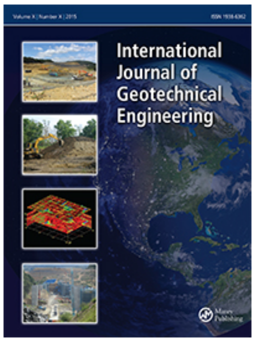

Taylor & Francis
Taylor & Francis Group

International Journal of Geotechnical Engineering

ISSN: 1938-6362 (Print) 1939-7879 (Online) Journal homepage: http://www.tandfonline.com/loi/yjge20

On the behaviour of shallow foundations constructed on reinforced soil slope – a numerical analysis

Hamed Javdanian

To cite this article: Hamed Javdanian (2017): On the behaviour of shallow foundations constructed on reinforced soil slope – a numerical analysis, International Journal of Geotechnical Engineering, DOI: 10.1080/19386362.2017.1416971

To link to this article: https://doi.org/10.1080/19386362.2017.1416971

Published online: 26 Dec 2017.

INTERNATIONAL JOURNAL OF GEOTECHNICAL ENGINEERING, 2017
https://doi.org/10.1080/19386362.2017.1416971

Taylor & Francis
Taylor & Francis Group

On the behaviour of shallow foundations constructed on reinforced soil slope – a numerical analysis

Hamed Javdanian

Department of Civil Engineering, Shahrekord University, Shahrekord, Iran

ABSTRACT

The bearing capacity of foundations is one of the interesting subjects in geotechnical engineering. In many cases, constructing foundations on natural or artificial soil slopes to develop the infrastructures is controversial. The construction of foundations on slopes can significantly affect the bearing capacity and slope stability. Soil stabilisation by polymer reinforcements is a modern method employed in various projects to prevent the failure of soil slopes and to improve the bearing capacity of foundations, subsequently. This paper aims to evaluate the bearing capacity of shallow strip foundations constructed on geosynthetic reinforced sand slope using a finite difference programme, FLAC. The effects of geometrical and resistivity parameters of reinforcements layers was investigated for determining the optimal values to achieve maximum bearing capacity. Furthermore, the effects of strength properties of sand embankment, foundation position and slope angle on the behaviour of strip foundation rested on reinforced soil slope were investigated. The results indicated that the bearing capacity of shallow foundations remarkably increased using geosynthetic reinforcement layers.

ARTICLE HISTORY
Received 28 July 2017
Accepted 10 December 2017

KEYWORDS
Shallow foundation; geosynthetic; soil slope; bearing capacity; FLAC

1. Introduction

Reinforcing soil by geosynthetics is one of the modern soil improvement techniques. During recent years, numerous studies have been carried out on the behaviour of reinforced sand (e.g. Marandi and Javdanian 2012; Javdanian et al. 2012a, 2012b; Ziaie-Moayed and Kamalzare 2015; Prasad et al. 2016; Oliaei and Kouzegaran 2017; Badakhshan and Noorzad 2017; Makkar et al. 2017a, 2017b; Mamatha and Dinesh 2017; Abu-Farsakh et al. 2017; Ardah et al. 2017; Saghebfar et al. 2017a) and reinforced clay (e.g. Otani et al. 1998; Thallak et al. 2007; Park and Lee 2010; Biswas et al. 2015; Javdanian 2017) soils. The results showed an improvement in the bearing capacity and the settlement of shallow foundations on geosynthetic reinforced soils (Javdanian et al. 2012c; Cicek et al. 2015; Rashidian et al. 2016; Javdanian and Bahrami 2016). It was also highlighted in a comprehensive study conducted by Das and co-workers (Shukla et al. 2009, 2011; Das 2016) on the role of geogrid, as one of the most widely used geosynthetics, in the bearing capacity improvement of soils.

Given the growing urban areas, construction in the vicinity of slopes has become inevitable which may cause numerous problems for geotechnical engineers. Construction projects, constructing roads, bridge abutments and in urban areas with insufficient space have to be carried out in mountainous areas (Javdanian and Shojaee 2017). Therefore, building foundations on the soil slopes is inevitable in such cases. On the other hand, irreparable damages have occurred in many cases due to incorrect assessment of bearing capacity of foundations and soil slope stability. Hence, researchers have been studying the behaviour of reinforced soil slopes through analytical (Sawicki and Lesniewska 1991; Zhao 1996; Michalowsk 1997; Zornberg et al. 1998a, 1998b) and laboratory (El Sawwaf 2007; Choudhary et al. 2010; El Sawwaf and Nazir 2012; Saghebfar et al. 2017b) studies.

Laboratory studies of Yoo (2001) on the bearing capacity of strip foundations rested on reinforced sand slopes indicated that the arrangement of reinforcements significantly affects the performance of reinforced soil–foundation system. Alamshahi and Hataf (2009) explored the behaviour of reinforced soil slopes using experimental study and finite element analysis. Their results demonstrate an increase in the bearing capacity of foundation located on a soil slope stabilised by various reinforcements.

Despite extensive studies on the behaviour of geosynthetic reinforced soils, any economic design and safe performance of substructure requires an in-depth investigating bearing capacity of foundations constructed on reinforced soil slopes under various conditions. Therefore, this research focuses on the bearing capacity of shallow strip foundations rested on geogrid-reinforced sand slopes through finite difference numerical analysis. The effects of reinforcement's geometric parameters, the effects of strength parameters of sand embankment, foundation position

CONTACT Hamed Javdanian javdanian@eng.sku.ac.ir

and slope angle on the behaviour of shallow strip foundation on reinforced slopes were investigated.

2. Numerical modelling

In this research, the finite difference (FD) programme, FLAC^{2D} (Fast Lagrangian Analysis of Continua) (Itasca 2011), was applied for modelling shallow foundation rested on geogrid-reinforced and unreinforced soil slope. The FD modelling was conducted to determine ultimate carrying loads (i.e. bearing capacity) of shallow strip foundation rested on soil slope stabilised with geogrid reinforcement layers. Many researchers have employed the FD programme of FLAC for investigation of the stress–strain behaviour of reinforced soil structure (e.g. Deb et al. 2007; Zhao and Wang 2008; El-Emam et al. 2012; Yu et al. 2015; Oliaei and Kouzegaran 2017; Benmebarek et al. 2017).

Figure 1 depicts the model configuration of foundation constructed on geogrid-reinforced soil slope. In this figure, *B*, *e*, *β*, *L*, *u*, *z*, *N* and *d* stand for width of the shallow strip foundation, distance of foundation to the slope crest, soil slope angle, width of the geogrid reinforcement layer, depth of the first geogrid layer from the foundation bottom, vertical spacing of reinforcement layers, number of reinforcement layers and depth of reinforced soil, respectively. The boundary conditions of reinforced soil slope are also demonstrated in Figure 1. The movement of the vertical boundaries is fixed in the horizontal direction and the bottom of the model is fixed in all directions. To eliminate the boundary effect on the assessment of ultimate carrying load, the boundaries of the FD models is considered far from the foundation (Figure 1).

The embankment was modelled as sandy soil and the Mohr–Coulomb failure criterion was applied for modelling soil behaviour. Geogrid reinforcement layers were modelled as linear elastic cable elements. These elements have tensile strength and no compression and flexural resistance. In order to simulation of soil-geogrid sliding (Bergado et al. 1993) the interface elements (Bergado and Teerawattanasuk 2008) was utilised. The properties of sandy soil, geogrid reinforcement, and interface elements utilised in the finite difference (FD) based modelling with FLAC are presented in Table 1. It is noted that, the foundation width (*B*), slope angle (*β*), and foundation distance to slope crest (*e*) were considered equal to 1.5 m, 35° and 1.5 m, respectively.

The ultimate bearing capacity (q_u) of foundations in FD numerical models was determined using load-displacement curves. The q_u was defined as the pressure corresponding to the settlement value equal to 0.1*B*. This criterion was utilised by many researchers to characterise ultimate bearing capacity of shallow and also deep full-scale foundations (e.g. Reese and O'Neill 1988; Ghionna et al. 1994; Amar et al. 1994; Ghazavi and Lavasan 2008). The improvement in ultimate bearing capacity of foundation due to reinforcement inclusion is quantified using the dimensionless parameter 'Bearing Capacity Ratio (BCR)' as Equation (1):

$$BCR = \frac{q_{u\text{-}reinforced}}{q_{u\text{-}unreinforced}} \tag{1}$$

where, $q_{u\text{-}reinforced}$ is the ultimate bearing capacity of foundation located on reinforced soil slope and $q_{u\text{-}unreinforced}$ is the ultimate bearing capacity of foundation located on unreinforced soil slope.

2.1. Model verification

In order to verify the validity of FD-based numerical models, the results of FLAC 2D modelling were compared with the laboratory results. For this purpose, the results of laboratory tests on foundations rested on reinforced and unreinforced soils, foundations rested on reinforced soil slope, and field experiments on large-scale foundations were used. The dimensions and specifications of the physical model were simulated and the results of the numerical method were compared with the experimental results.

2.1.1. Foundations on unreinforced/reinforced sand

Boushehrian and Hataf (2003) studied behaviour of circular model foundation on geogrid reinforced sand using an experimental programme. In their experiments, a tank with a diameter of 1 m and height of 1 m, as well as sandy soil with an internal friction angle of φ = 38° and relative density of D_r = 45% were utilised. The model involved a foundation with a diameter of 15 cm and geogrid reinforcement with a tensile strength of 28 kN/m. The pressure-settlement curves obtained from laboratory tests and modelling by FLAC under unreinforced and geogrid-reinforced conditions have been compared in Figure 2(a). Furthermore, Figure 2(b) shows the variations of bearing

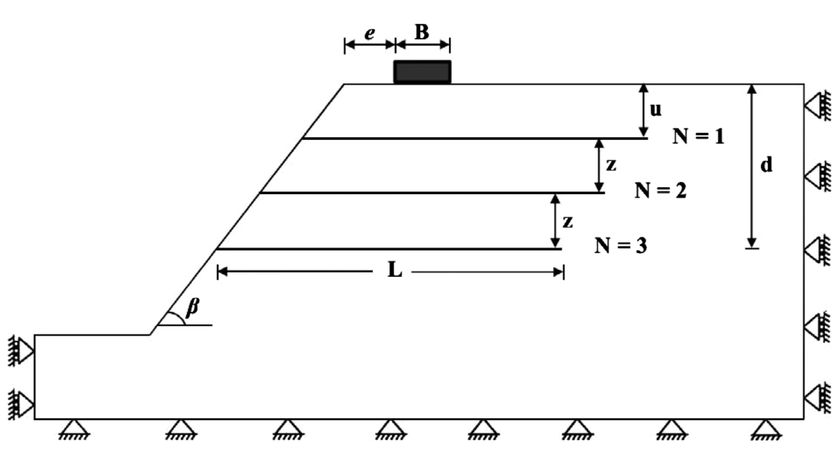

Figure 1. Geometrical parameters for model of foundation constructed on geogrid-reinforced soil slope.

Table 1. Properties of sandy soil, geogrid-reinforcement layers and interface elements in numerical modelling.

Sandy soil properties	
Unit weight, γ (kN/m^3)	18
Elastic modulus, *E* (kPa)	35,000
Shear modulus, *G* (kPa)	12,500
Cohesion, *c* (kPa)	1
Friction angle, φ (deg.)	37
Dilation angle, ψ (deg.)	7
Poisson's ratio, *v*	0.33
Reinforcement property	
Tensile strength, *EA* (kN)	100
Interface properties	
Friction angle, δ (deg.)	33
Cohesion, *c'* (kPa)	0.1

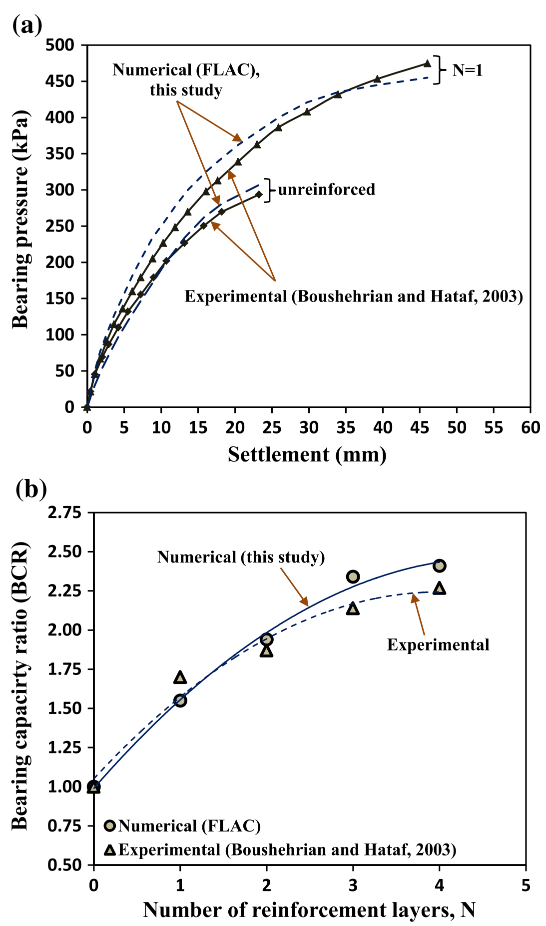

Figure 2. Verification for foundation on reinforced and unreinforced sand, (a) carrying capacity, (b) variation of BCR with *N*.

capacity ratio (BCR) against the number of geogrid reinforcing layers. There is satisfactory agreement between numerical and experimental results.

2.1.2. Foundations on unreinforced/reinforced sand slope

Alamshahi and Hataf (2009) investigated the behaviour of strip foundations located on reinforced soil slopes through laboratory studies. In their experiments, a tank with dimensions of 0.6 × 0.5 × 1.3 m and a strip foundation of 50 × 10 cm were used. The slope had an angle of 32˚. They employed CE131 geogrid with a tensile strength of 5.8 kN/m to reinforce the soil slope. The sandy soil had a relative density of 70%, unit weight of 16.9 kN/m^3 and friction angle of 38˚. The results of laboratory studies by Alamshahi and Hataf (2009) and FLAC modelling in unreinforced condition and reinforced with a geogrid layer have been shown in Figure 3.

2.1.3. Large-scaled foundation on unreinforced soil

In order to verify the numerical analysis under full scale condition, the field test results of loaded circular foundation reported by Consoli et al. (1998) was used. The field test was conducted on rigid steel plate with diameter of 60 cm. The soil layer where loading test was carried out is classified as low plasticity clay (CL) according to the Unified Soil Classification System (USCS) (Consoli et al. 1998). Also, the soil deposit had an average unit weight of 17.7–18.2kN/m^3, friction angle of $\varphi = 26°$, and a cohesion of 17 kPa. Figure 4 shows the measured and numerical evaluation of load-carrying characteristics of foundation. The numerical predictions obtained in this research seem reasonable and agree well with the measured (experimental and field) results.

3. Results and discussions

3.1. Geometrical and strength parameters of reinforcement layers

Reinforcement element is one of the main components of any reinforced soil slope and reinforced earth structure. Therefore, their characteristics affect the behaviour of foundations constructed on reinforced soil slopes. The behaviour and performance of reinforced soil foundation are substantially affected by geometric characteristics of reinforcements including distance between the first reinforcement layer and the foundation bottom (u), vertical distance between the layers (z), reinforcement layer width (b), number of layers (N), total reinforced depth (d) and the reinforcement's resistance parameter (i.e. tensile strength of geogrid). The following sections discuss the effect of each parameter on the behaviour of strip foundations rested on reinforced soil slopes.

3.1.1. Effect of depth of the first reinforcement layer

Figure 5 illustrates the variations of bearing capacity ratio (BCR) against the depth ratio of the first reinforcement layer (u/B) for single- and double-layer reinforcements. The load transfer mechanism was investigated using FD analysis. If the reinforcement layer placed near the foundation, the soil mass above the first geogrid layer becomes extremely thin and unable to produce enough resistance to prevent pulled out reinforcements. Therefore, it can be predicted that the reinforcements may be ruptured in practical cases due to failure wedge induced pressure underneath the foundation. Moreover, there will be small normal force applied on the geogrid surface as one of the factors contributing to proper operation of reinforcement layers. In reality, at low values of depth ratio, the lack of confining pressure for the first reinforcement layer results in its improper operation. For $(u/B)_{opt} = 0.3$, the reinforcement is able to distribute load across a wider surface below the foundation and can produce desirable pull-out resistance under extreme overhead pressure. In this case, the best load transfer mechanism can be adopted owing due to the involvement of reinforcements.

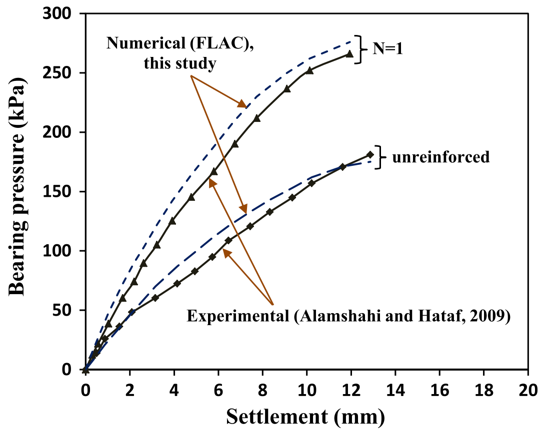

Figure 3. Verification for foundation on unreinforced and reinforced sand slope.

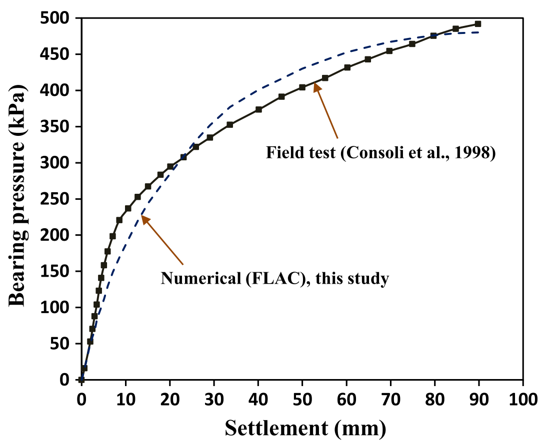

Figure 4. Verification of large-scale foundation on unreinforced soil.

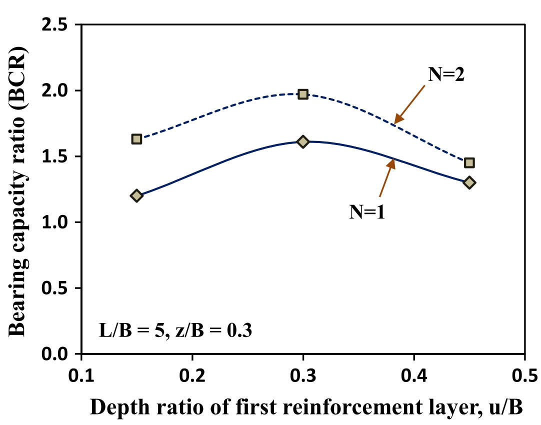

Figure 5. Variation of BCR with the depth ratio of first reinforcement layer.

Where the first reinforcement layer is placed at a great depth, the plastic deformation zone under the reinforcing layer does not spread and a failure zone produces above the layer. Therefore, it is ineffective to place the reinforcement under the optimum depth (which results in maximum bearing capacity), since the failure wedge lies on top of the reinforcement layer. For two reinforcement layers at $u/B = 0.3$, the bearing capacity ratio (BCR) significantly increases due to adjacency of the second geogrid layer to the failure zone (Figure 5).

3.1.2. Effect of width of reinforcement layer

Figure 6 shows the bearing capacity ratio versus the variations in reinforcement width ratio (L/B) for single-layer reinforcement ($N = 1$) condition. The results indicated that BCR generally increases at higher reinforcement width ratios. At greater reinforcement lengths, the frictional force increases as a result of applying normal forces per unit of reinforcement length, which in turn improves the reinforcement's frictional resistance. In fact, a part of geogrid layer placed outside the failure zone is supposed to produce sufficient frictional resistance against pull-out. Improvement of bearing capacity continues up to $(L/B)_{opt} = 5$ and beyond it remains approximately constant. The reason behind increased bearing capacity at greater L/B ratio is the delay in geogrid slip. At lower L/B ratios, the geogrid slip prevents the bearing capacity from being maximised. On the other hand, there is an increase in bearing capacity even at small L/B ratios. In fact, the presence of reinforcements in the soil is enough to increase the bearing capacity, but it is crucial to lengthen the reinforcements to enhance the efficiency of soil-reinforcement system.

3.1.3. Effect of vertical spacing of reinforcement layers

The results indicated that there is an optimal value for vertical distance between the reinforcement layers. Figure 7 illustrates the variations in BCR versus variations in the vertical distance ratio between reinforcement layers (z/B) for $N = 1$ and 2 conditions. As shown in this figure, $(z/B)_{opt} = 0.3$ has been obtained. The effect of vertical distance between the reinforcement layers on the bearing capacity can be associated with placement of next layers in the failure zone. By proper arrangement and placement in the failure zone, these layers modify the distribution of stresses.

3.1.4. Effect of number of reinforcement layers

This section deals with the effect of the number of reinforcement layers (N) on the bearing capacity ratio (BCR). The results of FD analysis using FLAC programme demonstrated that the number of reinforced layers has the greatest effect on bearing capacity compared to other parameters. Figure 8 shows the variations in bearing capacity ratio by changing the number of reinforcement layers. The analyses carried out with the depth ratio of the first reinforcement layer and the distance between reinforcement layers of $z/B = u/B = 0.3$.

Based on the results (Figure 8), the BCR increased with increasing of number of reinforcement layers up to $N = 3$ (proportional to the reinforced depth) and more than three layers the increasing value of BCR was insignificant. In fact, at $N = 4$, the fourth layer is located at a great depth to the foundation bottom, and the tensile strength of this reinforcement has not been much triggered by the involvement of above three reinforcement layers. Hence, the fourth layer has no significant effect on improvement of bearing capacity.

3.1.5. Effect of reinforced depth

Figure 9 shows the effect of reinforcement depth on the bearing capacity of foundations located on geogrid-reinforced soil slopes. The overall reinforcement depth can be defined as follows:

$$d = u + (N - 1)z \qquad (2)$$

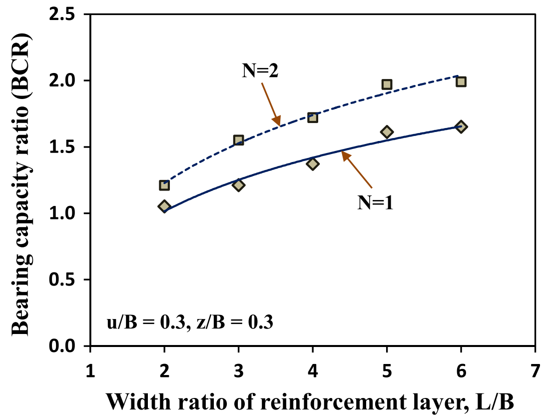

Figure 6. Variation of BCR with the width ratio of reinforcement layer.

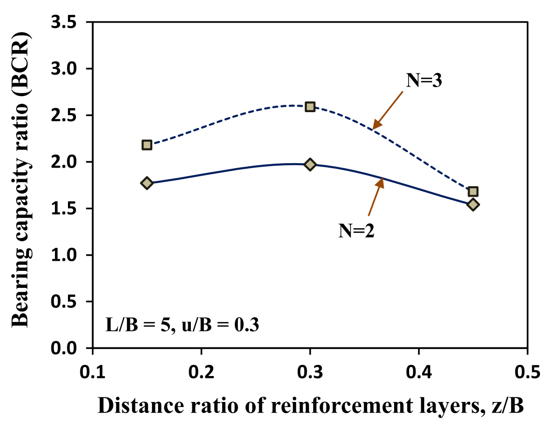

Figure 7. Variation of BCR with the vertical distance ratio of reinforcement layers.

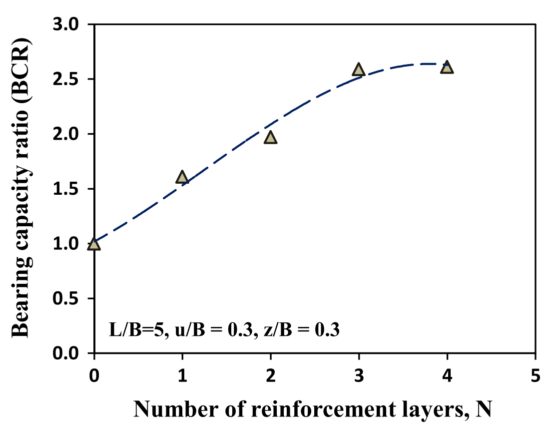

Figure 8. Variation of BCR with the number of reinforcement layers.

Figure 9 illustrates variation of BCR against the reinforced depth ratio (d/B) for the number of reinforcement layers equal to $N = 1, 2, 3$ and 4. Using Equation (2), the corresponding reinforcement depths are $d = 0.3, 0.6, 0.9$ and 1.2. In the Figure 9, based on the results of the previous sections, optimal geometric location of reinforcement layers were assumed equal to $u/B = z/B = 0.3$. According to the analyses, the reinforced depth (d) beyond $N = 3$ does not have a significant effect on improvement of bearing capacity. Hence, the placement of reinforcements at great depth will not improve the bearing capacity of foundation.

3.1.6. Effect of tensile strength of reinforcement layers

Figure 10 shows the variations of bearing capacity ratio (BCR) with reinforcement's tensile strength (EA) for number of layers equal to $N = 1$, 2 and 3. As shown in this figure, an increase in reinforcement's tensile strength up to approximately 100 kN/m leads to higher bearing capacity of reinforced soil slope. Beyond that level, there is no significant variation in the bearing capacity ratio. Therefore, it can be inferred that application of reinforcements with maximum design stress of 100 kN/m is desirable and safe in practical purposes. This suggests that increase in the strength of reinforcements beyond a certain level cannot improve the bearing capacity. It is best to achieve the desired bearing capacity by appropriate arrangement of reinforcement layers.

3.2. Strength properties of reinforced sand embankment

In a reinforced soil structure, embankment occupies the largest space in terms of volume. Due to interactions with its internal reinforcements, a reinforced embankment affects the shear stresses created in the reinforcement as well as the pull-out resistance of geogrid-reinforcements layers. In reinforced soil foundations, granular soils are used to maintain durability, high shear strength, and proper soil-reinforcement interaction.

3.2.1. Effects of internal friction angle of reinforced sand

The effect of internal friction angle (φ) on the bearing capacity of shallow strip foundations rested on reinforced soil slopes at one, two, and three reinforcement layers was investigated. The internal friction angle of sandy soil was changed from 25 to 45 degrees to evaluate its effect on the bearing capacity ratio (BCR). Figure 11 shows the BCR variations versus the friction angle of sandy soil ($\varphi = 25^\circ, 30^\circ, 37^\circ, 45^\circ$). As shown in this figure, the bearing capacity ratio decreases with increasing of internal friction angle of sandy embankment. This implies that improvement in bearing capacity of foundation decreased due to placement of geogrid-reinforcement layers at greater soil friction angle. This can be associated with dramatic increase in unreinforced soil bearing capacity at greater soil friction angle.

3.2.2. Effects of elasticity module of sandy soil

The effect of elastic modulus (E) of embankment on the bearing capacity of shallow strip foundation over reinforced soil slope was examined. In this regard, the modulus of elasticity varied from $E = 10$ to 70 MPa. Figure 12 illustrates the variations of tensile forces created in the reinforcement against the elasticity modulus of sandy soil for single-layer reinforcement. At greater elastic modulus and lower sand deformability, the strain and subsequently the tensile force reduced in the reinforcement (Figure 12). In general, the load in the reinforced soil system consists of two parts, which is carried by soil and reinforcement. Increasing elasticity modulus (E) or internal friction angle (φ) of the sandy soil lead to increase the soil's share in carrying load and subsequently decrease the tensile force the reinforcements.

3.3. Effect of foundation distance to the slope crest

This section explores the effect of foundation distance to the slope crest (e) on the bearing capacity of foundation located on one, two and three layers of geogrid-reinforced slope. The

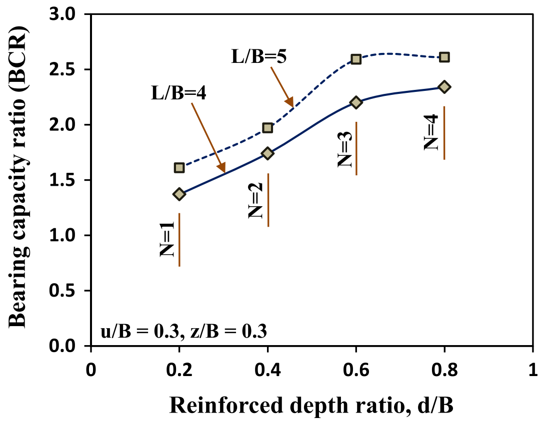

Figure 9. Variation of BCR with the reinforced depth ratio.

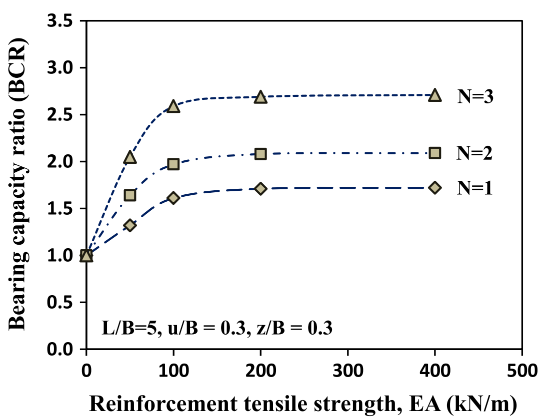

Figure 10. Variation of BCR with the tensile strength of reinforcement layer.

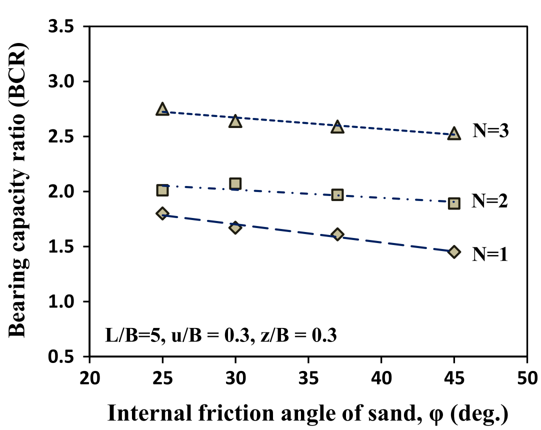

Figure 11. Variation of BCR with the internal friction angle of reinforced sand slope.

results of numerical modelling indicated that an increase in the foundation distance ratio from the top of the slope (*e*/*B*) leads to lower BCR (Figure 13). In fact, when the foundation lies near the slope, the reinforcement layers more effectively increase the bearing capacity. At distances beyond 2*B*, the behaviour of the slope-adjacent foundation becomes similar to that of a foundation on flat surface.

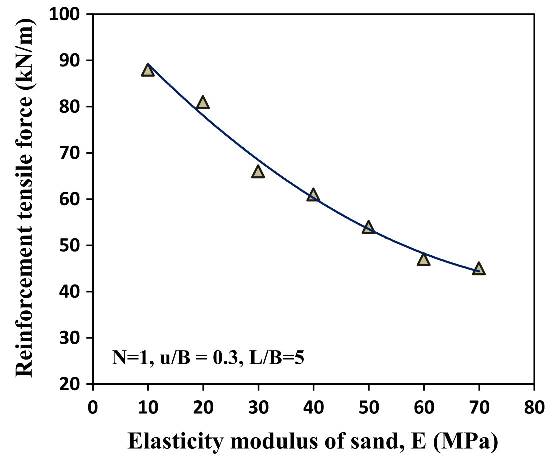

Figure 12. Variation of BCR with the elasticity modulus of sand slope.

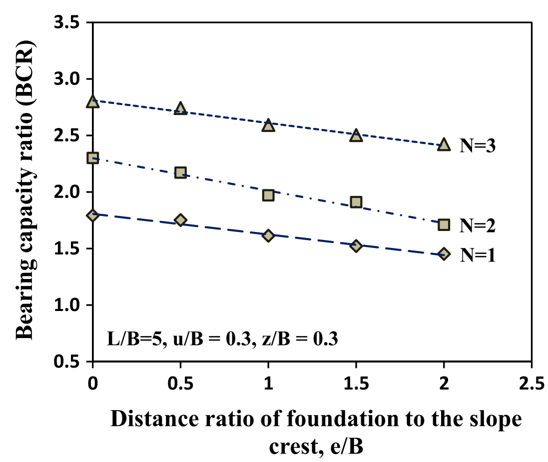

Figure 13. Variation of BCR with the distance ratio of foundation to the slope crest.

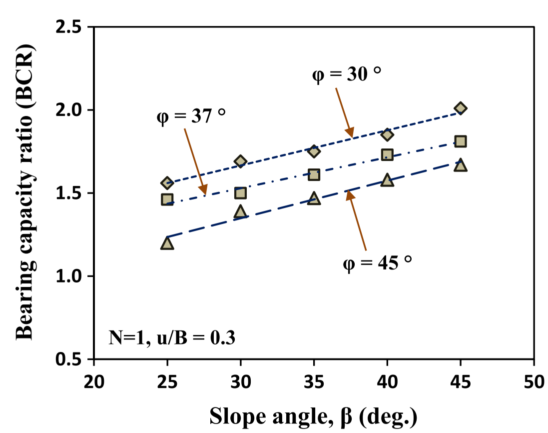

Figure 14. Variation of BCR with the soil slope angle.

3.4. Effect of soil slope angle

An increase in the soil slope angle (β) leads to lower bearing capacity, which is improved by application of geogrid-reinforcement layers (Figure 14). The results indicated that geosynthetic reinforcements on steeper slopes provide one of the most economical methods of soil stabilisation, which can remarkably enhance the bearing capacity of foundations constructed on steep slopes.

4. Conclusions

Given the growing urban areas, construction in the vicinity of slopes has become inevitable. This has given rise to numerous problems for engineers. The proper operation of foundations rested on soil slopes has a great importance. Soil rehabilitation by polymeric reinforcements such as geogrid layers has provided a new technique for stabilising soil slopes. This study focuses on the behaviour of shallow strip foundations constructed on geogrid-reinforced sand slopes. The effects of reinforcement arrangement, foundation position, soil slope, resistance properties of geogrid and sand embankment on the bearing capacity of strip foundation were investigated using a FD programme, FLAC^{2D}. Based on the numerical analysis conducted in this study, the following main results were obtained:

- Reinforcement layers cause increase in the bearing capacity of foundations constructed on reinforced soil slopes due to increase in the shear strength of soil and improvement of sandy soil behaviour in tension, subsequently.
- The optimum depth of reinforcement was obtained to be approximately $(u/B)_{opt} = 0.3$. The placement of reinforcement at low depths reduces the soil mass on top of the geogrid, thus hindering an ideal frictional resistance to prevent the pull-out of reinforcements. The reinforcement position in a depth exceeding $u/B \approx 0.45$ results in formation of a failure wedge above the reinforcement. Therefore, the reinforcement will no longer be effective in improving the bearing capacity of foundations on soil slopes.
- The optimum width of reinforcement layer was obtained at $(L/B)_{opt} = 5$ and greater amounts do not have significant effect on the bearing capacity of foundation over reinforced soil slopes. In fact, only the shear strength of a part of reinforcement in the failure zone underneath the foundation is mobilised. The excess length beyond this zone will be necessary as an anchorage to achieve the reinforcement pull-out resistance. Therefore, the reinforcement width is equal to the total shear zone and anchorage of two sides. Any additional width beyond this value is ineffective.
- The optimum value of the vertical distance ratio between the reinforcement layers was obtained at $(z/B)_{opt} = 0.3$.
- An increase in the number of reinforcement layers up to $N = 3$ will improve the bearing capacity of foundations. Beyond this, however, there is no significant effect on increasing the bearing capacity of foundations constructed on reinforced soil slopes.
- The results of numerical modelling indicated that application of geogrids with maximum tensile strength of $EA = 100$ kN/m will be suitable in practical projects.
- The increase in internal friction angle of sand embankment leads to lower BCR. This can be associated with significant increase in unreinforced soil bearing capacity at greater soil friction angle.
- An increase in the elastic modulus of sandy soil leads to lower sandy soil's deformability. Hence, the strain created and subsequently the tensile force in the reinforcement will reduce.
- Increase in the foundation distance from the slope crest (e/B) leads to lower BCR. When the foundation locates near the slope, the reinforcement layers more effectively increase the bearing capacity.
- Increase in the unreinforced soil slope angle leads to lower bearing capacity of the foundation, thus enhancing the improvement of bearing capacity arising from application of geogrid-reinforcements.

Disclosure statement

No potential conflict of interest was reported by the author.

Funding

This work has been financially supported by the research deputy of Shahrekord University [grant number 95GRN1M39422].

References

Abu-Farsakh, M., M. Saghebfar, A. Ardah, and Q. A. Chen. 2017. "Case Study on Evaluating the Performance of a Geosynthetic Reinforced Soil Integrated Bridge System (GRS-IBS)." *Geotechnical Frontiers*, 12–22.
Alamshahi, S., and N. Hataf. 2009. "Bearing Capacity of Strip Footings on Sand Slopes Reinforced with Geogrid and Grid-Anchor." *Geotextiles and Geomembranes* 27 (3): 217–226.
Amar, S., F. Baguelin, Y. Canepa, and R. Frank. 1994. "Experimental Study of the Settlement of Shallow Foundations." *Vertical and Horizontal Deformations of Foundations and Embankments, ASCE* 2 (40): 1602–1610.
Ardah, A., M. Abu-Farsakh, and G. Voyiadjis. 2017. "Numerical Evaluation of the Performance of a Geosynthetic Reinforced Soil-Integrated Bridge System (GRS-IBS) under Different Loading Conditions." *Geotextiles and Geomembranes* 45 (6): 558–569.
Badakhshan, E., and A. Noorzad. 2017. "Effect of Footing Shape and Load Eccentricity on Behavior of Geosynthetic Reinforced Sand Bed." *Geotextiles and Geomembranes* 45 (2): 58–67.
Benmebarek, S., S. Djeridi, N. Benmebarek, and L. Belounar. 2017. "Improvement of Bearing Capacity of Strip Footing on Reinforced Sand." *International Journal of Geotechnical Engineering* 11: 1–9. doi: 10.1080/19386362.2017.1309136.
Bergado, D. T., and C. Teerawattanasuk. 2008. "2D and 3D Numerical Simulations of Reinforced Embankments on Soft Ground." *Geotextiles and Geomembranes* 26 (1): 39–55.
Bergado, D. T., J. C. Chai, H. O. Abiera, M. C. Alfaro, and A. S. Balasubramaniam. 1993. "Interaction between Cohesive-Frictional Soil and Various Grid Reinforcements." *Geotextiles and Geomembranes* 12 (4): 327–349.
Biswas, A., M. A. Ansari, S. K. Dash, and A. M. Krishna. 2015. "Behavior of Geogrid Reinforced Foundation Systems Supported on Clay Subgrades of Different Strengths." *International Journal of Geosynthetics and Ground Engineering* 1 (3): 20.
Boushehrian, J. H., and N. Hataf. 2003. "Experimental and Numerical Investigation of the Bearing Capacity of Model Circular and Ring Footings on Reinforced Sand." *Journal of Geotextiles and Geomembranes* 21 (4): 241–256.
Choudhary, A. K., J. N. Jha, and K. S. Gill. 2010. "Laboratory Investigation of Bearing Capacity Behaviour of Strip Footing on Reinforced Flyash Slope." *Geotextiles and Geomembranes* 28 (4): 393–402.
Cicek, E., E. Guler, and T. Yetimoglu. 2015. "Effect of Reinforcement Length for Different Geosynthetic Reinforcements on Strip Footing on Sand Soil." *Soils and Foundations* 55 (4): 661–677.
Consoli, N. C., F. Schnaid, and J. Ilititsky. 1998. "Interpretation of Plate Load Tests on Residual Soil Site." *Journal of Geotechnical and Geoenvironmental Engineering* 124 (9): 857–867.
Das, B. M. 2016. "Use of Geogrid in the Construction of Railroads." *Innovative Infrastructure Solutions* 1 (1): 1–12.

Deb, K., N. Sivakugan, S. Chandra, and P. K. Basudhar. 2007. "Numerical Analysis of Multi Layer Geosynthetic-Reinforced Granular Bed over Soft Fill." *Geotechnical and Geological Engineering* 25 (6): 639–646.

El Sawwaf, M. A. 2007. "Behavior of Strip Footing on Geogrid-Reinforced Sand over a Soft Clay Slope." *Geotextiles and Geomembranes* 25 (1): 50–60.

El Sawwaf, M. A., and A. K. Nazir. 2012. "Cyclic Settlement Behavior of Strip Footings Resting on Reinforced Layered Sand Slope." *Journal of Advanced Research* 3 (4): 315–324.

El-Emam, M., M. Attom, and Z. Khan. 2012. "Numerical Prediction of Plane Strain Properties of Sandy Soil from Direct Shear Test." *International Journal of Geotechnical Engineering* 6 (1): 79–90.

Ghazavi, M., and A. A. Lavasan. 2008. "Interference Effect of Shallow Foundations Constructed on Sand Reinforced with Geosynthetics." *Geotextiles and Geomembranes* 26 (5): 404–415.

Ghionna, V. N., M. Jamiolkowski, S. Pedroni, and R. Salgado. 1994. "The Tip Displacement of Drilled Shafts in Sand." *Vertical and Horizontal Deformation of Foundations and Embankments, ASCE* 2 (40): 1039–1057.

Itasca. 2011. *FLAC: Fast Lagrangian Analysis of Continua. Version 7.0 [Computer Program]*. Minneapolis, MN: Itasca Consulting Group Inc.

Javdanian, H., A. Haddad, and B. Mehrzad. 2012a. "Interference Effect on Bearing Capacity of Multiple Shallow Foundations Supported by Geosynthetic-Reinforced Sand." In 5th Asian Regional Conference on Geosynthetics, Bangkok, Thailand, December 13.

Javdanian, H., A. Hamedi, and H. Ayoubi. 2012b. "Interference Effect on Bearing Capacity of Shallow Foundations Constructed on Geosynthetic-Reinforced Soil." In 9th International Congress on Civil Engineering, Isfahan, Iran, May 8.

Javdanian, H., A. Haddad, and B. Mehrzad. 2012c. "Experimental and Numerical Investigation of the Bearing Capacity of Adjacent Footings on Reinforced Soil." *Electronic Journal of Geotechnical Engineering* 17: 2597–2617.

Javdanian, H. 2017. "The Effect of Geopolymerization on the Unconfined Compressive Strength of Stabilized Fine-Grained Soils." *International Journal of Engineering-Transactions B: Applications* 30 (11): 1673–1680.

Javdanian, H., and M. Bahrami. 2016. "Review of Load Carrying Capacity of Adjacent Shallow Foundations." In 4th International Congress on Civil Engineering, Architecture and Urban Development, Tehran, Iran, December 27.

Javdanian, H., and M. Shojaee. 2017. "Investigating Behavior of Adjacent Strip Foundations on Stabilized Soil Slopes." In 5th International Congress on Civil Engineering, Architecture and Urban Development, Tehran, Iran, December 26.

Makkar, F. M., S. Chandrakaran, and N. Sankar. 2017a. "Behaviour of Model Square Footing Resting on Sand Reinforced with Three-Dimensional Geogrid." *International Journal of Geosynthetics and Ground Engineering* 3 (1): 3.

Makkar, F. M., S. Chandrakaran, and N. Sankar. 2017b. "Performance of 3-D Geogrid-Reinforced Sand under Direct Shear Mode." *International Journal of Geotechnical Engineering* 11:1–9. doi: 10.1080/19386362.2017.1336297.

Mamatha, K. H., and S. V. Dinesh. 2017. "Performance Evaluation of Geocell-Reinforced Pavements." *International Journal of Geotechnical Engineering* 11: 1–10. doi: 10.1080/19386362.2017.1343988.

Marandi, S. M., and H. Javdanian. 2012. "Laboratory Studies on Bearing Capacity of Strip Interfering Shallow Foundations Supported by Geogrid-Reinforced Sand." *Advanced Materials Research* 472: 1856–1869.

Michalowsk, R. L. 1997. "Stability of Uniformly Reinforced Slopes." *Journal of Geotechnical and Geoenvironmental Engineering* 123 (6): 546–556.

Oliaei, M., and S. Kouzegaran. 2017. "Efficiency of Cellular Geosynthetics for Foundation Reinforcement." *Geotextiles and Geomembranes* 45 (2): 11–22.

Otani, J., H. Ochiai, and K. Yamamoto. 1998. "Bearing Capacity Analysis of Reinforced Foundations on Cohesive Soil." *Geotextiles and Geomembranes* 16 (4): 195–206.

Park, H. I., and S. R. Lee. 2010. "Evaluation of Bearing Capacity for Multi-Layered Clay Deposits with Geosynthetic Reinforcement Using Discrete Element Method." *Marine Georesources and Geotechnology* 28 (4): 363–374.

Prasad, B. D., C. Hariprasad, and B. Umashankar. 2016. "Load-Settlement Response of Square Footing on Geogrid Reinforced Layered Granular Beds." *International Journal of Geosynthetics and Ground Engineering* 2 (4): 36.

Rashidian, V., S. A. Naeini, and M. Mirzakhanlari. 2016. "Laboratory Testing and Numerical Modelling on Bearing Capacity of Geotextile-Reinforced Granular Soils." *International Journal of Geotechnical Engineering* 10:1–11. doi: 10.1080/19386362.2016.1269042.

Reese, L. C., and M. W. O'Neill. 1988. *Drilled Shafts: Design Procedures and Design Methods*. Report No. FHWA-HI-88-042. Washington, DC: Federal Highway Administration, 564.

Saghebfar, M., M. Abu-Farsakh, A. Ardah, Q. Chen, and B. A. Fernandez. 2017a. "Performance Monitoring of Geosynthetic Reinforced Soil Integrated Bridge System (GRS-IBS) in Louisiana." *Geotextiles and Geomembranes* 45 (2): 34–47.

Saghebfar, M., M. Y. Abu-Farsakh, A. Ardah, Q. Chen, and B. A. Fernandez. 2017b. "Full-Scale Testing of Geosynthetic-Reinforced, Soil-Integrated Bridge System." *Transportation Research Record: Journal of the Transportation Research Board* 2656: 40–52.

Sawicki, A., and D. Lesniewska. 1991. "Stability of Fabric Reinforced Cohesive Soil Slopes." *Geotextiles and Geomembranes* 10: 125–146.

Shukla, S., N. Sivakugan, and B. Das. 2009. "Fundamental Concepts of Soil Reinforcement – An Overview." *International Journal of Geotechnical Engineering* 3 (3): 329–342.

Shukla, S., N. Sivakugan, and B. Das. 2011. "A State-of-the-Art Review of Geosynthetic-Reinforced Slopes." *International Journal of Geotechnical Engineering* 5 (1): 17–32.

Thallak, S. G., S. Saride, and S. K. Dash. 2007. "Performance of Surface Footing on Geocell-Reinforced Soft Clay Beds." *Geotechnical and Geological Engineering* 25 (5): 509–524.

Yoo, C. 2001. "Laboratory Investigation of Bearing Capacity Behavior of Strip Footing on Geogrid-Reinforced Sand Slope." *Geotextiles and Geomembranes* 19 (5): 279–298.

Yu, Y., I. P. Damians, and R. J. Bathurst. 2015. "Influence of Choice of FLAC and PLAXIS Interface Models on Reinforced Soil–Structure Interactions." *Computers and Geotechnics* 65: 164–174.

Zhao, A. 1996. "Limit Analysis of Geosynthetic-Reinforced Soil Slopes." *Geosynthetics International* 3 (6): 721–740.

Zhao, L., and J. H. Wang. 2008. "Vertical Bearing Capacity for Ring Footings." *Computers and Geotechnics* 35 (2): 292–304.

Ziaie-Moayed, R., and M. Kamalzare. 2015. "Effect of Moisture on Shear Strength Characteristics of Geosynthetic Reinforcement Subgrade." *Journal of Geotechnical and Transportation Engineering* 1 (1): 13–18.

Zornberg, J. G., N. Sitar, and J. K. Mitchell. 1998a. "Performance of Geosynthetic Reinforced Slopes at Failure." *Journal of Geotechnical and Geoenvironmental Engineering* 124 (8): 670–683.

Zornberg, J. G., N. Sitar, and J. K. Mitchell. 1998b. "Limit Equilibrium as Basis for Design of Geosynthetic Reinforced Slopes." *Journal of Geotechnical and Geoenvironmental Engineering* 124 (8): 684–698.