Jour. of the KGS Vol. 16, No. 3, June 2000, pp 57~65

Bearing Capacity of Strip Foundation on Geogrid-Reinforced Sand with Embedment Depth

기초의 근입깊이를 고려한 지오그리드 보강 사질토지반의 지지력

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요 지

다층의 지오그리드로 보강된 사질토 지반에 축조된 줄기초의 극한 지지력을 결정하기 위하여 실내모형실험을 실시하였다. 한가지 종류의 사질토와 지오그리드를 사용하였으며, 시험은 기초의 근입깊이(D_f)가 없을 때와 근입깊이(D_f)가 있을 때로 분류하여 시행되었다. 기초의 근입깊이(D_f)는 기초의 폭(B)보다 작도록 제한되었다. 시험결과, 주어진 보강깊이의 두께에 대하여 지지력비(BCR)는 기초의 근입깊이(D_f)가 0보다 클 때 증가하였다.

Abstract

Results of laboratory reduced-scale model tests conducted to determine the ultimate bearing capacity of a strip foundation supported by medium and dense sand reinforced by multiple layers of geogrid are presented. Only one type of sand and one type of geogrid were used. Tests were conducted for surface foundation conditions and for foundations at various depths; the foundation depths were limited to less than the width of the foundation. Based on the test results, for a given thickness of the reinforcement zone, the bearing capacity ratio increases when the depth of the foundation is greater than zero(i.e. the surface foundation conditions).

Keywords : Bearing capacity ratio, Foundation embedment, Geogrid, Sand, Strip foundation, Ultimate bearing capacity

1. Introduction

Recently, results of several laboratory reduced-scale model tests and large-scale field tests to determine the ultimate and allowable bearing capacities of shallow foundation supported by geogrid- reinforced sand (Fig. 1) have been published (Guido et al. 1985; Guid et al. 1986; Omar et al. 1993; Yetimoglu et al. 1994; Das and Omar 1994; Adams and Collin 1997). In Fig. 1, a strip foundal tion of width B is supported by a geogrid-reinforced sand. There are N layers of geogrid, each having a width equa to b. The depth of the foundation is D_f. The top layer of geogrid is located at a depth u below the bottom of the foundation. The distance between consecutive layers of geogrid is h. Hence, the thickness of reinforcement zone, d, below the bottom of the foundation can be express as:

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

The results of all laboratory model tests and large-scale

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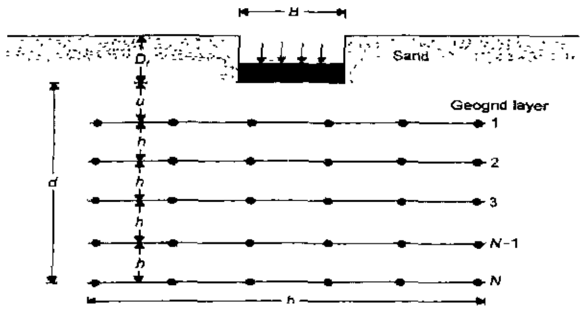

Fig 1 Strip foundation supported by geogrid-reinforced sand

field tests published thus far were conducted for a surface foundation condition, i.e. $D_f=0$. The increase in the bearing capacity due to the introduction of geogrid reinforcement has typically been expressed in a nondimensional form as:

$$BCR=\frac{q_{u(R)}}{q_u} \quad (2)$$

where: $q_{u(R)}$ = ultimate bearing capacity of reinforced sand; and q_u = ultimate bearing capacity of unreinforced sand. It has also been shown in the past that, for given b/B, h/B, and u/B ratios, there is a critical reinforcement-depth ratio, $d/B=(d/B)_{cr}$, at which BCR reaches a maximum value. Similarly, for given values of b/B, h/B, and u/B, there is a critical nondimensional reinforcement-width ratio, $b/B=(b/B)_{cr}$, at which the magnitude of BCR also reaches a maximum value.

The purpose of the current paper is to present the results of recent laboratory model tests related to the ultimate bearing capacity of a shallow strip foundation, with $D_f/B>0$, that is supported by sand with multiple layers of geogrid reinforcement.

2. Scope of Study

For vertical loading, the theoretical ultimate bearing capacity, q_u, of a strip foundation on unreinforced sand can be express as:

$$q_u=qN_qF_{qd}+\frac{1}{2}\gamma BN_\gamma F_{\gamma d} \quad (3)$$

where: $q=\gamma D_f$; D_f= depth of foundation; γ = unit weight of sand; N_q and N_γ =bearing capacity factors; and F_{qd} and $F_{\gamma d}$ =depth factors.

According to Hansen(1970), for $D_f/B\leq 1$:

$$F_{\gamma d}=1 \quad (4)$$

and

$$F_{qd}=1+2\tan\phi(1-\sin\phi)^2\frac{D_f}{B} \quad (5)$$

where ϕ is the soil friction angle.

Thus,

$$q_u=qN_qF_{qd}+\frac{1}{2}\gamma BN_\gamma \quad (6)$$

Similarly, the ultimate bearing capacity of a strip foundation on geogrid-reinforced sand, $q_{u(R)}$, subjected to a vertical load is assumed to be:

$$q_{u(R)}=q_u(BCR)=qN_qF_{qd}(BCR_q)+\frac{1}{2}\gamma BN_\gamma F_{\gamma d}(BCR_\gamma) \quad (7)$$

where BCR_q and BCR_γ are bearing capacity ratios

The bearing capacity ratios depend on several factors such as the relative density of the sand, D_r, the type of geogrid, and the ratios u/B, h/B, b/B, and d/B. For surface foundation conditions, $q=0$ since $D_f=0$. Hence:

$$q_{u(R)}=q_u(BCR)=\frac{1}{2}\gamma BN_\gamma(BCR_\gamma) \quad (8)$$

or

$$BCR=BCR_\gamma \quad (9)$$

In the current study, the laboratory variations of BCR, BCR_q, and BCR_γ with various values of D_f/B and d/B were determined and compared.

Table 1 Physical properties of the geogrid

Physical property	Value
Polymer type	Polypropylene
Structure	Biaxial
Mass per unit area	320 g/m^2
Aperture size	41mm (MD)×31mm (XMD)
Maximum tensile strength	14 5kN/m (MD), 20 5kN/m (XMD)
Tensile strength at 5% strain	5.5 kN/m (MD), 16.0 kN/m (XMD)
Note MD=machine direction: XMD=cross-machine direction.	

3. Laboratory Model Tests

Laboratory reduced-scale model tests were conducted in a wooden box with inside dimensions of 1,000mm(length) × 174mm(width) × 600mm(height). One long side of the box was made of Plexiglas with a thickness of 20mm. Sleepry vinyl sheet was attached to the inside of the other long side of the box to reduce friction between the edge of the model foundation and the box. Also, the edges of the model foundation were lightly coated with petroleum jelly. It is the opinion of the authors, that the frictional effect between the edges of the foundation and the inside of the test box was not large enough to affect the model test results. Angle irons were used to brace the outside of the test box to prevent yielding during construction of foundation soil and bearing capacity tests.

The model foundation was made from wood and measured 172mm(length)×67mm(width, B)×77mm (height). The aluminum plate which has a thickness of 10mm was attached on the top of wooden foundation for preventing deformation and a hole was made to ensure that the applied centric load during the tests remained vertical. The base of the model foundation was roughened by cementing a layer of sand with epoxy glue. A poorly graded silica sand, which had 100% passing 0.85mm size sieve and 0% passing 0.25mm size sieve, was used for the tests. The coefficient of uniformity, C_u, and coefficient of curvature, C_c, of the sand were 1.51 and 1.1, respectively. Tenax LBO 201 biaxial polypropylene geogrid was used for soil reinforcement, and its physical properties are given in Table 1.

For the bearing capacity tests, foundation soil in the test box was formed by a raining method. Accuracy of sand placement and consistency of the relative sand density were checked during construction of foundation soil by placing small cans of known volumes at different locations. Geogrid reinforcement layers were placed at predetermined depths below the bottom of the model

Fig 2 Bearing capacity testing equipment

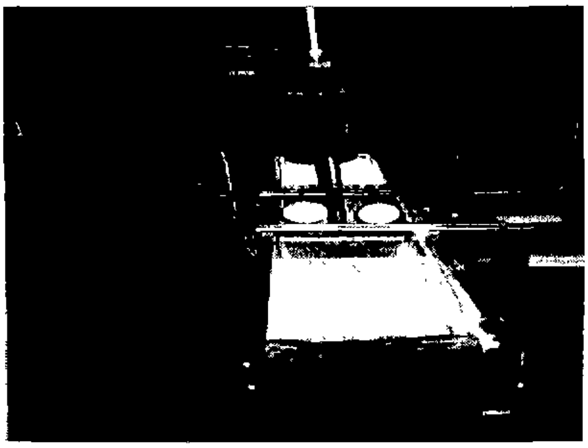

Fig. 3 Bearing capacity test set-up

Table 2. Summary of bearing capacity tests

Test Series	Test No	Relative density of sand, D_r(%)	D_f/B	Comments
A	A−1 A−2 A−3	59 59 59	0 0.37 0.75	Tests without reinforcement
	A−4 A−5 A−6	74 74 74	0 0.30 0.60	
B	B−1 through B−5	59	0	Tests with reinforcement ▸ N=1 ▸ u/B=0.2, 0.4, 0 6, 0.8 ▸ b/B=8
C	C−1 through C−5	59	0	Tests with reinforcement ▸ N=1 ▸ u/B=0.4 ▸ b/B=2, 4, 6, 8, 10
D	D−1 through D−6	59	0	▸ N=1, 2, 3, 4, 5, 6 ▸ u/B=0.4 ▸ b/B=6 ▸ h/B=0 4
	D−7 through D−12	59	0 37	
	D−13 through D−18	59	0.75	
E	E−1 through E−6	74	0	▸ N=1, 2, 3, 4, 5, 6 ▸ u/B=0.4 ▸ b/B=6 ▸ h/B=0.4
	E−7 through E−12	74	0.30	
	E−13 through E−18	74	0.60	

Note: Average unit weights of sand at D_r=59% and 74% were 15 7kN/m^3 and 16 5kN/m^3, respectively

foundation. During the model tests, the machine direction (MD) of the geogrid layers was parallel to the long side of the model test box. The model foundation was placed at desired D_f/B values. All tests were conducted at average relative densities of compaction, D_r = 59 % and 74 %, for which the maximum and minimum void ratios were 0.82 and 0.55, respectively. The peak soil friction angles determined at those relative densities using direct shear tests were 35° and 38°, respectively. Load was applied to the model foundation using an electric gear-controlled piston. The loading speed (piston movement) was maintained at 2 mm/minute. The load and corresponding foundation settlement were measured using a load cell which the maximum capacity is 5 ton and two dial gauges which accuracy is 0.01mm, respectively. Data from loadcell is recorded at the data logger. Fig. 2 and 3 show the installation of the test devices. Details of the bearing capacity tests are given in Table 2.

4. Model Test Results

4.1 Bearing Capacity without Soil Reinforcement

The load per unit area vs. foundation settlement plots obtained from test series A, which were conducted without reinforcement, are given in Fig. 4. Also, the ultimate bearing capacities, q_u, obtained from the load per unit area versus foundation settlement plots are given in Fig. 5. For test series A, the ultimate loads were obtained at a settlement level of $0.1B$ to $0.15B$.

Since the load per unit area of the model foundation itself indicating 0.41kN/m^2 was considerably small compared with the ultimate bearing capacities, the weight of model foundation was not considered in the evaluation of the ultimate bearing capacities. For estimating the ultimate bearing capacities, the peak point were chosen in the cases of showing the peaks, while in cases of indicating

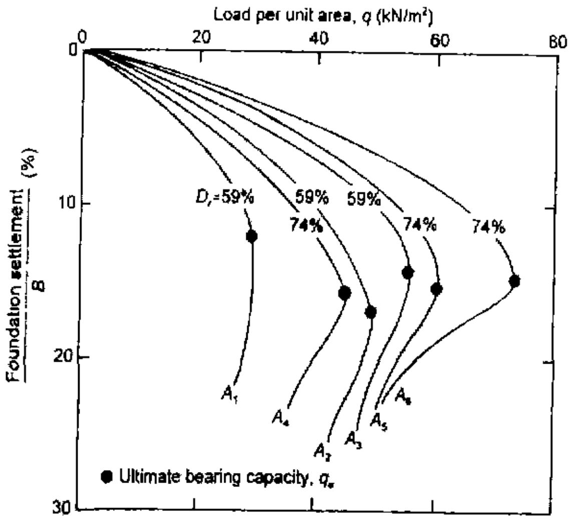

Fig. 4 The load per unit area vs. foundation settlement (Test series A, no reinforcement)

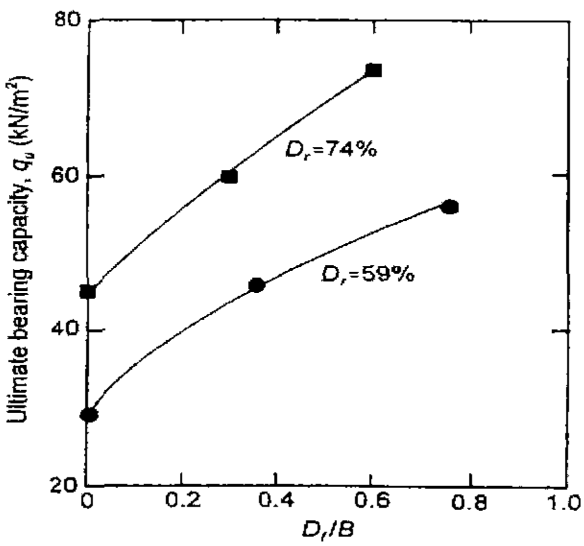

Fig. 5 Variation of q_u versus D_f/B (Test series A, no reinforcement)

residual bearing capacities, the bearing capacities of the crossing points for the two tangents drawn at the starting point and the linear part of the end of the curve were used.

4.2 Determination of the Optimum Value of u/B

Test series B was conducted to make a preliminary determination of the optimum value of u/B at which the maximum benefit from geogrid reinforcement is derived. These tests were conducted using a surface foundation

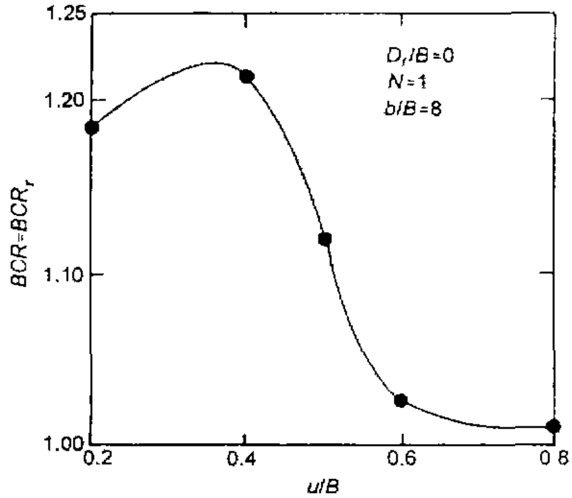

Fig. 6 Plot of $BCR=BCR_\gamma$ versus u/B (Test series B)

condition ($D_f/B=0$) with N=1, b/B=8, and $D_r=59\%$. The tests were conducted with u/B varying from 0.2 to 0.8. From Equations (8) and (9), and with $D_f/B=0$:

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

Based on the experimental values of q_u from Test A-1 and $q_{u(R)}$ from Tests B-1 through B-5, the variations of $BCR(=BCR_\gamma)$ were calculated and are shown in Fig 6. It can be seen from Fig. 6 that BCR initially increases with increasing u/B, and the maximum value of BCR is realized at $u/B=(u/B)_{cr}\approx 0.35$. Beyond this point, BCR decreases with increasing u/B. This is typical of several other published model test results (e.g. Guido et al. 1987, Akinmusuru and Akinbolande 1981, and Yetimoglu 1994). Based on the results from Test series A and B, it was decided to conduct all further tests (Tests Series C, D, and E) with $u/B\approx 0.4$.

4.3 Optimum Width of Reinforcement Layers

Fig. 7 shows the variation of $BCR=BCR_\gamma$ for tests conducted with $N=1$, u/B=0.4, and $D_r=59\%$(Test series C). In calculating the experimental values of BCR, the results of Test A-1 and C-1 through C-5 were used. The bearing capacity ratio increases with increasing b/B

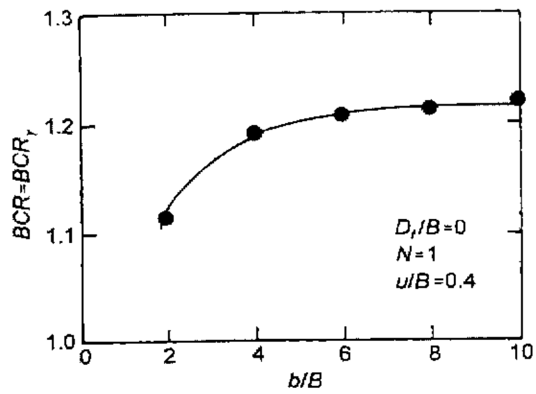

Fig. 7 Plot of $BCR=BCR_{\gamma}$ versus b/B (Test series C)

values up to a maximum value at $(b/B)_{cr}\approx 5$ to 6 and remains approximately constant thereafter. Similar values of $(b/B)_{cr}$ have been reported by other investigators with reinforcement layers consisting of geogrid, geotextile, aluminum foil strips, and wire mesh, and these results are summarized in Table 3.

Since the current test results yield similar results as those shown in Table 3, Test series D and E were performed using $u/B=0.4$ and $b/B=6$.

4.4 Variation of BCR, BCR_{γ}, and BCR_q

Test series D and E were conducted with $u/B=0.4$, $h/B=0.4$, and $b/B=6$. The foundation depth ratio, D_f/B, reinforcement-depth ratio, d/B, and the relative density of the sand, D_r, were varied. Fig. 8. shows typical plots of load per unit area, $q_{u(R)}$, vs. foundation settlement for Tests D-7 through D-12 (D_r = 59%, D_f/B = 0.37, $N=1$ to 6, $u/B=h/B=0.4$, and $b/B=6$).

Fig. 9 shows the experimental values of the ultimate bearing capacity versus D_f/B and d/B for Test series D and E . These tests were conducted primarily to observe

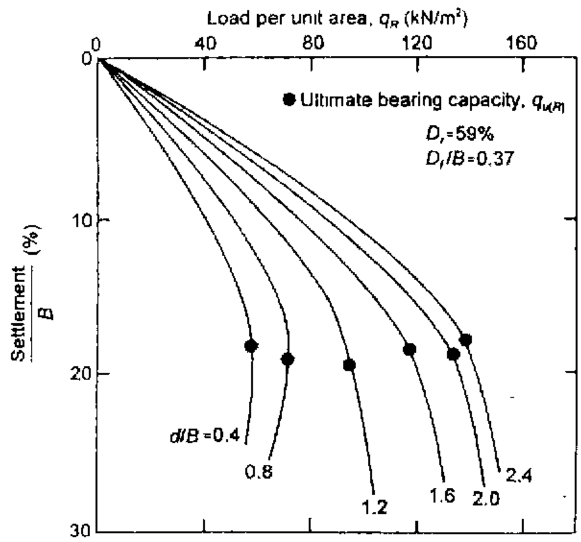

Fig. 8 Load per unit area, $q_{u(R)}$, vs. foundation settlement

the variations of BCR, BCR_{γ}, and BCR_q with D_f/B and d/B. In order to determine these quantities, the following procedure was used.

For given values of D_r, D_f/B, and d/B(depending on N), and from Equation (7):

$$BCR=\frac{q_{u(R)-N,D_f/B}}{q_{u,D_f/B}} \tag{11}$$

where : $q_{u(R)-N,D_f/B}$ = ultimate bearing capacity with N number of reinforcement layers and foundation depth ratio of D_f/B; and $q_{u,D_f/B}$=ultimate bearing capacity without reinforcement at a foundation depth ratio of D_f/B. However, from Equation (8):

$$BCR_{\gamma}=\frac{q_{u(R)-N,D_f/B=0}}{q_{u,D_f/B=0}} \tag{12}$$

Similarly, from Equation (7) and (8)

Table 3. Values of $(b/B)_{cr}$ from other published studies for strip foundation

Reference	Soil friction angle, ϕ(deg)	u/B	$(b/B)_{cr}$
Huang and Tatsuoka(1988)	49 8	0.3	>6
Mandal and Manjunath(1990)	38	0 25	5
Fragaszy and Lawton(1984)	41	0 334	7
Khing et al.(1993)	40.8	0 375	≈8

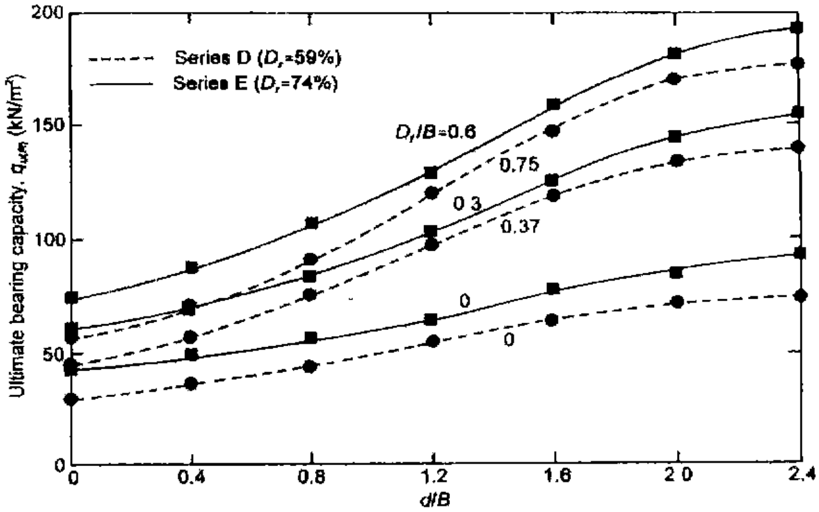

Fig. 9 Experimental ultimate bearing capacity, $q_{u(R)}$ (Test series D and E)

$$BCR_q = \frac{(q_{u(R)-N,D_f/B}) - (q_{u(R)-N,D_f/B=0})}{(q_{u,D_f/B}) - (q_{u,D_f/B=0})} \quad (13)$$

Using Equations (11), (12), and (13), and the experimental values of the ultimate bearing capacity shown in Fig. 9, the variations of BCR, BCR_γ, and BCR_q for Test Series D and E were calculated and are shown in Figures 10, 11, 12. Based on these plots, the following general observations can be made:

1. BCR, BCR_γ, and BCR_q for both relative densities of sand increase with increasing d/B to a maximum value at $d/B \approx 2 = (d/B)_{cr}$. This value of $(d/B)_{cr} = 2$ is consistent with that reported by Omar et al. (1993) for the condition of $D_f/B = 0$ (Figures 10, 11, and 12).

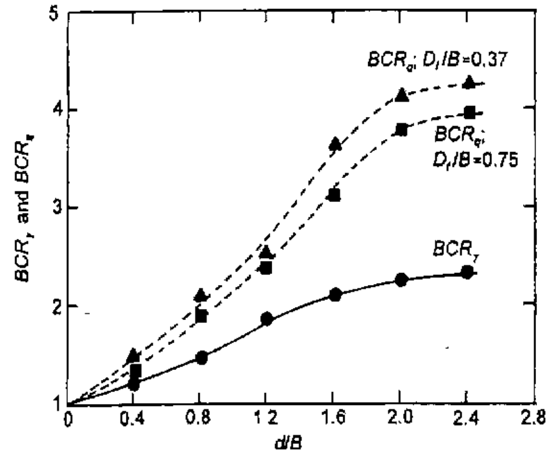

Fig. 10 Variation of BCR_γ and BCR_q with d/B (Test series D, D_r= 59%)

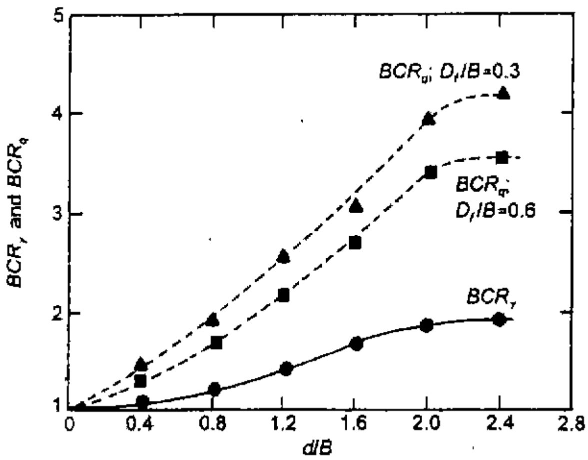

Fig. 11 Variation of BCR_γ and BCR_q with d/B (Test series E, D_r=74%)

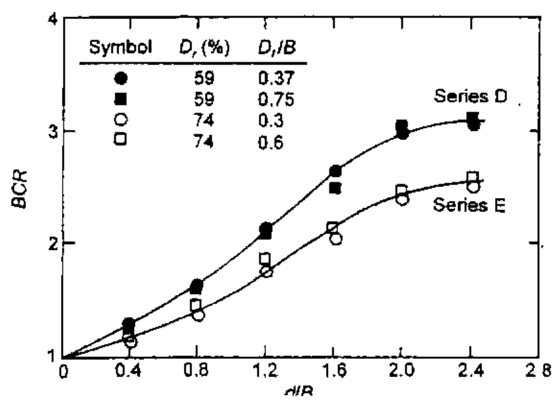

Fig. 12 Plot of BCR versus d/B (Test series D and E)

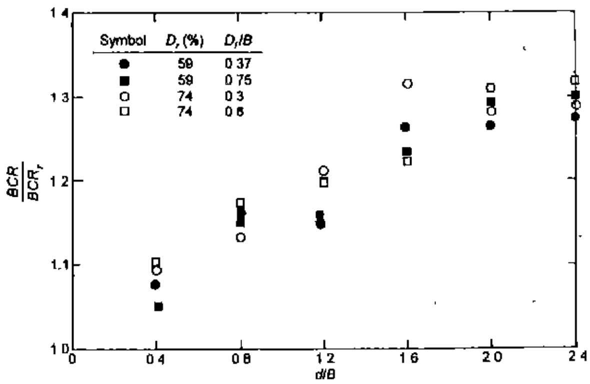

Fig. 13 Plot of experimental BCR/BCR_γ versus d/B (Test series D and E)

2. For a given relative density of the sand and, at any given value of d/B, the magnitude of BCR_q is larger than BCR_γ (Figure 10 and 11).
3. For $0.3 \le D_f/B \le 0.75$ and given values of D_r and d/B, the magnitude of BCR_q decrease with an increase in D_f/B(Figure 10 and 11).

For the test series D and E, the variation of the ratios of BCR/BCR_γ with d/B were calculated and are shown in Fig. 13, from which it can be seen that all of the data points fall in a narrow range. Also, for a given foundation depth, geogrid and configuration, the magnitudes of BCR and BCR_γ determined for surface foundations ($D_f/B=0$) will give a conservative estimation of $q_{u(R)}$ for $D_f/B>0$. BCR in Equation (11) has been taken into account of foundation embedment depth while BCR_γ in Equation (12) is not considered the foundation embedment depth. Therefore, the ratio of BCR/BCR_γ is the increment of bearing capacity with the increase of the foundation embedment depth.

5. General Comments

Model tests of the type discussed in the current paper provide many useful results; however, there are also several shortcomings. Small-scale model tests are always subjected to scale effects resulting in a larger value of the ultimate bearing capacity. In addition, the current study, and all other published laboratory studies, used full-scale geogrids for model footing tests. It would be helpful if geogrids could be modeled and scaled for compatibility.

6. Conclusions

Small-scale laboratory model test results of the ultimate bearing capacity of a strip foundation supported by sand reinforced with multiple layers of geogrid are presented. The tests were conducted with one type of sand compacted at two relative densities and only one type of geogrid. The foundation depth was varied from zero to $0.75\times$ (foundation width, B). Based on the model test results, the following conclusions can be drawn.

1) The critical reinforcement-depth ratio, $(d/B)_{cr}$, for BCR, BCR_γ and BCR_q is approximately 2 for multiple layers of geogrid reinforcement (where BCR = bearing capacity factor).
2) For the range of values used in the current tests ($0 \le D_f/B < 0.75$), BCR_q was larger than BCR_γ.
3) The magnitude of BCR for $0 < d/B \le 2$ is greater than BCR_γ. It implies that the BCR value determined from surface footing tests will provide conservative estimates of the ultimate bearing capacities for foundations at depths greater than zero.

References

1. Adams, M.T. and Collin, J.C., 1997, "Large Model Spread Footing Load Tests on Geosynthetic Reinforced Soil Foundations", Journal of Geotechnical and Geoenvironmental Engineering, Vol. 123, No. 1, pp. 66-72.
2. Akinmusuru, J.O. and Akinbolande, J.A., 1981, "Stability of Loaded Footings on Reinforced Soil", Journal of Geotechnical Engineering, Vol. 107, No. GT6, pp. 819-827.
3. Das, B.M and Omar, M.T., 1994, "The Effects of Foundation Width on Model Tests for Bearing Capacity of Sand with Geogrid Reinforcement", Geotechnical and Geological Engineering, Vol. 12, No. 2, pp. 133-141
4. Fragaszy, R.J. and Lawton, E.C., 1984, "Bearing Capacity of Reinforced Sand Subgrades", Journal of Geotechnical Engineering Division, Vol. 110, No. 10, pp. 1500-1507.
5. Guido, V.A., Biesiadecki, G.J. and Sullivan, M.J., 1985, "Bearing Capacity of a Geotextile Reinforced Foundation", Proceedings of the Eleventh International Conference on Soil Mechanics and Foundation Engineering, Balkema, Vol. 3, San Francisco, California, USA, August 1985, pp. 1777-1780
6. Guido, V.A., Chang, D.K. and Sweeney, M.A , 1986, "Comparison

of Geogrid and Geotextile Reinforced Earth Slabs", Canadian Geotechnical Journal, Vol. 23, No. 4, pp. 436-440.

7. Guido, V.A., Kneuppel, J.D. and Sweeney, M.A., 1987, "Plate Load Tests on Geogrid Reinforced Earth Slabs", Proceedings of Geosynthetics '87, IFAI, Vol 1, New Orleans Louisiana, USA, February 1987, pp. 216-225.

8. Hansen, J.B., 1970, "A Revised and Extended Formula for Bearing Capacity", Bulletin 28, Danish Geotechnical Institute, Copenhagen, Denmark, 21 p.

9. Huang, C.C. and Tatsuoka, F., 1988, "Prediction of Bearing Capacity in Level Sandy Ground Reinforced with Strip Reinforcement", Theory and Practice of Earth Reinforcement, Yamanouchi, T., Miura, N. and Ochiai, H., Editors, Balkema, Proceedings of the International Geotechnical Symposium on Theory and Practice of Earth Reinforcement, Fukuoka, Kyushu, Japan, October 1988, pp. 191-196.

10. Khing, K.H., Das, B.M., Puri, V.K., Cook, E.E. and Yen, S.C., 1993, "The Bearing Capacity of a Strip Foundation on Geogrid-Reinforced Sand", Geotextiles and Geomembranes, Vol. 12, No. 4, pp. 351-361.

11. Mandal. J.N. and Manjunath, V.R., 1990, "Bearing Capacity of Single Layer of Geosynthetic Sand Subgrade", IGC-90 on Advances in Geotechnical Engineering, Proceedings of the Indian Geotechnical Conference-1990, Vol. 1, Bombay, India, December 1990, pp. 7-10.

12. Omar, M.T., Das, B.M., Yen, S.C., Puri, V.K. and Cook, E.E., 1993, "Ultimate Bearing Capacity of Rectangular Foundations on Geogrid-Reinforced Sand", Geotechnical Testing Journal, Vol. 15, No. 2, pp. 246-252.

13. Yetimoglu, T., Wu, J.T.H. and Saglamer, A., 1994, "Bearing Capacity of Rectangular Footings on Geogrid-Reinforced Sand", Journal of Geotechnical Engineering, Vol. 120, No. 12, pp. 2083-2099.

(received on Apr., 12, 2000)