Behavior of a Circular Footing resting on Sand Reinforced with Geogrid and Grid Anchors

Rima Helis
LGC-ROI Civil Engineering Laboratory, Department of Civil Engineering, Faculty of Technology, University of Batna 2, Algeria
helis.r@univ-setif.dz
(corresponding author)

Tarek Mansouri
LGC-ROI Civil Engineering Laboratory, Department of Civil Engineering, Faculty of Technology, University of Batna 2, Algeria
t.mansouri@univ-batna2.dz

Khelifa Abbeche
LGC-ROI Civil Engineering Laboratory, Department of Civil Engineering, Faculty of Technology, University of Batna 2, Algeria
k.abbeche@univ-batna2.dz

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ABSTRACT

This study used finite element analysis to investigate the influence of using two reinforcing systems, the geogrid and the grid anchor, on the bearing capacity of a circular footing resting on sand. The parameters studied were the effect of the number of reinforcement layers (N), the depth ratio of the topmost layer of reinforcement (u/d), the vertical spacing ratio between consecutive layers (h/d), and the effect of reinforcement length (L). The results showed that the reinforcement layout had a very significant effect on the behavior of the reinforced sand foundation. The maximum bearing capacity for single-layer inclusion was obtained when reinforcement was placed at a depth of u/d=0.42. Bearing capacity was also found to improve when increasing the number of reinforcement layers from 1 to 3. Additionally, the analysis showed that the sand reinforced by grid anchors performed better than that reinforced by geogrid. Finally, an improvement in load capacity was obtained by increasing the length of the inclusions, and the optimal length of the reinforcements was determined at 5d for both inclusions.

Keywords-geogid; grid anchor; finite element analysis; circular footing; sand

I. INTRODUCTION

Geosynthetic reinforcing techniques is used to reinforce shallow foundations, improve bearing capacity, and reduce soil settlement below the foundation. Several studies investigated the bearing capacity of geosynthetic reinforced foundation soils using experimental, analytical, and numerical methods. One of the first experimental studies to analyze the bearing capacity of reinforced soils with metal strips was presented in [1-2]. Since then, many studies investigated the improvement of the load-bearing capacity of shallow foundations supported by sand and reinforced with different materials, such as metal strips and metal bars [3-5], rope fibers [6], geotextile [7], and geocells [8-10]. In addition, considerable studies were conducted to evaluate the bearing capacity of the reinforced soil by geogrid [11-18]. These studies confirmed the beneficial effect of reinforcement on improving the bearing capacity and reducing the settlement of footing. More recently, the use of geogrid in geotechnical engineering applications was considerably increased due to advantages such as cost reduction, simplicity, and ease of construction [19-20]. Laboratory scale model tests on a circular embedded footing supported on geogrid-reinforced sand beds were presented in [21], reporting an increase in ultimate bearing capacity with the embedding depth ratio of the foundation. In [22], the behavior of circular footing on sand was studied, showing that bearing capacity increased when the number of reinforcement layers increased if the reinforcements were placed within a range of effective depths. This study also showed that increasing the stiffness of the reinforcement did not always have a better effect on bearing capacity. A numerical study was conducted in [23] using finite element analysis to investigate the behavior of circular footing resting over reinforced sand, showing that the depth of the top layer plays an important role in the behavior of the reinforced soil, and reporting that the optimum depth of the top layer was 0.19 times the diameter of the footing. In [24], a small-scale laboratory model test was carried out on two closely spaced interfering footings resting on the surface of unreinforced and geogrid-reinforced sand bed, finding that the optimal depth of the geogrid layer for both interfering and isolated footings was one-third of the footing width. Therefore, footing interference had negligible or no effect on the optimum depth of the reinforcement layer for a single-layered reinforced sand bed. In [25], resting on a semi-infinite layer of reinforced sand with geotextiles was used to experimentally study the behavior of circular footings. Furthermore, analytical and numerical analyses were carried out to predict load-settlement behavior and compare them with the experimental observations. In [26], model plate load tests were conducted on various types of sand beds reinforced with geogrid, showing that substantial improvement in the load-settlement behavior can be obtained by increasing the number of geogrid layers (N) and decreasing the spacing between them. It was also shown that the load improvement ratio for the reinforced coarse sand was higher than that of the reinforced fine and medium sand. In [27], the behavior of geosynthetic-reinforced sandy soil foundations was investigated using laboratory model tests, showing that the settlement can be reduced by 20% at all footing pressure levels with two or more layers of geogrid. In [28], the upper bound theorem of limit analysis was used in conjunction with finite elements and linear optimization to determine the bearing capacity of a circular foundation embedded with horizontal layers of circular geogrid sheets. The optimal diameter and the critical positions of the reinforcement layers were established to achieve maximum bearing capacity, and a marked improvement in the bearing capacity was evident in the case of using two layers of reinforcement rather than a single. A laboratory model test of a surface strip footing on reinforced sand beds was presented in [29] to investigate the effects of reinforcement length with various types and numbers of reinforcements. An experimental study was conducted in [30] to assess the influence of the geogrid extension and embedment depth below strip footing rested on fine loose sand. In [31], a regression model was developed to determine the bearing capacity of a circular foundation supported on sand reinforced with geogrid. The results showed that the parameters studied had a significant influence on the performance of the footing in terms of bearing capacity. In [32-33], the bearing capacity of a strip footing subjected to inclined load and resting over a geogrid-reinforced sand bed was studied experimentally and numerically, showing that the footing performance could be substantially improved by including layers of geogrid, leading to an economic design of the footing. The effects of load eccentricity and inclination on the ultimate bearing capacity of shallow rectangular foundations placed over geogrid sand were studied in [34], finding that multiple geogrid-reinforced layers increased the ultimate bearing capacity by 75%. In [35], a strip foundation in weak soil was replaced with a granular trench and reinforced with geogrid, showing that the bearing capacity of a strip foundation could be significantly improved by replacing sand with granular materials up to 3 times. In addition, it was shown that placing the geogrid in the trench indicated a rise in the bearing capacity ratio. A new generation of reinforcement named grid-anchor was introduced in [36-37], showing its effect on the increase of bearing capacity of the foundation.

This study aims to evaluate the performance of using ordinary geogrid and grid anchor reinforcement in increasing the bearing capacity and reducing the settlement. To achieve this objective, a numerical model was determined using the Plaxis finite element software to investigate the bearing capacity of a circular footing resting over reinforced sand. Different parameters that affect the behavior of the reinforcement sand layer are discussed.

II. FINITE ELEMENT MODELING

The Plaxis software was utilized to perform a numerical finite element analysis by simulating a circular footing resting on sand reinforced by two reinforcement systems, GeoGrid (GG) and Grid Anchors (GA). Also, an axisymmetric analysis was performed. For all models, the boundary conditions in displacements were similar, such that the bottom boundary was assumed to be fixed and the vertical boundaries were constrained in motion in the horizontal direction. However, sand's behavior was supposed to be elastic and perfectly plastic, the Mohr-Coulomb rupture criterion was used, and the nonassociated flow rule was considered. A rigid circular footing with a 12cm diameter was simulated by applying a uniform downward displacement on the surface of the sandy soil. Table I shows the properties of the sand adopted in the model. Fifteen triangular plane strain elements were selected to model the soil, while the GG reinforcement was simulated with 5 node elastic elements. The GA was modeled using the fixed-end anchor option. Table II shows the physical and mechanical properties of GG and GA. The mesh refinement was adopted in the vicinity of the loading area around the foundation and GG layers to improve the accuracy of the numerical results.

TABLE I. SOIL PARAMETERS

Physical and Mechanical Property	Value
Maximum unit weight (kN/m^3)	16.4
Minimum unit weight (kN/m^3)	14.4
Maximum void ratio	0.890
Minimum void ratio	0.658
Specific gravity	2.72
Coefficient of uniformity	2.36
Coefficient of curvature	1.01
Classification	SP
Cohesion (kN/m^2)	0
Internal friction angle	39°

TABLE II. PHYSICAL AND MECHANICAL PROPERTIES OF GEOGRID AND ANCHORS

Description	Geogrid CE 131
Polymer	High-density polyethylene
Form	Sheet
Color	Black
Mesh aperture size	27×27mm
Mesh thickness	5.2mm
Structural weight (+5%)	660g/m^2
Elastic normal stiffness of geogrid	28.0KN/m
EA axial stiffness of anchors	0.18KN
Length of anchors (mm)	50mm

Figure 1 shows the prototype soil model with two systems of reinforcement, finite element mesh, and boundary conditions.

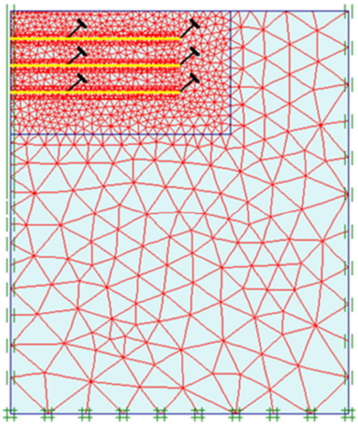

Fig. 1. The numerical model.

III. RESULTS AND DISCUSSION

Numerical tests were carried out to study the effects of inclusion reinforcement elements on a circular footing, constructed on unreinforced and multi-layered reinforced sand beds, and investigate the improvement of bearing capacity. A non-dimensional factor called the Bearing Capacity Ratio (BCR) was considered, defined as the ratio of the reinforced soil bearing capacity to the unreinforced soil:

$$BCR=\frac{q_R}{q_U} \quad (1)$$

where q_R and q_U are the bearing capacity values for reinforced and unreinforced soil foundations, respectively.

A. Effect of Reinforcement's Top Spacing

A numerical study was carried out to investigate the effect of the depth of the first reinforcing layer from the footing on the bearing capacity for different depth ratio values (u/d) with a single reinforcement layer in each reinforcing system, GG and GA. Figure 2 shows the variation of the BCR of the soil versus the different reinforcement depth ratios u/d. In the case of GG, as the depth ratio u/d increases from 0.2 to 0.42, the BCR also increases. However, between 0.42 and 0.8, a clear reduction in the BCR was found for both GG and GA.

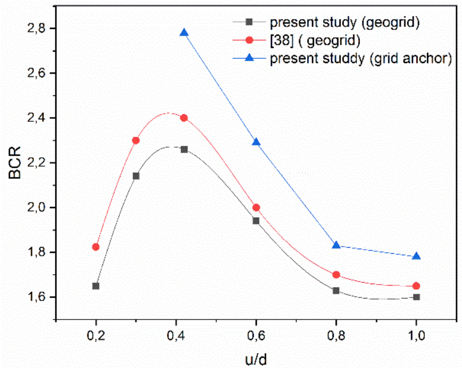

Fig. 2. Variation of BCR with depth ratio in single-layer reinforced sand.

Similar results were found in [31], where there is no increase in soil carrying capacity that exceeded u/d>0.75. Hence, the optimal value of the depth ratio was obtained when the reinforcement was placed at u/d equal to 0.42 in both systems. Therefore, it can be concluded that the results obtained for GG reinforcement are in good agreement with [38]. Figure 2 also shows that the effect of the presence of GA reinforcement on the bearing capacity of the circular footing on sand becomes important compared to those obtained by GG. In addition, a considerable improvement of about 52% was observed for the anchorage of the grids.

B. Effect of Vertical Spacing of Reinforcement Layers

This study aims to investigate the effect of the spacing between the reinforcing elements on the performance of reinforced sand under the circular footing. The GG and GA layers were tested with a top layer spacing at 0.42d and varied vertical spacing between the layers. Figure 3 shows the variation of the BCR with the vertical spacing ratio (h/B). The results showed that for GG reinforcement, the BCR increased to a maximum value at h/d=0.3d, but the GA had a critical value at u=0.42d. Then, a remarkable decrease was observed for both reinforcements until 0.6d. Beyond this value, BCR seems to stabilize, showing that adding inclusions is insignificant in this region. The trend of the curves is similar to that of [38]. Furthermore, in [28-31] it was shown that the increase in BCR was obtained when the vertical spacing between the reinforcement layers was between 0.25 and 0.40d, which justifies the present case study. Therefore, the variation in amplitudes and the modest divergence can be attributed to the adapted reinforcement pattern.

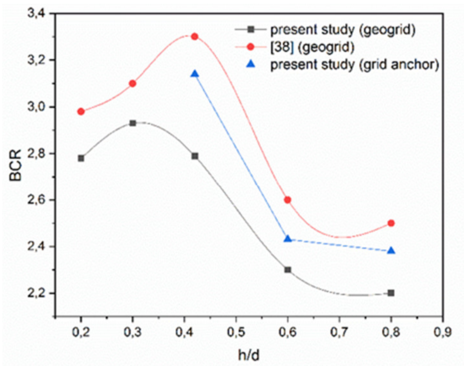

Fig. 3. Variation of BCR with the vertical spacing ratio of reinforced sand.

C. Effect of the Number of Reinforcing Layers

A series of numerical tests were conducted to study the influence of the variation of the number of reinforcement elements (N) on the behavior of a circular footing on reinforced sand. The depth of the first layer (u) was taken equal to 0.42d, while the vertical distance between the reinforcement layers (h) was equal to 0.3d for the GG and 0.42d for the GA. Figure 4 shows the variation of the BCR as a function of the number of reinforcement elements N. It can be observed that the increase in the BCR results from a considerable increase in the reinforcement elements up to an optimum value N=3, and a slight increase is observed over that. This confirms the findings of several studies [22-34, 37] that showed that increasing the number of reinforcement layers beyond a certain number would not increase the BCR.

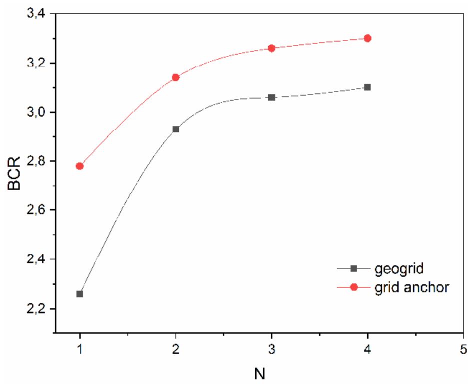

Fig. 4. Variation of BCR with the number of reinforcement layers.

D. *Effect of the Length of Reinforcement*

A circular foundation resting on sand was studied by keeping the number of geogrid layers N to 1 and depth of reinforcement at the optimal 0.42d, while the length of the reinforcement layer (L) varied between 4d, 4.5d, 5d, and 6d to investigate its effect on BCR. Figure 5 illustrates the variation of BCR with the different reinforcement length ratios (L/d).

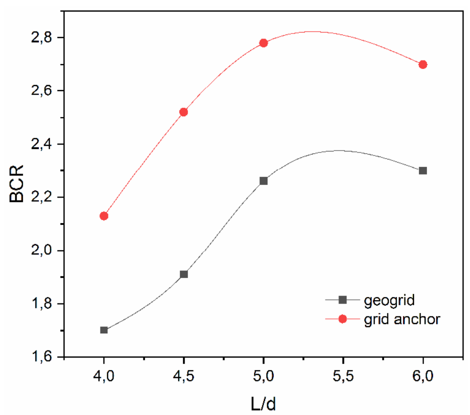

Fig. 5. Variation of BCR with the reinforcement layer's length.

As can be observed, BCR increases linearly with reinforcement length up to L/d=5, while reinforcement length beyond this value is ineffective on BCR for both reinforcement types. Therefore, the optimal length of reinforcement is obtained at 5 times the length of the footing, as in [39].

IV. CONCLUSION

This study caused finite element analysis to assess the behavior of a circular footing constructed on unreinforced and reinforced sand soil, drawing the following conclusions:

- An increase in bearing capacity was obtained when the depth of the first reinforcing layer to the footing diameter was equal to 0.42. This was considered an optimal depth of the top reinforcement layer from the bottom of the footing.
- A visible reduction was noted in the bearing capacity beyond 0.42d for both types of reinforcement.
- The effect of reinforcement cannot be seen when the installation depth is deeper than a certain depth (u/d≥0.80).
- There is an optimal value for the vertical spacing of the reinforcement layer where the BCR was the highest. This optimal value was found to 0.3d for Geogrid and 0.42d for Grid Anchors.
- The bearing capacity of reinforced soil increases with increasing the number of layers. In this study, the optimal number of layers obtained was 3 in both reinforcement types.
- The analysis clearly showed that using the Grid Anchor system reinforcement of circular footing on a sand bed causes a significant increase in the bearing capacity in comparison with the ordinary Geogrid.
- An improvement in the load capacity was obtained by increasing the length of the inclusions. The optimal length of the reinforcements was determined at 5d for both inclusions.

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