EFFECT OF BIAXIAL ECCENTRICITY IN GEOGRID REINFORCED SAND

Kaan DAL, Murat ORNEK and Yakup TUREDI

Iskenderun Technical University, Civil Engineering Faculty
Civil Engineering Department, Geotechnical Division
31200 Iskenderun / HATAY, TURKEY

ABSTRACT

This study aims to investigate the bearing capacity of embedded square footings rested on geogrid reinforced sand under eccentric loading conditions. The embedment depth of the footings was 0.25B (B=breadth of the footing) in the study. Single layer geogrid reinforcement was placed at four different depths (u/B=0.25, 0.50, 0.75 and 1.00) and the square footing was loaded in central, uniaxial and biaxial (also called double) eccentricity. Two different uniaxial and two different biaxial eccentric loading points were selected in the laboratory tests. The width of square model footing used in the model tests was 0.20m. The improvements in the bearing capacity were determined through the vertical load versus settlement curves which drawn after the test. Also variations in the bearing capacity were interpreted in terms of BCR (Bearing Capacity Ratio).

Another topic investigated in this study is the effect of footing size. For that purpose, three different square footing widths (B=0.20m, 0.30m and 0.40m) were used in the experimental study. Single layer geogrid reinforcement was placed at the four different depths and the footings were loaded only in biaxial eccentricity. The variations in the bearing capacity with different footing sizes and geogrid reinforcement depths were investigated.

The tests were performed in the Geotechnical Laboratory of Civil Engineering Department at Iskenderun Technical University, Iskenderun, Hatay, Turkey. A total of 33 laboratory model tests were performed in this study. The results showed that the geogrid reinforcement had a remarkable effect on the bearing capacity. The bearing capacity decreases with increasing eccentricity. Also it was observed that the depth of single layer geogrid reinforcement is a significant factor for the bearing capacity.

Keywords: Bearing Capacity, Biaxial Eccentricity, Square Footing, Geogrid Reinforcement, Size Effect

1) INTRODUCTION

Footings are build to transfer the loads from the structure to the soils. They have to satisfy some criteria such as bearing capacity, settlement and economy. Footings can be loaded centrally or eccentrically depend on the structural limitations. They may be loaded eccentrically in some structures such as retaining wall, footing of a high tower and buttress. Also footings may be under the effect of bending moments due to this non-centric loading types. The groundwater, earthquake or lateral soil pressure generate extra bending moments in the structures. In a shallow foundation, the eccentricity may be defined as the ratio of the moment to the vertical load.

The continually increasing population and rapid urbanization especially in the urban areas cause some problems such as decreasing in proper residential areas and great stress limits result from the increasing dimensions of the structures. In order to solve those problems, soil improvement methods have became more important in the recent years. Some main purposes of the soil improvement are increasing the bearing capacity, decreasing the settlement, lowering the groundwater level and decreasing the liquefaction potential of the soils (Dal et al., 2014).

Reinforced soil implementation is a improvement method which contains geosynthetics and metal strips. Geogrids are member of the geosynthtetics group. Geogrid reinforcement into the soil increases the bearing capacity and minimizes the settlement problems. In order to improve bearing capacity and tensile strength, geogrid materials have been successfully implemented in recent years with granular filling materials in geotechnical engineering works such as dam, slope, retaining walls, foundations and highways (Guido et al., 1986; Omar et al., 1993; Das et al., 1994; Adams and Collin, 1997; Alawaji, 2001; Dash et al., 2003; Shin et al., 2002; Laman and Yildiz, 2003; Patra et al., 2006).

Many studies have been performed on the bearing capacity, settlement analyses, eccentric loading and geogrid reinforcement in the soils. Laman and Yıldız (2003) investigated ring foundations on geogrid-reniforced sand with model tests. The optimum ring width, the effect of depth of first reinforcement, the number of reinforcement layers and the effect of reinforcement layer length were analysed. This study showed that the reinforcement had a significant effect on the ultimate bearing capacity. They reported that optimum geogrid reinforcement increases the ultimate bearing capacity up to three times that of the unreinforced case.

Binquet and Lee (1975a) carried out some model tests on the bearing capacity of the strip footings rested on reinforced sand soil with aluminium strips. The improvements on the bearing capacity and settlement were observed. Also the results showed that the most effective reinforced soil condition was obtained when u (depth of the first reinforcement layer) value was fewer than 0.67B (B=breadth of footing).

Akinmusuru and Akinbolade (1981) investigated the bearing capacity of square footing rested on the sand soil. Natural fibres were used as reinforcement in the study. The results indicated that the proper reinforcement increases the bearing capacity considerably.

Ornek (2013) conducted a total of 50 model tests to investigate estimation of ultimate loads of eccentric-inclined loaded strip footings rested on sandy soils. The parameters investigated were the eccentricity ratio, the load inclination angle, the footing size and the density of the sand soil. The results were shown that the soil density, the load eccentricity and the load inclination had important effects on the ultimate load of the strip footings.

Kolay et al. (2013) studied the improvement in the bearing capacity in silty clay soil with thin sand layer on top and placing geogrids at different depths. It was concluded that the bearing capacity increased by using single geogrid layer. Also they found that the location of the first layer of reinforcement has an important effect on the bearing capacity.

There are also several studies in the literature on the bearing capacity, the eccentric loading and the reinforced soil (Guido et al., 1986; Chen, 2007; Alawaji, 2001; Demir et al. 2013a; Wayne et al., 1998; Dal et al., 2014).

As seen from the literature review that the studies related to the non-centric loadings in the soils are in rare and only the uniaxial loading types were considered. This study aims to investigate the bearing capacity of embedded square footings rested on geogrid reinforced sand under eccentric loading conditions. For that purpose, experimental studies were conducted in the Geotechnical Laboratory of the Civil Engineering Department of the Iskenderun Technical University, Iskenderun, Hatay, Turkey. The loading points were selected in centric and four different non-centric loading forms. Two of these eccentric loading points are in biaxial eccentricity (also called double eccentric). Those points were designated considering the core area in the model footing with a breadth of 20cm. The eccentric points were positioned inside, on boundary and outside of the core. The single layer geogrid reinforcement was placed at different depths and the variations in the bearing capacity were interpreted through vertical load versus settlement curves. The embedment depth of the footing was kept constant as 0.25B (B=breadth of footing) in this study. The effect of the load eccentricity and the effect of geogrid insertion depth were examined in the section 3.1 and 3.2, respectively. Vertical load (Q) versus settlement (s) curves in the section 3.1 were interpreted in terms of BCR (Bearing Capacity Ratio) in the section 3.2. Also the effect of footing size was investigated in the section 3.3. For that purpose, three different square footing widths (B=0.20m, 0.30m and 0.40m) were used in the experimental study. Single layer geogrid reinforcement was placed at the four different depths and the footings were loaded only in biaxial eccentricity. The variations in the bearing capacity were investigated in the different footing sizes with variable single layer of the geogrid reinforcement depths.

2) EXPERIMENTAL STUDY AND METHODOLOGY

A model rigid square footing which manufactured from mild steel was used in this study. The breadth and thickness of the footing are 20cm and 10mm, respectively. The footing and the load application points (e_0, e_1, e_2, e_3 and e_4) are illustrated in Figure 1. Coloured area is the core area in the Figure 1. Model tests were performed in a rectangular section tank with dimensions of 125cm (length) x 100cm (width) x 100cm (depth). The frame of the tank was made from steel. The tank was fabricated considering side friction effect and lateral yielding. The front and rear surfaces are consist of 10-mm-thick glass, bottom and lateral surfaces are consist of 3mm-thick metal material. The dimensions are large enough to minimize or neglect the boundary effect. General overview of the test tank and apparatus used in the experimental study are shown in Figure 2.

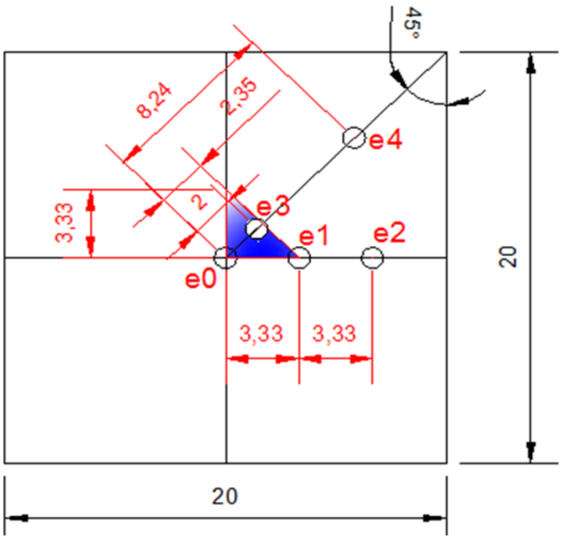


Figure 1. Model square footing and loading points (dimensions in cm)

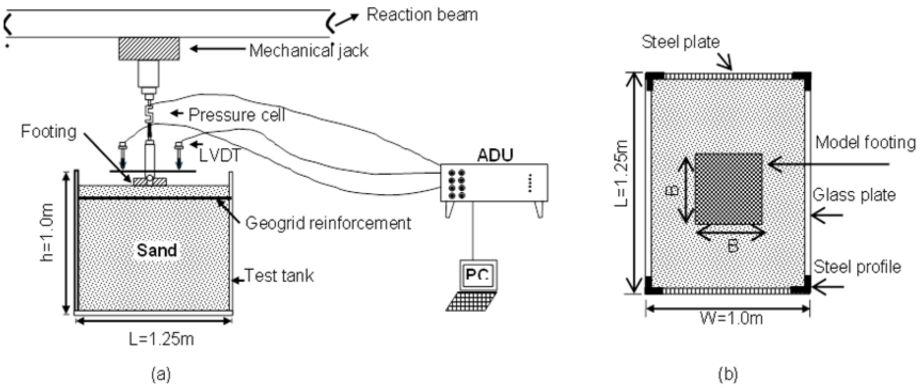


Figure 2. Test tank and apparatus used in the experimental study

The sand used in the experimental study was uniform and clean fine sand. It was obtained from Ceyhan River bed. Standard tests to determine soil parameters were performed in the Geotechnical Laboratory. Grain size distribution curve of the sand is presented in Figure 3. Also properties of the sand used in the study are shown in Table 1.

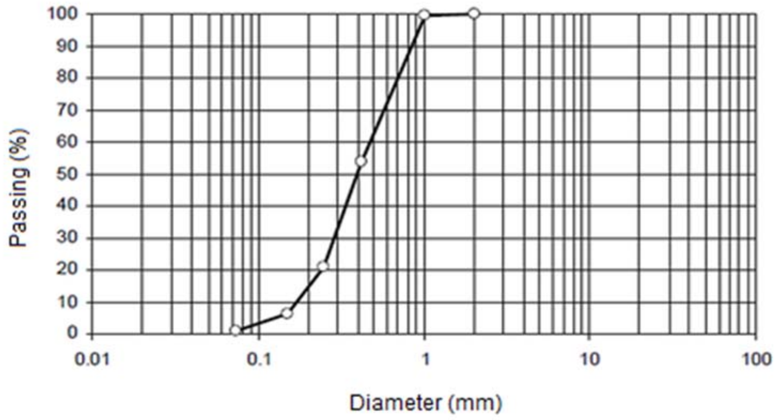


Figure 3. Grain size distribution curve of the sand

Table 1. Properties of the sand used in the study

Property	Unit	Value
Coarse sand fraction	(%)	0.00
Medium sand fraction	(%)	65.00
Fine sand fraction	(%)	35.00
D_{10}	(mm)	0.13
D_{30}	(mm)	0.28
D_{60}	(mm)	0.58
Üniformity coefficent, C_u	-	4.46
Coefficent of curvature, C_c	-	1.04
Cohesion (c)	kPa	0.00
Angle of internal friction (ϕ)	degrees	36.27
Classification (USCS)	-	SP

Note: USCS = Unified Soil Classfication System

Secugrid, Q1 (PP) biaxial geogrid reinforcement was used in the experimental study. The properties of the geogrid are presented in Table 2.

Table 2. Properties of the geogrid reinforcement

Property	Unit	Value
Type	-	Secugrid, Q1 (PP)
Raw material	-	Polypropylene, white
Structure	-	Biaxial
Weight	g/m^2	360
Ultimate tensile strength	kN/m	60
Elongate	%	8
Tensile strength at 2% - 5% elongate	kN/m	22 - 48
Aperture size	mm/mm	31/31

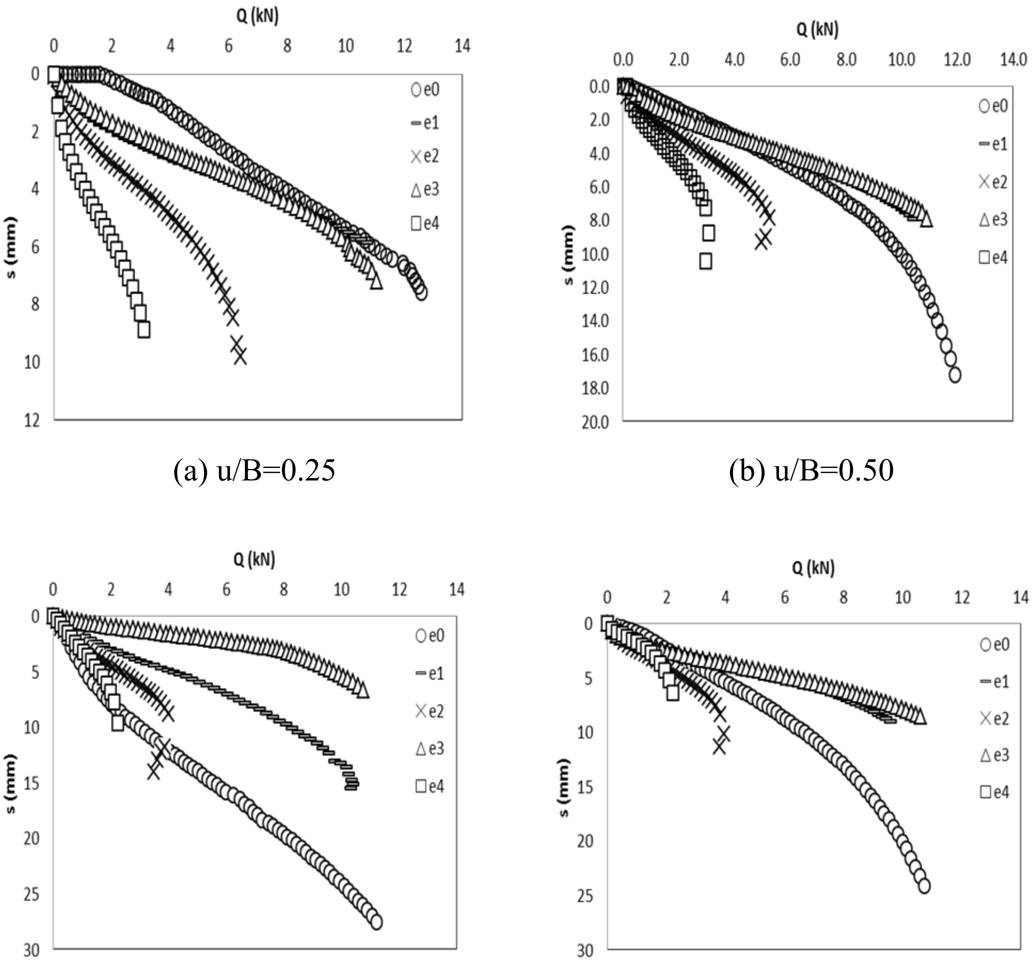
The loose sand was placed into the tank layer by layer. Single layer geogrid reinforcement and footing were embedded at predetermined depth ratios (u/B=0.25, 0.50, 0.75, 1.00 and D_f/B= 0.25). u is the distance between the base of footing and geogrid, while D_f is the distance between the footing and top surface of the sand soil. The load application system was placed one of the eccentricity points (e_0, e_1, e_2, e_3 and e_4) before each test and then footing was covered. The top surface of the sand was levelled using spirit level.

The settlement measurements of the footing were carried out by calibrated two LVDT (Linear Variable Displacement Transducer - Novotechnik TYP TR 50) devices. The devices were placed on either side of a rigid metal bar outside of sand. Load was vertically and gradually applied to the footing by a mechanical jack. Also the load was measured using a calibrated pressure cell. The rate of loading was constant during the model tests. The load and settlement values were recorded by a sixteen-channel data logger unit (MM700 series Autonomous Data Acquisition Unit). The values were converted load-settlement curves by Geotechnical Software-DS7 and Microsoft Excel on a computer. The tests were maintained until the vertical load obviously decreased or a remarkable settlement occurred with negligible increases in the vertical load. The sand was carefully excavated after each test.

3) FINDINGS and DISCUSSION

3.1. Effect of Load Eccentricity

The effect of load eccentricity was examined in this section. The embedment depth of the footing was kept constant as 0.25B. Model tests were conducted using different load eccentricities (e_0, e_1, e_2, e_3 and e_4) with the same geogrid reinforcement depths (u/B=0.25, 0.50, 0.75 and 1.00). The Q – s curves are shown in Figure 4.



(a) u/B=0.25

(b) u/B=0.50

(c) u/B=0.75

(d) u/B=1.00

Figure 4. Vertical load - settlement curves for different u values

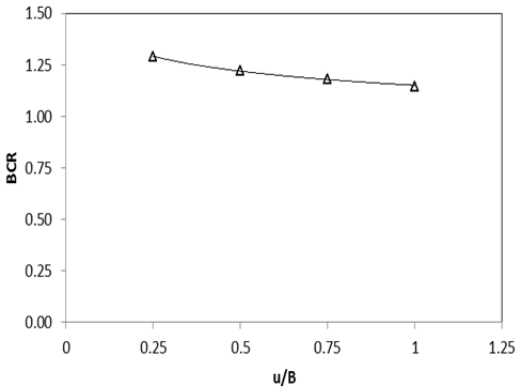
As seen from Figure 4 that the ultimate bearing capacities reached their maximum values at centric loadings (e_0) in all u/B ratios. Apart from the centric loadings, the highest values of the ultimate bearing capacities were obtained from e_1 and e_3 loading points, while minimum values were obtained from e_4 loading point in all u/B ratios. It was calculated that the ultimate bearing capacity value obtained from the centric loading (e_0) is 3.87 times higher than that of the e_4 loading. Besides, outside of the core area, e_2 loading gives higher bearing capacity value than e_4 loading.

3.2. Interpretation of the Variations in the Bearing Capacities

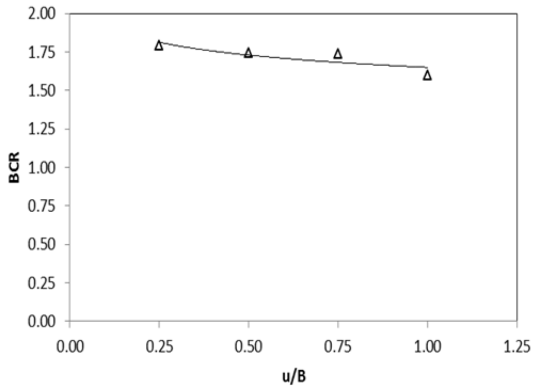
The changes in the bearing capacity were interpreted in terms of BCR (Bearing Capacity Ratio) in this section. BCR was defined to compare the test results of the reinforced and unreinforced soil conditions. BCR is calculated by using the following equation:

$$BCR = \frac{Q_{u(r)}}{Q_{u(o)}} \tag{1}$$

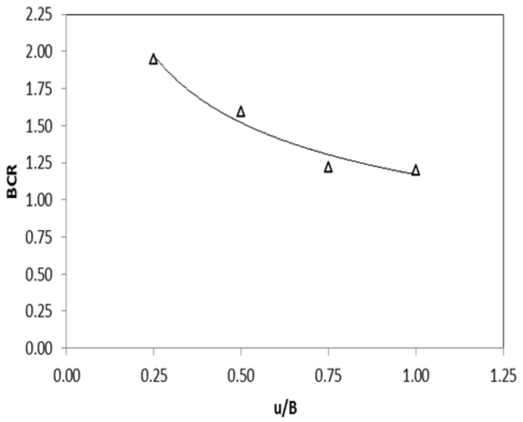
where, $Q_{u(r)}$ is the ultimate bearing capacity of the reinforced soil, while $Q_{u(0)}$ is the ultimate bearing capacity of the unreinforced soil. The embedment depth of the footing was kept constant as 0.25B. The u/B – BCR curves are presented in Figure 5.



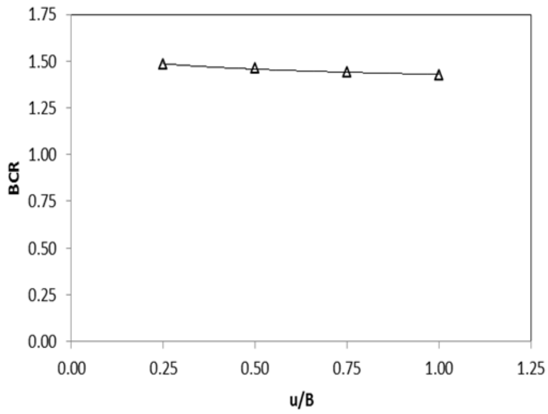
(a) e_0 loadings



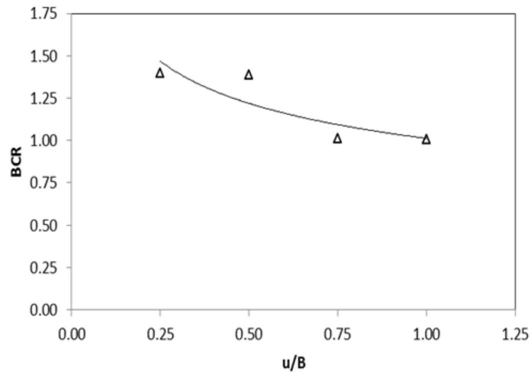
(b) e_1 loadings



(c) e_2 loadings



(d) e_3 loadings



(e) e_4 loadings

Figure 5. The u/B – BCR curves for different e loadings

From Figure 5, it is clear that the ultimate bearing capacity decreases with increase in the geogrid insertion depth in all eccentricity conditions. It was concluded that the ultimate bearing capacity value obtained from u/B=0.25 ratio is about 1.94 times higher than obtained from unreinforced sand.

3.3. Effect of Footing Size

The effect of footing size was investigated in this section. For that purpose, three different square footing widths (B=0.20m, 0.30m and 0.40m) were used in the experimental study. The embedment depth of the footing was kept constant as 0.25B. A single layer of geogrid reinforcement was placed at the four different depths (u/B= 0.25, 0.50, 0.75 and 1.00, individually) and the footings were loaded only in biaxial eccentricity (e_4). The changes in the bearing capacity were examined with different footing sizes and variable depths of the single layer geogrid reinforcement. Figure 6 shows the u/B – Q_u curves for different footing widths with constant eccentricity (e_4).

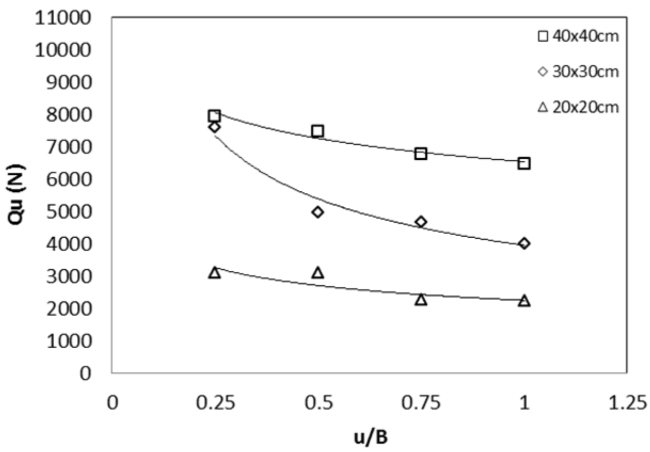


Figure 6. u/B – Q_u curves for different footing widths with constant eccentricity (e_4)

As seen from Figure 6, that the bearing capacity increases with increase in the model square footing widths. The other fact that the Q_u values decrease with increase in the geogrid insertion depth.

4) CONCLUSIONS

This study aims to investigate the bearing capacity of embedded square footings rested on geogrid reinforced sand under eccentric loading conditions. In accordance with this purpose a total of 33 laboratory model tests were performed. Main conclusions of the study can be listed as follows:

- It is observed that the ultimate bearing capacity values decrease with increase in the insertion depth of the single layer geogrid and eccentricity.
- Maximum values of the ultimate bearing capacity were obtained from centric (e_0) loadings in every geogrid insertion depths.
- It is calculated that the ultimate bearing capacity value obtained from the centric loading (e_0) is about 3.87 times higher than that of the e_4 loading condition.
- It is concluded that the ultimate bearing capacity value obtained from u/B=0.25 ratio is about 1.94 times higher than obtained from unreinforced sand.
- Outside of the core area, the ultimate bearing capacity values which obtained from e_2 loading are higher than obtained from e_4 loading in every single layer of geogrid insertion depth.
- It is observed that the bearing capacity increases with increase in the model square footing width and decreases with increase in the geogrid insertion depth.

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