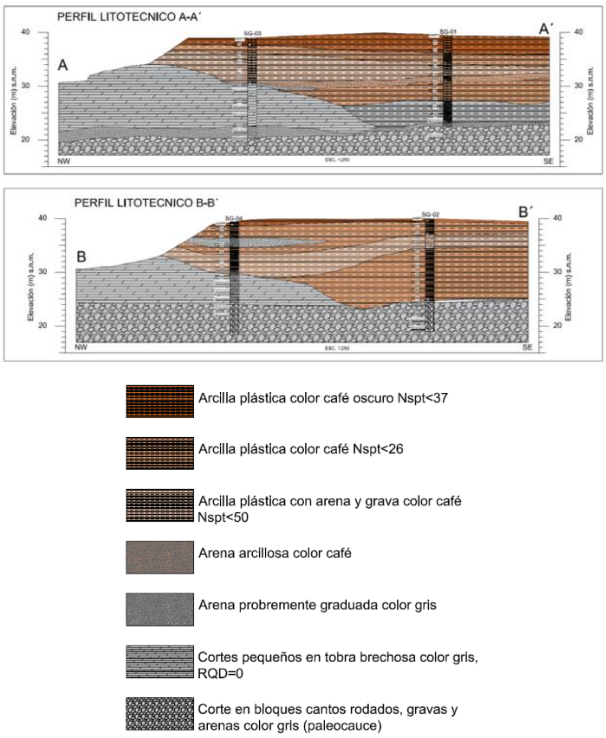

Figure 1. Geophysical profile at El Salvador shore

As part of the project quality control and design verification one test at each side of the river was planned and executed.

Usually, the structural capacity of a pile or micropile is greater than the geotechnical capacity. However, in this case, those capacities are similar and trying to verify that both conditions are comply entail some challenges on the preparation and execution of the tests.

2 Soil Investigation

Field investigations included Standard Penetration Test (SPT) with rotation drilling on some locations, and geophysical research. On both El Salvador and Guatemala shores, were carried out (4) SPT drilling and (2) geophysical profiles, one longitudinal and the other transverse to the bridge.

Figure 1 and *Figure 2* shows respectively the longitudinal geophysical interpretation profile of the El Salvador and Guatemala sides in conjunction with the geotechnical boreholes from the studies.

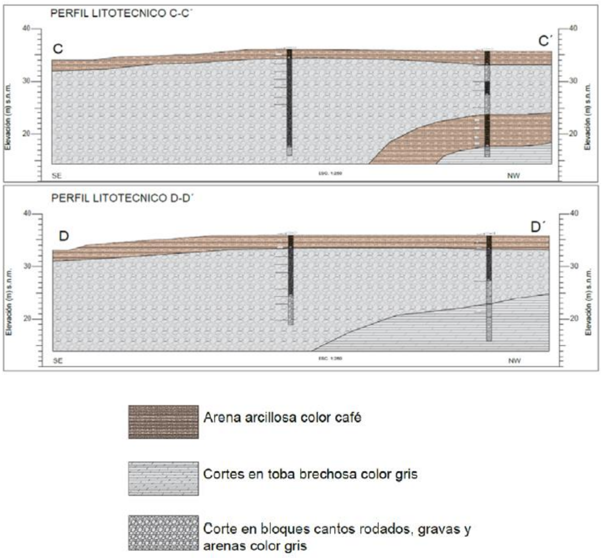

Figure 2. Geophysical profile at Guatemala shore

2.1 Soil Profile at El Salvador

The geotechnical profile at the Paz River is diverse in compacity and resistance. On the top there are clayey materials. Below volcanic weathered tuff emerges. Underneath these tuffs there are very coarse alluvial materials (blocks, boulders, gravel and sand) which are characteristic of the river bottom.

SPT values range from 15 to 50 blows on the upper 10 m of the soil profile and 100 blows (refusal) below this elevation.

2.2 Soil Profile at Guatemala

On Guatemala shore alluvial material surge above the tuff. On this side the micropiles where to be entirely constructed on the alluvial materials. Due to the absence of the clays and the tuff in the upper part of the profile, there were expected better resistance conditions at Guatemala, and i.e. smaller lengths for the micropiles.

3 Micropiles installation

A hydraulic drill, Casagrande C6 XP, with rotary percussive capabilities was used as seen on *Figure 3*. This includes the drill perforation, the installation of the steel pipe, and the injection of the cementitious slurry with pressures between 0,5-1,0 MPa and a final resistance of 25 MPa.

Due to the instability of the hole a casing is used after the perforation. Sections of the case are withdrawn during the injection of the micropile.

Figure 3. Perforation of one testing micropile

4 Load tests

The micropiles were tested to verify the design ultimate capacity, 2 755 kN, according to the designer. This is a relatively high for a micropile, and in this case coincides with its structural capacity. For easiness for the test a slightly higher round value was used, which was 3 000 kN (3 MN).

4.1 Reaction structure

For the execution of each test, it was required a reaction structure, and a jack activated by a hydraulic pump to apply the loads steps.

The reaction structure was composed of a main high profile fabricated beam and reaction tension piles. These reaction piles were 2-4 units, with the same diameter of the main piles and reinforced with either steel pipes or Dywidag rebars.

Also, a separate structure composed of two steel beams was used for reference of the measurement equipment. On the *Figure 4* it could be seen the hydraulic jack and the reaction and reference structures for the Guatemala test.

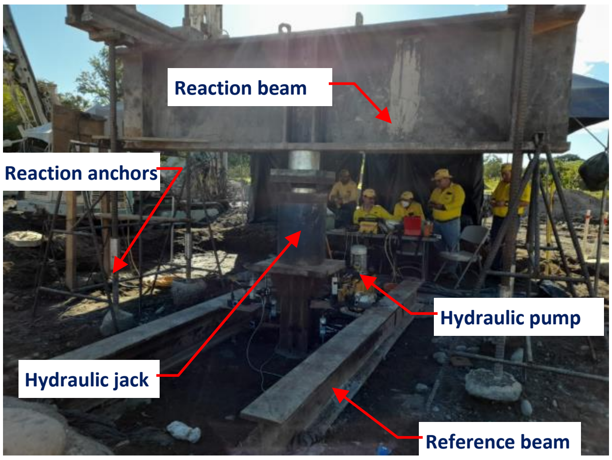

Figure 4. Reaction and reference structures

4.2 Instrumentation

The load measurement was done with a load cell. On the other side, the pressure on the hydraulic equipment was measured by two gauges, one digital and one analogical, as well as by a digital pressure sensor.

Settlements of the micropiles were measured, on the micropile head and toe, this last with tale-tails. The measurements were double independent: digital and analogic. Digitally through Linear variable displacement transducers (LVDT) meanwhile visual dial gauges were used for the analogic measure.

Also, both test micropiles were instrumented with strain gages located every 1.5 - 2 meters along its entire lengths for account for the load distribution at several levels.

Figure 5 shows the layout for the SLT instrumentation, including (2) LVDTs and (2) dial gauge to measure and average the head settlement and the same sensors for the toe. Also, 6 strain gauges were located at the centre of the micropiles at different elevations.

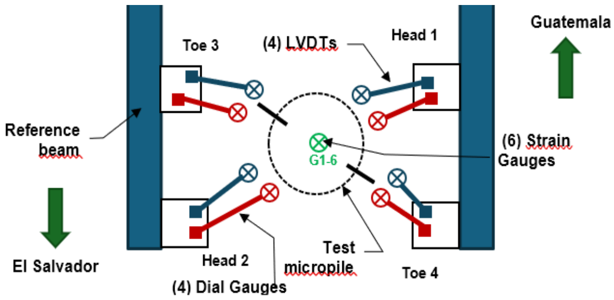

Figure 5. Layout of the instrumentation for SLT

All the digital measurements were recorded on a data acquisition system. In this case this system used was also capable of controlling the pump and increase and maintain the pressure required on the hydraulic jack. A photo of these equipment and its different parts are shown on *Figure 6*.

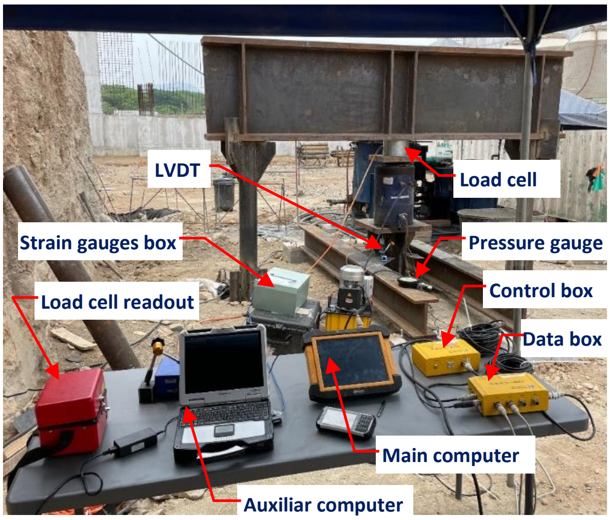

Figure 6. Instrumentation for El Salvador test

4.3 Procedure

The micropile tests were executed following the Quick Load Test or Procedure A from the ASTM D-1143 norm. Load steps were performed every 9 minutes, corresponding each step of 150 kN or 5% of the maximum test load 3 MN, for a total of 20 steps on loading. Once the ultimate test load is reached, it is followed by an unloading on 5 steps (i.e. 600 kN for step or 20% of the test load).

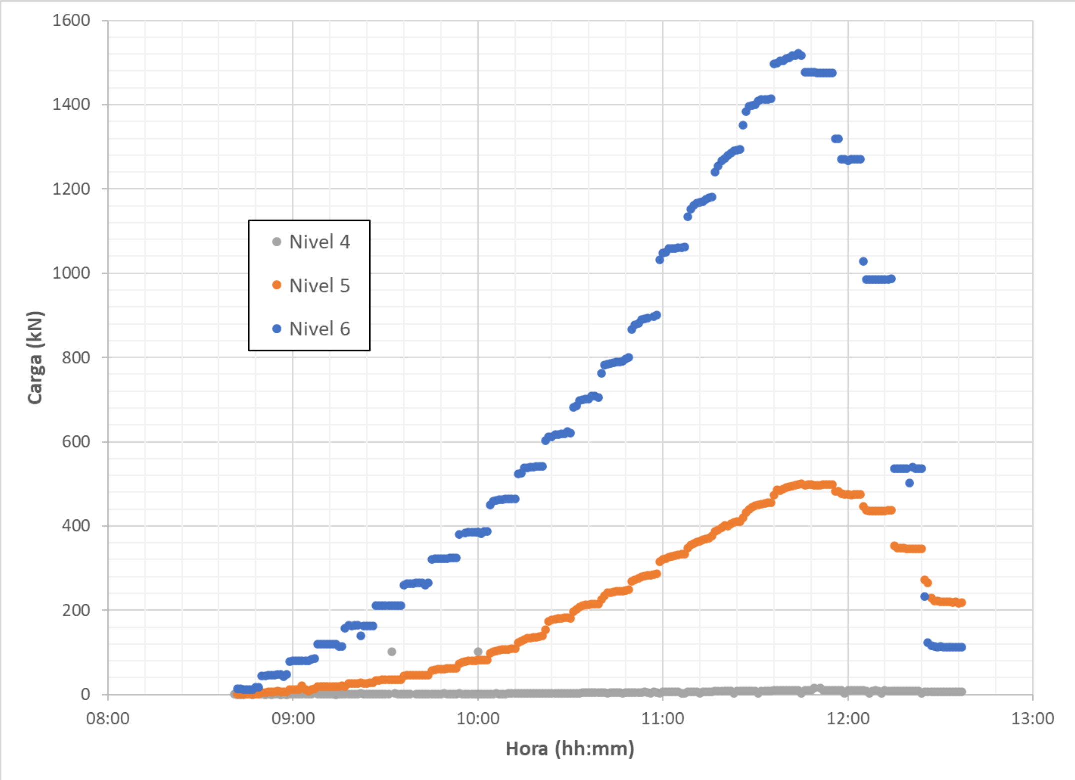

Figure 7. Load per strain gauges level vs time

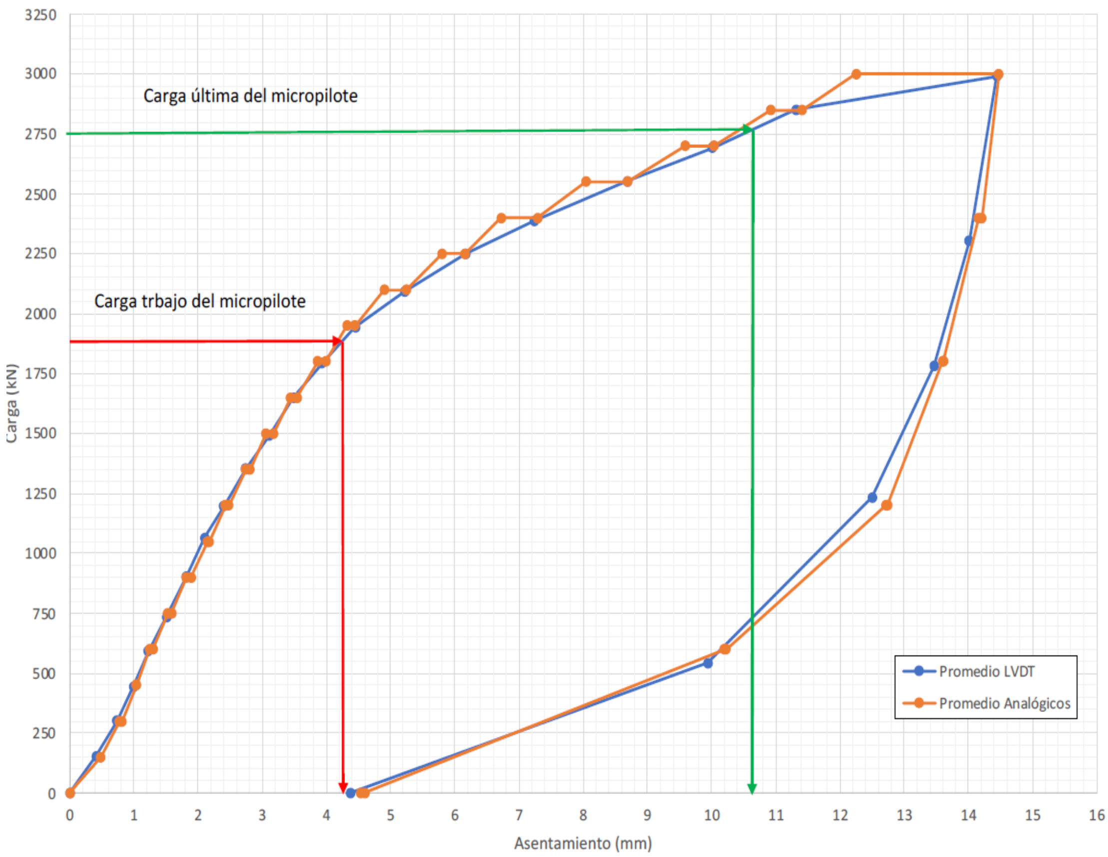

Figure 8. Load vs head settlement curve

The load steps for the different strain gauges elevations versus time could be seen on *Figure 7*.

5 Results

5.1 Vertical settlement

For this pile the load-head settlement curve for one of the tests is shown on *Figure 8*. On this figure the digital and analogical settlement measures are shown in the same graph, demonstrating the good agreement between them.

From the design log, expected settlement under the ultimate micropile load was about 14 mm, meanwhile from the two tests the maximum settlement occurred in Guatemala with a value of 10,6 mm for the ultimate load of 2 755 kN. For the total test load of 3 MN, the settlement was 14,4 mm with a residual settlement of 4,4 mm.

The load was even higher than the calculated capacity of the pile, however the micropiles did not fail either geotechnical or structurally. This is probably to the higher actual greater resistance of the steel, capacity of the slurry, and diameter of the micropile.

5.2 Lateral load distribution

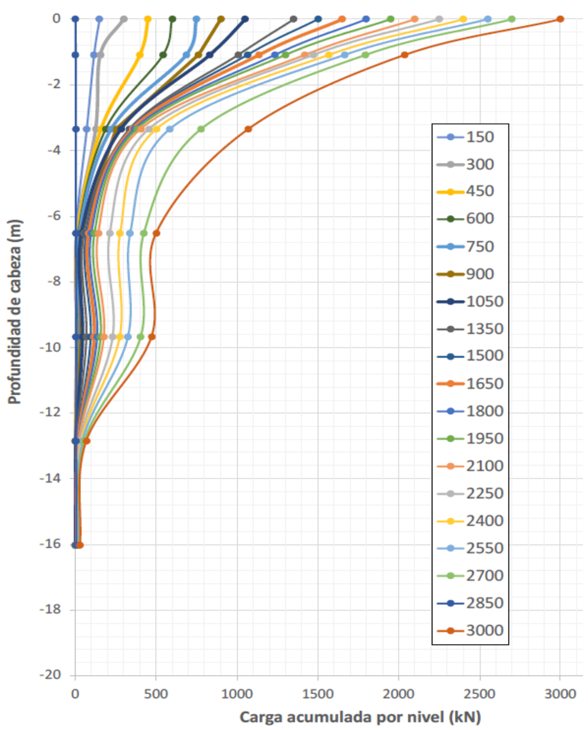

Figure 9. Load vs head settlement curve

Lateral load distribution for the Guatemala test is shown on *Figure 9*. The forces values for level are obtained multiplying the unitary deformation at the gauge level by the elasticity module (E) and area (A) at each level. The measurements at the top strain gauge with negligible lateral friction were used to determine the EA values, and correct the load distribution.

6 Discussion

6.1 Head settlement and FEM model

Head settlement was compared not only with the expected value from design, but also with the results of a finite element model (FEM) as show on *Figure 10*. This model includes the main test micropile and the reaction anchorages for the test.

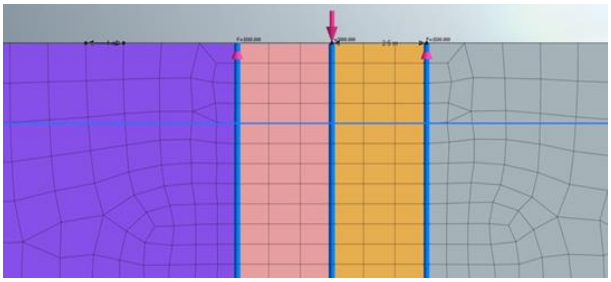

Figure 10. Finite element model for the test

The FEM also helped to review that the interference from the reaction micropiles or anchorages were not big enough to affect the results of the tests.

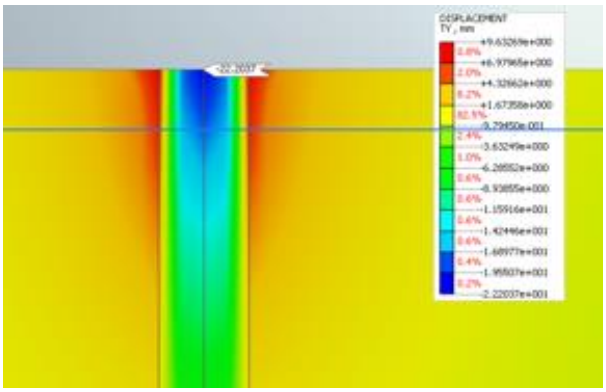

Figure 11. FEM settlement for a load of 2 700kN

As demonstrated on *Figure 11* FEM showed a higher settlement that the measured on the test (22 mm vs 11 mm), which is probably because of the soil parameters including the soil-micropile-anchorages interfaces.

However, the settlements from the analytical method on the calculation log, the FEM, and the test were on the same order of magnitude, which was considered acceptable.

Furthermore, the model could be calibrated and adjusted to the tests results to better understand the behaviour of the foundation under loads.

6.2 Unitary skin friction

The strain gauges allowed to understand the load distribution (friction) along the micropile length and calculate unit skin frictions.

Since load is applied from the top, the upper layers are loaded first than the lower ones. In some cases, the layer resistance limits of the upper layers are achieved but not necessarily happen the same with the soil layers underneath.

From the lateral load distribution, unitary skin friction could be obtained considering the micropile diameter and the distances between strain gauges. These unitary values range from 137 to 564 kN/m^2 at El Salvador, to 29 to 966 kN/m^2 in Guatemala.

The unitary skin friction of 966 kN/m^2 seems to be the limit for the alluvial layer. A value for the tuff could not be confirmed from the tests. Lower unitary skin friction values on both El Salvador and Guatemala, imply that not all the shaft was mobilized, and that geotechnical capacity is greater than obtained. However, it is not reachable due to the structural limitation of the micropiles.

7 Conclusion and recommendations

7.1 Conclusion

The SLT executed at both margins of the Paz River bridge was important to confirm the capacity of the micropiles on a lithological complex.

Furthermore, the test in Guatemala including the load distribution form the strain gauges showed that the micropiles could be shortened from 19 to 17 m, which was implemented on the final design. This value engineering was due to the execution and results of the load tests.

7.2 Recommendations

Implementing a SLT yields a significant amount of time and resources for its preparation and execution. Normally several days at relatively high costs are required for a limited quantity of tests. Therefore, it is important to consider certain recommendations to improve the success rate and obtain the most accurate and valuable information from them.

Furthermore, in the case presented in this paper, the micropile with similar structural and geotechnical capacities, complicated even more this endeavor.

a. Having redundant measurements is important if the main system fails. Also, the comparison between the measures (in our case the digital and analogical settlements), will prove the reliability of these measures.
b. Load tests are used to verify both capacity and settlement requirements for the micropiles. Several specifications reduce the safety factor or increase the resistance factor, which means that less or shorter could micropiles be used for the same structural loads.
c. Reaction piles and anchors distance to the main test pile should be far enough to avoid the affectation of the main pile settlement. FEM models could be used to justify the separation. Less separation implies lower reaction beam height and i.e. savings.
d. Strain gauges help to estimate the load distribution along the micropile. This is important information that could be used for optimizing micropiles lengths.
e. For determining the Modulus of Elasticity/area of the pile using a strain gauge on the top (without soil affectation) or other methods as the Incremental Rigidity Method could be used to correct the lateral load distribution.
f. Unitary skin friction values, principally if the ultimate capacity is achieved for certain layers, can be important data for optimizing the design of other stages, or nearby installations.
g. For micropiles, in which the geotechnical capacity is near the structural capacity, it should be reviewed all the details including the anchor tension capacities of the pipes and rebars because probably they are on the limit.