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Bearing Capacity of Two Closely Spaced Strip Footings on Geogrid Reinforced Sand

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Abstract

The finite element method is used to investigate the ultimate bearing capacity of two closely spaced strip footings on geogrid reinforced sand. The effect of variation of several parameters on the bearing capacity had been studied (number of reinforcement layers, optimum depth of the first and last layers of reinforcement). In this study the main results show that, the bearing capacity of the soil increases, and settlement decrease as with the number of reinforcement layers. The optimum depth of the first layer of reinforcement ranged between (0.375-1)B, while optimum depth of the last layer of reinforcement varies between (1.125-2.25)B depending on the angle of internal friction. The optimum number of reinforcement layers is ranged between (4-6) depending on the center to center spacing between the interfering footings and the angle of internal friction.

Key Words:- Bearing Capacity, Closely Spaced Footings, Finite Element method, Geogrid, Soil reinforcement

قابلية تحمل التربة لأساسين شريطيين متقاربين على تربة رملية مسلحة

الخلاصة

في هذا البحث تم دراسة توزيع الاجهادات وقابلية تحمل التربة لأساسين شريطيين متقاربين مستندين على تربة رملية مسلحة باستخدام طريقة العناصر المحددة. درس تأثير عدد من المتغيرات على قابلية تحمل التربة مثل العدد الأمثل لطبقا ت التسليح، والعمق الأمثل لأول وأخر طبقة من طبقات التسليح.

بينت النتائج التي تم الحصول عليها بان قابلية تحمل التربة تزداد بزيادة عدد طبقات التسليح في حين أن مقدار الهبوط يتناقص. كما وجد بان أقصى عمق لأول طبقة من طبقات التسليح يتراوح بين B (0.375–1) وان أقصى عمق لأخر طبقة من الطبقات يتراوح بينB (2.251.25–) اعتمادا على ثلاث قيم لزاوية احتكاك التربة (25°, 30°, 35°) كما وجد بأن امثل عدد لطبقات التسليح يتراوح بين (4–6) اعتمادا على المسافة بين مركزي الأساسين وعلى زاوية احتكاك التربة (25°, 30°, 35°).

الكلمات الدالة: قابلية التحمل، الأسس المتقاربة، طريقة العناصر المحددة، الجيوكرد، تسليح التربة.

Notation

B: Footing width
BCR: Bearing capacity ratio
c: Soil cohesion
d: depth of the last layer of reinforcement
h: Vertical distance between the geogrid layer
L: Length of the geogrid layer
N: Number of reinforcement layers
q_{ur} : ultimate bearing capacity of geogrid reinforced sand
$q_{u\,(iso)}$: ultimate bearing capacity of isolated footing for unreinforced sand
u: Depth of the first layer of reinforcement
φ:Soil internal friction angle
S: distance between two closely spaced strip footings

Introduction

The foundation of a structure is defined as that part of the structure in direct contact with the ground and which transmits the load of the structure to the lower part of the soil; therefore the soil must be capable of carrying the loads from any engineering structure placed upon it without shear failure and with resulting settlement being tolerable for that structure.

Due to heavy loads and the non-availability of good construction sites, engineers are often required to place footings at close spacing. Therefore, the footings in the field generally interfere with each other to some extent and are rarely isolated . Due to interference, unequal stress concentrations occur below a footing causes tilting which changes the behavior of the footing. Sometimes the bearing capacity of the soil is low; then it should be improved to meet the criteria for adequate bearing capacity and admissible settlement. Technique of reinforcing the soil is one of the latest and fast growing techniques in the field of geotechnical engineering. The effect of reinforcement is to arrest the lateral flow of soil through frictional bounding at the soil-reinforcement interface. This will substantially improve the load settlement behavior of the soil. Reinforced earth is a composite material, it consists of earth that is reinforced by layers of strips or sheets made of any material capable to carry a large tensile stress. So, the main function of the reinforcement is to take the tensile stress developed in the soil by means of interaction. Reinforced soil foundation may be used to construct shallow foundation on loose granular soil, soft fine soil or organic soil. There are a wide number of reinforcing materials which were used at many of works of geotechnical engineering, one of these material is geogrids Coduto[2].

The effect of the interference of two footings on geogrid reinforced sand have been studied by various researchers: Khing[3], presented a study regarding some laboratory model test results for the ultimate bearing capacity of an isolated, and two closely-spaced, strip foundation resting on unreinforced sand, and sand reinforced with layers of geogrid. Based on the model test results, the variation of the group efficiency with the center-to center spacing of the foundation has been determined.

Kumar and Saran[4], discussed the results based on a total of 74 tests performed on closely spaced strip and square footings on geogrid reinforced sand. This study was carried out to evaluate the effect of spacing between the footings, size of reinforcement, and the continuous and discontinuous reinforcement layers on bearing capacity and tilt of closely spaced footing.

Kumar and Saran[5], presented an analysis for calculating the pressure of an adjacent rectangular footing resting on reinforced sand for a given settlement. An approximate method has been suggested to compute the ultimate bearing capacity of adjacent footings resting on reinforced earth slab.

Kumar and Walla[6], presented an approximate method to calculate the ultimate bearing capacity of a square footing resting on reinforced layered soil. The soil is reinforced with horizontal layers of reinforcement at the top layer of soil only. An approximate method has been suggested to compute the ultimate bearing capacity of square footing on reinforced layered soil. The predicted values of ultimate bearing capacity are in very good agreement with the experimental results.

Saran and Garg.[7], presented a method of analysis for calculating the pressure intensity corresponding to a given settlement for eccentrically and obliquely loaded square and rectangular footings resting on reinforced soil foundation . In their analysis, a method suggested by Agrawal[1] has been used to draw pressure settlement characteristics of eccentrically and obliquely loaded footings on unreinforced soil.

El Sawwaf[8], studied the potential benefits of reinforcing a replaced layer of sand constructed on near a slope crest. Test results indicate that the inclusion of geogrid layers in the replaced sand not only significantly improves the footing performance but also leads to great reduction in the depth of reinforced sand layer required to achieve the allowable settlement. The objective of this research is to investigate the ultimate bearing capacity of two closely spaced strip footings on geogrids reinforced sand. The finite element method is used to simulate the behavior of the soil, footings and geogrids layers.

Finite Element Formulation

It were used (5-noded linear element) with two translation degrees of freedom at each node for corresponding the geogrid as shown in Fig. (1). While (15-node triangular element) were used for representing both of soil and footing as shown in Fig. (2).

The interface elements were used between the geogrid and the sand elements, as shown in Fig. (3). Sand, footing and geogrid tend to behave in a highly non-linear way under load. This non-linear stress-strain behavior can be modeled at several levels of sophistication. The number of model parameters increases with the level of sophistication. The well-known Mohr-columb model can be considered as a first order approximation of sand behavior, based on the fact that (elastic perfectly –plastic model) was used to describe the behavior of the (sand), while (linear elastic model was used to present the behavior of the footing and geogrid. Compressive forces are not allowed to occur in the geogrid. The finite element mesh used for modeling the problem is chosen on the basis of nature of the problem, its boundary conditions, properties of the material involved as shown in Fig. (4). Regarding the boundary conditions adopted, only the horizontal displacements at the side boundary were restrained, while the bottom boundary was fully restrained. The ultimate bearing capacity and the settlement were calculated numerically at the middle of the footings base.

A computer program called (PLAXIS) is used to simulate the behavior of two closely spaced strip footings on geogrid reinforced sand and to determine the ultimate bearing capacity of each footings system. PLAXIS is a finite element program for geotechnical application in which soil models are used to simulate the soil behavior. For more details regarding finite element for material modeling and computer program used , one can refer to reference (Al-Tikrity[9]).

Results and Discussion

Some parameters are varied through their reasonable ranges in order to establish their importance on the load settlement relationship of two closely shallow foundations on geogrid reinforced sand. All the dimensions adopted in the analysis are illustrated in the typical section shown in Fig. (5) for two closely spaced strip footings on reinforced sand. The mechanical properties and strength parameters of soil and concrete are given in Table (1), while the properties of geogrid used in this study are listed in Table (2). The studied parameters can be classified into the following major groups:

Effect of Number of Geogrids Layers

Figures (6) to (7) show the pressure-settlement relationship of two closely spaced shallow footings resting on reinforced sand. As shown in these figures, the bearing capacity of the soil increases with the increase in the number of reinforcement layers. Also a significant decrease in settlement can be noted with increasing the number of geogrids layers.

This behavior can be clarified througth Fig. (8) to (10) , it can be seen that, the length of the shear failure increased with increasing the numbers of geogrid layers. The second reason of this behavior is that by increasing the numbers of geogrid layers, the tensile stress which can be carried out by the geogrid will increase too. As Consequently, the resistance of the soil against shear failure will increased too. Also from the results it can be noted, that there is an optimum number of reinforcement layers, beyond which, the bearing capacity ratio (BCR) of the soil generally remains constant or it may decrease where, (BCR) is the ratio of the bearing capacity of two closely spaced footing on reinforced sand to the bearing capacity of isolated footing on unreinforced sand. Figures (11) and (12), show the relationship between BCR and N for different S/B ratio with two angles of internal friction. It can be noted that, the optimum number of reinforcement layers is varied from (4) to (6). This increase in number of reinforcement leads to a decrease in optimum distance between the geogrid layers. Hence, a reduction in soil bearing capacity.

Best Location of the First and Last Layer of Reinforcement

In order to obtain the best location of the first layer of reinforcement, (u) and the depth of the reinforcement block (d), the following steps was followed:

One layer of geogrid was taken and located it below the base of the footings at different depth (spacing between one location of successive geogrid layers is (0.25m) thought the cluster of the soil. When a sudden increase in bearing capacity through changing the position of the geogrid is occurred, then this is the proper position of the first layer of reinforcement, (u). Then the location of this layer of geogrid is gradually changed below the base of footing until obtaining a value of bearing capacity similar to the bearing capacity of the soil without reinforcement. This depth is the location of the last layer of reinforcement. Between these two depth, one, two, three, …layers of geogrid were put until reaching the optimum number of reinforcement layers.

Figures (13) to (14) show the variation of (BCR) with (u/B) for one layer of geogrid for different values of angle of internal friction (φ) for two closely spaced footings on geogrid reinforced sand. Figure (15) shows, the relationship between effective depth of reinforcement block and center to center spacing between the footings for three value of (φ). It can be seen from this figures that, the effective depth of reinforcement block increased with increasing the angle of internal friction (φ) and also decreased with increasing the center to center spacing between the two footings (S/B). The reason of this behavior can be explained noticing figures (16) to (17). It is clear that the depth of the wedge zone of the shear failure surface increased with increasing the angle of internal friction (φ) and decreasing the center to center spacing between the two footings (S/B). For the location of the first layer of reinforcement, (u), which increased with increasing the angle of internal friction (φ), and the center to center spacing (S/B) as shown in figure (18) due to the effect of the depth of the wedge zone of the shear failure surface also.

Variation of Number of Reinforcement Layers With (S/B)

Variation of the bearing capacity ratio (BCR) of two closely spaced strip footings with different the center to center spacing between the two footings (S/B) for different reinforcement layers are shown in Figures (13) and (14). From these figures it could be noted that, the added number of reinforcement layers had no effect on the behavior of the reinforced sand under two closely spaced strip footings.

Conclusions

1. The results show that as the number of reinforcement layers increase, there is an increase in the bearing capacity of the soil and a decrease in settlement. It was also found that there is an optimum number of reinforcement layers for each case of center to center spacing (S/B) and the angle of internal friction (φ). This optimum number occurs between (4-6) after that number, the bearing capacity ratio (BCR) of the soil generally remain constant or it may

decrease.

2. Best location of the first layer of reinforcement, (u) and the last layer, (d) depends on the center to center spacing (S/B) and the values of the angle of internal friction (φ).

3. It noted that, the number of reinforcement layers had no effect on the distance that obtaining at it maximum bearing capacity and on the distance that the interfering effect became disappear of the two interfering footings for the three angle of internal friction of the soil (25°, 30°, 35°).

4. As the spacing between the two footings decreased, there is increase in the bearing capacity of the soil due to the interfering effect, also there is increase in settlement of the foundation accompanied by increase in bearing capacity

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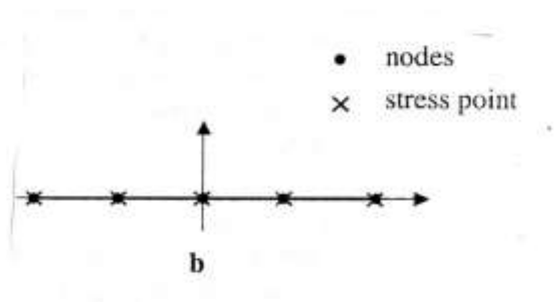


Fig. (1) 5-noded linear element

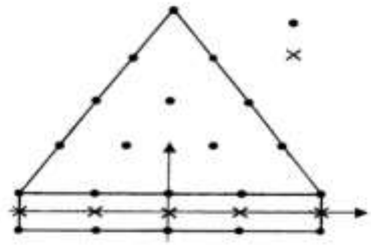


Fig. (3) Distribution of nodes and stress points in interface elements and their connection to soil elements

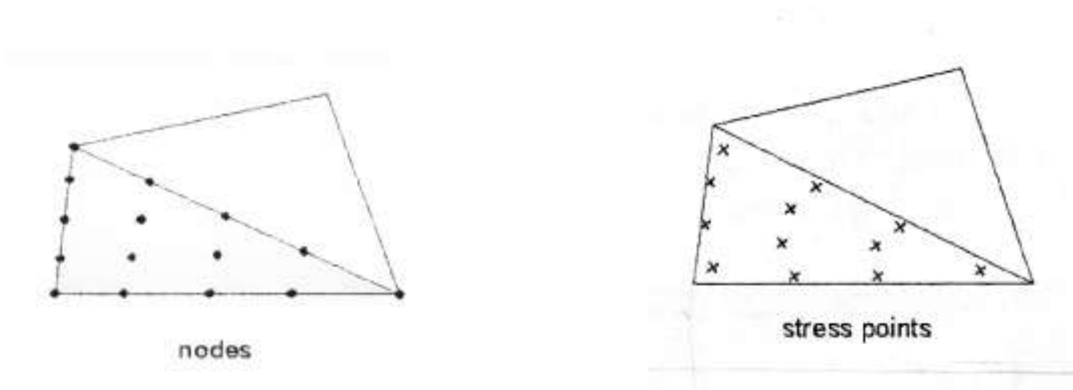


Fig. (2) 15-noded triangular element

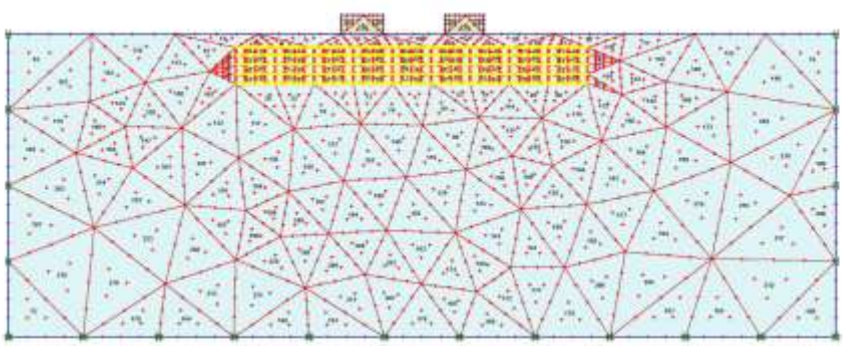


Fig. (4) Finite element mesh for two closely spaced strip footings on reinforced sand

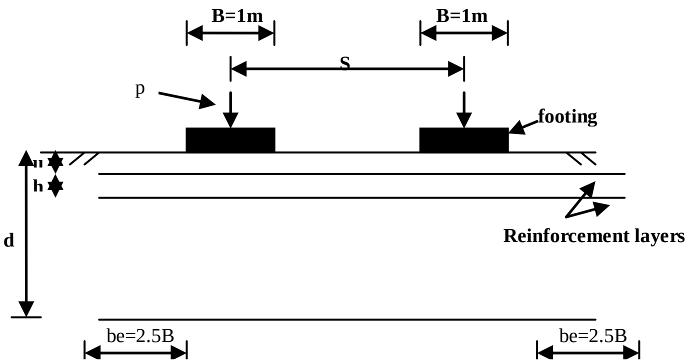


Fig. (5) Geometric configurations of the problem (not to scale)

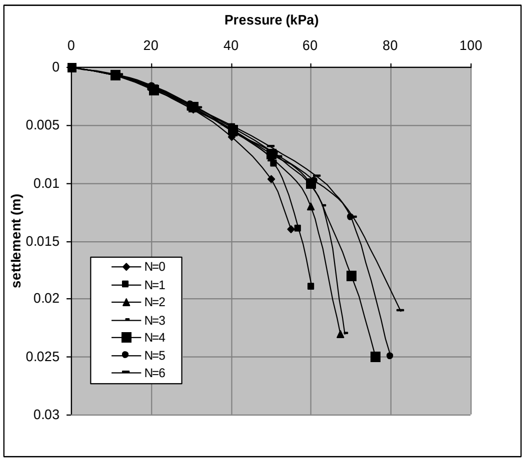


Fig. (6) Pressure-settlement relationship of two closely spaced footings on geogrid reinforced sand (S/B=1.25, φ=30°)

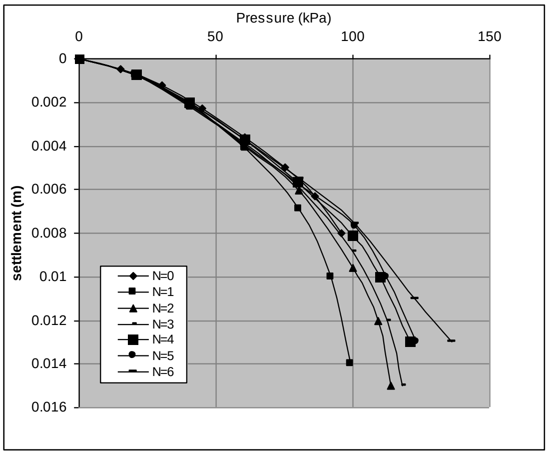
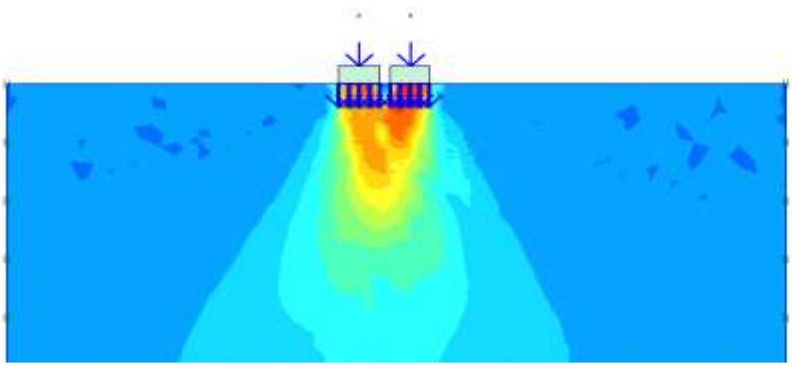


Fig. (7) Pressure-settlement relationship of two closely spaced footings on geogrid reinforced sand (S/B=1.25, φ=35°)



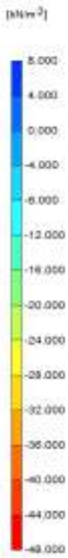


Fig. (8) Total displacement shading for (φ=35°, S/B=1.25, N=0)

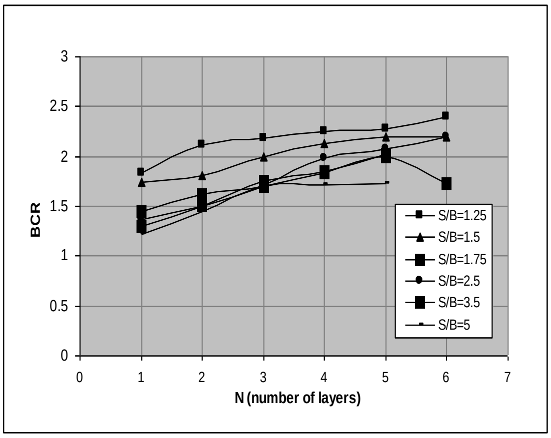


Fig. (9) Total displacement shading for (φ=35º, S/B=1.25, N=3)

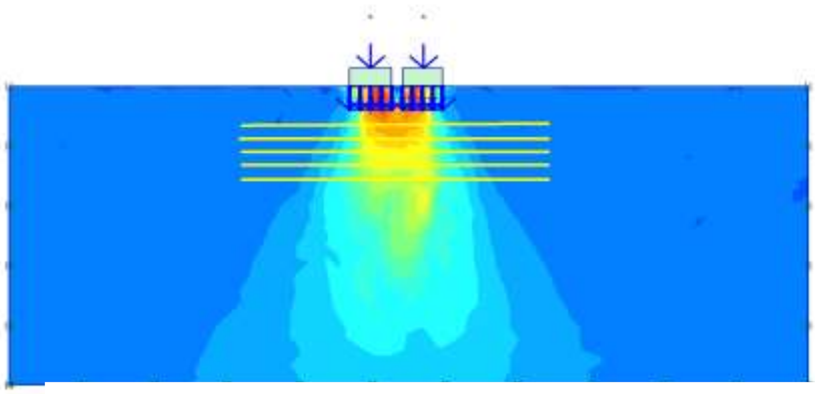
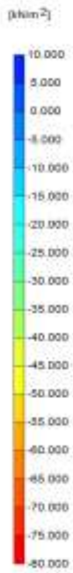



Fig. (10) Total displacement shading for (φ=35º, S/B=1.25, N=5)

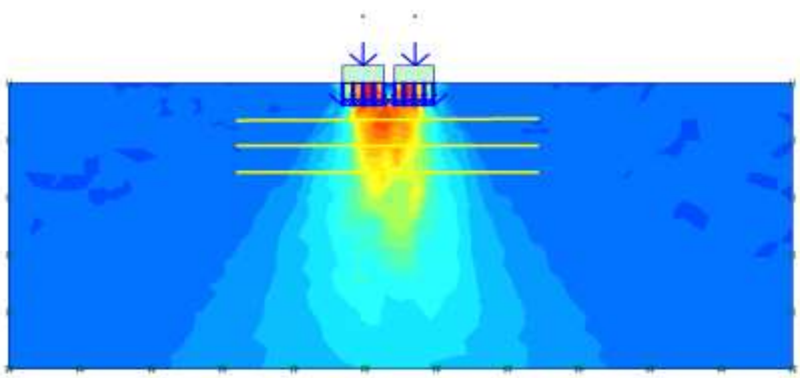
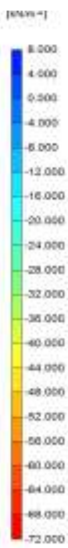



Fig.(11) BCR-Numbers of reinforcement layers relationship for different S/B (φ=30°)

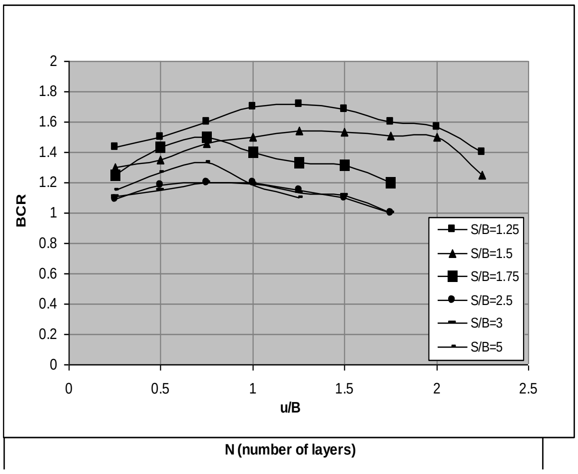


Fig.(13) BCR-u/B relationship for different S/B (N=1, φ=30°)

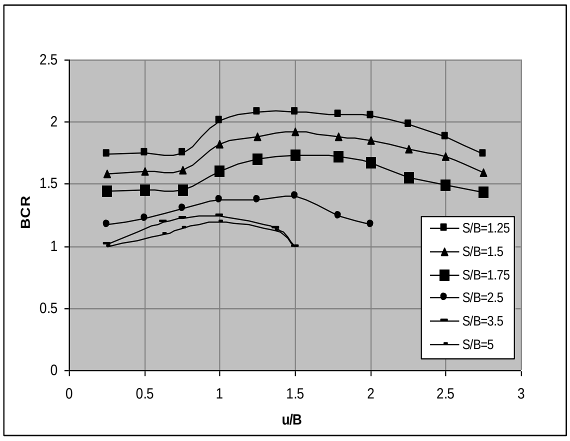


Fig.(14) BCR-u/B relationship for different S/B (N=1, φ=35°)

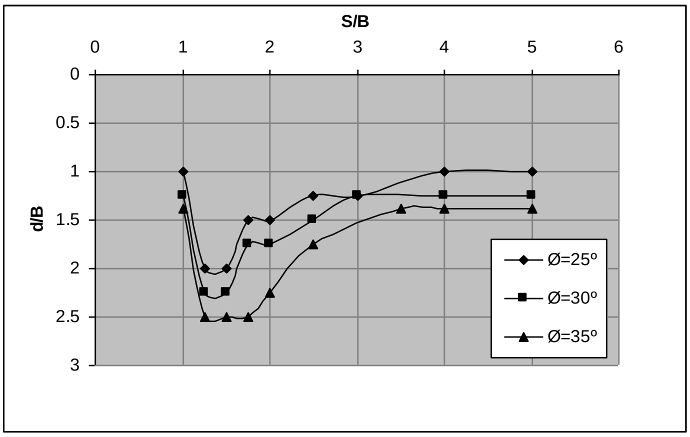


Fig.(15) d/B-S/B relationship for different value of angle of internal friction (φ)(N=0)

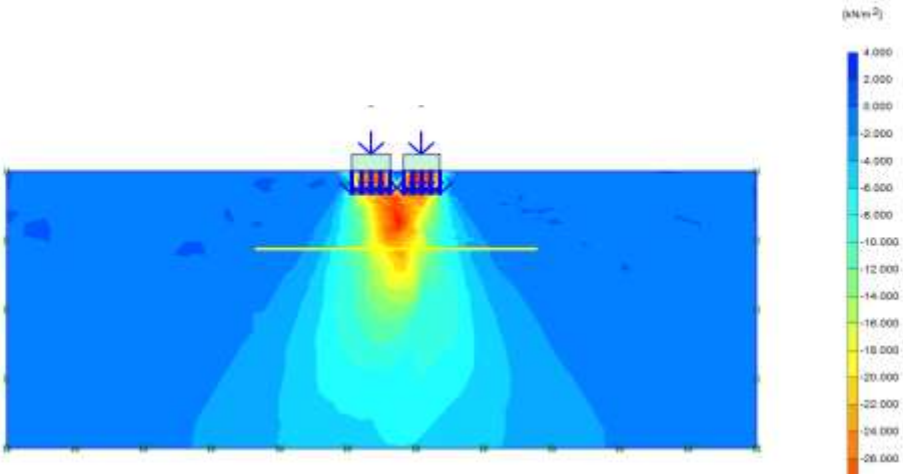


Fig. (16) Total displacement shading for (φ=30º, S/B=1.25, d/B=2.25)

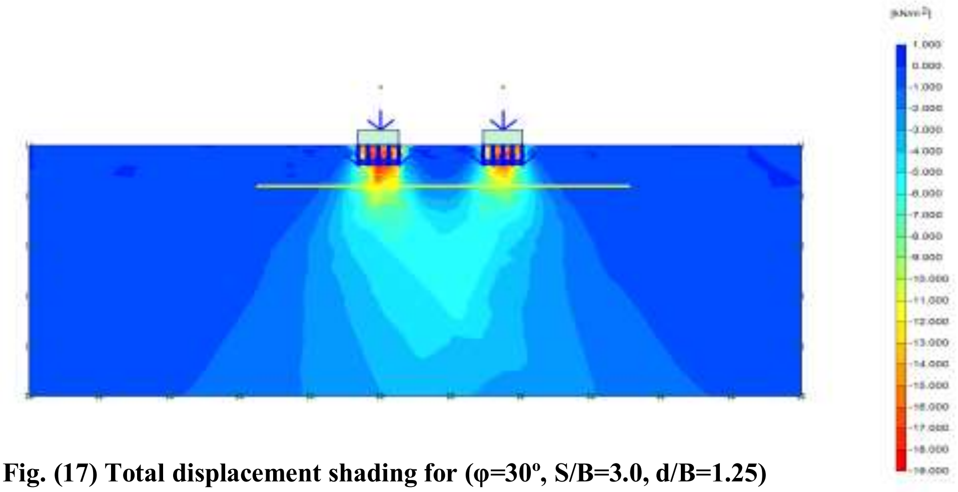


Fig. (17) Total displacement shading for (φ=30º, S/B=3.0, d/B=1.25)
inforced sand (φ=25°, S/B=1.25, N=0)

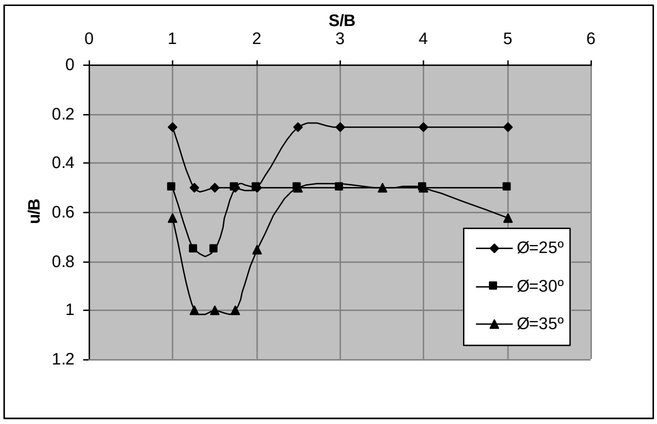


Fig. (18) Variation of (u/B) with (S/B) for different value of the angle of internal friction

Table(1) Soil and footings properties used in this study
reinforced sand (φ=25°, S/B=1.25, N=0)

E (kN/m²)	0.2×10^5	0.2×10^5	0.4×10^5	250×10^5
μ	0.25	0.25	0.25	0.15
φ(°)	25	30	35	-
c(kN/m²)	0	0	0	-
γ (kN/m³)	20	20	20	24

Table (2) Properties of Tenax TT Geogrid of high-density polyethylene

TENAX TT SAMP				
Product	Roll Dimension	Tensile Strength 2%	Connection Strength	LongTerm Strength (kN/m)
TTO45 SAMP	1× 100 m	11	40 kN/m	21.2
TTO60 SAMP	1× 75 m	17	54 kN/m	28.3
TTO90 SAMP	1× 50 m	26	81 kN/m	42.2
TT120SAMP	1× 30 m	36	110 kN/m	56.5