Hollow precast driven pile extended by a micropile: dynamic load tests and modelling

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ABSTRACT

The hollow precast driven pile (HCK) is a product developed by Rodio Kronsa. It consists of a concrete driven pile with a square cross section of 300, 350 or 400 mm side, and with a coaxial circular hole of variable diameters. This pile, just like any conventional precast pile, gets installed into the soil by driving the element until the hard material is reached at the toe. After that, we can take advantage of the inside hole for different purposes. One of the most frequent uses of hollow pile is to drill and install an inner micropile of a certain length below pile toe, through the resistant soil. The goal of this article is to show the results of dynamic load tests carried out on this compound element on a construction site. On site, some dynamic load tests were performed. After that, on the office, a CAPWAP analysis was also carried out, by making a discretization of the pile and the micropile, introducing the change of material at the pile toe. The compound pile was also modelled with finite elements and the results were compared.

Keywords: precast pile, dynamic load test, micropile, hollow, finite elements

1 INTRODUCTION

Driven piles are a competitive solution for deep foundations, but they are no able to penetrate through hard soil layers o became embedded in the underlying rock. On the other hand, micropiles can be easily installed into rock with the use of rotary-percussion hammers.

Precast driven pile can transmit higher vertical compression loads and support higher horizontal loads and bending moments than micropiles. However, in many situations, is necessary to penetrate a hard layer or deep rock due to high tension loads, such as basements of buildings under fluctuating water tables levels.

To unify the advantages of both typical concrete driven piles and micropiles, Rodio Kronsa has developed a precast concrete hollow pile to allow the later installation of a micropile through the pile and drilling under the pile toe to achieve penetrate with the micropile in a soil layer to resist high load in tension.

In the specific case of a construction site, a dynamic load test has been carried out before and after the installation of the micropile. With CAPWAP software, the mixed pile has been modeled and the results were analyzed.

On the other hand, a finite element modeling has been carried out to analyze the behavior of the composite pile and the results are compared with those obtained in the dynamic load test.

2 PILE AND MICROPILE SPECIFICATIONS

The pile was a precast square concrete pile of side 350 mm with a central axial cylindrical hollow diameter of 160 mm and a total length of 12.00 m. That pile was extended at its toe with an 11.5 m long TITAN self-drilling grouting micropile of 130 mm, reinforced with a steel tube of nominal outside diameter of 73 mm and a nominal inside diameter of 45 mm (Figure 1).

The characteristic strength of the hollow pile (f_{ck}) was 50 MPa.

For the micropile, the grout characteristic strength was f_{ck} = 30 MPa. Yield Stress of steel tube was 600 MPa and Yield Load 1270 kN for an Ultimate Load of 1585 kN.

Fig. 1. Precast pile with TITAN self-drilling grouting micropile.

3 SOIL PROFILE

The soil where the test was carried out can be described as a first layer of soft clayey silts about 10 meters thick followed by a layer of dense compact sandy gravels about 2.5 meters thick. Beneath this stratum there is a layer of silty clays/silts of very compact consistency until the end of the boreholes.

Water level is located at a depth of one meter at the time of the test.

4 DYNAMIC LOAD TEST BEFORE MICROPILE INSTALLATION

Precast hollow pile was first driven to a depth of 11.00 m. The set per blow was measured during driving. After 7 days, a dynamic load test was carried out on the pile before the micropile installation.

Table 1 shows shaft resistance and toe resistance mobilized in the test for this case.

Table 1. Shaft resistance and toe resistance.

Test ID	Shaft Resistance (kN)	Toe Resistance (kN)
Case 1	1420	1303

During the test, the pile moved 6 mm, so we can consider that the bearing capacity developed is quite close to the real one. Most of the pile capacity is developed in the embedment meter in the dense sandy gravels, either by the shaft or by developing significant resistance at the tip. Shaft resistance in the soft clayey silt layer was also mobilized, effectively contributing to the bearing capacity of the pile. It must be considered that, to carry out the test, a six meters excavation had previously been carried out until reaching the work platform.

Figure 2 includes a graph with the shaft and toe resistance distribution obtained after performing a CAPWAP analysis.

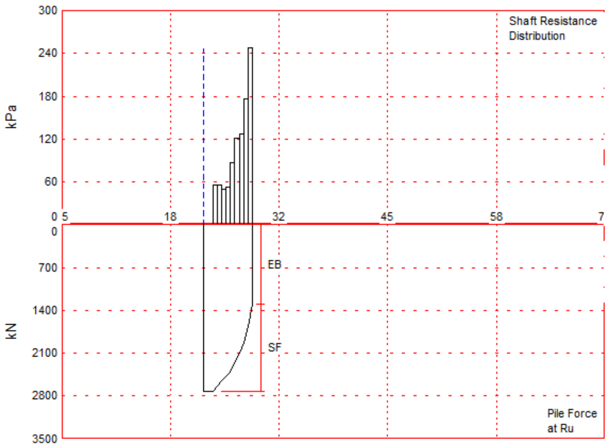

Fig. 2. Shaft resistance distribution before micropile installation.

5 DYNAMIC LOAD TEST AFTER MICROPILE INSTALLATION

As already indicated, the micropile was executed through the 160 mm central coaxial hole, extending the length of the pile 11.5 m under the tip. It is a self-drilling micropile with a nominal diameter of 130 mm reinforced with a tube of 73 mm in external diameter and an inside diameter of 45 mm.

Two weeks after the end of the execution of the micropile, the dynamic test was carried out. During the test, the mobilization of the pile was barely achieved, with permanent displacement of less than 1 mm using all the energy available when blowing with a 70 kN Junttan hammer.

Two criteria have been used for the CAPWAP analysis. In the first, the pile was modeled as if it were not composite, with the same criteria as in the test on the pile without a micropile, considering that the micropile provides an improvement in toe resistance. In the second analysis, the mixed pile formed by the pile plus the micropile was considered, introducing the impedance of both elements in the model.

It should be noted that the reinforcement of the micropile extends to the top of the pile and that the annular gap between the tube and the hole is filled with grout.

The photograph in figure 3 shows the pile prepared for the dynamic load test with the accelerometers and strain transducers placed on the pile.

Fig. 3. Pile ready for dynamic load test.

Table 2 shows shaft resistance and toe resistance mobilized in the test when pile was modeled as if it were not composite.

Table 2. Shaft resistance and toe resistance.

Test ID	Shaft Resistance (kN)	Toe Resistance (kN)
Case 2	1811	3308

As can be seen, there is a gain in resistance per shaft in the pile due to the time elapsed between the two tests, which has allowed the development of consolidation processes. The gain in tip resistance is obviously a consequence of the execution of the micropile. The increase in the tip resistance is approximately 2000 kN, although, as the pile has not moved in the test, we estimate that this value is conservative.

Finally, a CAPWAP analysis has been carried out modeling the pile as a composite element as shown in figure 4. The distribution of resistances per shaft for the pile and the micropile are attached in table 3. In the analysis, no resistance was obtained at the tip.

Table 3. Shaft resistance distribution.

Test ID	Pile Shaft (kN)	Micropile Shaft (kN)
Case 3	3060	2178

Although the final adjustment obtained has not been bad (MQ=2.46), transition between the pile and the micropile has presented adjustment problems, concentrating high shaft resistances in the sections close to this singularity. There really is a large difference in impedance between both elements and it is likely that the CAPWAP model does not adequately adapt to this situation. To carry out a deeper analysis, in the following section a finite element modeling is carried out in order to study in more detail the distribution of resistance between pile and micropile.

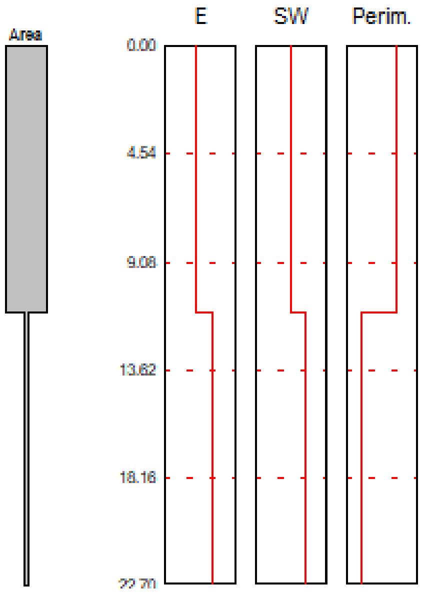

Fig. 4. Composite pile model.

6 FINITE-ELEMENT MODEL

The pile+micropile system is a mixed structure that interacts with the ground as we have been able to verify, the modeling of which has been studied in detail by Justo J.L. et. al (2015) [2] and Justo E. (2017) [3]. The possibilities of its modeling can be considered both by finite difference calculations based on the extension of the Poulos-Davis model, and by the finite element method. Figure 5 shows the model proposed by E. Justo et al.

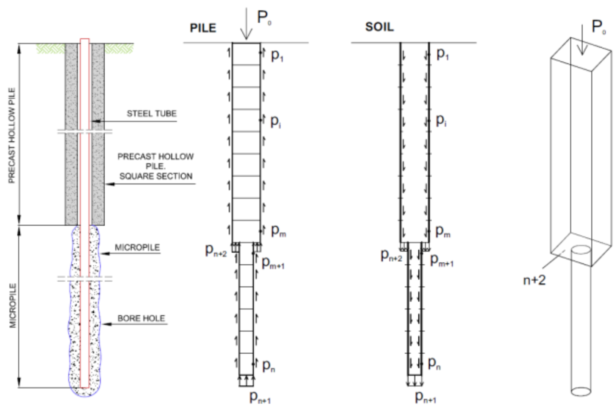

Fig. 5. Proposed pile model by E. Justo et al./ Computer and Geotechnics (2017).

In the case at hand, we have used the finite element method using volumetric elements, with a radial symmetry analysis to study the behavior of the pile+micropile against axial compression forces. For the ground behavior in which the pile is confined, a "hardening-soil" model was used using the PLAXIS 2D program. Figure 6 shows the PLAXIS model considered in the calculations.

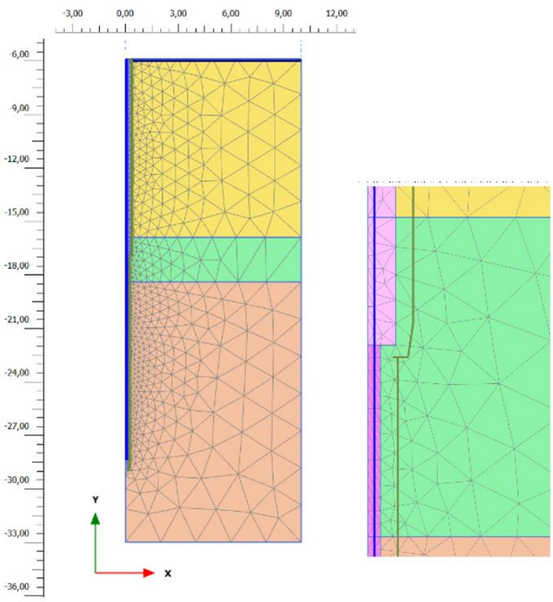

Fig. 6. Axil-symmetric model by finite elements.

Volumetric finite element modeling allows us to consider the change in section that occurs in the transition from pile to micropile, which is the singular point where we have found the most adjustment problems in the CAPWAP analysis of the composite pile.

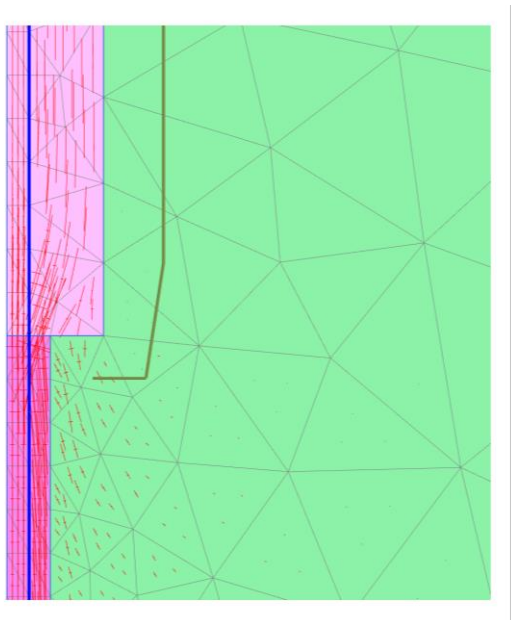

Fig 7. Detail of the transition between pile and micropile in the volumetric model.

In this type of modelling, an interface has been installed between the concrete of the pile and the ground to reproduce relative displacements and a reduction in resistance in that contact, which has been considered less in the micropile-ground contact due to the greater adherence of micropile injection.

The volume of the pile represents the equivalent of a square prefabricated pile with a side of 350 mm. The micropile represents a self-drilling TITAN bar type 73/45, with an equivalent injected diameter of 130 mm perforation.

At the top of the pile, different compression loads have been applied to check the distribution between the shaft of the pile and the micropile. The results are summarized in the Table 4.

Table 4. Shaft resistance distribution.

Applied Compresión (kN)	Pile Resistance (kN)	Micropile Resistance (kN)
1890	1074	816
3500	2040	1460
4000	2305	1695
4500	2588	1912

The results obtained show that, in compression, the load distribution between the micropile and the pile maintains its proportion of 58% of the load supported by the pile and 42% by the micropile, in all the load cases studied, as shown in figure 8:

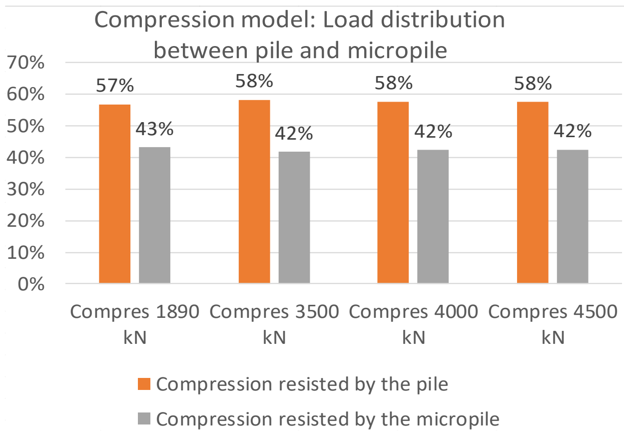

Fig. 8. Load distribution between pile and micropile

The previous results are consistent with those obtained in the CAPWAP analysis and confirm that the dynamic test can be useful for the evaluation of the behavior of the pile+micropile composite element.

7 CONCLUSIONS

The mixed pile developed by Rodio Kronsa is an advantageous solution that combines the advantages of the prefabricated driven pile and those of the micropile.

Dynamic load tests have been carried out with their corresponding CAPWAP analysis to determine the bearing capacity of the element and its shaft and tip distribution, and difficulties have been encountered in achieving a good match in the transition between pile and micropile.

A modeling with PLAXIS has been carried out to analyze the distribution of resistances and verify the results obtained in the CAPWAP analysis and the result has been consistent, validating the analysis performed.

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