University of Baghdad
College of Engineering
JOURNAL OF ENGINEERING

Journal of Engineering

journal homepage: www.joe.uobaghdad.edu.iq

Volume 28 Number 12 December 2022

Civil and Architectural Engineering

The Optimum Reinforcement Layer Number for Soil under the Ring Footing Subjected to Inclined Load

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ABSTRACT

The primary components of successful engineering projects are time, cost, and quality. The use of the ring footing ensures the presence of these elements. This investigation aims to find the optimum number of geogrid reinforcement layers under ring footing subjected to inclined loading. For this purpose, experimental models were used. The parameters were studied to find the optimum geogrid layers number, including the optimum geogrid layers spacing and the optimum geogrid layers number. The optimum geogrid layers spacing value is 0.5B. And as the load inclination angle increased, the tilting and the tilting improvement percent for the load inclination angles (5°,10°,15°) are (40%,28%, and 5%) respectively. The reduction percent of the lateral displacement for the spacing ratio (0.5B,0.75B,1B,1.25B) are (16%,10%,8%,7%), respectively.
The optimum geogrid layers number is found to be 4. As the load inclination angle increased, the tilting and the tilting improvement percent for the load inclination angles (5°,10°,15°) are (45%,33%, and 8%), respectively. The reduction percent of the lateral displacement for the reinforcement layers number (1,2,3,4) are (12%,16%,18%,20%), respectively

Keywords: Ring footing, Sandy soil, Geogrid, Carrying capacity, Inclined load

العدد الامثل لطبقات التسليح تحت الأساس الحلقي تحت تاثير حمل مائل

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Peer review under the responsibility of University of Baghdad.
https://doi.org/10.31026/j.eng.2022.12.02

Article received: 6/6/2022
Article accepted: 7/7/2022
Article published: 1/12/2022

الخلاصة

المكونات الرئيسية للمشاريع الناجحة هي الوقت,الكلفة,الجودة.استخدام الاساس الحلقي يضمن توفر هذه العناصر.يهدف هذا البحث لايجاد العدد الامثل لطبقات التسليح بالمشبكات تحت الاساس الحلقي تحت تاثير الحمل المائل.لهذا الغرض تم اجراء تجارب مختبرية.العوامل التي تم دراستها لايجاد العدد الامثل لطبقات التسليح تتضمن المسافة المثلى بين طبقات التسليح والعدد الامثل لطبقات التسليح. المسافة المثلى بين طبقات التسليح والعدد الامثل لطبقات التسليح كانت 0.5B وبازدياد زاوية تسليط الحمل يزداد الهبوط التفاضلي للاساس الحلقي ,نسبة تحسين الهبوط التفاضلي لزوايا التحميل (5°,10°,15°) كانت (40%,28%, and 5%) تواليا. نسبة التحسين للازاحة الجانبية للاساس للمسافات بين طبقات التسليح (0.5B,0.75B,1B,1.25B) كانت (16%,10%,8%,7%) تواليا .

عدد طبقات التسليح الامثل كان 4. وبازدياد زاويد تسليط الحمل يزداد الهبوط التفاضلي للاساس الحلقي ,نسبة تحسين الهبوط التفاضلي لزوايا التحميل (5°,10°,15°) كانت (45%,33%, and 8%) تواليا. نسبة التحسين للازاحة الجانبية للاساس لعدد طبقات التسليح (1,2,3,4) كانت (12%,16%,18%,20%) تواليا.

الكلمات الرئيسية: الاساس الحلقي, التربة الرملية, تسليط الحمل, الحمل المائل

1. INTRODUCTION

Ring footings are a unique type of shallow foundation in addition to carrying loads of axisymmetric structures such as bridges, piers, jacket structures, silos, wind turbines, and water tower structures **(Kadhum** and **Albusoda, 2021).** The ring foundation can be subjected to statues of different loads, such as inclined loads **(Majeed Ali, 2016)**. The load inclination significantly reduces the carrying capacity of supporting soil by tilting or foundation sliding and lifting the supporting soil **(Gupta** and **Mital, 2021)**. The issue becomes more complicated when the soil is weak, which might be avoided by either increasing the carrying capacity of the soil beneath the foundation or constructing the foundation with larger dimensions to minimize contact load, but this is costly and inefficient. Another solution is using the soil reinforcement material, which is the study's aim.**(Nakai et al., 2014)** and **(Morsy et al., 2019).** Generally, the soil has a low tensile strength. Therefore, it is often necessary to use soil reinforcement to improve the soil, increase its carrying capacity, and reduce differential settlement. Many researchers have written about how soil reinforcement can boost bearing capacity at a low cost. such as using reinforcement materials **(Al-Mosawe et al., 2010), (Al-Mosawe et al., 2008), (Al-Taie** and **Fattah, 2020), (Abbas** and **Hasan, 2017).**

(Thomas and **Philip, 2017)** investigated the bearing capacity of ring foundations resting on both unreinforced and reinforced sand by geonet. And found that the bearing capacity depends on the depth and the number of layers of reinforcements. If the number of layers increases, then the bearing capacity increases too. As the depth increases, the bearing capacity decreases.

The model simulated the effect of multi-layered soil in the research by **(Al-Khaddar and Al-Kubaisi, 2015)**. They investigated numerically the behaviors of ring footing located on two layers when applied inclined load. The results showed that both vertical and horizontal stresses are affected when the inclination angle of the load exceeds 45 degrees, with a reduction of (40-80) % when compared to those with an incline angle of zero degrees. Furthermore, the bending moment and shear forces within the footing were affected by the diameter ratio of the inner diameter to the outer diameter and by the inclination angle of the load.

In this paper, a small experimental model was used to evaluate the performance of ring footing resting on reinforced sandy soil resisting inclined loading, which is an unpopular topic, and there is a lack of studies about the ring footing subjected to inclined loads.

2. MATERIALS AND LABORATORY TESTING EQUIPMENT

2.1 Soil Used

The grain size distribution curve is shown in **Fig.1**. The sand properties and their values are listed in **Table 1**. The sand used in this study is Al-Ekhaither sand. The sand passing sieve No.10 was used**.**

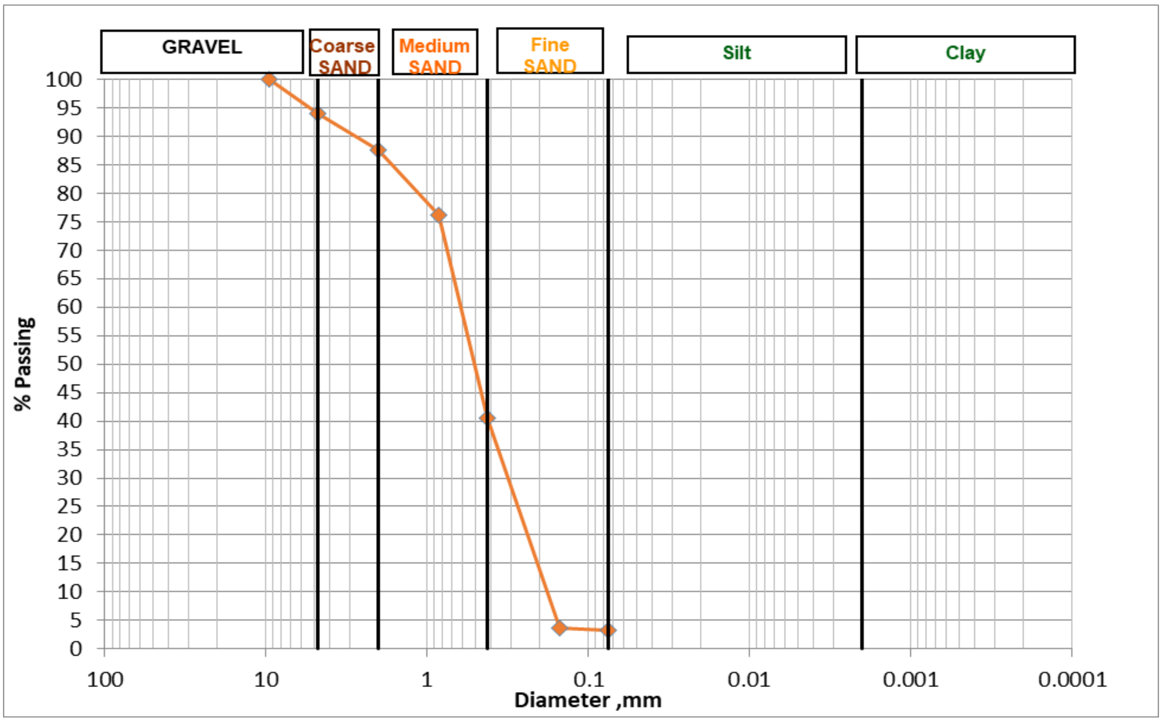


Figure 1: The grain size distribution curve

Table 1: Properties of used sand.

Property	value	Specification
Classification	SP	ASTM D 2487
Coefficient of uniformity (C_u)	4	ASTM D 422
Coefficient of curvature (C_c)	1	ASTM D 422
Specific gravity (G_s)	2.67	ASTM D 854
The angle of friction (Ø) dr=30%	32^o	ASTM D 3080
The angle of friction (Ø) dr=75%	35.6^o	ASTM D 3080
Dry unit weight in test (γ_d) dr=30%	14.6 kN/m^3	ASTM D 2049-69
Dry unit weight in test (γ_d) dr=75%	16.67 kN/m^3	ASTM D 2049-69
Minimum Dry unit weight in test (γ_d) dr=30%	14.2 kN/m^3	ASTM D 2049-69
Maximum dry unit weight (γ_d) dr=30%	17.4 kN/m^3	ASTM D 2049-69

2.2 The Reinforced Materials

In this study, geogrid was used as reinforcement material, and **Table 2** shows its physical properties

Table 2 Physical properties of geogrid.

property	data	property	data
mesh type	rectangle	roll width	1.2 m
rib thickness	1.5 mm	roll length	30 m
rib width	1.6 mm	elastic modules	0.26 Gpa
junction thickness	1.8 mm	tensile strength	2.25 Mpa

2.3 The sand container

A steel container with a dimension of 700x700 and500mm in height. A plate with a thickness of 3 mm was used as the container walls, while an angle section of 50x3mm was used as the frame. All parts were welded together using electrical welding, except one side was made from a bearing load glass. The internal walls of the box are covered with a nylon layer to reduce the friction which might be induced between the box walls and the soil.

2.4 The footing model

The footing used is a small-scale steel ring footing with 100 mm outer diameter, 40mm inner diameter, and 20 mm thickness.

2.5 Measurement instruments

Many devices were used to measure the load-settlement of the ring foundation. The load was measured using a load cell (SC516C) 1-ton capacity **Fig.2-a**. While the settlement and the displacement were recorded using a three-dial gauge Mitutoyo brand with a capacity of 50mm **Fig.2-b**

Figure 2. Measuring instruments (a-load cell, b-dial gauge).

2.6 Loading frame

The loading system was made using an electrical jack with the capacity of 3 tons working on a battery with 12V and 15A, as illustrated in **Fig.3**. The rate of loading was adjusted to be 1 mm/min

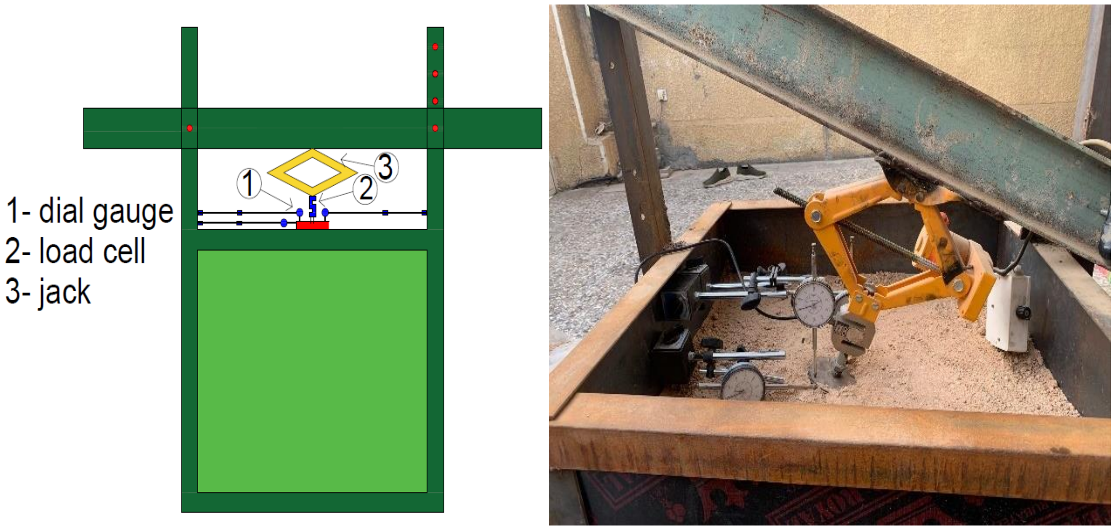


Figure 3. Loading system.

3. TESTING PROCEDURE

The rain technique was used to achieve the required unit weight of sandy soil. A mechanical system similar to that recommended by **(Bieganousky** and **Marcuson, 1976)** was used. Many researchers have used this technique **(Al-Khaddar** and **Al-Kubaisi, 2015), (Fakher** and **Fakhruldin, 2021)** and **(Irfan Ahmed, 2016).** Many tests have been done with various heights to obtain the desired unit weight. A height of drop of (15cm) was chosen, which gave a unit weight of (14.6 kN / m^3) as in **Fig.4**, which corresponds to the void ratio and relative density (0.79) and (30%), respectively, as in **Fig.5**.

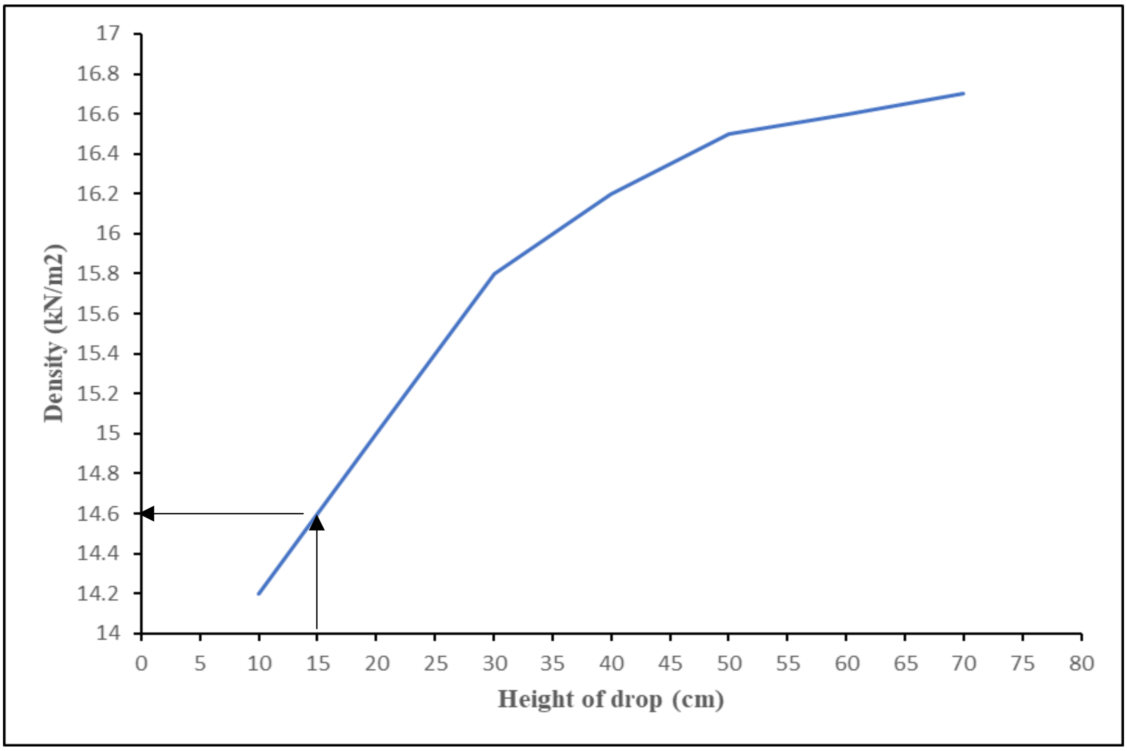


Figure 4. Relation between unit weight-height of drop.

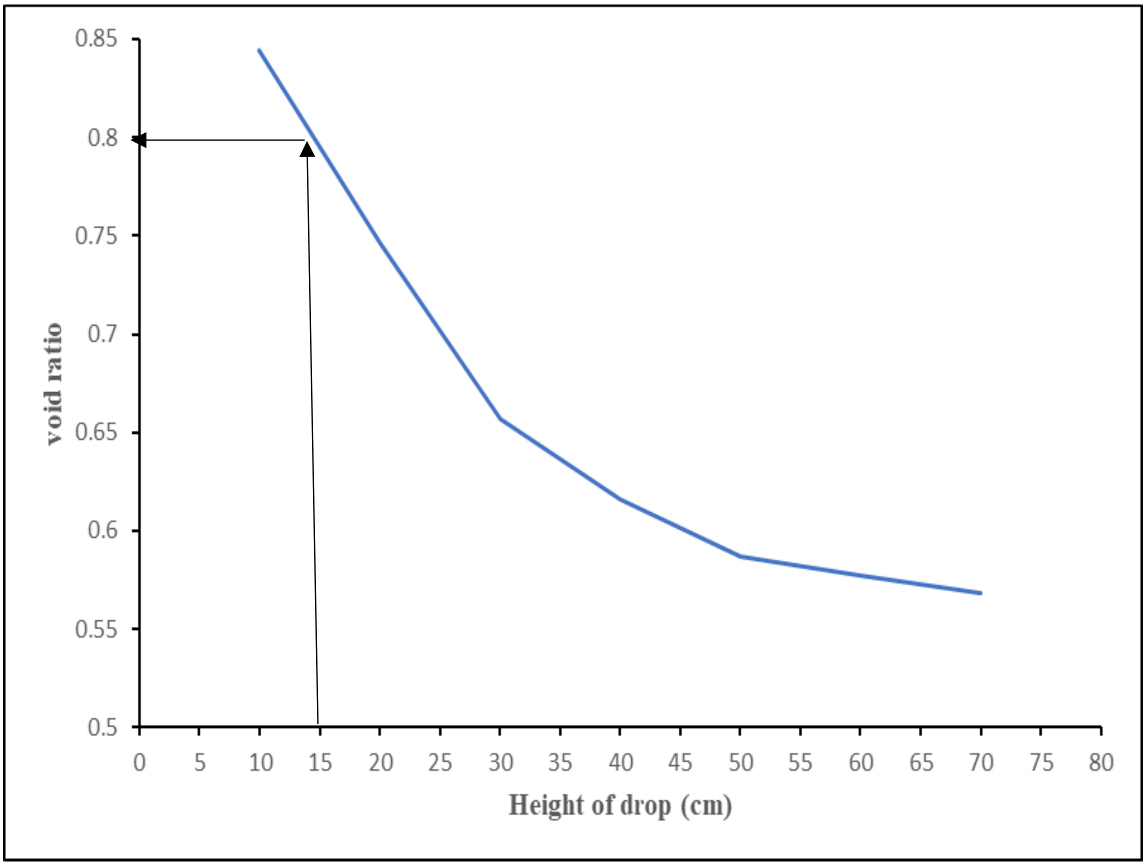


Figure 5 Relation between void ratio-height of drop.

The sand was poured for each test until the designed level of sand was reached, foundation model was placed centrally in the tank. The load was subjected to the footing through an electrical jack. The load is recorded from the load cells that are connected to the digital screen.
The dial gauges were installed on both sides of the foundation to read the differential settlement and lateral displacement. The reinforcement material was inserted into the sand according to the testing program in section 4.

4. STUDIED PARAMETERS

The parameters studied to evaluate the performance of ring footing are the geogrid layers spacing ratio (Z/B), (spacing between layers/ring foundation width), and the number of geogrid layers (N). The testing program is shown in **Table 3**.

Table 3. Testing program

Variables	Vertical spacing Z/B	No.of. geogrids N
Vertical spacing Z/B	(0.5B,0.75B, B,1.25B)	2
NO. of reinforcement N	optimum	1,2,3,4

5. RESULTS AND DISCUSSION

5.1 Effect of Spacing Ratio (Z/B)

To investigate the effect of vertical spacing ratio between reinforced layers (Z/B) where (z = vertical spacing between layers and B = footing width). Tests have been conducted on a footing model subjected to various load inclination angles α (0°, 5°, 10°, and 15°).
Fig.6 to Fig.9 shows the load-settlement/diameter and **Fig.10 to Fig.11** shows the load-horizontal displacement/diameter relationship.

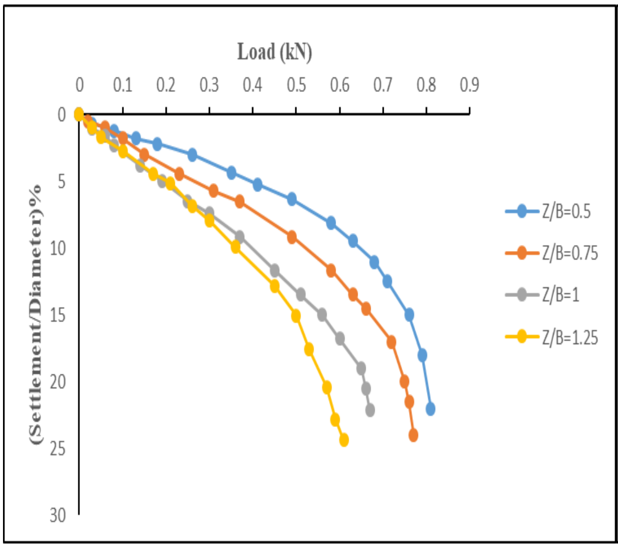


Figure 6. The relationship between

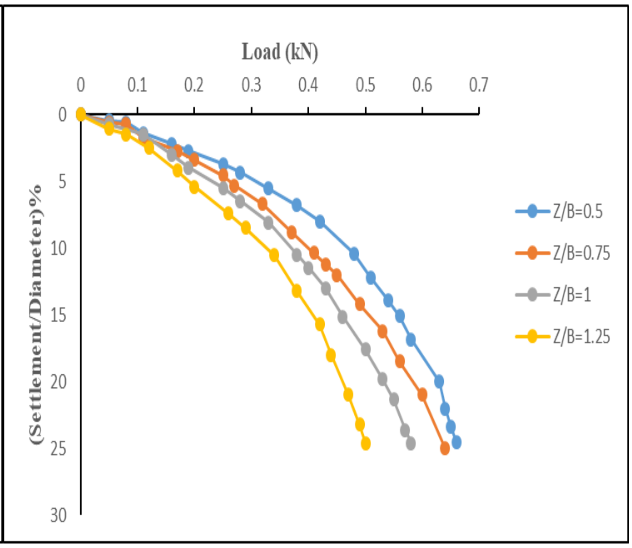
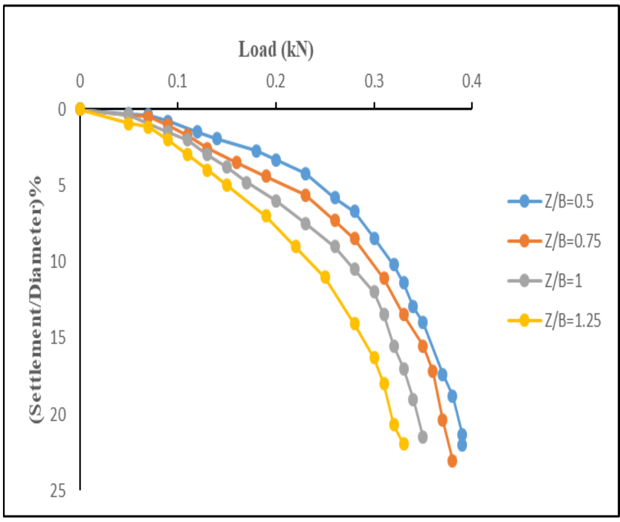


Figure 7. The relationship between

Load-settlement/diameter, (α=0°).

Load-settlement/diameter, (α=5°).



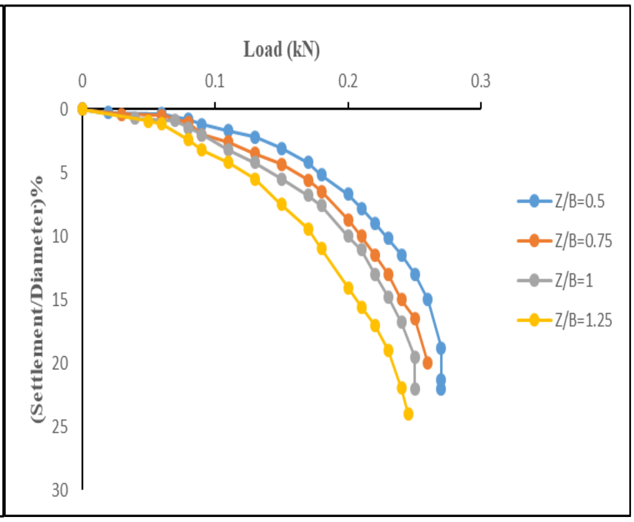
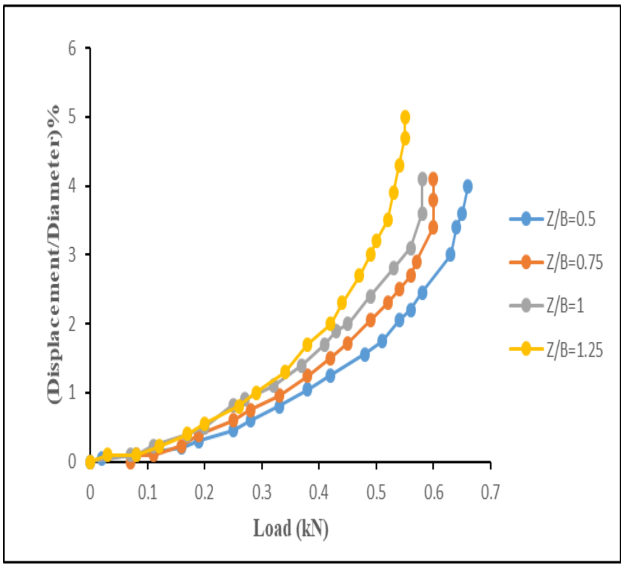


Figure 8. The relationship between Load-settlement/diameter, (α=10°).

Figure 9. The relationship between Load-settlement/diameter, (α=15°).



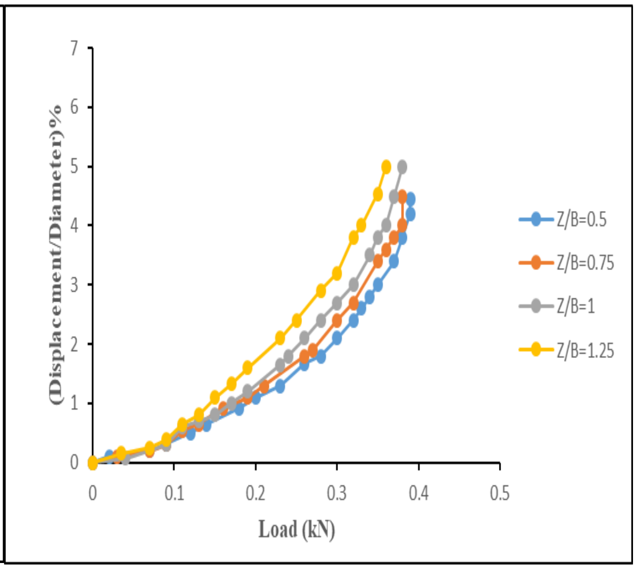


Figure 10. The relationship between Load-displacement/diameter, (α=5°).

Figure 11. The relationship between Load-displacement/diameter, (α=10°).

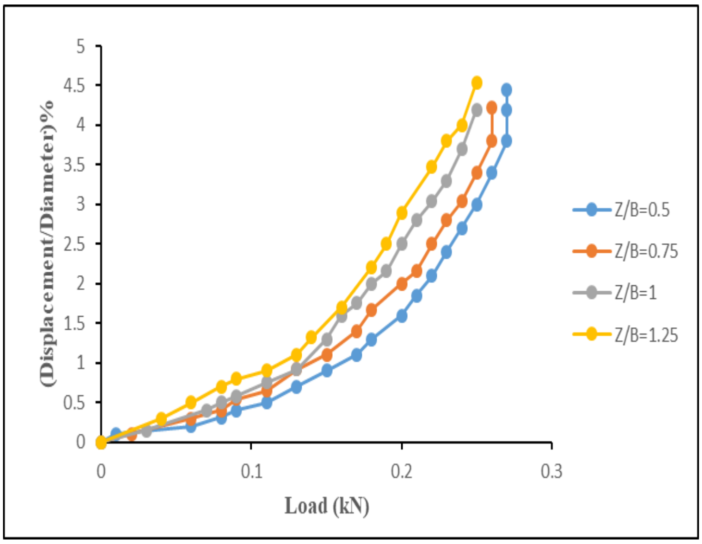


Figure 12. The relationship between Load-displacement/diameter (α=15°).

According to **Fig.6**. to **Fig.12**, the result shows that the required load to reach the failure (settlement equals 10% from the footing width) is higher when the spacing ratio of reinforcing layers is reduced for different inclination values.

Fig.10. to **Fig.12**. shows that the reduction percent of the lateral displacement for the spacing ratio (0.5B,0.75B,1B,1.25B) are (16%,10%,8%,7%), respectively.

From the illustrated figures and results, the optimum reinforcement spacing ratio that reduces settlement and reduces the footing lateral displacement is 0.5B

The load tilting relationship for the optimum spacing ratio shown in **Fig.13**

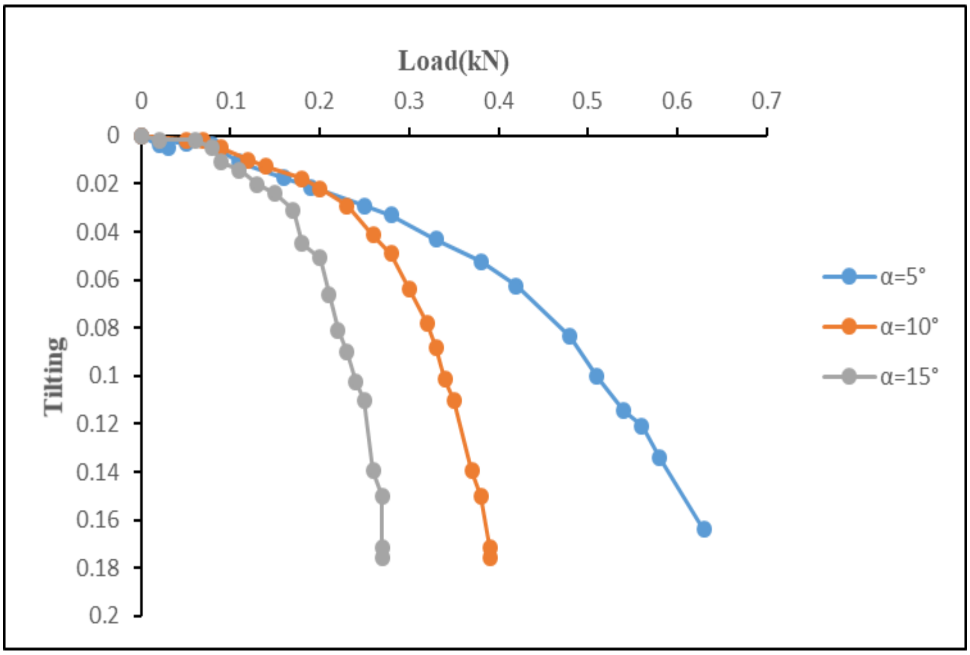


Figure 13. Load-tilting for reinforcement spacing ratio 0.25.

As shown in **Fig.13,** the load tilting relationship for the optimum spacing ratio shows that as the load inclination angle increased, the tilting increased, and the optimum spacing ratio affected the tilting value.

Figures 14 and 4 show the load-carrying improvement for the reinforcement spacing ratio.

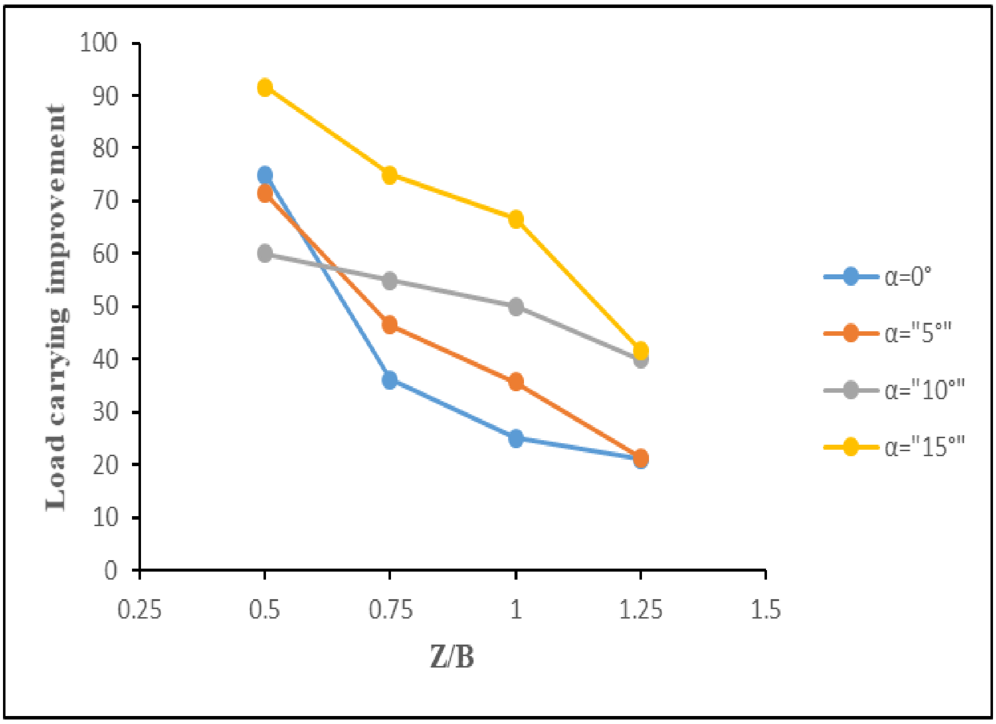


Figure 14. Load carrying improvement percent for various reinforcement spacing ratios

Table 4. Load carrying improvement percent for various reinforcement spacing ratios

Z/B	α=0°	α=5°	α=10°	α=15°
0.5	90%	88%	80%	60%
0.75	65%	70%	70%	50%
1	42%	60%	34%	36%
1.25	45%	30%	30%	45%

It's clearly seen in **Fig. 14** that the spacing ratio Z=0.5B has the highest load-carrying improvement (40%).

5.2 Effect of the Number of Reinforcement (N)

The bearing value changes more drastically with the reinforcement layer (N) number. **Fig.15 to Fig.18** show the load-settlement/diameter relation, and **Fig.19 to Fig.21** show the load-displacement/diameter relation for a different number of reinforcing layers (N) and inclination values.

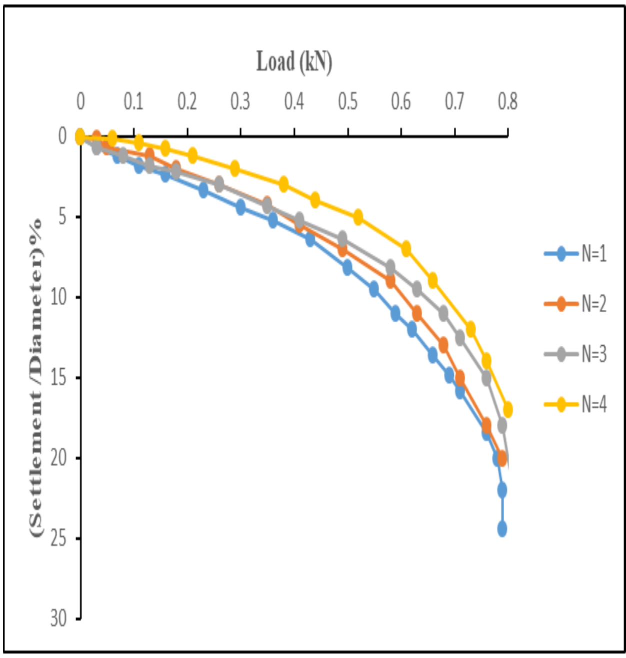


Figure 15. The relationship between Load-settlement/diameter, (α=0°).

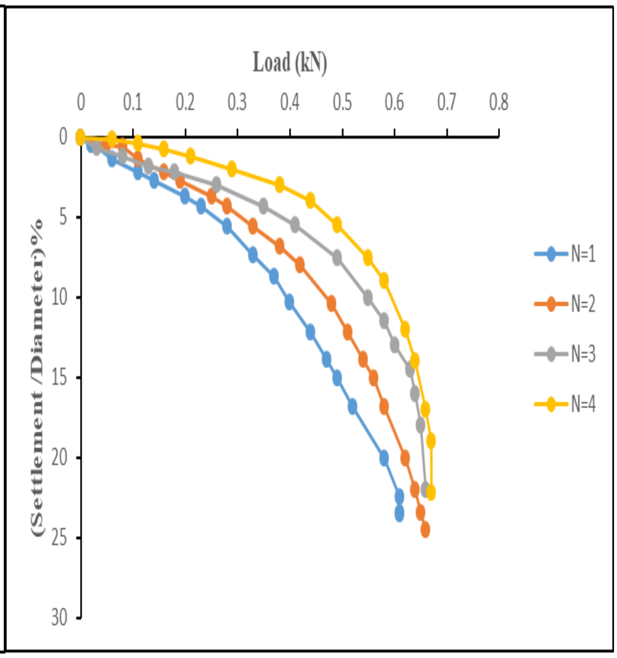


Figure 16. The relationship between Load-settlement/diameter, (α=5°).

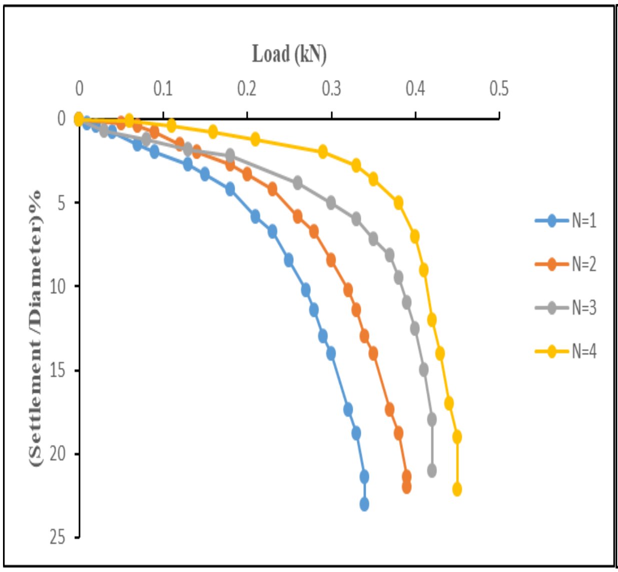


Figure 17. The relationship between Load-settlement/diameter, (α=10°).

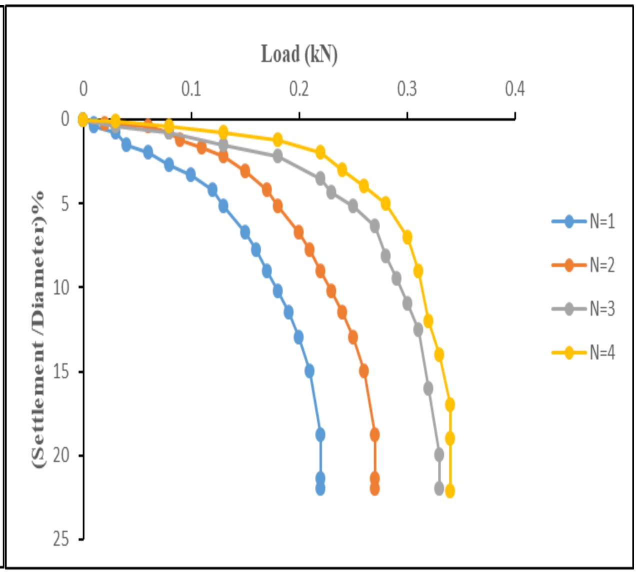


Figure 18. The relationship between Load-settlement/diameter, (α=15°).

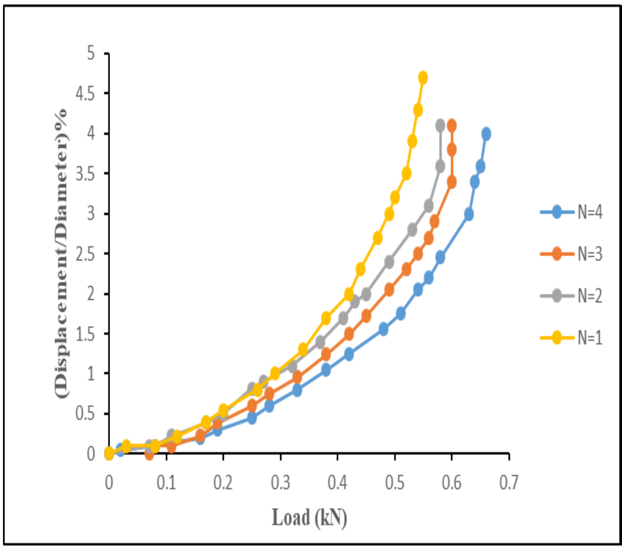


Figure 19. The relationship between Load-displacement/diameter, (α=5°).

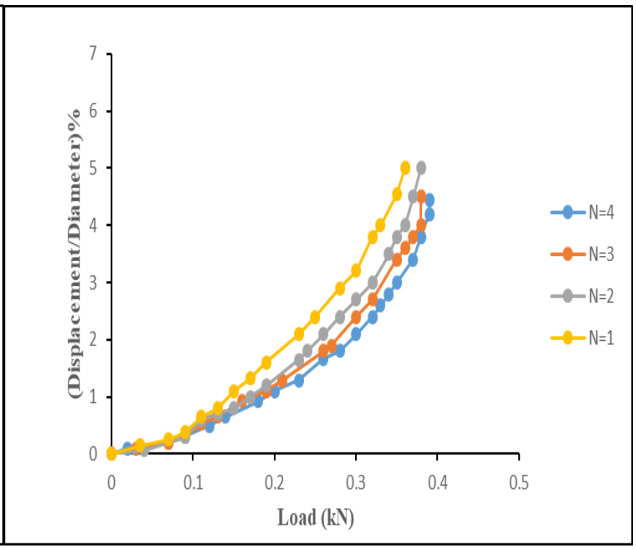


Figure 20. The relationship between Load-displacement/diameter, (α=10°).

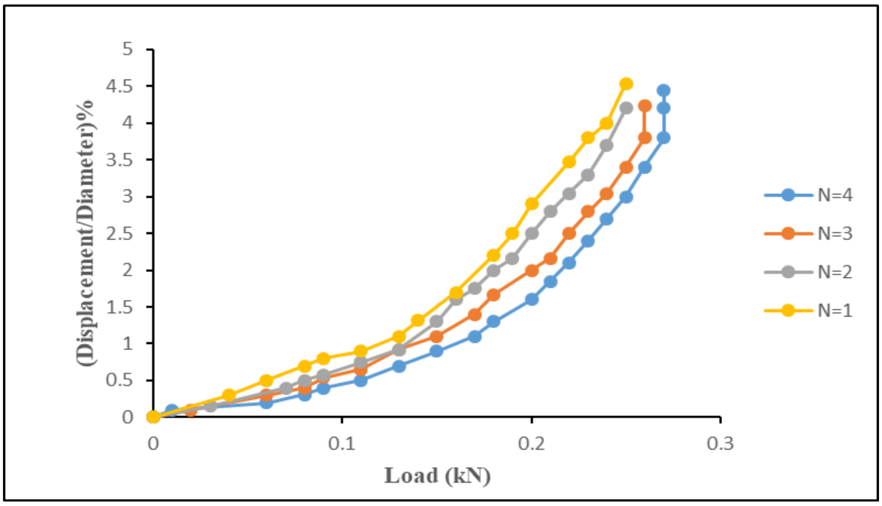


Figure21. The relationship between Load-displacement/diameter (α=15°).

As the number of reinforcement layers increased, the load required to reach the failure case (settlement equals 10% from the footing width) increased. The increase in the number of reinforcement layers leads to a decrease in lateral displacement. This behavior is due to the stiffening effect created by reinforcement. This stiffening refers to the frictional interaction within the mass of reinforced soil with increasing the number of reinforcement layers. The interaction increases, also causing more bonds between the soil and reinforcement and resulting in a more stable mass structure. According to the figures and results illustrated, the optimum number of geogrid layers is 4.

Fig. 22 shows the load tilting relationship for the optimum number of geogrid layers.

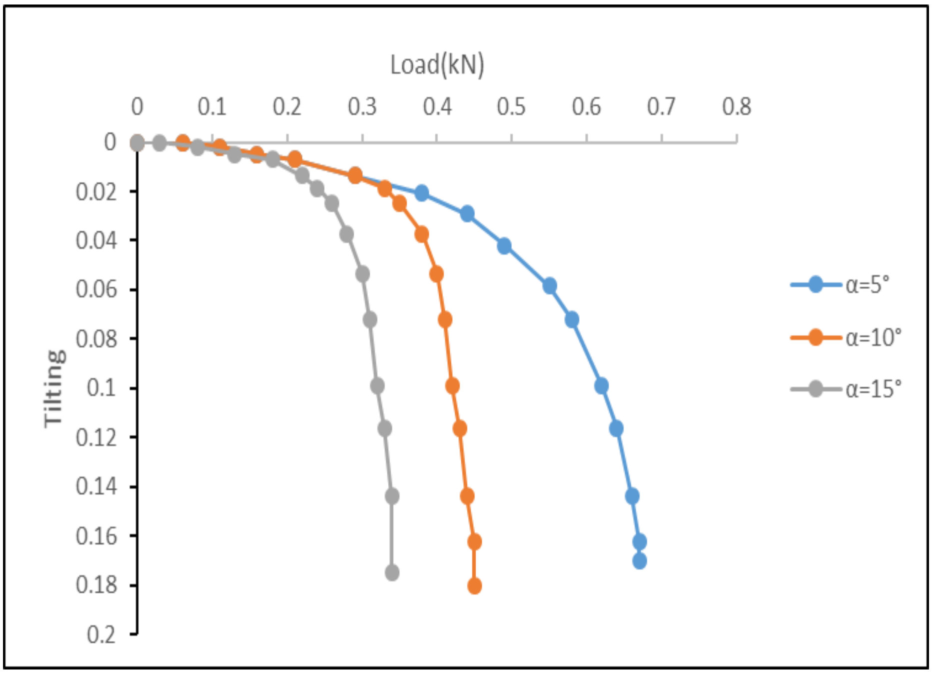


Figure 22. The relationship between load-tilting for a number of reinforcements = 4.

As shown in **Fig 22**, the load tilting relationship for the optimum geogrid layers is clear: as the load inclination angle increased, the tilting increased, and the optimum reinforcement layers number affected the tilting value.

Fig. 23 and **Table 5** show the load-carrying improvement for the reinforcement spacing ratio.

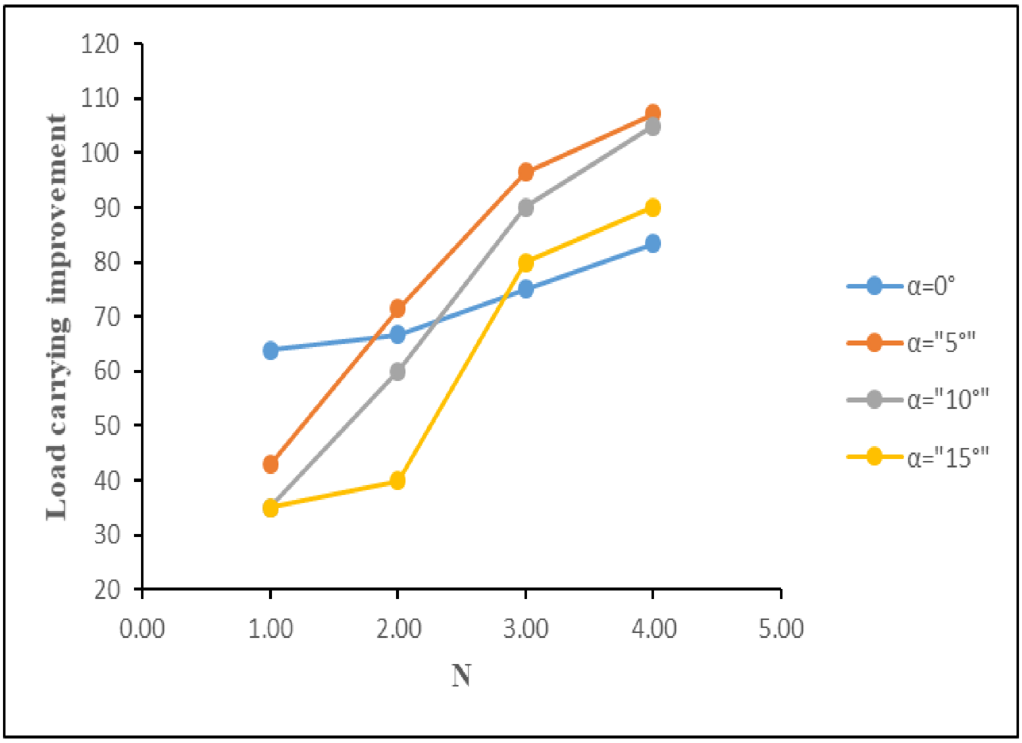


Figure 21. Load carrying improvement percent for various reinforcement spacing ratios

Table 5. Load carrying improvement percent for various reinforcement spacing ratios

N	α=0°	α=5°	α=10°	α=15°
4	95%	94%	85%	64%
3	63%	75%	75%	55%
2	47%	65%	38%	38%
1	40%	35%	33%	50%

It was indicated that the percentage of load-carrying improvement reduced as the load inclination angle increased. The highest reduction for the optimum geogrid number N=4 when the inclination angle α (0°, and 5°).

The bearing value changes more drastically with the reinforcement layer (N) number. This behavior is due to the stiffening effect created by reinforcement frictional. The interaction increases, causing more bonds between the soil and reinforcement and resulting in a more stable mass structure.
These results agreed with Vidal's (1969), in which the presence of reinforcement increases load carrying considerably.

6. CONCLUSIONS

1. The optimum reinforcement spacing ratio 0.5B.
2. The load reduction percent for the optimum reinforcement spacing ratio for the inclination angles α (0°,5°,10°,15°) is (48.86, 41.67, 40.22, 39.8), respectively.
3. The optimum reinforcement ratio has slightly decreased the tilting.
4. The optimum reinforcement number 5.
5. The load reduction percent for the optimum number of reinforcements for the inclination angles α (0°,5°,10°,15°) is (30, 18, 10, 10), respectively.
6. The optimum reinforcement number significantly affected the tilting. And the tilting improvement percent for the load inclination angles (5°,10°, and 15°) are (45%, 33%, and 8%), respectively.

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