Some mechanical differences between finite element modeling and testing for reinforced materials

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ABSTRACT: This study presents the results of Physical Model tests and Finite Element Model (FEM) results for reinforced sand foundations. Strip footing and plane strain conditions were selected to modeling. FEM analysis results were compared with laboratory tests for unreinforced and reinforced soils by using plate load tests. As reinforcement one Geotextile and three different Geogrids were used. By changing the number of reinforcement layers, load-settlement curves and Bearing Capacity Ratios were compared for medium dense sand. To model the geosynthetic reinforcement only elastic rigidity and interface was used. Finally, results were interpreted. The main conclusions were: The Load settlement behavior is similar for geotextile and geogrid reinforcement for loads below the unreinforced bearing capacity; As larger loads can be applied due to the effect of the reinforcement, the behavior of different reinforcement types show differences; Also the FE analyses cannot perfectly model the load settlement behavior for large loads.

Keywords: Finite element, mechanic properties, composite material, reinforced soil.

1 INTRODUCTION

Finite Element Model (FEM) is being used widely by researchers and design engineers to evaluate the effects of geosynthetic reinforcements. There can be many advantages of the modeling by FEM, however, the performance of reinforced soils depends not only on soil and reinforcement properties but also on the interaction between the soil and reinforcement. Hence, FEM procedure becomes complex as compared to the simulation of regular soil subgrades. Numerical modeling of reinforced soil foundation presented by some researchers can be categorized into two groups in literature. In the first group, the reinforcement and soil as two separate components (Kurian et al., 1997; Maharaj et al., 2003). Furthermore, the reinforcement is generally treated as a linear elastic material. In the second group, reinforced soil treats as an equivalent homogeneous continuum media (Yamamato and Otani, 2002). However, generally, in Finite Element Model studies the reinforcement is represented by a separate element.

In recent years some research has been conducted to understand the effect of the interface in Finite Element Models (Yu et al., 2015). The study demonstrates that results can be very different depending on the type of structure element used to model horizontal reinforcement layers that are discontinuous in the plane-strain direction. For modeling the reinforcement plane strain materials are used and they are represented only with their elastic rigidity. The interaction between the soil and reinforcement is generally modeled by using interface elements. However, these properties cannot be enough to model different type of reinforcements because aperture size of reinforcements can also be very important. Therefore, in this study different type of reinforcements will be investigate by laboratory test results and the behavior observed will be compared to FEM results.

Generally, geometry parameters are normalized with the width of the footing B such as first reinforcement depth ratio (u/B), vertical spacing ratio (h/B), etc. Sireesh et al. (2009) and Moghaddas Tafreshi and Norouzi (2012) reported that large-scale tests carried out by Milligan et al. (1986) and Adams and Collin (1997) indicate that the general mechanisms and behavior observed in the model tests are reproduced on a large scale. Also they noted that, qualitatively, their study which is based on small scale tests provides insight into the basic mechanism that establishes the behavior of bearing capacity responses of the reinforced sand bed overlying subgrade. Therefore, it shows that although the correlation between scaled model tests and full size foundations are not perfect, model scaled tests are helpful to understand the mechanism of models.

In this study Finite Element Model (FEM) procedures were investigated for unreinforced and reinforced sand soils. Strip and plane strain conditions were selected to model an unpaved road or strip footing behavior. FEM analysis results were compared with laboratory tests for unreinforced and reinforced soils by using plate load tests. As reinforcements one Geotextile and three different Geogrid models were used and by changing the number of reinforcement layers load-settlement curves and Bearing Capacity Ratios were compared for medium dense sand. Finally, comparison results were interpreted and FEM using procedures were detected for unreinforced and reinforced sand conditions.

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2 MATERIAL PROPERTIES AND TESTING PROCEDURE

The test tank used in the laboratory was 100 cm wide, 50 cm long and 100 cm high and strip footing width was 10 cm (B). A geotextile and three different geogrids were used in the experiments. The Geotextile and Geogrid-3 is made from polypropylene and Geogrid-1 and Geogrid-2 were polyester. Geotextile was woven, and Geogrid-1, Geogrid-2 and Geogrid-3 had aperture size as 20*20 (mm), 40*40 (mm) and 14*70 (mm), respectively. The tensile strength of the reinforcements were as follows: Geotextile: 60 kN/m, Geogrid 1: 35 kN/m, Geogrid 2: 55 kN/m and Geogrid 3: 45 kN/m (Cicek, 2011).

In the Finite Element Model boundary and loading conditions were modeled to represent the laboratory tests conditions. The vertical boundaries were chosen to have only horizontal fixity and bottom boundary has both horizontal and vertical fixities. The plane strain conditions and 2D under static load were chosen for modeling. The mesh size was taken as very fine and were further refined again in the near vicinity of plate. 15 node triangular elements were selected to increase the sensitivity of the analyses. The problem is symmetric about the center of footing, so only half of the system was modeled. The steel plate was modeled using 5 node beam elements and plate properties were represented with EI (flexural rigidity)=260 kNm^2/m, EA (axial stiffness)=$5x10^6$ kN/m. The soil properties were taken as: γ (unit weight)=15 kN/m^3, E (Elasticity modulus)=25000 kN/m^2, υ (Poisson ratio)=0.25, ϕ (friction angle)=38º . These properties of the soil were found by conducting laboratory tests, ie. Triaxial test. In the Finite Element Analyses, only Geotextile reinforcement was modeled, because there is no appropriate method that allows the representation of a reinforcement with apertures. Elastic rigidity for geotextile reinforcement was taken as J=550 kN/m (taken from manufacturers data sheet). The interfaces coefficient between soil and geotextiles was taken as R=0.7. The geometrical variables were chosen as: depth of the first reinforcement layer ‘u’, the vertical spacing between consecutive layers of reinforcement ‘h’, the total number of reinforcement layers 'N', the width of the geosynthetic reinforcement 'L' and total reinforced zone (d). Finite Element Model and mesh type can be seen in Figure 1. Additionally, to compare the data, the term Bearing Capacity Ratio (BCR) was used which is defined as: BCR=q/q_0. Here, q_0 is the average contact pressure of footing on unreinforced soil at a settlement 's' and q is the average contact pressure of the same footing on reinforced soil at the same settlement value 's'.

3 RESULTS

For Finite Element Analysis the same procedure and model should be used for unreinforced and reinforced models Also the same mesh size and same boundary elements were used for both models. This is important, because if the model changes it can affect the results. Boundary and scale effect was investigated by different models and literature studies, and suitable conditions were selected for this study. Firstly, to see the unreinforced model results test conducted in laboratory and FEM analysis results were compared in Figure 3. It can be noticed that the laboratory test results for unreinforced model showed a failure point at q=61 kPa, and the settlement at this point was approximately 10% of the plate width. To compare the effect of the reinforcement again FEM analyses were made. In models, the first reinforcement depth to plate, reinforcement length and vertical spacing between the reinforcement layers were taken constant as u=0.35B, L=3B and h=0.4B, respectively. These values were chosen as optimum values from literature studies. For reinforced models, in which reinforcements were used, the geotextile element was used. Only geotextile element was used, because in FEM for plane strain conditions only a continuous media can be modeled and the aperture and aperture sizes can't be modeled. From the load-settlement curves given in Figure 2, it can be seen as expected that when the number of reinforcements increases, higher loads can be applied to the footing and the failure occurred at larger settlement ratios. Using reinforcement can increase the value of pressure applied to almost 4 times of the unreinforced case. As it can be seen from the result, only by using reinforcement a reasonable improvement can be achieved and it can provide an economical solution.

For a single reinforcement layer, generally all reinforcements show similar load-settlement curves up to a settlement of s=1cm (=0.1B). Also the FEM gives a load settlement curve in agreement with the model tests. This means that in the model test different reinforcement types and the FEM give almost identical results. Yet, after this settlement has been exceeded each reinforcement shows different behavior as can be seen in Figure 3. In the model tests, generally, the load-settlement performance for Geogrid 1 is better than the other reinforcements for N=1. In all results, laboratory tests and FEM, curves start to show elastic behavior until approximately s=0.1B and afterwards plastic behavior starts (Cicek, 2011).

Figure 4 shows the comparison of FEM results and different reinforcement type behavior for load-settlement of soil for three layers of reinforcement (N=3). Physical model and FEM analysis results show similar load-settlement trends until approximately s=0.1B, however, the physical tests show a better result than the FEM. For larger settlements FEM values become smaller. Also, Geogrid has bigger effect on bearing capacity of soil and soil can be loaded more. Nevertheless, Geotextile has smaller effect than other reinforcements although it has bigger tensile strength. It can be speculated that aperture size is an important parameter for multi layered soils. Load-settlement curve behaved approximately linear until test finishes and a plastic point can't be seen for the load-settlement curves for this series.

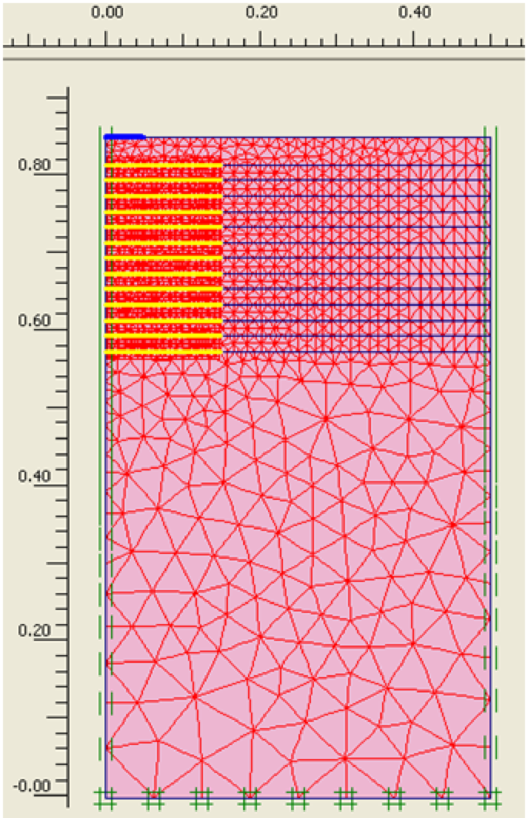

Figure 1: FEM mesh model

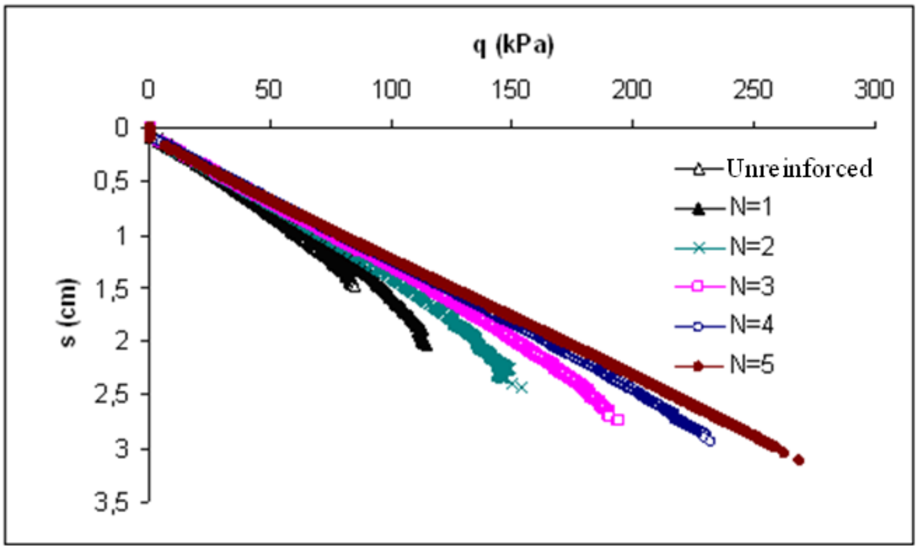

Figure 2: Load-settlement curve for different number of Geotextile layers in FEM analysis

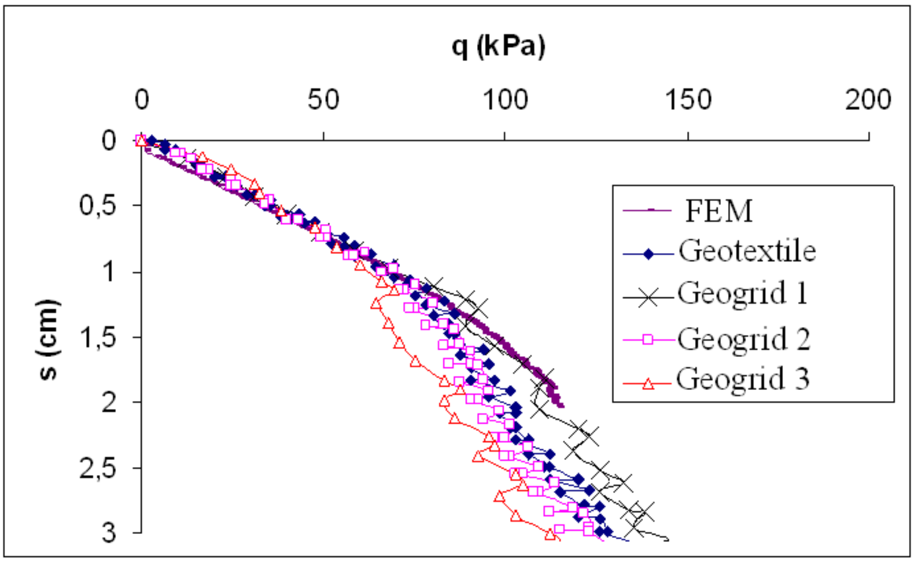

Figure 3: Comparing load-settlement curves for N=1

As for five reinforcement layered soil (N=5) in Figure 5, until a settlement of s=0.1B, FEM and physical test results show again a similar behavior and again for bigger settlements this agreement is changed and load-settlement curves for laboratory tests have different curves and with increasing load, smaller settlements occur.

Geogrid-1 has the minimum tensile strength compared to the other reinforcement types, but it showed a better performance for all reinforcement number combinations (N=1, 2 and 3). Geogrid-1 has the smallest aperture size among the geogrids. This can be interpreted as that aperture size is important for behavior of reinforced soils. However, this cannot be modeled in the current state of the art of FE modeling.

Additionally, when the applied load on the footing can reach high values due to the presence of the reinforcement, the sand may settle and consequently the soil may be compacted. This may lead to the fact that the soil properties change. Since such a change in soil parameters are not reflected to the FEM model, the FEM may give larger settlements than the laboratory test results.

In Figure 6 the Bearing Capacity Ratios (BCR) is compared for different type of geosynthetic reinforced soil model test results for different number of reinforcement layers and Finite Element analysis results. As it can be seen from Figure 6, all Geogrid models have similar BCR-N curve slopes, but Geotextile has a different trend. Also, it can be seen that, a single reinforcement layer can affect the bearing capacity significantly. Additionally, Geotextile reinforced models and FEM give same BCR-N values for small settlements (s=0.1B). However, other reinforced soils have different values from FEM results.

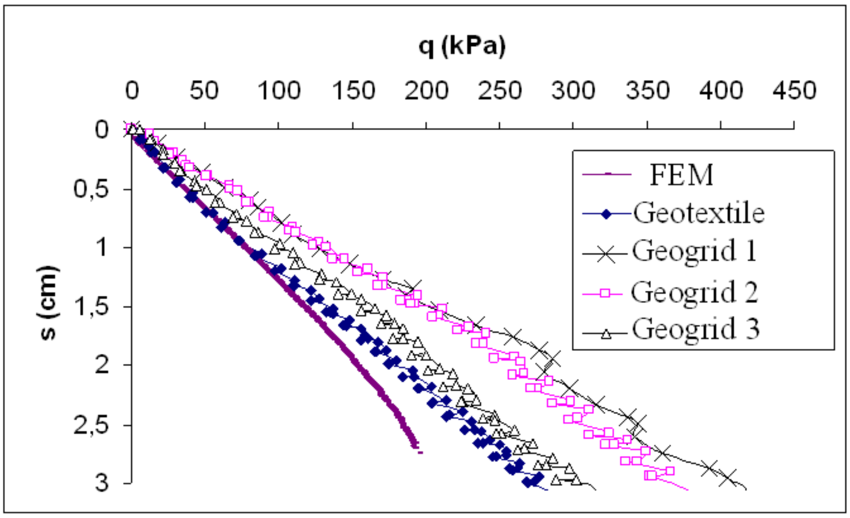

Figure 4: Comparing load-settlement curves for N=3

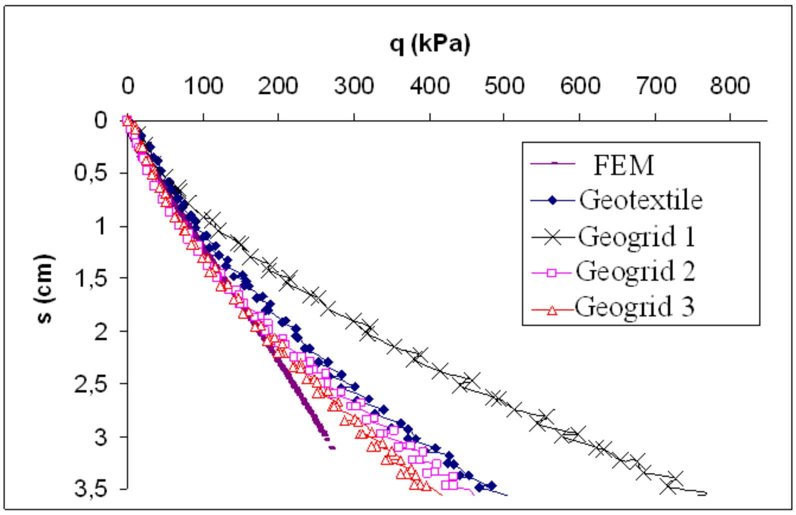

Figure 5: Comparing load-settlement curves for N=5

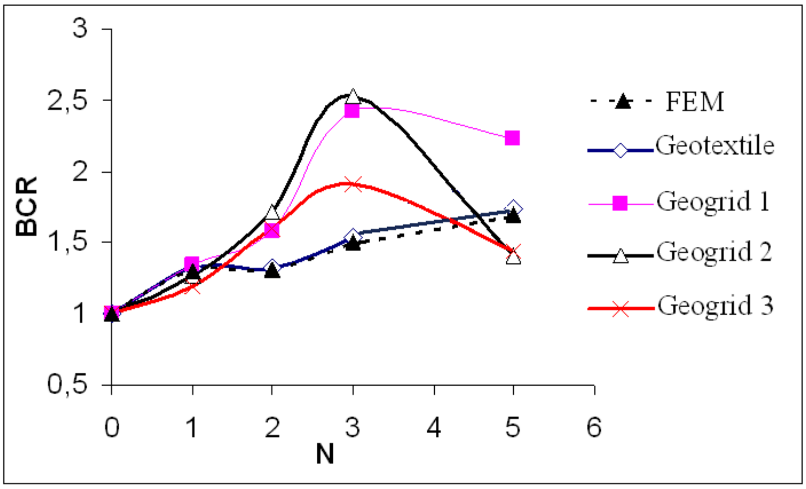

Figure 6: Comparing of BCR-N values for s/B=0.1

4 CONCLUSIONS

In this study by using sand raining technique a medium dense sand model was prepared without compaction Unreinforced and reinforced models have been constructed with one geotextile and three geogrid reinforcements. A footing sitting on this sand was loaded. Additionally FE analyses were conducted to model unreinforced and reinforced foundations. Conclusions can be summarized as below:

- The load settlement curves for the geotextile and three different geogrids were similar for loads below the bearing capacity of unreinforced sand.
- Finite Element Model was able to predict the load settlement behavior for small loading and settlement conditions relatively well for both geotextile and geogrid reinforcement.
- However, under loads exceeding the unreinforced bearing capacity, the differences become evident. The geogrid with the smallest aperture size gave the most favorable result for all configurations for the sand used in the experiments.
- As a result, it can be concluded that the load settlement behavior of reinforced foundations cannot be perfectly modeled using FE method.
- One reason for this can be the fact that the difference in reinforcement cannot be properly reflected to FE analyses because plane strain conditions do not properly allow to model for aperture effect and aperture size.
- A second consideration is that loading the sand beyond the unreinforced bearing capacity causes a compaction and as a result, the properties of soil change. This will inevitably effect the load settlement behavior.

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