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Effect of reinforcement type and number on the load-settlement behavior of strip footings

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ABSTRACT: In this paper, results of model tests are reported. The aim was to see how the numbers of reinforcement layers effect the settlement of footings and also to understand how the type of geosynthetic reinforcement effects the load-settlement relation. In laboratory tests, a strip footing was loaded on geosynthetic reinforced sand. First series of load tests were conducted on unreinforced sand to create a basis for comparison. Four such tests were carried out on unreinforced sand to ensure the repeatability of the tests. For the reinforced soil tests only reinforcement type and number of geosynthetic layers were changed. Other parameters were taken the same in all tests. As reinforcement, geogrid and geotextile were used. The test results showed that the load-settlement curves for the given geotextile and geogrid do not have many differences if only one layer of reinforcement is used. However, when more than one layer of reinforcement is used, settlements measured in geogrid reinforced soil were smaller than the settlements for the geotextile reinforced soil. Another observation was that geogrid reinforced soil could take larger loads than geotextile reinforced soil.

1 INTRODUCTION

Geosynthetic reinforcement is one of the alternative and economical soil improvement procedures. During the past 30 years, the use of reinforcement to support the foundation soil has received considerable attention. Experimental, numerical, and analytical studies have been performed to investigate the behavior of reinforced soil by using different soil, reinforcement and footing types (Binquet & Lee 1975a, b, Huang & Tatsuoka 1990, Omar et al. 1993, Latha & Somwanshi 2009, Sharma et al. 2009).

In this study the literature is reviewed to determine parameters affecting the behaviour of reinforced foundation soils under static loading conditions. In most literature reviewed, it was noted that one type of geosynthetic was used. Only a few researches have compared the behavior of different reinforcement types (Guido et al. 1986, Chen 2007, Latha et al. 2009). So effect of reinforcement type was not investigated thoroughly. However the performance of reinforced soil foundation depends on the interaction between the soil and reinforcement. For that reason different geosynthetic types were used to determine the load-settlement behavior of strip footing on reinforced sand in this study.

Another parameter that influences the behavior of reinforced foundations is the use of one layered versus three layered reinforcement. So in this study one layered and three layered reinforced soil was investigated. The results of model tests conducted on unreinforced and reinforced soils were presented and discussed.

2 LITERATURE REVIEW

To understand the role of reinforcement materials in improving the bearing capacity of foundation soils a lot of research was done. Different studies resulted in somewhat different specifications for reinforcement layouts. Several experimental studies were conducted to evaluate the bearing capacity of footings on reinforced sandy soil (Yetimoglu 1994; Adams & Collin 1997; Huang & Meng 1997; Wayne et al. 1998, Michalowski 2004, Patra et al. 2006, Ghazavi et al. 2008). These studies show that values of reinforcement configuration that give maximum bearing capacity value depend on the soil and footing types. A detailed literature survey was conducted to determine the optimum values of the following reinforcement configuration parameters: depth of first reinforcement layer, vertical spacing between reinforcement layers and length of reinforcement.

The first experimental study reported in the literature was conducted by Binquet and Lee (1975a) to determine the bearing capacity of sand reinforced by metal strips. In that study the maximum bearing capacity was obtained when the first reinforcement depth was chosen as u = 0.3B (B = footing width). Shin et al. (1993) conducted tests on geogrid reinforced clay soil and determined the optimum first reinforcement depth as u = 0.4B. Das et al. (1994) found the optimum first reinforcement depth as u = 0.3B for strip footing on sand soil. Basudhar et al. (2008) in a similar research determined this value as u = 0.6B for geotextile reinforced sand. According to these studies optimum first reinforcement depth for maximum bearing capacity may range between u = 0.2B – 0.6B.

A similar process was followed to determine the range of vertical spacing of reinforcement layers (h) that gives maximum bearing capacity as a result of literature survey Shin et al. (2002) determined optimum vertical spacing of reinforcement value as h = 0.2B by testing geogrid reinforced sand. Chen (2007) and Abu-Farsakh et al. (2008) found optimum h as 0.33B and Latha et al (2009) determined this value as h=0.5B. According to these studies optimum vertical spacing of reinforcement layers for maximum bearing capacity ranges between u = 0.2B – 0.5B.

Another variable that controls the degree of improvement is the length of the reinforcement. Guido et al. (1986) determined optimum length of reinforcement layer as L = 2.5B for a square footing on geogrid reinforced sand. Das et al. (1994) found optimum reinforced length for strip footing for reinforced sand and reinforced clay as L = 8B and L = 5B respectively. Ghosh et al. (2005) gave this value to be between L = 5B-7B. Dawson et al. (2010) and El Sawwaf & Nazir (2010) found optimum reinforcement length as L = 5B. According to these studies optimum length of reinforcement layer for maximum bearing capacity ranges between L = 2B – 8B.

3 MODEL TESTS

The model tests were conducted in a steel tank. Its dimensions are 100 cm (length), 50 cm (width) and 100 cm (height). The tank is made of steel plates where only the front face of tank is 1 cm thick tempered glass plate. The box was strengthened by three rows of steel I profiles to minimize lateral deformations of the box. The inside walls of the tank were polished to reduce friction as much as possible.

The model foundation was a steel plate with a thickness of 25 mm. It had a width of 10 cm (B) and a length of almost same as of the tank. The footing was centered in the tank, with the length of the footing parallel to the width of the tank and was placed directly on the surface.

The soil used in the present investigation was a dry sand with coefficient of uniformity (C_u) of 2.5, coefficient of curvature (C_c) of 1.0 and effective size of particle (D_{10}) of 0.22 mm. The soil can be classified as poorly graded (SP) according to the Unified Soil Classification System. Specific gravity is 2.65. The maximum and minimum dry unit weights of the sand are found to be 16.5 and 13.9 kN/m^3. In all model tests, the average unit weight and relative density of the sand were kept constant at 15.0 kN/m^3 and 46%, respectively. This relative density was achieved in the test tank using a sand raining technique. The height of raining to achieve the desired density was determined a priori by performing a series of trials with different heights of raining. Sand was placed in very thin lifts and the surface was checked at every 20-25mm for horizontality. The difference in densities for each test measured at various locations was found to be less than 1%. The friction angle of the sand was determined as 38°.

In the laboratory tests two different reinforcement type was used. One is a woven geotextile and the other was a geogrid. Geosynthetic reinforcement properties (obtained from the manufacturer firm) are shown in Table 1.

Table 1. Properties of reinforcements

Reinforcement type	Polymer type	Maximum tensile load (T_u, kN/m)	Aperture size (mm)
Geotextile	Polypropylene	60	-
Geogrid	Polyester	35	20x20

Before starting a new test, the sand in the tank from previous test was removed and all set up were regenerated. The footing was placed on the surface of the sand bed and load was applied by a hydraulic jack. The load was applied in small increments until settlement equal to about 50% of the footing width occurred. The settlements of the footing were measured using four laser sensor and two displacement gauges (LVDT). Laser displacement sensors were placed on each corner of footing and LVDTs were placed on either side of the model foundation. The load applied on strip footing was measured by a load cell with the help of a data logger.

First unreinforced soils were tested. Four tests where all the conditions were the same were carried out. Then reinforced soil model tests were conducted. The reinforcement configuration was chosen based on the information obtained from the literature survey, to achieve maximum benefit from the reinforcement. Therefore the following parameters were adopted for the geosynthetic reinforcement layers; u/B = 0.35, h/B = 0.40, L/B = 3.

These ratios were used in all tests. Figure 1 shows the reinforced testing model. Only reinforcement type and number of geosynthetics were changed. Geogrid and geotextile was used as reinforcement. The number of reinforcement numbers used in the model tests were N=1 and 3.

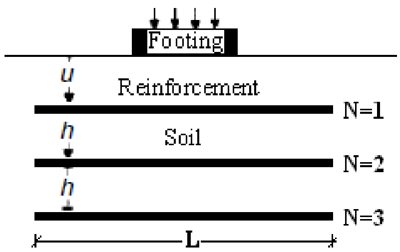


Figure 1. Schematic of reinforced soil model.

4 TEST RESULTS

Test results of strip footing on unreinforced sand soil are shown in Figure 2. As can be seen from this Figure, four separate model tests were conducted to ensure the repeatability of the testing system. The load-settlement curves are nearly similar for same conditions. The failure surfaces started to develop in the soil when the load value reaches q_{u1}=61 kPa and the settlement ratio (s/B) was approximately 10-15% (s≈1-1.5 cm). Ultimate bearing capacity value for strip footing according to Terzaghi (1943) was calculated as q_u=59 kPa from the formula $q_u = 0.5\ \gamma B N_\gamma$ (where γ = average unit weight, B = width of the strip footing, N_γ = bearing capacity factor). This result shows that there is good agreement between experimental measurements and the Terzaghi bearing capacity theory.

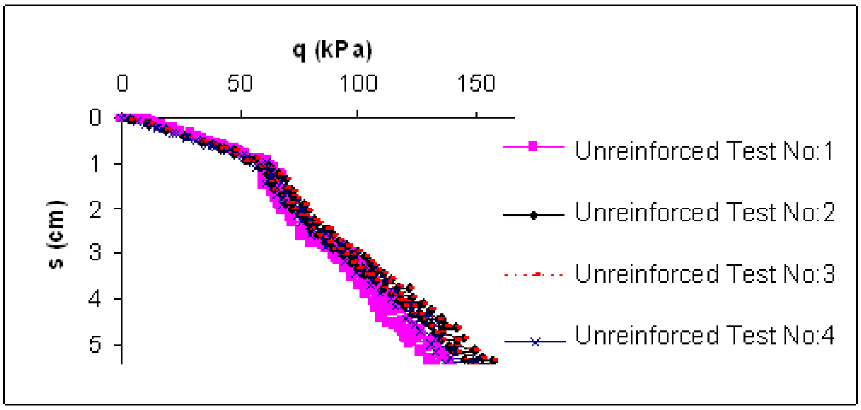
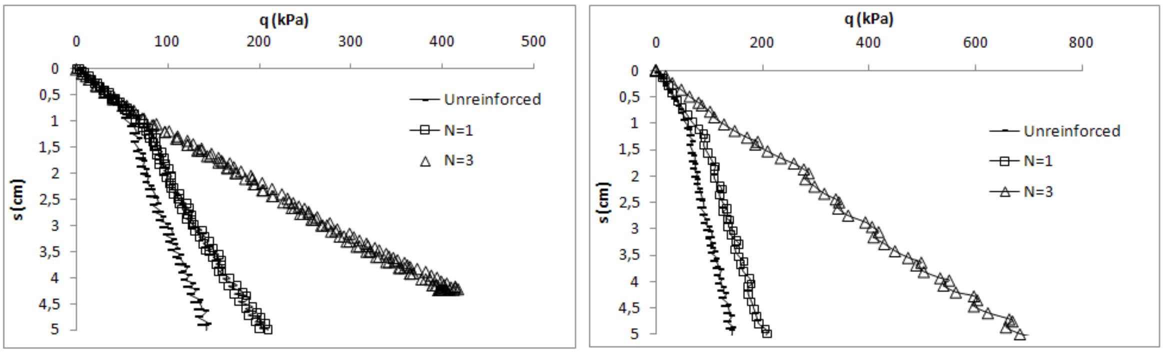


Figure 2. Load-settlement curves for strip footing on unreinforced sand.

Tests on reinforced soil were conducted for the same u/B, h/B and L/B values as stated above for two different geosynthetic types. Only reinforcement type and number of geosynthetics (N=1-3) were changed. Tests were repeated in laboratory and the variation of load-settlement curves between these tests was less than ±5%. Figure 3 shows load-settlement curves of reinforced sand and unreinforced sand.



a b

Figure 3. Load-settlement curves for strip footing on reinforced sand; a. geotextile, b. geogrid reinforced.

It can be seen from Figure 3 that settlements decreased under the same load values when number of reinforcements was increased. Even one layered reinforced soil changes the behavior of strip footing settlement for two different reinforcement types. It was also seen that the footing on the reinforced soil could be loaded more than the footing on unreinforced as expected.

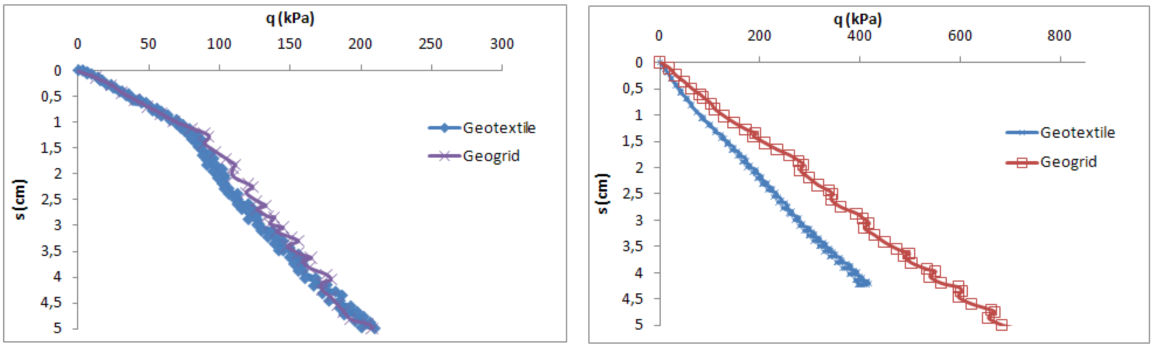
One layered and three layered reinforced soils have different load-settlement curves. When the curve of one layered reinforced soil is examined, it is seen that as the load increases, the settlement ratio increases after 10-20% settlement ratio. But for three-layered reinforced soil, the load settlement curve remains almost linear during the test.

Figure 3.a shows that the behavior of load-settlement curves of geotextile reinforced soil are similar for N=0, 1 and 3 until a footing settlement ratio (s/B) of 10% (s≈1 cm) is reached. This level of deformation coincides at the same time approximately with the bearing capacity of the

unreinforced sand. After this level of loading reinforced soils show smaller settlements under the same load.

In Figure 4b, the load settlement graph of geogrid reinforced sand and unreinforced sand is given. Here again the behavior shows a change after approximately 10% (s≈1 cm) footing settlement ratio for a single layer of geogrid reinforcement. However for three-layered reinforced soil, an almost linear load-settlement curve is observed and the load-settlement ratio remains the same until the end of the test. For a single layer of reinforcement a change in the load-settlement curve is observed almost same that of the unreinforced bearing capacity value. However this effect is not seen when three layers of reinforcement is used.

The comparison of different geosynthetic reinforcements is shown in Figure 4. The load-settlement curves of geotextile and geogrid do not have many differences if only one layer of reinforcement is used (Figure 4.a). But when three layers of reinforcement are used, the settlement values of geogrid reinforced soil are measured to be smaller than the geotextile reinforced soil (Figure 4.b). The difference in settlement increases even further with increased load acting on the footing.



a b

Figure 4. Comparison of geotextile and geogrid reinforced soil; a. N=1, b=N=3.

For example one layer of reinforcement increases the vertical load up to approximately 1.5 times than of unreinforced soil. Three layered geogrid reinforcement increase the vertical load approximately more than 3 times than one layered reinforcement at a footing settlement value of s=4 cm. At same settlement value three layered geogrid reinforced sand carries approximately 3 times the load of a single layered reinforced soil.

5 CONCLUSIONS

For similar reinforcement conditions, settlements decreased under the same load values when number of reinforcements was increased. Even one layered reinforced soil changes the behavior of strip footing settlement. It was also seen that the footing on the reinforced soil could be loaded to more than the footing on unreinforced soil as expected.

One of the most important conclusions drawn from the experimental studies is that one layered and three layered reinforced soils have different load-settlement curves. When the curve of one layered reinforced soil is examined, it is observed that as the load increases the settlement ratio increases after about 10-20%. But for three-layered reinforced soil, a linear load-settlement curve is seen and load-settlement ratios remain almost constant throughout the test.

The test results showed that the load-settlement curves of geotextile and geogrid which were used in this study do not have many differences if only one layer of reinforcement is used. But when three layers of reinforcement are used, the settlement values of geogrid reinforced soil are measured to be smaller than the geotextile reinforced soil.

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