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## **Finite element analysis of reinforced sand under circular footing**

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This paper presents the results from numerical investigations carried out on circular footing rests on Geo-grid reinforced sand. The finite element program (Plaxis-2D) was used to study experimental results carried out by [1]. This experimental work was used to study the effect of variation of Geo-grid reinforced layers number ( $N = 0, 1, 2, \text{ and } 3$ ) under circular footing. The numerical validation with experimental work was considerably agreed with an average percentage of 93%. Then a parametric study was conducted to evaluate the soil performance under circular footing, while applying the same loading conditions. Several parameters have been investigated to identify the optimum soil behaviour that achieves optimum bearing capacity and minimum settlement under the footing. The parameters include number of Geo-grid layers ( $N$ ), the Geo-grid layer width ( $L$ ), the spacing between the footing base and topmost Geo-grid layer ( $U$ ), the spacing between Geo-grid layers ( $h$ ) and the Geo-grid stiffness ( $K$ ). The results indicated that by increasing the number and the width of the Geo-grid reinforced layers the bearing capacity ratio increases up to a limited extent. Moreover, the optimum number of Geo-grid layer equals four layers for circular footing.

**Keywords:** bearing capacity, footing shape, reinforced soil, Geo-grid layer.



## 1. Introduction

Construction of superstructures on loose soil requires enhancement to the soil performance to increase the bearing capacity of the soil and decrease the settlement. Soil reinforcement using Geo-grid products has been widely expanded in the last three decades. The optimum Geo-grid soil reinforcement behaviour could be achieved by investigating several reinforcement parameters such as Geo-grid type, number of layers (N), width of reinforced layers (L), spacing between the reinforced layers (h), distance between the footing and the top reinforced layer (U), footing width (B), and the depth of footing (Df). As shown by [2], [3] footing geometry rests on reinforced soil significantly affect the soil performance. These parameters are investigated to achieve the optimum soil behaviour in the study. However, some soil properties which affect the behaviour of the reinforced soil are not considered in this paper such as relative density ( $D_r$ ), cohesion (C), and friction angle ( $\phi$ )

Ultimate bearing capacity of reinforced soil could be calculated using several methods, as showed by [4]. In this paper, the tangent method was adopted to determine the ultimate bearing capacity for unreinforced and reinforced soil. Bearing capacity ratio (BCR) is a suitable technique to determine the degree of enhancement in the bearing capacity of any type of soil. It is defined as the ratio between the ultimate bearing capacity of reinforced soil to the ultimate bearing capacity of unreinforced soil, as shown in eq (1)

$$BCR = \frac{q_{u \text{ reinforced}}}{q_{u \text{ unreinforced}}} \dots\dots\dots \text{eq (1)}$$

### 1.1 Effect of Geo-grid layers number.

[1], [3], [5] and [6] showed experimentally that the soil performance could be improved by increasing the number of Geo-grid layers to three layers, that improvement could be translated as increasing in the bearing capacity and decreasing of the settlement. [7] showed that The optimum number of reinforcing layers (N) ranges between four to six-layers. [8],[9] and [10] proved numerically and experimentally that the best soil behaviour occurs when the number of reinforced layers is four. Also, it was found that the relationship between the number of reinforcing layers and the bearing capacity ratio (BCR), is directly proportional also, it is inversely proportional between the footing width and the BCR. Best BCR value could be achieved when the number of layers is three.

### 1.2 Effect of Geo-grid width.

[11] showed that the optimum width of the reinforced layers to footing diameter (L/D) equals 4.9 for circular footing. The width of reinforcing layers is about four times the width of the square footing as showed by [12] and [13]. [6], [14] and [15] showed experimentally that the best results for ultimate bearing capacity of Geo-grid reinforced soil could be achieved when the Geo-grid width is greater than or equal five times the footing width (L/B = 5). [8] showed numerically that the optimum width of the reinforced layers (L/B) equal to 7.5B. From the experimental and numerical study carried out by [10] the optimum ratio between the width of Geo-grid and width of foundation (L/B) is 4.5.

### 1.3 Effect of the spacing between footing to topmost Geo-grid layer.

[14] showed experimentally that the best results on strip footing could be achieved when the topmost Geo-grid reinforcement layer is placed at 0.35B from the base of the footing. [7] showed that BCR is better when U/B is less than 0.67. [8] proved that it is more effective to use (U/B) equals to 0.25. In another experimental study [13], it was found that the bearing capacity under shallow foundation increases by decreasing the vertical spacing between Geo-grid layers and footing until that the top Geo-grid layer lies in the range of 0.2 - 0.3 the footing width. From the experimental and numerical study carried out by [10], it was concluded that the ratio (U/B) = 0.25.

### 1.4 Effect of the spacing between Geo-grid reinforcing layers.

Experimental and numerical studies carried out by [12] on square footing resting on sand found that, the optimum spacing between the reinforced layers (h) is about 0.4 times the width of the footing. [14] showed experimentally

that the second layer should be placed at 0.25 B from the top layer. [8] showed that optimum (h/B) equals 0.75 under a strip footing. From the numerical study carried out by [16] the layers placed at a distance 0.4375B gives the best results for the bearing capacity. From the experimental and numerical study carried out in [10] the ratio between the spacings to width of foundation (h/B) is 0.2.

### 1.5 The effect of footing shape

According to [17], the shape of footing also control in BCR .the performance of the Geo-grid reinforced soil supporting circular footing is better than the performance of reinforced soil supporting square footing.

$$BCR = \frac{Q_u \text{ reinforced}}{Q_u \text{ unreinforced}}$$

## 2 Objectives

The aim of this numerical study is to improve the reinforced soil performance to increase its failure limit, which occurs at a settlement of 10 % of footing width [11]&[18]. Plaxis-2D was used to validate experimental results carried out by [1]. After validation with experimental work, a parametric study has been conducted to evaluate the soil performance under circular footing, keeping the same loading conditions (loading cell capacity). The parametric study was performed to investigate the influence of varying the following parameters (Figureure (1)):

1. The Geo-grid layers number (N).
2. The Geo-grid width (L) relative to footing width.
3. The spacing between the footing and top-most Geo-grid layer (U).
4. The spacing between the Geo-grid layers (h).
5. The Geo-grid stiffness (K).

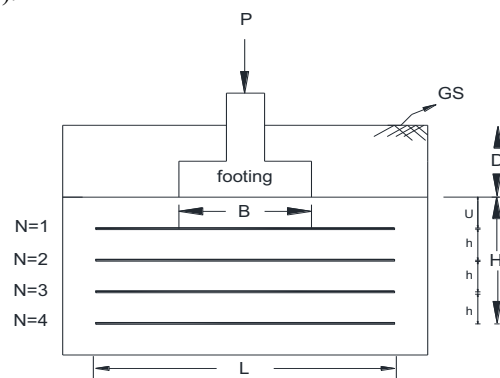


Figure 1: The Geometric parameters of Geo-grid reinforced sand

## 3 Experimental work

In the experimental work, [1], a cubic testing tank of side length 0.8 m was used. To avoid the boundary conditions effect, the ratio between the circular footing diameter and tank width is 6.5. A circular steel plate with thickness 15 mm and diameter 120 mm was used to represent the footing. Incremental loading was applied using a hydraulic jack. The settlement was measured by displacement reader as shown in Figure (2).The soil used is poorly graded sand with unit weight of 14.4 KN/m<sup>3</sup>, coefficient of uniformity (C<sub>u</sub>) 2.89, coefficient of curvature (C<sub>c</sub>) 1.05, effective size (D<sub>10</sub>) 0.27, internal friction angle of 39°, specific gravity was 2.65 with maximum and minimum dry densities 1.64 (g/cm<sup>3</sup>), 1.44 (g/cm<sup>3</sup>) and maximum and minimum void ratios of the sand were found to be 0.89 and 0.65, respectively. High-density polyethylene (HDPE) geo-textile layers with a tensile strength of 7.68 KN/m were

used. A square formed reinforcement layer, 4.5 times the diameter of circular footing ( $b/D = 4.5$ ), was used, where the layer's configuration was  $U/D = h/D = 0.42$ .

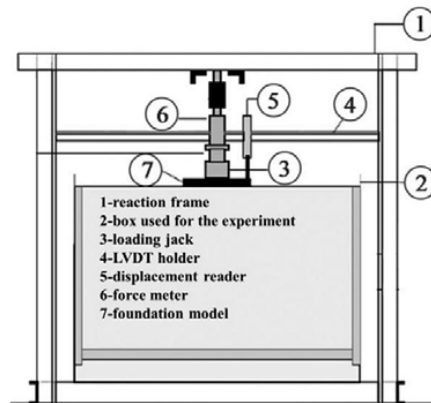


Figure 2 : Schematic view of the experimental equipment [1]

#### 4 Finite Element model

##### a. Introduction

Plaxis-2D was used to simulate and analyze the Geo-grid reinforced soil. Two different models could be generated using Plaxis-2D, an axisymmetric and plain strain model. These models could be used to solve and simulate different types of foundation. Generally, the axisymmetric model is used to solve circular footing while plain strain model could be used for simulating strip footing. Meshing size could be varied from very coarse, coarse, medium, fine, and very fine. Solution accuracy and computational time effort depends on mesh size. Mohr-coulomb and hardening soil model are the most common models used for modeling the reinforced sandy soil [19].

**The finite element model was created to verify:**

- 1- Assuring model quality by validating its results with those of experimental results.
- 2- Studying the results of changing the parameters as shown in chart (1).

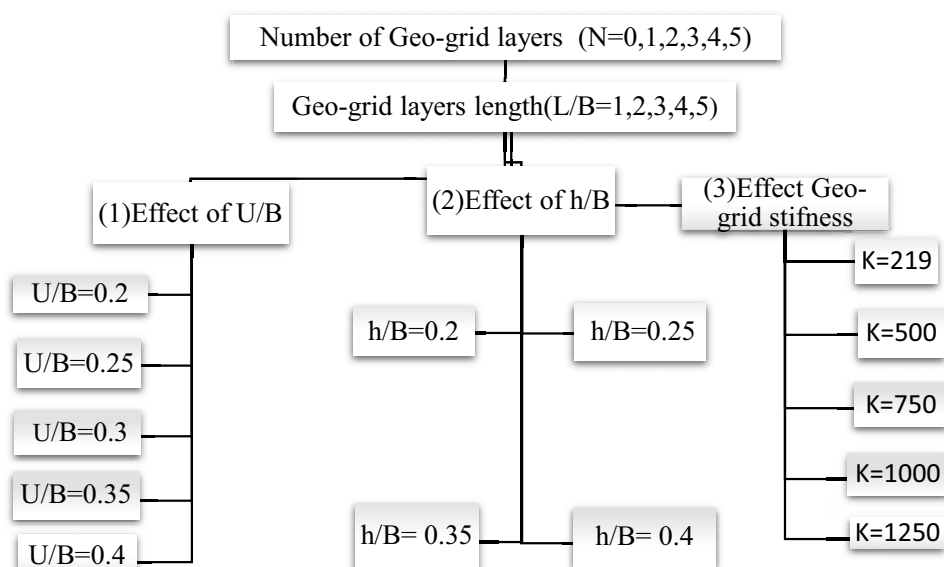


chart 1: Studying cases of the Geo-grid reinforced soil under circular footing

### b. Numerical Model discretization

In this study, the same bin dimensions, as in experimental work, were used (0.8 x 0.8 m). Sandy soil with unit weight 14.4 KN/m<sup>3</sup>, Young's modulus 40000 KN/m<sup>2</sup>, Poisson's ratio 0.3, cohesion 1 KN/m<sup>2</sup>, friction angle 39° and dilatancy angle 9°[20] was represented by hardening soil model. The axial stiffness (EA) of the Geo-grid reinforcing layer was 219 KN/m[21], [15], [7], and [11]. The same plan area of the steel plate was used to simulate the circular footing which equal (0.0113 m<sup>2</sup>). Very fine meshing with 15-Noded element was used to increase the accuracy of the results. Refining mesh was performed in Geo-grid reinforcing layers to increase the simulation accuracy as shown in the Figure 3. Axisymmetric model was used to reduce the computational time. The boundary conditions were fixed at the bottom of the bin and roller on the sides to allow the sand to move freely in the vertical direction. The load applied to the steel plate was distributed and applied gradually.

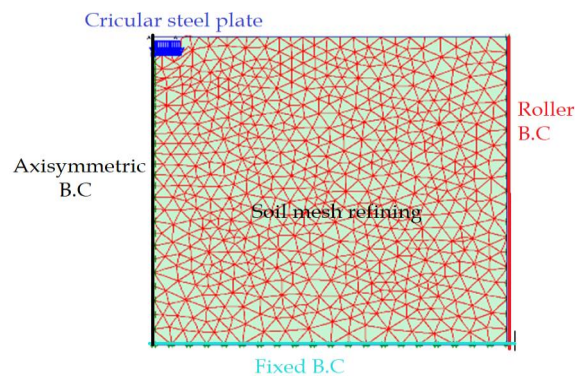


Figure3 : Boundary conditions for the numerical model

### i. Validation between the numerical model and experimental work

The FE model was carried out to simulate the circular footing over unreinforced and reinforced soil. The soil was reinforced using 1, 2, and 3 Geo-grid layers. The Finite element model results were in a good agreement with the experimental model. It worth mentioning that the un-reinforced soil results were more accurate due to the absence of the interaction definition between the Geo-grid layers and the soil. However, all the results were acceptable, with a maximum tolerance of 10%.

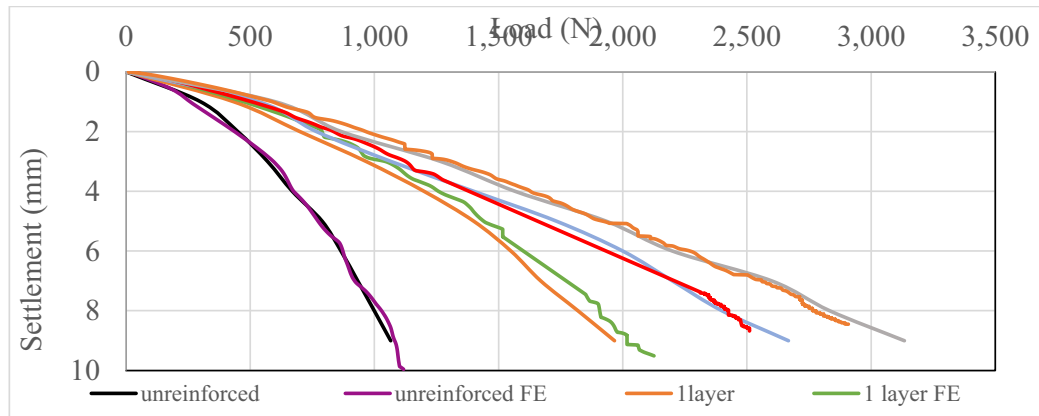


Figure 4 : The load settlement of validation with the experimental work

### c. Parametric study

This parametric study was performed for the evaluation of the effect of each parameter separately, as shown in chart 1, while fixing the others. The individual parameter under the investigation will be varied and the values of the others are as follows: spacing between topmost layer and the footing is  $U/B=0.42$ , spacing between the layers is  $h/B = 0.42$  which equals about five cm as shown in [1], the tensile stiffness for Geo-grid ( $EA$ )=220 KN/m, the number of geo-grid layers is four, and the width of geo-grid layers is equal  $5B$ .

#### i. The effect of layers number (N)

The optimum number of Geo-grid reinforced layer was investigated. Figure 5 showed numerically a comparison of Load-Settlement curve of a different number of reinforced layers  $N=0, 1, 2, 3, 4,$  and  $5$  under circular footing. Figure 5 showed that the inclusion of one reinforcing layer had a significant effect on the load capacity of the system compared with the unreinforced soil. This effect started to decrease by increasing the number of reinforcing layers. Data illustrated that insignificant enhancement in the load capacity was achieved after increasing the reinforcing layers number more than three layers. Consequently, the optimum number of layers is three layers.

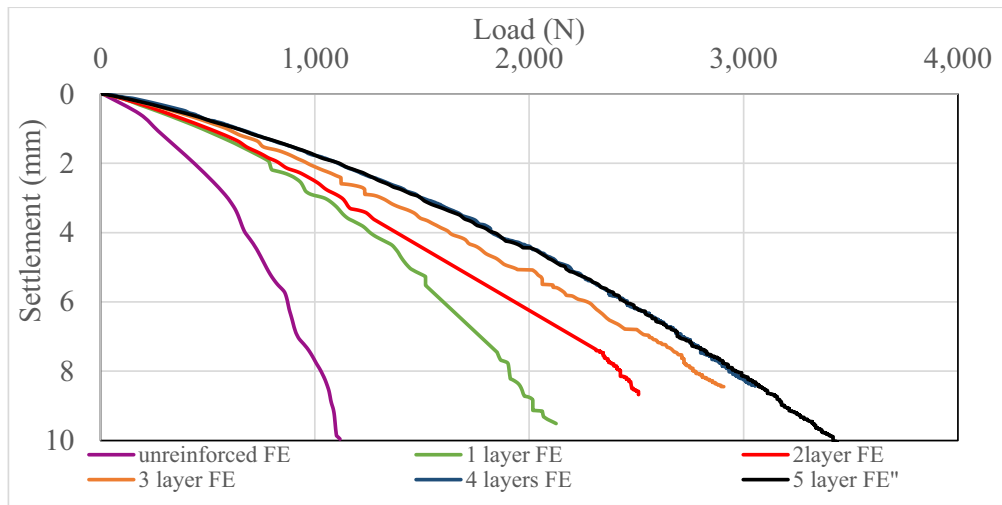


Figure5 : Numerical load settlement curve of reinforced layers N=0, 1, 2, 3, 4, and 5

Figure (6) showed that the stress distribution due to the inclusion of the reinforcing layers. Generated load transfer mechanisms due to the inclusion of the reinforcing layers resulted in redistribution process of stresses in the soil. Reinforcing layers and the trapped soil in between its apertures forms a stiff layer, at which stress is redistributed on a wider area, hence; a lower value of stress was transferred underneath it.

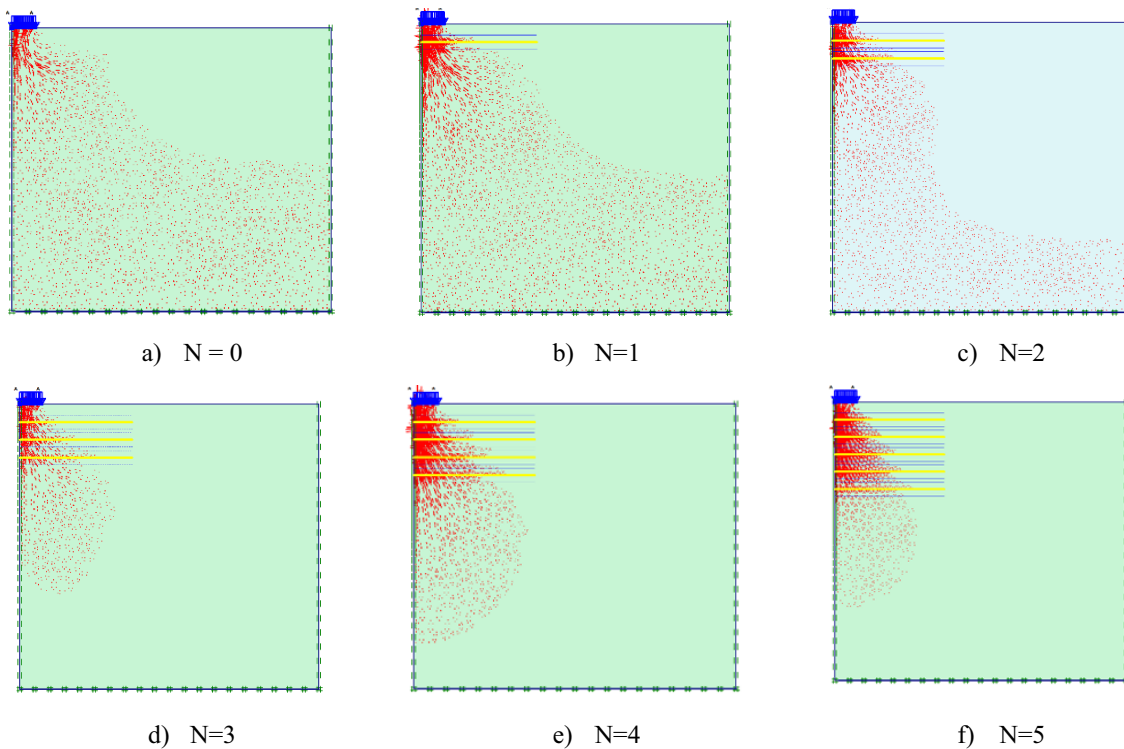


Figure 6 : plastic points under circular footing



## ii. The effect of layers width (L)

The width of the Geo-grid layers to the footing diameter ( $L/D = 1, 2, 3, 4, \text{ and } 5$ ) was studied as shown in Figure (7). The Geo-grid layers should cover all soil failure zones assumed by Terzaghi (Figure 8). Zone I is the elastic zone (Red zone), Zones II is the radial shear zone (Blue zone) and zone III is the Rankine passive zone (Yellow zone). Hence, the reinforced Geo-grid width depends mainly on the depth of Geo-grid layers and soil angle of friction.

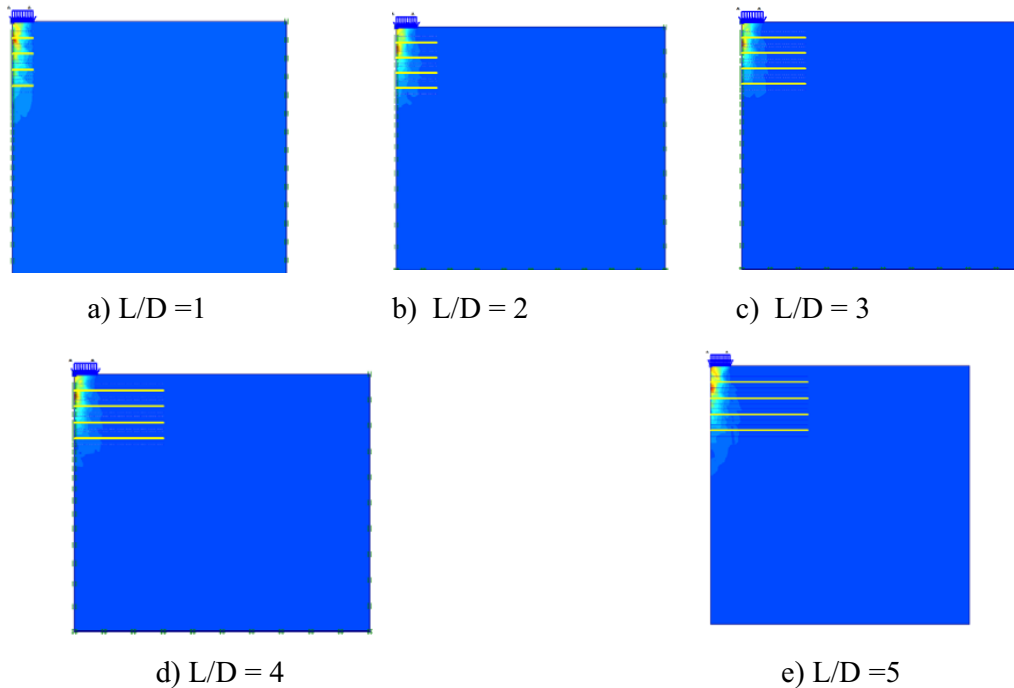


Figure 7 : The different geo-grid width under circular footing

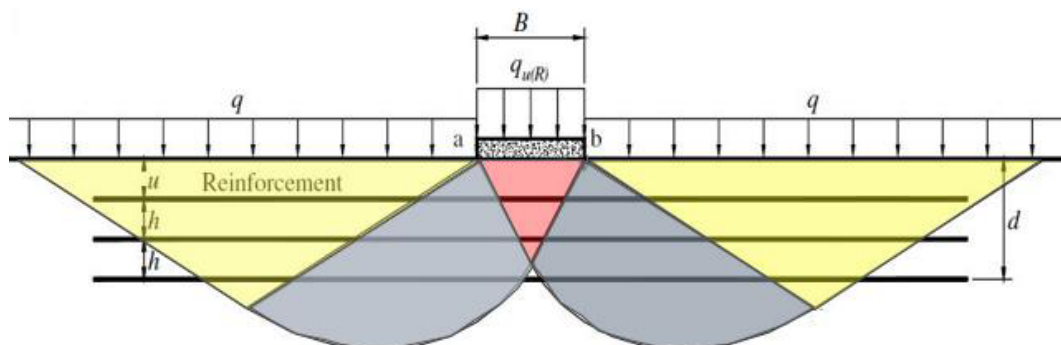


Figure 8: Failure zones assumed by Terzaghi.

Figure (9) shows the load settlement curve of the mentioned Geo-grid widths on reinforced soil performance under the circular footing. it is concluded from Figure (9) that the bearing capacity ratio (BCR) increases by increasing

Geo-grid width. however, the more increasing in Geo-grid width the more increase in the bearing capacity ratio. Significant improvement achieved using first case ( $L/D = 1$ ) and gradually the improvement starts to decrease, until ( $L/D = 4$ ) then the IR begins to be insignificant at  $L/D = 5$ . Finally, we can conclude that the optimum width of Geo-grid reinforced layers to footing diameter is  $L/D = 4$ .

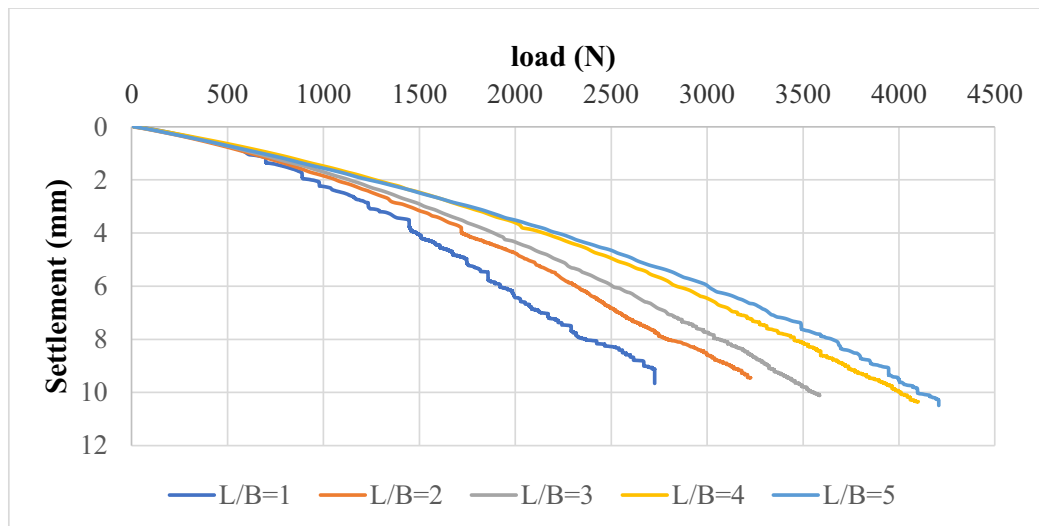


Figure (9) Load-settlement of reinforced soil with a different Geo-grid width

iii. The effect of distance between the foundation and top Geo-grid layer(U)

The optimum spacing between the topmost Geo-grid layer and the footing on soil performance was investigated ( $U/D = 0.2, 0.25, 0.3, 0.35,$  and  $0.4$ ). Figureure (10) represents the load settlement curve using the mentioned ratios under the circular footing. Very small improvement was occurred by increasing  $U/D$ . it could be concluded from Figureure (10) that the soil behavior using  $U/D=0.4$  has the highest bearing capacity ratio.

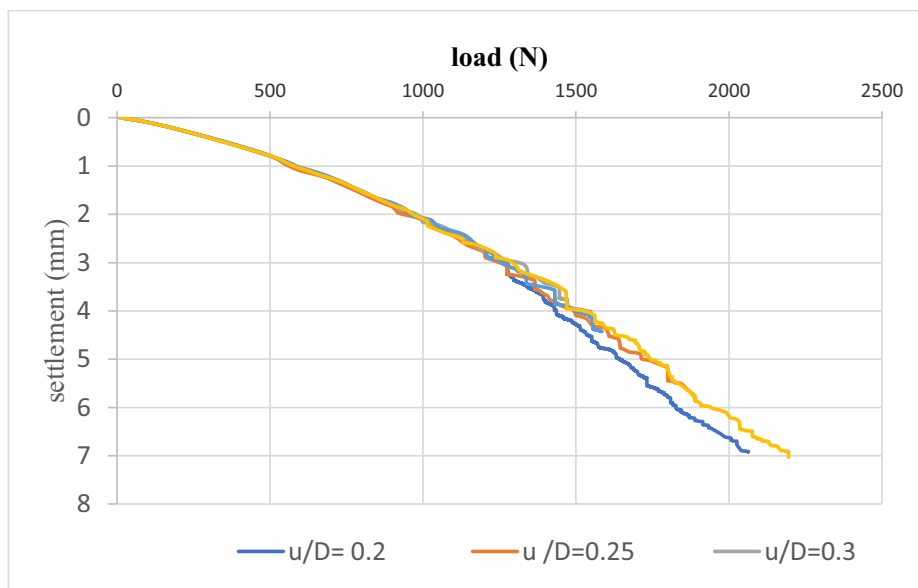


Figure 10 : Load settlement curve with different spacing between the top Geo-grid layer and the footing base

**iv. The effect of distance between the Geo-grid layers (h)**

The optimum spacing between the Geo-grid layers (h) on soil performance was performed. In this study, different ratios between the Geo-grid layers relative to the footing diameter ( $h/D = 0.2, 0.3, 0.4, \text{ and } 0.5$ ) and its effect on the BCR was investigated. Figureure (11) shows the load settlement curve using the mentioned  $h/D$  ratios. A very small difference was noticed by varying  $h/D$ . However, it could be concluded from Figureure (12), which shows the improvement ration under circular footing, that the optimum  $h/D$  ratio is equal 0.3.

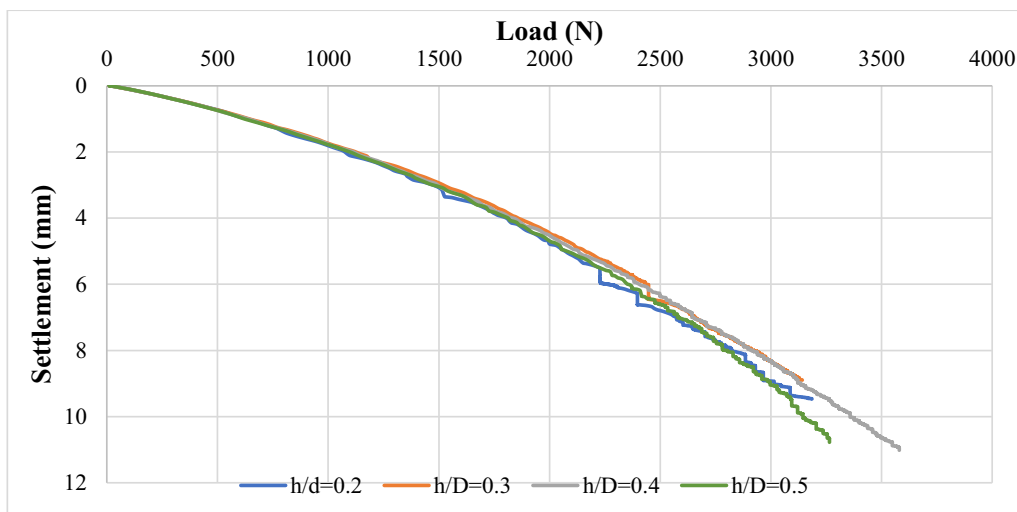


Figure11 : The load-displacement curve with different spacing between the Geo-grid layers.

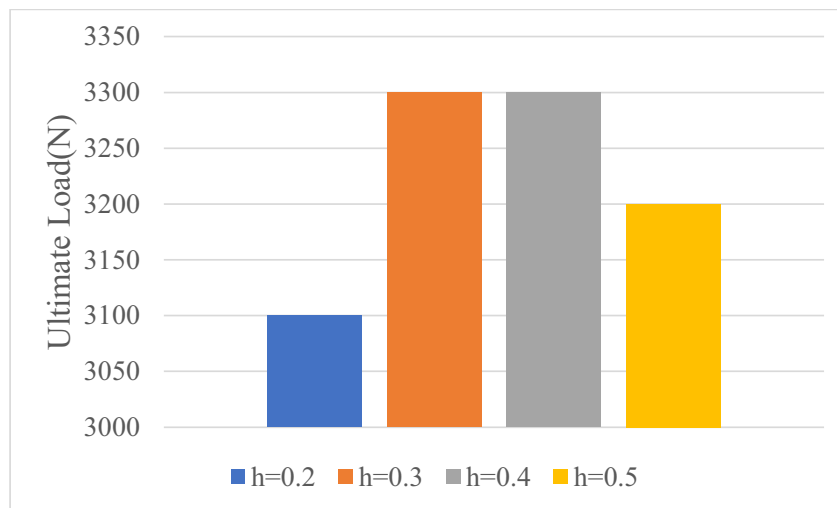


Figure12 : The improving ratio of the spacing between the Geo-grid layers

#### v. The effect of varying the Geo-grid layers stiffness (K)

Validation of Geo-grid reinforced layer stiffness was studied under the circular footing. Figure (13) shows the effect of varying the stiffness of the Geo-grid layers (K) on reinforced soil performance. The Geo-grid layer was represented in the finite element program as an Elastoplastic material or elastic material.

Elastic material requires the Axial/Normal Stiffness (EA). While elastoplastic material requires ultimate tensile strength of the Geo-grid ( $N_p$ ). The values of the stiffness were varied as reported in Table (2)

Table 2 The properties of Geo-grid layers reinforced(KN/m)

	Case (1)	Case (2)	Case (3)	Case (4)	Case (5)
Ultimate tensile strength of the Geo-grid ( $N_p$ ) KN/m	Elastic material	45	50	55	60
Axial/Normal Stiffness (EA)KN/m	219	500	750	1000	1250

Figure (13) shows the load settlement curve using the aforementioned geo-grid stiffness. The higher the stiffness the higher bearing capacity and the improvement ration as well. However, a significant improvement was occurred by increasing the Axial/Normal Stiffness (EA) from 219 to 750 KN/m then the improvement starts to decrease above the (EA) equal 750KN/m. The improvement ratio or bearing capacity ratio decreases from 4% to 1.5% by changing the normal stiffness from EA =750 KN/m to EA = 1000 KN/m and the same reduction ratio by changing the normal stiffness from EA = 1000 KN/m to EA = 1250 KN/m. It could be concluded that an optimum Axial/Normal Stiffness (EA) equal 750KN/m with the ultimate tensile strength of the Geo-grid ( $N_p$ ) 50 KN/m. The key to determine the optimum Geo-grid layers stiffness (K) is that the cost of the high stiffness geo-grid is high comparatively with the improvement ratio.

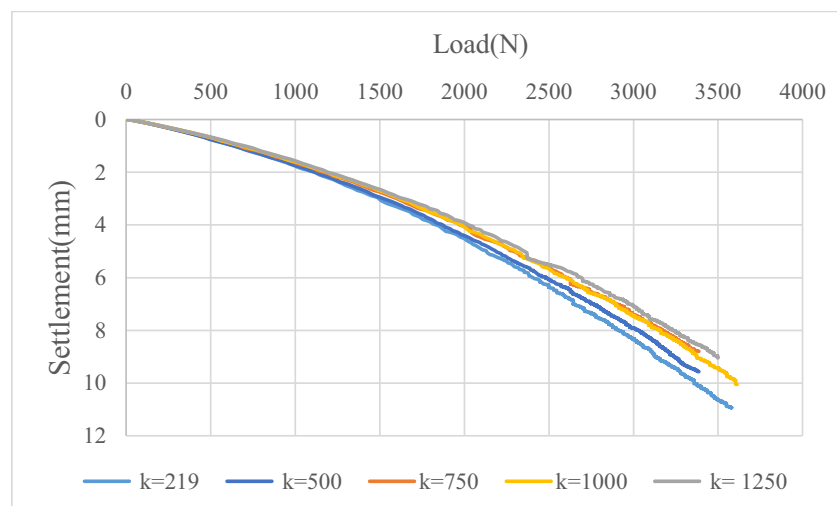


Figure 13: The effect of varied the Geo-grid layers stiffness (K)

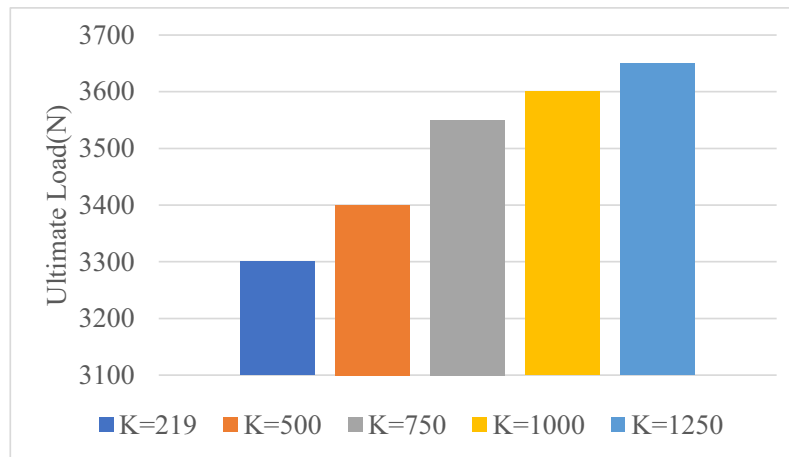


Figure14 : The improving ratio of the Geo-grid layers stiffness (K)

## 5 Conclusion:

In this paper, the reinforced medium sand behavior under the circular footing was studied numerically after a validation with a previous experimental work. A numerical model was used to simulate the bearing capacity ratio by varying five parameters. The five parameters that have been analyzed in this study are: Number of Geo-grid layers (N), geo-grid layers width (L), distance between the foundation and topmost Geo-grid layer (U), the distance between the Geo-grid layers (h), the Geo-grid layers stiffness (K) on soil performance under circular footing.

The conclusion could be drawn as the follows.

1. The numerical analysis of validation with the experimental results is agreeable by the ratio about 93%.
2. The optimum number of Geo- grid layer (N) is three layers for circular footing.
3. The more increasing of the Geo-grid width the more improvement in the bearing capacity results and the optimum ratio between the length of Geo-grid layer to footing diameter is ( $L/D=4$ ).
4. The proper distance between the foundation and topmost Geo-grid layer ( $U/D$ ) equal 0.4.
5. The optimum distance between the Geo-grid layers was ( $h/D$ ) equals 0.3.
6. The optimum Axial/Normal Stiffness (EA) equal 750KN/m with ultimate tensile strength of the Geo-grid ( $N_p$ ) 50 KN/m for circular footing.

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