Sand Piles for Shallow Foundations
Pilotes de Arena para Cimentaciones Superficiales

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Abstract

A common practice in some littoral cities of Northeastern Brazil is to install sand piles for the purpose of densifying loose soil. Significant increases in bearing capacity can be achieved with this ground improvement technique which allows the use of shallow foundations, even in the case of high buildings. In this work forty eight sand piles 0.30 m of diameter and 3.5 m long were installed in three different groups at varying distance between the piles. The standard penetration test (SPT), cone penetration test (CPT) and static load test were made before and after sand pile installation. The comparison between the tests allows quantifying soil improvement by sand piles. Empirical relationships between N_{SPT} values before and after improvement were established. A prediction of shallow foundation bearing capacity in sandy soil improved by sand piles, based on N_{SPT} values is presented.

Resumen

Una práctica común en algunas ciudades litorales del nordeste de Brasil es instalar pilotes de arena con el fin de densificar los suelos sueltos. Se puede alcanzar un aumento significativo en capacidad portante mediante el uso de esta técnica de mejora del terreno, lo cual permite el uso de cimentaciones superficiales, inclusive en el caso de edificios altos. En este trabajo se instalaron 48 pilotes de arena de 0,3 metros de diámetro y 3,5 metros de longitud, divididos en tres grupos diversos con distancia entre pilotes variable. Se llevaron a cabo ensayos de penetración estándar (SPT), ensayos de cono de penetración (CPT) y ensayos de carga estática antes y después de la instalación de los pilotes de arena. La comparación entre los ensayos permite cuantificar la mejora del suelo inducida por los pilotes de arena. Se establecieron relaciones empíricas entre la mejora de los valores N_{SPT} obtenidos antes y después de la instalación de los pilotes. Se presenta una predicción de la capacidad portante de cimentaciones superficiales en suelos arenosos mejorados por medio de pilotes de arena, basada en valores de N_{SPT}.

1 INTRODUCTION

Soil improvement with the use of sand piles happens through a compacting process, in which the sand and cement piles are placed in low strength soils, which are then improved by dynamic force or vibration. The piles promote neighboring soil compacting, thus improving the bearing capacity and decreasing the foundation settlement, making possible the use of footing.

Soil reaction during the compacting treatment changes with soil type and energy source. Beneficial effects decrease sharply when there is an excessive fine particle fraction in the soil. Granular soil properties are improved by the compacting process through physical displacement of the particles, which decreases the soil void ratio, increasing the relative density and bearing capacity. The technique has been widely employed in Northeastern Brazil since the 50s, with good results, according to Gusmão (2000).

1.1 Experimental Field

The field experiments were carried out on the coast of the city of João Pessoa in Northeastern Brazil. Following Conciani *et al.* (1999), the region presents sandy subsoil composed of marine sediments from the Holocene (quaternary age). Those sediments are composed of sands superposed in layers of different compactness degrees. This stratification may have arisen from the rise and fall of ocean levels through the ages.

The experimental field was divided into four areas, one of them related to natural soil and the other three to compacted soil. In the natural soil area, three SPT and two CPT experiments were performed as well as two load tests on plate.

In each compacted area, a sand and cement (1:15 by volume) pile group was installed by the vibro-displacement method. Each pile measured 30 cm in diameter and 3.5 m in length. Each group had 16 piles arranged in a square (4x4), with distances between the piles of 80 cm for one group, 90 cm for another and 100 cm for another. In the same way as for the natural soil, for each pile group, two SPT experiments, two CPT experiments and two load tests on plate with a 0.4 m diameter were performed. Each experiment was carried out in the soil between the piles.

2 ANALYSIS

2.1 Standard Penetration Test

Figure 1 shows the geological profile with the average N_{SPT} values before and after soil improvement.

Comparing the results from the natural soil borings to those from the pile groups, we correlated the average N_{SPT} values before and after compacting the soil in the three areas, as shown in Figures 2 - 4.

From Terzaghi's classic formula for the bearing capacity of shallow foundations supported on sand,

$$\sigma_r = \gamma \cdot H \cdot N_q + 0.4 \cdot \gamma \cdot B \cdot N_\gamma \quad (1)$$

where H = 1,5 m, γ = 18 kN/m^3, the safety coefficient equals at 3, and the relationship between the friction angle from the sand and N_{SPT} is:

$$\phi = \sqrt{20 \cdot N} + 15 \quad (2)$$

Teixeira (1996) presented a formula for calculating allowable stress in shallow foundations on sand:

$$\sigma_a = 50 + (10 + 4B)N_{SPT} \quad (3)$$

(B in meters and σa in kPa) where B = footing side and N_{SPT} = SPT number ($5 < N_{SPT} < 25$).

Teixeira's formula was chosen for the analysis due to its direct relation between σ_a and N_{SPT}.

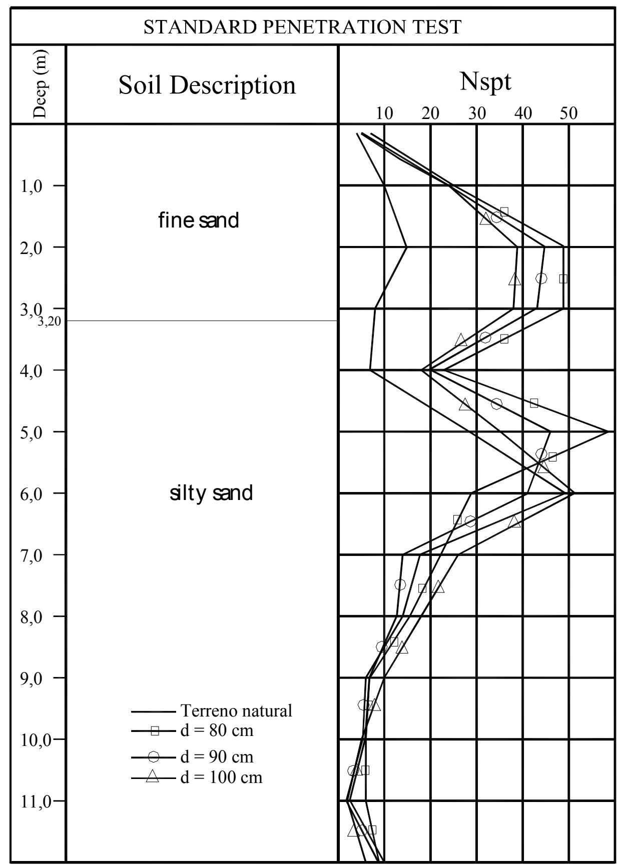

Figure 1. N_{SPT} values before and after soil improvement

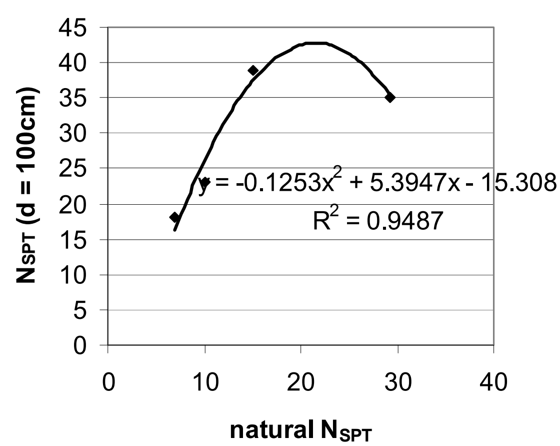

Figure 2. Relationship between the N_{SPT} values in natural and compacted soil between piles separated by 100 cm

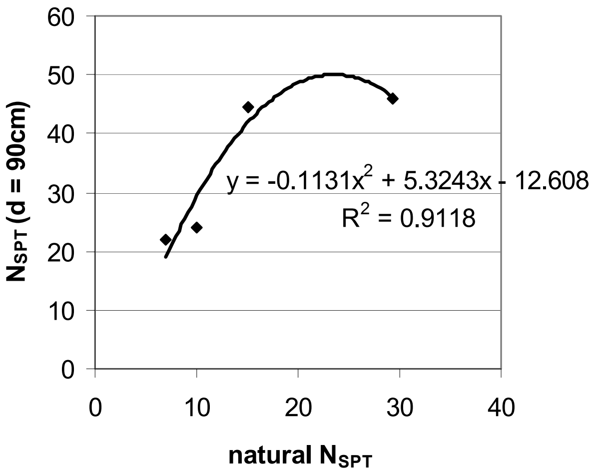

Figure 3. Relationship between the N_{SPT} values in natural and compacted soil between piles separated by 90 cm

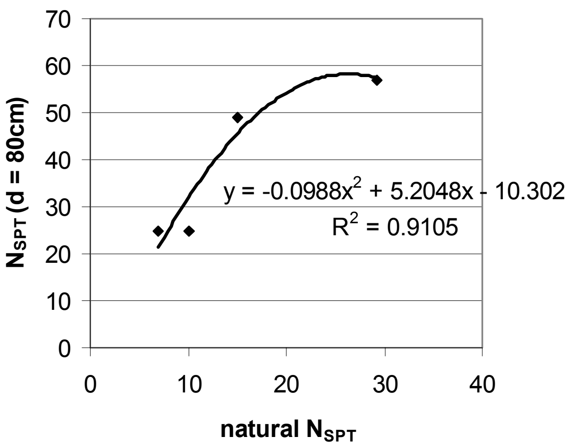

Figure 4. Relationship between the N_{SPT} values in natural and compacted soil between piles separated by 80 cm

Next, a theoretical graph was plotted with allowable stress values, estimated by Eq. 3 as a function of N_{SPT} of the natural soil for square footing, with side B between 1 and 3m. Figures 5 - 7 show the allowable stress values for natural and compacted soils, as a function of natural N_{SPT}.

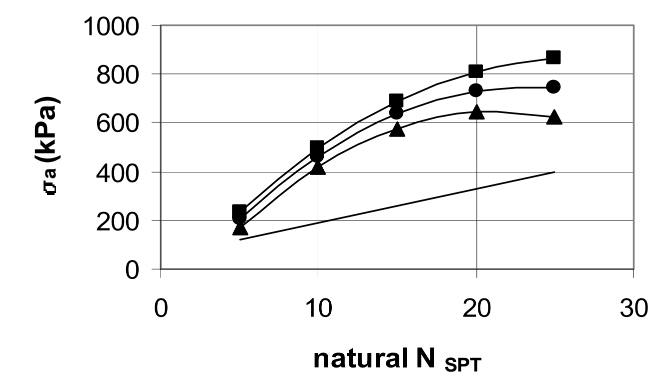

Figure 5. Graph of allowable stress x natural N_{SPT} when square footings of side B = 1.0 m

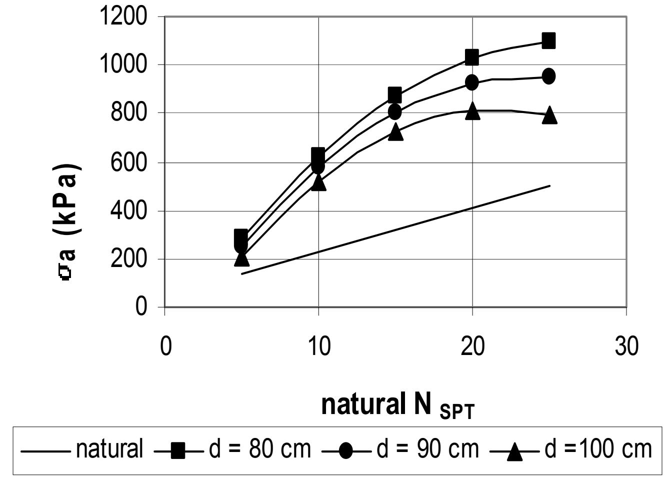

Figure 6. Graph of allowable stress x natural N_{SPT} when square footings of side B = 2.0 m

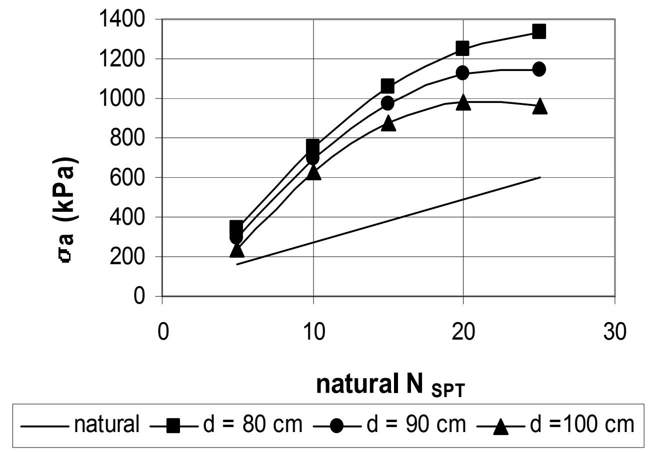

Figure 7. Graph of allowable stress x natural N_{SPT} when square footings of side B = 3.0 m

The obtained allowable stresses are only safe with respect to the failure, leaving allowable stress calculation for settlement still to be done. At the research location, the Schmertmann (1970) method was employed, using a maximum settlement of 30 mm, γ of 18 kN/m^3, at a 1.5 m depth, and safety coefficient of 1.5. The deformity modulus was found through the following formula: $E = 3KN_{SPT}$, where K is the relationship between qc e N_{SPT}, according to Aoki & Velloso (1974). K unit is kPa and the adopted values were 1000 kPa for sands and 800 kPa for silty sands. The settlement increase effect with time was not taken into consideration. Figure 8 shows the graph of allowable stress x side B of the footing, obtained by the Schmertmann method for natural and compacted soils.

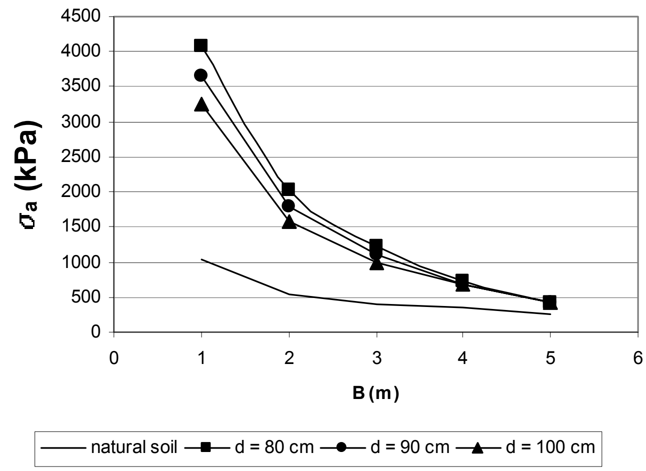

Figure 8. Graph of allowable stress x footing side

Figures 9 - 12 show allowable stress values, found through settlement and failure criteria, as a function of side B from a square footing for natural and compacted soils.

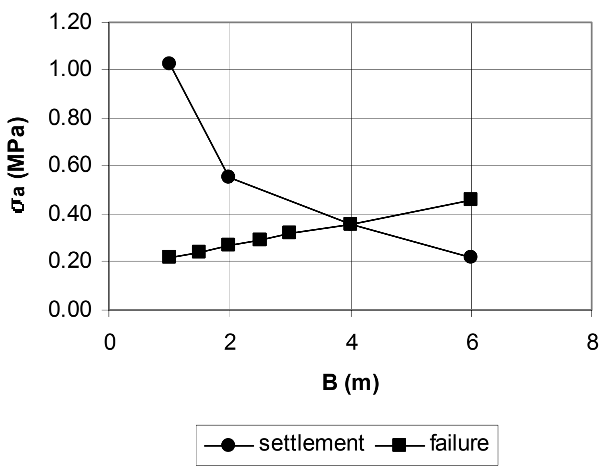

Figure 9. Allowable stress in natural soil

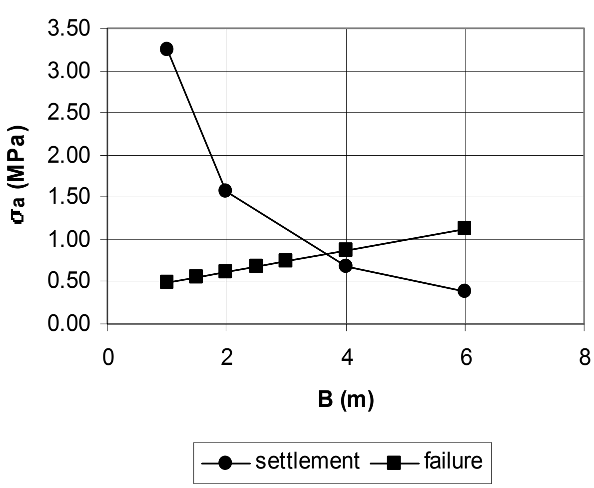

Figure 10. Allowable stress in compacted soil with 100 cm distance between piles

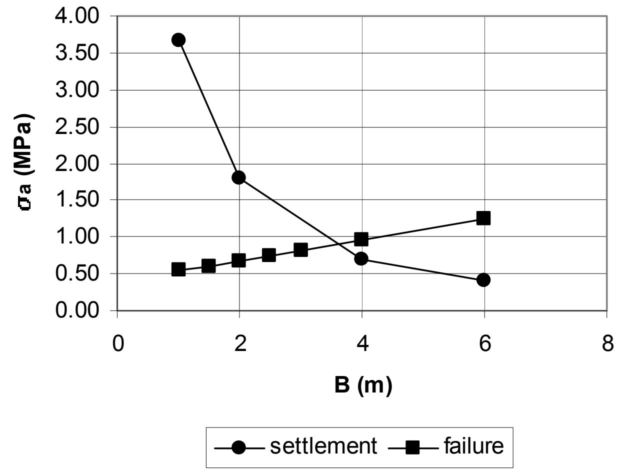

Figure 11. Allowable stress in compacted soil with 90 cm distance between piles.

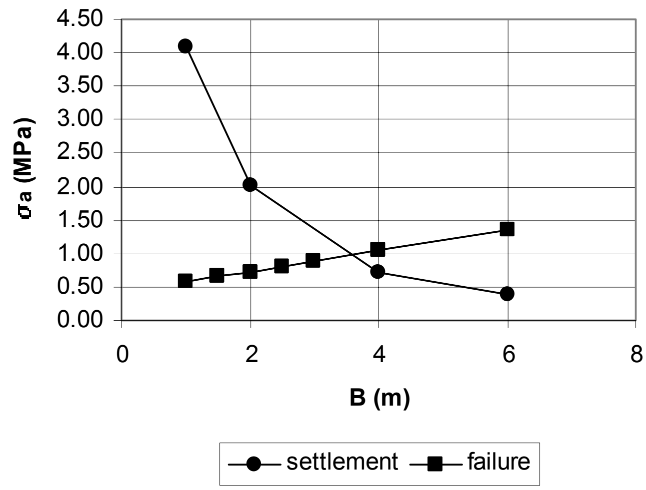

Figure 12. Allowable stress in compacted soil with 80 cm distance between piles

In order to evaluate settlement decrease in compacted soil, a graph of settlement x side B of the footing (Figure 13) was plotted. The settlements were calculated by the Schmertmann (1970) method, for an allowable stress of 0.5 Mpa.

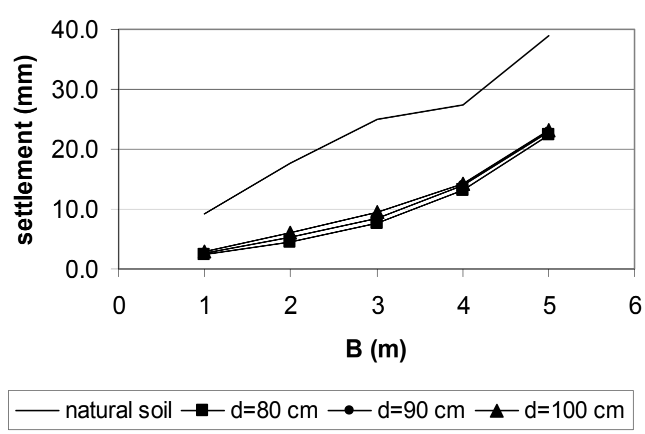

Figure 13. Graph of settlement x square footing side

There is a greater decrease on settlements for smaller footings. For B = 1.0 m the average decrease on compacted soil was 72%. For B = 5.0 m, average decrease was 41%. Figure 14 shows settlement decrease for each pile group as a function of side B of a square footing.

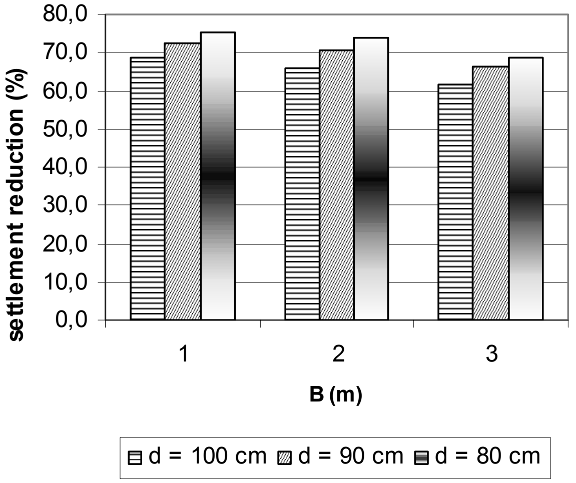

Figure 14. Settlement reduction in compacted soil

A similar analysis of the allowable stress in function of cone bearing (qc) from CPT experiments is shown by Soares (2002).

2.2 LOAD TEST ON PLATE

Figure 15 shows the graphics stress x settlement from the load tests done on natural and compacted soil.

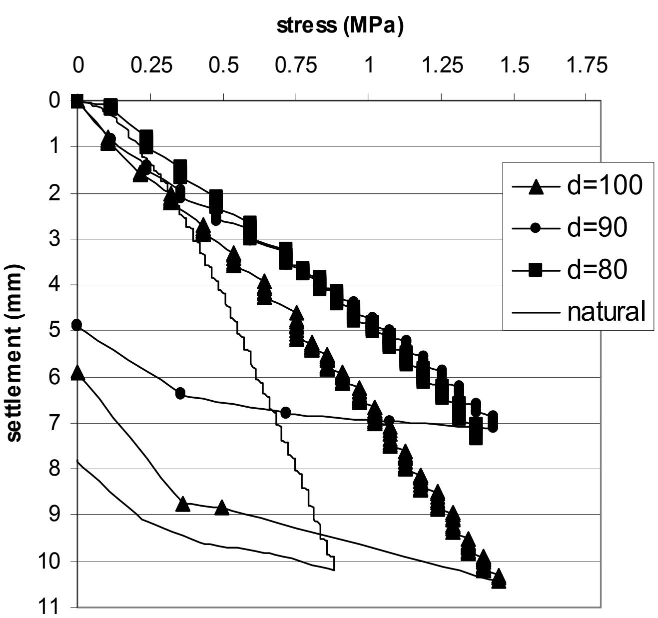

Figure 15. Graphics stress x settlement

Since the failure was not defined, the criterion selected for allowable stress calculation, is that of the stress corresponding to a maximum allowable settlement, taken as 30 mm for footings of side B changing from 1 to 3 m. For plates of 40 cm, a maximum settlement proportional to 30 mm from the footings was fixed. Figure 16 shows the allowable stress values calculated by the load test for natural and compacted soil.

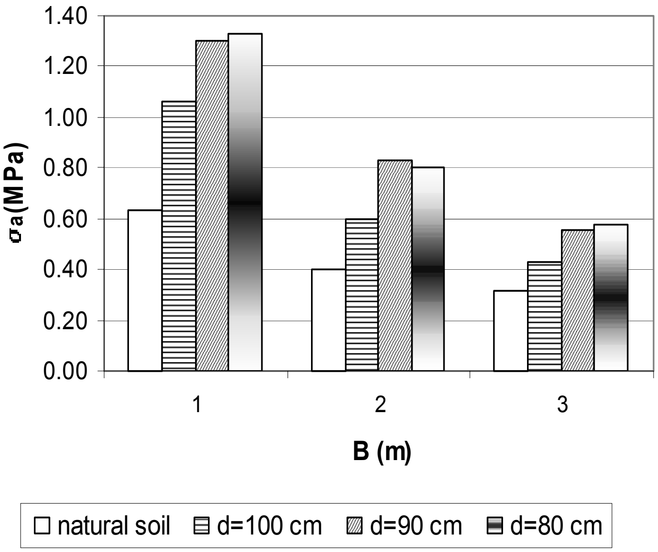

Figure 16. Graph of allowable stress x footing side in natural and compacted soil

3 CONCLUSIONS

In any pile in any of the 3 groups (spacing from 0.8 to 1.0 m between the piles), improvement was greater along the natural N_{SPT} period between 5 and 10; after compacting, N_{SPT} values increased up to three times. For the natural N_{SPT} period between 15 and 20, the compacting produced N_{SPT} maximum absolute values of up to 50, which tended to keep steady.

A small influence of the spacing between the piles and the stress obtained based upon N_{SPT} was observed: compared to results of the natural soil, the allowable stress increased from 57% to 63% when the distance decreased from 1.0 to 0.8m between the piles.

The allowable stress estimated by the settlement criterion showed an exponentially decreasing variation with footing width. For the natural soil, allowable stress decreased from about 1.0 MPa for B = 1.0m, to about 0.2 MPa for B = 6,0 m. At the compacted soil, the allowable stress decreased from about 3.2 to 4.1 MPa for B = 1.0 m, and, depending on the group, down to approximately 0.4 MPa.

In a conservative way, it was found that soil improvement with compacting piles increased allowable stress of the experimental field from 0.2 MPa to 0.5 MPa at distances of B = 1.0 to 5.0 m.

The results of load tests on plate (40 cm diameter), showed allowable stress values too high for smaller footings. For footings with side B = 1.0 m in compacted soil in the groups of 0.80 and 0.90 m, allowable stress was about 1.3 MPa. For 1.0 m group, allowable stress when B = 1.0 m is about 1.1 MPa. But for a value of B = 3.0 m, for all three groups, the allowable stress was about 0.5 MPa. For natural soil, the allowable stress decreased from about 0.6 MPa for B = 1.0 m, to about 0.3 MPa when B = 3.0 m.

The load tests show that the allowable stress average increase at the three pile groups, changes between 96% and 86% for B between 1.0 and 3.0 m.

The allowable stress calculation methods, as to the failure criterion, show quite high values, after soil compacting. Therefore, a thorough study of settlement is necessary, since compacting effects are observable as deep as 5.0 m, with pile of 3.5 m in length.

In compacted soil estimated by the Schmertmann method, the settlements suffered an average decrease of 72% for square footings with side B = 1.0m. When B = 5.0 m, the average decrease was 41%.

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