INTERNATIONAL SOCIETY FOR SOIL MECHANICS AND GEOTECHNICAL ENGINEERING

XIII ICSMFE, 1994. New Delhi, India / XIII CIMSTF, 1994. New Delhi. Inde

BEARING CAPACITY OF FOUNDATION ON GEOGRID-REINFORCED SAND

CAPACITE PORTANTE DE LA FONDATION SUR LE SABLE RENFORCE PAR GEOGRID

M.T. Omar **B.M. Das** **V.K. Puri** **S.C. Yen** **E.E. Cook**

Southern Illinois University at Carbondale
Illinois, U.S.A.

SYNOPSIS: Laboratory model test results for the ultimate bearing capacity of shallow rectangular foundations supported by geogrid-reinforced sand are presented. The width-to-length ratio of the foundations was varied as 0 (strip), 0.333, 0.5 and 1.0. Based on the model test results, the maximum required depths of reinforcement and the sizes of the geogrid layers for obtaining maximum bearing capacity ratios are presented.

INTRODUCTION

Results of several laboratory studies are presently available in the literature which relate to the evaluation of improvement of the ultimate bearing capacity of shallow square and strip foundations supported by reinforced sand (e.g., Binquet and Lee, 1975; Fragaszy and Lawton, 1984; Huang and Tatsuoka, 1988; Huang and Tatsuoka, 1990; Akinmusuru and Akinbolande, 1981; Guido, Biesiadecki and Sullivan, 1985; Guido, Chang and Sweeney, 1986). Various types of reinforcing materials were used in these studies, including aluminum foil, galvanized metal strips, wire mesh, geotextiles, and geogrids. In those studies, improvement of the ultimate bearing capacity due to soil reinforcement was expressed in terms of a nondimensional quantity referred to as the bearing capacity ratio, BCR, which can be defined as

$$BCR = \frac{q_{u(R)}}{q_u} \tag{1}$$

where $q_{u(R)}$ = ultimate bearing capacity with soil reinforcement and q_u = ultimate bearing capacity without soil reinforcement.

More recently, the use of geogrids for soil reinforcement has increased greatly. Geogrids are now primarily used for reinforcement of slopes, highway base courses, and in backfill of retaining walls. However, they can be used as a reinforcing material for improvement of the load-bearing capacity of shallow foundations. Laboratory model studies of Guido et al. (1986) on a square foundation supported by geogrid-reinforced sand showed considerable increase in the ultimate bearing capacity due to the reinforcement. This paper presents some recent model test results relating to the ultimate bearing capacity of shallow rectangular foundations supported by a sand layer reinforced with layers of geogrid.

GENERAL CONSIDERATIONS

Figure 1 shows the cross section and plan of a rectangular surface foundation on a sand layer reinforced with N layers of geogrid. The width and length of the foundation are B and L, respectively. Each geogrid layer measures b × l. The first layer of geogrid is located at a depth u from the bottom of the foundation, and the vertical distance between consecutive geogrid layers is h. Thus, the extent of the geogrid reinforcement d can be given as

$$d = u + (N - 1)h \tag{2}$$

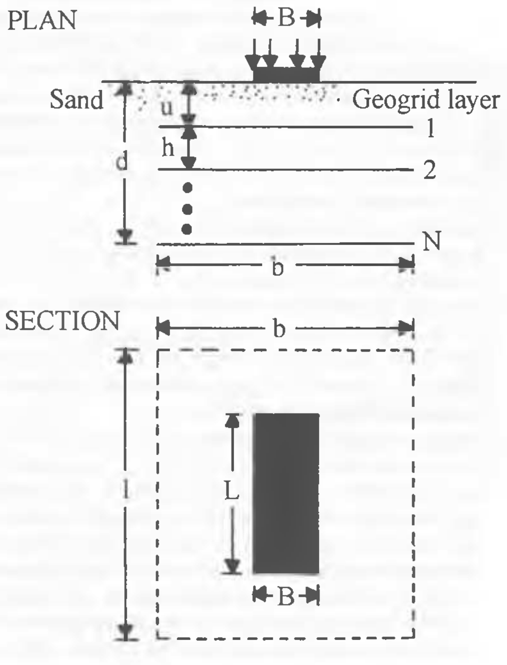

Fig. 1. Geometric parameters for a foundation

With the presence of soil reinforcement, the ultimate bearing capacity of the foundation will be $q_{u(R)}$. If the unit weight and the friction angle of soil, and the type of geogrid layers, remain the same, then

$$q_{u(R)} = f\left(\frac{B}{L}, \frac{u}{B}, \frac{h}{B}, \frac{d}{B}, \frac{b}{B}, \text{ and } \frac{l}{B}\right) \tag{3}$$

In order to derive the maximum benefit from the soil reinforcement, it is essential that u/B be kept at less than 0.67 to 0.75 (Binquet and Lee, 1975; Guido et al., 1985, 1986). If u/B is greater than about 0.75, then the top layer of geogrid behaves somewhat as a semi-rigid surface located at a limited depth below the foundation, and the failure surface will then be located entirely in the soil mass above the top geogrid layer. Also, for a given B/L, u/B, h/B, b/B and l/B, the magnitude of the BCR will increase with the number of layers of reinforcement (i.e., d/B). However there will be a reinforcement depth ratio [i.e., d/B = $(d/B)_{cr}$] beyond which the increase of BCR will be minimal or negligible. In a similar manner, with other factors remaining the same, there are optimum values of b/B = $(b/B)_{cr}$ and l/B = $(l/B)_{cr}$ in excess of which their contribution to the increase of BCR will be negligible.

The purpose of this paper is to report some laboratory model test results to determine the variation of $(d/B)_{cr}$, $(b/B)_{cr}$ and $(l/B)_{cr}$ with B/L of rectangular foundations. Four different model foundations with B/L = 0 (strip), 0.333, 0.5 and 1.0 were tested.

LABORATORY MODEL TESTS

The model foundations were made out of aluminum plates. Three model foundations measuring 76.2 mm × 76.2 mm, 76.2 mm × 152.4 mm, and 76.2 mm × 228.6 mm were used for the present test program, giving B/L ratios of 1.0, 0.5, and 0.333. A fourth model foundation with dimensions of 76.2 mm × 304.8 mm was used for the strip foundation (B/L = 0) bearing capacity tests. The width, B, of each model foundation was the same. Rough base condition was achieved by cementing a thin layer of sand onto their bases with epoxy glue.

Bearing capacity tests on the strip foundation were conducted in a box measuring 1.1 m (length) × 304.8 mm (width) × 914 mm (depth). The inside walls of the box were polished to reduce friction as much as possible with the edges of the model foundation. Bearing capacity tests on the rectangular foundations were conducted in another box measuring 0.91 m × 0.91 m × 0.91 m. The sides of both boxes were braced with stiffeners to avoid lateral yielding during soil placement and loading of the model foundation.

A rounded silica sand was used for the tests. It had 100% passing No. 20 U.S. sieve (0.85-mm opening), 26% passing No. 40 U.S. sieve (0.425-mm opening), and 0% passing No. 60 U.S. sieve (0.25-mm opening). A biaxial geogrid was used for reinforcement. The physical properties of this geogrid are: structure--punched sheet drawn; polymer --PP/HDPE co-polymer; junction method--unitized; aperture size (MD/XMD)--25.4 mm/33.02 mm; nominal rib thickness--0.762 mm; nominal junction thickness--2.286 mm.

In conducting a model test, sand was poured into the test box in 25.4-mm thick layers using a raining technique. The accuracy of sand placement and consistency of placement density were checked by placing small cans with known volumes at different locations in the box. Geogrid layers were placed in the sand at desired values of u/B and h/B. The model foundation was placed on the top of the sand bed, and load on the model foundation was applied by a hydraulic jack. The load and corresponding foundation settlement along the center line were measured by a proving ring and two dial gauges. For all tests, the average values of the unit weight and the relative density of compaction of the sand were 17.14 kN/m^3 and 70%, respectively. The average friction angle at this relative density of compaction determined from direct shear tests was 40.3°. Figure 2 shows a plot of the variation of the friction angle with the relative density (D_r) of sand. Details of all tests conducted under this program are given in Table 1.

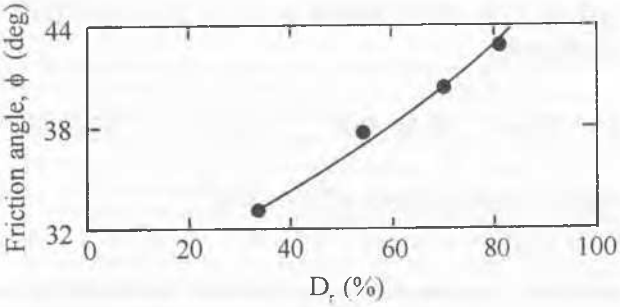

Fig. 2. Variation of soil friction angle, ϕ, with relative density, D_r

Table 1. Details of Model Tests

Test Series	Details
A	Tests on unreinforced sand
B	Variable parameter: N for determination of $(d/B)_{cr}$ Constant parameters: u/B = h/B = 0.333, b/B and l/B
C	Variable parameter: b/B for determination of $(b/B)_{cr}$ Constant parameters: N, u/B = h/B = 0.333, and l/B
D	Variable parameter: l/B for determination of $(l/B)_{cr}$ Constant parameters: N, u/B = h/B = 0.333, and b/B

MODEL TEST RESULTS

Test Series A

These tests were conducted on unreinforced sand at an average relative density of 70%. The ultimate bearing capacities q_u obtained from these tests are shown in Fig. 3.

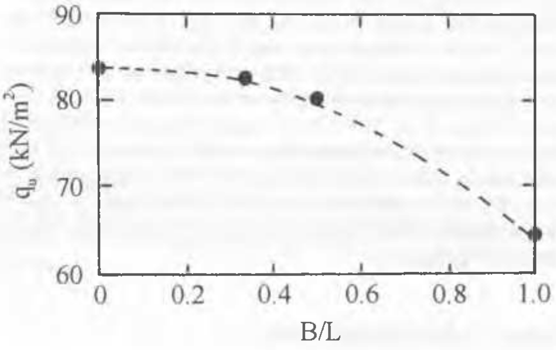

Fig. 3. Variation of q_u with B/L (Test Series A)

Test Series B

The tests in this series were conducted to determine $(d/B)_{cr}$. Figure 4 shows the plots of load per unit area (q) versus settlement (s) as obtained for the case of the strip foundation. For all foundations tested, the ultimate load increased with the increase of N (i.e., d) accompanied by an increase of settlement at ultimate load. The failure mode in soil at ultimate load was observed by conducting some supplementary tests with thin layers of colored sand. This was done only for the case of the strip foundation. The tests were conducted in a separate box whose sides were made of Plexiglas. Figure 5 shows the typical failure pattern. Based on the experimental values of $q_{u(R)}$ obtained from this series and the values of q_u obtained from Series A, the variations of the bearing capacity ratio BCR with d/B for four model foundations are shown in Fig. 6. For a given value of B/L, the magnitude of BCR increases approximately to a maximum at d/B = $(d/B)_{cr}$ and remains practically constant thereafter. Figure 7 shows the plot of $(d/B)_{cr}$ with B/L obtained from Fig. 6. The magnitude of $(d/B)_{cr}$ decreases with the increase of B/L and can be approximated as

$$\left(\frac{d}{B}\right)_{cr} = 2 - 1.4\left(\frac{B}{L}\right) \qquad \left(0 \le \frac{B}{L} \le 0.5\right) \tag{4}$$

and

$$\left(\frac{d}{B}\right)_{cr} = 1.43 - 0.26\left(\frac{B}{L}\right) \qquad \left(0.5 \le \frac{B}{L} \le 1\right) \tag{5}$$

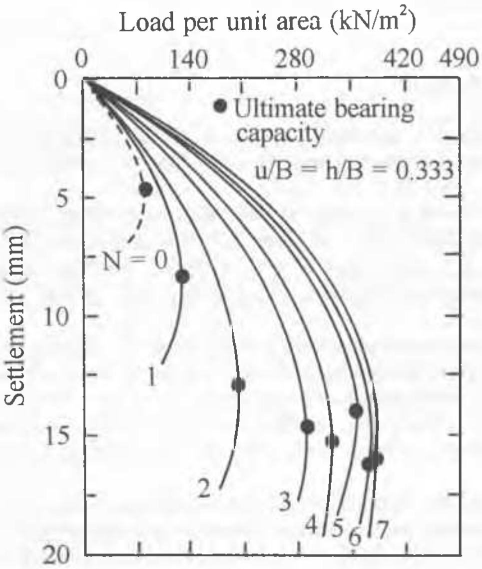

Fig. 4. Load per unit area vs. settlement (Test Series B; B/L = 0)

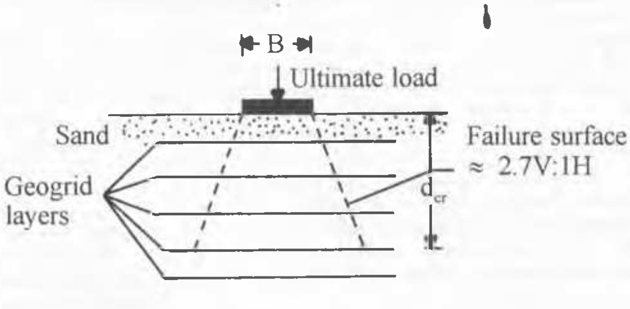

Fig. 5. Typical failure pattern in soil (B/L = 0)

Test Series C

Based on the experimental values of the ultimate bearing capacity $q_{u(R)}$ obtained from this series and those from Series A, the variations of BCR with b/B are shown in Fig. 8. For any given foundation, the

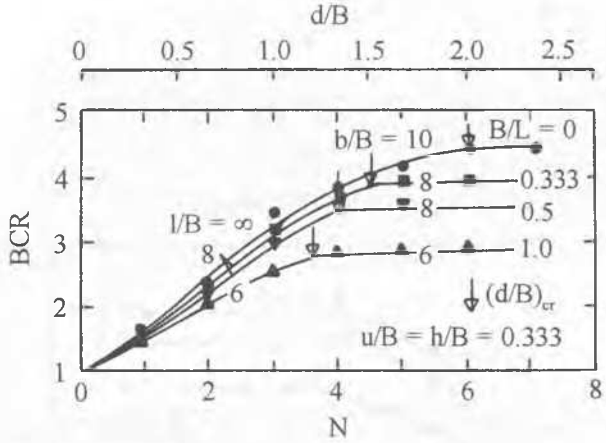

Fig. 6. Variation of BCR with N and d/B (Test Series B)

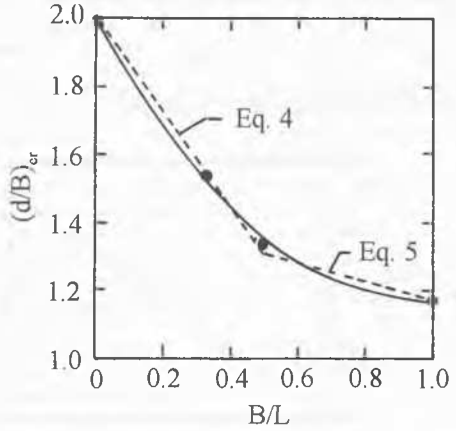

Fig. 7. Variation of $(d/B)_{cr}$ with B/L (from Fig. 3)

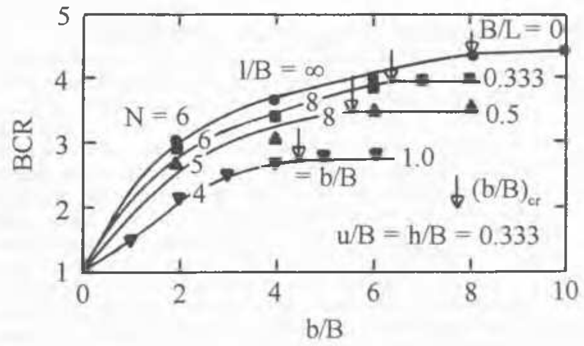

Fig. 8. Variation of BCR with b/B (Test Series C)

bearing capacity ratio increases with b/B and reaches a maximum value at b/B = $(b/B)_{cr}$. The $(b/B)_{cr}$ values obtained from this figure are plotted against B/L in Fig. 9. The variation of $(b/B)_{cr}$ can be approximated as

$$\left(\frac{b}{B}\right)_{cr} = 8 - 3.5\left(\frac{B}{L}\right)^{0.51} \tag{6}$$

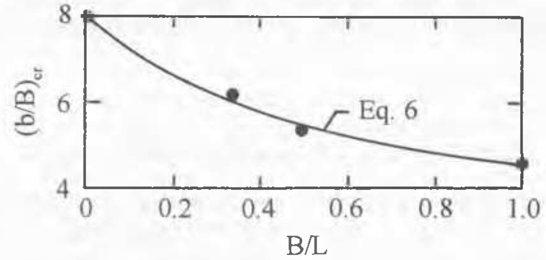

Fig. 9. Plot of $(b/B)_{cr}$ versus B/L (Test Series C)

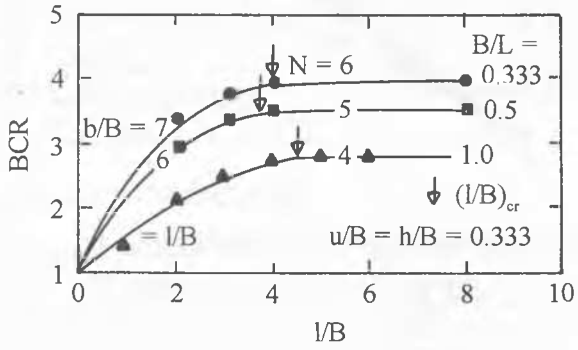

Fig. 10. Plot of BCR versus l/B (Test Series D)

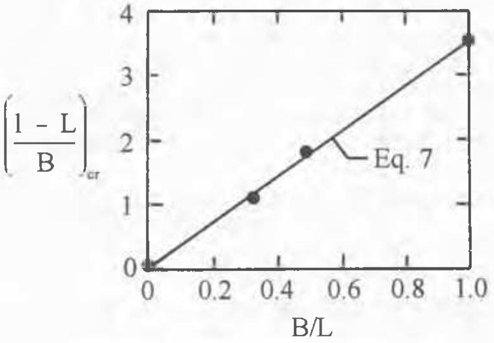

Fig. 11. Variation of $[(l - L)/B]_{cr}$ with B/L (Test Series D)

Test Series D

Figure 10 shows the plots of the experimental BCR with l/B for three foundations used in this test program. For strip foundation, l/B = ∞. The nature of each plot is similar to that obtained in Fig. 8. Figure 11 shows a plot of $[(l - L)/B]_{cr}$ versus B/L obtained from Fig. 10. Based on the experimental values, it appears that

$$\left(\frac{l}{B}\right)_{cr} = 3.5\frac{B}{L} + \frac{L}{B} \tag{7}$$

CONCLUSIONS

The results of a number of laboratory model tests to determine the ultimate bearing capacity of rectangular foundations supported by geogrid-reinforced sand have been presented. Based on the model test results, the following conclusions can be drawn.

(1) For a given sand at a given relative density of compaction and type of geogrid, the critical depth of reinforcement for mobilization of maximum possible ultimate bearing capacity ratio decreases with the width-to-length ratio of the foundation. It is about 2B for strip foundations and about 1.2B for square foundations.

(2) The optimum size of the reinforcing geogrid layers will vary based on the B/L ratio of the foundation and can be approximated by Eqs. (6) and (7).

REFERENCES

Akinmusuru, J.O. and Akinbolande, J.A. (1981). Stability of loaded footings on reinforced soil. *Jl. Geot. Eng. Div.*, ASCE, 107:819-827.

Binquet, J. and Lee, K.L. (1975). Bearing capacity analysis of reinforced earth slabs. *Jl. Geot. Eng. Div.*, ASCE, 101:1257-1276.

Fragaszy, R.J. and Lawton, E.C. (1984). Bearing capacity of reinforced sand subgrades. *Jl. Geot. Eng. Div.*, ASCE, 110:1500-1507.

Guido, V.A., Biesiadecki, G.I., and Sullivan, M.J. (1985). Bearing Capacity of a geotextile reinforced foundation. *Proc of 11th Inter. Conf. on Soil Mech. and Found. Eng.*, Vol. 3, pp. 1777-1789.

Guido, V.A., Chang, D.K., and Sweeney, M.A. (1986). Comparison of geogrid and geotextile reinforced slabs. *Canadian Geot Jl.*, 23:435-440.

Huang, C.C. and Tatsuoka, K. (1988). Prediction of bearing capacity in level sandy ground reinforced with strip reinforcement. *Proc of Intl. Geot. Symposium on Theory and Practice of Earth Reinforcement.* Fukuoka, Japan, 191-196.

Huang, C.C. and Tatsuoka, K. (1990). Bearing capacity of reinforced horizontal sandy ground. *Geotextiles and Geomembranes*, 9:51-82.