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SUCCESSIVE LOAD TESTS ON BORED PILES

PRUEBAS DE CARGA SUCESSIVAS EN PILOTES EXCAVADOS

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SYNOPSIS. The paper presents the results obtained in successive load tests performed on bored instrumented piles. Each pile was submitted to four testes, being two with slow (SML) loading and two with quick loading (QML). Load x pile penetration curves are presented as well as curves of lateral and point load against pile penetration. It is pointed out that the ultimate load values, obtained in each test, increase with the pile penetration, reaching a value that tends to become constant. Are analyzed the ultimate load values obtained in the load tests and those predicted by empirical relationships commonly used in the engineering foundation practice in Brazil.

1. INTRODUCTION

With the installation of the Foundation Experimental Field of EESC-USP, some bored cast in place piles were submitted to load tests. Trying to take the maximum profit of the total investment the piles have been submitted to varied loading. The interest in researching this subject was created by the fact that when reloading one pile of the experimental field a different behavior was obtained when compared with that of the first loading. The difference in bored piles behavior, when submitted to successive loading has already been pointed out by MASSAD (1.992), SACILOTTO (1.992), MANTILLA (1.992).

2. EXPERIMENTAL FIELD

The Foundations Experimental Field of EESC-USP (Civil Engineering School of São Carlos - University of São Paulo) subsoil conditions have already been described by CARVALHO (1.991), MANTILLA (1.992), CINTRA ET ALII (1.991). A typical subsoil profile is presented in



figure 1, where the results obtained for boring no.5 are reproduced due to the fact that this is the closest boring to the tested piles analyzed in this paper.

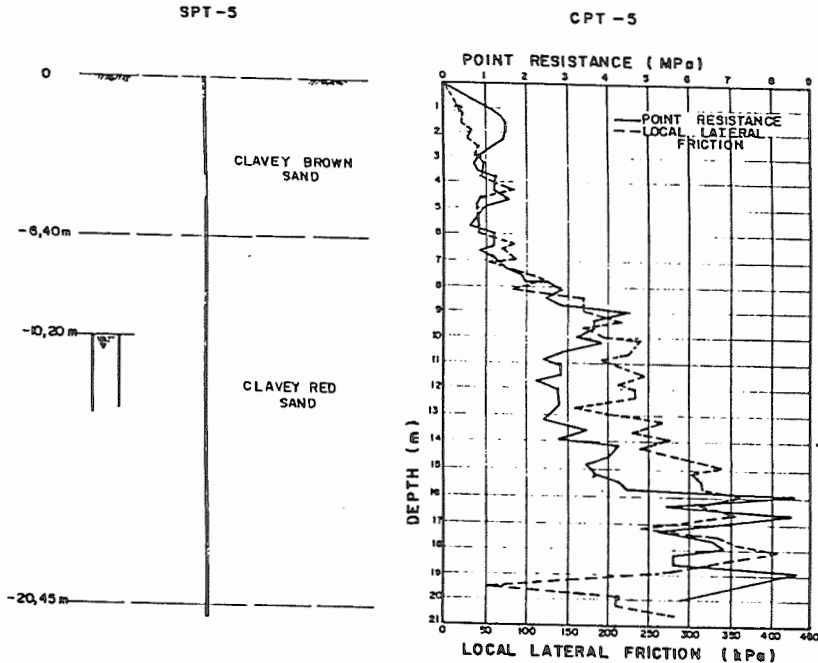


FIG. 1 - TYPICAL SUBSOIL CONDITIONS FOR THE EXPERIMENTAL FIELD
SOIL PROFILE FOR BORING N. 5
SPT AND CPT

The piles are cast in place, in bored holes executed with a mechanical auger with nominal diameters of 0.35m, 0.40m and 0.50m. These piles will be designated, in this paper by the numbers 1, 2 and 3, respectively. The piles are 10m long and after the pile cap construction they result with 9.40m embedded in soil. Two strain-gages were placed in five different levels, along the pile reinforcement. This instrumentation allows to obtain the load acting on the pile section, at the instrument level, during the load test.

3. LOAD TESTS

Four load tests, in compression, were performed in each pile being the 1st and 4th of the slow type (SML) whereas the 2nd and 3rd are of the quick loading type (QLM). The pile top settlements were measured with 4 mechanical extensometer, with 0.01mm precision, bearing in the pile cap. The loads were applied to the pile cap with hydraulic jacking and their values registered in load cells. Figures 2, 3 and 4 present curves of load x pile penetration for the performed tests.

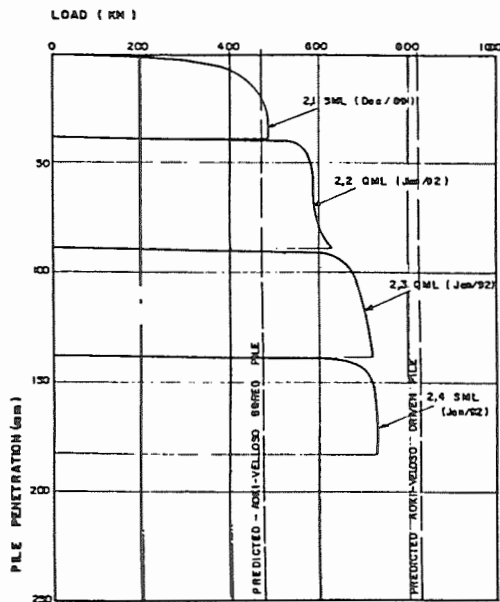


FIG. 3 - LOAD vs PILE PENETRATION
PILE NO 2 - DIAMETER 0,40 m

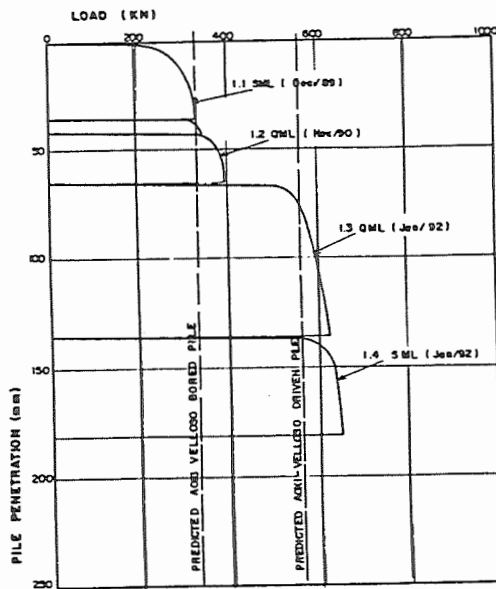


FIG. 2 - LOAD vs PILE PENETRATION
PILE NO 1 - DIAMETER 0,35 m

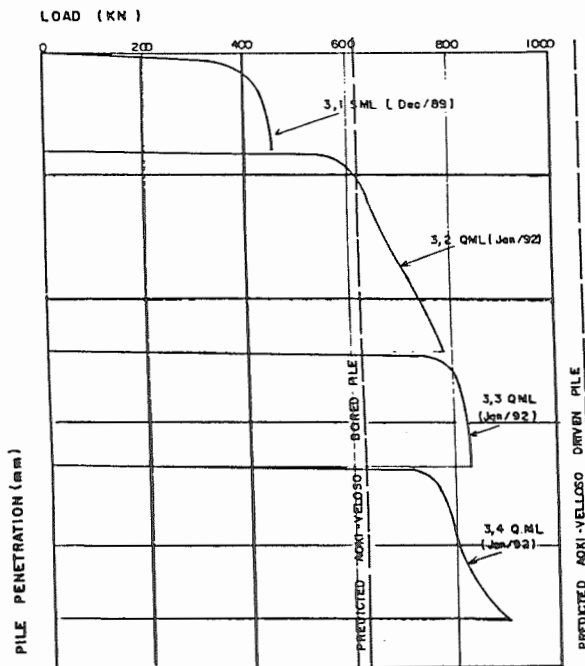


FIG. 4 - LOAD vs PILE PENETRATION
PILE NO 3 - DIAMETER 0,50 m

Based on the values given by the instrumentation the point loads were obtained. The pile point penetration is determined by computing the elastic compression of the pile and subtracting from the pile top penetration. The plot of point load x point penetration for the pile no. 3 (diameter 0.50m) is presented in figure 5.

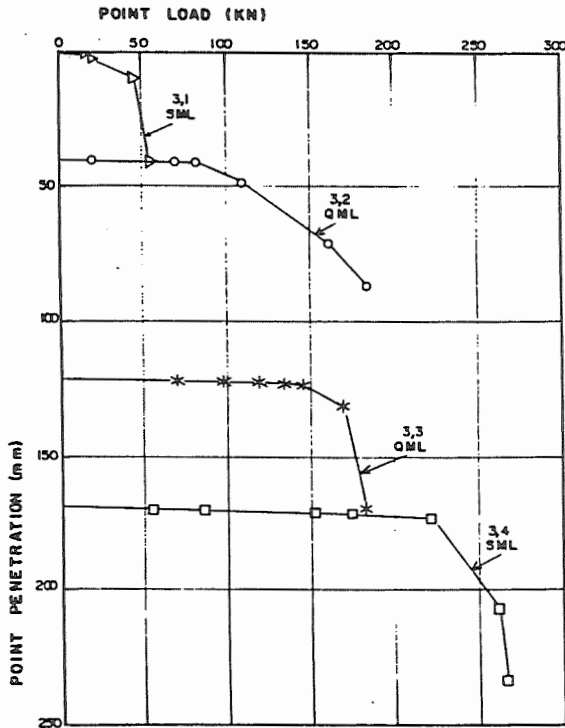


FIG. 5 - POINT LOAD x POINT PENETRATION
PILE Nº 3 - DIAMETER 0,50 m

In figure 6 is presented the lateral load x pile penetration plot and in figure 7 the load transfer curves for the test 1.3 (load test number 3 for the pile number 1 - 0.35m in diameter).

Aiming to maintain an uniform analysis for the data of all load tests, the ultimate load was calculated using VAN DER VEEN (1.953) criterion. The ultimate load values thus obtained are reproduced in Table 1 where also are presented the values of lateral and point load computed from the instrumentation.

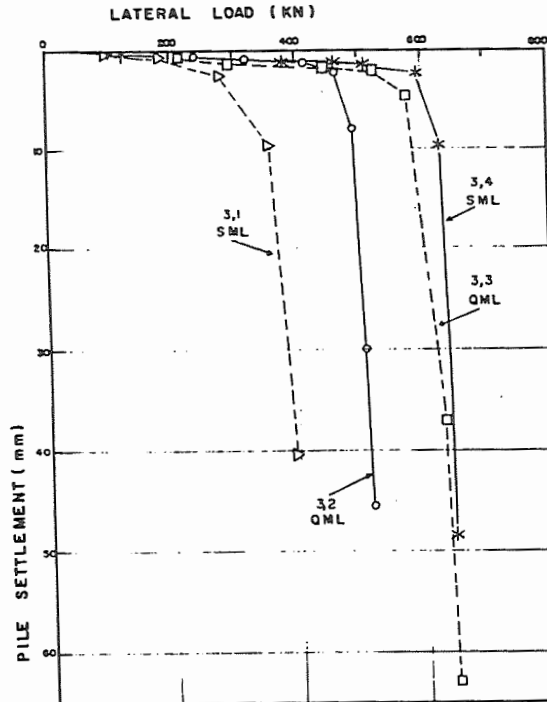


FIG. 6 - LATERAL LOAD x PILE SETTLEMENT
PILE Nº 3 - DIAMETER 0,50 m

TABLE I VALUES OBTAINED IN THE LOAD TESTS

D	Nº	LOAD TEST	DATE	LOAD (KN)			
				Q_{avg}	QI	Qp	$\frac{QI}{Qp}$
D = 0.35 m	1.1	SML	12/89	3 46	—	—	
	1.2	QML	11/90	3 89	—	—	
	1.3	QML	01/92	6 27	395	229	0.63
	1.4	SML	01/92	6 45	—	—	
D = 0.40m	2.1	SML	12/89	4 87	173	—	0.36
	2.2	QML	01/92	5 99	5 51	46	0.92
	2.3	QML	01/92	7 25	5 55	170	0.77
	2.4	SML	01/92	7 25	4 15	3 10	0.57
D = 0.50 m	3.1	SML	12/89	4 50	395	55	0.88
	3.2	QML	01/92	6 52	4 89	1 63	0.75
	3.3	QML	01/92	6 30	6 47	1 63	0.78
	3.4	SML	01/92	9 10	6 48	2 62	0.71

4. PREDICTED VALUES FROM EMPIRICAL FORMULAS

Based on the penetration resistance values from SPT tests, and in cone resistance measured in CPT tests, the values of the ultimate load were predicted using the empirical formulas of AOKI-VELLOSO (1.975), DECOURT-QUARESMA (1.978), PEDRO PAULO VELLOSO (1.981) and MEYERHOF (1.976). Results are summarized in tables 2, 3 and 4. A comparative analysis of these formulas is presented in ALBIERO (1.990).

To predicting ultimate load the piles were considered as bored and as driven one. Trying to improve these predictions, for each pile the results of the closest borings were used. In this way for piles 1, 2 and 3 the borings (2, 5), (5) and (1, 5) were respectively utilized. The values obtained are in tables 2, 3 and 4. Considering that the Meyerhoff formula was calculated for the American standards for SPT, that furnishes values higher than those obtained for the Brazilian standards, corrected values of the ultimate loads are presented. This correction is made using a factor 1.5 even though foundation engineers in Brazil recommend higher factors, around 2.4.

TABELA 2 PREDICTED VALUES FROM EMPIRICALS FORMULAS (D=0.35m)

FORMULAS		BORED PILE		DRIVEN PILE	
		qc	N	qc	N
AOKI - VELLOSO	Q _i	87	142	148	244
	Q _p	93	192	159	328
	Q _u	180	336	307	572
DECOURT QUARESMA	Q _i	/	314	/	448
	Q _p	/	108	/	188
	Q _u	/	422	/	636
PEDRO P. VELLOSO	Q _i	93	144	186	288
	Q _p	117	213	234	426
	Q _u	210	357	420	714
MEYERHOF	ORIGINAL	Q _i	/	58	115
		Q _p	/	167	334
		Q _u	/	225	449
	CORRECTED	Q _i	/	87	173
		Q _p	/	251	50
		Q _u	/	338	674

TABELA 3 PREDICTED VALUES FROM EMPIRICALS FORMULAS (D=0.40m)

FORMULA		BORED PILE		DRIVEN PILE	
		qc	N	qc	N
AOKI - VELLOSO	Q _i	100	198	171	340
	Q _p	117	276	201	472
	Q _u	217	474	372	812
DECOURT QUARESMA	Q _i	/	386	/	551
	Q _p	/	153	/	272
	Q _u	/	539	/	823
PEDRO P. VELLOSO	Q _i	100	168	200	336
	Q _p	146	266	292	532
	Q _u	246	434	492	868
MEYERHOF	ORIGINAL	Q _i	/	67	134
		Q _p	/	218	436
		Q _u	/	285	570
	CORRECTED	Q _i	/	101	201
		Q _p	/	327	654
		Q _u	/	428	855

TABELA 4 PREDICTED VALUES FROM EMPIRICALS FORMULAS (D=0.80)

FÓRMULA		BOREO PILE		DRIVEN PILE	
		qc	N	qc	N
AONI VELLOSO	Q _i	132	225	226	386
	Q _p	177	393	302	672
	Q _u	309	616	528	1058
DECOURT QUARESMA	Q _i	/	447	/	639
	Q _p	/	247	/	442
	Q _u	/	694	/	1061
PEDRO P. VELLOSO	Q _i	132	192	264	383
	Q _p	210	343	420	687
	Q _u	342	535	684	1070
ORIGINAL	Q _i	/	77	/	153
	Q _p	/	353	/	707
	Q _u	/	430	/	860
MEYERHOF CORRECTED	Q _i	/	116	/	230
	Q _p	/	530	/	1061
	Q _u	/	646	/	1291

The ultimate load values predicted by the empirical formulas based on SPT values were compared to those obtained in load tests using the VAN DER VEEN(1953) criterion (Table 5). In table 6 are presented the relationships of the values of the ultimate loads from the VAN DER VEEN criterion and those predicted by the empirical formulas.

TABELA 6 ULTIMATE LOAD VALUES EMPIRICALS FORMULAS PREDICTED ULTIMATE LOAD

		D = 0.35 m		D = 0.40m		D = 0.60m		
		1.1	1.4	2.1	2.4	3.1	3.4	
PROVA	Q _u APT	346	645	487	725	490	910	
FÓRMULAS	AONI VELLOSO	BORED	336		474		613	
		DRIVEN		572		612		1058
	DECOURT QUARESMA	BORED	422		539		694	
		DRIVEN		636		823		1061
	PEDRO P. VELLOSO	BORED	357		434		535	
		DRIVEN		714		868		1070
	MEYERHOF CORRECTED	BORED	336		428		646	
		DRIVEN		674		855		1291

5. ANALYSIS OF THE RESULTS

When analyzing the plot of the lateral load x pile penetration one notes that the lateral resistance is fully mobilized with small settlements from 5 to 9 mm. The point resistance is completely mobilized with large settlements that, in this research, have resulted around 40% to 50% of the pile diameter. These observations agree with the experiments related by VESIC (1.975).

As the bored piles are being submitted to successive loading the ultimate load value increases as is shown in figures 2, 3, 4. In these figures are also presented the values of the ultimate load predicted with the AOKI-VELLOSO formula, using SPT values, for bored and for driven pile. These differences in the pile behavior are not due to the different types of tests used. The pile behavior, in the case, is the same for SML or QML test as can be shown in the 3rd and 4th tests. In these tests the behaviors are alike independent of the test type for all 3 piles.

According to MASSAD (1992) there is, in the load x settlement curve of the 1st loading, a point which corresponds to the full mobilization of the lateral resistance and to the beginning of mobilization of the point of the pile. This same point, associated to the second loading curve has an analogous meaning but is moved to the right of the point of the 1st curve. These would explain why the settlements x loads plots are more curved in the first loading than in the subsequent ones.

In the second cycle of loading the pile exhibits a higher lateral resistance as can be seen in figure 6. Indeed a true increase in the lateral resistance does not occur but this is a result of the presence of residual stresses due to the former loading. When unloading the pile residual stresses, in the soil-pile system, keep acting in such a way that when reloading the pile a portion of the applied load is used to compensate the existing residual stresses. Only after the compensation of the residual stresses the load begins to be transferred to the soil resulting, in this way, an apparent increase in the lateral resistance. Residual lateral stresses measured in test 1.3 are shown in Figure 7. According to MASSAD (1992) this would not mean an increase in the total lateral resistance but that due to the restrained load a part of the point reaction already acts when the second loading is applied.

As the pile is forced to penetrate in the soil its behavior changes, and the ultimate load increase. After a certain penetration the pile behavior tend to be the same occurring small increments in the ultimate load value due to the increase in the depth and in the density of the soil around the pile point.

Comparing the ultimate load predicted from empirical formulas with the values defined by the VAN DER VEEN criterion one observes that if the piles are considered to be bored the values predicted from empirical expressions are close to those defined in the 1st and 2nd test, and if the piles are considered to be driven, the ultimate load values predicted by empirical formulas are close to those defined in the 3rd and 4th load tests. This means that the

piles, initially bored, begin to exhibit a behavior close to the one of a driven pile, as can be shown by the data on table 5 and by the figure 8.

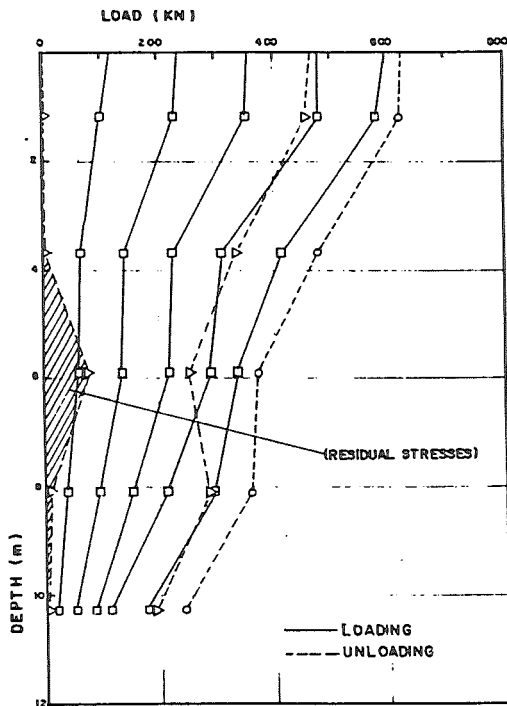


FIG. 7 - LOAD TRANSFER CURVES
LOAD TEST 13 - QML
PILE N° 1 - DIAMETER 0,35 m

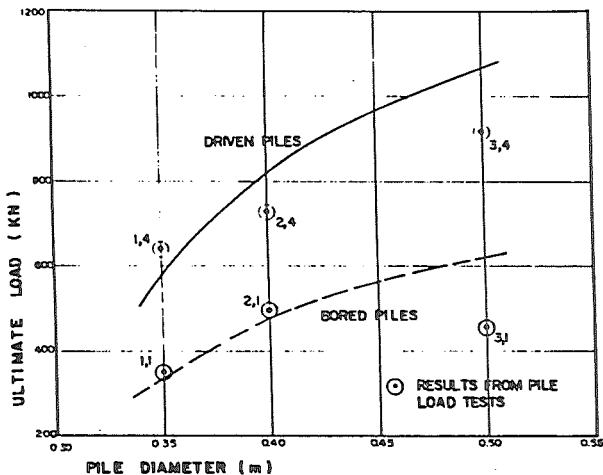


FIG. 8 - PILE DIAMETER & ULTIMATE LOAD PREDICTED BY AOKI-VELLOSO AS A FUNCTION OF SPT VALUE.

The empirical formulas may be used for driven and for bored pile. Defining the relationship:

$$R = \frac{Q_{u \text{ driven}}}{Q_{u \text{ bored}}}$$

For the empirical expressions of Aoki-Velloso, Pedro Paulo Velloso this relationship presents constant values of 1.71 and 2.00 respectively. For the expressions of Decourt-Quaresma and Meyerhoff the relationship R is a function of the percentage of the total load that is transferred to the soil by the lateral load.

$$S_p = \frac{Q_{lu}}{Q_u} \times 100\%$$

This relationship S_p , for the pile load tests of this work, decreases as the successive loading are performed and presents an average value of 75% thus resulting:

Decourt-Quaresma	R = 1.53
Meyerhoff	R = 2.00 a 2.25

It seems reasonable to admit that, according to those empirical formulas, if the load test were performed on a driven pile instead of a bored pile, with the same pile and soil properties the relationship should be around 2.00.

The ultimate load values defined in the first and last tests are compared to those predicted for bored and driven piles respectively (Table 6). One can notice that this relationship is close to 2 and could be said that the bored piles, after forced to penetrate in the soil, pass to exhibit a behavior similar to that of a driven pile.

6. CONCLUSIONS

The results obtained for the bored piles in the EESC-USP Foundation Experimental Field, when submitted to successive loading allow, for this type of soil, to draw some tentative conclusions:

- lateral resistance are fully mobilized with small pile settlements (5 to 9mm) whereas the point resistance needs great displacements (35% to 40% of the diameter) to be completely mobilized;
- there are no significant differences in the results of load tests conducted in quick (QML) or slow (SML) loading;
- the results obtained in successive loading are different and tend to be the same as the pile, initially bored, begin to behave like a displacement pile, for the lateral load as well as for the point load;

d) - the necessary settlement to modify the behavior of the bored pile to a displacement pile is small (0.30m to 0.40m);

e) - it is possible to execute small bored piles, jack them against a reaction load, or the structure itself, thus forcing a penetration in the soil, and thus obtain an improvement in the pile behavior;

f) - this technique would allow to transform small bored pile in ones with a behavior similar to that of a displacement pile, without the inconveniences of vibrations and difficult length predictions, and would provide a way of conducting a quality control for small bored piles.

7. ACKNOWLEDGMENTS

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