Numerical Analysis of Geosynthetic Reinforced Soil Slabs

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ABSTRACT: Presented are experimental data and Finite Element Method (FEM) analyses performed to model the application of soil reinforcement to granular soil. The problem was initiated as an application to the rehabilitation of a gantry crane. The ties are equivalent to footings, modelled as beam elements with very high stiffness. The soil was modeled using quadralatral plane-strain elements. These elements had hyperbolic stress-strain relationship with Mohr-Coulomb limiting yield criterion. The reinforcement was modeled using bar elements and was placed at different depths. For the study presented vertical, eccentric and inclined line loads were applied in increments. The finite element analysis produced similar results to the experimental tests. The settlement was reduced by the introduced reinforcement. The reduction in settlement increased as the reinforcement was placed at shallower depths.

1 INTRODUCTION

During the past two decades soil reinforcement as a method of soil improvement has gained considerable attention. The method has been used to improve the properties of soils behind retaining walls, inside embankments, below roads and below railway tracks. On existing facilities, such as railway roadbeds, the cost of undercutting to place reinforcement increases significantly as the undercut depth increases. Thus, for railways the use of a single reinforcing layer is common. The investigation herein is confined to evaluating the effect of a single reinforcing layer through the use of model testing and the Finite Element Method (FEM) of analysis.

2 OBJECTIVE AND TESTING MODEL

The objective of the tests was to investigate the effect of the reinforcement on the bearing capacity of footings on granular soil. Full details of the plane-strain test apparatus has been presented previously by Raymond *et al.*, (1992) and Abdel-Baki *et al.*, (1993).

3 RESULTS ON UNREINFORCED SOIL

The first test series was performed on unreinforced granular soil. Using the ultimate bearing capacity obtained for a vertically concentrically loaded footing as reference the results are compared to Meyerhof's modification theory (1953) for eccentric loads in Figure 1 and for inclined loads in Figure 2. The results in the figures show that the theoretical values calculated from Meyerhof's theory, for surface footings on unreinforced soil subjected to eccentric and inclined loads, are in good agreement with the experimental values.

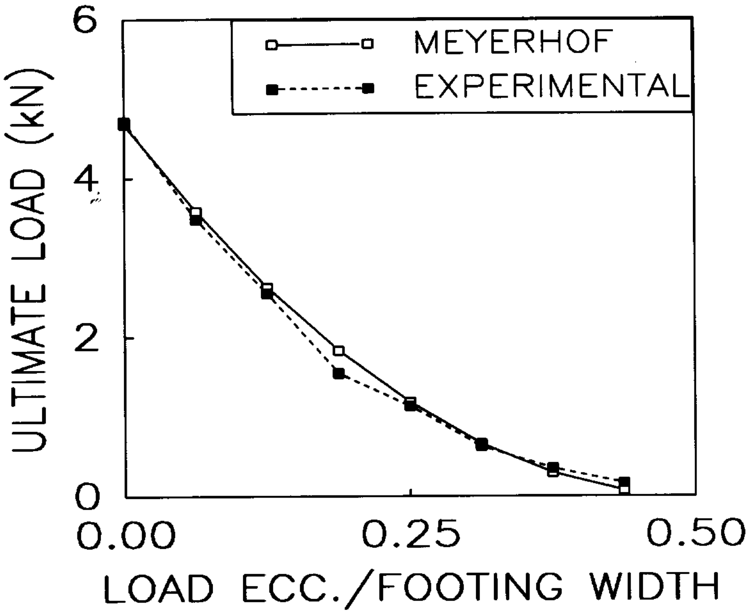

Figure 1. Comparison: eccentrically loaded footings on unreinforced granular soil.

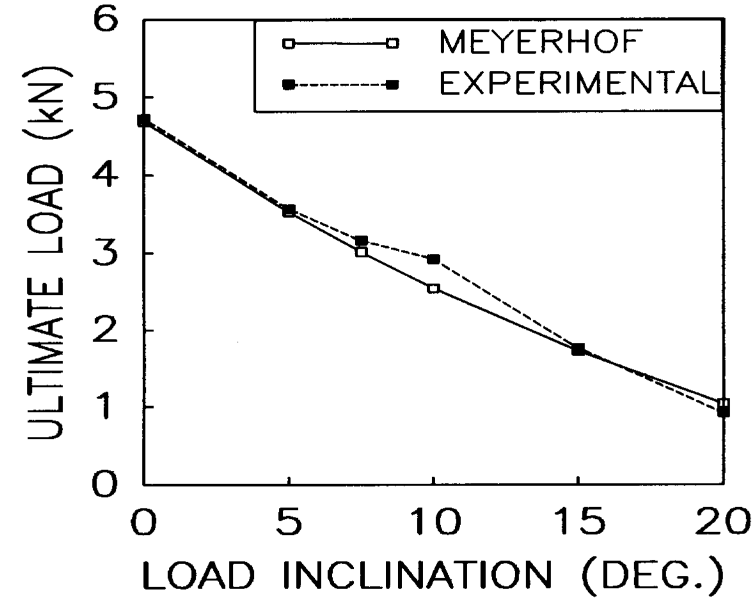

Figure 2. Comparison: Inclined loaded footing on unreinforced granular soil.

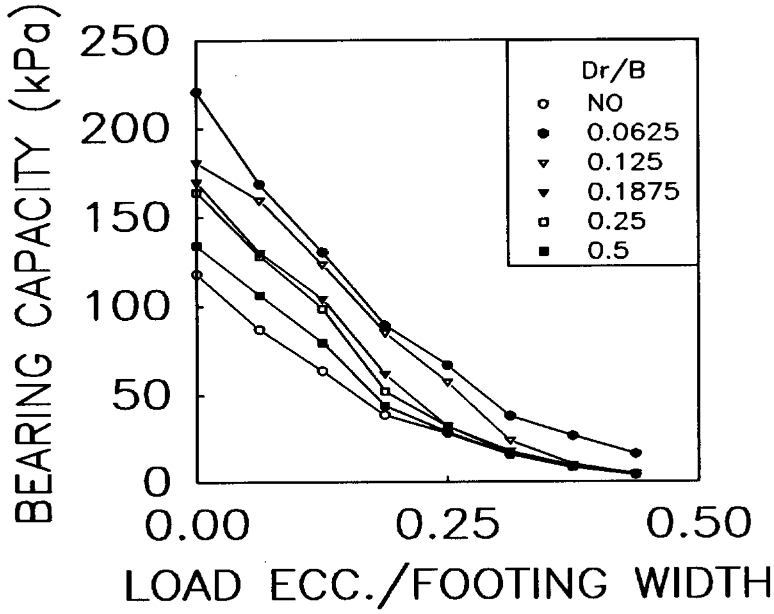

Figure 3. Ultimate bearing capacity of eccentrically loaded footings on reinforced granular soil.

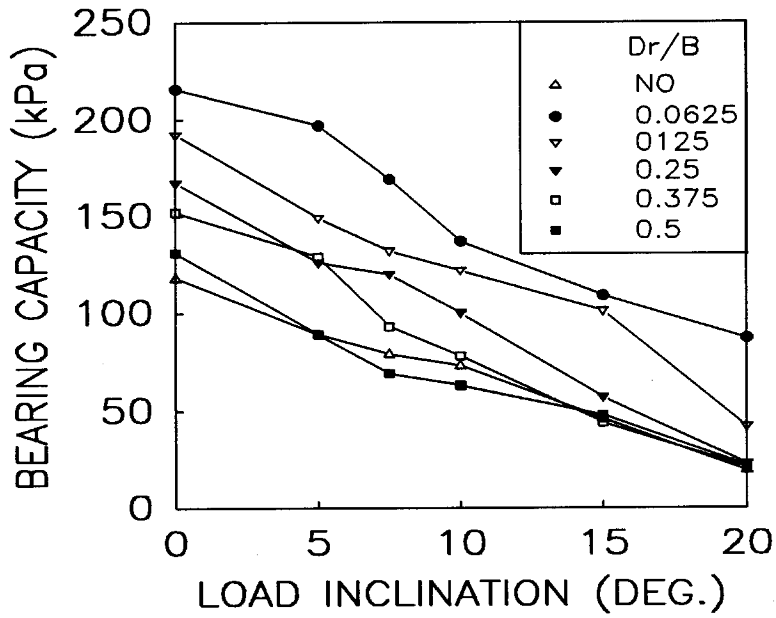

Figure 4. Ultimate bearing capacity of inclined loaded footings on reinforced granular soil.

4 FOOTINGS ON REINFORCED SOIL

The second test series was performed on reinforced soil. The loads were applied at the same eccentricities and inclinations as the unreinforced case. The reinforcement was placed at six different depths. The ratios of the depths of the reinforcement to the footing width, Dr/B, ranged from 0.0625 to 0.5. Tests were performed using a variety of reinforcement. Both geogrid and steel mesh were used. In no case was the reinforcement weak enough to fail. For these unfailed different reinforcement materials no discernable difference was noted between the results obtained. These and other repeat tests added confidence to the accuracy of the test values obtained.

Failure for concentric loading cases occurred by general shear failure in a manner similar to the unreinforced case. The results of all the tests are shown in Figures 3 and 4. It can be seen that for all cases as the depth of the reinforcement increased the bearing capacity decreased until the reinforcement was deep enough to have no effect. For concentric loads the depth at which little or no improvement occurred was at about 0.4 times the footing width. For the eccentric and inclined loading the depth was shallower.

It is observed that for the reinforcement to have any effect on the bearing capacity, it must be placed within the confinement wedge below the footing. The wedge is shallower for the case of eccentric and inclined loadings. For eccentric loadings it may be assumed that the wedge has a depth related to an effective footing width of *(B-2e)* rather than *B*. Similarly the wedge is shallower in the case of inclined loads (Meyerhof, 1953).

In order to demonstrate the significance of the reinforcement position, the Bearing Capacity Ratio (BCR) = $q_{reinforced}/q_{unreinforced}$, is plotted for different depths ratios of *Dr/B* of the reinforcement in Figures 5, and 6 for the eccentric and inclined loadings respectively. It can be seen that the BCR is much higher when the reinforcement is placed at shallower depths. For shallower reinforcement depths, the BCR increased as the load eccentricity or inclination increased.

5 FINITE ELEMENT ANALYSIS

The finite element method (FEM) was used to make comparative predictions of the reinforcement on the bearing capacity. An elasto-plastic program, Analysis of Reinforced Geotechnical Structures (ARGS), was developed. The constitutive model used is an expanded Hyperbolic model similar to that used by Raymond *et al.*, (1992). The original hyperbolic model, Duncan *et al.*, elements were available. No slippage occurred either in the modelling or in the experiments. Most calculations were done without their use. The pattern of failure for *e/B* of 0.0 and 0.2 is shown in Figure 7 and 8 respectively.

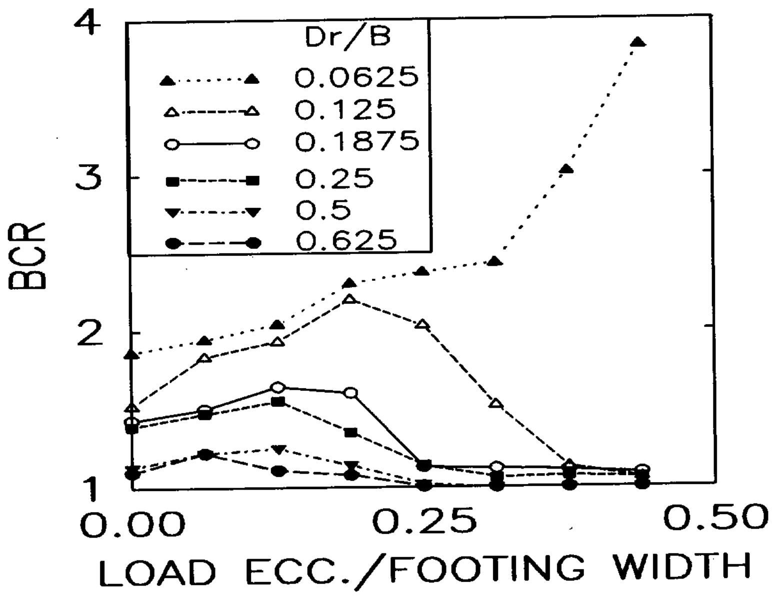

Figure 5. Bearing Capacity Ratio for eccentrically loaded footings on reinforced granular soil using different Dr/B ratios.

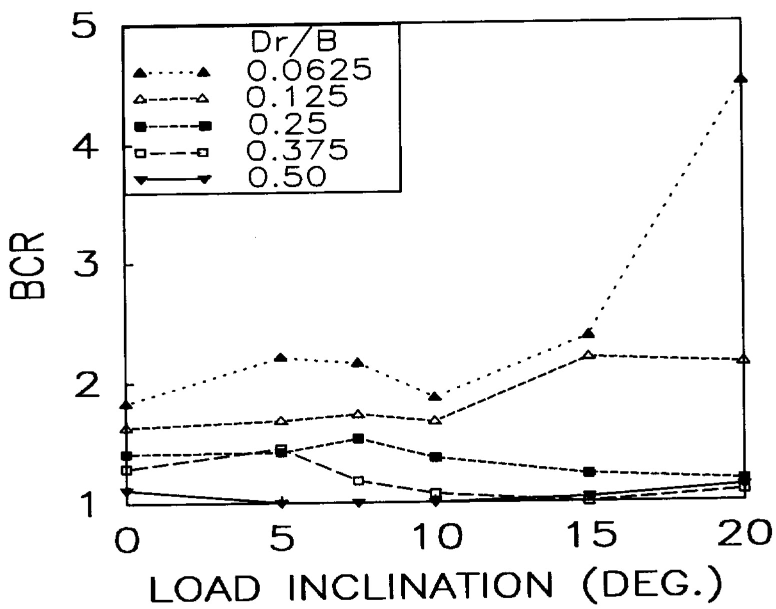

Figure 6. Bearing Capacity Ratio for inclined loaded footings on reinforced granular soil using different Dr/B ratio.

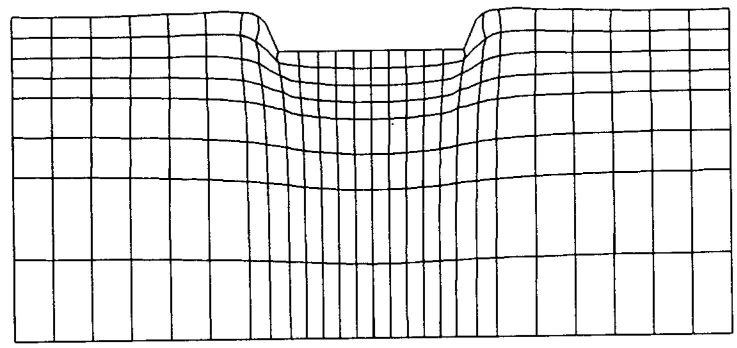

Figure 7. Finite Element Method deformation pattern: footing load at e/B=0.

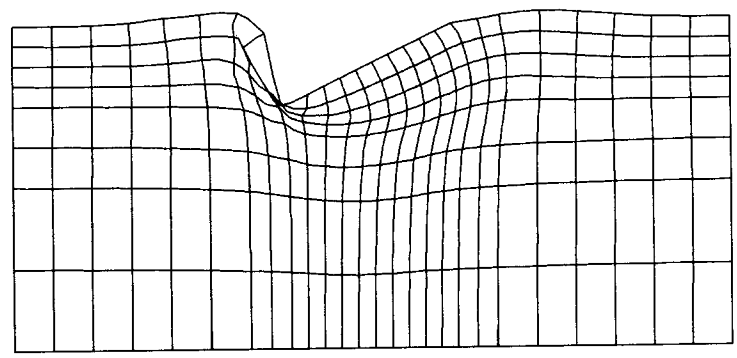

Figure 8. Finite Element Method deformation pattern: footing load at e/B=0.2.

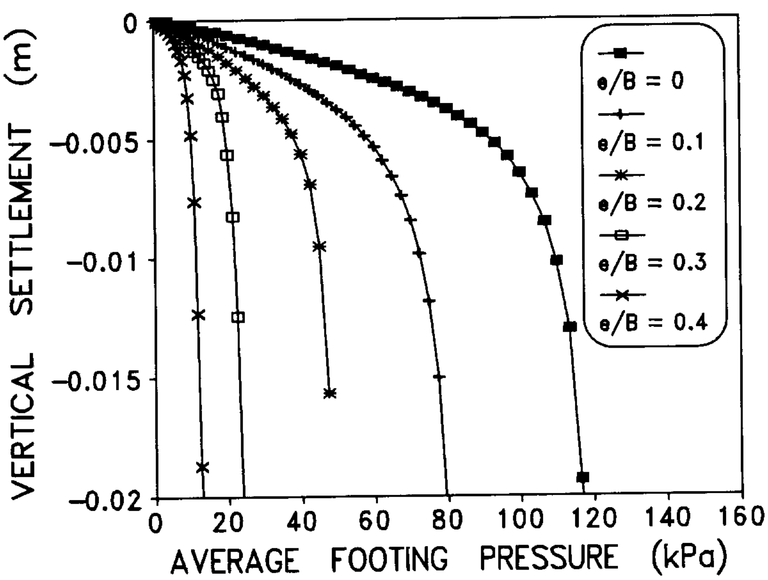

Figure 9. Finite Element Method load-settlement: eccentrically loaded footing on unreinforced soil.

(1980), is a purely elastic model. It is not capable of correcting the stresses that exceed the yielding limit, nor predicting shear dilations, nor modelling plastic yield.

Prior to yield ARGS uses the same parameters as used by Duncan *et al.* (1980). At yield a Mohr-Coulomb surface is used to model plastic flow. When the stresses lie outside the yield surface they are corrected back to the yield surface along the plastic flow path in the manner described by Nayak and Zienkiewicz (1972). The stresses are always kept within the yield surface. An eight nodded element with a reduced integration scheme (2 X 2 rather than 3 X 3) was used for the ground elements after Nagtegaal *et al.*, 1974, and Sloan and Randolph, 1982. Three nodded bar elements modelled the reinforcement. Beam elements modelled the rigid body motion of the footing. Slip

The FEM results for eccentric loading footings on unreinforced soil are shown in Figure 9. As for the experimental results (Figure 1) it is seen that the bearing capacity decreased as the load eccentricity increased.

The FEM results for the centrally loaded footings on reinforced soil are shown in Figure 10. Again the experimental results (Figure 2) show similar trends to those obtained from the FEM.

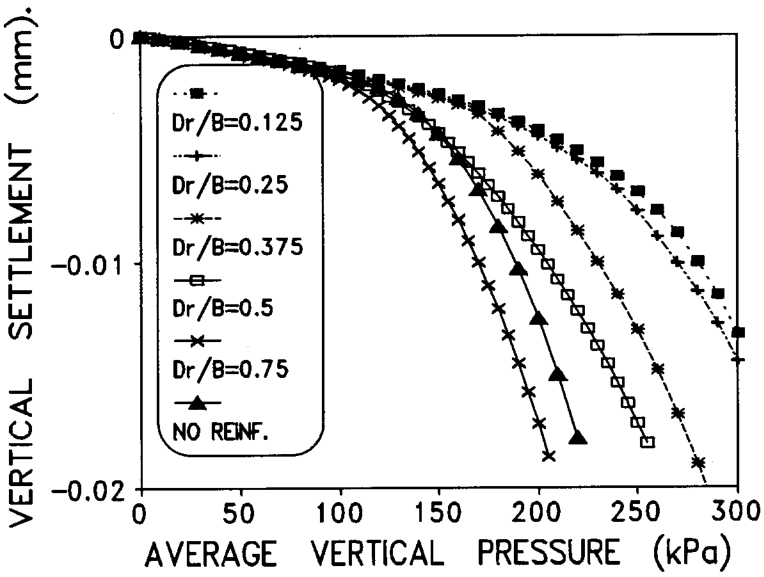

Figure 10. Finite Element Method load-settlement: centrally loaded footings on reinforced soil.

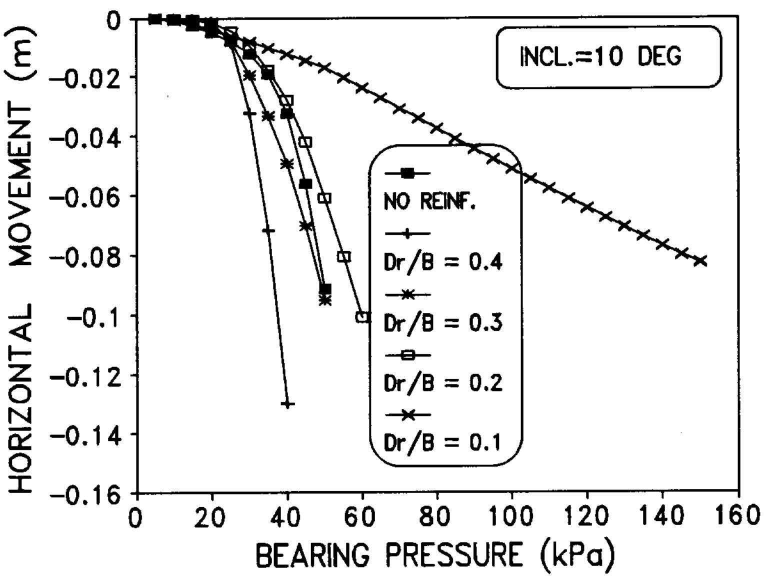

Figure 11. Finite Element Method inclined load-horizontal settlement: *i* of 10°.

The versatility of the FEM was demonstrated in the analysis of the inclined loading. Figure 11 shows the lateral deformations for the footing subject to an inclination of 10°.

6 CONCLUSIONS

A finite element model (FEM) was developed and has been shown capable of predicting the failure patterns of model tests for both reinforced and unreinforced granular soil. The FEM demonstrated its practical significance in so far as it confirmed the test results. These results showed that a single strong reinforcement layer has a significant effect on the bearing capacity of footings, particularly in practical applications where loads are eccentric and/or inclined such as under railways, paved and unpaved roads and gantry cranes.

The comparative results, referred to in the last paragraph, where obtained between experimental test data and FEM analyses for footings, on granular soil reinforced by a single strong layer of reinforcement, subject to concentric, eccentric, and inclined loads. The results proved that the reinforcement had a major beneficial effect, increasing the bearing capacity ratio dramatically as the load eccentricity and inclination increased.

7 ACKNOWLEDGEMENT

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