International Journal of GEOMATE, May, 2020, Vol.18, Issue 69, pp. 216 - 223
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2020.69.29454
Geotechnique, Construction Materials and Environment

BEARING CAPACITY IMPROVEMENT OF SHALLOW FOUNDATION ON MULTILAYERED GEOGRID REINFORCED SAND

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*Corresponding Author, Received: 14 Nov. 2019, Revised: 15 Dec. 2019, Accepted: 05 Feb. 2020

ABSTRACT: Low bearing capacity of the soil causes failure of the foundation. Ones of soil types that has low bearing capacity is sand. Geogrid is used to increase bearing capacity of the sand by interlocking its particle, it also increases the tensile strength of the soil. Soil reinforcement using geogrid is effective, low budget, and has simple installation method. Therefore, it is needed to do sustainability research to know the variable that can increase the bearing capacity of loose sand optimally. This study is measuring the failure mechanism on bearing capacity and the settlement of footing using hydraulic jack and dial LVDT. Each model of footing with be conducted under some of different variable. This study used a variation of the ratio the distance between geogrid with width of the footing (h/B) of 0.2; 0.25; 0.3, and the ratio of first layers of geogrid with width of the footing (u/B) 0.3; 0.4; 0.5. The footings' size that used are 12x12 cm and 12x24 cm. The footings would be tested in depth 0.3B with 3 layers of geogrid. According to the results under variation of the distance between the geogrid (h), the larger value of h/B then the bearing capacity of sand tends to decline, so that the maximum value for h/B generated is when h/B of 0.2. As for the variation of the distance of the first layer geogrid (u) get that the maximum value at this variation is obtained when the value u/B is 0.3.

Keywords: Bearing capacity, Distance between geogrid, First layer spacing, Footing length, Geogrid.

1. INTRODUCTION

Since the past some decades, the experiment that used geogrid as an improvement material for sand soil have been done in some research, such as Patra, Das, and Shin [14]; Shin and Das [17]; Taha and Altahe [20]; Yetimoglu, Wu, and Saglamer [24]. Geogrid clearly established to improve the bearing capacity of sand soil. However, most of these studies are on strip footing, despite rectangular and square footing is also commonly use. Some research conduct the square footing on geogrid reinforced sand are limited. Earlier research on square footing conducted by Omar, Das, Puri, and Yen [13], determining the bearing capacity of strip footing and square footing resting on reinforced sand. From the study concluded by using geogrid evidently improved the bearing capacity on sand soil (granular soil).

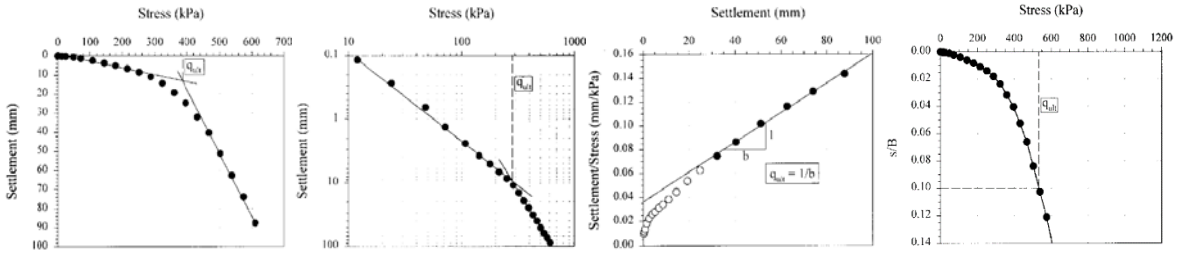
Almost all of the research conducted square footing rested on the top of the sand. Qiming Chen [15] conducted square footing with the ratio of width with embedment depth (Df/B) 0 and 1, it gets the result that the footing that used embedment depth have higher ultimate bearing capacity than the footing that not used embedment depth.

In this paper, result from laboratory model test without and with reinforcement are discussed. The primary object on this study to evaluate the performance of soil reinforced with multilayer geogrid in improving bearing capacity of loose sand on square footing and to analyze the influence by the different parameter. Square footing conducted with embedment depth and multilayered geogrid. The primary objects on this research are vertical displacement and bearing capacity of sand soil with and without reinforcement. Parameter used on the model test were footing length, space between geogrid, and first layer geogrid space. The bearing capacity equation arranged by three factor that dependent on the friction angle of the soil.

2. LITERATURE REVIEW

2.1 BEARING CAPACITY

Bearing capacity soil is the capability of soil to restrain external and also self-weight load. Parameter of bearing capacity defined by two factors; cohesion factor (c) and frictional factor (Ø). On granular soil, especially loose sand, the cohesion factor is ignored and the load taking factor is frictional. According to Lutenegger and Adams [1] there is some method to define bearing capacity (Fig. 1). A different method is used to determine the ultimate bearing capacity that closed to the actual condition, in addition not all of the experiment have no ultimate bearing capacity value from the graph. Most of the experiment of bearing capacity improvement today using 0.1B method.



(a) (b) (c) (d)

Fig. 1 Method to define bearing capacity; a)Tangent Intersection method, b) Log – log method, c) Hyperbolic method, d) 0,1B method (Lutenegger and Adams, 1998)

Before load applied, the soil below the footing is in elastic equilibrium. Then with increasing the load, the soil passes from elastic to plastic equilibrium. Vesic [23], divided three types of failure mechanism for unreinforced soil footing:

a. General shear failure

Failure zone on general shear failure can be identified clearly. Downward movement of the footing trigger vertical movement on the plastic zone. With increasing the load, the plastic zone passes then the soil bulges out. It occurs in relatively incompressible soil with relative density greater than 70% fails under general shear failure.

b. Local shear failure

Larger deformation than general shear failure may occur below the footing. After vertical deformation fully developed then the plastic zone has been cleared and continuous with lateral movement and slightly bulging was occur. This type of failure may take place in fairly soft or loose and compacted soil and have relative density between 50% – 70% fails under local shear failure.

c. Punching shear failure

Punching lateral failure has no lateral movement at all. It happened on loose sand that when the load of the soil was increased then the vertical movement of the footing occurs. Relative density less than 35% could trigger the punching shear failure.

Terzaghi was the first presented the theory to calculate ultimate bearing capacity on shallow foundation. Terzaghi theory assumed the footing as a strip footing with rough base, and the soil above the bottom of the footing is considered as additional load ($q = \gamma.Df$). Strip footing in well-known equation:

$$q_{ult} = c.\ N_c + q.\ N_q + \tfrac{1}{2}.\gamma.\ B.\ N_\gamma \quad (1)$$

Where c is soil cohesion, γ is soil unit weight or density, B is footing width, and N_c, N_q, N_γ is bearing capacity factor that given by Terzaghi as a soil friction angle (Ø) function. Then the equation was modified for other footing shapes, as example for square footing as given by the equation below:

$$q_{ult} = 1.3\ c\ N_c + q\ N_q + 0.4\ \gamma\ B\ N_\gamma \quad (2)$$

Meyerhof extended the bearing capacity theory. The base equation is not that far from Terzaghi's theory but completed with shape. Depth, and inclined factor that given from friction angle (Ø). The equation for ultimate bearing capacity is follow:

$$q_{ult} = c\ N_c\ F_{cs}\ F_{cd}\ F_{ci} + q\ N_q\ F_{qs}\ F_{qd}\ F_{qi} + \tfrac{1}{2}\ \gamma\ B\ N_\gamma\ F_{\gamma s}\ F_{\gamma d}\ F_{\gamma i} \quad (3)$$

Where $F_{cs}\ F_{qs}\ F_{\gamma s}$ is shape factor, $F_{cd}\ F_{qd}\ F_{\gamma d}$ is depth factor, and $F_{ci}\ F_{qi}\ F_{\gamma i}$ is inclination factor.

The performance improvement of the bearing capacity increase due to geogrid reinforcement is qualified by ratio parameter (non-dimensional parameter). Bearing capacity ratio (BCR) is given by the equation below:

$$BCR = \frac{qu_R}{qu} \quad (4)$$

Where qu_R is the bearing capacity of reinforcement soil and qu is the bearing capacity soil without reinforcement.

2.2 Geogrid

Geogrid is one of the geosynthetics that designed for reinforcement. Geogrid has high tensile strength with large enough of aperture. This aperture allows interlocking with the surrounding soil to perform the reinforcement function. Study the function of geogrid as reinforcement and found while soil and geogrid are combined, both endure the train so that could improve the bearing capacity and reduce the settlement.

2.3 Failure Mechanism On Geogrid Reinforced Soil

Since four decades, it has been a lot of study and experiment about geogrid as soil improvement material, but compared to the number of experiment that has been done, the number of theoretical analysis on bearing capacity reinforced soil is relatively rare, especially for square footing. Some study to analyze theoretical bearing capacity have been done by Huang and Menq [8] and this method used as the basic of theoretical analysis.

Huang and Menq, evaluated the failure mechanism of soil reinforced under strip footing rested on the top of multilayer geogrid reinforced sand. According to the failure mechanism bearing capacity on reinforced soil improved depend on two factors, i.e. width of footing and depth of lowest geogrid. The concept of failure mechanism on geogrid is the footing with footing width B equivalent with B +ΔB, which ΔB is the additional width on the lowest depth of geogrid, as shown in Fig. 2. The value of ΔB is depended on stress distribution angle (α).

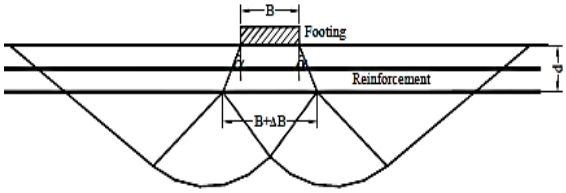


Fig. 2 Failure mechanism soil reinforced geogrid (Qiming Chen, 2007)

According to the Fig. 2 ΔB is the increase of footing width due to inclusion parameter:

$$\Delta B = (2 \times d) \tan\alpha = (2 \times d)(0.680 - 2.071h/B + 0.743CR + 0.03l/B + 0.076N) \quad (5)$$

Where h is vertical spacing between reinforcement, CR is covering ratio of reinforcement, l is length of reinforcement, and N is the number of reinforcement layer. Theoretical bearing capacity of reinforced soil footing shown as:

$$qu_R = \eta \times \gamma \times (B + \Delta B) \times N_\gamma + \gamma \times d \times Nq \quad (6)$$

qu_R is the bearing capacity of reinforcement soil, η coefficient of footing shape, N_γ, Nq is the bearing capacity factor, γ is dry unit weight soil.

2.4 Scale Factor Of Model Footing And Prototype

The Main bearing capacity equation is arranged by three bearing capacity factor (Nc, Nq, Nγ) that depend on the friction angle of the soil. All of the bearing capacity factors only depend on friction angle except Nγ, beside depend on friction angle but also related to soil unit weight. It has been found that bearing capacity factor, Nγ, have corresponding with footing size, which has relation to relative density, that has been researched by Cerato and Lutenegger [2].

Most of the bearing capacity which used on the full-scale footings are derived from extrapolation of model-scale footing test. The large space between the result of bearing capacity factor of model-scale footing test and full-scale footing become problem apart. Then it important enough used exact extrapolation formula. It is shown that the model scale footing test had greater Nγ than the full scale. In addition, some research has indicated that the main grain size influences the value of Nγ on small scale footing.

Some research has suggested the modified bearing capacity factor of the scale model footing so it can be approximate full-scale footing condition. Shiraishi [19] suggested the modified bearing capacity factor could be express as a function below:

$$\frac{N_\gamma^*}{N_\gamma} = \frac{\left(1+\left(\frac{B_i}{B}\right)^{1/3}\right)}{\left(1+\left(\frac{B}{B_i}\right)^{1/5}\right)} \quad \text{or} \quad N_\gamma^* = \left(1+\left(\frac{B_i}{B}\right)^{1/3}\right)\left(1+\left(\frac{B_i}{B}\right)^{1/5}\right)N_\gamma \quad (7)$$

Where Nγ* is modified bearing capacity factor; Nγ is Theoretical value (Terzhaghi's value); Bi is reference footing width (1.4m, i.e width of the footing base where Nγ*/Nγ = 1); and B is width of actual footing (m). The empirical equation comes from model the test that conducted by De Beer (1963) using square and circle footing test with ranging width from 0.05 m – 0.2 m and the range of friction angle was 41˚ – 44˚.

The empirical equation from Eq.(8) cautioned by Shiraishi to avoid the over-estimation of the Nγ* then it suggested using "engineering practice" equation that reduces the value of Nγ* around 30% smaller, as shown as:

$$N_\gamma^* = \frac{0.71 N_\gamma}{B^{0.2}} \quad (8)$$

Where N γ* is modified bearing capacity factor; N γ is reference bearing capacity factor; and $B^{0.2}$ is footing width (m).

3. MATERIAL AND METHOD

3.1 Material

The sand used in this research is fine-grained to coarse-grained soil. Particle size distribution determined using dry sieving method. The characteristics such as diameters corresponding to percent finer or particle size are D_{10}=0.32, D_{30}=0.56, D_{60}=1.2. Thus, uniformity coefficient (C_u) 3.75, coefficient of gradation (C_c) 0.82, and specific gravity 2.64. Soil dry density is obtained from the standard compaction method, and find the optimum soil dry density is 1.73 gr/cm^3. According to the Unified Soil Classification System (USCS), the soil used in this model test classified to poorly graded sand (SP). Relative Compaction (RC) used in this research is 85%, with the addition of water depend on the density of the soil. Therefore, dry density used on the model test is 1.44 gr/cm^3. The estimated internal friction angles of the sand determined from direct shear tests using dry sand on RC 85% is 31.7˚.

The footing used on this research is made from steel plates with 10 mm thickness to provide

the rigid footing condition. The dimension of square footing 120 mm x 120 mm and rectangular footing 120 mm x 240 mm. Miragrid GX 40/40 is used as geogrid reinforcement material, and the specification of geogrid is shown in Table 1.

Table 1 Properties of geogrid.

Structure	Biaxial Geogrid
Aperture Shape	Square
Aperture Size (mm x mm)	25 x 25
Polymer Type	Polyester Fibers
Tensile Strength (kN/m)	40
Stain at strength (kN/m)	11

3.2 The Experimental Test Procedure

A series of model test is conducted in a rectangular test box, 100 cm width, 150 cm length, and 100 cm depth. The box made of steel sheet in order to make the box to be rigid. It is needed to maintain the vertical load and the strain from the model test (sand). Steel column and beam completed the box to restrain the load from hydraulic jack.

Loose sand is compacted each layer with 10 cm height. To obtain uniform compaction, each layer will be rolled 23 times using approximately 12 kg concrete cylinder is tamped on the test box. The density ring test is used to control soil density and water content each 10 cm and take three samples randomly. The density of the sand that will be accepted is about ±10% from 1.44 gr/cm^3.

The footing is placed on soil surface with embedment depth as planned. The loading test carried under a constant load using hydraulic jack on the center of the box. This method used to prevent the shear failure area to reach the box, because it will affect the bearing capacity. The load increment process in this study used stress control that connected with Linear Variable Displacement Transducers (LVDT).

To find out the footing's settlement that occurs, LVDT placed on two points. The LVDT placed on the center of the footing and on the corner of the footing. This placement intended to control the tilt of the settlement. Therefore, the tilt of the footing caused by loading test is calculated by the average value of two LVDT. The loading test will be handed with a constant load every 5 kg and should be done if settlement reach 10 mm. The tests performed under displacement control condition.

Dial gauge placed on the center of the footing to prevent the tilt. If the inclination occurs unexpectedly it will be accepted with ±10% tolerance in each LVDT. To determine the bearing capacity of the model test, the 0,1B method is used in this study.

The parameter of the variable each model test shown in Table 2. The constant parameters used in this model test are embedment depth (u/B = 0.1) and the number of geogrid layers (N= 3).

Table 2 Parameter of the variable used in experiment.

Series	Constant Parameter	Variable Parameter
0	Unreinforced Sand	B/l= 1 and B/l = 2
A	Reinforced Sand, B/l=1, u/B = 0.3	h/l = 0.2, 0.25, 0.3
	Reinforced Sand, B/l=1, u/B = 0.4	h/l = 0.2, 0.25, 0.3
	Reinforced Sand, B/l=1, u/B = 0.5	h/l = 0.2, 0.25, 0.3
B	Reinforced Sand, B/l=2, u/B = 0.3	h/l = 0.2, 0.25, 0.3
	Reinforced Sand, B/l=2, u/B = 0.4	h/l = 0.2, 0.25, 0.3
	Reinforced Sand, B/l=2, u/B = 0.5	h/l = 0.2, 0.25, 0.3

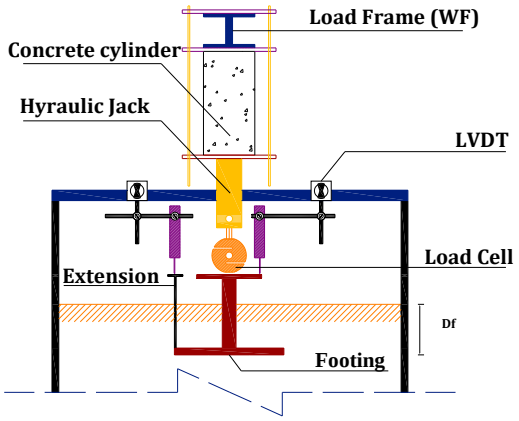
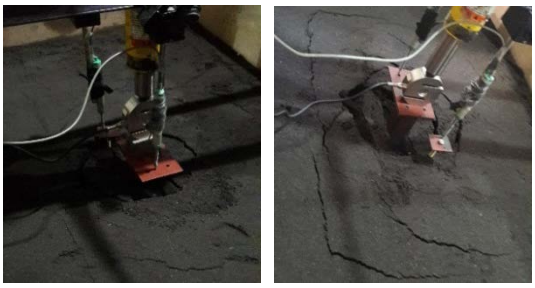


Fig. 3 Layout of loading method on model test

4. RESULT AND DISCUSSION

Small scale laboratory model test is conducted to determine bearing capacity of footing with the same width on the multilayer geogrid reinforcement. A total of 20 tests were carried out with centric load on both unreinforced and reinforced test samples. The ultimate bearing capacity is obtained from the curves of bearing pressure (q) and settlement using 0.1B Method because this method has not distinct failure pattern of the model test. Thus, that ultimate bearing capacity is obtained based on allowed settlement method. The research used 0.1B method that limited the settlement until 10%B. If the curve settlement reached 10%B then the pressure that occur in the soil considered as ultimate bearing capacity. As shown at Fig. 5 and Fig. 6, the bearing capacity value is taken when the settlement is 10% from width of the model footing.



(a) (b)

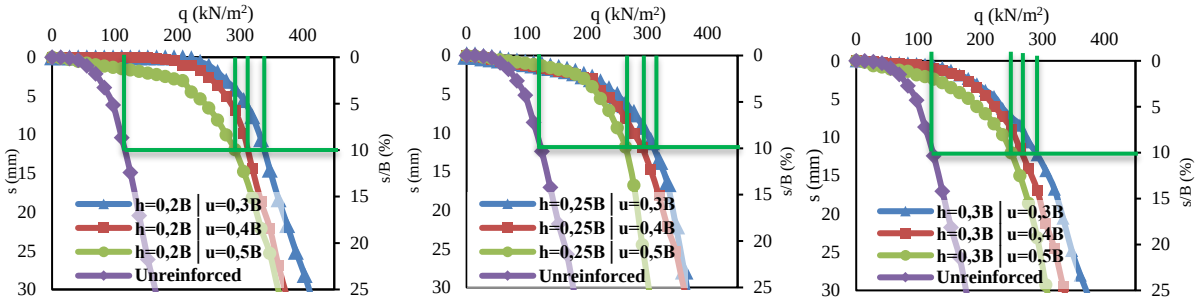
Fig. 4 Typical soil failure of model footing test on unreinforced soil (a) l/B=1; (b) l/B = 2.

The theory before has been explained by Vesic, the type of failure on model test footing is local shear failure because it has large deformation after reached the bearing capacity point (Fig. 5 and 6), and the bulge slightly occur (Fig. 4) because vertical deformation fully developed then the plastic zone has been cleared and continuous with lateral movement. It also used loose sand that become the one characteristic of local shear failure. Fig. 5 shows that the bearing capacity of model test footing is improved significantly using multilayered geogrid and with increasing ratio u/B and h/B the curve become steeper. Same as for variable l/B=2 which shown by Fig. 6.

4.1 Effect Of First Layer Geogrid And Distance Between Geogrid

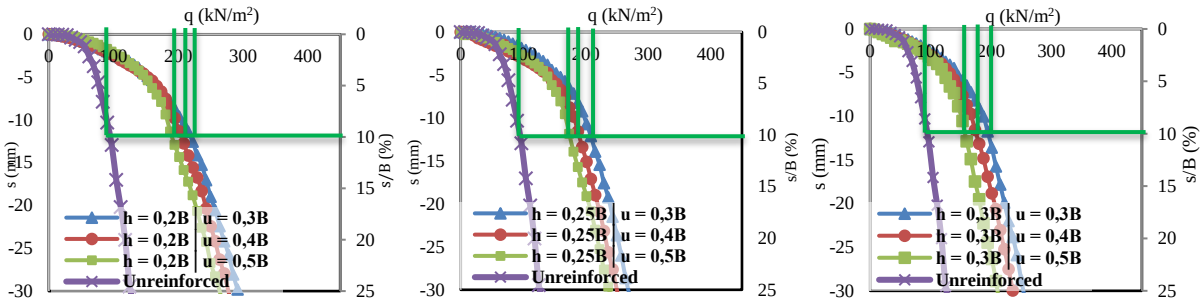
The experiment conducted on multi layered geogrid reinforcement resulted significant increase in the bearing capacity on the loose sand.

To investigate the effect of first layer geogrid, the test conducted in different length of footing series A with ratio l/B = 1, and series B with ratio l/B = 2. Fig. 7 shows with increasing ratio u/B, the BCR is decreasing. The maximum BCR value occur when the ratio u/B is 0.3. The optimum bearing capacity only occur on the certain space between first layer geogrid and base of the footing, on this study writers could not get the conclusion that the optimum bearing capacity at u/B = 0.3, it needed more research on parameter less than u/B 0.3. As theory Huang and Menq which had been explained before, the soil settlement occurs when the footing loaded by certain weight the first soil layer will get failure then it will be transferred to geogrid layer. In that case, the soil not only transferred the vertical load vertically but also horizontally, the soil could not bear the horizontal force. Therefore, the soil which moves horizontally will be resisted by geogrid, geogrid interlock the soil by the hole of the geogrid.



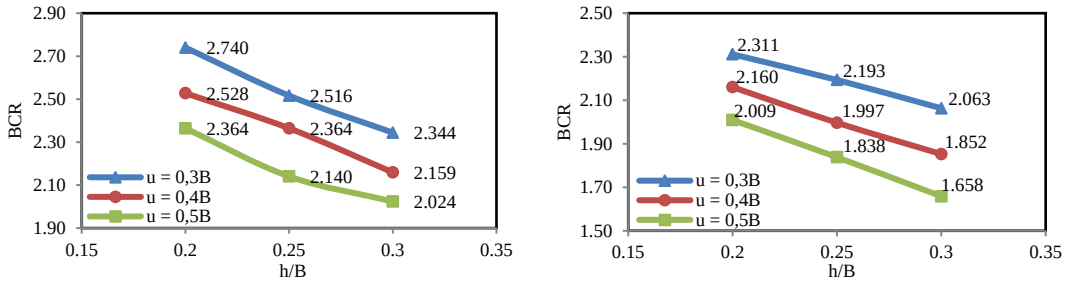
(a) (b) (c)

Fig. 5 Pressure-settlement curves for model footing with l/B=1, (a) h=0.2B; (b) h=0.25B; (c) h=0.3B



(a) (b) (c)

Fig. 6 Pressure-settlement curves for model footing with l/B=2, (a) h=0.2B; (b) h=0.25B; (c) h=0.3B



(a) (b)

Fig. 7 BCR - h/B at different u/B in loose sand (a) l/B = 1; (b) l/B = 2

At the ratio l/B = 1, Fig. 7a shows that the bearing capacity reached its maximum value at h/B = 0.2, if the ratio increases then the value of BCR decreases. Same as parameter u/B which reached the maximum BCR at u/B = 0.3 and decreased by increasing u/B ratio. Fig. 7b shows ratio l/B = 2, its maximum BCR at ratio u/B = 0.3 and h/B = 0.2 and it is decreased with increasing the ratio u/B and h/B. Based on the comparing Fig. 7a and 7b, it can conclude that the bearing capacity improvement at ratio l/B = 1 is higher than at l/B = 2, remembering that the value of qu on each ratio l/B is only one sample.

4.2 Effect Of Length Footing

Footing length ratio, spacing between geogrid ratio, distance first layer geogrid ratio had each maximum bearing capacity. Therefore, to determine that have biggest effect to improve the bearing capacity, it calculated on Table 3 and Table 4 below.

Table 3 BCR improvement at parameter spacing between geogrid (h).

Vari -able	Footing length	Parameter alteration	Improvement (%)		
			u/B = 0,3	u/B = 0,4	u/B = 0,5
h/B	L = B	0.2-0.25	8.161	6.461	9.471
		0.25-0.3	6.835	8.671	5.450
	L = 2B	0.2-0.25	5.372	8.192	9.291
		0.25-0.3	6.325	7.793	10.845

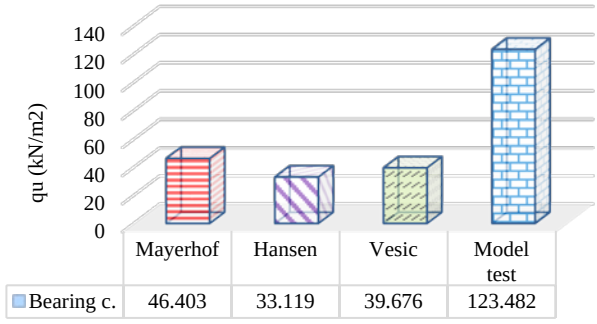
Table 4 BCR improvement at parameter distance first layer geogrid (u).

Vari -able	Footing length	Parameter alteration	Improvement (%)		
			h/B = 0,2	h/B = 0,25	h/B = 0,3
u/B	L = B	0.3-0.4	7.743	6.035	7.887
		0.4-0.5	6.461	9.471	6.277
	L = 2B	0.3-0.4	6.985	9.848	11.365
		0.4-0.5	7.539	8.631	11.706

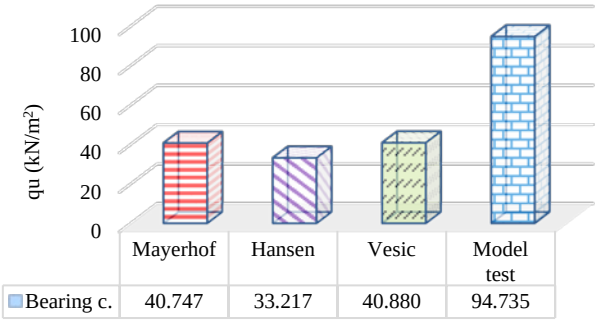
Table 3 shown that the highest improvement is the parameter L=2B with spacing between geogrid ratio increased up to 10.845%, then from Table 4 seen that the highest BCR improvement is L=2B with distance first layer geogrid increased up to 11.706%. Compared to both highest result it shown that distance first layer geogrid ratio become variable that give the highest improvement in this study.

4.3 Scale Factor

From the result of modeling experiment is compared with theoretical equation, Terzhagi (1943), in the same condition as the model test. From the Fig. 8 shows that the value of model test and theoretical equation result have high difference. Model test has higher value than the theoretical result, and it is affected by scale effect.



(a)



(b)

Fig. 8 The differences between teoritical and experimental bearing capacity, (a) l/B=1;(b) l/B=2.

To analyze the scale effect in model test, some addition model tests performed in the steel box as the other experiment before and used variable

l/B=1; 1.5; 2. Each model test performed in the different pit fill, where the densities could be different by up to 10%. This condition will make different result of bearing capacity and the back calculated Nɣ value for the same size footing and soil density. In addition particle size, shape, and gradation also affected the bearing capacity, better graded the soil could achieve denser state of packing and resist shear. As explained before, that all of the factor only affected by friction angle, only Nɣ that corresponding with width of the footing. Fig. 9, shown that the greater size of footing then the Nɣ result approximate the value of Nɣ theoretical result. It means more resemble the model test by the full scale footing, then more resemble value of Nɣ theoretical equation with the real condition.

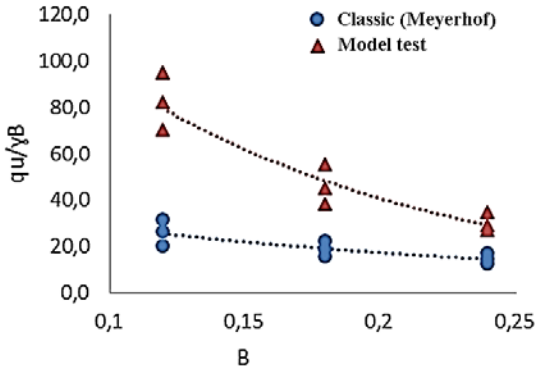


Fig. 9 Comparison qu/ɣB between the model test and Meyerhof theoretical equation.

As explained before, some researchers suggested that the value of Nɣ had to be corrected for the scale effect. Fig. 10 shown that the difference between theoretical equation and model test footing by Nɣ value almost three times higher than theoretical equation result. One of the methods recommended by Shiraishi.

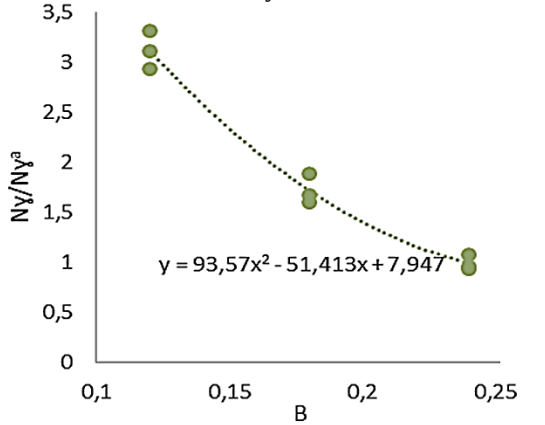


Fig. 10 Nɣ model test footing and Nɣ* theoretical analytic comparison.

Cerato and Lutenegger (2007), in their study used modification method by Shraishi (1990) to modify the value of Nɣ model test footing to full scale footing. Beside Nɣ factor there is also Nq factor that had to be calculated, but it is ignored in this study because less of literature then Nq reputed as a constant factor, and only Nɣ as scale factor.

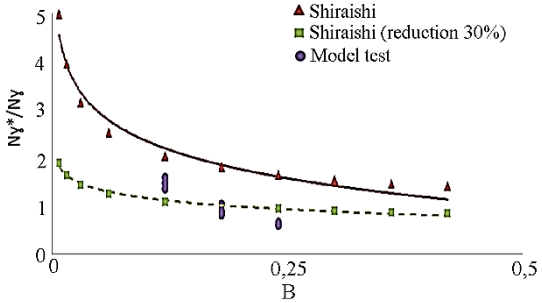


Fig. 11 Nɣ analytical result using Shiraishi's Method (1990).

In this study used Terzhagi theoretical equation as the value of Nɣ, then to correct the account for scale affect seen in scale factor of model footing and prototype. One of the recommended methods to use is Shiraishi theory, suggested that modified bearing capacity factor can be expressed as a function of footing width. Shiraishi theory [Eq. (7)] and reduction equation of Nɣ* [Eq.(8)] were compared with the result of model footing test in this study (Fig. 11). Shiraishi model reduction is better than the original equation in this study.

5. CONCLUSION

1. Bearing capacity of model test with geogrid reinforcement is increased significantly than model test without reinforcement.
2. Bearing capacity in this study increased along the decreasing of ratio h/B and ratio u/B.
3. In the model test of square footing with dimension 12cm x 12cm, the variation of ratio h/B and u/B gave almost a similar effect of the bearing capacity improvement. Besides, different result occurs in the rectangular footing model with dimension 12cm x 24cm. The variation of ratio u/B improves the bearing capacity higher than ratio h/B.
4. The result of the bearing capacity will be approximately the theoretical equation in the model test which has close size with the actual footing size.

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