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# Experimental Study of Rectangular Footing under Inclined and Eccentric load on Geogried Reinforced Sand

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Bearing Capacity, Eccentric load, Inclined load, Geo-grid, Reinforced Sand, Rectangular Footing.

**ABSTRACT**
This study investigates the behavior of a rectangular footing subjected to inclined and eccentric load on geo-grid reinforced sand by using laboratory modeling. Small model was used to simulate the behavior of rectangular surface footings (length to width ratios of the footings were equal to 1, 1.25, and 1.5). The effect of the eccentricity and inclination of applied load on the bearing capacity, settlement, horizontal displacement and tilt were investigated. The load eccentricity varies from (0, 0.05B, 0.1B to 0.15B) and the load inclination varies from ($0^0$, $5^0$, $10^0$, $15^0$) . The dry sand is reinforced by multiple layers (1, 2, 3, 4 and 5) of Geo-grid. The results illustrated that by increasing the number of reinforcement layers, the bearing capacity increased, but there is an optimum value (5). In general, for central, inclination and eccentricity loading the results indicated that by increasing the number of reinforcement layers (N) the bearing capacity increased while settlement, horizontal displacement and tilt decreased.



# دراسة تجريبية لأساس مستطيل تحت حمل مائل ولا مركزي على رمل مسلح بالمشبكات الأرضية

**الخلاصة**
تستكشف هذه الدراسة قابلية التحمل لأساس مستطيل خاضعة لحمل مائل ولا مركزي على رمال مسلح بمشبكات أرضية باستخدام نموذج مختبري. تم استخدام نموذج صغير لمحاكاة سلوك الأسس السطحية المستطيلة (كانت نسب الطول إلى العرض لأسس تساوي 1، 1.25، 1.5). تأثير ألامركزية وميلان الحمل المسلط على قابلية التحمل والهبوط و الإزاحة الأفقية وميلان الأساس تم استكشافها. تم تسليح الرمل بعدة طبقات من المشبكات الأرضية (1،2،3،4،5). اللامركزية في الحمل المسلط تتغير من ( 0.01B، 0.1B الى 0.15B ) وان ميلان الحمل المسلط يتغير من ( $0^0$، $5^0$، $10^0$ الى $15^0$). أظهرت النتائج بزيادة عدد طبقات التسليح تزداد قابلية التحمل ولكن هنالك قيمة مثلى لعدد طبقات التسليح وهي (5). بصوره عامة ولحمل مركزي أو لا مركزي أو مائل فان زيادة عدد طبقات التسليح يزيد من قابلية التحمل ويقلل من الهبوط و الإزاحة الأفقية وميلان الأساس .

**الكلمات المفتاحية**
قابلية التحمل ، حمل لا مركزي ، حمل مائل ، رمل مسلح ، أساس مستطيل

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**Notations**

B : actual width of foundation.
b : width of reinforcement layer.
BCR : bearing capacity ratios, which is the ultimate bearing capacity of reinforced soil to that for unreinforced soil
Cc : curvature coefficient.
Cu : uniformity coefficient.
d: depth of reinforcement below footing base.
e : load eccentricity .
Gs : specific gravity.
h : vertical distance between consecutive geo-grid layers.
N : number of reinforcement layers.
P : applied load.
qur: Ultimate bearing capacity of rectangular footing subjected to inclined and eccentrically load on reinforced sand.
qu: Ultimate "bearing capacity" of rectangular footing on unreinforced sand.
$R_D$ : Relative density.
T : footing tilt.
U : depth of the topmost layer of geo-grid layer.
of soil.
α : angle of load inclination with vertical.
$\gamma$ : Unit weight of soil.
$\gamma_{dfield}$: Density of the soil in the test box.
$\gamma_{dmin}$: Minimum value of dry density obtained in the laboratory.
$\gamma_{dmax}$ : Maximum value of dry density obtained in the laboratory.

**Introduction**

Foundation is the most important lower hidden part of any structure whether it is onshore or offshore structure. It is the part which receive huge amount of load from superstructure and distribute it to ground. So the foundation should be strong enough to carry the load of superstructure. The performance of a structure mostly depends on the performance of its foundation. Since it is a very important part, so it should be designed properly. Design of foundation consists of two different parts: one is the ultimate bearing capacity of soil below foundation and second is the acceptable settlement that a footing can undergo without any adverse effect on superstructure. Ultimate bearing capacity problem can be solved with the help of either analytical solution or experimental study. First one can be studied using theory of plasticity or finite element method, while the second is reached through performing laboratory model test.

Increasing of inclination and eccentricity of load caused decreasing the bearing capacity of the supporting soil by tilting or sliding the footing and heaving the supporting soil. This might be avoided either by constructing the footing with larger dimensions to reduce the contact pressure which lead to uneconomical design or by increasing the bearing capacity of the supporting soil [1].

Several studies [2,3,4,5] have shown the importance of successful use of sand reinforcement as a cost-effective method of increasing the ultimate bearing capacity and decreasing the settlement below the rectangular foundation. This was achieved by removing the weak sand existing to a certain depth and then replacing the soil or filling the same soil again with the inclusion of horizontal layers of the geo-grid under different depths. Thus, with the potential benefit of the use of sand reinforcement, depending on the type and size of the footing may change leading to economic design.

A literature survey on this subject shows that the majority of the bearing capacity theories involve centric vertical load on the rectangular footing. However in some of the cases, footing undergo eccentric loading due to the eccentrically located column on footing or due to the horizontal force along with vertical load acting on the structure. Footing located at property line, machine foundation, portal frame buildings are some examples where the foundations experience eccentric loading, [6,7].

A foundation under load will undergo settlement due to the horizontal and vertical movement of hand if the load is eccentric, the stress distribution below the footing will be not uniformed causing unequal settlement at two edges which will result in the tilt of footing. The tilt will increase with the increasing eccentricity to width ratio (e/B). When eccentricity to width ratio (e/B) is greater than 1/6, the edge of the footing away from load will lose its contact with the sand which will result in the reduction of effective width of footing and hence reduction of ultimate bearing capacity of foundation. The inclined load applied to the footing increased the composite horizontal force causing an increase in horizontal displacement. When the inclined increased the composite horizontal force increased and thus increasing the likelihood of failure.

The main aim of this study is to investigate behavior of rectangular footing under inclined and eccentric load on geo-grid reinforced sand using

## Laboratory Model Tests

The testing equipment's consist of four main parts, test tank, model of footing, loading system, and vibratory system.

## The Test Box

The sand beds were prepared in a steel box with inside dimensions 900mm × 900mm and 550mm in height. The sides and the bottom were made of 6 mm thickness plate; the plate was supported by four steel channels, with 150 mm high from the base of the steel box. The internal faces of the box were painted (in order to reduce the slide friction which may develop during the process), Mark lines were drawn to give the required thickness of the layers and the location of geo-grid.[3,6]. Fig .1. shows the test box used in this study.

**Figure 1: Test box**

## The Footing Models

In this study three footing models with dimensions ((100*100) mm, (100*125 )mm, (100*150)mm) are used. Thickness 30mm made of two layers of plastic glasses each one (15 mm) is used for made theses footing models. A 1mm deep circular grove is made to hold the metallic ball on one face of the footing at center and at an eccentricity of (0.05 B, 0.1B & 0.15B) from the center as shown in Fig.2. The sand was placed on the other face of footing with the help of rough surface so that friction between footing and foundation soil can develop during application of load.

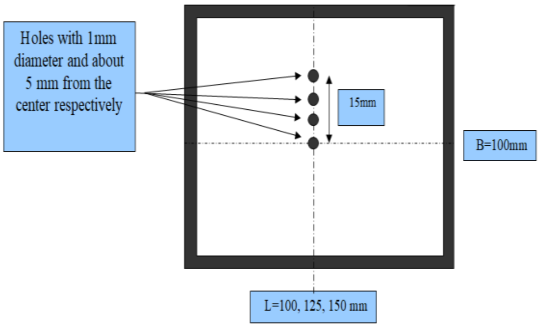


**Figure 2: Plan of the footing models**

## The Loading Frame

The test box was placed over 1100×1100mm strong steel base of 80mm thick. The base was connected to a stiff loading frame, which was locally manufactured as shown in Fig.3. The frame consists of two columns of steel channels 1520 mm height, which intern bolted to a loading platform. The platform was designed to slide along the columns and can be fixed at any desired height by means of slotting spindles and holes provided at different intervals along the two columns. The two steel columns were fixed by four short steel angle pieces connected to the lower plate in the frame.

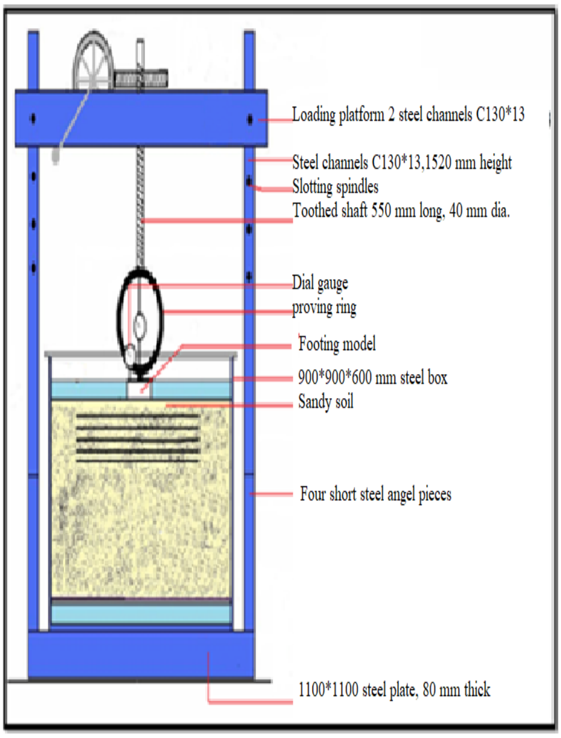


**Figure 3:.Loading Frame**

**The loading system**

The experimental work is done in the Geotechnical laboratory/Civil engineering department/ Engineering college/ Tikrit University. The Laboratory model was manufactured locally. Load was applied by the mechanical arrangement technique used for testing. The proving ring has been fixed on a 550mm diameter cylindrical shaft with a diameter of 40 mm, which transfers the load to the footing and help to be adjusting the height of ring to any position required before or after test. A steel plate was made for each one of the footings, as shown in Plate (1).which attached at the end of the proving ring, and work to transfer loading as equally distributed line load. Three dial gauges were attached to the footing and fixed to measure, where the first dial gauge measuring device was installed inside the proving ring to measure the load, the second dial gauge was fixed with a steel arm located on the internal face of the testing box to measure the vertical settlement and the third dial gauge was fixed with another steel arm tomeasure the horizontal displacement. The accuracy of the dial gauges used was 0.01 mm and maximum travel was 25 mm.

**Plate (1).Loading system**

**Vibration System**

To achieve the required relative density of (70%), it is easier to use an electrical vibrator. This method based on placing the soil in the box in layers each layer of thickness (**50**mm) then placing a plate (700×700mm) then moving the vibrator over the whole area of the plate in a specified time .The time needed to reach the required relative density was achieved by performing a series of trials with different measured time. In each trail, the densities were calculated by collecting samples in small aluminum cans of known volume put at different locations in the test tank [8].

**Material Properties**

**Sand properties**

In this study a poorly graded sand passing sieve No.4 is used. In order to remove as much dust as possible the sand was washed with running water. The properties of the sand used were obtained through carrying out classification tests and some Engineering tests include direct shear. All tests are done according ASTM [9]. The properties of the sand used are shown in Table (1) and grain size distribution is shown in Fig.4.

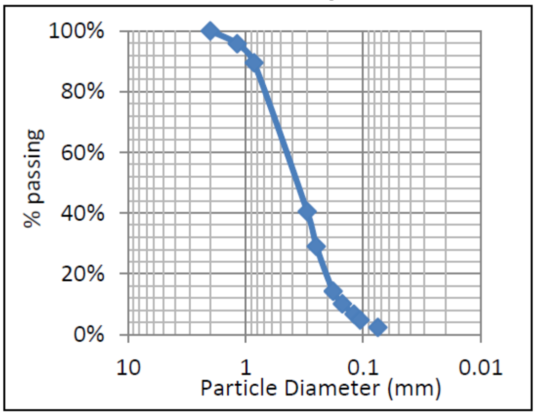


**Figure 4:Grain size distribution of the sand**

**Table (1). Properties of sand**

| Property | value | Specification |
|---|---|---|
| Specific gravity | 2.6 | ASTM D-854 |
| Maximum dry unit weight (kN/m³) | 17.2 | ASTM D-1557 |
| Minimum dry unit weight (kN/m³) | 14.3 | ASTM D-4254 |
| $\gamma_d$ for relative density 70% (kN/m³) | 16.2 | ASTM D-4254 |
| Coefficient of uniformity $C_u$ | 2.9 | ASTM D-421 |
| Coefficient of curvature $C_c$ | 1.08 | ASTM D-421 |
| c (kPa) | 0 | ASTM D-3080 |
| For relative density 70% $\phi$ (degree) | 40 | ASTM D-3080 |

**Geogrid**

One type of geogrid was used TriAx® TX140 Geogrid produced from a punched polypropylene sheet, which is then oriented inthree substantially equilateral directions so that the consequent ribs have a high degreeof molecular orientation, which continues atleast in part through the mass of the integralnode. The characteristics contributing to theperformance of a mechanically stabilizedlayer are illustrated in Table (2).

**Table (2). Engineering characteristics of Tenax TT Samp geogrid**

| Index properties | Longitudinal | Diagonal | Transvers | General |
|---|---|---|---|---|
| • Rib pitch(2),mm(in) | 40(1.6) | 40(1.6) | - | |
| • Mid-rib depth(2),mm(in) | - | 1.2(0.05) | 1.2(0.05) | |
| • Mid-rib width(2),mm(in) | - | 1.1(0.04) | 1.1(0.04) | |
| • Rib shape | | | | Rectangular |
| • Aperture shape | | | | Triangular |
| Structure Integrity | | | | |
| • Junction efficiency % | | | | 93 |
| • Aperture stability, kg-cm/deg, kg-cm(2) | | | | 3 |
| • Radial stiffness at low strain, KN/m@0.5% | | | | 225 |
| Durability | | | | |
| • Resistance to chemical degradation | | | | 100% |
| • Resistance to ultra-violet light and weathering | | | | 100% |

## Experimental Program

The effect of the following parameters on the ultimate bearing capacity of rectangular footing on reinforced sand has been studied: the load inclination (α) (0°, 5°, 10°, and 15°), the load eccentricity ratio (e/B) (0, 0.05, 0.1 and 0.15), the number of geo-grid layers (N) from (1 to 5 layers), length to the width ratio (L/B) (1, 1.25, 1.5). The depth of topmost layer of geo-grid (U/B) chose (0.35) for centric, inclined and eccentrically loaded case is the same that concluded by several researchers, Patra[13], Haripal[10] and Al- Taay[5]. The distance between consecutive layers (h/B) varied was chosen (0.25) for centric, inclined and eccentrically loaded case, this value was used by, Patra[10] and Haripal[11]. All the above parameters are studied for relative densities (70%) to represent dense sand.

The term bearing capacity ratio (BCR) is used to express the effect of soil reinforcement on the bearing capacity and it can be written as follows:

$$\mathrm{BCR} = \frac{q_{uR}}{q_u}$$

Where

$q_{uR}$: Ultimate bearing capacity of rectangular footing on reinforced sand.

$q_u$: Ultimate bearing capacity of rectangular footing on unreinforced sand (α=$0^0$ and e/B=0).

Fig.5. showed the major reinforcement parameters of rectangular footing under inclined and eccentric load on geo-grid reinforced sand, respectively.

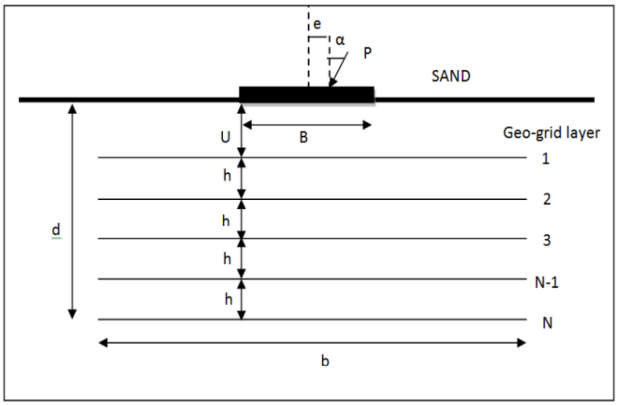


**Figure 5: Major Reinforcement parameters of inclined and eccentric loaded rectangular footing on geo-grid reinforced sand**

## Results and Discussions

### Bearing Capacity of Unreinforced Sand

Tests were done on unreinforced sand using three different shapes of rectangular footings (L/B=1, 1.25, and 1.5) for (α = $0^0$, e/B = 0) and sand having (RD=70%). Each test was repeated at least three times to ensure repeatability of the results. Fig.6. shows the experimental bearing capacity values with vertical settlement. It is obvious from Fig.6 that for surface footing on unreinforced sand increasing (L/B) causes to decrease in the bearing capacity of sand. And noted that the behavior is close and the level of settlement was within the same range also noted that the highest settlement in the failure of the model (B/L=1.5) and the highest value of settlement when was (B/L=1.25)

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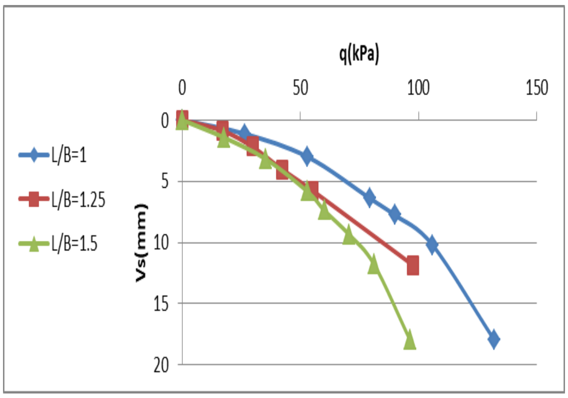


**Figure 6:Experimental bearing capacity values for unreinforced sand with vertical settlement**

### Effect of Geo-grid Reinforced Layers (N) on (BCR)

Fig.7.and Fig.8 showed that (BCR) significantly increased with the increase of the number of geo-grid layers. In addition, it is noticed that there is an optimum value of (N) after which little increase in the value of (BCR) is observed and

finally the experimental data showed that there is an optimum (L/B)=1.25 after which (BCR) begins to decrease and the optimum value of (N=5) and that is because the observable increasing in (BCR).The main work of the geo-grid layer was to increase the bearing capacity of the sand to the loads that are placed on it and thus the probability of failure is decrease.

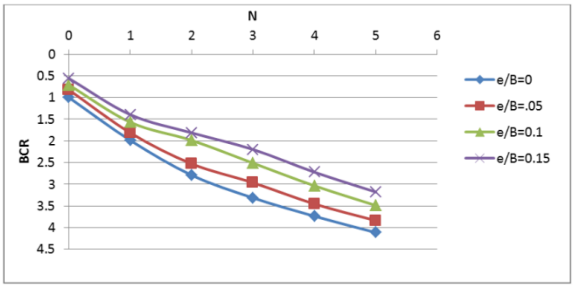


**Figure 7: N-BCR curves for different (e/B) and ($\alpha=0^0$)**

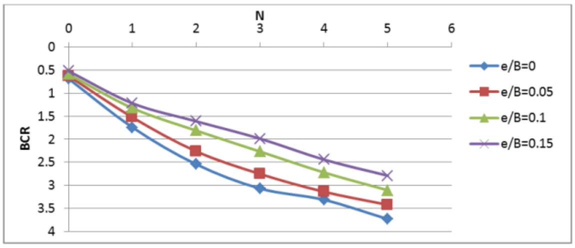


**Figure 8: N-BCR curves for different (e/B) and ($\alpha=5^0$)**

## Effect of Geo-grid Reinforced Layers (N) on Vertical Settlement

From Fig.9 to Fig.12 showed that the load settlement curves for unreinforced sand were similar to those for reinforced sand and the failure was easier to detect and suffers excessive settlement at the beginning of loading similar to that of unreinforced sand then it starts to harden gradually. It was observed that ultimate bearing capacity decreases when eccentricity (*e/B*) and inclination ($\alpha^0$) increases. The vertical settlement decrease as the number of geo-grid increase for the same load, while after frailer the vertical settlement increase as the number of geo-grid layers increase.

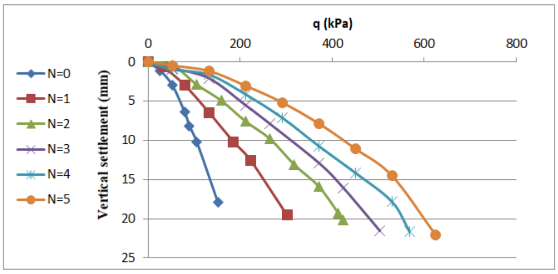


**Figure 9: Pressure-settlement curves for different (N), ($\alpha=0^0$) and (e/B=0)**

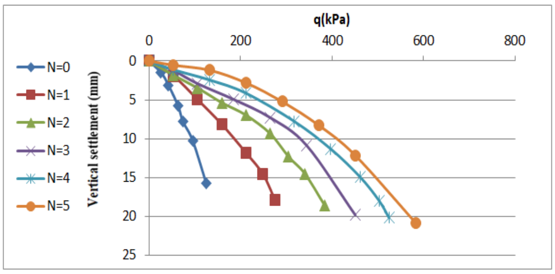


**Figure 10: Pressure-settlement curves for different (N), ($\alpha=0^0$) and (e/B=0.05)**

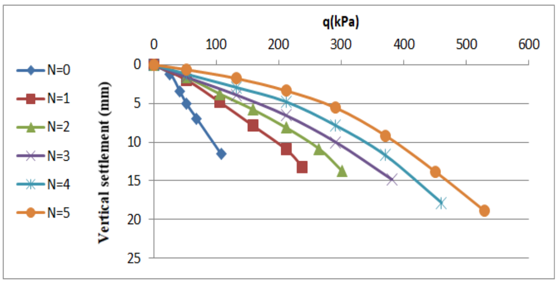


**Figure 11: Pressure-settlement curves for different (N), ($\alpha=0^0$) and (e/B=0.1)**

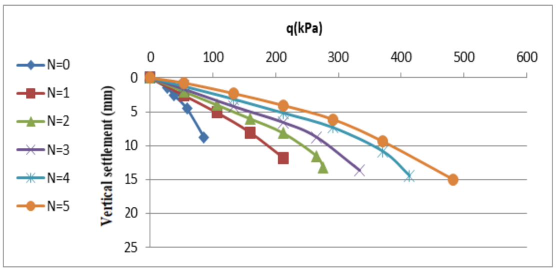


**Figure12 Pressure-settlement curves for different (N), ($\alpha=0^0$) and (e/B=0.15)**

## Effect of Number of Geo-grid Layers (N) on horizontal displacement

The relationship between load and horizontal displacement was showed in Fig.13. to Fig.16 .The load- horizontal displacement curves for unreinforced sand were similar to those for reinforced sand and the failure was easier to detect. The load- horizontal displacement curves for the reinforced sand with 70% relative density suffers excessive settlement at the beginning of loading similar to that of unreinforced sand then it starts to harden gradually. The horizontal displacement decreases as the number of geo-grid increase for the same load, while after frailer the horizontal displacement increases as the number of geo-grid layers increase due to increasing in the ultimate load at failure.

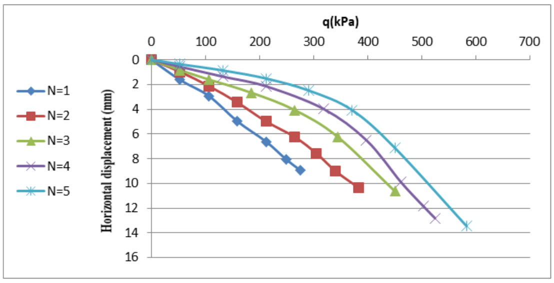


**Figure 13:Pressure-horizontal displacement curves for different (N), (α=$0^0$) and (e/B=0.05)**

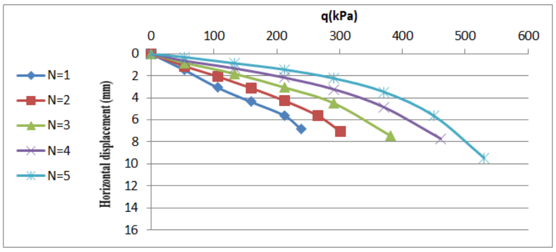


**Figure 14: Pressure- horizontal displacement curves for different (N), (α=$0^0$) and (e/B=0.1)**

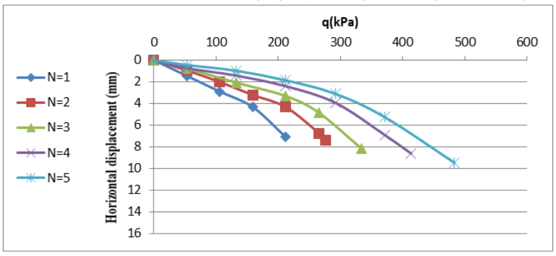


**Figure 15: Pressure- horizontal displacement curves for different (N), (α=$0^0$) and (e/B=0.15)**

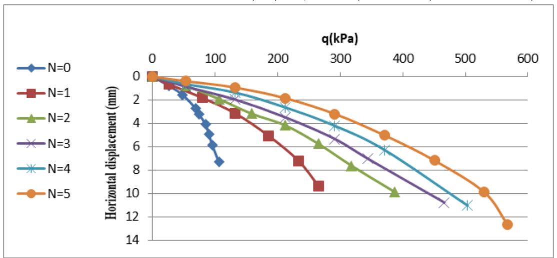


**Figure 16: Pressure- horizontal displacement curves for different (N), (α=$5^0$) and (e/B=0)**

**Effect of Number of Geo-grid Reinforced Layers (N) with Tilt**

The relationship between tilt and load showed in Fig.17.to Fig.20. The load tilt curves for unreinforced sand were similar to those for reinforced sand and the failure was easier to detect. The tilt decrease as the number of geo-grid increase for the same load, while after frailer the tilt increase as the number of geo-grid layers increase. At failure the footing tilt value for the same pressure increased, when the reinforced geo-grid increased. The tilt increase when the eccentricity increases, but the effect less when the inclination of the load increase. From the relationship between the applied load on the footing and the tilt of the footing, the highest values were found for sand bearing capacity.

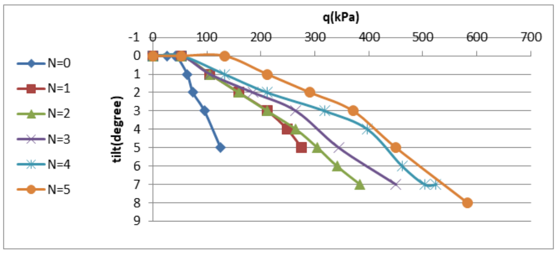


**Figure 17: Pressure-tilt curves for different (N) and (α=$0^0$) and (e/B=0.05)**

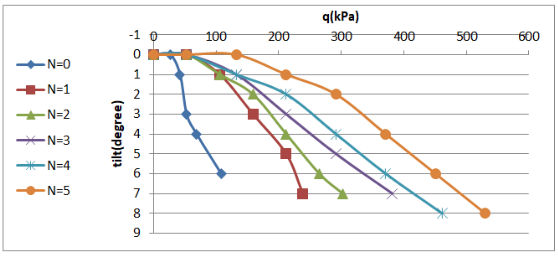


**Figure 18: Pressure-tilt curves for different (N) and (α=$0^0$) and (e/B=0.1)**

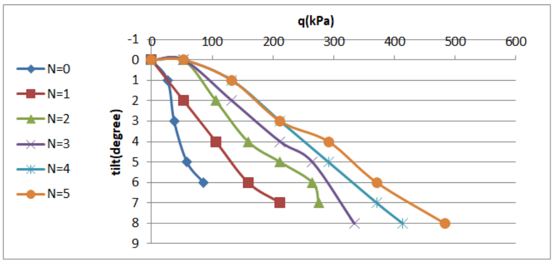


**Figure 19: Pressure-tilt curves for different (N) and (α=$0^0$) and (e/B=0.15)**

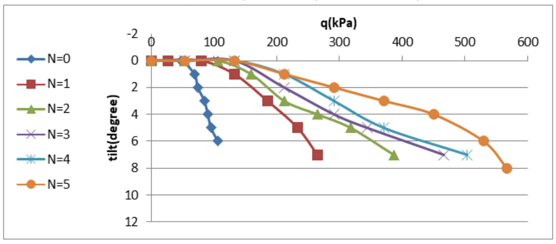


**Figure 20: Pressure-tilt curves for different (N) and (α=$5^0$) and (e/B=0)**

**Conclusions**

1. The results show that increasing the number of geo-grid layers (N) significantly increases the ultimate bearing capacity, but there is an optimum value after which little effect is observed. This optimum value is (N=5) for relative density (70%).
2. Bearing capacity ratio (BCR) on sand with (70%) relative density maximum (5.875), and it reaches optimum when (N=5).
3. Increasing the number of reinforcement layers (N)at the failure leads to :

1) Increasing the vertical settlement.
2) Increasing the horizontal displacement.

3) Increasing the footing tilt.

**4.** From experimental investigation, the main effective factors on the ultimate bearing capacity of the rectangular footing under inclined and eccentric load on geo-grid reinforced sand in this study are as follows :

The load inclination angle (α):

**1)** Increasing (α) decreased the ultimate bearing capacity.
**2)** Increasing (α) decreased the vertical settlement due to failure pressure.
**3)** Increasing (α) increased the horizontal displacement of the footing.
**4)** Increasing (α) had not effected on the depth zone of reinforcing.
**5)** Increasing (α) had no direct effect on the optimum number of geo-grid layers.

The load eccentricity (e):

**1)** Increasing (e) decreased the ultimate bearing capacity.
**2)** Increasing (e) decreased the vertical settlement due to failure pressure.
**3)** Increasing (e) increased the tilting of the footing.
**4)** Increasing (e) had directed effected on the depth zone of reinforcing.
5) Increasing (e) had no directed effect on the optimum number of geo-grid layers.

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