Ultimate bearing capacity of shallow foundation on geogrid-reinforced sand

Capacité portante maximale de fondations superficielles avec armature géogrille

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ABSTRACT

Results of laboratory model tests for the ultimate bearing capacity of strip foundations on geogrid-reinforced sand are presented. The depth of embedment of the model foundation was varied from zero to B (width of foundation). The results have been compared with the existing bearing capacity theory.

RÉSUMÉ

Présente des résultats d'essais en laboratoire d'un modèle pour la détermination de la capacité portante maximale de fondations filantes reposant sur du sable armé de couches de géogrille. Lors de ces essais la profondeur du lit de fondation a été variée de zéro à B (la largeur de la fondation). Les résultats sont comparés aux résultats obtenus par la théorie.

1 INTRODUCTION

Since 1985, the results of a number of studies relating to the evaluation of the ultimate bearing capacity of foundations on sand reinforced with geogrid layers have been published (e.g. Omar et al., 1993; Adam and Collin, 1997; Yetimoglu et al., 1994). Practically all of these studies are based on small-scale model tests conducted in the laboratory. Takemura et al. (1992) have provided a limited number of centrifuge model test results. However, all of the investigations reported so far are for surface foundation condition (that is, depth of foundation, $D_f = 0$).

More recently Huang and Menq (1997) have provided a tentative guideline for estimating the ultimate bearing capacity for surface strip foundations supported by geogrid-reinforced sand. This theory is primarily based on the so-called "wide slab" failure mechanism in soil proposed by Schlosser et al. (1983).

The purpose of this paper is to present some recent laboratory model test results on a strip foundation on geogrid-reinforced sand with the depth of embedment D_f equal to and greater than zero. The experimental results will be compared with the bearing capacity theory of Huang and Menq (1997).

2 GEOMETRIC PARAMETERS AND BEARING CAPACITY THEORY

Figure 1 shows a strip foundation of width B on geogrid-reinforced sand. The depth of the foundation is D_f. The first layer of geogrid is located at a depth u below the bottom of the foundation, and the distance between the consecutive layers of geogrid is h. The width of each geogrid layer is b. The depth of reinforcement is d, or

$$d = u + (N-1)h \tag{1}$$

where N = number of geogrid layers.

According to the wide-slab mechanism proposed by Schlosser et al (1983), if a load is applied on the foundation, it spreads out along the depth of reinforcement at an angle β with respect to the vertical. At a depth d, the width over which the foundation load is distributed is equal to $B + \Delta B = B + 2d\tan\beta$. At ultimate load, the failure in soil may be assumed to take place below a foundation having a width $B' = B + 2d\tan\beta$.

Huang and Menq (1997) suggested a tentative relationship to determine the ultimate bearing capacity of a strip surface foundation ($D_f = 0$) on reinforced sand based on this mechanism as

$$q_{u(R)} = 0.5(B+\Delta B)\gamma N_\gamma + \gamma d N_q \tag{2}$$

where γ = unit weight of soil
$q_{u(R)}$ = ultimate bearing capacity on reinforced sand
N_q, N_γ = bearing capacity factors (Vesic, 1973)

$$N_q = e^{\pi\tan\phi'}\left(\frac{\pi}{2}+\frac{\phi'}{2}\right) \tag{3}$$

$$N_\gamma = 2(N_q+1)\tan\phi' \tag{4}$$

where φ' = effective friction angle of sand

$$\Delta B = 2d\tan\beta \tag{5}$$

$$\tan\beta = 0.68 - 2.071\left(\frac{h}{B}\right) + 0.743(\mathrm{CR}) + 0.03\left(\frac{b}{B}\right) \tag{6}$$

where CR = cover ratio = w/W (Fig.2).

Equation (2) is valid for

$0 \le \tan\beta \le 1$	$1 \le b/B \le 10$
$0.25 \le h/B \le 0.5$	$1 \le N \le 5$
$0.02 \le \mathrm{CR} \le 1.0$	$0.3 \le d/B \le 2.5$

For $D_f > 0$, it appears reasonable to assume that

$$q_{u(R)} = 0.5(B+\Delta B)\gamma N_\gamma + \gamma(D_f + d)N_q \tag{7}$$

It may also be noted that Eqs. (2) and (7) do not have any depth factors associated and, hence, will provide conservative results.

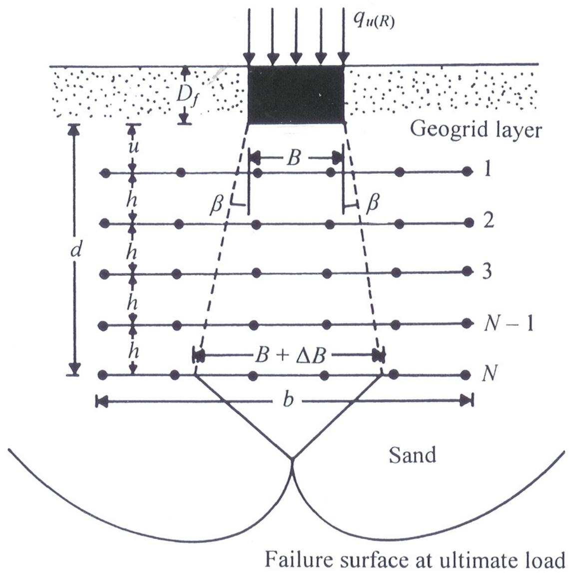

Figure 1. Strip foundation supported by sand reinforced by multiple layers of geogrid.

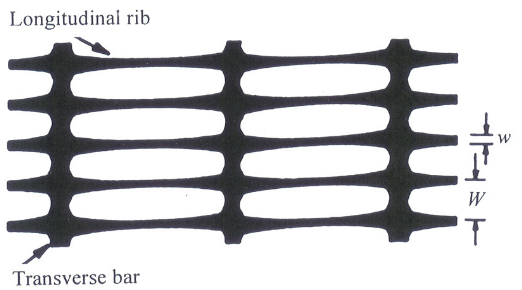

Figure 2. Definition of cover ratio, CR.

3 LABORATORY MODEL TESTS

The model foundation used for this study had a width of 80 mm and a length of 360 mm. It was made out of a mild steel plate with a thickness of 25 mm. The bottom of the model foundation was made rough by coating it with glue and then rolling it over sand. Bearing capacity tests were conducted in a box measuring 0.8 m (length) × 0.365 m (width) × 0.7 m (depth). The inside walls of the box and the edges of the model were polished to reduce friction as much as possible. The sides of the box were heavily braced to avoid lateral yielding. Locally available sand dried in an oven was used for the present model tests. The sand used for the tests had 100% passing 1.18-mm size sieve and 0% passing 0.075-mm size sieve. For all tests, the average unit weight and the relative density of compaction were kept at 14.81 kN/m³ and 71%, respectively. The average peak friction angle φ' of the sand at the test conditions as determined from direct shear tests was 41°. A uniaxial geogrid was used for the present tests. The physical properties of the geogrid are given in Table 1.

Table 1. Physical Properties of the Geogrid.

Peak tensile strength	60 kN/m
Tensile strength at 2.0% strain	14 kN/m
Tensile strength at 5.0% strain	30 kN/m
Strain at break	8%
Aperture size	94 mm × 42 mm

In conducting a model test, sand was placed in layers of 25 mm in the test box. For each layer, the amount of soil required to produce the desired unit weight was weighed and compacted using a flat bottomed wooden block. Geogrid layers were placed in the sand at desired values of u/B and h/B. The model foundation was placed on the surface as well as at desired depths below the surface of the sand bed. Load to the model foundation was applied through an electrically operated hydraulic jack. The settlement of the foundation was recorded by two dial gauges having 0.01-mm accuracy and placed on either side of the model foundation. Load was applied in small increments and the resulting deformations recorded so that the entire load-settlement curve could be obtained. Since the length of the model foundation was approximately the same as the width of the test box, it can be assumed that an approximate plane strain condition did exist during the tests.

For the present test program, the following parameters were adopted for the geogrid reinforcement layers: $u/B = 0.35$, $h/B = 0.25$, $b/B = 5$, $N = 2$, 3, and 4 (that is, d/B varying from 0.6 to 1.1). The sequence of the model tests is given in Table 2.

Table 2. Details of Model Tests.

Test series	N	b/B	D_f/B
I	0	—	0-1.0 (unreinforced sand)
II	2, 3, 4	5	0
III	4	5	0, 0.25, 0.5, 0.75, 1.0

Note: $u/B = 0.35$ and $h/B = 0.25$ for all tests

4 MODEL TEST RESULTS

Figure 3 shows the load per unit area, q, versus settlement, s, for tests conducted in Series I (that is, tests on unreinforced soil). Figure 4 shows the plot of ultimate bearing capacity versus embedment ratio obtained from Fig. 3. For vertical loading condition the ultimate bearing capacity, q_u, of a strip foundation on unreinforced soil can be expressed as

$$q_u = \frac{1}{2}\gamma B N_\gamma F_{\gamma d} + q N_q F_{qd} \tag{8}$$

where $q = \gamma D_f$; N_q and N_γ = bearing capacity factors [Eqs. (3) and (4)]; $F_{\gamma d}$ and F_{qd} = depth factors.

The depth factors can be expressed as (Hansen, 1970)

$$F_{qd} = 1 + 2\tan\phi'(1-\sin\phi')^2 \frac{D_f}{B} \tag{9}$$

$$F_{\gamma d} = 1 \tag{10}$$

Using the above relationships, the theoretical ultimate bearing capacities for the present test conditions have been calculated in Fig. 4 along with the experimental values. Generally, the experimental values are higher than those obtained using Eq. (8). As has been pointed out by several investigators in the past, this is not very unusual primarily due to the inherent difficulty in establishing the proper magnitude of φ' for bearing capacity calculations. From Eq. (8), for surface foundation (that is., $D_f/B = 0$), $q_u = 1/2\gamma B N_\gamma$, or $N_\gamma = 2q_u/\gamma B$. Using the experimental values of q, γ, and B, the experimental value of N_γ was back calculated. This value of N_γ corresponds to about 44° [Eq. (4)]. Using this deduced value of $\varphi' = 44°$, the variation of q_u with D_f/B was calculated, and this is also shown in Fig. 4. The general agreement of this theoretical variation with experimental results appears to be excellent.

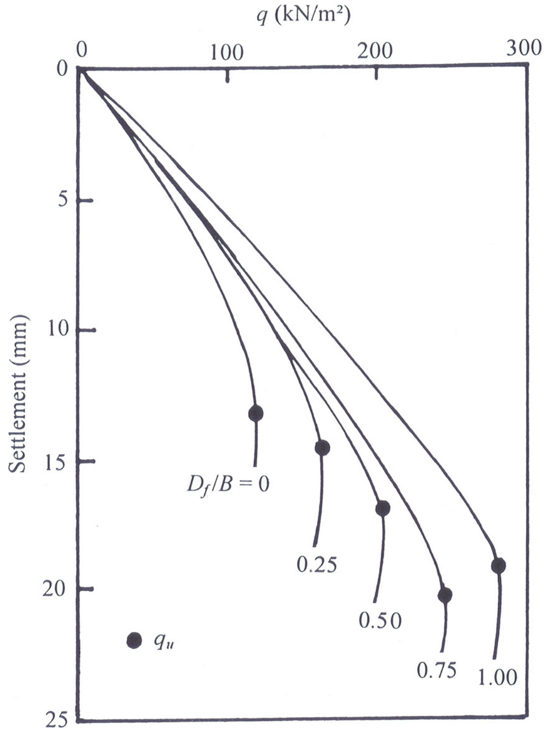

Figure 3. Plot of q versus settlement (Series I).

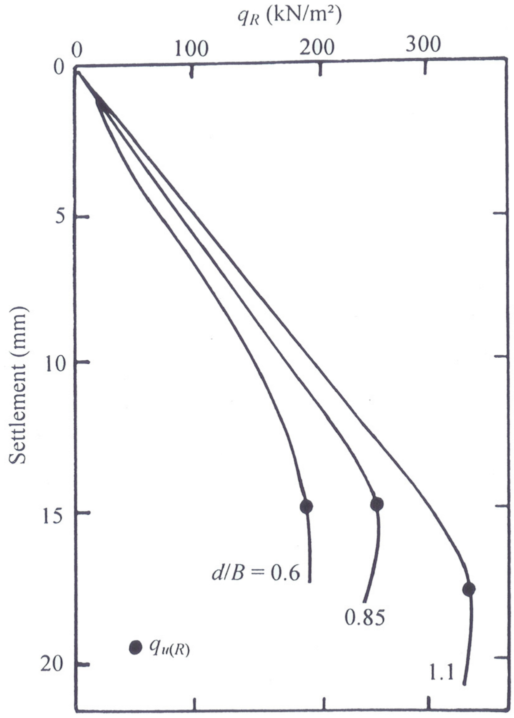

Figure 5. Plot of q_R versus settlement for surface foundation on reinforced soil (Series II).

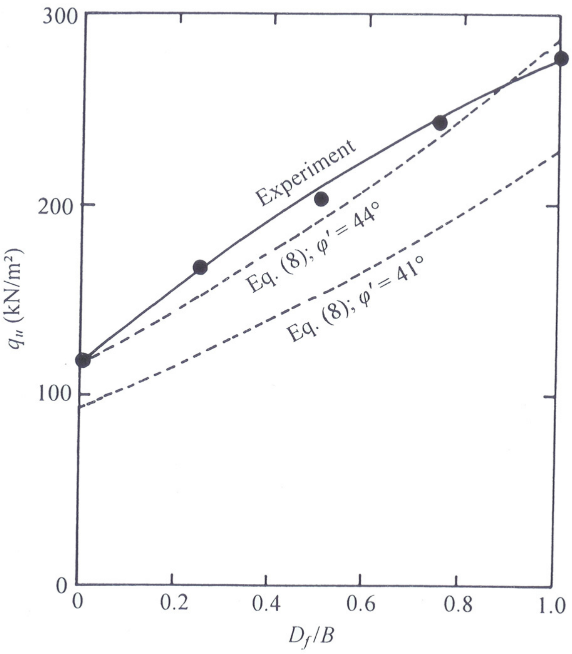

Figure 4. Variation of q_u with D_f/B (Series I).

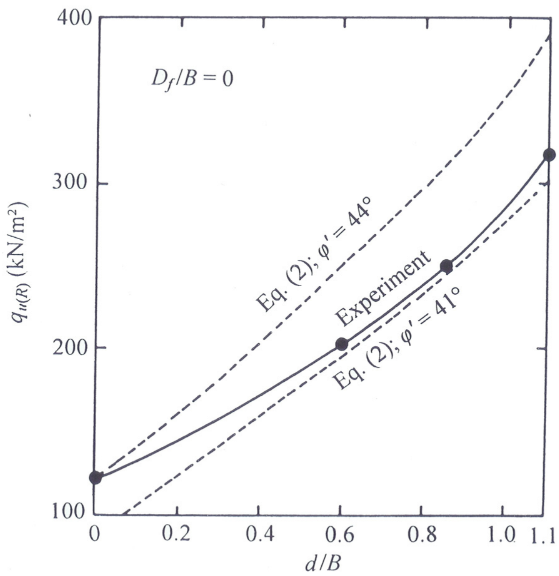

Figure 6. Variation of $q_{u(R)}$ with D_f/B (Series II).

. Test series II was conducted on a surface foundation supported by multiple layers of geogrid reinforcement (that is, d/B = 0.6, 0.85, and 1.1). The variations of load per unit area, q_R, versus settlement for the three tests in this series are shown in Fig 5. The ultimate bearing capacities, $q_{u(R)}$, obtained from Fig. 5 are shown in Fig. 6. Using the experimental values of d, B, h, b, w, W, and φ' (= 41°) in Eq. (2), the theoretical variation of $q_{u(R)}$ can be obtained, and this is shown in Fig. 6. There appears to be an excellent agreement between the theory and experimental values.

Similar calculations for $q_{u(R)}$ with the deduced value of φ' = 44° were done. This variation of $q_{u(R)}$ with D_f/B is also shown in Fig. 6. It may be seen that, for this case, the theoretically obtained $q_{u(R)}$ is somewhat higher that than obtained experimentally. At d/B = 1.1, the theoretical value of $q_{u(R)}$ is about 20% higher than that obtained from the experiment.

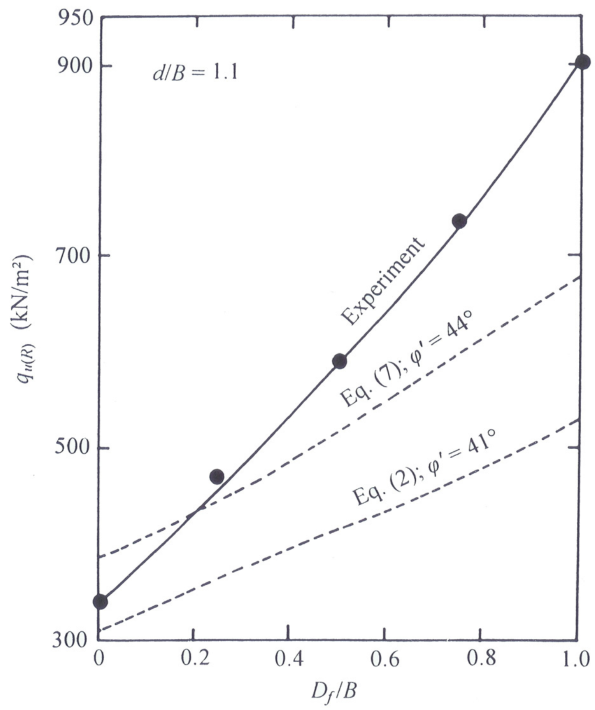

Figure 7. Variation of $q_{u(R)}$ with D_f/B.

In test series III, all tests were conducted with $d/B = 1.1$ and D_f/B varying from zero to 1.0. Figure 7 shows the variation of $q_{u(R)}$ with D_f/B. Using Eq. (7) and proper parameters for the present tests and $\varphi' = 41°$, the variations of $q_{u(R)}$ with D_f/B have been calculated and are also shown in Fig. 7. The experimental values are about 15 to 70% higher than those obtained from Eq. (7). The difference increases with the increase in D_f/B; thus, Eq. (7) provides a conservative value of $q_{u(R)}$. As in Figs. 4 and 6, using $\varphi' = 44°$ and other proper values in Eq. (7), the variations of $q_{u(R)}$ with D_f/B were obtained and are also plotted in Fig. 7. It can be seen that these values, in general, are lower than the experimental values. At $D_f/B \approx 0.25$ and 1, the differences were about 0 and 35%, respectively.

5 CONCLUSIONS

Laboratory model tests for an embedded strip foundation supported by geogrid-reinforced sand have been presented. The ultimate bearing capacities obtained from these tests have been compared with the theory developed by Huang and Menq (1997). Based on the present tests, the following conclusions can be drawn:

a. For the same soil, geogrid, and configuration, the ultimate bearing capacity increases with the increase in embedment ratio, D_f/B.
b. The theoretical relationship for ultimate bearing capacity developed by Huang and Menq (1977) provides somewhat conservative predictions.

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