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Bearing capacity of square footings on sand reinforced with dissimilar geogrid layers

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KEYWORDS

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Abstract. This paper aims to investigate the likely effects of geogrid reinforcement configuration on the bearing capacity of footings. Using geogrid reinforcement layers with certain total areas in various uniform and non-uniform arrangements, the bearing capacities of footing models on reinforced sand beds were determined and compared. The first arrangement was the conventional uniform layout in which three geogrid layers of equal dimensions were considered. In the second group, the same amount of geogrids was used in a trapezoidal profile in which smaller sized geogrids were placed at upper layers and the geogrid dimensions increased with embedment depth. The third group consisted of arrangements in which the same amount of geogrids was used in an inverse trapezoidal layout, i.e. the layer sizes decreased with embedment depth. The effect of soil density on the footing performance was also investigated. The tests results indicated that in all soil densities, the greatest bearing capacities were obtained for the sand beds reinforced with inverse trapezoidal reinforcement layouts, while the least bearing capacities were determined for trapezoidal arrangements. The improvement ratio of bearing capacity due to geogrid reinforcement varied from 1.8 to 5.35 depending on the reinforcement layout and the sand bed density.

1. Introduction

Soils are the most common construction materials encountered almost in all civil engineering projects. A known weakness of soil is lack of tensile strength which makes necessary to reinforce it for proper performance in certain usages. Numerous methods have been introduced for improving soil mechanical properties, amongst them may be referred to reinforcement with tensile elements. The reinforced soil consists of two materials, i.e. soil and reinforcing elements which are placed within the soil to enhance its resistance against tensile stresses. This concept is somehow similar to the usage of steel bars in reinforced concrete to increase its tensile strength. Till now, various reinforcing elements in strips, bars, grids, fibers, textiles, and combined forms of different metallic materials such as steel and aluminum as well as polymeric materials, known as geosynthetics, have been used for soil reinforcement. Geogrids are a very common type of geosynthetic products widely used for enhancing the bearing capacity and reducing the settlement of foundation soils.

The role of reinforcement in improving the bearing capacity of foundation soils has been investigated by several researchers, such as Fragaszy and Lawton (1984), Huang and Tatsuoka (1990), Khing et al. (1993), Yetimoglu et al. (1994), Shin and Das (2000), Dash et al. (2003), Michalowski (2004), Patra et al. (2005, 2006), Basudhar et al. (2006), El Sawwaf (2007), Moghaddas Tafreshi and Dawson (2010), Yadu and Tripathi (2013) [1-13]. The focus of most of these

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studies was on strip footing models and the length of reinforcing layers for achieving maximum bearing capacity found to be in a range of 5 to 8 times of footing width. Several other studies on the bearing capacity of square footings on reinforced soils have also been reported, amongst them may be referred to Omar et al. (1993), Adams and Collin (1997), Kumar and Saran (2003), Bera et al. (2005), Ghosh et al. (2005), Kumar and Walia (2006), Chung and Cascante (2007), Ghazavi and Lavasan (2008), Sharma et al. (2009), and Latha and Somwanshi (2009a-b) [14-24]. In more recent research studies, Bai et al. (2013) conducted large site loading on a square footing placed on a geobelt-reinforced crushed stone layer underlain by a soft soil [25]. It was found that the bearing capacity of the crushed stone cushion might enhance up to 70% for two-layer geobelt reinforcement. Several other large scale loading tests on geogrid reinforced granular soils have recently been reported, amongst them may be referred to Demir et al. (2013) and Liu et al. (2014) [26,27]. Abu-Farsakh et al. (2013) indicated that reinforcement configuration has significant effects on the response of geosynthetic-reinforced sand foundation [28]. They found an effective geosynthetic reinforcement length of $6B$ for square model footings. Based on the reported studies, the effective length of reinforcing layers for achieving maximum bearing capacity found to be in a range of 3 to 6 times of square footing width. The optimum number of reinforcement layers was found to be 3 to 4 layers used in a uniform arrangement, i.e. the same length for all layers in the reinforcement block. However, it seems that the reinforcement efficiency changes with placement depth and an optimum non-uniform reinforcement arrangement may be found to achieve maximum bearing capacity.

In this paper, results of laboratory loading tests on model footings on reinforced sand beds with conventional uniform as well as various non-uniform reinforcement arrangements are reported and discussed. The main objective of this study was to search for the optimum reinforcement arrangement which may yield more efficient improvement in the footing bearing capacity. The influence of sand bed density on the footing bearing capacity was also considered.

2. Testing materials

2.1. Soil

The soil used in this study was fine dry sand with effective particle size (D_{10}) 0.18 mm, coefficient of uniformity (C_u) 1.61, and coefficient of curvature (C_c) 1.13. The soil grading curve is shown in Figure 1. Based on the particle grading data, the soil is classified as SP (poorly graded sand) according to the unified classification system [29]. The specific gravity of the sand was measured 2.69. The minimum and maximum

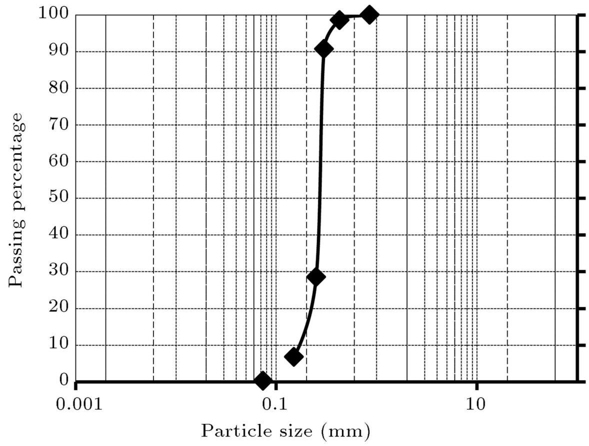

Figure 1. Particle size distribution of the testing soil.

dry unit weights of the soil were obtained as 1.57 g/cm^3 and 1.81 g/cm^3, respectively. The friction angles of the sand at 3 relative densities of 55, 70, and 85% were measured through direct shear tests as 36°, 39°, and 41°, respectively.

2.2. Geogrid

The geogrid used to reinforce sand bed in the model tests was made of high density polyethylene (HDPE) with commercial brand of CE16. It was a weak biaxial geogrid with opening size of 10×10 mm and tensile strength of 6.7 kN/m.

3. Test set-up

The load tests were carried out on sand beds reinforced with various reinforcement arrangements. The sand beds were prepared in a test box with internal dimensions of 48 × 48 × 48 cm. The test box consisted of transparent compacted plastic walls with thickness of 6 mm encased into steel frame. The supporting steel frame was also used as a solid support for the magnetic base of dial gauges used to measure the footing settlements. The model footing used for the tests was square rigid aluminum plate dimensioned 70×70×15 mm. The base of the model footing was roughened by gluing a proper sand paper on it. To prevent any eccentric loading, the model footing was prepared with a centric semispherical hole on its top side in which the loading rod rested during the loading tests.

The load application on the model footing was made by a hydraulic jack assembled within a steel reaction frame. The reaction frame was firmly connected to the solid slab of laboratory floor. The applied load was measured by a 30 kN proving ring with precision of 10 N. The test loading was provided through strain control system adjusted at the rate of 0.67 mm/min which remained constant for all tests. The reaction load was recorded for every 0.5 mm settlement. The

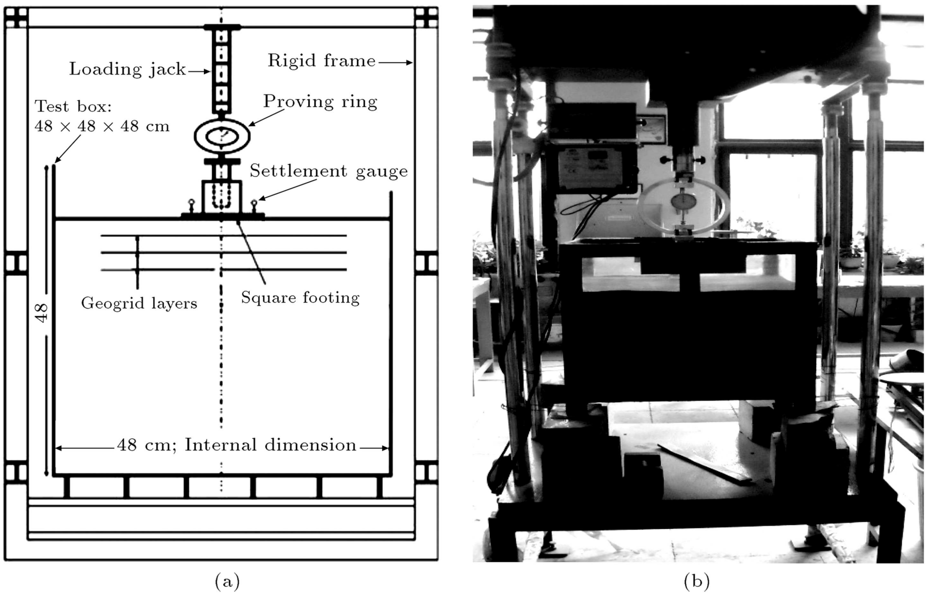

Figure 2. Testing set-up: (a) Schematic details; and (b) overall view.

footing settlements were recorded by two 0.01 mm divisions of dial gauges which were fixed to the opposite sides of the test box through their magnetic bases. A schematic diagram of the test set-up is shown in Figure 2.

4. Preparation of sand bed

The sand bed was prepared in three different relative densities. For each density, the required amount of sand was first predicted. The sand was then placed in the test box using a mixed pluviation (raining) and tamping technique. An aluminum funnel with 10 kg capacity was used for this purpose through which the sand was poured in the test tank from a constant height. The funnel length was equal to the width of test box. The total height of sand in the test tank was considered to be 35 cm. The first 25 cm was filled through 5 layers of 5 cm height and the next 10 cm was placed in 5 layers of about 2cm height.

5. Geogrid placement configurations

Figure 3 shows the typical layout of multi-layered geogrid reinforced sand bed adopted as a conventional layout of uniform reinforced base in which all geogrid layers have the same plan size. Based on previous experiences such as those reported by Abdrabbo et al. [30], Gosh et al. [18], Kumar and Walia [19], Latha and Somwanshi [24], the depth of placement of the first reinforcement layer from the bottom face of the footing, u, and the spacing between consecutive layers of reinforcement, h, both were selected to be $0.3B$ in which B is the footing width. The optimal number of reinforcement layers was adopted to be 3 for the uniform reinforcement layouts, although up to 4 layers were used in dissimilar reinforcement arrangements. The reinforcement width was also selected to be $3B$ in the uniform reinforcement layouts, which was an economic size to achieve optimum bearing capacity improvement based on previous experiences (Section 1). As the experimental research included numerous testing cases, for easy presentation, an abbreviated code was selected for each testing case as shown in Figures 3 to 7. Also, the NR code was used for non-reinforced sand bed. For easy access, the tested reinforcement configurations are listed as follows:

- UR: Uniform reinforcement with $3B$, $3B$, $3B$ arrangement (conventional layout; Figure 3);

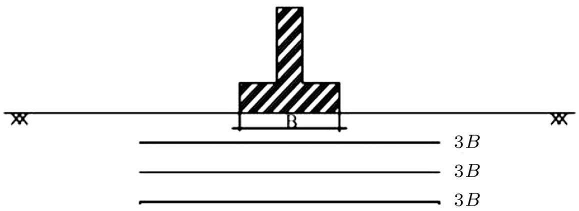

Figure 3. Uniform reinforcement in 3 layers (UR).

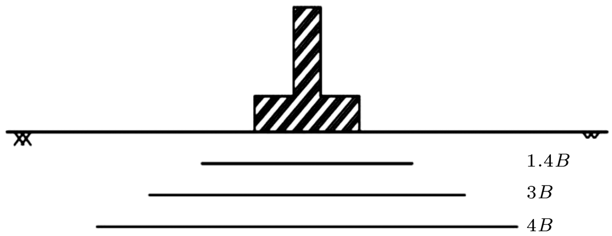

Figure 4. Trapezoidal reinforcement layout in 3 layers (T1).

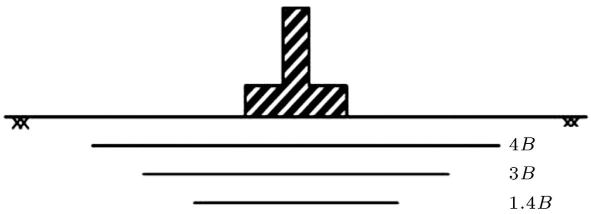

Figure 5. Inverse trapezoidal reinforcement layout in 3 layers (IT1).

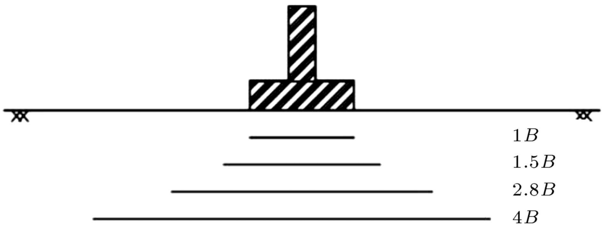

Figure 6. Trapezoidal reinforcement layout in 4 layers (T2).

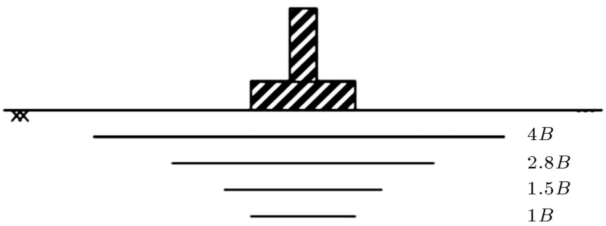

Figure 7. Inverse trapezoidal reinforcement layout in 4 layers (IT2).

- T1: Trapezoidal reinforcement layout in 3 layers with 1.4B, 3B, 4B arrangement (Figure 4);
- IT1: Inverse trapezoidal reinforcement layout in 3 layers with 4B, 3B, 1.4B arrangement (Figure 5);
- T2: Trapezoidal reinforcement layout in 4 layers with 1B, 1.5B, 2.8B, 4B arrangement (Figure 6);
- IT2: Inverse trapezoidal reinforcement layout in 4 layers with 4B, 2.8B, 1.5B, 1B arrangement (Figure 7).

It should be mentioned that the same total reinforcement areas of $27B^2$ (1323 cm^2) were used in all the tests.

6. Tests results

In the following sections, the results of loading tests carried on the square footing model in terms of bearing pressure versus settlement plots at three relative densities of 55, 70, and 85% are presented. Based on the load-settlement curves, the ultimate bearing capacity for each loading test was determined. As in most cases, the load-settlement curves had no distinct peak point, the bearing pressure at a certain settlement (corresponding to 10% of footing width, i.e. $S/B = 10\%$) was determined as the footing ultimate bearing capacity. The selection of bearing pressure at the settlement ratio, S/B, of 10% as the footing ultimate bearing capacity was made based on previously reported studies, such as Lutenegger and Adams (1998) [31].

The effect of various forms of reinforcement of the sand bed on the bearing capacity of the footing model was introduced through a non-dimensional parameter, the Bearing Capacity Ratio (BCR) which is defined as follows:

$$\mathrm{BCR} = \frac{q_{sr}}{q_s}, \tag{1}$$

where q_{sr} is the bearing pressure of the reinforced sand bed at certain settlement (10% of footing width, i.e. $S/B = 10\%$), and q_s is the bearing pressure of unreinforced soil at the same settlement. Then the footing performance improvement due to provision of various reinforcement layouts was evaluated in terms of the bearing capacity ratio, BCR, and the results were compared with each other.

6.1. Reinforced sand bed at 55% D_r

Figure 8 presents the variation of bearing pressure with footing settlement from load tests on the square footing model placed on the sand bed of 55% relative density for all the considered reinforcement layouts. The bearing pressure-settlement response of the unreinforced sand bed is also presented in the plot for comparison. Bearing capacity ratios were determined for all the tests and presented in the bar diagrams of Figure 9. Figures 8 and 9 clearly show that the bearing capacity of the footing noticeably improve with inclusion of geogrid layers. Meanwhile, comparing

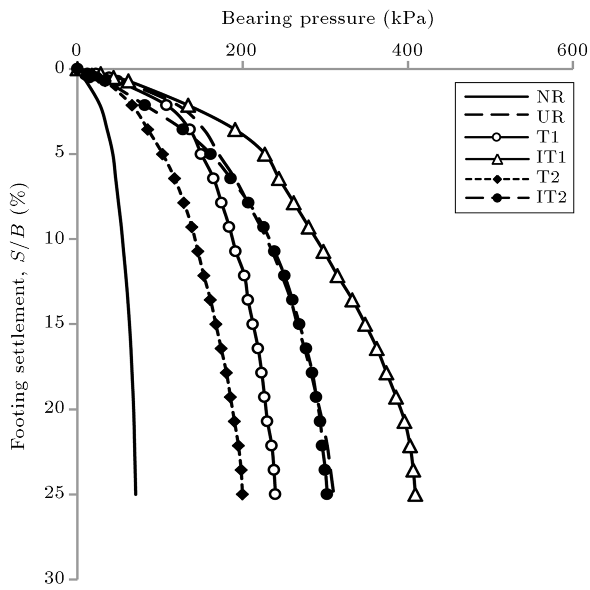

Figure 8. Variation of bearing pressure with settlement of square footing on sand bed of 55% D_r for different reinforcement layouts.

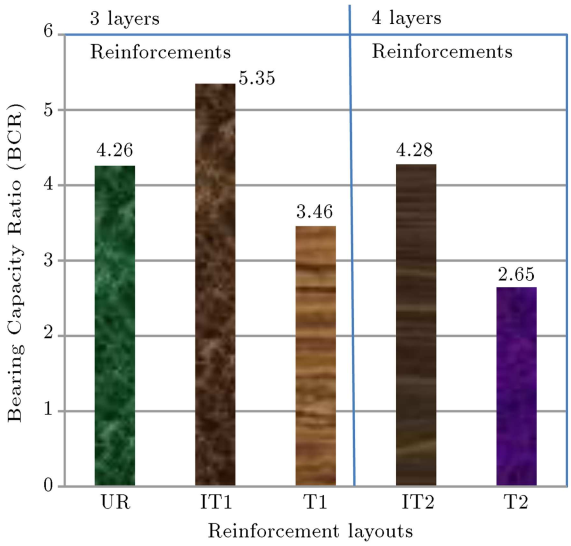

Figure 9. BCR Values of square footing on sand bed of 55% D_r for various reinforcement layouts.

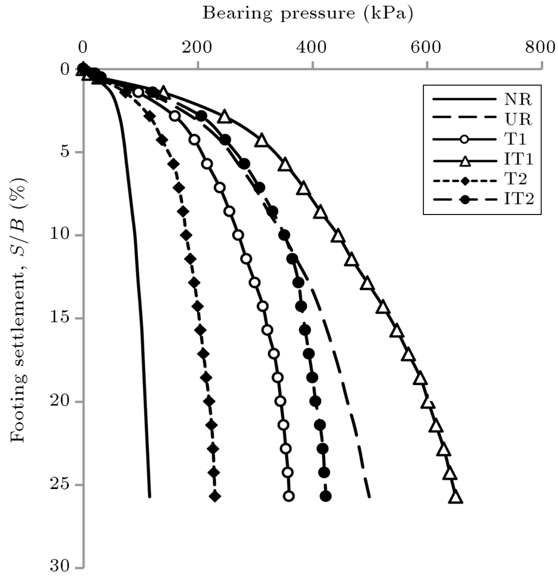

Figure 10. Variation of bearing pressure with settlement of square footing on sand bed of 70% D_r for different reinforcement layouts.

the results of different reinforcement layouts indicates that the amounts of bearing improvement are different for various reinforcement arrangements. The inverse trapezoidal reinforcement layout in three layers (IT1) was found to be the most efficient reinforcement arrangement, while the trapezoidal reinforcement layout in 4 layers (T2) showed to be the least effective reinforcement. The BCR values ranged from 2.65 to 5.35 depending on the reinforcement layouts. In the case of similar-size reinforcement in 3 layers (UR; Uniform Reinforcement layout, i.e. conventional arrangement), the BCR value was about 4.26, while for inverse trapezoidal reinforcement layout in 3 layers (IT1), the BCR increased to 5.35. These results indicate that by rearranging the same amount of geogrid used in the uniform reinforcement to the inverse trapezoidal reinforcement layout led to an increase of about 26% in the BCR value.

6.2. Reinforced sand bed at 70% D_r

Figure 10 shows the variation of bearing pressure with footing settlement from load tests on the square footing rested on the sand bed of 70% relative density for all the considered reinforcement layouts along with that of unreinforced sand. Bearing capacity ratios were also determined for all the tests and presented in the bar diagrams of Figure 11. Similar to the previous case, these results indicate that the bearing capacity improvement are different for various reinforcement layouts. The inverse trapezoidal reinforcement layout in three layers (IT1) was again the most efficient reinforcement arrangement, while the trapezoidal reinforcement layout in 4 layers (T2) showed to be the least effective reinforcement. The BCR values ranged from about 2 to 4.94 depending on the reinforcement layouts. In the case of similar-length reinforcement

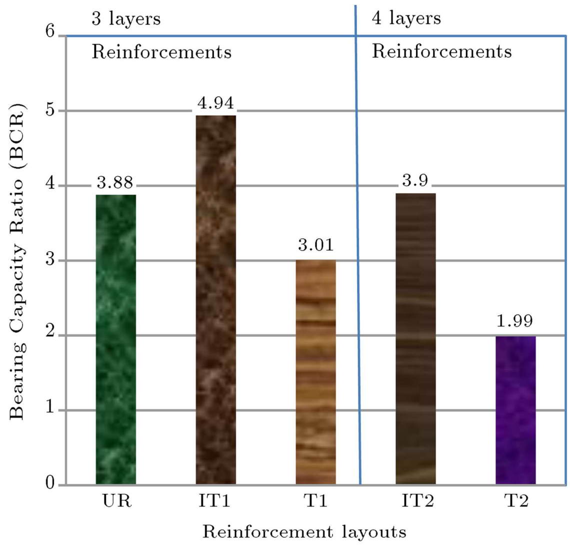

Figure 11. BCR values of square footing on sand Bed of 70% D_r for different reinforcement layouts.

in 3 layers (UR; uniform reinforcement layout i.e., conventional arrangement), the BCR value was about 3.9, while for inverse trapezoidal reinforcement layout in 3 layers (IT1), the BCR was 4.94. This result indicates that rearranging the same amount of geogrid used in the conventional uniform reinforcement to the inverse trapezoidal reinforcement layout leads to an increase of more than 27% in the BCR value.

6.3. Reinforced sand bed at 85% D_r

The results of load tests on the square footing on the reinforced sand bed of 85% relative density are discussed in this section. Figure 12 shows the variation of bearing pressure with settlement for various

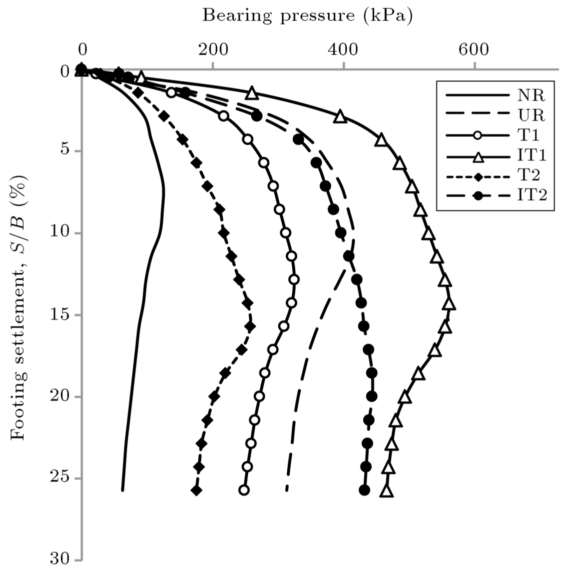

Figure 12. Variation of bearing pressure with settlement of square footing on sand bed of 85% D_r for different reinforcement layouts.

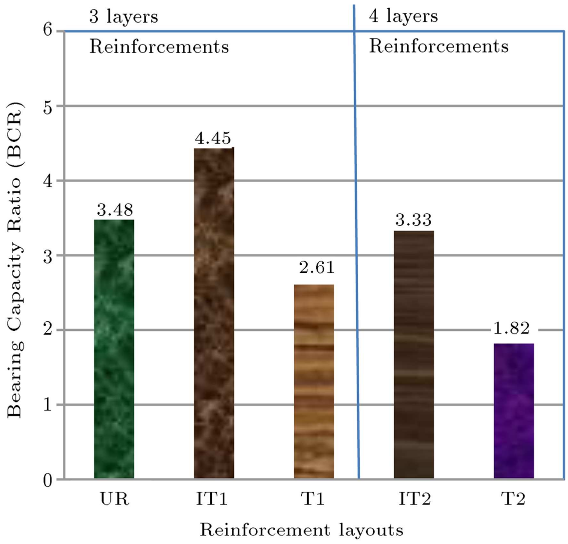

Figure 13. BCR values of square footing on sand bed of 85% D_r for different reinforcement layouts.

reinforcement layouts along with that of unreinforced sand. Bearing capacity ratios were also determined for all cases and presented in the bar diagrams of Figure 13. Unlike to previous cases, the load-settlement curves had a distinct peak point, which may be regarded as an indication of the failure type of general shear in the soil base. All the load-settlement curves began with a relatively steep slope which decreased gradually with settlement increasing before getting at the peak point and finally ended with nearly sympathized vertical direction. As the peak value of bearing pressure mostly occurred at relative settlements more than 10%, the pressure corresponding to relative settlement of 10% was determined as the ultimate bearing capacity.

In the cases of soil base with high relative density, the bearing capacity improvement was also dependent on the type of reinforcement layout. The inverse trapezoidal reinforcement layout in three layers (IT1) with bearing capacity of 530 kPa was again the most efficient reinforcement arrangement, while the trapezoidal reinforcement (T2) with bearing capacity of 285 kPa was determined as the least effective reinforcement. Depending on the reinforcement layouts, the BCR values were obtained in the range of 1.82 to 4.45. In the case of similar-length reinforcement in 3 layers (UR; uniform reinforcement layout, i.e. conventional arrangement), the BCR value was 3.48, while for inverse trapezoidal reinforcement layout in 3 layers (IT1), the BCR was 4.45. This result indicates that rearranging the uniform reinforcement to the inverse trapezoidal reinforcement layout leads to an increase of nearly 28% in the BCR value. For the high density sand bed, BCR values obtained in 4 layers reinforcement layouts were also smaller than those of corresponding 3 layers reinforcement layouts.

For all the three density levels of sand bed, the test results clearly indicate that the most effective reinforcement arrangements are those in which the lengthy layers are located in upper levels near to the footing base, i.e. IT1 layouts. For instance, adding a forth layer to the reinforcement in cost of decreasing the length of three upper layers caused a decrease in the footing bearing performance (compare the BCR of IT1 with that of IT2 layouts). Moreover, regarding the constructional features, it seems that IT1 layout is an easier and more economic alternative in comparison with other reinforcement layouts. This is because the IT1 layout needs the least volume of excavation and refilling in comparison with other alternatives.

6.4. Comparison of results

The BCR values versus relative density of sand base for various reinforcement layouts have been presented in Figure 14. As found in the previous sections, the BCR values of inverse trapezoidal layout of IT1 were apparently much higher than those of other cases. The reinforcement layouts of UR and IT2 yielded nearly the same values of BCR for D_r of up to 70%, while the BCR of IT2 was slightly higher at D_r 85%. The 3 layer inverse trapezoidal layout seems to provide proper effective lengths of reinforcements in the influence zone of $1B$ underneath the footing and thus yield higher bearing capacity. This is because, the reinforcement layout represents an appropriate coverage of assumed failure zones underneath footings in limit equilibrium based methods.

Figure 14 shows that the BCR values generally decreased with increasing the sand bed relative density. For example, for IT1 reinforcement layout, the BCR reduced from 5.35 to 4.45 as D_r of the sand bed

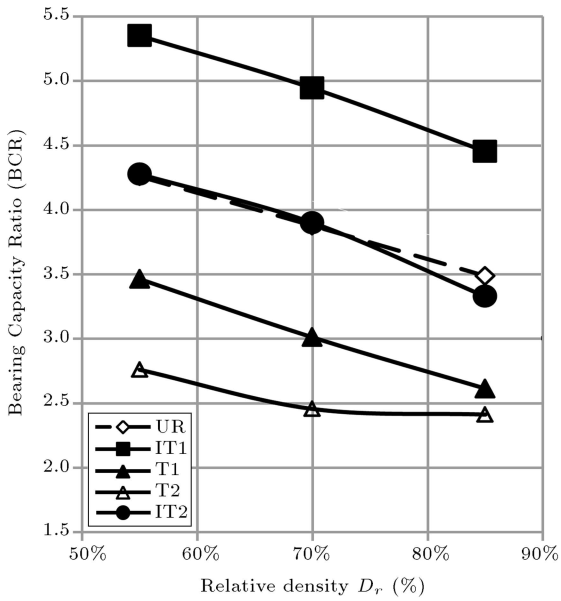

Figure 14. The BCR values versus relative density of reinforced sand bed with various layouts.

increased from 55% to 85%. This is an indication of this reality that the reinforcement efficiency is generally higher for looser sand beds. Similar conclusions were also reported in several previous studies, such as Abdrabbo et al. [30], Das and Omar [32], etc. It was also found that the BCR variations with D_r were nearly linear for most of the considered reinforcement layouts.

7. Conclusions

In the following, conclusions are outlined based on the results obtained from the laboratory model tests of square footings placed on geogrid reinforced sand beds with conventional uniform as well as various non-uniform reinforcement layouts.

1. In general, the inverse trapezoidal reinforcement layouts seem to present better and more appropriate coverage of assumed failure zones underneath footings in limit equilibrium based methods and thus are more effective in the footing's bearing capacity enhancement;
2. Inverse trapezoidal layout with 3 layers of reinforcement, IT1, was found to yield the greatest BCR values. This may be attributed to the fact that putting lengthy layers of reinforcement at upper levels near to the footing base may lead to higher efficiency of bearing capacity improvement;
3. The least BCR values were found for T2, i.e. trapezoidal layout with 4 layers ranged from 1.82 to 2.65 depending on the relative density of sand bed. This may be considered as an indication that placing small size layers in upper levels of sand bed may yield low reinforcement efficiency;
4. The BCR values generally decreased with increasing sand bed relative density so that highest values of BCR for all reinforcement layers were obtained when sand bed was at relative density of 55%;
5. Increasing the number of reinforcement layers to 4 with the same total area as that of 3 layers was not efficient; on the contrary, it mostly decreased bearing capacity improvement;
6. The maximum BCR values were found for IT1, i.e. inverse trapezoidal layout with 3 layers which ranged from 4.45 to 5.35 depending on the relative density of sand bed. The range of BCR values for conventional uniform reinforcement layouts with the same total area was 3.48 to 4.26. Thus using IT1 layout caused an average increase of 27% in the BCR value.

References

1. Fragaszy, R.J. and Lawton, E. "Bearing capacity of reinforced sand subgrades", *Journal of Geotechnical Division, ASCE*, **110**(10), pp. 1500-1507 (1984).
2. Huang, C.C. and Tatsuoka, F. "Bearing capacity of reinforced horizontal sandy ground", *Geotextiles and Geomembranes*, **9**, pp. 51-82 (1990).
3. Khing, K.H., Das, B.M., Puri, V.K., Cook, E.E. and Yen, S.C. "The bearing capacity of a strip foundation on geogrid reinforced sand", *Geotextile and Geomembranes*, **12**, pp. 351-361 (1993).
4. Yetimoglu, T., Wu, J.T.H. and Saglamer, A. "Bearing capacity of rectangular footings on geogrid-reinforced sand", *Journal of Geotechnical Engineering, ASCE*, **120**(12), pp. 2083-2099 (1994).
5. Shin, E.C. and Das, B.M. "Experimental study of bearing capacity of a strip foundation on geogrid-reinforced sand", *Geosynthetics International*, **7**(1), pp. 59-71 (2000).
6. Dash, S.K., Sireesh, S. and Sitharam, T.G. "Model studies on circular footing supported on geocell reinforced sand underlain by soft clay", *Geotextiles and Geomembranes*, **21**, pp. 197-219 (2003).
7. Michalowski, R.L. "Limit loads on reinforced foundation soils", *Journal of Geotechnical and Geoenvironmental Engineering, ASCE*, **130**(4), pp. 381-390 (2004).
8. Patra, C.R., Das, B.M. and Atalar, C. "Bearing capacity of embedded strip foundation on geogrid-reinforced sand", *Geotextiles and Geomembranes*, **23**, pp. 454-462 (2005).
9. Patra, C.R., Das, B.M., Bhoia, M. and Shin, E.C. "Eccentrically loaded strip foundation on geogrid-reinforced sand", *Geotextiles and Geomembranes*, **24**, pp. 254-259 (2006).
10. Basudhar, P.K., Saha, S. and Deb, K. "Circular

footings resting on geotextile-reinforced sand bed", *Geotextiles and Geomembranes*, **25**(6), pp. 377-384 (2006).

11. El Sawwaf, M. "Behavior of strip footing on geogrid-reinforced sand over a soft clay slope", *Geotextiles and Geomembranes*, **25**, pp. 50-60 (2007).

12. Moghaddas Tafreshi, S.N. and Dawson, A.R. "Comparison of bearing capacity of a strip footing on sand with planar form of geotextile reinforcement", *Geotextiles and Geomembranes*, **28**(1), pp. 72-84 (2010).

13. Yadu, L. and Tripathi, R.K. "Effect of the length of geogrid layers in the bearing capacity ratio of geogrid reinforced granular fill-soft subgrade soil system", *Procedia - Social and Behavioral Sciences*, **104**, pp. 225-234 (2013).

14. Omar, M.T., Das, B.M., Puri, V.K. and Yen, S.C. "Ultimate bearing capacity of shallow foundations on sand with geogrid reinforcement", *Canadian Geotechnical Journal*, **30**, pp. 545-549 (1993).

15. Adams, M.T. and Collin, J.G. "Large model spread footing load tests on geosynthetic reinforced soil foundations", *Journal of Geotechnical and Geoenvironmental Engineering, ASCE*, **123**(9), pp. 818-827 (1997).

16. Kumar, A. and Saran, S. "Closely spaced footings on geogrid-reinforced sand", *Journal of Geotechnical and Geoenvironmental Engineering, ASCE*, **129**(7), pp. 660-664 (2003).

17. Bera, A.K., Ghosh, A. and Ghosh, A.M. "Regression model for bearing capacity of a square footing on reinforced pond ash", *Geotextiles and Geomembranes*, **23**, pp. 261-285 (2005).

18. Ghosh, A., Ghosh, A.M. and Bera, A.K. "Bearing capacity of square footing on pond ash reinforced with jute-geotextile", *Geotextiles and Geomembranes*, **23**, pp. 144-173 (2005).

19. Kumar, A. and Walia, B.S. "Bearing capacity of square footings on reinforced layered soil", *Geotechnical and Geological Engineering*, **24**, pp. 1001-1008 (2006).

20. Chung, W. and Cascante, G. "Experimental and numerical study of soil-reinforcement effects on the low-strain stiffness and bearing capacity of shallow foundations", *Geotechnical and Geological Engineering*, **25**, pp. 265-281 (2007).

21. Ghazavi, M. and Lavasan, A.A. "Interference effect of shallow foundations constructed on sand reinforced with geosynthetics", *Geotextiles and Geomembranes*, **26**, pp. 404-415 (2008).

22. Sharma, R., Chen, Q., Abu-Farsakh, M. and Yoon, S. "Analytical modeling of geogrid reinforced soil foundation", *Geotextiles and Geomembranes*, **27**, pp. 63-72 (2009).

23. Latha, G.M. and Somwanshi, A. "Effect of reinforcement form on the bearing capacity of square footings on sand", *Geotextiles and Geomembranes*, **27**, pp. 409-422 (2009).

24. Latha, G.M. and Somwanshi, A. "Bearing capacity of square footings on geosynthetic reinforced sand", *Geotextiles and Geomembranes*, **27**, pp. 281-294 (2009).

25. Bai, X., Huang, X. and Zhang, W. "Bearing capacity of square footing supported by a geobelt-reinforced crushed stone cushion on soft soil", *Geotextiles and Geomembranes*, **38**, pp. 37-42 (2013).

26. Demir, A., Laman, M., Yildiz, A. and Ornek, M. "Large scale field tests on geogrid-reinforced granular fill underlain by clay soil", *Geotextiles and Geomembranes*, **38**, pp. 1-15 (2013).

27. Chia-Nan Liu, C., Yang, K. and Nguyen, M.D. "Behavior of geogridereinforced sand and effect of reinforcement anchorage in large-scale plane strain compression", *Geotextiles and Geomembranes*, **42**, pp. 472-493 (2014).

28. Abu-Farsakha, M., Chen, Q. and Sharma, R. "An experimental evaluation of the behavior of footings on geosynthetic-reinforced sand", *Soils and Foundations*, **53**(2), pp. 335-348 (2013).

29. Liu, C. and Evett, J.B., *Soil Properties; Testing, Measurement, and Evaluation*, 4th Ed., Prentice Hall (2000).

30. Abdrabbo, F.M., Gaaver, K.E. and Elwakil, A.Z. "Behavior of square footings on single reinforced soil", *Geotechnical Special Publication*, **124**, pp. 1015-1026 (2004).

31. Lutenegger, A.J. and Adams, M.T. "Bearing capacity of footings on compacted sand", *Proceedings of the 4th International Conference on Case Histories in Geotechnical Engineering*, pp. 1216-1224 (1998).

32. Das, B.M. and Omar, M.T. "The effects of foundation width on model tests for the bearing capacity of sand with geogrid reinforcement", *Geotechnical and Geological Engineering*, **12**, pp. 133-141 (1994).

Biographies

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