

THE EFFECT OF SPACING BETWEEN GEOGRID AND FOOTING LENGTH ON RECTANGULAR FOOTING UNDER ECCENTRIC LOAD

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ABSTRACT: Designing a foundation needs to be done carefully because of its important function to support the upper structure, including the soil condition. The soil must be able to withstand the load which applied above it. Recently, a lot of construction was built in areas with an insufficient bearing capacity of soil due to the limitation of the area. Therefore, It is needed to reinforce the soil and improve the bearing capacity by adding synthetic materials, such as geogrid. In this study, sand soil with a relative density of 80% will be tested under several variations in the length of the foundation (L) and vertical spacing between geogrid layers (h). The tests were carried out in the laboratory using rectangular footing with 10×12 cm, 10×14 cm, 10×16 cm in sizes and vertical spacing between geogrid layers 1 cm, 2 cm, 3 cm. The loading test was carried out using hydraulic jack and load cell on the model with eccentricity (e) 1 cm and the number of geogrid reinforcement (n) 3 layers. To observe the settlement that occurs, the value of the digital dial gauge was read every 50 kilos. The reinforced models, both L and h variation, showing the greater value of bearing capacity than the unreinforced model. Based on the analysis results, the test model produces the maximum of Bearing Capacity Ratio (BCR) 1.75 when the dimension of the rectangular footing is 10×12 cm and vertical spacing between geogrid layers is 3 cm.

Keywords: Bearing capacity, Geogrid, Rectangular footing, Sand soil, Eccentric load

1. INTRODUCTION

Numerous experiments about bearing capacity of loose sand using square footing have been done; instance, the experiment by Huang and Menq [6] which strengthens loose sand using geogrid. Geogrid is commonly used because it is easy to install, economical, and able to resist pulling force. Therefore, geogrid is sufficient to be material for strengthening the soil.

Many studies were conducted to know about both the advantages and the failure mechanism of the reinforcement soil layer using geogrid. The results of the study prove that the addition of geogrid as soil reinforcement was able to increase the bearing capacity of sand soil [7-9]. On the other hand, when the reinforced soil receives an eccentric load, the failure of foundation mechanisms commonly occurring on one side. This failure driving the soil mass on the surface of the potential area only. The existence of eccentric load can reduce the value of bearing capacity of sand soil [12].

Therefore, the purposes of this experiment are: to obtain the increase of bearing capacity, to obtain the optimum spacing between geogrid layers, and to determine the effect of variations in the vertical spacing between geogrid layers and foundation lengths on bearing capacity increase of the soil with eccentric loads.

2. LITERATURE REVIEW

2.1 Relative Density Of Sand Soil

Sand soil is categorized as loose granular material that has a weak bond. Sand is composed of granules measuring between 1/16 to 2 mm. The relative density of sand is the percentage of a certain density as the ratio of the maximum dry volume weight in the field to the maximum dry volume weight in the laboratory according to standard compaction experiments. Below is the equation to calculate the relative density.

$$RC = \frac{\gamma_{d \text{ field}}}{\gamma_{d \text{ lab}}} \times 100\% \quad (1)$$

Where $\gamma_{d \text{ field}}$ is dry volume weight in the field and $\gamma_{d \text{ lab}}$ is dry volume weight in the laboratory.

2.2 Contact Pressure Due To Eccentric Load

Contact pressure is the pressure acting at the bottom of the foundation due to the load from the upper structure load. If the foundation receives an eccentric load, the contact pressure is assumed to decrease linearly from one end (toe) to the other end (heel) of the foundation. Below is the contact pressure equation.

$$\sigma = \frac{Q}{A} \pm \frac{M_{y,x}}{I_y} + \frac{M_{x,y}}{I_x} \quad (2)$$

Where Q is the total axial load, A is the area of the foundation, Mx and My are moment to x and y-axis on the foundation, x and y are eccentricities towards the center of the foundation to x and y-axis, Ix and Iy are inertia moment of foundation in respect to x and y-axis.

2.3 One-Way Eccentricity

One-way eccentricity on the foundation may occur if the vertical load has an eccentricity towards the center of the foundation on one of its axes (x or y) or if the foundation receives a moment other than vertical load. The pressure distribution under the foundation can be calculated according to the following equation.

$$q_{\frac{\max}{\min}} = \frac{Q}{A'} \left(1 \pm \frac{6e}{B} \right) \quad (3)$$

Where Q is the total axial load, A' is the effective area of the foundation, e is the eccentricity, B is foundation width.

2.4 Bearing Capacity Failure On Foundation

Vesic (1963) divides the mechanism of bearing capacity failure as shown in Fig. 1 below.

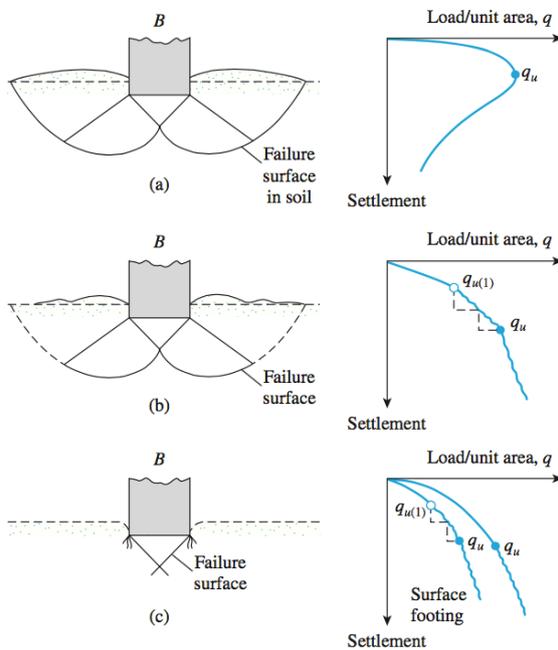


Fig. 1 Types of bearing capacity failure on soil: (a) General shear failure; (b) Local shear failure; (c) Punching shear failure (Principles of Foundation Engineering, by Braja M. Das, 2014)

2.5 Analysis Bearing Capacity Of Unreinforced

Soil

Bearing capacity of the soil is the ability of the soil to hold the load acting on it, generally from the upper structure through the foundation. Below are the equations to calculate the bearing capacity of the soil developed by Meyerhof, Hansen, and Vesic.

a. Meyerhof's Equation

$$q_u = cN_c\lambda_{cs}\lambda_{cd}\lambda_{ci} + qN_q\lambda_{qs}\lambda_{qd}\lambda_{qi} + \frac{1}{2}\gamma B'N_\gamma\lambda_{\gamma s}\lambda_{\gamma d}\lambda_{\gamma i} \quad (4)$$

b. Hansen and Vesic's Equation

$$q_u = cN_c\lambda_{cs}\lambda_{cd}\lambda_{ci}\lambda_{c\beta}\lambda_{c\delta} + qN_q\lambda_{qs}\lambda_{qd}\lambda_{qi}\lambda_{q\beta}\lambda_{q\delta} + \frac{1}{2}\gamma B'N_\gamma\lambda_{\gamma s}\lambda_{\gamma d}\lambda_{\gamma i}\lambda_{\gamma\beta}\lambda_{\gamma\delta} \quad (5)$$

Where c is the coefficient of cohesion (kN/m²), q is the overburden pressure on foundation base (kN/m²), γ is volume weight of soil (kN/m³), B' is effective length of foundation (m), N_c, N_q, N_γ are bearing capacity factor, λ_{cs}, λ_{qs}, λ_{γs} are shape factor, λ_{cd}, λ_{qd}, λ_{γd} are depth factor, λ_{ci}, λ_{qi}, λ_{γi} are load inclination factor, λ_{cβ}, λ_{qβ}, λ_{γβ} are surface inclination factor, λ_{cδ}, λ_{qδ}, λ_{γδ} are foundation inclination factor.

2.6 Analysis Bearing Capacity Of Reinforced Soil

Huang and Menq [6] conducted a study of bearing capacity of sand soils that was reinforced by geo-synthetic. This study is based on two failure mechanisms namely the deep-footing mechanism and the wide-slab mechanism.

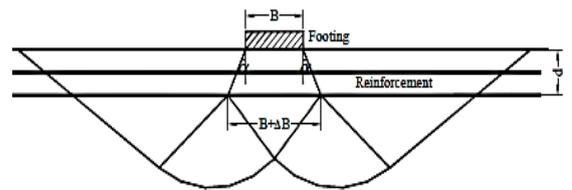


Fig. 2 Mechanism of bearing capacity failure on reinforced soil (Huang and Menq, 1997)

Based on the results, an equation to determine the limit of bearing capacity based on a wide-slab mechanism is obtained as follows.

$$q_u = \eta(B + \Delta B)\gamma N_\gamma + \gamma d N_q \quad (6)$$

$$\Delta B = 2d \tan \beta \quad (7)$$

$$\tan \beta = 0,860 \times 0,00077^{h/B} \times 4,890^{CR} \times 1,111^{l/B} \times 1,323^n \quad (8)$$

Where η is shape factor ranged from 0,5 for strip footing to 0,5 – 0,1(B/L) for rectangular

footing, B is foundation width, N_q and N_γ are bearing capacity factor, γ is volume weight of soil, d is depth of reinforced zone calculated using formula $d = u + (n - 1) \times h$; where u is vertical spacing between the first layer of reinforcement and foundation, n is amount of reinforcement, h is vertical spacing between reinforcement. CR is Coverage Ratio calculated using the formula $CR = w/W$; where w is the width of rib (longitudinal), W is aperture size, b is the width of reinforcement.

2.7 Bearing Capacity Of Eccentrically Loaded Soil

To calculate the bearing capacity with eccentric loads on the foundation with reinforcement, the Reduction Factor Method of Purkayastha and Char is used with the equation as follows. [10]

$$q_{uR(e)} = (1 - R_{KR}) \times q_{uR(e=0)} \tag{9}$$

Where R_{KR} is the reduction factor, $q_{uR(e)}$ is the bearing capacity of reinforced soil with an eccentric load, $q_{uR(e=0)}$ is the bearing capacity of reinforced soil with a centric load.

2.8 Reduction Factor For Bearing Capacity Of Eccentrically Loaded Soil

The Reduction Factor Method [10] is continuously developed by other researchers such as Omar [8]; Patra, Das, Bhoi, and Shin [9]; and Shamshad Alam [12]. The similarities between the studies can be seen in the following table.

Table 1 Reduction Factor Equation

Research	Reinforcement	Reduction Factor Equation
Omar	Geogrid	$R_{KR} = 5,11 \left(\frac{d_f}{B}\right)^{-0,14} \left(\frac{e}{B}\right)^1$
Patra, Das, Bhoi, and Shin	Geogrid	$R_{KR} = 4,97 \left(\frac{d_f}{B}\right)^{-0,12} \left(\frac{e}{B}\right)^1$
Shamshad	Geogrid	$R_{KR} = 5 \left(\frac{d_f}{B}\right)^{0,5} \left(\frac{e}{B}\right)^{1,21}$

2.9 SOIL COMPACTION

Compaction is a method for increasing soil density by removing air in the soil pores with the help of mechanical energy. The density of a soil is measured by the value of dry volume weight. When water is added during compaction, water has the function to smooth soil particles. The particles then move and fill the soil pores that are initially filled with air. The dry volume weight will

increase along with the increase of soil moisture content. At certain water content, a maximum weight value will be generated. This moisture content is called Optimum Moisture Content (OMC).

2.10 Geogrid

Geogrid is used to improve the technical properties of composite soils mechanically. Geogrid is net-shaped that is organized and connected so it has interlocking or locking the material around it as a filler. Geogrid is the development of geo-synthetic technology created to overcome the strengthening mechanism and the stiffness of a material.

2.11 Bearing Capacity Ratio (BCR)

Bearing Capacity Ratio (BCR) is the ratio between the bearing capacity of the reinforced soil and the bearing capacity of the unreinforced soil. Below is the equation of BCR.

$$BCR = \frac{q_{u(R)}}{q_u} \tag{10}$$

Where $q_{u(R)}$ is the bearing capacity of reinforced soil, q_u is the bearing capacity of the unreinforced soil.

3. RESEARCH METHOD

3.1 The Pre-Laboratory Test

The pre laboratory test is done to determine the characteristic of the sand. The tests conducted in this research are;

- a. Grain Size, ASTM C-136
- b. Direct Shear, ASTM D-3080-72
- c. Standard Compaction, ASTM D-698-70
- d. Specific Gravity, ASTM D-854-58

3.2 Amount Of Samples

In this research, there are 12 samples that consist of 3 unreinforced samples and 9 reinforced samples. For the reinforced samples, there are 3 variations in the spacing between the geogrid (h) and 3 variations in the length of the foundation (L). The eccentricity distance given in the rectangular footing model is 1 cm in the x-axis direction (L direction).

The model both unreinforced and reinforced samples will be tested under the same condition, for the bearing capacity can be compared. The study is conducted using a test box measuring 100 × 150 × 100 cm. Detailed info regarding the samples is shown in Table 2.

Table 2 Parameter of Variable in Experiment

No.	Sample Code	Rectangular Footing's Dimension (cm)	Vertical Spacing Between Geogrid (h)
1	A ₀		-
2	A ₁	10 × 12	0.1B
3	A ₂		0.2B
4	A ₃		0.3B
5	B ₀		-
6	B ₁	10 × 14	0.1B
7	B ₂		0.2B
8	B ₃		0.3B
9	C ₀		-
10	C ₁	10 × 16	0.1B
11	C ₂		0.2B
12	C ₃		0.3B

3.3 Experimental Test Procedure

The test box with 100x150x100 cm size was made as rigid as possible using steel sheet. This box has transparent side to make the observation more easily. Besides, the frame of the box made from steel column and beam due to restraining the load from the hydraulic jack

The sand soil compacted by being crushed 36 times using cylindrical concrete each half-height of the 10 cm layer, which is 5 cm. The compaction in this way is based on controlled volume. After compacting the layer, the sand soil controlled using the density ring which takes randomly in three places. Prior to testing, sand soil settling for ± 30 minutes for the soil particles can be shifted to fill the voids that still can fill.

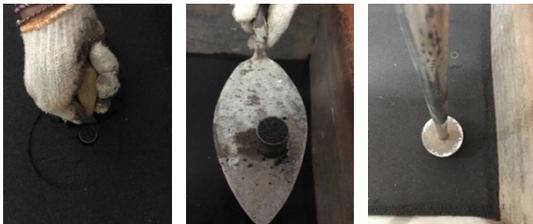


Fig. 3 Step by step of the density control process.

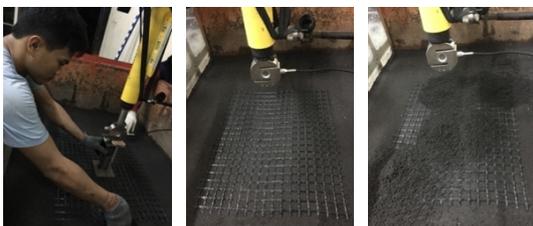


Fig. 4 Step by step of the model setting process .

The rectangular footing will be placed in 10 cm depth and tested under the eccentricity of load 0,1B using a hydraulic jack that has been connected with the load cell and the digital dial gauge. The settlement reading will be held in every 50 kg load increase and be discontinued when the settlement reached 30 mm (30% B). In this study,

the tests performed under displacement control conditions.

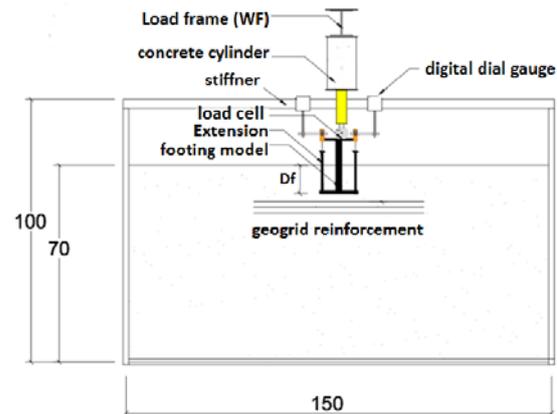


Fig. 5 Detailed layout on model test.

3.4 Method Of Analysis

Based on the loading test, it will give two kinds of data which are the maximum load and the value of settlement. The bearing capacity will be calculated based on the following equation.

$$q = \frac{Q}{A'} \left(1 - \frac{6e}{L} \right) \tag{11}$$

Where Q is total axial load, A' is effective area of the foundation, e is eccentricity, L is length of foundation.

4. RESULT ANALYSIS

4.1 The Result Of Bearing Capacity Of Unreinforced Soil

This test is carried out to obtain the maximum bearing capacity of the sand soil that may occur in the model. Dense soil has residual strength, so the load can be given gradually. Therefore, the maximum carrying capacity is obtained through the s/B ratio of 10%. The bearing capacity of unreinforced models is shown in Fig. 6.

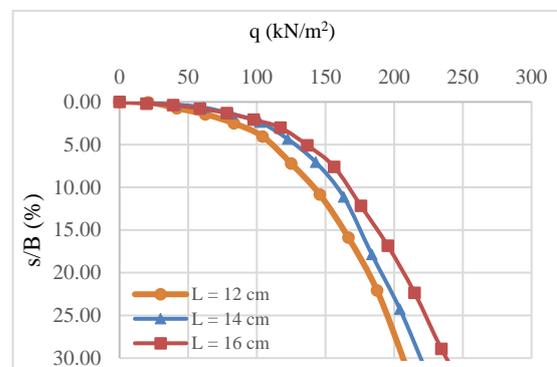


Fig.6 Bearing capacity–settlement curve for unreinforced models

The greater L of foundation, under the same settlement, the greater the stress that occurs (Fig. 6). At $s/B = 10\%$, the foundation with a value of $L = 12$ cm has the smallest stress of 140.96 kN/m^2 . For foundations with $L = 14$ cm at 157.56 kN/m^2 and foundations with $L = 16$ cm at 166.48 kN/m^2 . For the comparison of value between theoretical and experimental bearing capacity can be seen in Fig. 7.

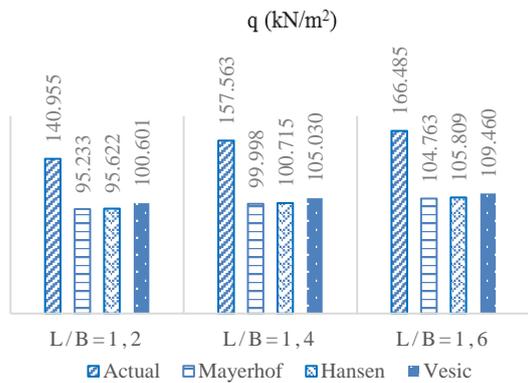


Fig. 7 Comparison of bearing capacity for unreinforced models.

4.2 The Result Of Bearing Capacity Of Reinforced Soil

Meanwhile, after the results of the theoretical and experimental bearing capacity of reinforced models are compared, there are quite significant differences. From Fig. 8, the actual bearing capacity continues to increase with the increasing of foundation length and the vertical spacing between geogrid layers. However, there are differences in the value of theoretical bearing capacity. It continues to increase with increasing foundation length, yet continues to decrease with the increasing of vertical spacing between geogrid layers. This decrease is caused by factors ΔB and $\tan \beta$ in Eq. (7) and Eq. (8).

Besides, there is a possibility that the geogrid works as group reinforcement which has a smaller bearing capacity than it is considered as single reinforcement. This is influenced by the optimum spacing between geogrid layers that affects the interlocking performance between geogrid and may cause of the declination of data in theoretical calculation.

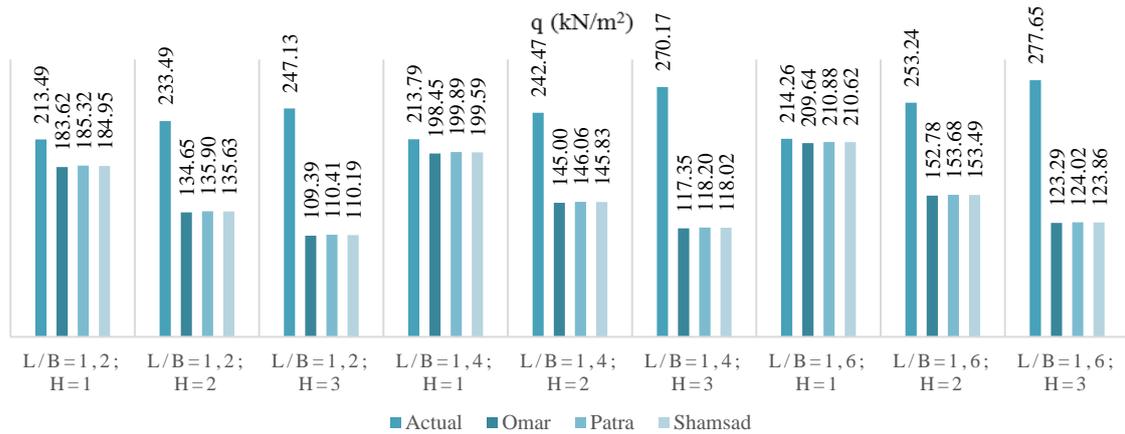


Fig. 8 Comparison of bearing capacity for reinforced models.

4.3 Discussion

Based on the comparison results between unreinforced and reinforced models for variation L, there is no significant increment in the bearing capacity of the model, yet the foundation length (L) affects the settlement and bearing capacity of the soil (Fig. 9).

The greater the value of L, the greater the bearing capacity that occurs under the same settlement. Since the bearing capacity that occurs is greater, the working load will be even greater. Therefore at the same value of the settlement, the foundation with greater L can hold a greater load than the others.

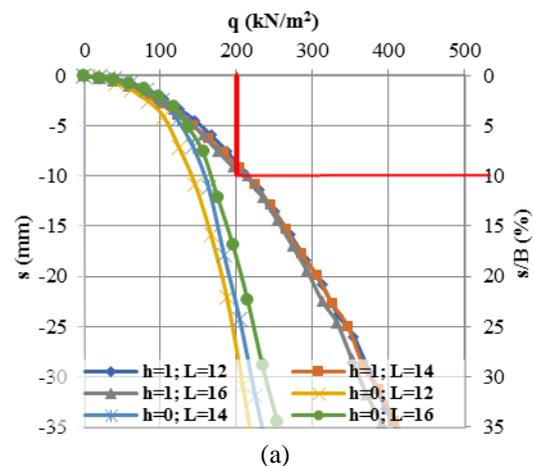


Fig. 9a Bearing capacity-settlement curve

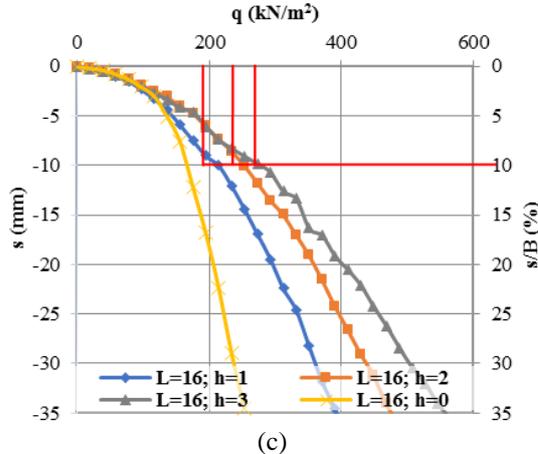
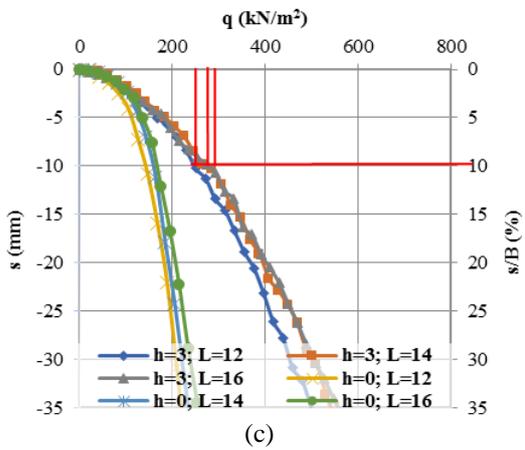
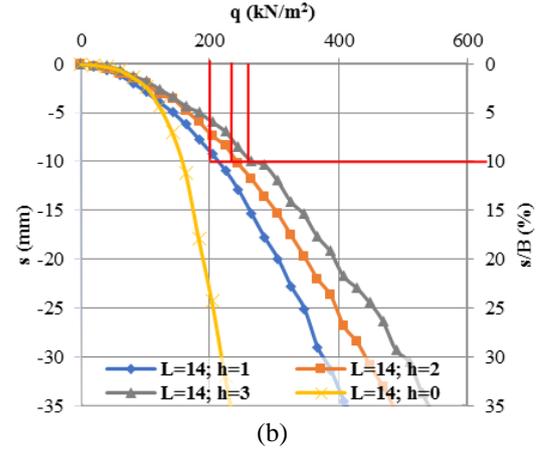
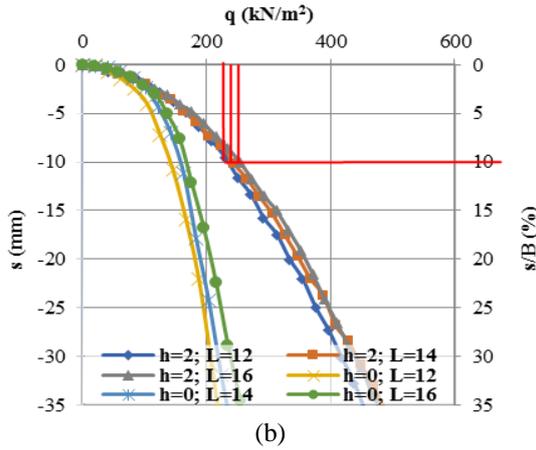


Fig. 9 Bearing capacity-settlement curve for models with variation L at different h (a) h = 1 cm; (b) h = 2 cm; (c) h = 3 cm

Fig. 10 Bearing capacity-settlement curve for models with variation h at different L (a) L = 12 cm; (b) L = 14 cm; (c) L = 16 cm

On the other hand, the variation of vertical spacing between geogrid layers for each L value also affects the increase of bearing capacity. The amount of sand soil between the geogrid layers increase as if the farther vertical spacing between geogrid layers. Therefore, the sand to have a greater interlocking force and increase its bearing capacity. The detailed test results are presented in Fig. 10.

4.4 Bearing Capacity Ratio (BCR) Analysis

The comparison of BCR values for variations of foundation length (L) can be seen in Table 3 and Fig. 11.

Table 3. BCR value for variation of foundation length (L)

No.	h (cm)	q _u (kN/m ²)	L (cm)	q _{uR} (kN/m ²)	BCR
1	1	140.96	12	213.49	1.47
		157.56	14	213.79	1.36
		166.48	16	214.26	1.29
2	2	140.96	12	233.49	1.66
		157.56	14	242.47	1.54
		166.48	16	253.24	1.52
3	3	140.96	12	247.13	1.75
		157.56	14	270.17	1.71
		166.48	16	277.65	1.67

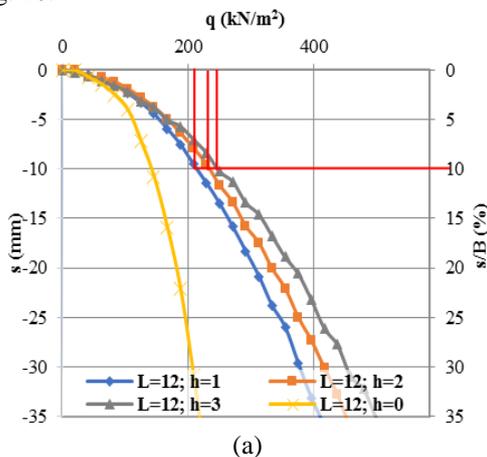


Fig. 10a Bearing capacity-settlement curve

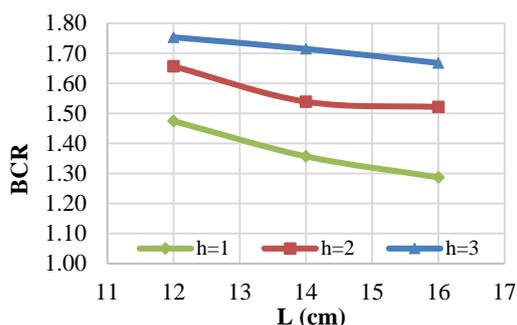


Fig. 11 BCR of the models for variation of foundation length (L).

From Fig. 11 it can be concluded that the greater the L value, the BCR value will decrease. When the vertical spacing between geogrid layers is 3 cm, the increasing of L does not result in a significant decrease in BCR value. However, when the vertical spacing between geogrid layers is decreased to 1 or 2 cm, an increase of L will result in a significant decrease of BCR value. For the comparison of BCR values for variations of vertical spacing between geogrid layers (h) can be seen in Table 4 and Fig. 12.

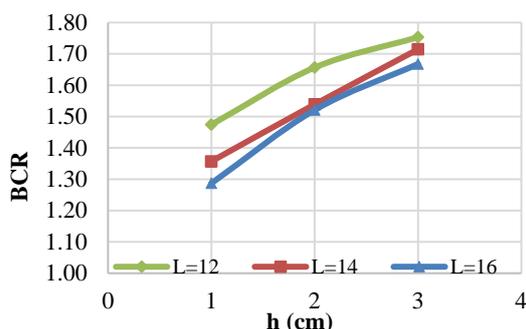


Fig. 12 BCR of the models for variation of vertical spacing between geogrid layers (h).

Table 4. BCR value for variation of vertical spacing between geogrid layers (h)

No.	L (cm)	q _u (kN/m ²)	h (cm)	q _{uR} (kN/m ²)	BCR
1	12	140.96	1	213.49	1.47
			2	233.49	1.66
			3	247.13	1.75
2	14	157.56	1	213.79	1.36
			2	242.47	1.54
			3	270.17	1.71
3	16	166.48	1	214.26	1.29
			2	253.24	1.52
			3	277.65	1.67

Based on Fig. 12, it can be concluded that the greater the vertical spacing between geogrid layers, the BCR value will increase. It can also be seen from the graph that the value of L influences the increase in BCR value. When L = 12 cm, the BCR values ranged from 1.47 to 1.75. For the value of L = 14 cm, the BCR values ranged from 1.36 to 1.71. And for the value of L = 16 cm, the BCR values ranged from 1.29 to 1.67.

5. CONCLUSIONS

Based on the research that has been done, the following conclusions can be drawn:

1. The bearing capacity of the reinforced sample is greater compared to the unreinforced, in both variations of the foundation length and the vertical spacing between geogrid layers. The maximum bearing capacity, $q_u = 277.65 \text{ kN/m}^2$, shown in the reinforced model with the dimension of the foundation is $10 \times 16 \text{ cm}$ and vertical spacing between geogrid layers is 3 cm.
2. In the model with variations of foundation length, the greater the length, the bearing capacity at the same settlement would be even greater. For instance, the bearing capacity of the model with the vertical spacing of geogrid layers 3 cm and length of foundation 12 cm, 14 cm, and 16 cm in sequences are 247.13 kN/m^2 , 270.17 kN/m^2 , and 277.65 kN/m^2 . Because the bearing capacity which occurs is greater, the working load that could be held also increases.
3. In the model with variations of vertical spacing between geogrid layers, the greater the vertical spacing, the greater the bearing capacity that can be produced. To exemplify it, the bearing capacity of the model with dimension $10 \times 16 \text{ cm}$ and the vertical spacing of geogrid layers 1 cm, 2 cm, and 3 cm in sequences are 214.26 kN/m^2 , 253.24 kN/m^2 , and 277.65 kN/m^2
4. In the BCR analysis, the BCR value will increase as the foundation length gets smaller, but the vertical spacing between geogrid layers is greater. From the analysis results obtained the maximum BCR is 1.75 which occurs in the model with the dimension of the foundation $10 \times 12 \text{ cm}$ and vertical spacing between geogrid layers 3 cm

6. ACKNOWLEDGMENTS

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