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A Novel Reinforcement to Improve the Bearing Capacity of Soil: Experimental Investigation

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Abstract

Keywords:

Grid anchor,
strip footing,
reinforced clayey slope,
bearing capacity ratio (BCR),
finite element model.

The paper presents a study of the behavior of model strip footings supported on a reinforced clayey slope with geogrid and grid anchor reinforcements subjected to both monotonic loads. The effect of grid anchor reinforcement was investigated both experimentally. The footing supported on reinforced slope samples were loaded step by step until it is failed. The affecting factors including the vertical spacing between the reinforcements, the number of reinforcement, type of reinforcement, and the location of footing relative to the slope crest were studied. The bearing capacity ratio (BCR), and settlement of the model footing rested on a clayey slope, un-reinforced, and reinforced with geogrid and grid anchor were obtained and compared. The results indicate that, in comparison with the un-reinforced and reinforced slope with geogrid, the inclusion of grid anchor reinforcement in the clayey slope not only significantly increases the BCR of the clayey slope itself but also decreases much the settlements leading to an economic design of the footing. However, the efficiency of the grid anchor systems depends on the properties of the reinforced slope such as the mentioned affecting factors. Based on the test results, good comparison with the experimental outputs, and previous studies demonstrate that the multidisciplinary applications of the present achievement.

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1 Introduction

In the last three decades the use of geosynthetic materials for retaining walls and reinforcing slopes has increased significantly throughout the world. Use of various reinforcement types to improve load-bearing capacity of foundation has been extensively studied by researchers [1-3]. These studies have demonstrated that both the settlement characteristics and ultimate bearing capacity of the foundation can be significantly improved by the inclusion of an appropriate reinforcement system within the fill [4, 5].

In most situations such as foundations constructed on hill slopes and/or foundation of a bridge abutment, the foundations need to be located either on the slope itself or on the top of a slope. When a foundation is constructed on a reinforced slope, the bearing capacity of the foundation will be significantly changed depending upon the reinforcement type with respect to the location of the footing and the slope. The soil–reinforcement interaction mechanism has a decisive importance in the design of reinforced soil structures. Vieira, et al. [6] stated this mechanism depends on the reinforcement characteristics, the soil properties, and the interaction between components (reinforcement and soil). Therefore, one of the very important aspects of geotechnical engineering practice is the improvement of load carrying capacity (here the term bearing capacity ratio, BCR, is used) of such loaded slopes. One of the possible solutions to improve the BCR would be to reinforce the sloped fill with series of more efficient layers of geogrid.

A lot of studies on bearing capacity behaviour of strip footings on a reinforced slope have been investigated in the literature where the studies were conducted with sandy and clayey soil [7-11]. All reported case studies described the successful use of geogrids to reinforce a weak subgrade such as variable soft clay or sandy soil.

In addition, many researchers advocated the conditions which causes optimum improvement in ultimate bearing capacity of a strip footing on a reinforced slope [12, 13]. Tsukada, et al. [14] investigated the use of geogrids for roadway foundation and reported that pressure distributions and settlement response were directly related to the thickness and configuration of the geogrid-reinforced foundation. Omar, et al. [15] reported that, for strip footing on geogrid-reinforced sand, the effective reinforcement length was around 8.0B. Yoo (2001) used finite element analysis (GEOFE 2D) and small-scale laboratory tests to study bearing capacity of a strip footing on a reinforced sandy slope. He recommended that for optimum improvement in ultimate bearing capacity of strip footing on a reinforced sandy slope the L/B ratio (L_r = length of reinforcement, B = footing width) should be in the range of 5.5–7.0. The author further suggested that each geogrid layer be extended approximately 3.0B beyond the potential failure surface of unreinforced slope [12]. Ghosh and Kumar [16] reported that maximum improvement in bearing capacity of strip footing rested on a reinforced slope is obtained when length of reinforcement (L_r) becomes equal to seven times footing width (B). Sommers and Viswanadham [17] conducted a series of centrifuge model tests. They observed that when a footing rested on a reinforced slope is subjected to vertical loading the vertical spacing between reinforcement layers has extensive impact on the stability of reinforced slope. Also, the less vertical distance between reinforcement layers allows the slope to tolerate much greater loads. It is also suggested that reinforcing the subsoil after replacing the top layer of soil with a well-graded soil is beneficial as the mobilization of soil-reinforcement frictional resistance will increase [18]. El Sawwaf [19] reported that to derive maximum improvement in bearing capacity, the vertical spacing between reinforcements should be 0.5B. Otani, et al. [10] investigated the behavior of strip footing rested on reinforced clayey slope. Settlement was reduced with the increase in reinforcement stiffness, size, and number of layers.

Mahmoud and Abdrabbo [20] investigated on bearing capacity of strip footing resting on reinforced sand subgrades experimentally. They have reinforced a layer of sand subgrades utilizing vertical non-extensible reinforcement. The test results indicate that this type of reinforcement increases the bearing capacity of subgrades and modifies the load-displacement behaviour of the footing.

The load carrying capacity of a footing has been found to increase especially when the changes in the reinforcement characteristics are provided. Anubhav and Basudhar [1] modeled a surface strip footings resting on double-faced wrap-around vertical reinforced soil walls numerically. They constructed a small-scale model geosynthetic-reinforced, double-faced, vertical soil walls with sand backfill and wrapped facing using varying spacing, overlap length of reinforcement layers and footing widths. The objective was to evaluate their effects on its load-deformation behavior. On the other hand, a plane-strain finite element simulation of the model walls, using commercially available Plaxis software, was performed to predict their behavior under strip loading. The predicted bearing capacity of the footing resting on these walls and the horizontal displacement of the wall face compared and showed reasonable agreement with the experimental data.

Mosallanezhad, et al. [21] studied on the Three dimensional bearing capacity analysis of granular soils, reinforced with innovative grid-anchor system. Results show that the Grid-Anchor system of reinforcing can increase the bearing capacity up to 2.74 times greater than that for ordinary geogrid and 4.43 times greater than for non-reinforced sand.

Tafreshi, et al. [22] investigated on a shallow strip footing on geogrid-reinforced sand bed above a void experimentally. The results demonstrate that the bearing pressure and footing settlement significantly improved as the three parameters namely; the void embedment depth, relative density of the replaced sand, and, the number of reinforcement layers below the footing base were increased due to arching of the soil mass overlying the void. They also concluded that with unreinforced sand, the undesirable structural effects of the void can be eliminated only by using sand with a relative density of 72% for a void embedded at a depth of around 3.5-4 times the void's diameter (D). Alamshahi and Hataf [23] studied the bearing capacity of strip footings on sand slopes reinforced with geogrid and grid-anchor. They have performed both experimental and numerical models. They used finite elements software PLAXIS 8.0 to study the bearing capacity of a strip footing having width of 10 cm near the slope. They showed that the effect of bearing capacity by comparing grid anchor with geogrid as reinforcements is significant. They observed that the critical values for u/b, h/b, d/b, and N (the mentioned variables are discussed later) were 0.75, 0.75, 1.5, and 2, respectively. Mosallanezhad, et al. [24] introduced a novel strip-anchor for pull-out resistance in cohesionless soils. A total of 55 pull-out tests were performed to evaluate the pull-out resistance and optimum geometry of the new system. Test results showed that the use of strip anchors increased the ultimate pull-out resistance under surcharge pressures of 50, 100, 120 and 150 kPa by factors of 7.4, 4.95, 4.3 and 4.3, respectively, in comparison with conventional strips.

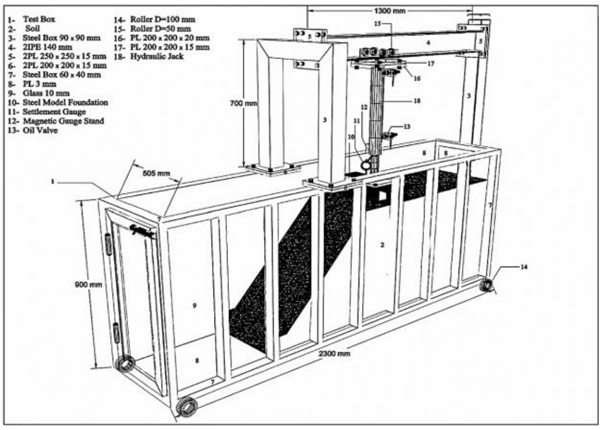
The main objective of present research is to evaluate both experimentally and numerically the increase in the bearing capacity of strip footing rested on a clayey reinforced slope with grid anchor. It is also important to find the optimum values for the design of reinforced slope with the grid anchor systems such as u, h, and N.

2 Material and Methods

2.1 Experimental Test

It is well established that large scale experimental test can give a more reliable test outputs comparing with numerical modeling. This is because it can deal with the real soil and loading condition. It is important to use the loading condition, soil type, and reinforcement system which can simulate the real in situ condition. In order to assess the bearing capacity of strip footing rested near a reinforced clayey slope a series of laboratory test was conducted in a test box made of steel frame. The test box had inside dimensions of 2.3 × 0.5 m in plan and 0.9 m in height. The two sidewalls of the test box were constructed using transparent glasses for ease of monitoring the failure mechanism during testing. In addition, a rough base condition of a 100 mm-broad model footing made of steel was prepared at the bottom of the footing. The box was sufficiently rigid to remain plane strain conditions in the reinforced slope models. Since the walls of the test tank were firmly held in position by steel melting and the wall friction was kept to the minimum, plane strain conditions were considered for all model tests. Figure 1.a shows different parts of testing apparatus.

A stress controlled loading equipment was developed on top of the test box. For each test the loading equipment was able to change the location of the loading spot in both directions. The strip footing was simulated using a rectangular steel profile. The footing was 0.499 m in length, 0.2 m in width, B, and 0.01 m in thickness. The footing was located on the crest of clayey slope. The length of the footing equal to the full width of the tank. The length of the footing was made almost equal to the width of the tank in order to maintain the plane strain conditions. The two ends of the footing plate were polished smooth to minimize the end friction effects. A rough base condition was provided by using rough sandpaper on the base of the model footing. In this study a 70 kN hydraulic loading apparatus capacity was used to apply the load on the footing. The loading system could be controlled where anytime that the stain rate reduced to a minimum of 0.02 mm/min automatically the loading will move to the next stage. This continues until the footing rested on the reinforced slope failed. The applied load was constant during each stage and this helps to have a more uniform pressure on the footing during the experiments. Details of experimental apparatus is depicted in Figure 1.b.



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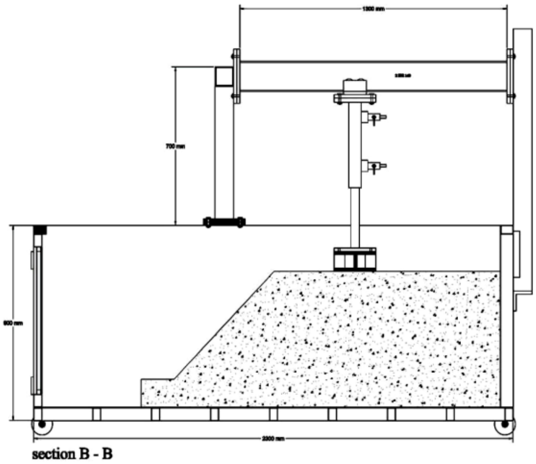


(b)

Fig.1: Details of experimental apparatus.

2.2 Clayey Soil Properties

The soil is classified as clay with low plasticity limit (CL). The shear strength parameters of the soil is obtained from the direct shear test. Clayey samples were collected and sealed to maintain soil moisture in accordance with the British Standard Institution (BS) methods of test for soils (British Standard Institution 1990) from several locations of Shiraz, Fars, Iran. The containers for the disturbed soil were capable of being sealed to prevent any loss or gain of the moisture. Precautions were taken to avoid any kind of jolting during the transportation of the soil. The physical properties of the used clay (three samples are performed for each parameter) in this study are presented in Table 1. Figure 2 also shows the grain size distribution of the clayey soil used in this study.

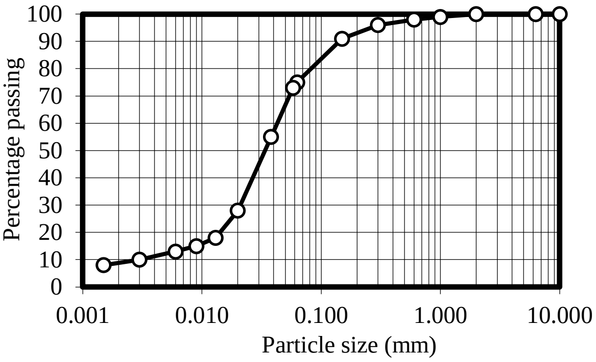


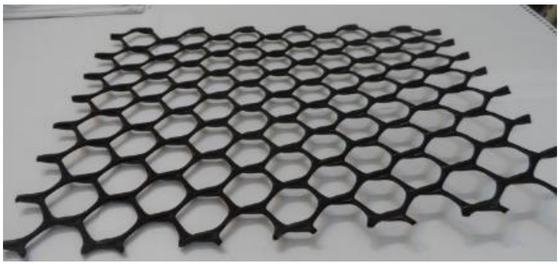
Fig.2: grain size distribution of the clayey soil

Table 1: The soil properties used in this study

Parameter	Value	Units
USCS	CL	
Liquid limit	28	%
Plastic Limit	17	%
Plastic index	11	%
Optimum water content	12.9	%
Internal friction angle Ø	21	degree
Cohesion (c)	29	kPa
Initial loading stiffness E_{ref}	12000	kPa
Poisson ratio (υ)	0.3	--
Dilatancy angle (ψ°)	0	--
Interface reduction ration (R_{int})	0.6	
Wet unit weight of the soil	18.1	kN/m^3
Saturated unit weight of the soil	20	kN/m^3

2.3 Geosynthetics

The geogrids used in this study are shown in Figure 3. Both geogrid and grid-anchor were made of high-density polyethylene. The geogrid tested in this study was CE 131, the same geogrid tested by Alamshahi and Hataf [23]. It has a mesh aperture size of 27 × 27 mm and a maximum tensile strength of 5.80 kN/m. Gridanchor has also a mesh aperture size of 8 × 6 mm and a maximum tensile strength of 5.8 kN/m. Width of reinforcement, b; number of reinforcement layers, N; length of reinforcement, L; distance to the first layer of reinforcement, u; and distance between the reinforcement layers, h used in model. Physical and mechanical properties of geogrid and anchors are also given in Table 2. Alamshahi and Hataf [23] stated that the grid-anchor has great pullout strength than the common geogrid when it deals with the sandy soil. The basic difference between common geogrids and grid-anchor is existence of short anchors attached to the geogrid on one side which provides great pullout strength for grid-anchor.



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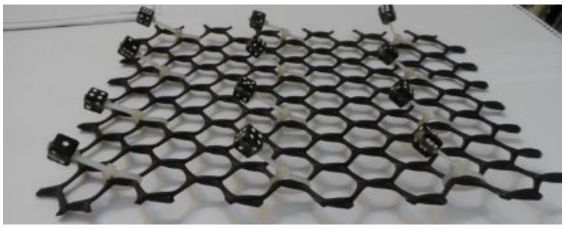


(b)

(c)

Fig.3: Geosynthetics used in this study, (a) Geogrid CE 131, (b) Grid anchor, (c) The anchor detail in grid anchor system

Table 2: Physical and mechanical properties of geogrid (Geogrid CE 131) and anchors.

Description	Values	Units
Bending stiffness (EI)	340.3	$kN.m^2/m$
Axial Stiffness (EA)	400000	kN/m
Tension strength of Anchors	2.0	kN
Tension strength of Geogrid	7.11	kN/m
Polymer	High-density polyethylene	
Form	Sheet	
Color	Black	
Mesh aperture size	27 × 27	mm
Mesh thickness	5.2	mm
Elastic normal stiffness of geogrid	28.0	kN/m
Structural weight (+5%)	660	g/m
EA Axial stiffness of anchors	0.18	kN
Length of anchors (mm)	50	mm

2.4 The Experimental Setup and Test Program

An experimental program was carried out to investigate the partial replacement of soft clay slope and to evaluate the effects of new grid anchor reinforcement reinforcing the replaced pad of clay on the bearing capacity of a strip footing adjacent to the slope crest. The procedures for the construction of reinforced model slopes are different depend upon the soil and reinforcement type. For example in the reinforced sandy soil researchers preferred to use a particular relative density from sand pouring method [11, 20, 23, 25]. However, those of other researchers like Otani, et al. [10] and El Sawwaf [19] who investigated on cohesive soil such as clayey soils followed the optimum water content to compact the model.

The slope size was kept constant in all experiments. There are several recommendation from previous researchers like Omar, et al. [15] and El Sawwaf [19]. Omar, et al. [15] stated that to minimum the side effect a minimum distance from the side of container should be at least two times footing width. In this experiment to eliminate possibility of side effect the distance of three time footing width was considered. For the minimum height of the slope Omar, et al. [15] suggested the minimum of 60 cm where in this research the slope height was taken 70 cm. For toe of the slope, the minimum height of the toe is suggested by El Sawwaf [19] to be 0.5B (in this research is about 10 cm).

The soil in slope samples were constructed in layers with the bed level and slope observed through the front glass wall. The soil was set up to form a 45 degree slope of 1 (H): 1 (V). Model clay slopes were constructed 700 mm in height and 1000 mm in length with a slope angle of 45 by pouring and compacting of 50 mm of clay soil layers to cover the entire area of the test tank. Great care was given to level the slope face using special rulers so that the density of the top surface was not affected. The proposed testing geometry of the slope was first marked on the transparent glass walls for reference. The footing was placed at desired position and the load was applied incrementally by the hydraulic jack until reaching failure. Each load increment was maintained constant until the footing settlement had stabilized. This settlement was recorded using two 0.001 mm accuracy dial gauges, placed on opposite sides across the centre of the footing.

As stated earlier the soil layer with the 7 cm height were compacted (10 uniform layers) by adding water content near to the optimum water content of the clay soils. The soil layers was compacted with a 10 kg steel hammer of 30×35 cm having the 30 cm height. Every soil layer was compacted with 50 blows. During the compaction process the soil is compacted uniformly. In the last layer after the compaction of the soil, the area under the strip footing and top of the slope were controlled to be clear and smooth. After finishing the preparation of the slope samples, the surface soil was covered with plastic to present any water loss.

The loading were performed based on the stress controlled condition. For every loading step 10 kPa and 40 kPa were considered for the unreinforced and reinforced condition, respectively. Every loading stage were kept and the rate of settlement is monitored. After loading the settlement was simultaneity started. The rate of settlement at the start of each steps was high however it was decreased with time. The loading was moved to the next step when the rate of settlement reduced to the 0.02 mm/min. The loading stages are continued until the footing reached to its ultimate bearing capacity. The test duration time the sample preparation and the above loading stages was approximately 5 hours for the unreinforced slope. However, for the similar condition, the duration of the test was increased with the addition of reinforcement. For instance, the grid anchor reinforcement system takes the longest test duration which was about 14 hours approximately.

Figure 4 showed a schematic view of a reinforced slope with the grid anchor system. A strip foundation with the width of B are placed on top of the slope having the distance of b near to the slope. The slope is reinforced with the grid anchor system. The first layer is having the distance of u from the top and the rest of reinforcement layers are separated with the distance of h from each other. Placement of beam, gauges and footings in the tests is presented in Figure 5.

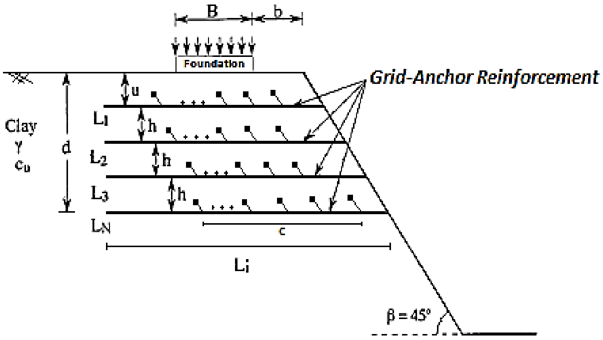
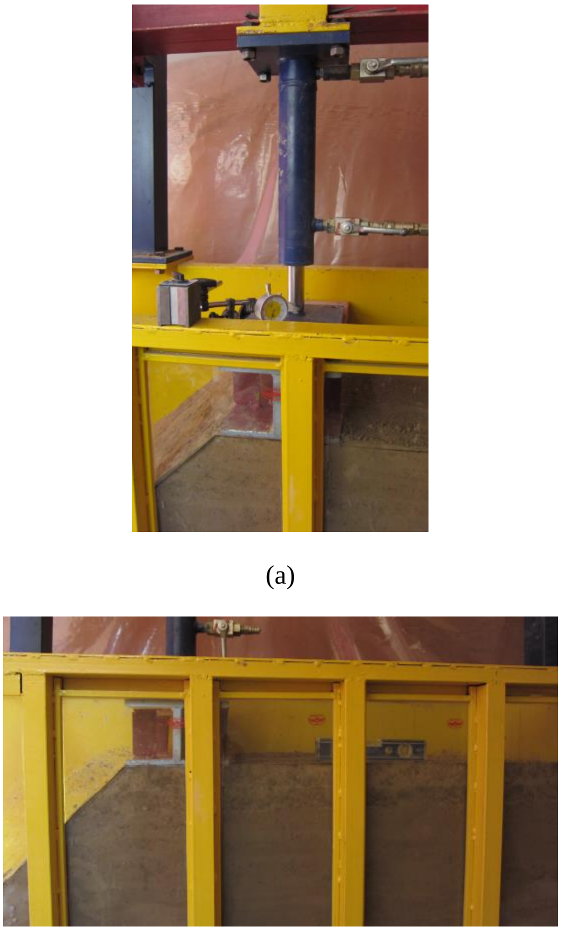


Fig.4: Schematic view of a reinforced slope with the grid anchor system



(a)

(b)

Fig.5: Placement of beam, gauges and footings in the tests

The conditions tested in experimental model tests are illustrated in Table 3.

Table 3: Conditions tested in experimental model tests

b/B	N	u/B	h/B	L/B	c/B
0, 1	0, 1, 2, 3, 4	0.25, 0.5, 0.75, 1	0.25, 0.5, 0.75, 1	3,4,5	1.5, 2.5, 3.5, 4.5

The grid anchors are provided using a 1×1×1 cm box which connected to the original geogrid with the 45 degrees angle connectors. Besides, the grid anchor elements which used by previous researchers showed very high values of anchor force absorption, as it has been fixed along the geogrid, which may not be reliable. However in this study instead of fixing the grid anchors with anchors, a secondary short layer of geogrid is attached to the main geogrid layer. In order to show how much the bearing capacity of the reinforced slope increased, a new term called bearing capacity ration (BCR) is introduced. The BCR is observed from the Equation 1.

$$BCR = \frac{q_{u(R)}}{q_u} \qquad (1)$$

where, $q_{u(R)}$ is the ultimate measured bearing capacity of reinforced slope, and q_u is the ultimate bearing capacity of the unreinforced slope.

In the reinforced slope modeled in the Plaxis the number of horizontal reinforcement layer was shown by n, the first reinforcement placed at depth u below the foundation, the various distance between the reinforcement (h), with the various reinforcement length (L; here L was chosen to be 100 cm) and effective anchor length of c. Therefore, the entire reinforcement depth (d) can be obtained as Equation (2).

$$d = u + (n+1)h \qquad (2)$$

3 Results and Discussion

In this section the impact of affecting factors such as grid anchored length, number of reinforcement, the type of reinforcement, depth of first reinforcement layer, and vertical spacing between the reinforcements for various test conditions are illustrated. Generally, results from both experimental test show that the conventional Geogrid is less efficient than the grid anchored system. Due to the existence of anchor in the grid anchored system the pull out resistance were highly improved. This causes more strain absorption into the reinforcement system which eventually lead to less settlement of the reinforced slope.

3.1 The impact of grid anchored length (c)

In this study the portion of reinforcement layer's length that is covered by the grid anchor (c = anchored length) is normalized by the footing width (B). The variation of the c/B with the BCR is presented in Figure 6. In order to evaluate the impact of the grid anchored length four series of the experiments are performed. The BCR increased from 1.06 to 1.45 when the c/B changed from 1.5 to 4.5, respectively. It can be seen that when the anchored length increased the BCR values is significantly increased. Decreasing the anchored length leading to an economic design of the footing. In this experiments the c/B was limited to 4.5. However it is clear that the BCR increases until reaching to the ultimate tension capacity of the layer of grid anchor base or the anchor connected to the reinforcement layers. Another reason to limit the term c/B was the size of the slope samples and the size of the container.

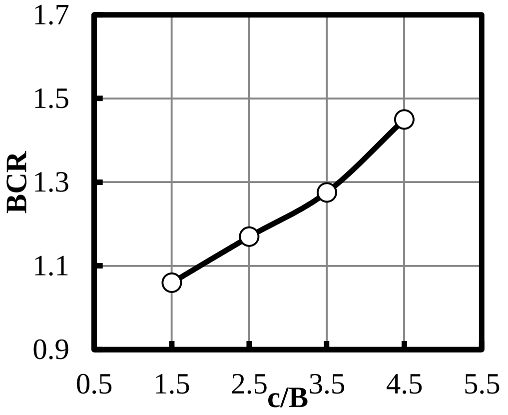


Fig.6: The variation of the c/B with the BCR (b/B=0, u/B=0.5, N=1)

3.2 The impact of first layer depth (u)

The impact of first reinforcement layer depth in a clayey slope reinforced on the BCR results from both experimental tests are presented in Figure 7), respectively. In both the experimental and the 2D FEM model only one reinforcement layer used with a specific depth (u) from the slope crest level. In addition, to assess the efficiency of the new grid anchor system comparing to the conventional geogrid system, the reinforcement system altered between conventional geogrid and grid anchor as well. In the first test series, the footing was located at the slope crest toe at distance of b=0 (i.e. b/B=0) however in the second series of tests and simulation the footing was rested on the distance of B from the slope crest toe (i.e. b/B=1). The term depth ratio is presented by u/B that was varied between 0.25 and 1 during the experiments. For both of the geogrid and grid anchor reinforcement systems the maximum BCR obtained when the u/B was equal to 0.5. The highest BCR values were obtained from the grid anchored system when the footing was located at distance of b=B from the slope crest toe. The BCR values for the grid anchor system and footing rested on b/B=1 were 1.2, 1.52, 1.37, and 1.11 for the u/B equal to 0.25, 0.5, 0.75, and 1, respectively (Figure 7). As result of numerical simulation, the BCR value in the geogrid system reinforced slope when the b/B=0 were almost 1.02 for the u/B between 0.25 and 1, respectively. However, for the similar range of b/B and u/B the BCR value for the grid anchor system was varied between 1.14 and 1.06, having the maximum of 1.165 at u/B equal to 0.5 (Figure 7). The BCR was much higher when the footing far away from the crest toe. In the models that b/B=1, for the geogrid reinforced slope the BCR varied between minimum of 1.087 at u/B=0.25, and maximum of the 1.13 at u/B of 0.5. The grid anchor however showed a significant improving up to the maximum BCR value of 1.434 in the u/B equal to 0.5 (Figure 7).

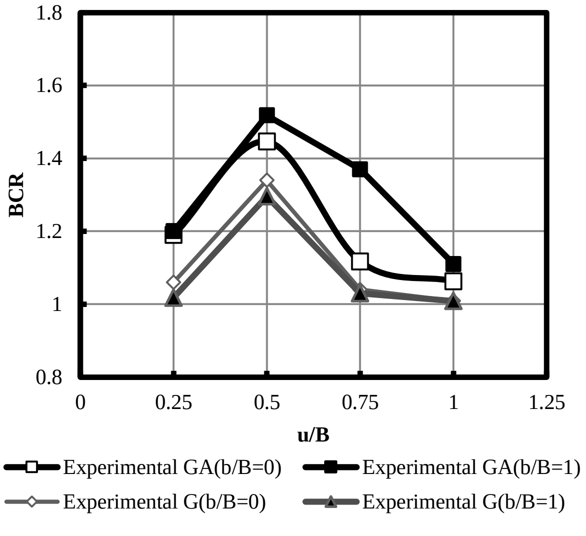


Fig.7: The variation of experimental results of BCR with the first reinforcement layer depth in the clayey slope reinforced with Geogrid (N=1), and Grid anchor (c/B=4.5, N=1);

For a clayey reinforced slope with the depth ratio (u/B) larger than 1 the BCR results for a particular the reinforcement systems are almost same. This means the effect of footing location has no impact on the BCR results when the first reinforcement layer depth (u) is taken more than the footing width. This issue can be clearly seen in the geogrid reinforcement system, where the BCR was also almost 1. This means the considered reinforcement layer is not effective.

3.3 Vertical spacing between the reinforcements

The variation of BCR with the vertical reinforcement layer distances in the clayey slope reinforced with Geogrid, and Grid anchor is presented in Figure 8. In both experimental and FEM model the slope were constructed using the optimum obtained reinforcement depth from the previous stage, u/B equal to 0.5. As stated the term b/B is equal to 0 when the footing is located at the slope crest toe, however the term b/B is equal to 1 when the footing is rested at a distance of B from the slope crest toe. In this part the laboratory test (Figure 8) were created with two reinforcement layers. Both types of conventional geogrid and new grid anchor reinforcement are used to compare their efficiency as a reinforcement. In this series of experiments two layers of the reinforcement were used with the length of the reinforcement (L) was taken 5 times of the footing width (B).

From laboratory models, the results of BCR for the grid anchor system were higher in comparison with the geogrid reinforcement system. The optimum value of the BCR is achieved when the term h/B was equal to 0.5. This was more evident when the b/B consider to be 0 and the grid anchor reinforcement system was used. Laboratory tests of a footing having the b=0, the reinforced clayey slope with the grid anchor system resulted the BCR of the 1.47, 1.6, 1.47, and 1.43 for the h/B equal to 0.25, 0.5, 0.75, and 1, respectively. In a similar condition of footing and slope samples reinforced with the conventional geogrid, for the h/B equal to the 0.25, 0.5, 0.75, and 1, the BCR values were 1.36, 1.41, 1.38, and 1.33, respectively. The BCR results of the footing located at b=B with the grid anchor reinforced slope were approximately 10.3% (in average) lower than footing on a grid anchor reinforced slope at distance of b=0.

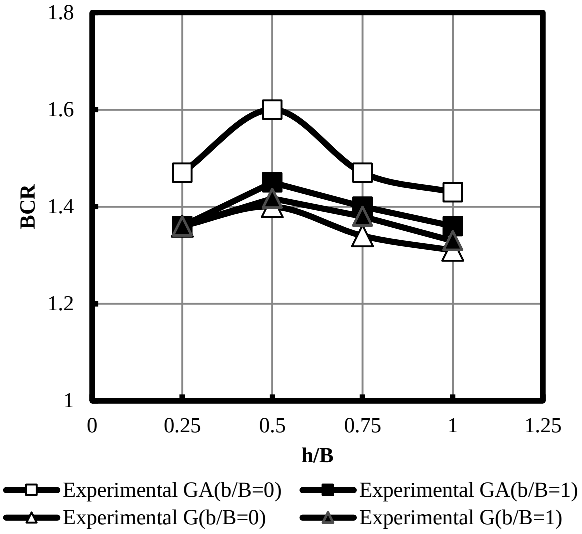


Fig.8: The Experimental results from variation of BCR with the vertical reinforcement layer distances in the clayey slope reinforced with Geogrid (u/B=0.5, and N=2), and Grid anchor (u/B=0.5, c/B=4.5, N=2)

The results showed that in the grid anchor reinforced system, the maximum BCR for the b/B=0 and b/B=1 were 1.467, and 1.27, respectively. Similar to the laboratory results, the maximum BCR values were obtained when the h/B equal to the 0.5 (Figure 8). This is about 13.4% increase on the grid anchors reinforcement efficiency when the h/B changes from 0.25 to 0.5 . This shows how important can be the placement of the footing near the slope as it affect the amount of tensions transfer to the reinforcement. It should be mentioned that for h larger than the B, the second reinforcement in depth will not affect the BCR which means it will not be useful in the reinforcement system. Therefore, the best condition will achieve only when the grid anchor reinforcement system normalized distance (h/B) taken to be 0.5. It is also observed that the second layer of the reinforcement could be neglected if reinforcement layer’s height (h) is taken more than the width of the footing (B).

3.4 The number of reinforcement layers (N)

The result of BCR altered with the number of reinforcement layers (N) in the reinforced slope with both geogrid and grid anchor. In both cases the models were analyzed having the b/B=0, 1, and u/B =0.5. Up to a particular number of reinforcement layer, the BCR of footing rested on the reinforced slope with grid anchors system was increased. Afterward, increasing the number of reinforcement had no effect on the BCR values. It can be seen that the grid anchor reinforcement system can sustain from much higher loads than the conventional geogrid reinforcement system. For instance, footing located in b/B=0 with three reinforcement layer, the BCR were 1.66, and 2.59 for the conventional geogrid and grid anchor reinforcement system, respectively (Figure 9). The BCR for 1, 2, 3, and 4 grid anchor reinforcement layers, similar condition stated above, were 1.435, 1.467, 1.549, and 1.56, respectively. This means the footing can resist against higher load to about 1.6 times bigger than the unreinforced condition. In addition, the BCR for the grid anchor reinforcement system in was significantly higher than the BCR results obtained from the geogrid reinforcement layer (Figure 9).

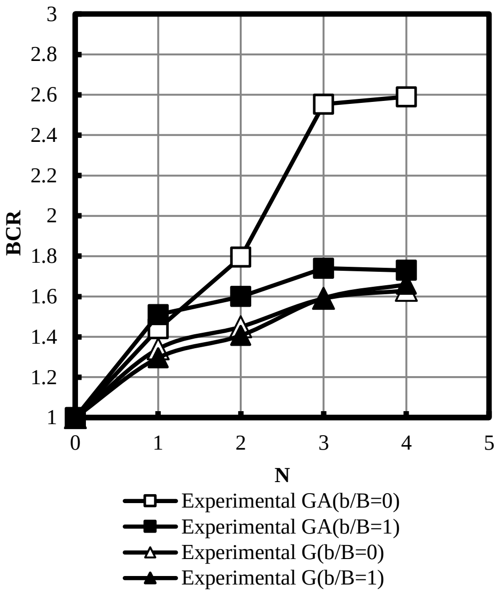


Fig.9: The variation of BCR with the number of reinforcement layer in the clayey slope reinforced with Geogrid (u/B=0.5, b/B=0, 1, and h/B=0.5), and Grid anchor (u/B=0.5, b/B=0, 1, c/B=4.5, h/B=0.5)

As can be seen from the results of the FEM model the BCR for both reinforcement types were increased up to 3 reinforcement layer however after that the BCR did not show any considerable change. This indicates that three reinforcement layers is the optimum number of reinforcement where it can absorb the stain in its maximum amount. It is noteworthy that increasing in the number of horizontal reinforcement layers could most probably cause sliding for the lower part of the slope sample leading the BCR to slightly decrease. Figure 10 is also shows the displacement of grid anchor reinforced slope after loading for the test condition b/B=0, u/B=0.5, and h/B=0.5.

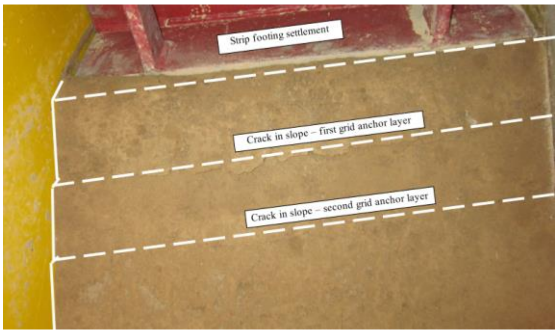
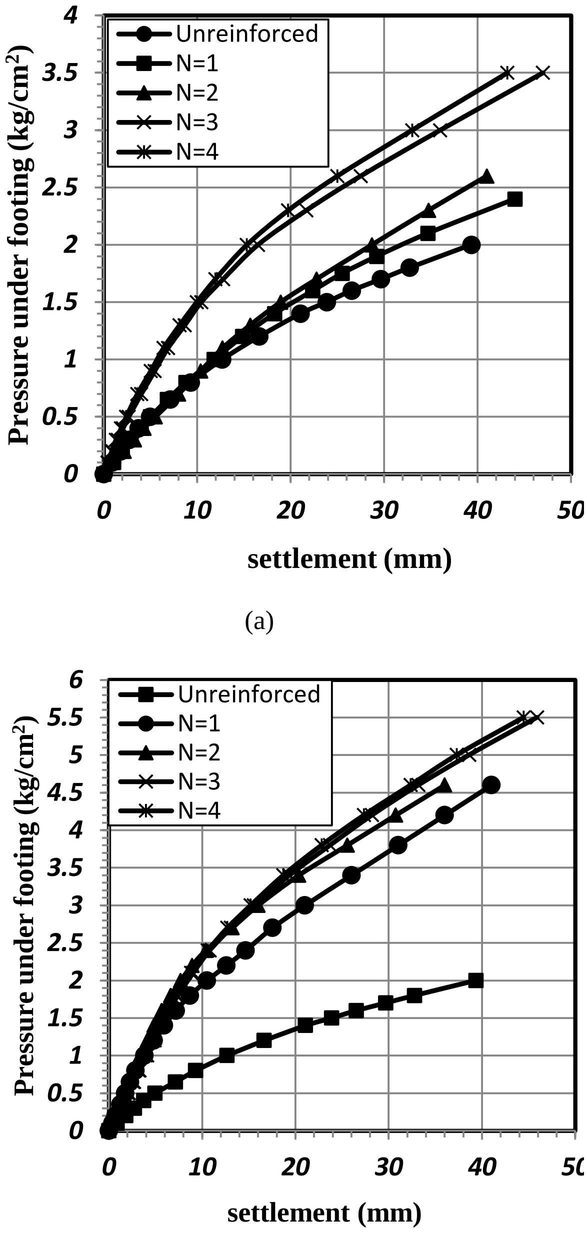


Fig.10: Displacement of grid anchor reinforced slope after loading

As stated earlier, designing a footing on a reinforced sloped fill requires a thorough understanding of both the bearing capacity behaviour of the footing and mechanical behaviour of the reinforced slope. Variation of the pressure under footing versus settlement for both of the geogrid and grid anchor reinforcement systems are presented in Figure 11. It can be seen that the higher the number of reinforcement layer the higher the footing pressure can be obtained. The higher footing pressure in in contrary with higher BCR. The footing pressure at a unique settlement like 30 mm for the unreinforced, reinforced with 1, and 3 layers of geogrid, were 1.7, 1.9, and 2.8 kg/cm^2, respectively. Although there is a big different between 1 layer geogrid and 3 layers geogrid, the different narrow after the three reinforcement layers (Figure 11.a). The footing pressure was significantly increased when grid anchor reinforcement system was used. For a same settlement of 30 mm under the footing, the pressure under footing for three layers of the geogrid and grid anchor reinforcements were 2.8, and 4.4, respectively. This means the use of three layers grid anchor caused about 57% increases in the allowable footing pressure (Figure 11.b).



(a)

(b)

Fig.11: The variation of the pressure under footing versus settlement (b/B=0, u/B=0.5, h/B=0.5, c/B=4.5 only for the grid anchor); (a) geogrid, (b) grid anchor.

4 Conclusion

In this research experimental investigation on the bearing capacity of strip footing located on clayey un-reinforced and reinforced slope with conventional geogrid and grid anchor reinforcement system. Based on the results of this study the following conclusions are obtained:

- The BCR values is significantly increased when the anchored length ratio (c/B) increased. An economic design of the footing rested on grid anchor reinforced slope requires adjustment between the ultimate tension capacity of the layer of grid anchor base, the tension capacity of the anchor connected to the reinforcement layers, and the reinforcement length.
- It is observed that the geometry of the reinforcement layers is important to be considered. A more effective geometry tend to absorb more tension stresses along with its length. Results show that the conventional Geogrid is less efficient than the grid anchor system. The grid anchors could significantly improve the BCR values. The optimum BCR values for the footing rested on a grid anchor reinforced clayey slope were obtained when the u/B and h/B were equal to 0.5. The more stresses transfer into the reinforcement causes strain absorption which lead to higher bearing capacity in the reinforced slopes.
- From laboratory models, the optimum number of reinforcement layers was obtained to be three. The results of BCR and the pressure under the footing for three and four reinforcement layers were almost same. Therefore, it is not economically logical to use four layer of reinforcement.

It is observed that the effect of grid anchor reinforcement system become less and less by increasing the distance of footing from the slope crest toe.

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