DYNAMIC TESTING OF MICROPILES. COMPARISON OF STATIC AND DYNAMIC TEST RESULTS

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ABSTRACT

Micropiles are used for many applications, including underpinning existing foundations. Improving of technique is required to support large loads and quick control methods are demanded. Under this project, a micropile test site was established at Algete in Madrid, Spain. Three micropiles were installed with 3, 5 and 7 meters each in length, borehole diameter of 150 mm and a steel casing external diameter/thickness of 88.9/9 mm. Dynamic load testing was performed in the test area. A little hammer was developed for testing with a variable mass between 500 Kg and 1000 Kg that can run along one meter. The Pile Driving Analyzer (PDA) technique was used to investigate the ultimate capacity of the micropiles. A static load test was performed to estimate the bearing capacity of the micropiles. The results of the testing program demonstrate that PDA testing may provide accurate information using 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 a static load test.

1. INTRODUCTION

Micropiling works are very common in Spain and are used for many applications and in various soils. Heavily reinforced micropiles with high axial load-carrying capacities are often used, having borehole diameters of up to 300 mm with bearing capacities over 2500 kN with applications including building, tank and bridge foundations.

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

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

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

A “Class A”, prediction 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 performed on previously tested micropiles.

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

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 measured from ground surface at the moment of test execution.

3. MICROPILE TEST 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 mm.

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

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

After grouting, the provisional casing was retracted and removed.

3.1.2 Hammer system

Introduction of an automatic hydraulic free fall hammer was carried out. This hammer can be mounted on a standard retroexcavator machine. This allows for rapid positioning at every micropile to be tested.

The hammer allows for repetitive blows by the hydraulic power of the excavator. The ram mass is formed by a compact block of 500 kg plus additional mass that can be increased 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 of about 1.5% of the static resistance to be used. In the test, static resistance mobilized was very high, necessitating a maximum drop hammer height, while assuming risks with regard to micropile integrity.

3.1.3 PDA and CAPWAP method

Dynamic measurements of strain and acceleration under hammer impacts are the basis for modern dynamic pile testing. The equipment consists of two each of strain transducers and accelerometers, bolted to the steel casing of the micropile approximately one meter below its head, and a Pile Driving Analyzer, PAK model (PDI, 2004). Basically, it applies Case Method equations to pile force and velocity data in real time between hammer blows after providing signal conditioning, amplification, filtering, and calibration to measured signals and data quality assessment. High strain dynamic pile testing has been incorporated into many standards and specifications and is now a routine procedure in modern deep foundation practice worldwide.

The micropile has a composite section which must be considered in the analysis. The wave speed should be calculated form the average modulus and specific weight of the steel/concrete composite. On the other hand, the micropile is non-uniform, and we cannot properly use the Case Method and assume a “uniform pile”. In this case, we must analyze the data with the Case Pile Wave Analysis Program (CAPWAP). This signal matching analysis program is considered a standard procedure for the capacity evaluation from high strain dynamic pile testing data. Using one pile top measurement, like the downward stress wave, CAPWAP iteratively alters the soil model to calculate and obtain a best match with the complimentary wave, such as the measured upward traveling wave. Previous studies of databases, and individual experiences, have demonstrated generally good correlation of CAPWAP signal matching results on dynamic restrike tests with static load tests, mainly, on precast driven piles and drilled shaft piles. However, there are relatively few experiences with micropiles.

3.1.4 Dynamic test results

In order to perform the dynamic testing the micropiles needed to be prepared. The micropile reinforcement consisted of a cylindrical steel casing where were made eight drills. On the other hand, the head of each pile was fitted with reinforcing bars welded to the steel casin. Two piezoelectric accelerometers and two strain transducers were attached to the micropile head with the help of the drills.

Photo 1. Hammer system and micropile with instrumentation.

Cushioning was provided between the head of the pile and the hammer, consisting of a cylindrical piece of oak wood, having a 10 cm thickness.

In order to mobilize as much soil resistance as possible 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 (head) was recorded for all blows (Kormann et al. 2000)

In addition to PDA testing, 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 during final blows. When the micropile shaft was broken (meaning by broken?), the capacity reduced quickly. In last blows, micropile was practically driven with set per blow close to 20 mm.

The Ultimate Capacities for the 3, 5, and 7 m length micropiles are shown graphically in Fig. 2, 3 and 4. These values are based on CAPWAP analyses.

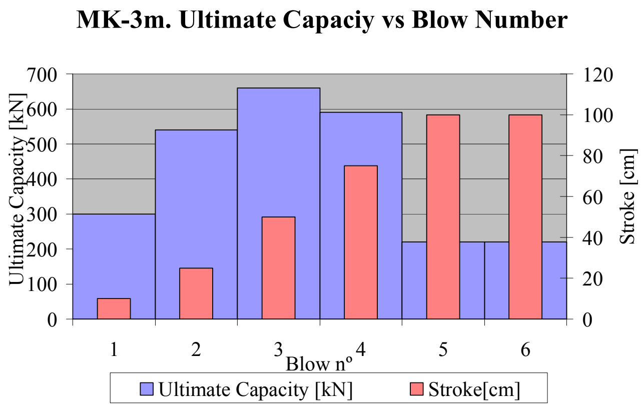

Figure 1. Ultimate Capacity micropile 3 m length from CAPWAP and stroke per blow.

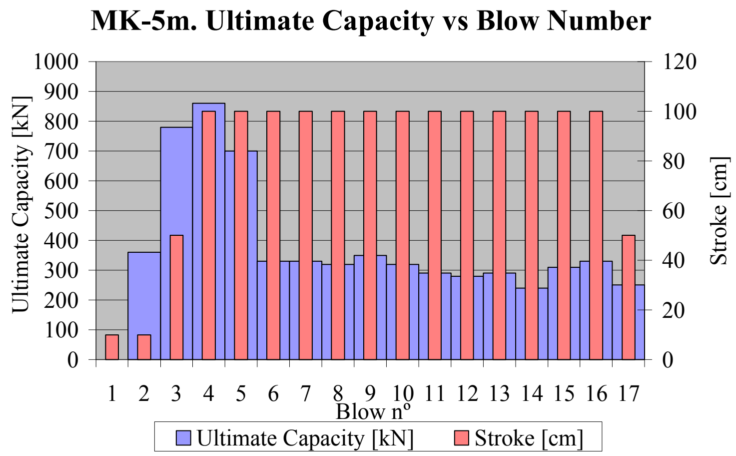

Figure 2. Ultimate Capacity: Micropile (5 m length) from CAPWAP and stroke per blow.

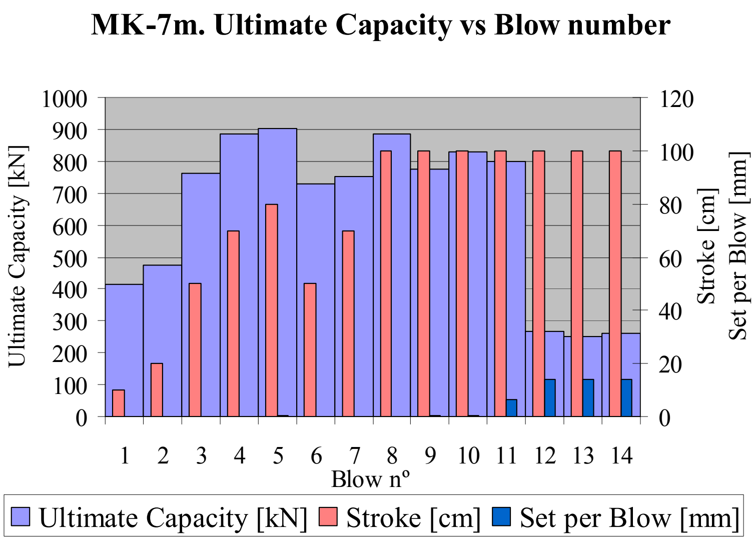

Figure 3. Ultimate Capacity: Micropile (7 m length) from CAPWAP and stroke per blow.

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 piles 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 bond length 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, reacting 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.

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

Photo 2. 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 had a 50 mm travel and 0.01 mm precision. The displacement indicators were positioned over small horizontal steel plates welded to the micropile reinforcement steel casing 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 measurement and reference systems.

Load was applied in two cycles; the first cycle until the micropile nominal working load reached 33 t (323 kN) and the second cycle until the failure of the micropile was reached. Load increments of 25% nominal working load were applied until 100% nominal working load was reached, with increments of 12 t (118 kN) until reaching failure. The first cycle was unloaded 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 total vertical axial displacement in the first cycle until nominal working load was reached was 1.95 mm. In the unloading phase, the residual displacement was 0.3 mm.
- The micropile failed suddenly at a load of 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 unloading began when the vertical axial displacement reached 43 mm. The resulting residual displacement was 34.6 mm.

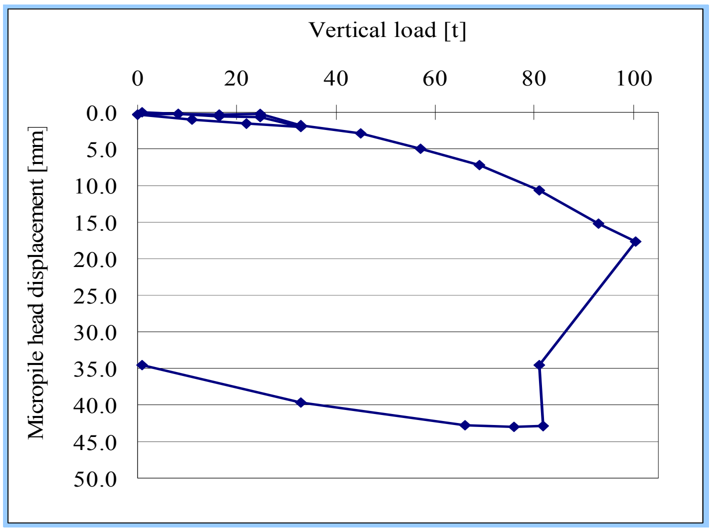

Figure 5. Static load test results on micropile.

3.3 Comparison of static and dynamic test results

The records of several blows were analyzed using non-uniform pile CAPWAP methods. The mobilized capacities determined are comparable with the results of the static load test.

The results of the static and dynamic tests have been plotted on Figure 6 and 7. Figure 6 shows blow nº3 and nº4 from the CAPWAP analysis, where pile displacement was zero, compared with the first cycle of the static load test.

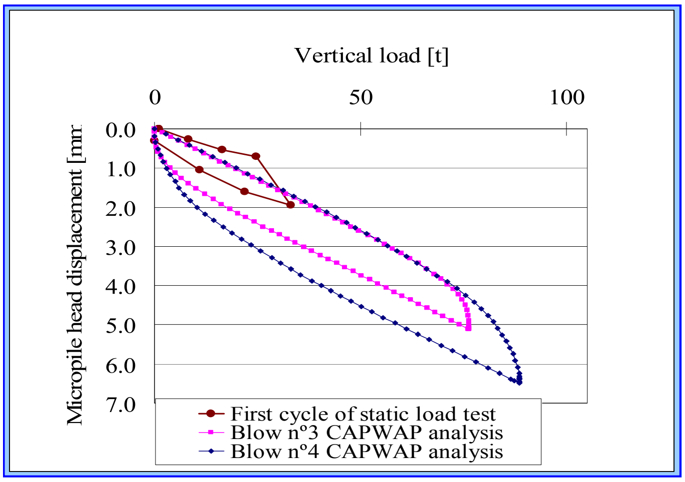

Figure 6. First cycle of static load test and CAPWAP static simulation for blows nº3-4.

Figure 7 shows blow nº11 from the CAPWAP analysis, where pile displacement was 6.5 mm, compared with results from the static load test.

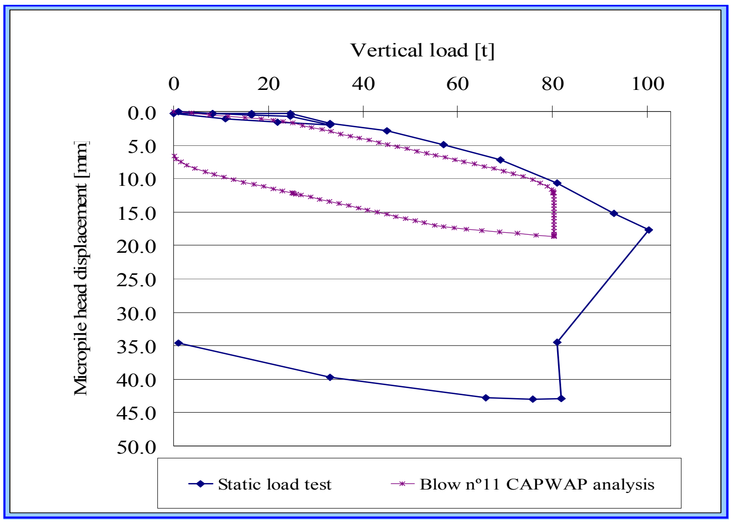

Figure 7. Static load test results and CAPWAP static simulation for blow nº11.

It can be seen that the CAPWAP analysis provided conservative load-deflection behavior compared to the static test 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 Increase in load resistance with time

A new dynamic test was performed on this micropile in December 2007. Considerable resistance recuperation was computed with in comparison with final blows carried out a year before; about 75 % of initial failure load was again recovered as demonstrated from results of CAPWAP analysis.

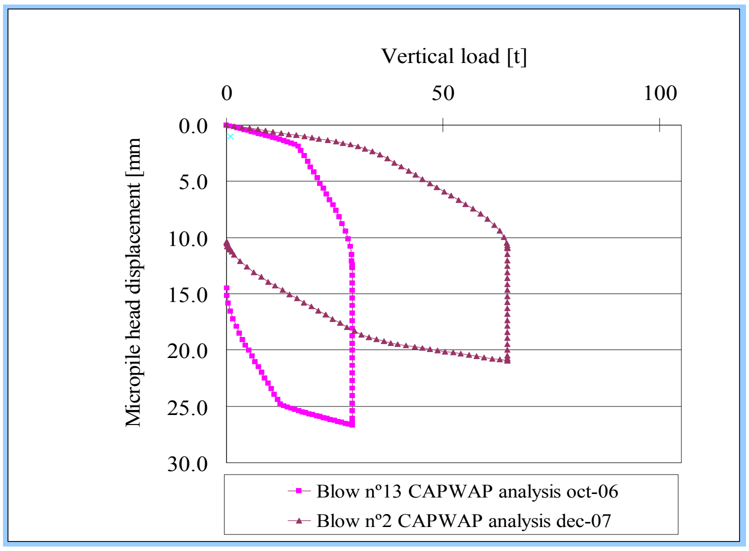

Figure 7. CAPWAP static simulation for blow nº13 (oct-06) and blow nº2 (dec-07)

3.5 Discussion of results

The simulation plotted shows a remarkable agreement between the static load test within the service load range of the load-settlement curve and the dynamic load test. It can be observed that the maximum micropile head displacement observed with the dynamic load test did not exceed 6.5 mm in blow nº11. This might explain why this method encountered more difficulties in predicting pile behavior under large displacements. On the other hand, shaft resistance was partially broken in previous blows. Consequently, ultimate capacities as predicted by dynamic load test results were smaller than that obtained by static load testing.

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 for a more accurate determination of the micropile integrity

4. CONCLUSIONS

From research results presented herein, the following conclusions can be made:

1. The maximum capacities determined from the “Class A” CAPWAP analysis present good agreement with the results obtained from the static test.

2. The load-deflection behavior showed 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 high strain dynamic testing as a valuable tool for the assessment of the behavior of the micropiles.

REFERENCES

Gomez, J., Cadden A., and Webster C. (2004). *“Micropile Foundations in Karst: Static and Dynamic Testing Variability”*, Proceedings of Fifth International Conference on Case Histories in Geotechnical Engineering, Paper No. 9.05.

Hussein, M., Likins, G., Rausche F. (1996). *“Selection of a hammer for high-strain dynamic testing of cast-in-place shafts”*, Proceedings of Fifth International Conference on the Application of Stress-Wave Theory to Piles: 759-772.

Kormann, A., Chamecki, P., Russo, L., Antoniutti, L., Bernardes, G. (2000). *“Behavior of short CFA piles in an over consolidated clay based on static and dynamic load test”*, Proceedings of Sixth International Conference on the Application of Stress-Wave Theory to Piles: 707-714.

Klingberg, D. and Mackenzie, P., (2000). *“Static and dynamic testing of the ‘Campile’ - A displacement, cast-in-situ pile*, *Selection of a hammer for high-strain dynamic testing of cast-in-place shafts”*, Proceedings of Sixth International Conference on the Application of Stress-Wave Theory to Piles: 715-718.

Holeyman, A., Maertens, J., Huybrechts and Legrand, C., (2000). *“Results of an international pile dynamic testing prediction event”*, Proceedings of Sixth International Conference on the Application of Stress-Wave Theory to Piles: 725-732.

William, J., Luiz, R. (2004). *“Comparison of static and Dynamic Load Tests Results”*, Proceedings of Seventh International Conference on the Application of Stress-Wave Theory to Piles: 527-533.

CAPWAP Manual (2006). Pile Dynamics Inc. Cleveland, Ohio.

Poulos, HG., (2000). *"Pile load test methods applications and limitations"*. Libro homenaje a J. A. Jiménez Salas. Ministerio de Fomento, CEDEX y Sociedad Española de Mecánica del Suelo e Ingeniería Geotécnica, Madrid.

American Society for Testing and Materials. *"Standard Test Method for Deep Foundations Under Static Axial Compressive Load"*, ASTM D 1143M-07.