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Settlement and bearing capacity of footings on reinforced sand

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ABSTRACT: The results from numerical investigations using the finite element method considering the nonlinear behavior of sand and incremental method of load application are presented. The effect of width of footing, number, spacing, and length of sheets are addressed. The results indicate that the inclusion of reinforcement increases the stiffness and reduces the settlement of a loose sand. The increase in bearing capacity varies with the size of the footing and number of layers. There is reduction in induced vertical stresses and shear stresses in the case of reinforced sand.

1. INTRODUCTION

The concept of strengthening soil with fibers is not new. Since Roman times, builders have been aware of the beneficial effects of the reinforcing elements in earthwork. The reinforcement of granular soil and its use for foundations has received attention of researchers. Results of laboratory model studies and theoretical works have been reported (Binquet and Lee, 1975). This study pertains to strip footings resting on loose cohesionless sand, reinforced by galvanized steel strips. Effects of a few parameters such as width of footing, spacing of strips, and number of layers are investigated.

2. MATERIAL PROPERTIES AND METHODOLOGY

A simple and practical expression for describing the nonlinear behavior of soil was suggested by Duncan and Chang (1970). This hyperbolic formulation is utilized in this study, to consider stress dependency and nonlinearity of sand in the finite element analysis. The density of loose sand is 14.4 kN/m^3, and angle of shearing resistance is 34 degrees. The hyperbolic parameters K, n, and R_f are respectively 345, 0.54, 0.85 for the sand used in this study. Three footings of widths 0.9, 1.8 and 2.7m were studied. The depth of the base of the footing was 0.9m below the ground surface. The reinforcing strips used in this study were of galvanized steel. Each strip was 0.635mm thick, and 102.0mm wide. The modulus of elasticity of the material was 2.15 x 10^5 MPa. and a Poisson's ratio of 0.30 was used. Linear elastic behavior was assumed for this material.

The strip footing resting on sand was considered as a plane strain problem. In order to reduce the computational effort involved, a simplified procedure suggested and used by Al-Hussaini and Johnson (1979), was adopted for this study. The reinforcing strips are replaced by a sheet extended in the lateral and longitudinal directions of the footing. It is assumed that the stiffness of the strips is equal to the equivalent stiffness of the sheet that substitutes for each row of strips. An equivalent modulus was used as a substitute modulus of elasticity for sheets in the analysis. The finite element analysis uses quadrilateral elements, and incremental method for load application. To evaluate the interaction effects between sheets and sand, interface elements were used. Trial runs were made to calibrate the computer program and results were checked against those available (Binquet and Lee, 1970).

To evaluate the influence of reinforcement on the settlement behavior of loose sand, the sheets were placed at selected depths in the sand. The number of sheets used varied from one to four. For the footings of 0.9m and 2.7m width, only two sheets located at 0.25B and 0.5B where B is the width of the footing were used. In the case of 1.8m footing, one sheet was placed at 0.25B, two sheets at 0.25B and 0.5B, three sheets at 0.125B, 0.25B, and 0.5B, and four sheets at 0.125B, 0.25B, 0.5B, and 1.0B. The full length of sheets is about 6B. To ascertain the effect of the length of sheets on sand behavior, the lengths of the sheets were "cut off" or reduced to a length of 2B. Nonlinear finite element analysis was performed in each case of footing resting on sand without and with reinforcement by full and "cut off" sheets.

3. ANALYSIS OF RESULTS

3.1 Influence on bearing capacity

The loose sand was reinforced by placing the predetermined number of strips at selected depths and the applied pressure - settlement relationships for the three sizes of the footings were obtained. An example is shown in Figure 1 for a 1.8m footing reinforced with four full length sheets. The ultimate bearing capacity of the footing-soil system with and without reinforcement q and q_o respectively, was obtained from the pressure - settlement relationship as the pressure corresponding to a predetermined settlement. The settlement used in this study is equal to 10 percent and 15 percent of the footing width. This is consistent with the methods used by others (Vesic 1976, Ismail and Raymond 1995). Then the Bearing Capacity Ratio (BCR) defined as BCR = q / q_o was computed in each case. The Figures 2 and 3 show the variation of BCR with number of sheets and the width of the footing. The Figure 2 is for a 1.8m footing reinforced with four full sheets. The Figure 3 shows the effect of two full sheets of reinforcement for all the three sizes of footings. It is seen from Figures 1 and 2 that the reinforcement has the effect of increasing the ultimate bearing capacity of the footing and decreasing the settlement at any given pressure. The general trend is that higher bearing capacity is associated with the stiffer soil and less induced settlement. The capacity to withstand additional pressure increases with the increase in the number of sheets of reinforcement. As can be seen from Figure 2, for the 1.8m footing the average increase in bearing capacity varies from 25 percent to 70 percent as the number of sheets increase from one to four. Although the BCR increases for all footing sizes, the effect is more predominant as shown in the Figure 3 in smaller size compared to larger sizes.

3.2 Influence on settlement

In the case of loose sand alone the settlement of footing will increase in unpredictable fashion as the applied pressure increased. Figure 1 illustrates that settlement is reduced in the case of sand reinforced with full sheets. This indicates that the inclusion of sheets in a loose sand tends to confine and essentially stiffens the loose sand and increases its deformation resistance. The amount of reduction in settlement, in the case of sand reinforced with two full sheets is shown in Figure 4 for the three footings studied. The percent reduction is plotted against footing widths in Figure 4 for various applied pressures. It shows that for a given pressure the effect of reinforcement in reducing the settlement, decreases as the width of the footing increases. For a given width of footing the percent reduction in settlement is more at higher pressures than at lower pressures. A similar trend was also observed in the case of sand reinforced with cutoff sheets. However, for any footing and at a given pressure the percent reduction in settlement was less than that obtained with full sheets.

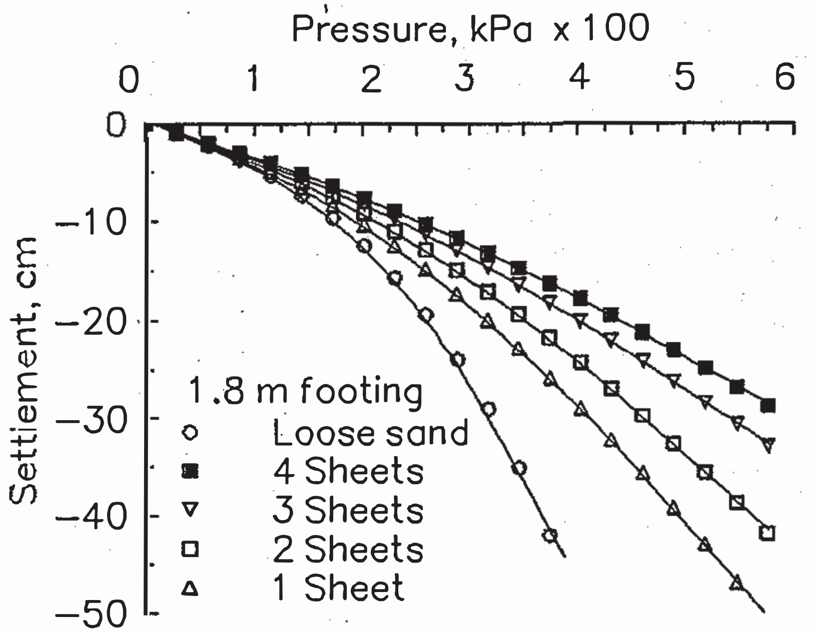

Figure 1. Pressure – Settlement curves

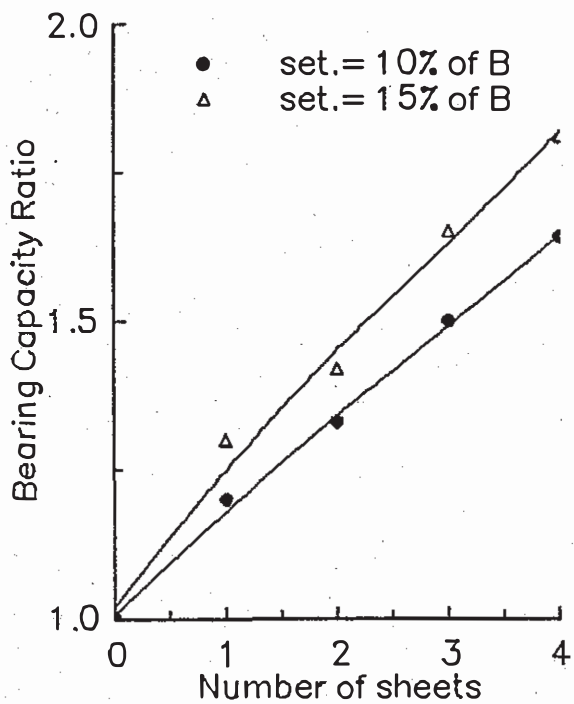

Figure 2. No. of sheets Vs BCR

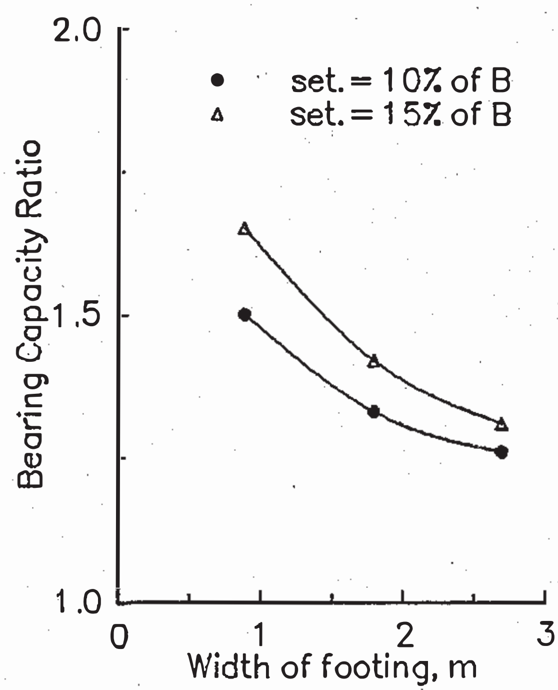

Figure 3. Effect of width on BCR

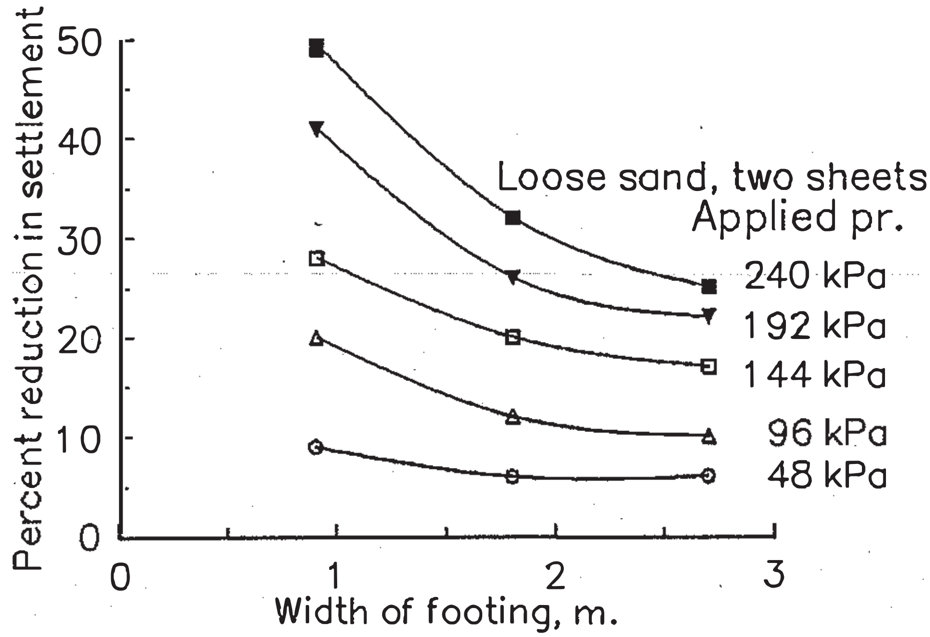

Figure 4. Reduction in settlement

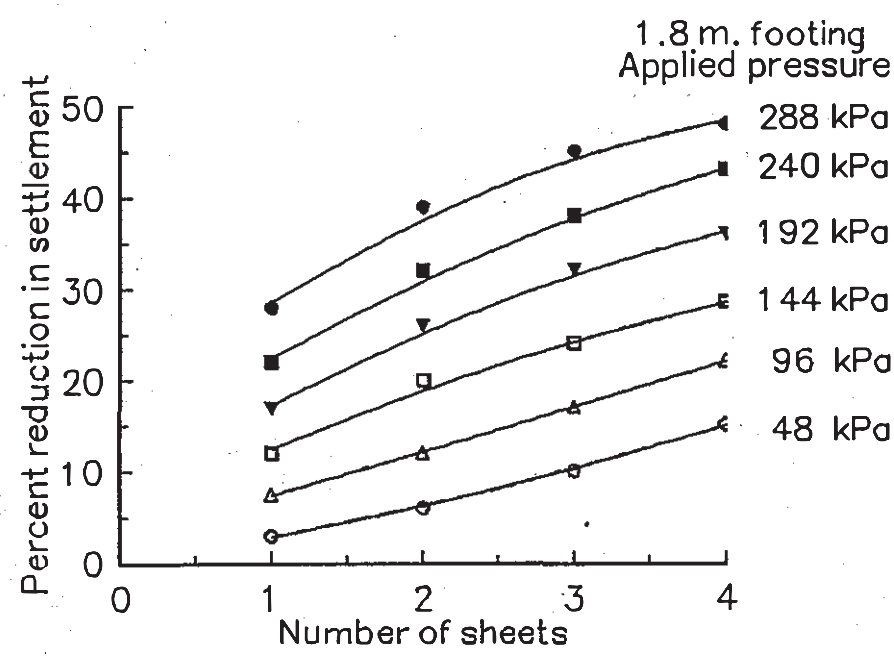

Figure 5. Influence of number of sheets

The pressure-settlement relationships for a 1.8m footing resting on loose sand, and sand reinforced with four full sheets was shown in Figure 1. The percent reduction in settlement, shown in Figure 5 increases as the number of sheets increase. Further, the percent reduction in settlement is more at higher pressures. Similar relationships exist for the cases with spliced sheets, though the settlement reduction is not as large as with full sheets. For the three footings studied, the percent reduction in settlement due to reinforcement ranged from 10 to 50 percent depending on the footing size and pressure.

A study of figures 1 through 5 show that the depth of placement of sheets influence the bearing capacity and settlement. The placement of sheets beyond 0.5B do not show substantial increase in bearing capacity or decrease in settlement. A perusal of Terzaghi's bearing capacity theory shows that, the point of the wedge zone beneath the footing would be located at a depth of 0.5B Tan ϕ, where B is the width of footing, and ϕ is the angle of shearing resistance. Beyond this point the two radial shear zones begin. Hence placement of reinforcement within a depth of 0.5B Tan ϕ beneath the footing may have beneficial effects. This depth of placement is about 0.3B for the size of footings used in this study. Additional studies are in progress to determine the optimum depth of placement of reinforcement.

3.3 Influence of reinforcement on vertical stress distribution

The variation of vertical stress under the center of a 1.8m footing is shown in Figure 6 for sand only and reinforced case with 4 full sheets. For the sake of clarity in the figure, only selected cases of applied pressures are shown. Although the nature of the vertical stress distribution appears to be similar to that observed in case of unreinforced sand, the induced vertical stresses are appreciably reduced in the case of reinforced sand. At low applied pressures there is less than 5 percent reduction in vertical stress. The effect of reinforcement in reducing the vertical stress gradually increases as applied pressure increases. It can be seen that the maximum reduction in vertical stress occurs at depths within 0.5B to 1.0B where B is the width of the footing. Interestingly, in the case of sand reinforced with cutoff sheets the results indicate that the vertical stresses under the center of the footing are very much similar to that with full sheets. In other words, the length of sheets beyond a certain length appears to have little influence on the vertical stress distribution.

3.4 Influence of reinforcement on shear stress distribution

The distribution of shear stresses at any depth beneath a footing are known to vary with the horizontal distance from the center of the loaded area. The results from this study indicate that the inclusion of reinforcement reduces the shear stress. From the shear stress distribution curves at any depth for loose sand alone and reinforced sand, the percent reduction in maximum shear stress can be computed. In general at any depth, the percent reduction in maximum shear stress varies with the applied pressure. The amount of reduction gradually increases to a maximum and then reduces. It was observed that the percent reduction in shear stress is more in the case of full length reinforcement than with "cut off" sheets. Further as the number of sheets increase there is an increase in the percent reduction of shear stress. It was also observed that the reduction is more at shallow depths than at larger depths.

The availability of experimental test results to compare the shear stress distribution is very limited. However, an approximate analysis as per suggestions of Binquet and Lee (1975), and Das (1995) indicate that the results obtained are in order qualitatively and quantitatively. Additional investigations are needed in this aspect of reinforced earth. Similar comments apply for the case of vertical stress distribution. This may be due to the fact that major thrust of the experimental programs

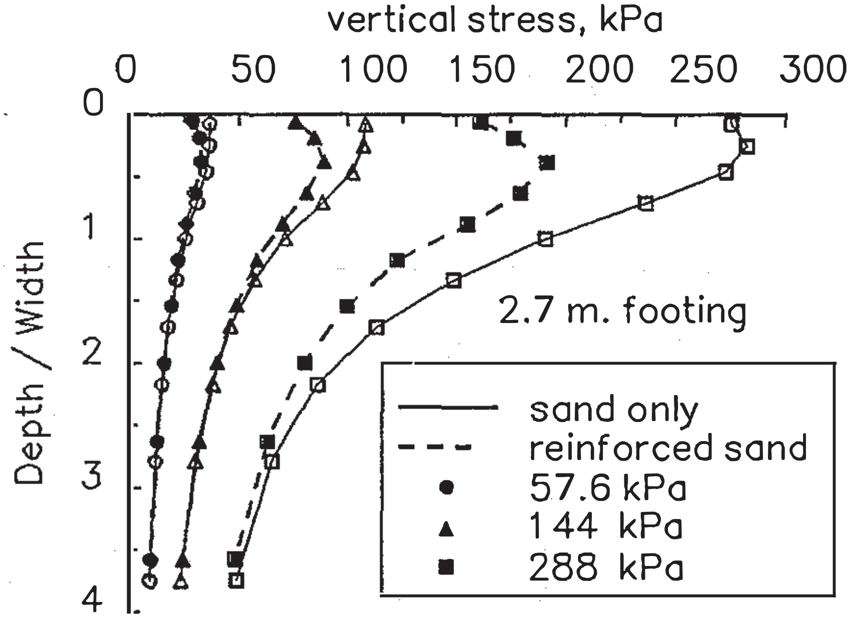

Figure 6. Stress distribution

has been to investigate the effect of reinforcement on bearing capacity.

4. CONCLUSIONS

The inclusion of reinforcement sheets in a loose sand results in increased stiffness of sand and reduces settlement by a substantial amount. Increased amount of reduction in settlement is achieved by using larger number of sheets. Longer sheets are relatively more effective than shorter sheets in decreasing the settlement. Results further indicate that for a footing of given width resting on reinforced sand, pressures larger than normally imposed on unreinforced sand can be applied to maintain a desired settlement. The percent increase in bearing capacity varies with the size of the footing and number of sheets used. For the 1.8m footing the increase in bearing capacity varies from about 25 percent to 70 percent as the number of full sheets increase from one to four. In general the contribution of sheets in increasing the bearing capacity is more evident in footings of smaller size than in larger sizes.

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