Vertical Load Tests on Instrumental Root-Piles

Essais des Pieux-Racines Solicités Verticalement

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SYNOPSIS Vertical Slow ML Tests, with maximum loads of 735 kN, were carried out on small diameter bored injection piles (root-piles), instrumented with electrical strain-gages throughout their lengths. The root-piles were installed in three different conditions, namely, floating, point bearing on top bedrock and embeded in rock. The subsoil consisted of a residual soil with boulders on top of bedrock 5 to 15 m in depth.

Besides the interpretation of the data from the load tests the paper is concerned with theoretical analyses, based on a model which assumes the Cambefort's laws to describe the soil-pile interaction.

One achievement of the study was that for the safe load of 434kN, for bedrock distant 12 m or more from the surface, floating piles could be used; if this distance is not more than 8 m, the piles must be embeded in the rock; otherwise, point bearing piles on top of bedrock could be indicated.

INTRODUCTION

As a part of a study to choose the more adequate type of foundation to support a structure in the ETA Guaraú, a water treatment station in the Horto Florestal District in S. Paulo city, three root-piles, 110mm nominal diameters, were constructed, instrumented throughout their lengths and subjected to Vertical Slow ML Tests. The subsoil in the site is composed mainly of a residual soil with boulders, on top bedrock 5 to 15m depth (see figure 1).

The construction procedure involved the augering of a hole in the soil to the chosen depth varying roughly from 5 to 10m and putting a 160 schedule steel tube, with sleeve valves, which provided the way to inject grout the same manner as used for anchors. The steel tubes were incorporated to the root-piles.

The root-piles were installed in three different conditions, namely:a) root-pile E-1, embeded in the rock; b) root-pile E-2, point bearing on top bedrock; and c) root-pile E-4, floating in the soil. Their lenghts were 5.6m, 9.9m and 7.2m, respectively.

Besides the interpretation of the data from the load tests, the paper presents theoretical analyses based on a mathematical model which assumes the Cambefort's laws to describe the soil-pile interaction and takes into account the pile compressibility.

LOAD TESTS

Vertical Slow ML Tests were carried out on the root-piles, instrumented with dial gages on their top, with 0.01 mm sensitivity, and electrical strain-gages throughout their lengths. The strain-gages with a resolution of 5×10^{-6} were applied to an instrumented column, that is a steel pipe, 12.7mm diameter, placed in the center of the 160 schedule tube. The spacings of the strain-gages were set, varying roughly from 1.50 to 2.50m. Care was taken in waterproofing the gages, protecting them from mechanical damage during the deposition of cement in the annular space between the instrumented column and the steel tube.

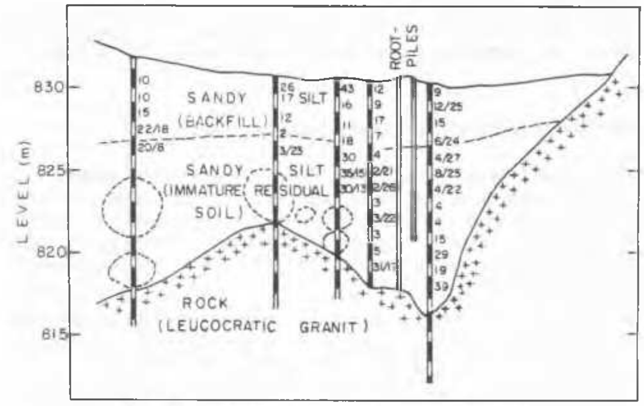

FIG. 1 - TYPICAL SUB-SOIL CROSS-SECTION WITH VALUES OF N-SPT.

As the top of the root-piles were designed to be 2.9 to 3.2m below the natural ground surface, pillars made out of structural concrete were built as shown in figure 2, free of friction against the suroundinq soil.

The majority of the gages responded properly and the data obtained, considered in their entirety, appear to be consistent.

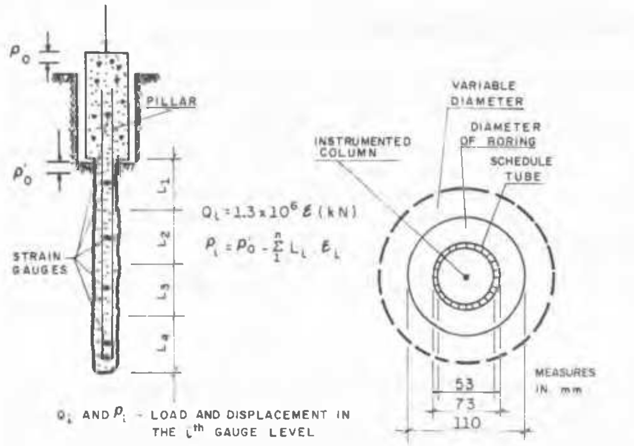

FIG. 2 - CROSS-SECTIONS OF ROOT-PILE

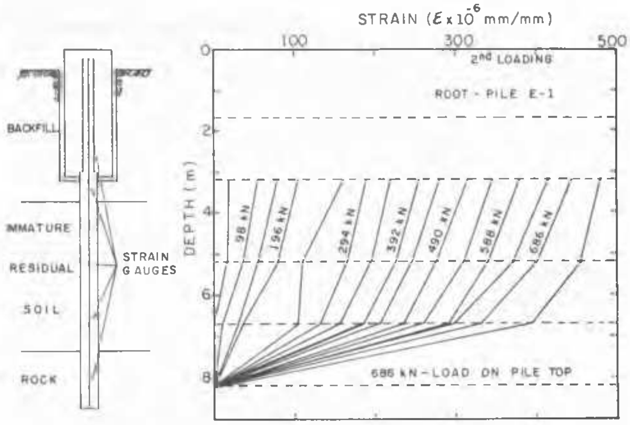

FIG. 3 - MEASURED SPECIFIC STRAINS VS. DEPTH

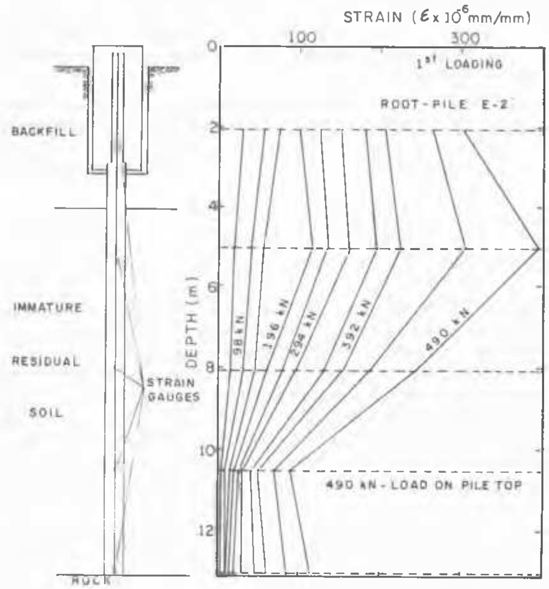

FIG. 4 - MEASURED SPECIFIC STRAINS VS. DEPTH

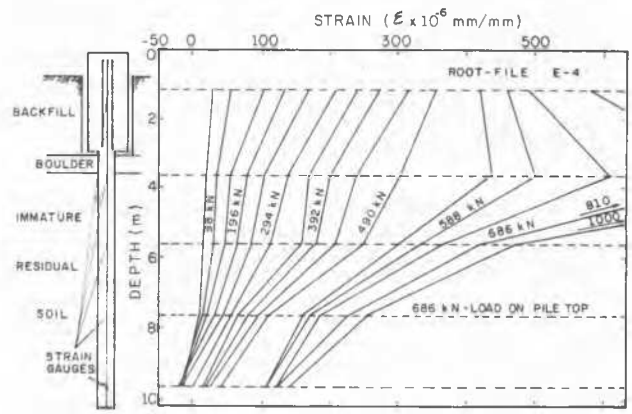

FIG. 5 - MEASURED SPECIFIC STRAINS VS. DEPTH

The load was applied to the root-piles in increments of 49kN up to 735kN, the maximum load reached. The unloading was proceeded by means of decrements of 147kN. The root-piles E-1 and E-2 were subjected to two loading applications.

The load-settlement relationships measured on top of the root-piles allowed the safe load prediction, according to the Brazilian Norm NB-51, that is, half ultimate load if it is reached or could be predicted; otherwise, the maximum load divided by 1.5. The values obtained were 490, 441 and 372kN for root-piles E-1, E-2 and E-4, respectively, with a mean value of 434kN.

INTERPRETATION OF EXPERIMENTAL DATA

The results of the load tests were analysed in themselves and in the optics of a theoretical procedure for predicting soil response. These two lines, i.e., the experimental and the theoretical, were combined in a counterpoint movement.

Figures 3, 4 and 5 show measured specific strains as a function of depth for some of the loadings applied to root-piles E-1, E-2 and E-4.

The loads and displacements along the root-piles were determined assuming compatibility of deformation; the computation procedures are indicated in figure 2. For these computations values of the Young's Modulus for the pillars and the root-piles were required, besides the actual pile diameter after cement injection. The Young's Modulus (E) were determined using the response to the applied loads of the electrical strain-gages placed: a) in the pillars (root--piles E-2 and E-4) and b) near the root-piles top (root-piles E-1, first and second loading applications) (see figure 6). It was figured up for the pillars E values ranging from 9.84 GPa to 13.25 GPa and for the root-piles, ES values roughly 1.3 GPa.m^2, where S is its cross sectional area. The concrete and the cement were cured for 15 to 20 days prior to loading.

The actual pile mean diameter (D) was not measured up to now due to a delay in test site excavation. For this reason many parameters will be presented affected by a factor proportional to D or D^2. Based on previous experiences with

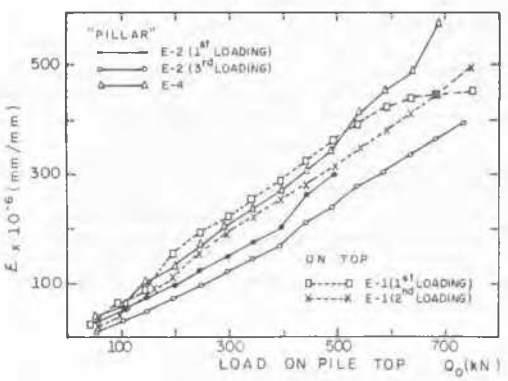

FIG. 6 - GAUGES LOAD-STRAIN RESPONSES

anchors, whose bulbs diameters were measured after excavation of the overlying soil, it is expected that D ranges from 20 to 25 cm.

The theoretical analysis was based on a model developed by Baguelin et al (1971), which assumes the pile compressibility and the Cambefort's laws shown schematically in figure 7 to describe the soil-pile interaction. One difference was introduced, i.e., Cambefort (1964) assumed constant values for the tip reaction after a certain displacement level y_2, that Baguelin et al called saturation phase (see figure 7). This extension was needed, as we will see later on. Figure 8 illustrates for root-pile E-4 the Cambefort's laws and Table I resumes the parameters obtained and used in the computations.

Fortunately, the theoretical values of the loads depend on terms like ED^2, AD, BD, QD^2, RD^2, etc., which are known. This means that all the theoretical analyses results presented below are independent on the knowledge of the actual pile mean diameter (D).

Some results of the analysis carried out are plotted in figures 9 to 11.

All the root-piles tested behaved as short piles in the meaning set forth by Baguelin and colaborator, i.e., the tip transfers loads to the soil before the side friction reaches its maximum value.

First of all, it is worth noting that the theoretical curves approached the experimental ones. As an example, the differences for root--pile E-1 were of the order of 9%, excepting the inicial values (see figure 9), due to the simplifying assumptions made in the theory (soil with an elastic-plastic behaviour). In the particular case of root-pile E-4, the differences between theory and field results in the final parts of the curves, presented in figures 11 and 12, were due chiefly to a "hardening" of the soil, as shown in figures 8-a and b. This "hardening" led to an extension not only of the 2nd Cambefort's Law but also of the 1st one. As it can be seen in figures 11 and 12, the theoretical curves related to this small modification are in better agreement with the measured ones.

Finally, the analysis of the load transfer to the pile tips revealed that:

a) for root-pile E-1, embeded in rock, more than

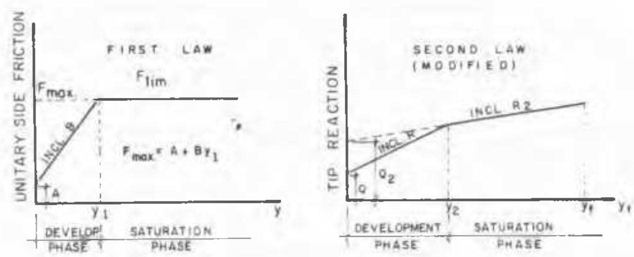

FIG. 7 - CAMBEFORT'S LAWS

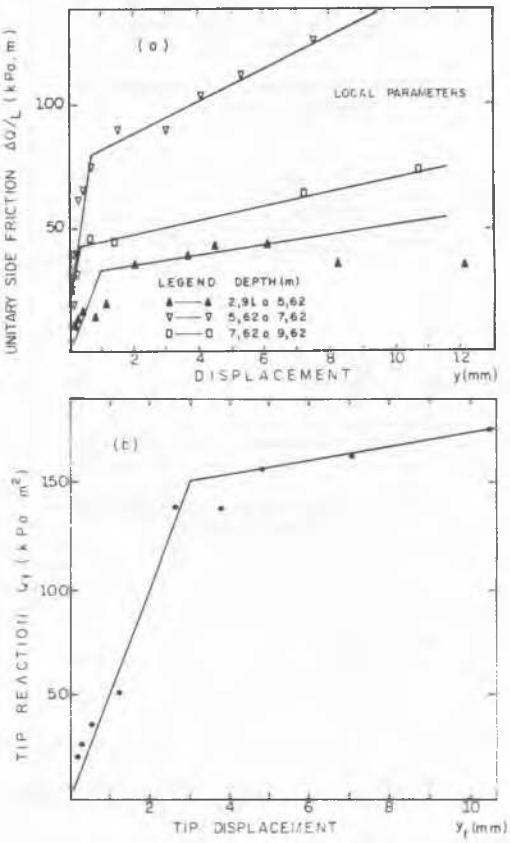

FIG. 8 - CAMBEFORT'S LAW'S FOR ROOT - PILE E-4

TABLE I

CAMBEFORT'S PARAMETERS

PARAMETER	ROOT-PILE E-4		ROOT-PILE E-2				MEAN PARAMETERS		
			1st LOADING		2nd LOADING				
	LOCAL	TOTAL	LOCAL	TOTAL	LOCAL	TOTAL	FLOATING	ON TOP BEDROCK	EMBEDED IN ROCK
A.π D (kPa.m)	10.9	10.2	2.7	2.0	10.2	6.8	8.8	8.8	8.8
B.π D (MPa)	61.0	57.6	51.0	55.8	40.3	46.8	47.4	47.4	47.4
y_1 (mm)	0.73	1.00	0.51	0.48	0.90	1.02	1.00	1.00	1.00
Fmax.π D (kPa.m)	50.8	67.8	29.1	31.2	37.9	54.2	56.2	56.2	56.2
Q.S (kPa.m²)	0	0	18.6	18.6	74.5	74.5	0	46.6	74.5
R.S (MPa.m)	50.3	50.3	175.2	175.2	117.0	117.0	50.3	145.3	∞ *
y_2 (mm)	3.00	3.00	3.00 *	3.00 *	2.20	2.20	3.00	2.60	0 *
Q_2.S (kPa.m²)	139.8	139.8	544.1 *	544.1	335.4	335.4	139.8	424.5	0 *
R_2 S (MPa.m)	3.5	3.5	0 *	0 *	0	0	3.5	0	0 *
y_f (mm)	10 *	10 *	5 *	5 *	5 *	5 *	10 *	5 *	0 *

* ADOPTED VALUES

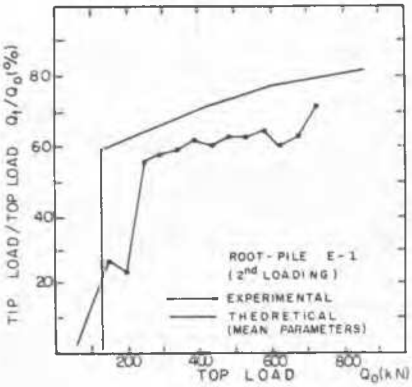

FIG.9 - EXPERIMENTAL AND THEORETICAL ANALYSIS RESULTS

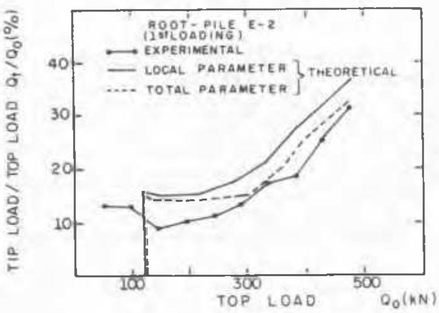

FIG.10 - EXPERIMENTAL AND THEORETICAL ANALYSIS RESULTS

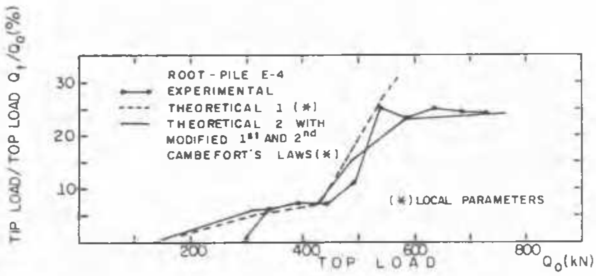

FIG.11 - EXPERIMENTAL AND THEORETICAL ANALYSIS RESULTS

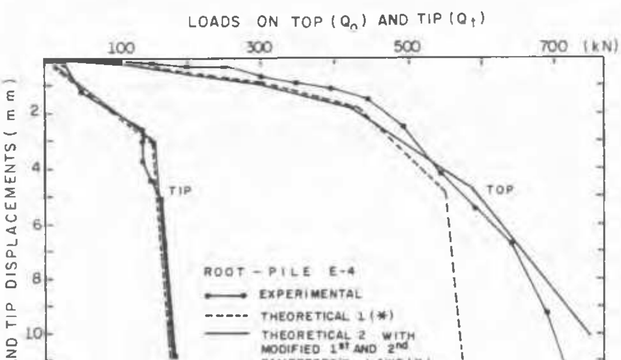

FIG.12 - LOAD - DISPLACEMENT CURVES

60% of the loads above 245kN were applied to the base (see figure 9);

b) for root-pile E-2, point bearing on top bedrock, and a load of 128kN (see figure 10) 10% represented point resistance; for a load of 490kN this value was 30%. The corresponding theoretical figures were 15 and 30%; and

c) for root-pile E-4, floating pile, the point resistance was only mobilized when the loads reached 294kN (see figure 11); for loads up to 390kN, more than 90% were carried by skin friction. Moreover, when the loads were above 550kN, the tip beared 25% of the applied loads due to the soil hardening in the pile base as explained above.

THEORETICAL ANALYSIS TOWARD DESIGN

With the purpose of eliminating the tests contingencies, represented by the pile lengths and the point bearing conditions, another theoretical analysis was carried out, simulating load tests. The Cambefort's parameters used are listed in the three last columns of Table I.

Four different lengths values were taken, namely, 4, 8, 12 and 16m, together with three point bearing conditions, i.e., floating, point bearing on top bedrock and embeded in the rock.

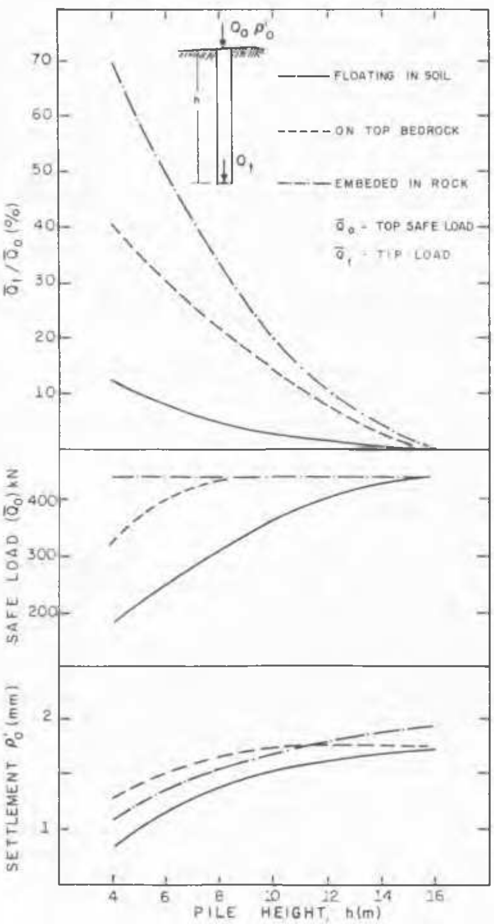

FIG.13 - THEORETICAL STUDY OF ROOT-PILES BEHAVIOR ON DIFFERENT CONDITIONS

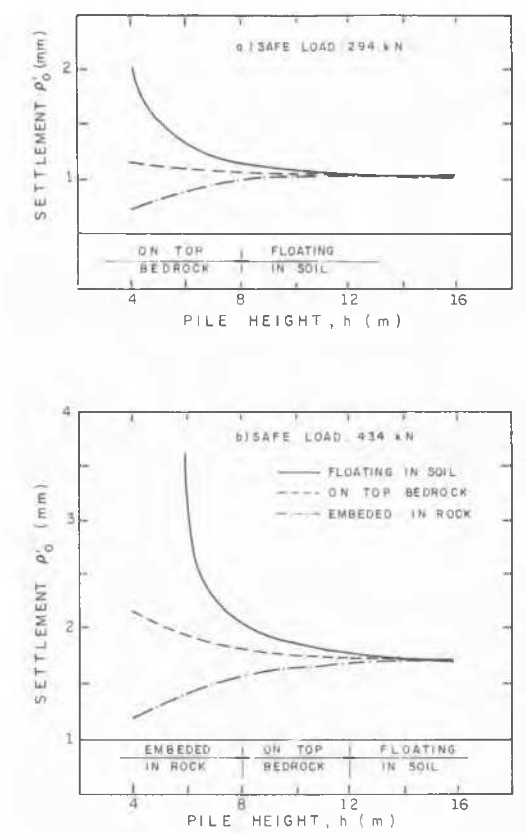

FIG. 14 - THEORETICAL SETTLEMENT RESULTS FOR TWO SAFE LOADS

A computer program was developed to make the computations. For each of the simulated load tests it was possible to determine the safe load ($\bar{Q}_o$) according to the Brazilian Norm NB-51, the top settlement (ρ'_o) and the load fraction transmitted to the tip ($\bar{Q}_t/\bar{Q}_o$) under this safe load. A figure of 434kN, mean experimental value, was taken as an upper bound of the safe load (see figure 13b).

One consequence that could be drawn was that for pile lengths greater than 16 m, all the piles behave as floating piles, regardless their point bearing condition.

Another result of this study can be derived from the plots of figure 14, which shows the top settlements of piles of varying lengths under the same safe load. As can be seen, in order to maintain the settlements up to a certain level, floating piles can be used with minimum lengths of 12m, if the safe load is set in 434kN. For this same load, for bedrock distant not more than 8m, the piles must be embeded in the rock; otherwise point bearing piles on bedrock top are indicated. These achievements would imply in a safe in costs estimated in 20 or 30% when compared with solutions which consisted of point bearing piles on top bedrock or piles embeded 1 m in rock, respectively.

CONCLUSIONS

Vertical Slow ML Tests, carried out on three instrumented root-piles, installed in three different conditions, namely floating piles, point bearing on top bedrock and embeded in the rock revealed an actual safe load of the order of 434kN against 294kN, nominal value.

The experimental study of the load transfer mechanism showed that the loads transmitted to the tips were 7, 25 and 60% of the actual safe load applied on pile top, respectively, for the three point bearing conditions just listed.

From the theoretical analyses based on the Cambefort's laws and the assumption of pile compressibility, it was found out that for the safe load of 434kN the piles, regardless their installation condition, behave as friction piles for length greater than 16m. Another conclusion was that for this safe load, for bedrock distant 12m or more from the surface, floating piles could be used; if this depth is not more than 8m, the piles must be embeded in the rock; otherwise point bearing piles on top of bedrock would be indicated. These achievements would imply in a safe in costs estimated in 20 or 30% compared with solutions which consisted of point bearing piles on top of bedrock or piles embeded 1 m in rock, respectively.

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