High strain dynamic testing in micropiles. Comparison of static and dynamic test results

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ABSTRACT: Micropiles are used for many applications, including underpinning existing foundation. Improving of technique is required to support large loads and quick control methods are demanded. Under this project, a micropile trial site was established at Algete in Madrid (Spain). Three micropiles were executed with 3, 5 and 7 meters length, borehole diameter of 150 mm and a steel pile external diameter/thickness of 88.9/9 mm. Dynamic load testing was performed in trial area. A little hammer was developed for testing and Pile Driving Analyzer (PDA) was used to investigate the ultimate capacity of the micro piles. The hammer has a variable mass between 500 Kg and 1000 Kg that can run along one meter. A static load test has been performed to estimate the bearing capacity of micropiles. The results of the testing program will show if PDA testing may provide accurate information in this technique. The paper, therefore, will discuss the techniques used for PDA testing of the micropiles, and compare the results of the PDA tests to the data from static load test. The paper also contains a brief discussion on the construction method used and its influence on micro pile resistance. Local soil characteristics (silty clay with fine sand) will be taken in consideration to analyze the correlation between static and dynamic load tests. Finally, precautions to prevent micropile damage are studied, and several recommendations will be given after analyzing the damages in the micropiles.

1 INTRODUCTION

Micropiling works are very common in Spain and are used for many applications and soils. Heavily reinforced micropiles with high axial load-carrying capacities are demanded in the market and borehole diameter of 300 mm with bearing capacity over 2500 kN are present in building, tank and bridge foundations.

The testing of individual micropiles is often stipulated as part of a project specification in big construction. Dynamic micropile testing can become an integral part of a quality assurance system in the sense of confirmatory testing and a good complement or alternative to static vertical load test.

Kronsa Internacional S.A. together with A Coruña University initiated in October 2006 a research programme involving the construction and testing of three micropiles with 3, 5 and 7 metres length.

Dynamic load test were carried out using an specially developed hydraulic free fall hammer. PDI equipment was used and CAPWAP analyses were performed.

A prediction of the “Class A”, without knowledge of the static test result, was done.

In December 2007, a new micropile with 7 meters length was installed close to the dynamic testing area and a static load test was carried out. Simultaneously, a new dynamic test was made in previous tested micropiles.

This paper presents the outline of the test micropile programme, summarises the results of dynamic test and provides a comparison of these results with the static test data.

Recommendations to prevent micropile damage are also included.

2 SOIL CHARACTERIZATION OF THE TEST AREA

The soil where the tests were carried out can be described as a gravel layer about 2 meters thick, overlying silty clay with a fine sand layer with a thickness greater than 20 meters.

Water level was about 1 meter deep at the moment of test execution.

3 TEST MICROPILE PROGRAMME

3.1 High strain dynamic load test

3.1.1 Micropile installation

Kronsa installed the micropiles by pre-drilling with a Head Hammer and using simultaneous injection of
water throughout the process. A provisional casing was also used. The borehole diameter of the installed micropiles was 150 millimeters.

Once pre-drilling completed, the reinforcement, a cylindrical steel tube with external diameter of 88.9 mm and 9 millimeter of thickness was introduced inside of the predrilled hole.

For grouting, a tremie pipe was inserted to the bottom of the hole to gravity fill grout, and continued until the grout reached the top of the casing.

After grouting, provisional casing was retired.

3.1.2 Hammer system
Development of an automatic hydraulic free fall hammer was carried out. This hammer can be mounted in a standard retroexcavator machine. This allows rapid positioning at every micropile to be tested.

The hammer allows repetitive blows worked by the hydraulic power of the excavator. The ram mass is formed by a compact block of 500 kg plus additional mass that can grow progressively to 1 ton. The maximum stroke is 1 meter (max. energy 1 m·t), but this height is also adjustable.

For a proper selection of the hammer to be used for dynamic testing, Hussein et al. (1996) suggests a ram weight about 1.5% of the static resistance to be verified. In the test, static resistance mobilized was very high, and we have to use maximum drop hammer height, assuming risks with regard to micropile integrity.

3.1.3 Dynamic test results
In order to perform the dynamic testing the micropile tops were prepared. The micropile reinforcement consisted of a cylindrical steel tube where were made eight drills. On the other hand, the top of each pile was fitted with reinforcing bars welded to the steel tube. Two piezoelectric accelerometers and two strain transducers were attached to the micropile top with the help of the drills. A Pile Driving Analyzer, PAK model, was employed (PDI, 2004).

Cushioning was provided between the head of the pile and the hammer and it consists of a cylindrical piece of oak wood with 10 cm of thickness.

In order to mobilize as much as possible the soil resistance, the test employed increasing hammer energies. Testing of each micropile was performed by striking the pile initially with a low energy blow. The drop height was increased until the micropile was moved several centimeters. The set of the pile top were recorded for all blows (Kormann et al. 2000).

In addition to PDA testing, Case Wave Pile Analysis Program (CAPWAP) analyses were performed on all blows and micropiles in order to get additional data on pile response to loading and to confirm the capacity obtained from PDA testing.

During testing, large displacements at the head of the micropile were noticeable in last blows. When shaft micropile was broken, the capacity went down quickly. In last blows, micropile was practically driven with set per blow close to 20 millimeters.

The Ultimate Capacity for 3, 5, 7 m length micropile is shown graphically in Figs. 3, 4 and 5. These values are based on CAPWAP analyses.

Figure 1. Hammer system detail.

Figure 2. Hammer system and micropile with instrumentation.

Figure 3. Ultimate Capacity micropile 3 m length from CAPWAP and stroke per blow.
3.2 Static vertical load test

3.2.1 Micropile and anchor installation
A new 7 meter length micropile was installed to be tested statically. This micropile was placed a few meters away from the three ones tested dynamically, in the same soil conditions, on December 4th, 2007.

Three vertical anchors were also installed with a free length of 8 m and a bulb of 15 m, to avoid interaction with the micropile.

3.2.2 Procedure for static vertical load test
Static load was applied with one hydraulic jack on the top of a steel plate over the micropile head, and acting against an anchored reaction frame. The main characteristics of the hydraulic jack were:
- Maximum force = 2,243 kN;
- Maximum oil pressure = 700 bar;
- Maximum stroke = 160 mm.

An electric hydraulic pump was used, with the help of a manual pump for initial small loads. Internal jack pressures have been measured by using a calibrated digital manometer. The hydraulic jack was calibrated in a static-dynamic press model MTS in a Certified Calibration Laboratory.

Anchored reaction frame was a monolithic steel beam with T shape, of sides 3.3 m and 2.95 m. It was anchored to ground with three cement-grouted cable anchors. Anchors were pre-tensed placing the reaction frame over three short steel columns. Minimum distance from micropile tested to columns and anchors was 1.0 m. Several steel bearing plates and one hemispherical bearing were used to get good contact between the hydraulic jack and reaction frame.

Two electronic and one dial displacement indicators were used to measure micropile settlement during testing. Electronic indicators were two lineal potentiometers of 75 mm travel and 0.1 mm precision. The dial indicator was 50 mm travel and 0.01 mm precision. The displacement indicators were positioned over small horizontal steel plates welded to the micropile reinforcement steel tube under the micropile head. Measurements of electronic indicators were taken automatically every 5 seconds using a data-logger and a PC.

Displacement indicators were mounted attached to two parallel reference beams 5 m long. Beams were firmly supported to the ground at a clear distance from the ground anchors and reaction frame columns. A sunshade was installed to prevent direct sunlight and precipitation from affecting the measuring and reference systems.

Load was applied in two cycles. The first one until the micropile nominal working load of 33 t (323 kN) was applied and the second cycle until reaching the failure of the micropile. Load increments were of 25% nominal working load until 100%, and increments of 12 t (118 kN) until reaching failure. First cycle was discharged in 3 equal decrements and second cycle in 4 decrements. During each load interval, load was kept constant until the rate of axial movement did not exceed 0.02 mm/5 minutes (0.25 mm/hour), with a maximum of 15 minutes (10 minutes in discharge).

3.2.3 Static vertical load test results
The results of static vertical load test were:
- The vertical axial displacement in the first cycle until nominal working load was 1.95 mm. In the discharge, the remaining displacement was 0.3 mm.
The failure of micropile arrived suddenly at load 100.4 t (984 kN), when vertical axial displacement was 17.7 mm. After the sudden failure, the micropile was not capable of sustaining the failure load. The maximum load applied while the vertical displacement continued to increase was 81.8 t (802 kN). The final discharge began when the vertical axial displacement arrived to 43 mm. The remaining final displacement was 34.6 mm.

3.3 Comparison of static and dynamic test results

The records of several blows were submitted to non-uniform pile CAPWAP analysis. The obtained mobilized capacities are compatible with the results of the static load test.

The results of the static and dynamic tests have been plotted on Figs. 8 and 9. Fig. 8 shows blow no 8 CAPWAP analysis, where pile displacement was zero, compared with first cycle of static load test.

Fig. 9 shows blow no 11 CAPWAP analysis, where pile displacement was 6.5 mm, compared with complete static load test.

It can be seen that the CAPWAP analysis provided conservative load-deflection behavior compared to the static reference data until reaching about 80% of the failure load. For settlements greater than 10 mm in second cycle the prediction is not good.

3.4 Discussion on results

The simulation plotted shows a remarkable agreement between the static load test within the service load range of the load-settlement curve and dynamic load test. It can be observed that the maximum micropile head displacement in dynamic load test did not exceed 6.5 mm in blow no 11. That might explain why this method encountered more difficulties in predicting pile behavior under large displacements.

Dynamic load test results are very close to the static load test ultimate capacity even though dynamic test did not predict the pile behavior for settlements greater than 20 mm.

Concerning the micropile integrity, a hammer with a heavier ram should have been used to decrease stroke. Visual shaft inspection of the micropile when it is extracted will allow to be made a more accurate commentary.

A new dynamic testing was performed in the micropiles in December 2007. An considerable resistance recuperation was recorded respect to last blows carried out a year before. About 80% of initial failure load was again calculated in CAPWAP analysis.

4 CONCLUSIONS

At the current stage of the research here presented, the following conclusions can be outlined:

1. The maximum provided capacities in the "Class A" CAPWAP analysis presented a good agreement with the results of the static test.
2. The load-deflection behavior showed a good agreement with the static load test within the service load range of the load-settlement curve.
3. The results have demonstrated the potential of the high strain dynamic testing as a valuable tool for the assessment of the behavior of the micropiles.
REFERENCES


