Static and Dynamic Load Tests of Driven Precast Piles

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ABSTRACT

Two test piles have been installed for the foundations of the future expansion of an infrastructure in Spain. The piles were precast reinforced concrete, installed by driving with a hydraulic hammer. A load test campaign has been carried out by various methods and on various dates, which has served to validate the design of the projected foundation system. The article analyzes the results of the load tests carried out on the two piles. On the one hand, the ultimate resistance obtained with the two test methods, static and dynamic, is compared, observing that they reach quite similar values. On the other hand, the evolution of the ultimate resistance is analyzed over the months after the drive, with no significant increases being observed. Changes are observed in the resistance distribution between base and shaft of the pile.

Keywords: design by testing, driven precast pile, static load test, dynamic load test

1 INTRODUCTION

This article describes the load tests carried out by various methods on two precast driven piles, to determine their bearing capacity for the project of an expansion of an infrastructure in Castilla y León, Spain. In the design stage of the test plan, locations were established compatible with the infrastructure activity, which would not affect its safety and operability. This article describes the geotechnical properties of the soil, the type of piles installed, the development of load tests and the results obtained.

2 GEOTECHNICAL INVESTIGATIONS

Prior to the execution of the load tests, mechanical soundings and continuous dynamic penetration tests until rejection were carried out. Pressuremeter tests were carried out in the soundings. Later, various laboratory tests were carried out on the samples taken, both for resistance and characterization. The geotechnical design profile is given below.

2.1 Upper level: artificial embankment

Embankment executed with tertiary soils from excavations in the same area, with an average thickness of 6.50 m. In the DPSH super-heavy dynamic penetration tests performed, the average index is N_{DPSH}=15.

2.2 Pile embedment level: Tertiary rock substrate

The predominant lithological unit in the area belongs to the Tertiary. It is made up of reddish and greenish-gray clayey sands and sandy clays, between which fine or coarse silty sands and sands are interspersed. The values of the pressuremeter modulus E_M vary between 30 and 200 MPa. The limit pressure values fluctuate between 4500 and 7000 kPa. In the DPSH super-heavy dynamic penetration tests performed, the average index is N_{DPSH}=45.

The geotechnical design parameters assigned to these materials are listed in Table 1.

Table 1. Geotechnical design parameters.

Level	USCS classif.	Specif. weight (kN/m^3)	Effec. friction angle (°)	Effec. cohesion (kPa)	Undr. shear strength (kPa)
Embankment	CL-SC	19	26	10	80
Substrate	CL-SC	21	34	70	400

3 DESIGN OF PILE FOUNDATION

The existing infrastructure foundation to be expanded is a combination of footings, shafts, and piles. The pile chosen for the expansion is precast reinforced concrete type, driven until rejection, penetrating the existing fillings until it is embedded in the substrate. Figure 1 shows the foundations of the current infrastructure and the location of the test area on the right.

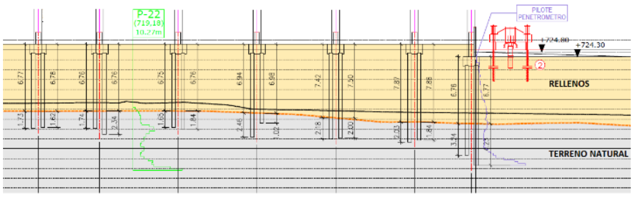

Fig. 1. Geotechnical section.

4 PRECAST PILES

The section of the two piles is square 270x270 mm. The pile reinforcement consists of a longitudinal reinforcement composed of 4Ø20 with a Ø6 spiral every 15 cm. Based on the geotechnical profile of both locations, a fabrication length of 10.00 m was determined for the test pile P1 and 13.00 m for P2. The piles were instrumented using vibrating wire extensometers, welded to the longitudinal reinforcement at opposite edges (Figure 2), separated every 2.0 m (P1) and 2.2 m (P2). In the upper part of the pile there is a box designed to house all the connection wiring to the measurement equipment which allows it to be protected during the driving.

Fig. 2. Vibrating wire extensometer.

5 PILE DRIVING AND INITIAL DYNAMIC TESTS

On January 14, 2020, the two test piles were installed using a Woltman rig with a 7000 kg PVE-7NL hydraulic hammer of variable fall height up to 1.20 m. The rejection criterion used was the "Dutch Formula" for a design load of 1050 kN. The behavior of the piles during driving was as expected according to the geotechnical information available. The P1 pile reached the rejection criterion at a depth of 6.8 m and the P2 at a depth of 11.8 m.

Fig. 3. Sensors placement for dynamic load test.

Dynamic load tests (DLT) were performed according to ASTM-D 4945-17. The signals captured by two pairs of sensors were recorded using a model PAX8 analyzer from Pile Dynamics Inc. The analysis of the results was performed using the Case and Capwap methods. Table 2 shows a summary of the results of the Capwap analysis referring to one of the final blows (EOD) of each pile.

Table 2. Summary of results of the Capwap analysis at the end of the initial drive (EOD).

Pile	P1	P2
Mobilized total resistance (kN)	2661	2599
• Base resistance (kN)	2117	2086
• Shaft resistance (kN)	544	513

6 DYNAMIC LOAD TESTS IN RESTRIKE

On February 25, 2020, 39 days after initial driving, dynamic load tests in restrike (BOR) were carried out on the two piles. A 7t Junttan hammer owned by Rodio Kronsa was used for this. Subsequently, the numerical analysis was carried out with the Capwap program on the most representative blows, obtaining the summarized results that appear in Table 3.

Table 3. Summary of dynamic tests results in restrike (BOR).

Pile	P1	P2
Mobilized total resistance (kN)	2767	2903
• Base resistance (kN)	1880	1437
• Shaft resistance (kN)	887	1466

Fig. 4. Dynamic load test.

7 STATIC LOAD TESTS

Static load tests (SLT) were carried out on piles P1 and P2 on July 14 and 15, 2020, six months after installation. The piles were trimmed prior to the test.

7.1 Load and measurement systems

The vertical compression test load was applied by means of a 4300 kN hydraulic cylinder acting vertically on the pile head, having as a reaction a metallic frame anchored in its four corners to four specifically installed micropiles. A spherical ball joint was arranged on the cylinder head. The pressure in the hydraulic circuit was measured for calculating the load on the pile head, using a triple redundant system. In the P1 pile test, its head broke before the maximum test load was reached, so it was decided to reinforce the P2 pile head prior to the test.

Four linear displacement potentiometric meters were used to measure the settlement of the pile head. Topographic checks were carried out as a general check of the measurements and to ensure the safety of the test. The deformations inside the pile were measured using vibrating wire extensometers, which had been left embedded before concreting.

7.2 Development of tests and notable incidents

The test load was applied following the rapid method of the ASTM D1143M-07 standard, in a single load-unload cycle applied in 20 loading and 5 unloading steps, each lasting 10 minutes, except for the maximum loading step that lasted 30 minutes and the final discharge that lasted 20 minutes. The maximum test load was 2587 kN. In pile P1, the maximum expected load could not be reached, since the pile head broke when a load of 1800 kN had been registered, so the test had to be interrupted, without any signals being detected of geotechnical failure of the pile up to that point.

Fig. 5. P1 static test setup.

7.3 Results obtained in the SLT tests

Table 4 shows the numerical values of the settlement at the end of each loading and unloading step.

Table 4. Final pile head settlement in each load step.

Step No.	Load (kN)	P1 (mm)	P2 (mm)	Step No.	Load (kN)	P1 (mm)	P2 (mm)
0	0	0	0	13	1682	5.74	8.23
1	129	0.13	0.19	14	1811		9.43
2	259	0.50	0.39	15	1940		10.24
3	388	0.81	0.48	16	2070		11.81
4	517	1.29	1.26	17	2199		13.62
5	647	1.74	1.63	18	2328		15.04
5bis	686	1.88	1.83	19	2458		16.85
6	776	2.17	2.24	20	2587		19.82
7’	882	2.59	2.73	21	2070		18.43
8	1035	3.17	3.6	22	1552		15.43
9	1134	3.56	4.08	23	1035		11.92
10	1234	3.95	4.83	24	517		8.21
11	1423	4.76	6.15	25	0		4.14
12	1552	5.27	7.18				

7.4 Analysis of static test results

The load settlement curves of the two tests are shown in Figures 6 and 7, based on Table 4. They include the determination of the ultimate load according to Davisson's criteria, provided for in the approved test procedure. The ultimate load of the pile is defined according to this criterion as the point at which the load settlement curve obtained in the test crosses the elastic line of the pile supposedly isolated and working as a column, which originates from an initial settlement of 4 mm + b/120, where b is the equivalent diameter of the pile, and as slope EA/L, where E is the elastic modulus of the pile, A is its cross section, and L is its length. In our case we have used E = 34000 MPa.

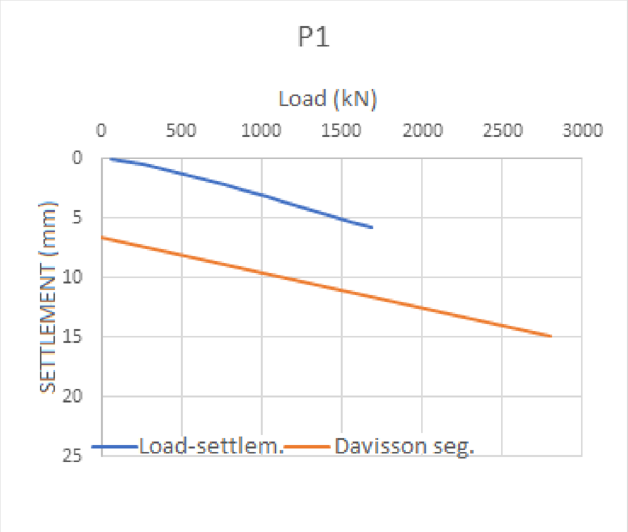

Fig. 6. Load settlement graph of P1 with ultimate criterion.

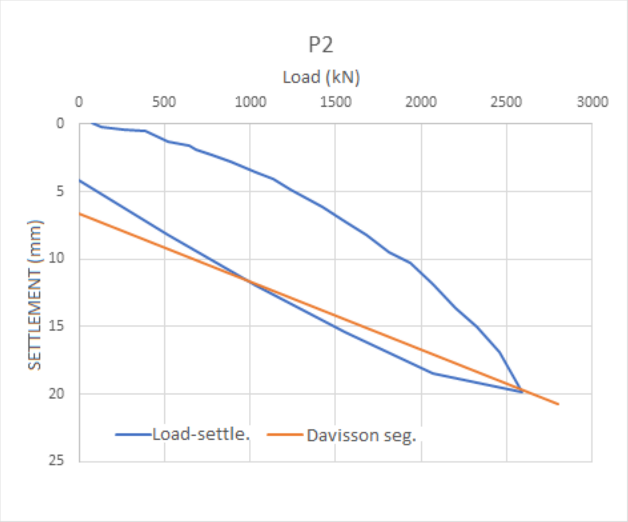

Fig. 7. Load settlement graph of pile P2 with ultimate criterion.

As can be seen in Figure 6, at the time of interruption of the test P1 the load settlement curve was still far from crossing the segment that shows the Davisson criterion. It can therefore be stated that the test carried out shows that the ultimate load of the pile P1 is greater than 1800 kN, which is the load at which the pile head broke

From the load settlement curve of the pile P2 (Figure 7), it can be deduced that the load line crosses the Davisson segment just when the maximum test load is reached. The ultimate load, according to this criterion, is 2587 kN, a number that is like the ultimate strength obtained in the dynamic load tests on this pile.

Table 5. Load in the pile at 1 m above the base (SLT).

Pile	P1 (1)	P2
Maximum test load (kN)	1682	2587
Load reaching 1 m above the base (kN)	974	1085
Percentage of maximum	58%	42%

Note: (1) Test that did not reach the predicted load due to the breaking of the pile head.

The strain inside the pile have been measured at various levels using extensometers that had been left embedded in concrete. Table 5 shows the values of the load reaching the deepest extensometer level, which is 1.0 m above the base of the pile.

8 COMPARATIVE ANALYSIS OF THE RESULTS

The results of the two dynamic load tests (DLT1 and DLT2) and of the static load test (SLT) carried out on each of the two piles can be summarized in Table 6. Working load is 897 kN.

Table 6. Comparative table of the results of the different load tests.

Pile P1	DLT1	DLT2	SLT (1)
Test date	14/1/2020	25/2/2020	14/7/2020
Mobilized resistance (kN)	2661	2767	1682
Load reaching the pile base (kN)	2117	1880	974 (2)
Percentage of maximum	80%	68%	58%
Settlement at working load (mm)	3.8	3.6	2.8
Safety factor over working load	3.0	3.1	N.A.

Pile P2	DLT1	DLT2	SLT
Test date	14/1/2020	25/2/2020	15/7/2020
Mobilized resistance (kN)	2599	2903	2587
Load reaching the pile base (kN)	2086	1437	1085 (2)
Percentage of maximum	80%	50%	42%
Settlement at working load (mm)	4.7	3.1	2.8
Safety factor over working load	2.9	3.2	2.9

Notes: (1) Test that did not reach the predicted load due to the breaking of the pile head. (2) 1.0 m over pile base

The two graphs in Figure 8 show for each pile the load settlement curves of the three load tests carried out, two dynamic and one static.

9 CONCLUSIONS

In view of the above considerations, we can draw the following conclusions.

The load settlement curves of the three load tests carried out on each pile (two dynamic and one static) coincide reasonably well.

It is observed that the ultimate resistance obtained with the two test methods, static and dynamic, has quite similar values.

The evolution of the ultimate resistance is analyzed over the time after the driving, observing little significant changes. Changes are observed in the resistance distribution between the base and shaft of the pile. At the end of driving, the base resistance mobilized in the dynamic load tests was of the order of 80% of the total resistance, and weeks and months later it was reduced to approximately 50%.

The results of the static tests carried out do not support a methodology that some consultants apply to the determination of the ultimate resistance of the pile in dynamic load tests, by which they combine the highest value of the base resistance obtained at the end of driving with the shaft resistance obtained a few weeks later, so that the maximum values are added, and the result is higher than the resistance obtained in each of the tests.

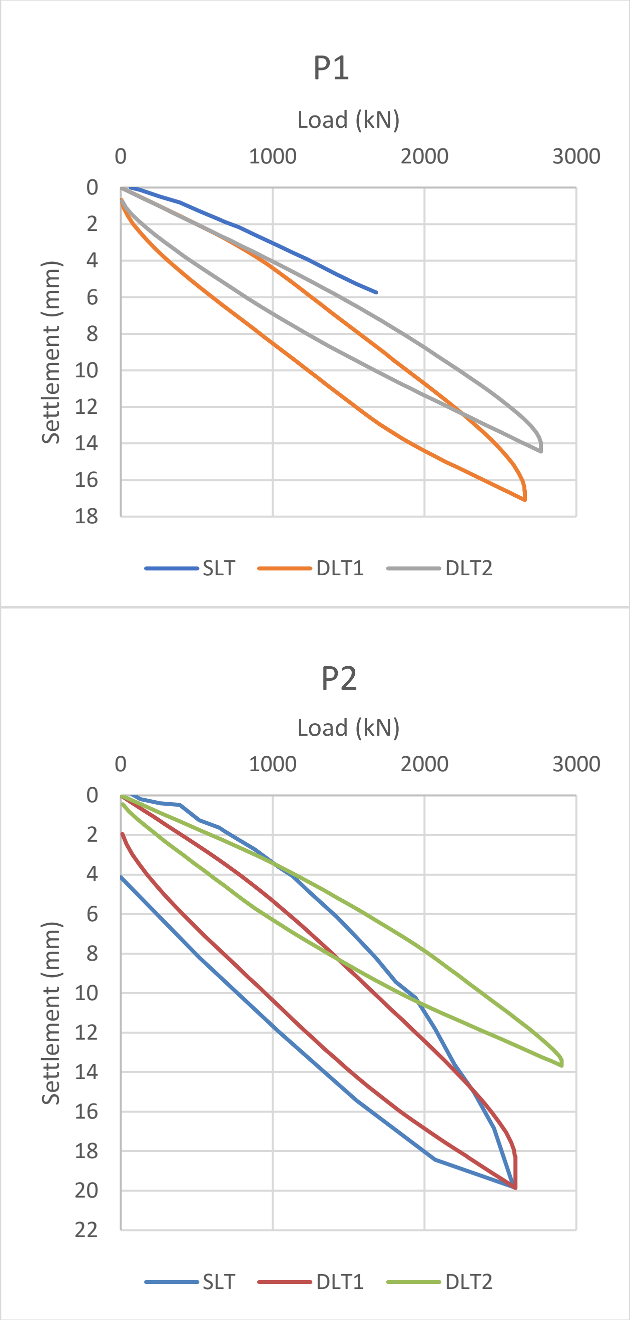

Fig. 8. Load settlement curves of the load tests carried out in P1 and P2.

ACKNOWLEDGEMENTS

The authors thank the companies Eptisa Servicios de Ingeniería, S.L., Sixsense Iberia, S.L., Becsa, S.A., and Instrumentación Geotécnica y Estructural, S.L. (Inge), for their collaboration in the preparation and execution of the load tests.

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