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Ultimate Bearing Capacity of Strip Foundation on Geogrid-Reinforced Clay Slope

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Abstract

Laboratory model results for the ultimate bearing capacity of a surface strip foundation on a saturated slope reinforced with geogrid layers are presented. The angle of the slope with the horizontal was varied from 35° to 50°.

A biaxial geogrid was used as reinforcement for all of the model tests. The location of the top geogrid layer with respect to the bottom of the foundation, center-to-center spacing of the geogrid layer, and depth of geogrid reinforcement were varied. Based on the model test results a preliminary outline for estimating the ultimate bearing capacity is presented.

Keywords . *bearing capacity, geogrid reinforcement, clay slope, strip foundation*

1. Introduction

During the last ten to fifteen years, a number of small-scale laboratory model test results related to the ultimate and allowable bearing capacities of shallow foundations supported by sand reinforced with layer(s) of geogrid were published in the literature (Guido et al., 1986, 1987; Khing et al., 1992; Omar et al., 1993). Yoo et al., (1996) studied the bearing capacity of strip footing on geogrid-reinforced cohesionless slopes. In contrast, similar results for foundations on geogrid-reinforced clayey soils are rather limited (Shin et al., 1993). Results of practicably all studies related to bearing capacity of foundation available at the present time were determined from small-scale laboratory model studies. These studies show that, in general, the ultimate and allowable bearing capacities of shallow foundations can be

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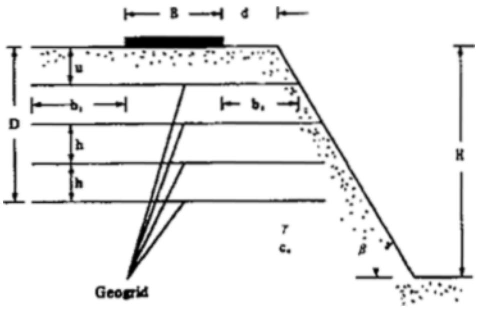


Fig. 1 Geometric Parameters for a Surface Strip Foundation on Geogrid-reinforced Clay Slope

improved by incorporating geogrid reinforcement. The present paper is an extension of the work of Shin et al., 1993) in which the bearing capacity of a strip foundation located at the top of a clay slope has been experimentally investigated in the laboratory.

Laboratory model tests of this type have several inherent drawbacks, such as the presence of scale effect which is predominant in tests conducted in sand. Also, the use of full-scale geogrid as reinforcement for model tests may give questionable results. In spite of these shortcomings, model tests do provide reasonable understanding of the influence of geogrid reinforcement in the bearing capacity improvement of shallow foundations.

2. Geometric Parameters

The geometric parameters of the bearing capacity study reported in this paper are shown in fig. 1. The saturated clay slope shown has a height H and it marks an angle β with the horizontal.

The undrained shear strength and the saturated unit weight of the clay are c_u and γ respectively. There are n layers of geogrid reinforcement with the first layer located at a depth u below the bottom of the foundation. Thus the total depth, D, of reinforcement measured from the bottom of the foundation can be given as

$$D = u + (n-1)h \tag{1}$$

where h = vertical spacing between consecutive layers of geogrid

The geogrid-reinforced clay slope supports a surface strip foundation of width B. The distance between the edge of the strip foundation and the edge of the slope is d. The width of each geogrid layer is b and can be expressed as

$$b = b_1 + B + b_2 \tag{2}$$

Shin et al.(7) showed that, for horizontal ground surface(i.e., β=0), for mobilization of the maximum ultimate bearing capacity

$$b_1 = b_2 \approx 2B \tag{3}$$

Therefore, in this study, b_1/B was kept at 2 for all tests. However, depending on the magnitude of D/B and slope angle β, b_2 was equal to or less than 2B.

3. Model Tests

Model tests were conducted in a box having inside dimensions of 1.22m (length) × 152.4mm (width) × 610mm (depth). The sides of the box were braced with angle irons to prevent yielding during soil compaction and application of load to the model foundation. The inside of the box was made as smooth as possible to minimize friction with the edges of the model foundation during load application. The model foundation was made from hard wood with dimensions of 76.1mm(B)×152.4mm (length)×38.1mm (thickness). To ensure rigidity, an aluminum plate of the same width as the model foundation was mounted on its top. The base of the model foundation was made rough by cementing a thin layer of sand to it with epoxy glue. A hole was made on the top of the foundation to ensure that the applied centric load remained vertical during the tests.

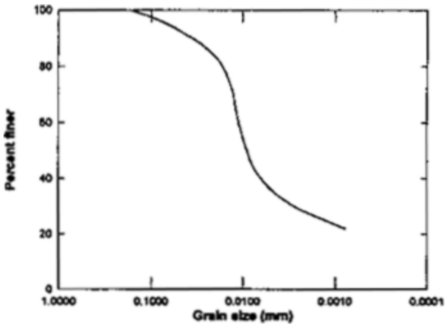


Fig 2. Grain-size Distribution of Soil used in the Model Tests.

Table 1 Details of the Compacted Soil and Geogrid

Item	Quantity
Compacted Soil	
Unit weight during test	18.25kN/m³
Moisture content during test	35.8%
Degree of saturation during tests	98%
Undrained vane shear strength	9.1kN/m²(±6%)
Geogrid	
Structure	Punctured sheet drawn
Polymer	PP/HDPE co-polymer
Junction	Unitized
Aperture size(MD/XMD)	25.4mm/33.0mm
Nominal rib thickness	0.76mm
Nominal junction thickness	2.29mm

A natural clayey soil was used for the tests. The grain size distribution of the soil is shown in fig. 2. The liquid limit and the plasticity index of the soil were determined to be 44% and 20%, respectively. The soil was pulverized in the laboratory and then thoroughly mixed with water. In order to ensure uniform moisture distribution, the most soil was then placed in several plastic bags and cured for about a week before use.

In starting the tests, the moist soil was placed in the test box and compaced in 25.4-mm thick layers. The compaction was achieved using a flat-bottomed hammer. A biaxial geogrid was used for reinforcement. It is one of the weakest geogrids available commercially in the market. The geogrid reinforcement layers having $b=5B$ were placed at desired values of u/B and h/B. After completion of compaction, the slope was formed by trimming the compacted soil. For all tests, b_1 was kept at 2B. As mentioned before, the magnitude of b_2 was kept less than or equal to 2B, depending on the slope angle β and depth of reinforcemt D.

Once the slope was formed, the model foundation was placed at the top of the slope a desired d/B. The model test box was then placed under a steel frame. Load to the foundation was applied with a hydraulic jack. The load and corresponding settlement were measured by a proving ring and dial gauges, respectively. The undrained shear strength, c_u, of the compacted clay was determined at the end of each bearing capacity test with a hand-held vane

Table 2 Details of Model Tests

Series	β(deg)	d/B	n	u/B	h/B	Remarks
A	35, 40, 45, 50	0, 1, 2	-	-	-	Unreinforced clay
B	0, 35, 40, 45, 50	0, 1, 2	1, 2, 3, 4, 5, 6	0.4	0.333	Reinforced clay
C	45	1	3	0.25, 0.4, 0.6, 0.8, 1.0	0.333	Reinforced clay
D	45	1	2, 3, 4, 5	0.4	1.332, 0.666, 0.444, 0.333	Reinforced clay

Note For all tests, $H=0.533m$

shear device. Details of the physical parameters of the compacted soil and the geogrid are given in Table 1. The ultimate load for each test was determined from the load-settlement curves using the procedure described by Vesic (1973). A total of 104 tests were conducted and the sequence of the model tests is summarized in Table 2.

4. Test Results

4.1 Test Series A

The bearing capacity tests conducted in this series were on unreinforced clay. Meyerhof(1957) provided the theory for the ultimate bearing capacity of a strip foundation on a saturated clay slope (ϕ=0 condition). According to this theory,

$$q_u = c_u N_{cq} \tag{4}$$

where q_u = ultimate bearing capacity on unreinforced clay

N_{cq} = bearing capacity factor

For surface foundation, $N_{cq} = N_c$

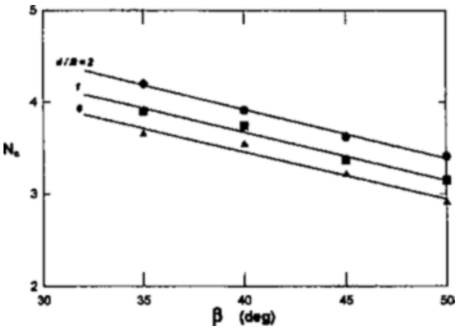


Fig. 4 Experimental values of N_c (Series A)

Hence

$$N_c = \frac{q_u}{c_u} \tag{5}$$

Fig. 3. shows typical plots of s/B (s = foundation settlement) versus load per unit area of the foundation along with the ultimate bearing capacity, q_u.

The experimentally-derived bearing capacity factors(N_c) for tests conducted in Series A for various values of d/B and slope angle (β) are shown in fig. 4.

The comparison shows that, for β less than 50°, the experimental values

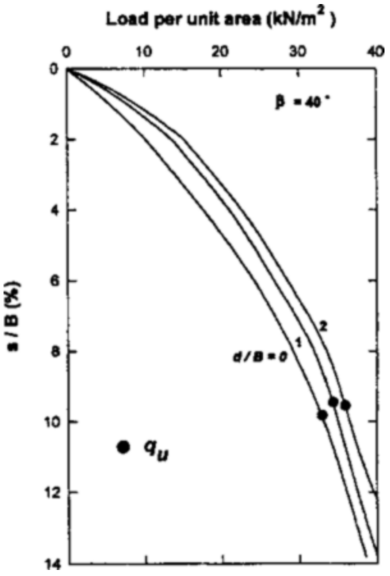


Fig 3 Typical Plots of Load per unit area Versus s/B—Tests on Unreinforced Alope (Series A)_

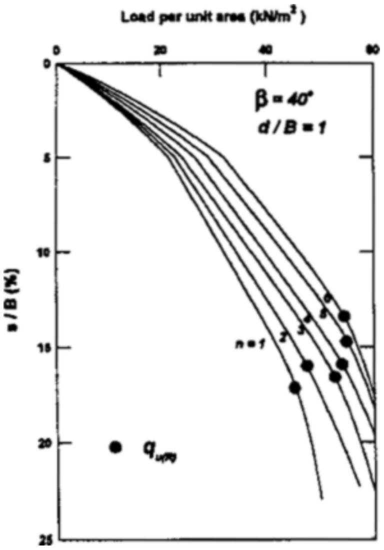
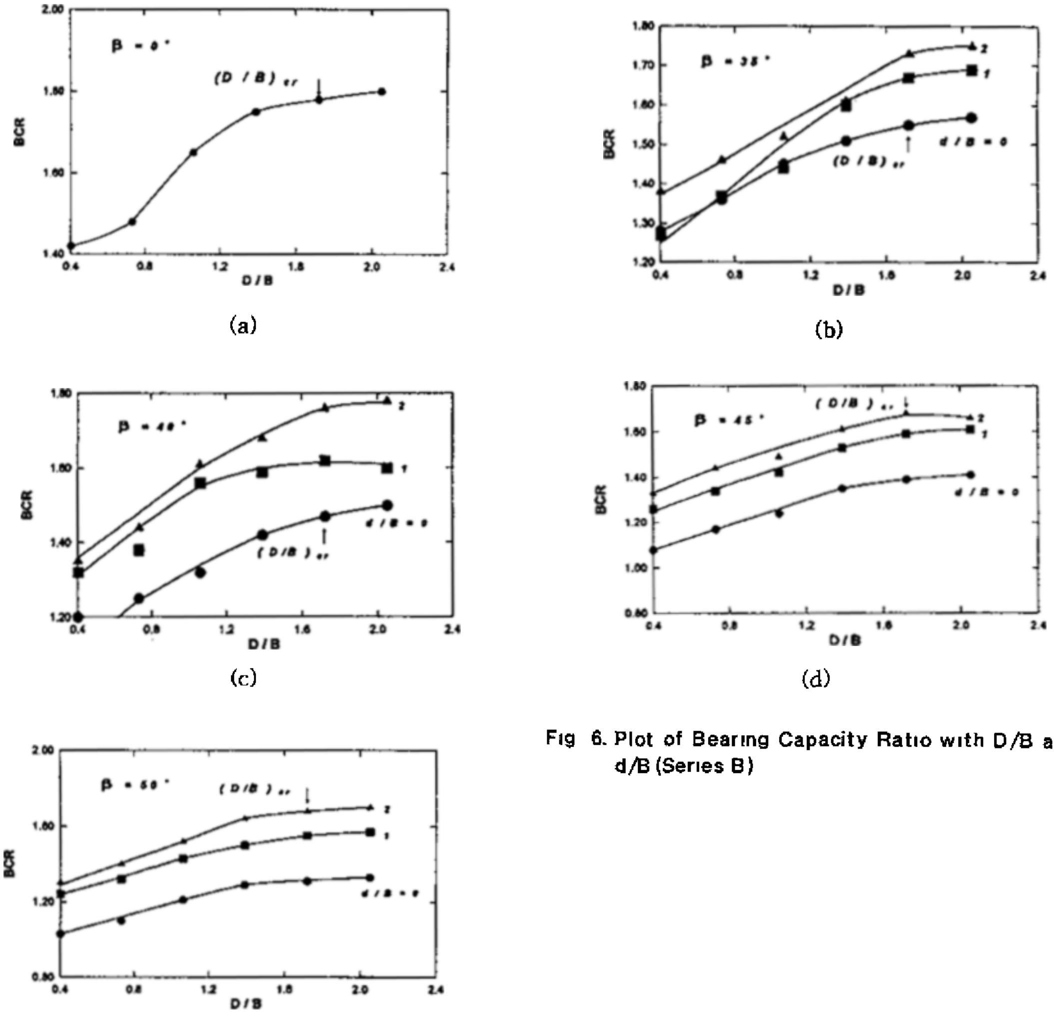


Fig 5 Typical Plots of Load per unit area Versus s/B—Tests on Reinforced Slope (Series B, u/B = 0 4, h/B = 0 333).



(a)

(b)

(c)

(d)

(e)

Fig 6. Plot of Bearing Capacity Ratio with D/B and d/B (Series B)

are somewhat higher than those predicted by theory.

4.2 Test Series B

The tests in this series were conducted to determine the critical depth of reinforcement, $D/B = (D/B)_{cr}$, beyond which the contribution of reinforcement to the improvement of the bearing capacity is practically negligible. All tests were conducted at $u/B = 0.4$ and $h/B = 0.333$. fig. 5. shows typical plots of s/B vs. load per unit area on the foundation (for $\beta = 40°$ and $d/B = 1$) along with ultimate bearing capacity on reinforced clay slope, $q_u(R)$. For similar values of β, d/B and H/B, the ultimate bearing capacity can be expressed in a nondimensional form as

$$BCR = \frac{q_{u(R)}}{q_u} \tag{6}$$

Fig. 6 shows the experimental variations of BCR for $\beta = 0°$ to $50°$ and $d/B = 0$ to 2. In all cases BCR increases with D/B up to an approximate maximum value and remains constant thereafter. Hence as shown in fig. 6., for all cases irrespective of β and d/B,

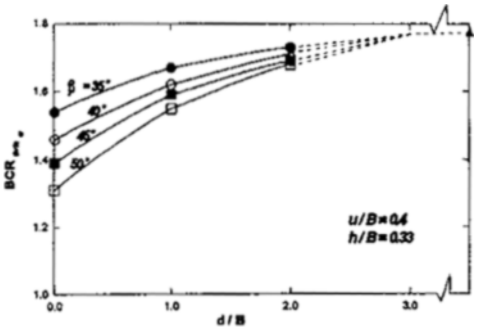


Fig 7 Plot of Experimental $BCR_{(D/B)_{cr}}$ with d/B (based on Fig 6)

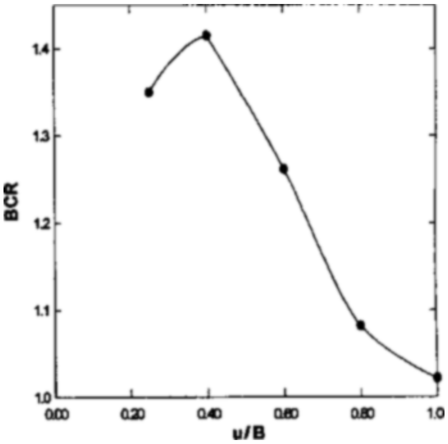


Fig 8 Plot of BCR Versus u/B (Series C β = 45°, d/B = 1, h/B = 1/3, n = 3)

the value of $(D/B)_{cr}$ is about 1.72.

A plot of $BCR_{(D/B)cr}$ with d/B for various values of the slope angle β obtained from fig. 6. is show in fig. 7. From this fig it can be seen that, for d/B > 3, the slope angle β has no effect on the bearing capacity ratio.

4.3 Test Series C

The tests in Series C were conducted to determine the critical values of u/B [i.e., $(u/B)_{cr}$] for mobilization of maximum ultimate bearing capacity(for similar values of β, c_u and d/B). In this test series, for $\beta = 45°$, d/B = 1, h/B = 0.333 and n = 3, the magnitude of u/B was varied. The experimental bearing capacity ratios (BCR) obtained are shown in fig. 8. Note that the BCR increase from u/B = 0.25 and reaches a maximum value at u/B = 0.4. Thus, the critical u/B [i.e., $(u/B)_{cr}$] is about 0.4.

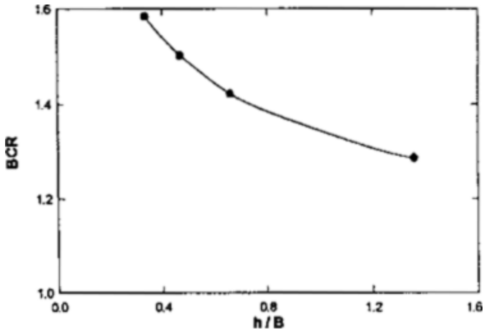


Fig 9 Plot of BCR Versus h/B (Series D)

4.4 Test Series D

Tests in this series were conducted to determine the effect of h/B on BCR. In conducting the tests, u/B = $(u/B)_{cr}$ = 0.4, d/B = 1, D/B = $(D/B)_{cr}$ and $\beta = 45°$ were kept constant, however, h/B was varied by changing the number of reinforcement layer (n). Based on the experimental results, the variation of BCR with h/B is shown in fig. 9. From this figure it appears that, for all practical purpose, the effect of reinforcement of BCR is negligible for h/B > about 0.8.

5. Considerations to Estimate Ultimate Bearing Capacity

Based on the present tests, a preliminary attempt to estimate the ultimate bearing capacity of a strip foundation on geogrid-reinforced saturated clay clay be developed as follows.

$$q_{u(R)} = c_u N_{c(R)} + \gamma D_f \qquad (7)$$

where $N_{c(R)}$ is the modified bearing capacity factor which is a function of d/B, D/B, u/B and h/B. D_f is the depth of foundation.

The modified bearing capacity factor can be expressed as

$$N_{c(R)} = N_c \, \alpha_D \, \alpha_u \, \alpha_h \, BCR'_{(D/B)_{cr}-\beta} \tag{8}$$

where N_c is the bearing capacity factor for unreinforced slope with $D_f/B = 0$. α_D and α_h are the reinforcement depth factor and the spacing factor. α_u is the location factor for the first layer of geogrid

$BCR'_{(D/B)_{cr}-\beta}$ is the bearing capacity factor for a slope angle β with h/B = 1/3, u/B = 0.4 and D/B = $(D/B)_{cr}$ = 1.72

Based on many tests of this type using several types of geogrid and soil, it is the opinion of the author that the magnitude of $BCR'_{(D/B)_{cr}-\beta}$ varies between 1.6 to 1.8 and can be estimated to have an average of about 1.7.

Fig. 10. shows a plot of α_D vs. D/B for various values of β and d/B. The parameter α_D can be expressed as (for a given u/B, h/B, d/B and β)

$$\alpha_D = \frac{BCR_{(D/B)-\beta}}{BCR_{(D/B)_{cr}-\beta}} \tag{9}$$

The plots of α_D shown in fig. 10. were obtained from the experimental values of *BCR* shown in fig. 6.(Series B tests). In spite of some scatter it appears that, for all values of β and d/B.

$$\alpha_D \approx 0.179(D/B) + 0.72 (\text{for } D/B \le 1.4) \tag{10}$$

$$\alpha_D \approx 0.094(D/B) + 0.94 (\text{for } 1.4 \le D/B \le 1.72) \tag{11}$$

For a give slope angle β, h/B, d/B and D/B, the term α_u can be defined as

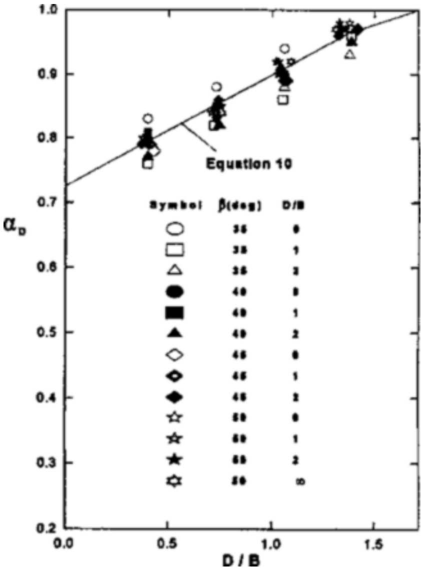


Fig 10 Plot of a_D Versus D/B for Various Values of β and d/B Obtained for Fig 6 (Series B)

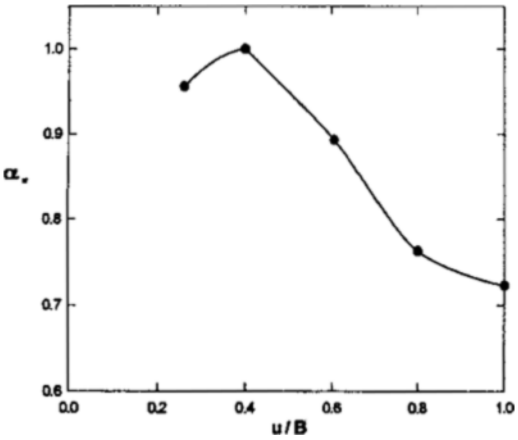


Fig. 11 Plot of a_u Versus u/B Based on Fig 8 (Series C).

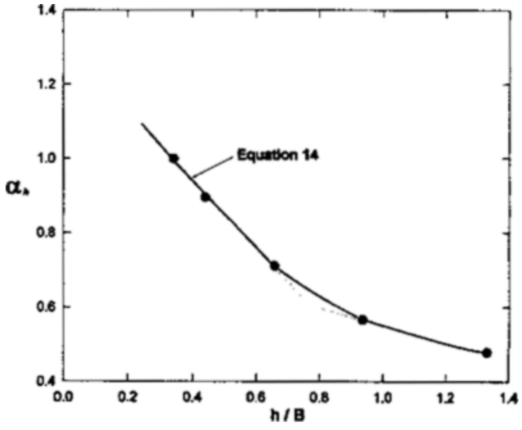


Fig 12 Plot of a_h Versus h/B Based on Fig 9 (Series B)

$$\alpha_u = \frac{\mathrm{BCR}_{(u/B)-\beta}}{\mathrm{BCR}_{(u/B)_{cr}-\beta}} \qquad (12)$$

The variation of α_u with u/B derived from the experimental values shown in fig. 8. is given in fig. 11.

Again, for a given slope angle β, D/B, *u/B* and d/B, the spacing factor α_h can be written as,

$$\alpha_h = \frac{\mathrm{BCR}_{(h/B)}}{\mathrm{BCR}_{(h/B=0.333)}} \qquad (13)$$

Fig. 12. shows the plot of α_h versus rm h/B based on the results shown in Fig. 9. From the plot it appears that

$$\alpha_h \approx 1.3 - 0.9(h/B) \ (\text{for } h/B < 0.8) \qquad (14)$$

6. Conclusions

The results of a number of bearing capacity tests for a model strip foundation supported by a geogrid-reinforced clay slope were presented. Based on these results, the following conclusions can be drawn.

1. Other conditions remaining the same, the first layer of geogrid should be located at a depth of 0.4B below the foundation for maximum increase in the ultimate bearing capacity derived from reinforcement.
2. The maximum depth of reinforcement which contributes to the bearing capacity improvement is about 1.72B.
3. A tentative procedure is suggested for estimating the ultimate bearing capacity of strip foundation.

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