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Static Load Test on Pipe Piles for a Vehicle Bridge in the Gulf of Mexico Area

Walter PANIAGUA[a], Asael ELVIRA[a,1], Claudia PINEDA[a], Erika VALLE[a] and Cecilia HERNÁNDEZ[a]
[a] *Pilotec, S.A. de C.V.*

Abstract. Results are presented for nine static load tests on eight pipe piles along the three kilometers length of a vehicle bridge in the coastal area of Campeche State in the Gulf of Mexico. The project is distinguished by variations in the stratigraphy and depth of the seabed with water levels between 6 and 16 m, approximately. Of the tested piles, seven are located on the seabed and one on the beach. Additional to the test results, the construction process and solution of equipment assembly for load tests in the sea, are described.

Key words. Pipe piles, pile driving, static load tests.

1. Introduction

Results are described for the static compressive load tests conducted on driven piles in the seabed for a 3+ km long bridge on the coast of the Gulf of México. As part of the control and quality assurance program, 9 tests were performed, one of which is described in detail this article, including the procedure, as the others are essentially the same. Test results are shown at the end of the paper, as well as the comparison of results for all the tests.

2. Project Description

2.1. General project characteristics

The bridge's length between extreme axes is approximately 3,284 m with a grade line that is up to 15.0 m above the maximum water level. Transversally, its width is14.00 m, that host two lanes, shoulders and sidewalks.

The project has 74 supports with 7, 8 and 10 pile arrangements each; the 72 support piles are founded on the seabed and two on the beach area, one at each end of the bridge, and are called supports. The support distribution is described in Table 1.

[1] Corresponding Author; E-mail: asael@ingenieros.com.

Table 1. Pile distribution under each support.

Number of piles in each support	Pile diameter, m	Support N°
7	1.20	2 to 37, 57 to 64, 68 al 73, support 1 & 74
8	1.50	65 to 67
10	1.20	38 to 56

2.2. Geotechnical site conditions

Three exploration campaigns were conducted [1], the last one with 17 borings, and depths ranging from 39.00 m to 43.65 m; The exploration techniques were electric cone, standard penetration and unaltered samples with Shelby tube. Stratigraphic variation in the more than 3 km bridge length can be seen in Figure 1, with the stratigraphic interpretation of the zone and the different layers of clayey sand or clay-clayey clay, from 1 to 5.

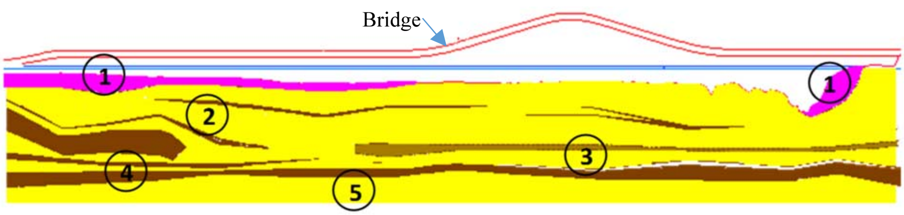


Figure 1. Stratigraphic variation along the length of the bridge.

Stratigraphy is divided into 5 primary strata, described as follows:

Table 2. Stratigraphic description in the bridge area, referred to the upper part of the layers.

Unit	Depth, m	Description
N/A	0.00-7.20	Platform and water level.
1	7.20-9.00	Sandy clay and clayey sand with seashells, light grey color, loose to moderately compact.
2	9.00-14.40	Clay with variable sand content, clumps and seashells, light grey color, firm to hard consistency.
3	14.40-25.80	Clay with sand, clumps and localized small gravel, light grey and brown-green, firm to hard, with STP blow count between 11 to over 50.
4	25.80-39.00	Clay with sand, clumps and small gravel, light grey and brown-green color, firm to hard consistency, with light grey silt lenses.
5	39.00-42.23	Sand, silt and clay with small gravel and isolated clumps, brown-green and light brown, very compact, with STP blow count over 50.

2.3. Foundation characteristics

Piles are made of steel pipe between 1.20 and 1.50 m in diameter, manufactured from a ¾” diameter steel plate, rolled, with a helical seam. The steel pipe was driven by strikes; subsequently, 8 m were drilled under the seabed, hydraulic concrete was poured and reinforcement steel added for creation of the concrete plug after drill, for a future connection with the top. All abutments contain vertical piles except abutment 67, that has piles with a 3-degree batter.

The piles have a 35 m maximum length, depending on the depth of the seabed and ground embedding with a 25 m to 33 m variation.

2.4. Foundation construction procedure

The steel pipes were placed at the driving point by their own weight; they were subsequently driven into the ground with a 225-kJ diesel hammer until the desired project depth or by following a criterion of driving suspension, according to the number of blows necessary to penetrate a determined length (5 blows/inch). The pile construction process is shown in Figure 2, (a) driving of steel pipes, (b) drilling and spoil extraction from inside the pipes and (c) concrete casting using a pump. In line with the project, the drilled depth is less than the total pipe length because it was programmed to keep a ground column inside the pipe, which adds friction force between the ground and the pipe walls, increasing the pile's bearing capacity.

(a) (b) (c)

Figure 2. Pile construction process.

3. Description of the static load tests

The test elements consisted of a reaction system, composed of a metallic structure; hydraulic equipment for application of a 1000 t load; electronic and mechanical equipment to register pile head movements. As reaction elements, adjacent piles were used to work under tension during the test.

To convey the load to the reaction piles, concrete blocks were built on the pile heads, serving as an intermediate element between the reaction system and the piles. A concrete header was built on the test piles, on top of which, steel plates were placed to support the double action hydraulic cylinders and create the correct stress distribution. The cylinders were connected to a hydraulic pump as part of the security measures for test execution. Load cells were used to measure the load on the test head, Figure 3.

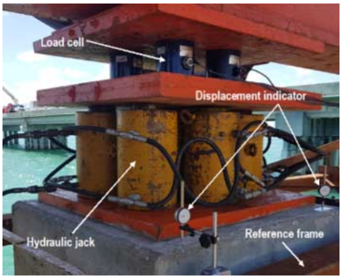


Figure 3. Hydraulic cylinder system and load cells.

The reaction frame was composed of rectangular steel beams, 9 and 15 m in length, 1.70 and 1.90 m thickness and 0.60 m width; two to three beams were placed depending on the abutment with an average weight of 30 t on the head.

High-resistance steel bars, with full-length thread by which the reaction frame was rigidified and fastened to the concrete blocks were used for load transference. Once the load was applied, the bars worked as a restrictive element to the reaction frame, creating pressure from the hydraulic cylinders to act inversely, displacing the pile and causing it to penetrate the ground or deform.

Displacement indicators supported by the reference beams were used to measure displacements on the pile heads. Three indicators were placed on the concrete head stem with 120° between them; each instrument's resolution was 0.001 of an inch, with a 2-inch stem stroke. The indicators were fastened by means of magnetic bases to square section steel profiles, anchored to the adjacent test piles, parallel to each other to two head flanks. The profiles were fastened to one of the ends of each section, allowing free deformation by temperature change. Measurements were taken directly by reading the displacement in each instrument following each load increment; due to not being able to restrict the effect of the wind, a criterion was put in place to measure the displacements, that consisted of taking the highest reading the displacement indicator showed in each register; Figure 4, displacement indicators.

Additionally, a graded scale with a 1 mm resolution was placed in order to obtain measurement redundancy and was read by means of a wireline and mirror to avoid parallelism errors, Figure 5.

Figure 4. Displacement indicator measurement system

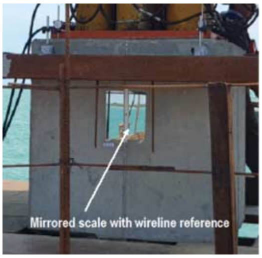


Figure 5. Grades scale measurement

In general, two different arrangements were used depending on the type of abutment:

Type 1 abutment (7 piles); three reaction piles were used, Figure 6.

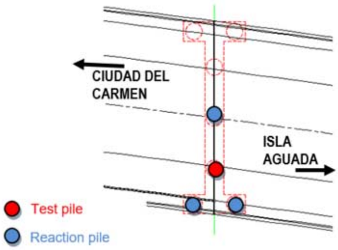


Figure 6. Reaction frame arrangements on type 1 abutment.

Type 2 abutment (8 to 10 piles); two reaction piles were used, Figure 7.

Figure 7. Reaction frame on type 2 abutment.

4. Assembly conditions for static load tests

4.1. Assembly and execution programming challenges

Geographic location and test logistics. Given the site conditions where the bridge was built, between Terminos Lagoon and the Gulf of Mexico, 90% of the construction work was performed with self-erec ting and floating service platforms, pushers and boats. Additionally, static load campaign activities were programmed in combination with pile construction; the work cycle began with block construction and ended with removing the reaction structure.

Equipment assembly arrangement. In line with the bridge's general logistics and construction procedures, the equipment used for pile driving, drilling and casting was the same used for the reaction structure assembly in all test loads. More specifically, a mechanical 60 t capacity crane with a 18 m boom and a floating platform with a 600-t full capacity; additionally, a pair of pushers were used to position de platform. The inclusion of each load test execution time to the original program, delayed pile driving, drilling and casting at least one week after each test, 9 tests in all.

Weather conditions. One of the main challenges for test assembly and execution were effective work hours because weather conditions are a determining element when using floating platforms. Currently, we have climate forecast systems that allow time approximation in terms of events like waves, wind gusts and rain, etc.; therefore, work was scheduled through these systems. However, authorization was required at the beginning of each workday in order to have every activity performed in line with the work safety protocol. The duration of a test execution cycle was between 5 and 7 days, while the execution interval between them lasted up to 40 days.

4.2. Technical Challenges towards text execution

Placement of reference beams. Given that the abutments next to the test site had at least 45.00 m separation between them, anchoring the reference beams to one of them was not feasible; therefore, the option was fastening the beams by welding them to the piles adjacent to the test pile within the same abutment. Rebar tensors and sole were used to provide rigidity to the element; this activity took up most part of the assembly time.

Work platform. Due to work-site conditions and test site location in the Terminos Lagoon, it was necessary to build a platform composed of wood and steel beams and attaching the surrounding piles to the test pile; access to this platform was exclusively by a metal ladder that worked as a bridge between the piles and the floating platform where the crane and the electronic instruments for processing information and auxiliary metallic parts for the assembly of the reaction structure, generators for energy and light were placed. During each workday, the tide level changed, therefore, the ladder – bridge had to be relocated several times a day.

Readings and measurements. The wooden platform was one meter in diameter; therefore, due to security, only one person could remain on it at one time. In order to take the readings in the time intervals after each load increment, it was necessary to access the fixed platform and return to the floating platform as many times as intervals were registered. This task required higher effort from the technical personnel performing the load test.

5. Test Results

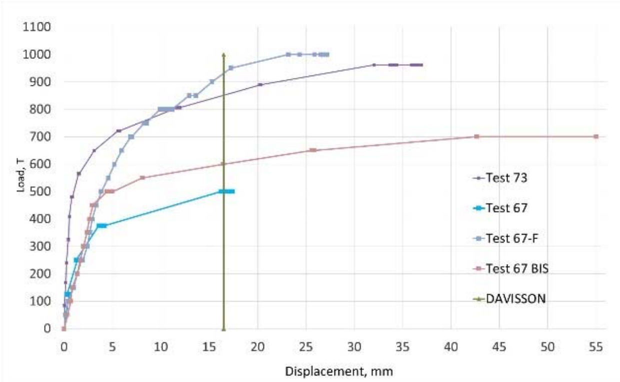
Load test interpretation. The general results for the nine test loads are shown on Table 3. It is worth noting that the allowed load for each pile (667 t), was deduced from the parameter set forth by the project owner which was the maximum load test of (1000 t).

Figure 8 shows the load-displacement graph with the obtained registers for the performed tests, (a) 1.50 m diameter piles and (b) 1.20 m diameter piles. In every case, the Davisson criterion was used for obtaining the ultimate load (Qu), by the graphic method obtain skin friction (Qu_1) and toe capacity (Qu_2), based in Figure 9 interpretation.

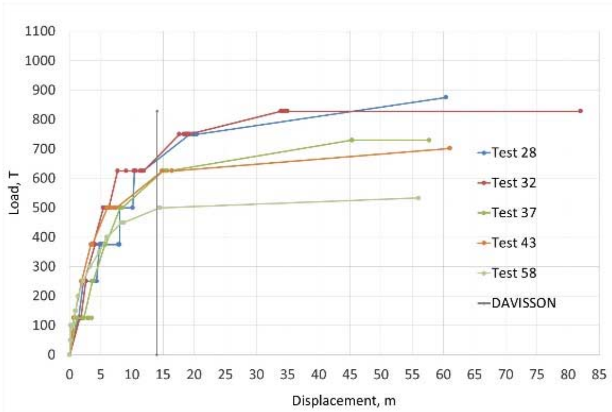
Table 3. Load test results [2].

Test	Abutme-nt	Length (m)	Diameter (m)	Q max (t)	D max (mm)	Qu (t) Davisson	Qu $_1$(t) Skin Friction	Qu $_2$ (t) Toe
1*	73	32.90	1.50	963	36.96	850	510	453
2	28	28.02	1.20	875	64.00	675	680	195
3	32	25.02	1.20	828	82.00	625	610	218
4	37	25.00	1.20	730	57.70	625	520	210
5*	67	31.96	1.50	533	65.00	500	335	198
6	43	25.00	1.20	702	61.00	613	360	342
7*	67 BIS	31.96	1.50	700	55.00	600	400	300
8*	67-F	31.96	1.50	1000	28.00	925	470	530
9	58	25.90	1.20	533	56.00	500	330	203

*Test performed on abutments near the beach area
Qmax Maximum load measured
Dmax Maximum displacement measured



(a)



(b)

Figure 8. Determination of ultimate load *Qu*, through the Davisson method, a) 1.50 m and b) 1.20 m diameter piles.

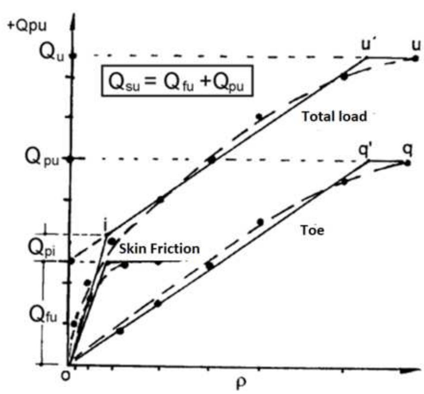


Figure 9. Graphic method for estimate skin friction in piles, (Tamez. 2003) [3].

We can see that the 1.50 m diameter piles near the beach area behaved better due to embedding into the resistant stratus and ultimate load obtained with the Davisson method, as in all cases.

The ground – pile system for both tested diameters show similar behavior due to the employed construction procedure, leaving a ground plug and a concrete section, without the location's geotechnical conditions being determining element.

Comparison of test under different conditions. Figure 10 shows a graph with displacements for 200 t load increment. Tests 28, 32, 37, 43, 67, 67-BIS and 58, show similar elasto-plastic behavior, while tests 67-F and 73 (the latter performed on the beach area), show a similar elastic behavior between them.

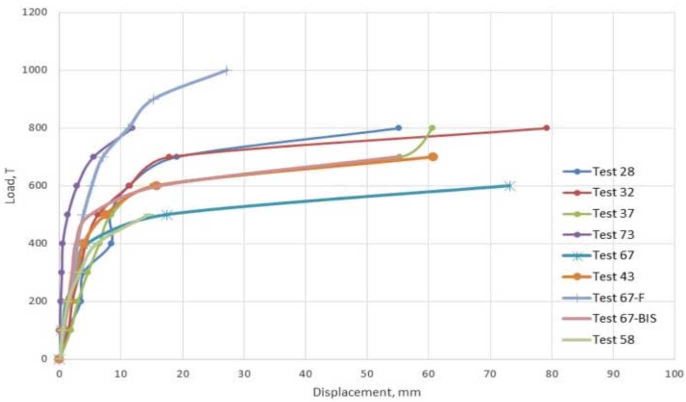


Figure 10. Displacements for 200 t for the different tests.

6. Conclusions

The general characteristics for conduction of static loads tests on a vehicle bridge in the Gulf of Mexico are shown. Logistic challenges are highlighted for abutments tests located on the seabed. General behavior results for the tests are shown; the benefits of the conducted construction processes that allowed overcoming project challenges with regard to spatial variations in the geotechnical conditions encountered, is noted. It was validated that, conduction of this type of tests is fundamental for the assurance and quality control in this type of projects.

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