FULL-SCALE LOAD TEST OF THE NUCLEP PIER

Final Report

26th September 2011

Client
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1 – Introduction

The Nuclep pier is located in the city of Itaguaí, state of Rio de Janeiro, Brazil. The pier consists of a concrete deck supported by concrete piles. The deck is a reinforced concrete flat slab with length, width and depth of 46.0 m, 23.0 m and 0.8 m respectively. The piles have a cross section of 54 x 54 cm.

The goal of the load test was to assess the pier capacity of supporting an injection gas compression module, made of steel, weighting 927 tf, which is to be transported by two trailers weighting 126 tf. Thus, the total weight will be 1053 tf.

The load test was designed in such a way that it would represent, as close as possible, the real situation at the time of the module transportation along the pier. The load test was carried out on 26th august 2011, with the same trailers that will be used to transport the module, loaded with steel plates and water tanks.

Based on the load test results, as it will be justified in the following sections of the present report, the main conclusions are:

1. the maximum weight of the system consisting of trailers, steel plates and water tanks, used in the load test, reached 1207 tf, which represents 1.15 times the total weight of the trailers plus the weight of the module to be transported;
2. the maximum rotation measured on the pier deck was approximately 1:6000 which is much smaller than the limit value 1:750, given in the Brazilian Standard NBR 6122/2010, for angular distortions be considered a risk for the structure;
3. the maximum measured vertical displacement was 1.1 mm which is a very small value for a full-scale load test of the magnitude of the present one;
4. the strain values measured in the piles during the load test were low, indicating that the load level on the piles was well below their capacity;
5. all response measurements taken during the load test indicated that the structure of the pier performed well and that it is able to support the injection gas compression module with sufficient safety margin.

2 - Testing procedure

Two 18 axle trailers loaded with steel plates and water tanks (Figure 1) were used to apply the load on the pier. The two trailers moved slowly side by side into the deck. Seven controlling stages of load application were defined as described in Table 1. Stage 0 corresponds to the pier unloaded. Stages 1 to 6 correspond to trailers positioned on the deck as shown in Figure 2. In stages 1 to 5, the trailers were loaded with steel plates only. From stage 5 to 6, the load was increased by pumping water into the tanks. Stage 7 corresponds to the situation after trailers removal (Deck unloaded). Load values were obtained from the trailers manometers and their precision is ±10%.

Values of total applied load on the pier showed in Table 1 were calculated by dividing the weight of the loaded trailers by the number of axles (18) and multiplying the result by the number of axles on the deck for trailers positions indicated in Figure 2. In stage 6, for example, the total applied load on the pier is (1207/18) x 15 = 1006 tf.

The total time spent in the load test was 4 hours, 29 minutes and 20 seconds. Most of this time was spent to increase the total applied load from 796 tf (stage 5) to 1006 tf (stage 6) which took 3 hours, 58 minutes and 49 seconds.

A set of response measurements, such as vertical displacements, deck rotations and specific strain in some piles, was made during the load test in order to assess the overall pier behavior. These measurements are described in the following section.

Table 1 – Controlling stages for load application

Stage	Total applied load on the pier (tf)	Time of day (hh:mm:ss)	Elapsed time (hh:mm:ss)
0	**0**	18:05:35	0
1	Steel plates + trailer = 138 + 22 = **160**	18:06:13	00:00:38
2	Steel plates + trailer = 276 + 43 = **319**	18:06:30	00:00:55
3	Steel plates + trailer = 414 + 64 = **478**	18:08:20	00:02:45
4	Steel plates + trailer = 552 + 85 = **637**	18:09:07	00:03:32
5	Steel plates + trailer = 690 + 106 = **796**	18:11:26	00:05:51
6	Steel plates + trailer + water tanks = 690 + 106 + 210 = **1006**	22:10:15	04:04:40
7	**0**	22:34:30	04:29:20

Figure 1 – Two 18 axle trailers used in the load test

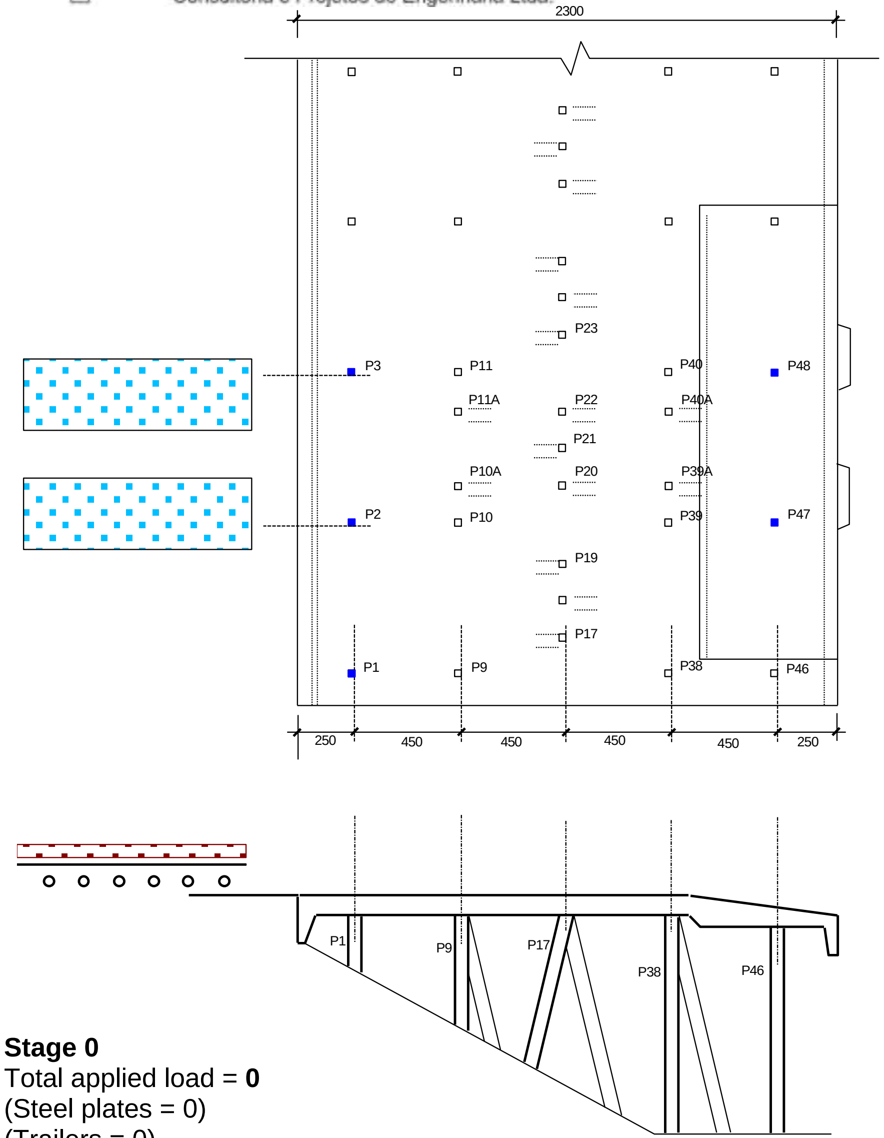
3 - Instrumentation

3.1 – Vertical displacements and deck rotations

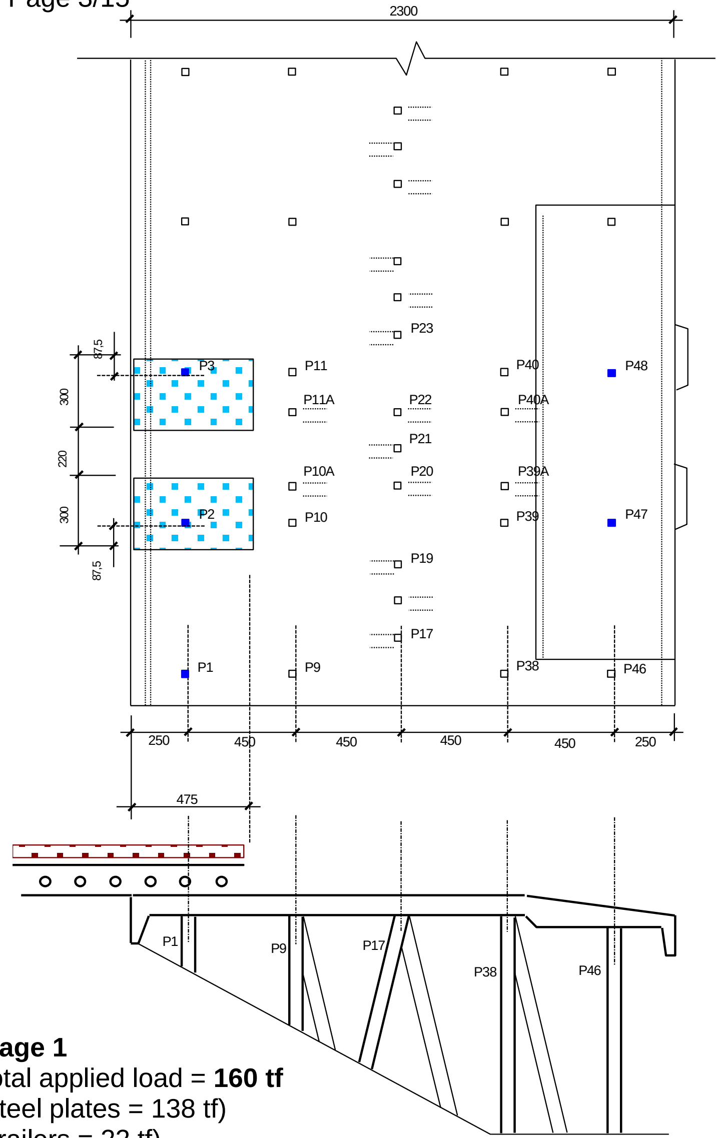
Vertical displacements were measured at the top surface of the slab using a Leica NA3003 digital level (accuracy of 0.01 mm) at points PT1, PT2 and PT3 (Fig. 3), and the rotations were measured at points EL01 to EL16 by using electrolevels distributed as shown in Figure 3.

3.2 – Specific strains in piles

In a previous structural analysis described in Reference Document No. 5 (see section 6) it was found that the piles under maximum loads during the load test would be P2, P3, P47 and P48. Therefore, these were the piles chosen to be instrumented. In these piles, specific strain values were measured with electrical strain gauges located as indicated in Figures 4 and 5.

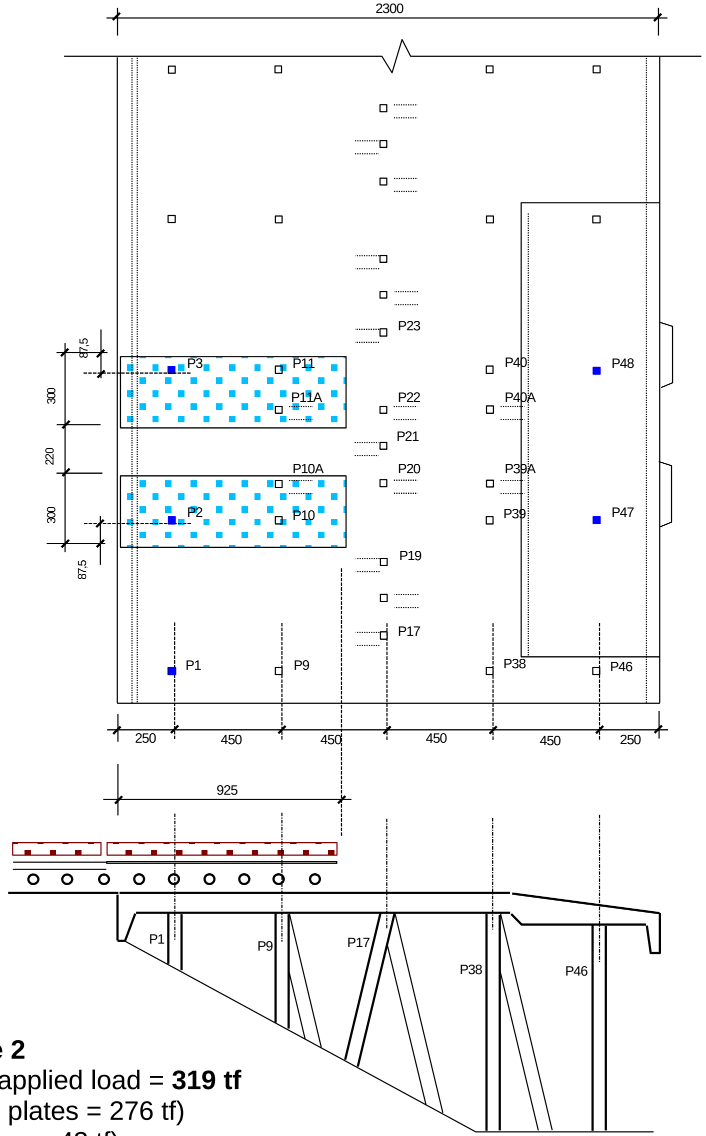


Stage 0
Total applied load = **0**
(Steel plates = 0)
(Trailers = 0)

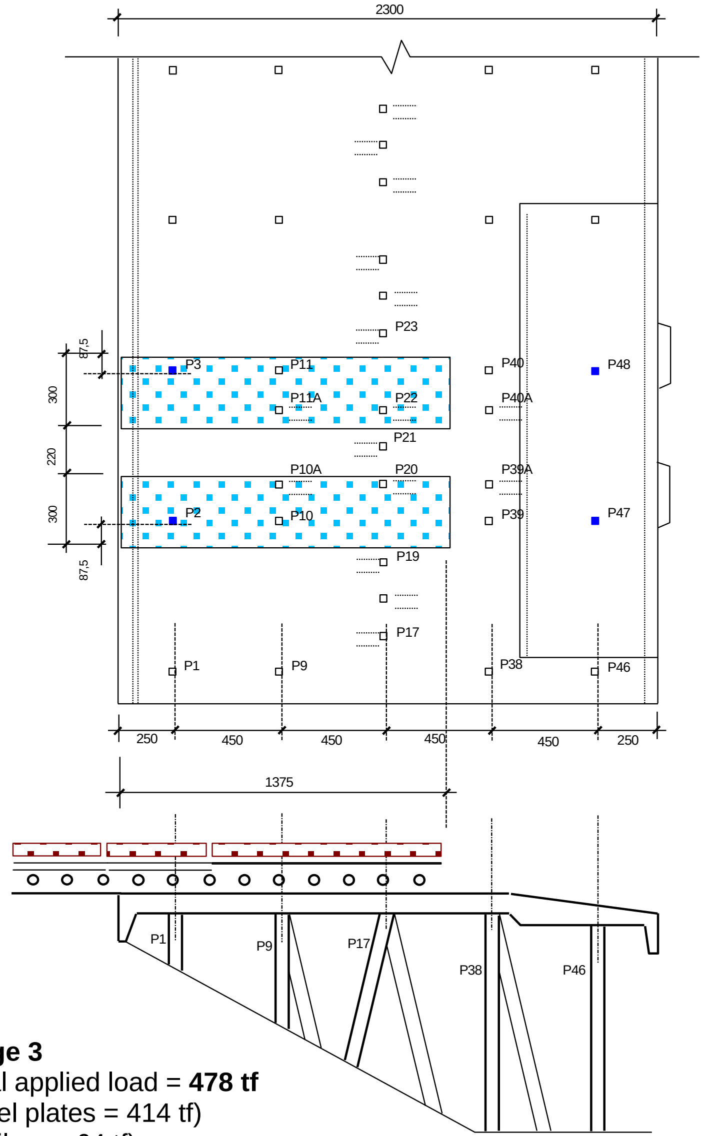


Stage 1
Total applied load = **160 tf**
(Steel plates = 138 tf)
(Trailers = 22 tf)

Figure 2 – Load application procedure (Dimensions in cm)

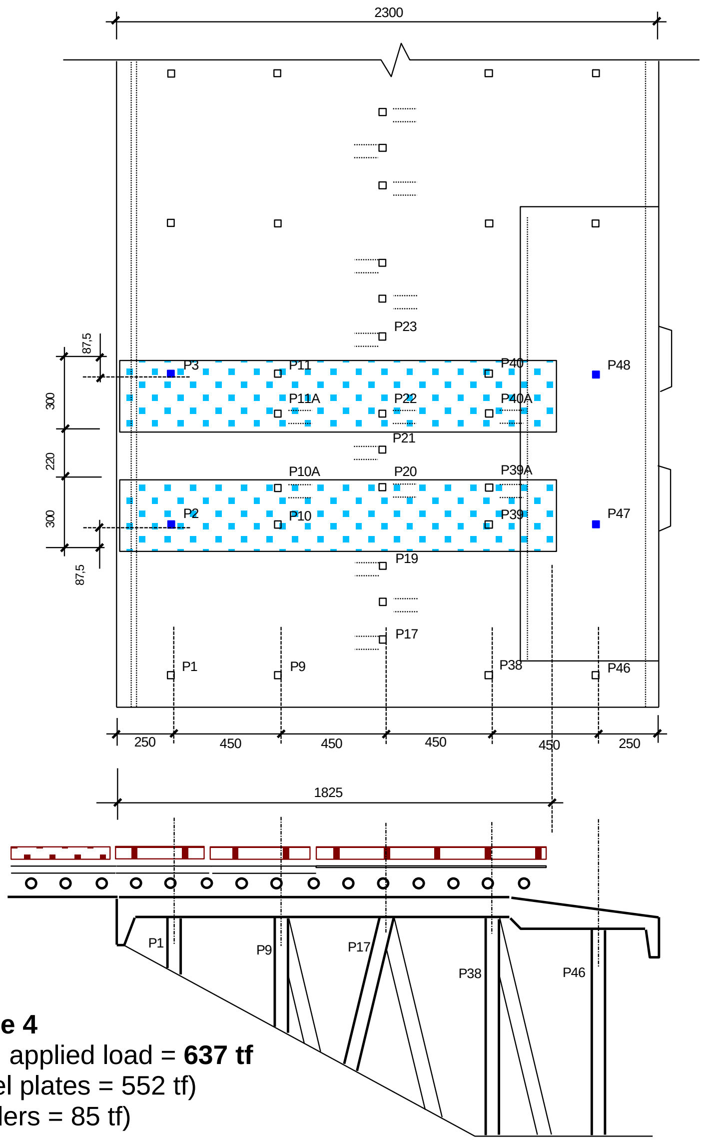


Stage 2
Total applied load = **319 tf**
(Steel plates = 276 tf)
(Trailers = 43 tf)

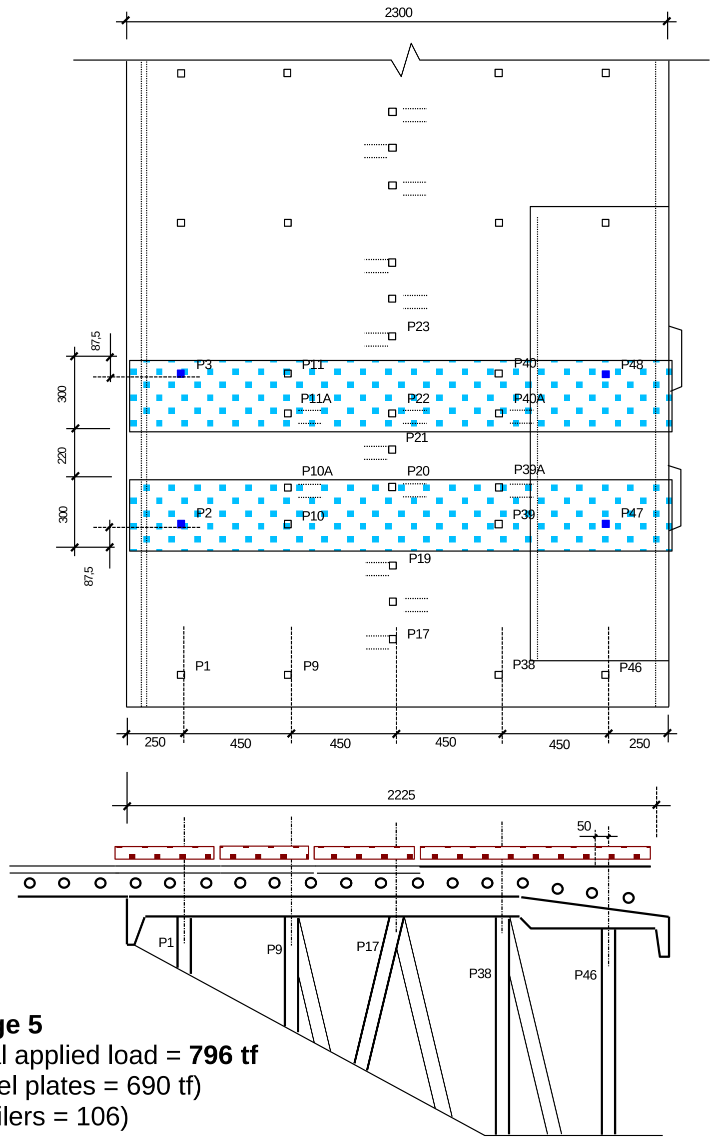


Stage 3
Total applied load = **478 tf**
(Steel plates = 414 tf)
(Trailers = 64 tf)

Figure 2 – Load application procedure (Dimensions in cm) (continued)

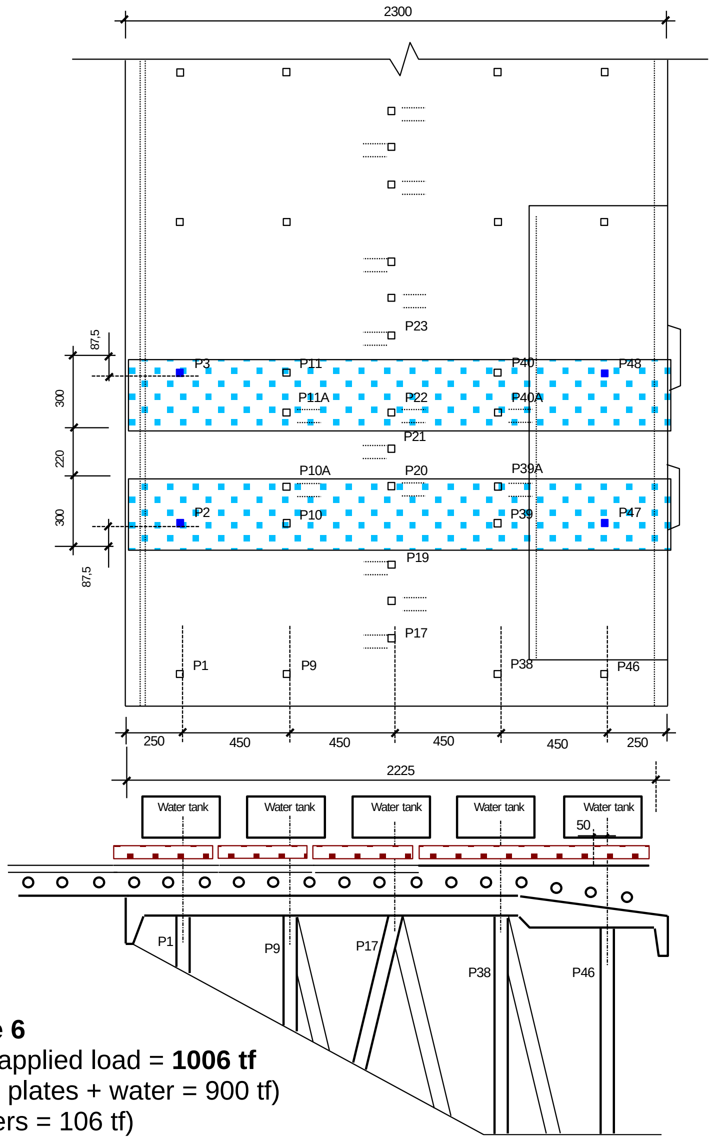


Stage 4
Total applied load = **637 tf**
(Steel plates = 552 tf)
(Trailers = 85 tf)

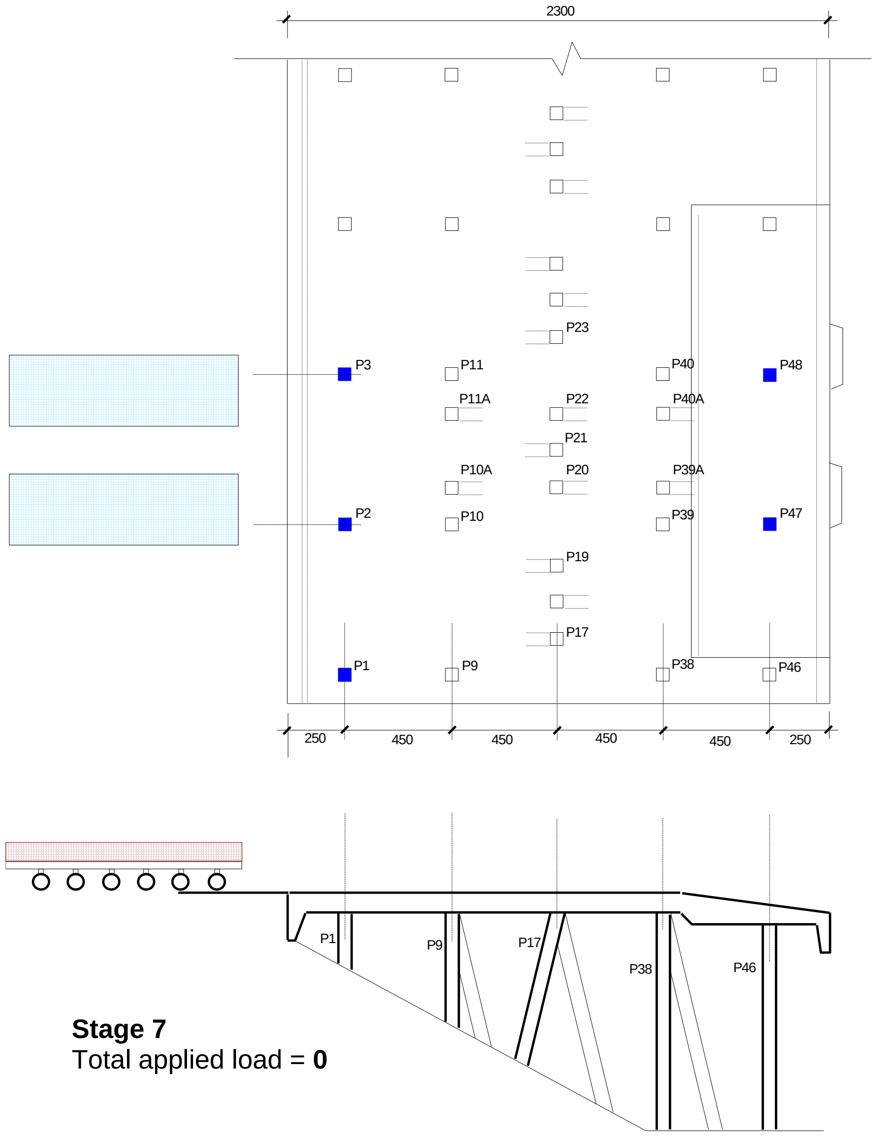


Stage 5
Total applied load = **796 tf**
(Steel plates = 690 tf)
(Trailers = 106)

Figure 2 – Load application procedure (Dimensions in cm) (continued)



Stage 6
Total applied load = **1006 tf**
(Steel plates + water = 900 tf)
(Trailers = 106 tf)



Stage 7
Total applied load = **0**

Figure 2 – Load application procedure (Dimensions in cm) (continued)

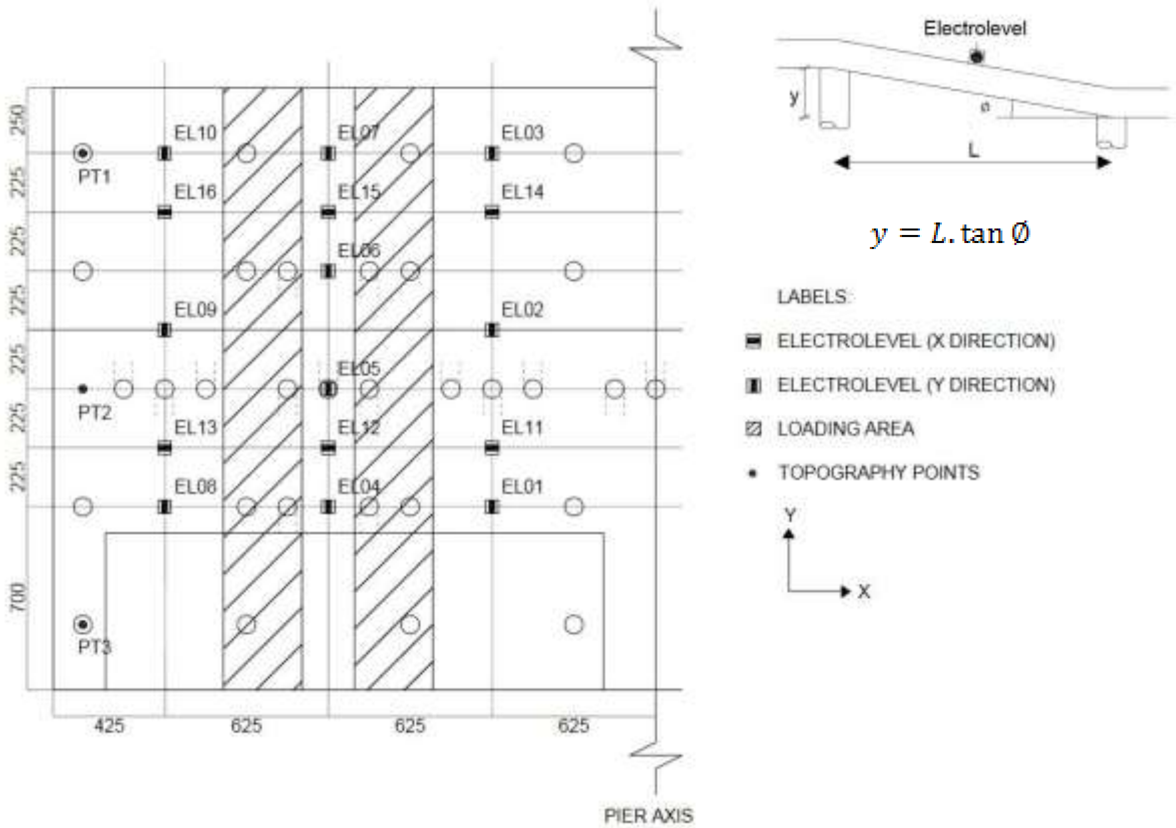


Figure 3 – Electrolevels positioning (Electrolevel in Y direction measures rotation about x axis)

Figure 4.a

Figure 4.b

Figure 4.c

Figure 4.d
Figures 4.a.b.c.d - Details of the installation of the electrolevels**.**

Figure 4.e- Details of the data acquisition system.

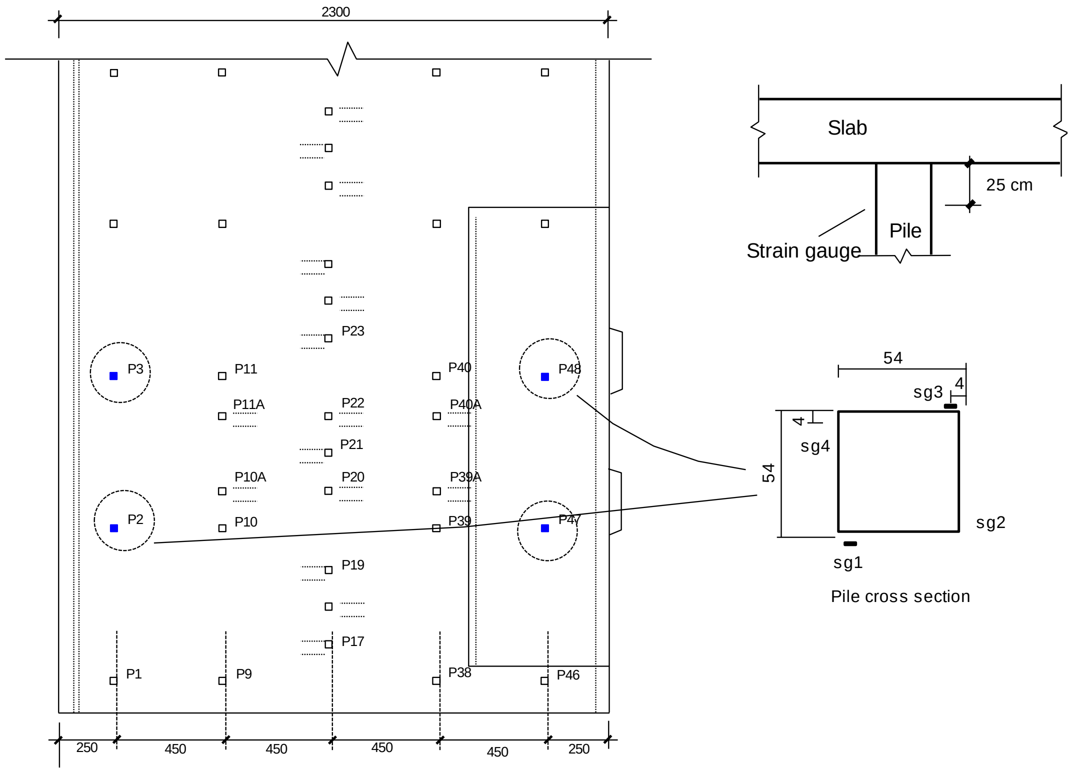


Figure 5 – Strain gages locations in piles P2, P3, P47 and P48

Figure 6 – Strain gages in piles P2 and P3

4 - Load test results

4.1 – Vertical displacements and deck rotations

Vertical displacements measured at points PT1, PT2 and PT3 are given in Figure 7 and 8. The values observed in these points were of the same order of magnitude, and the maximum displacement was 1.10 mm at Point 2. After load removal from the pier, the maximum residual displacement was 0.38 mm at Point 3, on the corner of the pier.

Vertical displacement values include elastic shortening and settlements of piles. Since the specific strains were totally recovered after load removal, as shown in section 4.2, the residual values of vertical displacements correspond to piles settlement.

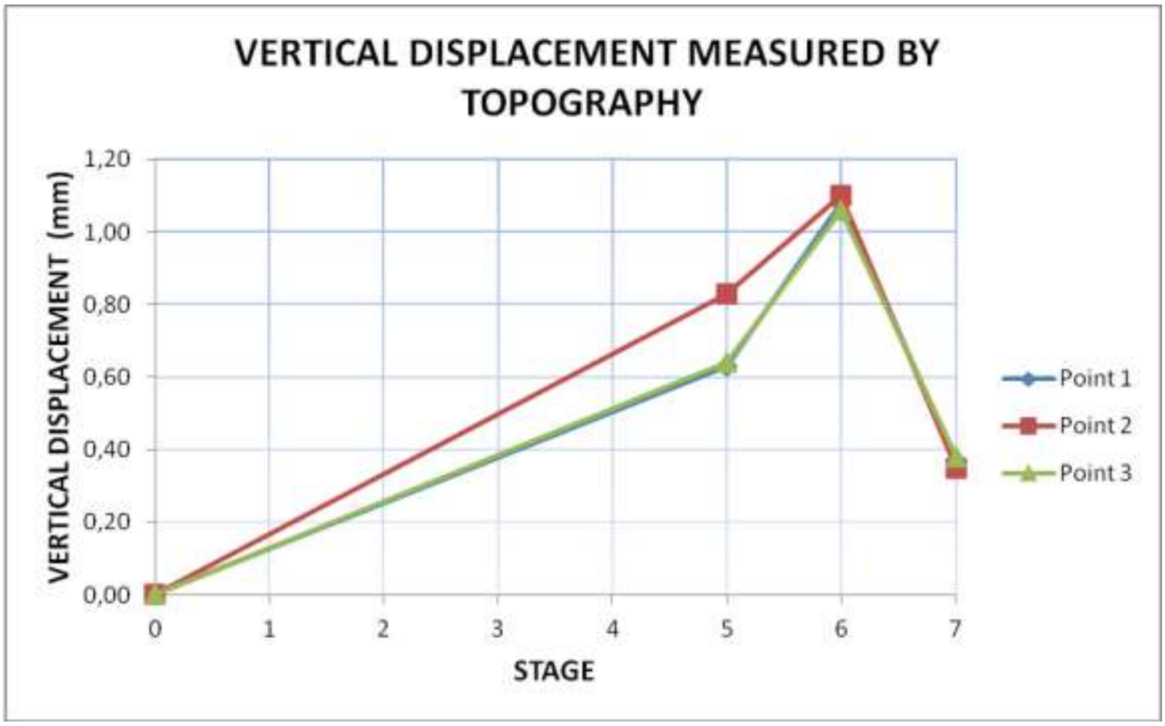


Figure 7 – Vertical displacements versus stages of load

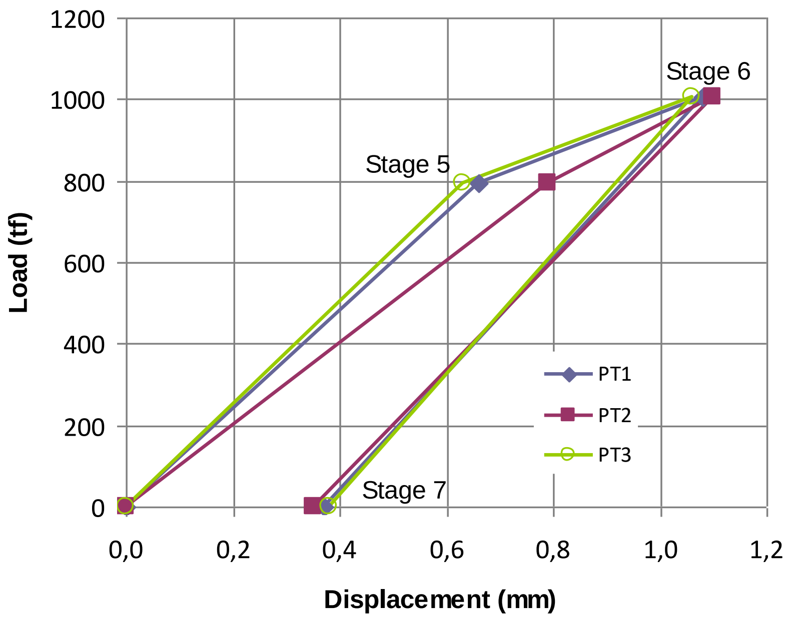


Figure 8 – Vertical displacements versus load on the pier

Rotation angles were monitored continuously throughout the load test with readings taken at every ten seconds. The readings were transformed into angles according to each electrolevel calibration factor.

Figure 9 below shows the angles of rotation obtained from the electrolevels throughout the load test stages. There is an apparent increase of the rotation angles between stages 5 and 6 because it was required four hours to finish the water tanks filling (stage 6), while the entrance of the load (stage 1 to 5) required only five minutes.

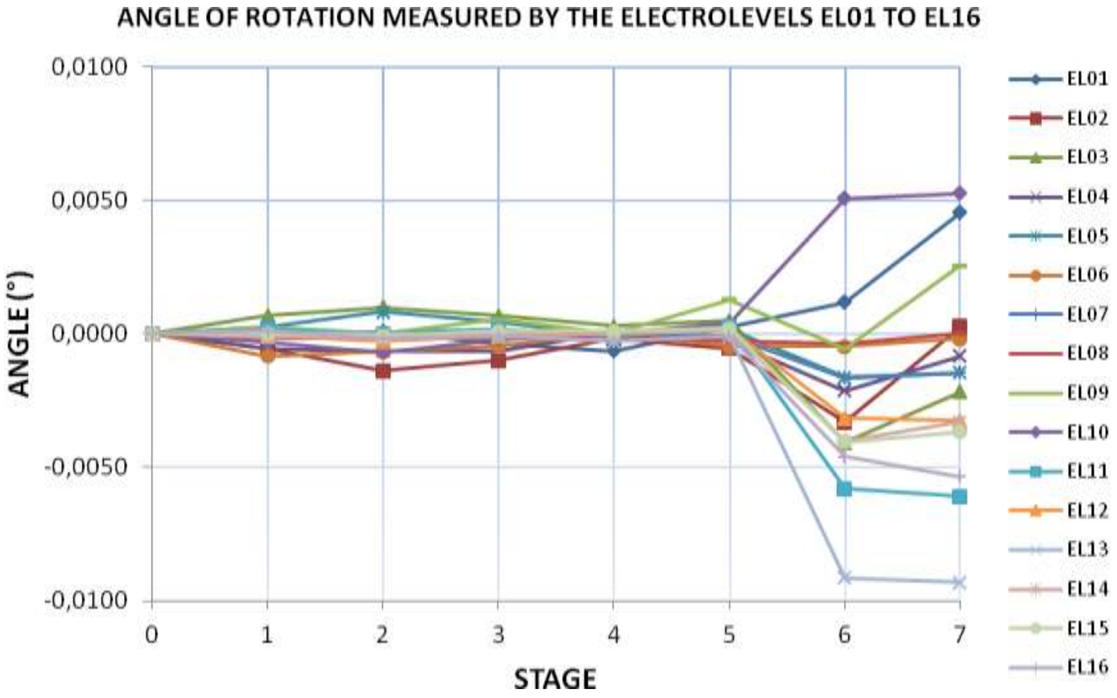


Figure 9 – Angle of rotation measured by the electrolevels

The maximum angular distortion obtained was approximately 1:6000. According to the recommendations of the Brazilian Standard NBR 6122/2010 (Figure 9), which is based on the criteria suggested by Bjerrum (1963), the limit value for angular distortions is around 1:750. Therefore, the measured angular distortion is far from being considered a risk for the structure of the pier.

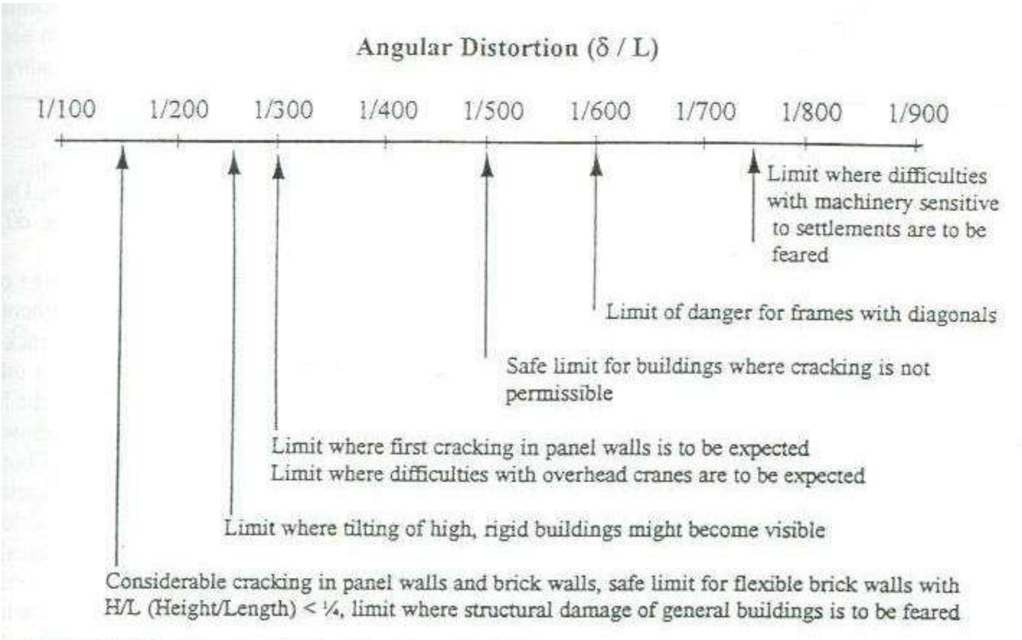


FIGURE 7.25 Damage criteria. (*After Bjerrum, 1963.*)

Figure 10 - Limit values for angular distortions

4.2 – Specific strains in piles

Strain values in piles P2, P3, P47 and P48, measured during the load test, are shown in Figures 11 to 14. Maximum values were observed in piles P2 and P3 as expected. In pile P2, the maximum value was 0.10 mm/m.

In order to verify the performance of the piles, the mechanical concrete properties must be updated. Reference Document Nº 1 shows that the specified characteristic cylinder strength (f_{ck}) of the piles was 25 MPa. Since the pier was built in the 1980's, the current mechanical concrete properties will be updated considering an elapsed time of 20 years. According to Eurocode 2, the mechanical concrete properties may be updated as follows.

Mean compressive strength at 28 days: $f_{cm} = f_{ck} + 8$ (MPa) = 25 + 8 = 33 MPa

Mean compressive strength at an age of *t* days: $f_{cm}(t) = \beta_{cc}(t) f_{cm}$

$$\beta_{cc}(t) = \exp\left[s\left(1 - \left(\frac{28}{t} \right)^{0.5} \right) \right]$$

s = 0,25 (normal hardening cement)

t = 20 x 365 = 7300 days

$\beta_{cc}(7300) = 1.26$

$f_{cm}(7300)$ = 1.26 x 33 = 41.6 MPa

Modulus of elasticity: $E_{cm} = 22(f_{cm}/10)^{0,3} = 22(41.6/10)^{0,3} = 33{,}7$ GPa = 33700 MPa

Modulus of elasticity at an age of *t* days: $E_{cm}(t) = (f_{cm}(t)/f_{cm})^{0,3} E_{cm}$

$E_{cm}(7300) = (1.26)^{0,3}\, 41{,}6$ = 36.1 GPa = 36100 MPa

To obtain the total strain in the piles, the strain caused by the self weight of the pier must be included. The structural analysis already mentioned in section 3.2 showed that the forces on the piles were as given in Table 2.

Table 2 – Force, stress and strain on piles obtained in a structural analysis

Pile	P_q (tf)	P_q (tf)	σ_g (MPa)	ε_g (mm/m)
P2	111	101	3.8	0.105
P3	100	96	3.4	0.094
P47	108	98	3.7	0.102
P48	104	89	3.6	0.100

P_q = theoretical force on pile due to pier self weight

P_q = theoretical force on pile due to applied load (trailers)

σ_g = mean normal stress on pile cross-section

ε_g = mean specific strain = $\sigma_g/E_{cm}(7300)$

If the ε_g values given in Table 2 are added to the strain values measured in the load test, then the total strain values would be around 0.200 mm/m. A reinforced concrete element under compression, such as the piles treated here, reaches its load capacity when the strain value in its cross section is around 2.0 mm/m. Therefore, the load level observed in the load test was well below the piles load capacity.

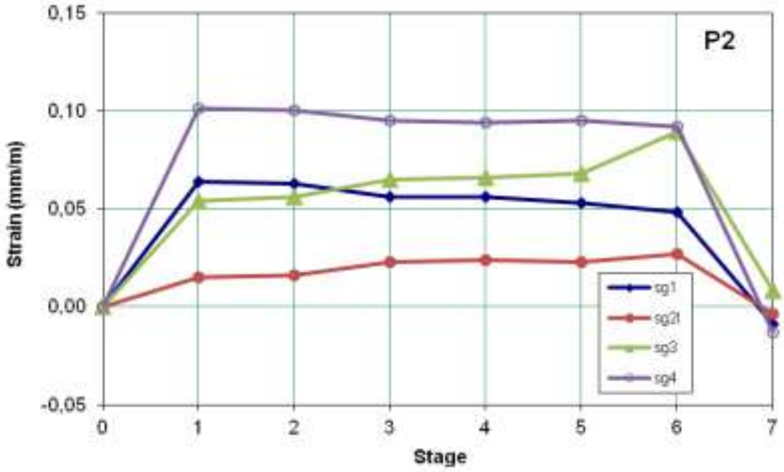


Figure 11 – Strains measured in pile P2.

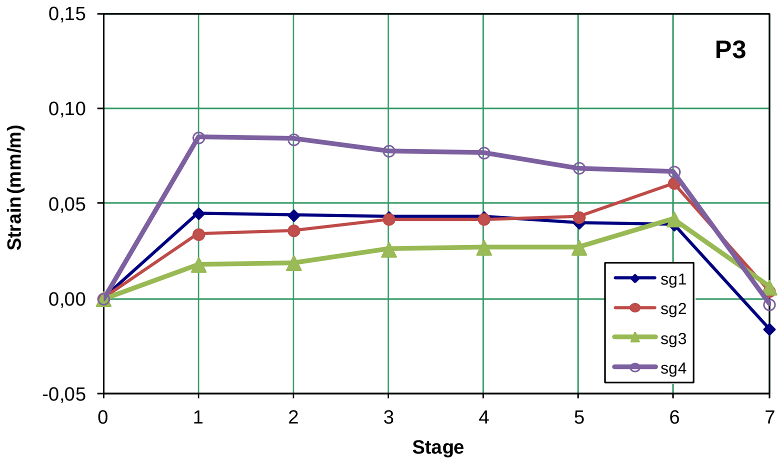


Figure 12 – Strains measured in pile P3

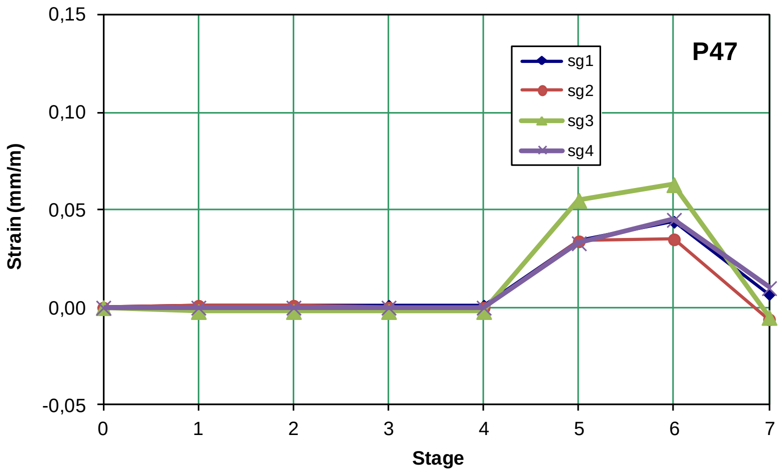


Figure 13 – Strains measured in pile P47

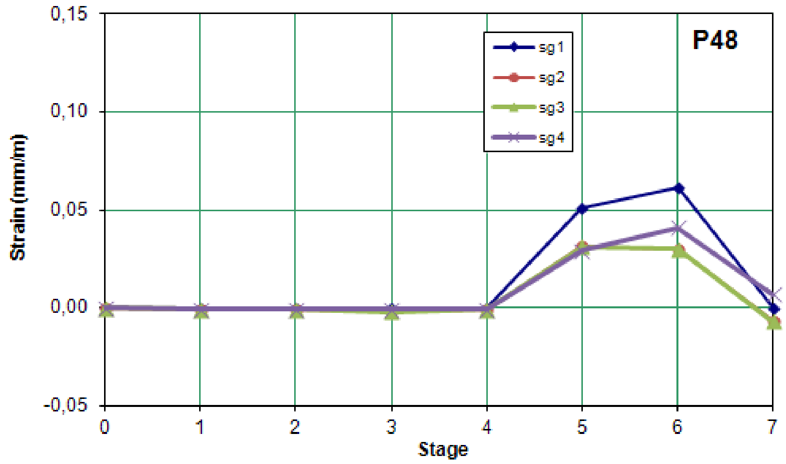


Figure 14 – Strains measured in pile P48

5 - Conclusions

Load test results showed that:

1. the maximum weight of the system consisting of trailers, steel plates and water tanks, used in the load test, reached 1207 tf, which represents 1.15 times the total weight of the trailers plus the weight of the module to be transported;
2. the maximum rotation measured on the pier deck was approximately 1:6000 which is much smaller than the limit value 1:750, given in the Brazilian Standard NBR 6122/2010, for angular distortions be considered a risk for the structure;
3. the maximum measured vertical displacement was 1.1 mm which is a very small value for a full-scale load test of the magnitude of the present one;
4. the strain values measured in the piles during the load test were low, indicating that the load level on the piles was well below their capacity;
5. all response measurements taken during the load test indicated that the structure of the pier performed well and that it is able to support the injection gas compression module with sufficient safety margin.

6 - Reference documents

1) Des. Nº 712-PE-002 – Rev. 3 – Estaqueamento
2) Des. Nº 712-PE-003 – Rev. 3 – Plataforma - Formas
3) Des. Nº 712-PE-010 – Rev. 1 – Plataforma – Armação inferior
4) Des. Nº 712-PE-011 – Rev. 0 – Plataforma – Armação superior
5) G.B. Guimarães, “Verificação do Projeto Estrutural do Cais do Terminal Marítimo da Nuclep”, 17 de junho de 2011.

7 - PMMR technical personnel.

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Rio de Janeiro, 26th September 2011

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