Behaviour of a large diameter bored pile in a sandstone

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ABSTRACT: Results of an instrumented loading test carried out on a large diameter concrete bored pile with 1,27m diameter and 35,80m total length, reinforced with 26 steel bars (25,4mm diameter) are analysed.

This pile was part of the foundation of a huge pier structure of an ocean terminal to berth iron ore carriers. The pile was bored in a sandstone, being the embedded and free lengths respectively of 13,7m and 22,1m and was instrumented using 21 sister bars.

The results obtained along the free length were used to obtain values of the Young's Modulus of the reinforced concrete and was compared with those obtained from laboratory test carried out on several samples taken during concrete pouring.

For each load increment the mechanism of load transfer were obtained along the three vertical lines of the embedded length. It was found that, for this pile condition, mainly the shaft resistance supported the load.

1 INTRODUCTION

A vertical load test was carried out in a large concrete bored pile instrumented with 21 electrical resistance strain gauges sister bars, fixed along three vertical lines of the reinforcement.

This pile was made to carry out a trial load test to verify the performance of the foundation of a large pier structure, having a total deck of 570m and supported by 212 piles. This pier, owned by the CVRD- Vale do Rio Doce Company, located at the Maranhao State-north of Brazil, constitutes part of the expansion of the ocean terminal to berth iron ore carriers. The tide variations in the area were of 6,5m and imposed strong currents, acting on the structure. The pile was formed using the already existing part of the deck, with the following construction sequence: 1- lowering of a 30m long steel casing with 1,27m inside diameter, a wall thickness of 9mm that weight 95KN; 2- installing the drilling equipment in the top of the casing (the combined weight of the casing and drilling equipment was 455KN, causing the casing to penetrate the loose to medium compact sand on the sea bed); 3- drilling to the required depth below the casing into the sandstone; 4- installing of the cage (reinforcement); 5- concreting to the specified level and 6- cutting the excess casing.

Figure 1 presents the general layout of the finished test pile having, total length of 35,70m, free length of 22,0m and embedded length of 13,7m. The top 7,2m of which was cased, leaving 6,5m cast-in-place in the sandstone.

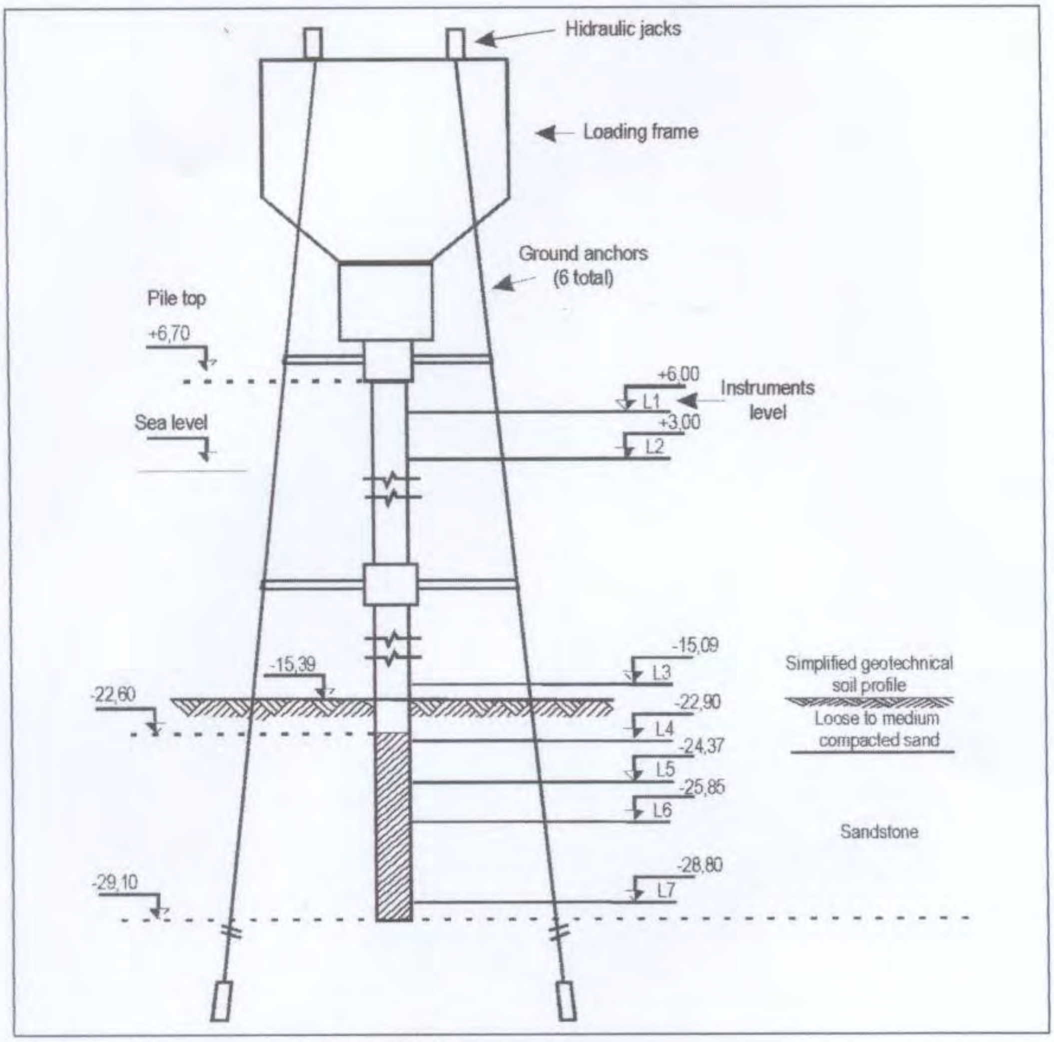
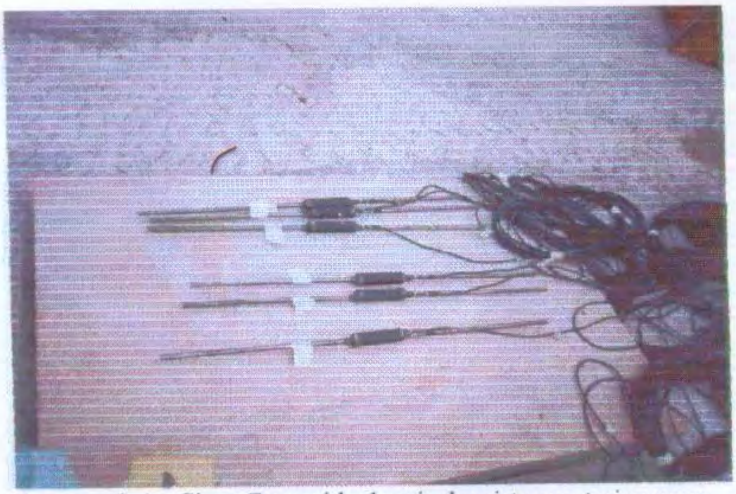


Figure 1 - General lay-out of the pile test

2 INSTRUMENTATION

In order to examine the pile behaviour and to obtain the mechanism of load transfer along the pile shaft, sister bars with electrical resistance strain gauges were used. These sister bars, having 12,7mm diameter and 1,1m length, were prepared in the laboratory using electrical resistance strain gauges, Kyowa KFG-5-120-C1-11, Gage Factor= 2.12 +/- 1%. The strain gauges were fixed axially (one quarter of the Wheatstone bridge connected with waterproof electrical cable – type 3x1mm , with three wires) in the middle of the sister bars using cyanoacrylate adhesive and being covered by four layers of isolating coating. The mechanical protection consisted of a PVC sleeve filled with a triple coating rubber epoxy (photograph 1). For the data acquisition system it was used a Lynx ADS2000, with two AD2160 signal conditioners and a notebook Toshiba, Pentium III, 500MHz. The measurement uncertainty was the order of +/- 20 μm/m. They were fixed along three equally spaced reinforcement bars (photograph 2), arranged at seven levels, being three levels along the cased length and four levels along the bored cast-in-place length.


Photograph 1 – Sister Bars with electrical resistance strain gauge


Photograph 2 – Sister Bars fixed inside cage

The maximum load applied incrementally in ten stages, was up to 8100KN and the reaction was provide by six inclined multiple ground anchors being tensioned by six mechanical jacks, automatically controlled by electrical oil pumps. Four dial gauges measured the settlement of the pile top.

3 ANALYSIS OF THE RESULTS

Table 1 presents the results of the applied load and the measured settlement (mm) of pile top, as indicated by the four dial gauges and also the measured micro strains as indicated by the sister bars.

For the initial loading, it was also observed big discrepancies among the four readings. The maximum total settlement measured was of the order of 8,65mm.

Table 1 – Values of measured top settlements and micro strains

INSTR.	81 t	162 t	243 t	324 t	405 t	486 t	567 t	648 t	689 t	729 t	810 t	810 t	608 t	405 t	203 t	0 t
DG1	0,5	0,99	1,68	3,16	3,95	4,93	4,94	5,39	5,7	5,83	8,62	8,85	7,59	6,77	5,48	4,86
DG2	1,3	1,98	1,97	3,33	4,94	5,97	6,2	5,24	6,93	7	8,06	8,12	7,73	5,61	4,97	3,95
DG3	1,3	1,76	1,9	4,07	5,02	6,93	8,57	8,74	10,1	9,79	9,22	9,22	9,21	7,97	7,2	5,6
DG4	0	1,47	2,69	4,4	5,56	6,38	6,6	8,02	8,44	9,08	8,75	8,74	8,77	8,27	7,05	5,46
G11	-20	-30	-50	-80	-80	-120	-200	-230	-230	-240	-260	-230	-200	-100	-60	-50
G21	-30	-40	-100	-130	-160	-220	-270	-320	-330	-340	-380	-370	-350	-260	-200	-120
G31	-10	-38	-65	-117	-120	-181	-220	-263	-248	-311	-323	-311	-272	-226	-157	-56
G41	-35	-40	-114	-147	-192	-240	-273	-261	-270	-288	-372	-372	-345	-270	-188	-104
G51	-23	-26	-53	-44	-63	-117	-184	-211	-205	-220	-220	-190	-181	-105	-62	-41
G61	-19	-24	-37	-37	-52	-91	-145	-142	-151	-148	-139	-130	-121	-91	-64	-40
G71	-8	-10	-4	7	7	-26	-62	-65	-68	-68	-40	-28	-13	4	7	4
G12	-34	-53	-77	-78	-120	-172	-237	-261	-276	-294	-267	-264	-239	-172	-108	-25
G22	-37	-64	-92	-98	-153	-214	-284	-345	-366	-381	-351	-342	-317	-241	-168	-64
G32	-18	-39	-61	-64	-95	-140	-213	-282	-310	-307	-273	-267	-240	-182	-121	-69
G42	-20	-51	-78	-93	-126	-175	-244	-319	-341	-347	-335	-328	-307	-247	-183	-111
G52	-22	-38	-47	-50	-65	-107	-152	-191	-200	-209	-194	-173	-158	-112	-74	-43
G62	2	-13	-16	-31	-20	-58	-97	-112	-112	-121	-115	-112	-97	-61	-34	-10
G72	-2	4,6	-16	-17	1	-5	-53	-50	-68	-26	-33	-31	-33	-26	-2	1
G13	-38	-37	-101	-116	-167	-213	-279	-237	-270	-285	-339	-324	-285	-261	-188	-89
G23	-40	-50	-98	-172	-209	-243	-280	-319	-322	-361	-454	-456	-392	-325	-220	-132
G33	-38	-47	-78	-90	-130	-193	-211	-269	-281	-293	-330	-320	-311	-240	-163	-84
G43	-27	-45	-73	-87	-112	-151	-196	-232	-247	-247	-368	-274	-256	-205	-142	-75
G53	-18	-33	-54	-66	-87	-133	-184	-205	-208	-186	-226	-217	-220	-168	-115	-60
G63	2	-13	-32	-28	-44	-95	-132	-147	-162	-144	-146	-144	-128	-98	-68	-34
G73	2	-3	-22	-19	-13	-7	-28	-22	-22	-10	-7	15	21	24	18	12

DG- Mechanical dial gauges. Gij- sister bars (i-gauge level; j-vertical line)

The load settlement curve indicated by the average dial gauge values is shown in Figure 2 and the mechanism of load transfer along the pile shaft, for the three vertical lines and for each stage of loading are presented in Figure 3. For the initial stages of loading, the results along the cased length have indicated some discrepancies among the three lines. This due to the bending moment caused by the strong ocean currents, inducing the top part of the pile to oscillate. These effects were reduced with the increase of the vertical load.

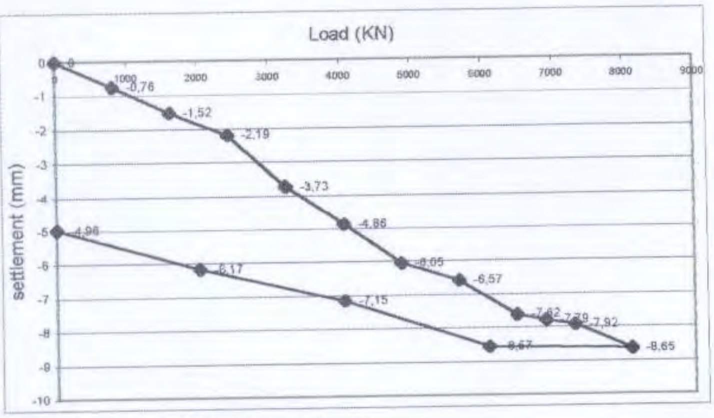


Figure 2 – Load X Settlement curve

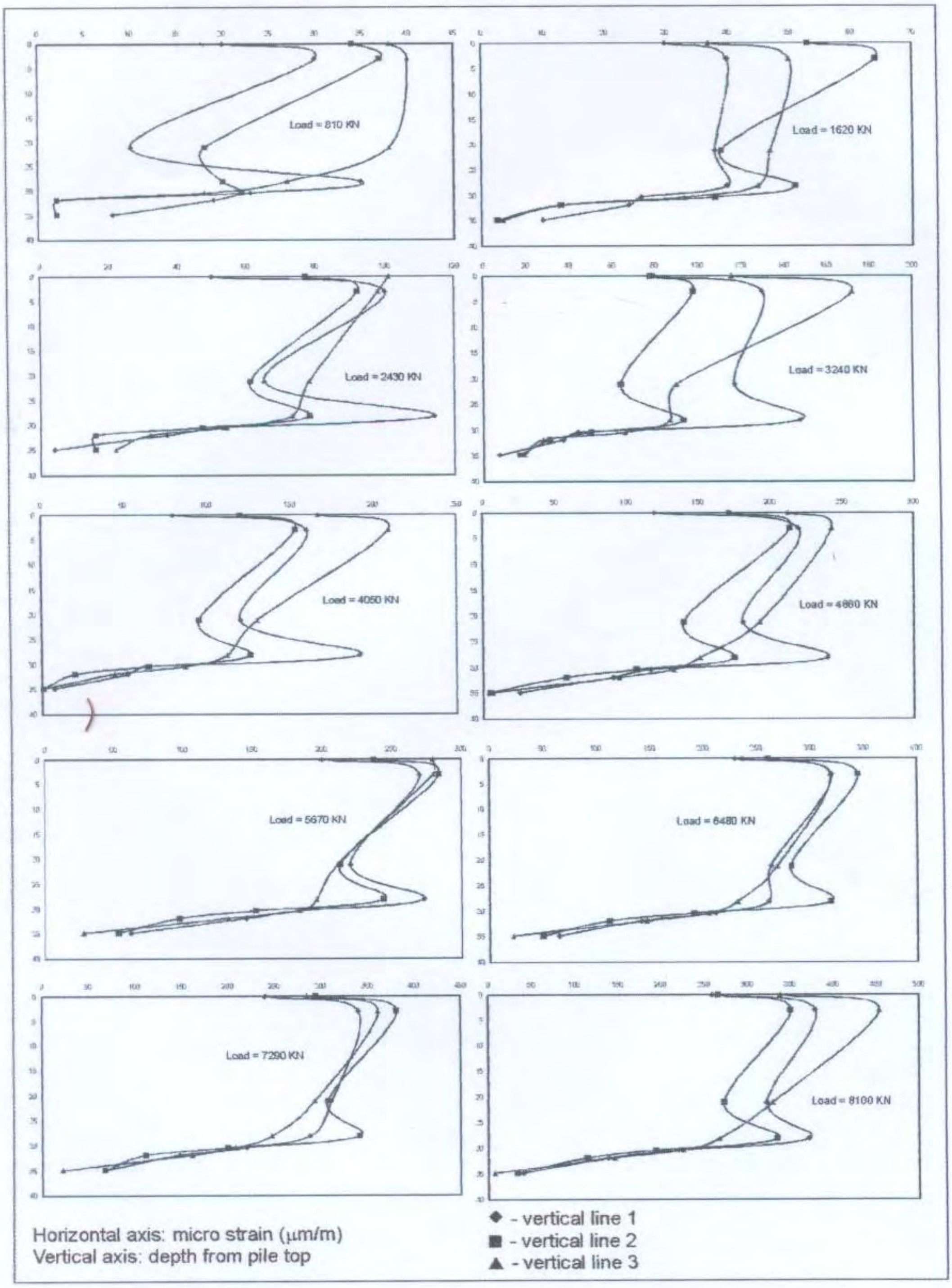


Figure 3 - Load Transfer along Pile Shaft

The results of the micro strain obtained along the free length (levels 1; 2 and 3) were used to determine values of the Young's Modulus of the reinforced concrete. Figure 4 presents values of the aplied load versus the measured micro strain.

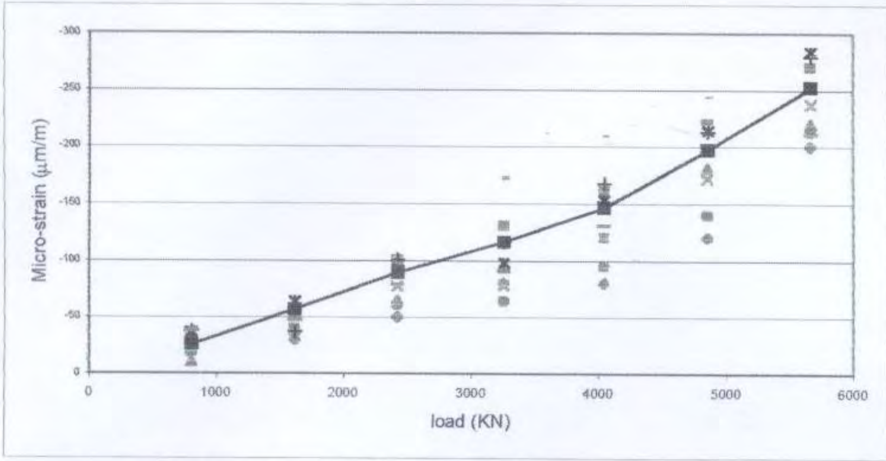


Figure 4 – Load X Micro Strains along free length

Figure 5 presents values of the secant Young's Modulus obtained using the following expression:

$E= F/S.\varepsilon$ ---------------------Equation 1

where F is the applied load (KN); S is the pile cross section area ($1,277m^2$) and ε is the corresponding average value of the micro strain.

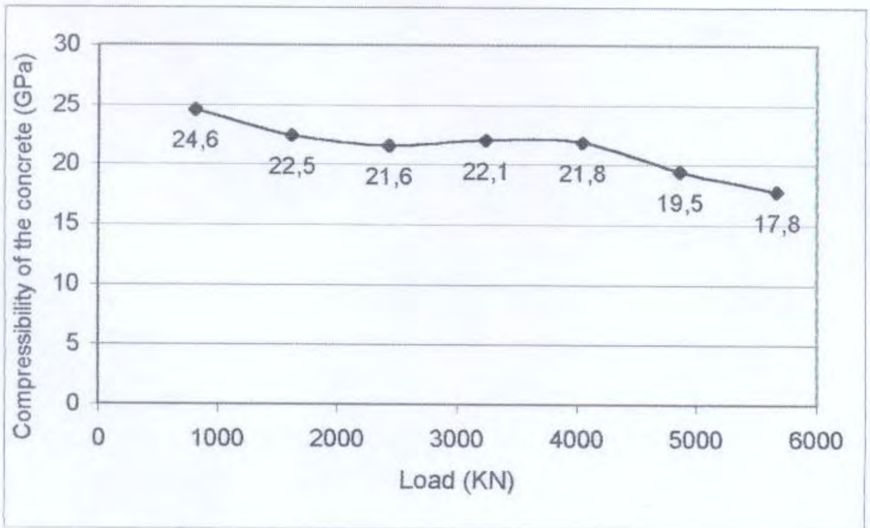


Figure 5 – Pile Compressibility

Values of E_p varied from 24,6 GPa to 17,6 GPa, indicating a variation around +/- 17% compared to the recommended value of 21,0 GPa. It is interesting to note that values of the micro strain at the second level were systematically higher than the corresponding values at the first and third levels. As expected these two levels have indicated close values, as a signal of no load transfer along the free length. This discrepancy at the second level could be caused by the combined effect of non-uniform load applied at the pile top and also by the end effect, due to the direct contact of the loading frame and the pile head (no use of spherical setting at the contact).

The results have indicated that the load transfer occurred along the bottom short length of the pile, with a small percentage of the applied load being transferred to the base of the pile.

4 COMPRESSIBILITY OF THE SANDSTONE

To determine the compressibility of the sandstone, it was proceeded a back analysis considering a floating pile. Two assumptions were made: firstly, a short pile with 6,50m length embedded in an homogeneous half-space (ignoring the embedded cased length), and secondly, a pile with 13,7m length embedded in a double layer system, having $E_1 = 0{,}2E_2$ (considering, in this case a top layer with a low compressibility. For these two cases, Poulos and Davis (1980) have provided solutions based on the theory of elasticity. For the case 1 the solution for a floating piles acting in homogeneous elastic half-space, can be expressed as:

"Es" = (P.I)/ ρ.D ---------------------Equation 2

Where: P is the applied top load; ρ is the settlement corresponding to the measured value at the top of the pile minus the elastic shortening of the "free length", d is the pile diameter = 1,27m; I is the settlement influence factor including corrections factors to account for pile compressibility, soil Poisson's ratio. These corrections factors are mainly function of the length-to-diameter ratio (L/D= 6,5/1,27=5,12-short pile)) and of the pile stiffness factor (Ep/Es-concrete-to-soil compressibility ratio).

Values of the equivalent homogeneous Young's Modulus for the sandstone resulted of the back analysis ranged from 177 MPa to 133 MPa corresponding respectively to 810 KN and 4860 KN applied top load.

For a nonhomogeneous soil profile (double layer) the solution is given as:

E_2 = P.I/ ρ.L ----------------------------Equation 3

Where: definitions are the same as equation 2, but the settlement influence factor is also function of the ratio between the top layer thickness and the pile length (h_1/L=7,2/13,7=0,52).

For this analysis, values of the Young's Modulus of the sandstone ranged from 220MPa to 168MPa.

Mobilized Shear Resistance

The shear resistance mobilized along the pile shaft (ΔT) was obtained using the equilibrium equation governing the mechanism of load transfer along the shaft, expressed as:

ΔT = Δσ. D/ 4. ΔL = ΔF/ π. D. ΔL. ---------------------Equation 4

For the maximum top load of 8,1MN the corresponding maximum shear stresses mobilized along the embedded pile shaft were:

Inst. level	Load transfer	Shaft length	Mob. Shear Stress
4- 5	3,35 MN	1,47m	0,57 MPa
5- 6	1,85 MN	1,48m	0,31 MPa
6- 7	2,06 MN	2,95m	0,17 MPa

5 CONCLUDING REMARKS

Sister bars were used to determine the mechanism of load transfer of a long pile with a short embedded length in a sandstone. Results of the micro strains obtained along the free length have indicated values of the Young`s Modulus of the reinforced concrete varying from 24,6 to 17,6 GPa. Values of the equivalent homogeneous Young`s Modulus of the sandstone obtained from the back analysis considering as a floating pile were in the range of 220MPa to 133MPa. The maximun shear stress mobilized along the pile shaft was 0,57 Mpa.

6 REFERENCE

Poulos, H.G. and Davis, E.H. (1980)- Pile Foundation Analysis and Design. John Wiley and Sons.

7 ACKNOWLEGMENTS

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