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Geogrid로 보강된 사질토층에 정방향 얕은 기초의 허용지지력에 관한 연구

Allowable Bearing Capacity of Shallow Foundation on Geogrid-Reinforced Sand

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Abstract

Laboratory model test results for bearing capacity of a square shallow foundation supported by a sand layer reinforced with layers of geogrid have been presented. Use of geogrids provides an economical and time efficient method for improving load-settlement, and strength characteristics of weak soils. Especially the geogrid reinforced soil will be necessary in the case of foundations supporting machines, embankments for railroads, and foundations of structures in earthquake-prone areas. Based on the present model test results, the bearing capacity ratio (BCR) with respect to the ultimate bearing capacity (UBC), at levels of limited settlement of the shallow foundation, has been determined. Also, it appears that significant improvement in the UBC of medium sands can be achieved by reinforcing elements which shows promise for future work.

요 지

본 논문은 Geogrid로 보강된 사질토층에 지지되고 있는 정방향 얕은 기초 지지력에 대한 실내 모형실험 결과를 제시하였다. Geogrid의 사용은 연약 지반의 강도 특성 및 하중-침하 관계에서의 개선을 위한 경제적이면서도 시간 절약의 효과를 가져올 수 있다. 특히 Geogrid로 보강된 지반은 기계 기초, 철로 제방, 그리고 지진 예상 지역의 구조물 기초 등에 필수적이다. 모형 실험결과 얕은 기초의 한계 침하에서 극한 지지력에 대한 지지력 비율이 결정되었다. 또한 상대 밀도가 중간 정도인 사질토층에 보강재를 설치하였을 때 극한 지지력이 상당량 증가됨을 알 수 있었으며, 향후 현장에서 유용하게 사용될 새로운 보강토 방법을 제시하였다.

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1. INTRODUCTION

Several laboratory model test results are presently available which examine the beneficial effects of soil reinforcement in sand on the UBC of shallow square and strip foundations. The soil reinforcements include metal strips [Binquet *et al.*[1]; Fragaszy *et al.*[3]; Huang *et al.*[6]] metal bars (Huang *et al.*[7]), rope fibers (Akinmusuru *et al.*[1]), geotextiles (Guido *et al.*[4]), and geogrids (Guido *et al.*[5]). The studies cited above have, in general, determined the optimum values of fundamental parameters such as u/B, d/B and b/B (B = width of foundation, u = distance of the first layer of reinforcement from the bottom of the foundation, d = depth of reinforcement, and b = width of reinforcement as shown in Fig. 1) for realization of the maximum UBC for a given soil and type of reinforcement. The increase in the UBC has been expressed in a nondimensional form as:

$$BCR_u = \frac{q_{ur}}{q_u} \tag{1}$$

where

BCR_u = BCR with respect to ultimate load

q_{ur} = UBC with the inclusion of reinforcement in soil

q_u = ultimate bearing capacity in unreinforced soil.

It has also been observed that, when geotextiles and geogrids are for the soil reinforcement, the UBC as well as the settlement of the foundation at ultimate load increases compared to that in unreinforced soil as shown in Fig. 2. In most cases, shallow foundations are designed for a limited settlement, s (Fig. 2); hence, it is essential to determine the UBC at various levels of settlement to aid in the design process of a foundation. The BCR with respect to the settlement (BCR_s) can be defined as:

$$BCR_s = \frac{q_r}{q} \tag{2}$$

where

BCR_s = BCR with respect to the settlement

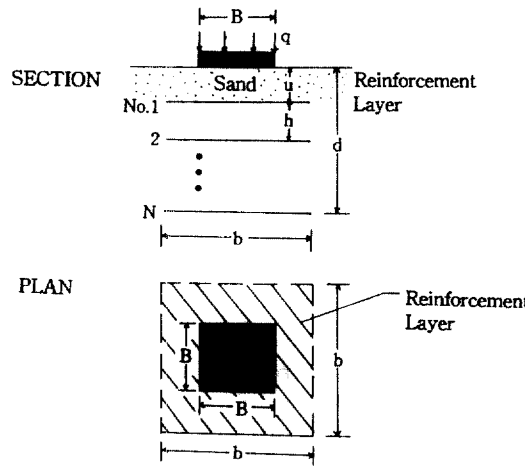

Fig. 1. Square foundation on sand reinforced with N number of reinforcement layers.

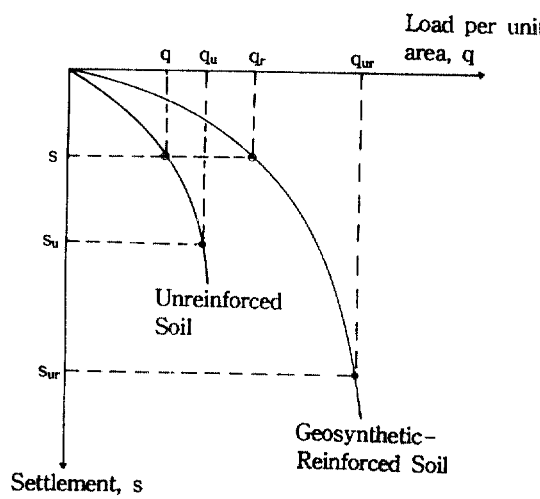

Fig. 2. General nature of load-displacement plots for unreinforced and geosynthetic-reinforced sand supporting a shallow foundation.

q_r & q = Load per unit area on the foundation at a settlement levels, s, with and without reinforcement in the supporting soil.

Several laboratory model studies have been conducted by investigators to determine the effect of soil reinforcement on the UBC of shallow foundations supported by sand. The reinforcing materials used for the studies have been metal strips, rope fibers, and metal bars. Guido *et al.*[4,5] have reported the model tests for determination of UBC of square foundation supported by reinforced layers of geotextile or geogrid. In 1986, Guido *et al.* used geogrid (Tensar SS1) with a relative density of 55%. This paper presents some laboratory model test results on a square foundation (B×B) supported by sand reinforced with layers of geogrid (Tensar BX1000, SS0). The purpose of this study is to present on a square model foundation to evaluate critical values of u, d, and b for mobilization of maximum BCR for a given sand-geogrid system. Based on the model test results, the variations of BCR_u, BCR_s at various levels of foundation settlement, and BCR_u/BCR_s with d/B, b/B, and u/B have been determined. Although laboratory model tests usually do not address the scale effects, the results will provide some indication of the degree of bearing capacity improvement at allowable settlement levels.

2. LABORATORY MODEL TESTS

The laboratory bearing capacity tests were conducted using a model foundation, made from an aluminum plate, with dimensions (B×B) of 76.2 mm×76.2 mm (3 in.×3 in.). A fine round silica sand was used for the model tests, and the grain-size distribution of the sand is shown in Fig. 3. All model tests were conducted at an average relative density, Dr, of 70%.

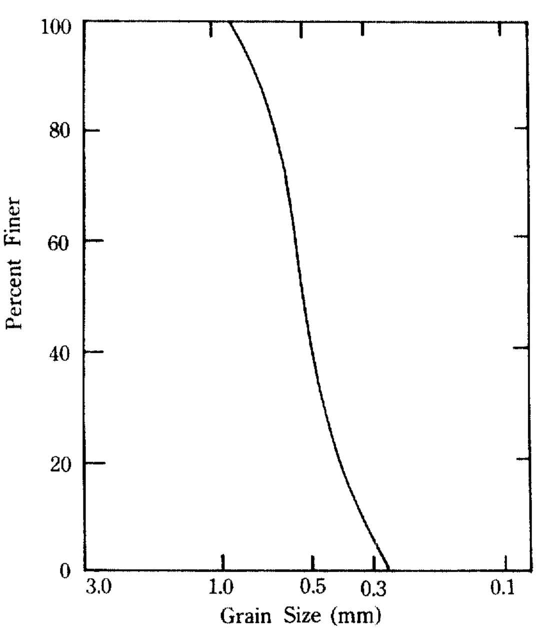

Fig. 3. Grain size distribution of sand used for model tests.

The average physical properties of the sand during the laboratory tests are given in Table 1. A biaxial geogrid was used for reinforcement. The physical properties of the geogrid are given in Table 2.

Laboratory model tests were conducted in a box measuring 760 mm×760 mm×760 mm (30 in.×30 in.×30 in.). Rough base condition of the model foundation was achieved by cementing a thin layer of sand onto its base with epoxy glue. In conducting the tests, sand was poured into the box in 25.4 mm (1 in.) layers using a raining technique. The accuracy of the sand placement and the consistency of the placement density were checked during raining by placing small cans with known volumes at different locations in the box. Geogrid

Table 1. Average physical properties of the sand during the model tests

Parameter	Quantity
[a]Maximum dry unit weight, kN/m^3	18.94
[a]Minimum dry unit weight, kN/m^3	14.07
Dry unit weight during model tests, kN/m^3	17.14
Relative density of compaction during model tests, %	70.00
[b]Angle of friction during model tests, deg.	40.30
Note: [a]ASTM test designation D-4253 [b]From direct shear test	

Table 2. Physical properties of the geogrid

Parameters	Description/quantity
Structure	Punctured sheet drawn
Polymer	PP/HDPE co-polymer
Junction method	Unitized
Aperture size (MD/XMD)	25.4 mm/33.02 mm
Natural rib thickness	0.762 mm
Nominal junction thickness	2.286 mm

layers were placed in the sand at desired values of u/B and h/B (h = center-to-center spacing of the geogrid layers as shown in Fig. 1). After completion of the sand placement, the model foundation was placed on the surface of the sand layer. Load to the model foundation and the corresponding settlement were measured by a proving ring and two dial gauges. Four series of tests were conducted, the details of which are given in Table 3.

3. MODEL TEST RESULTS

3.1 Test Series A

The load per unit area (q) versus foundation settlement (s) obtained from the test on unreinforced sand is shown in Fig. 4. For the present test, the UBC was achieved at an $s/B = s_u/B$ value of 2.8%.

3.2 Test Series B

The tests in this series were conducted to determine the critical depth of reinforcement ($d = d_{cr}$) beyond which the increase in the bearing capacity with respect to ultimate load (BCR_u) is practically negligible. For these tests, the magnitude of u/B, h/B and b/B were kept constant at 0.333, 0.333 and 6, respectively. Fig. 5 shows the plots of q versus s for various numbers of reinforcement layers, N. The depth of reinforcement can be related to N as:

$$d = u + (N-1)\ h \tag{3}$$

The ultimate bearing capacity (q_{ur}) for each one of these q versus s plot is shown in Fig. 5. It is important to note that, as the number of reinforcement layers (and thus the magnitude of d/B) increased, the UBC increased accompanied by an increase of the settlement at ultimate load. Based on the values of q_u and q_{ur} obtained from Fig. 4 and 5, the variation of BCR_u has been plotted with d/B and N in Fig. 6. From the plot, it appears that the magnitude of BCRu increases with d/B

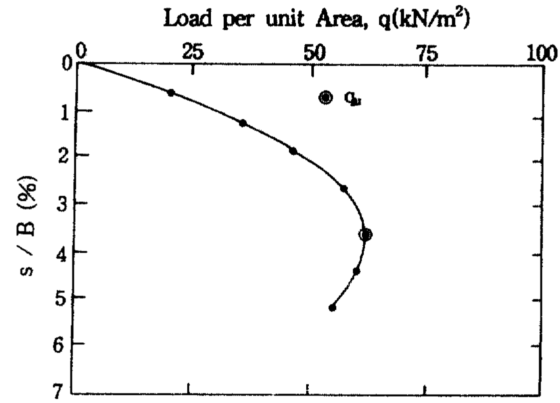

Fig. 4. q vs. s/B for Test Series A.

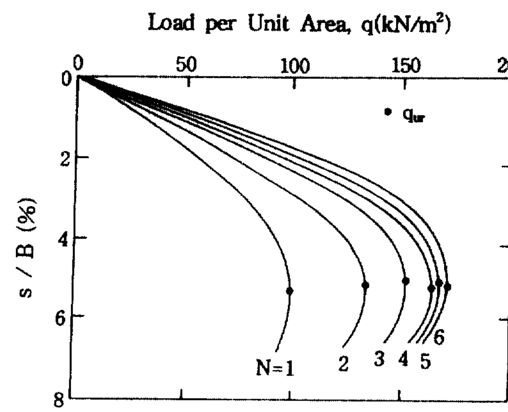

Fig. 5. q vs. s/B for Test Series B.

Table 3. Details of the model tests

Test series	Constant parameters	Variable parameters
A	Dr = 70%	Test on unreinforced sand
B	Dr = 70%, b/B = 6 u/B = h/B = 1/3	N = 1, 2, 3, 4, 5, and 6
C	Dr = 70%, N = 4 u/B = h/B = 1/3	b/B = 1, 2, 3, 4, 5, and 6
D	Dr = 70%, b/B = 4 N = 4, h/B = 1/3	u/B = 0.333, 0.500, 0.667, 1.000 1.200, 1.500, and 1.800

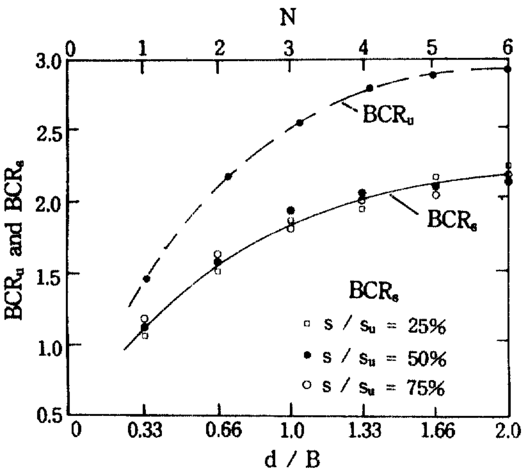

Fig. 6. Variation of BCR_u and BCR_s with N and d/B for Test Series B.

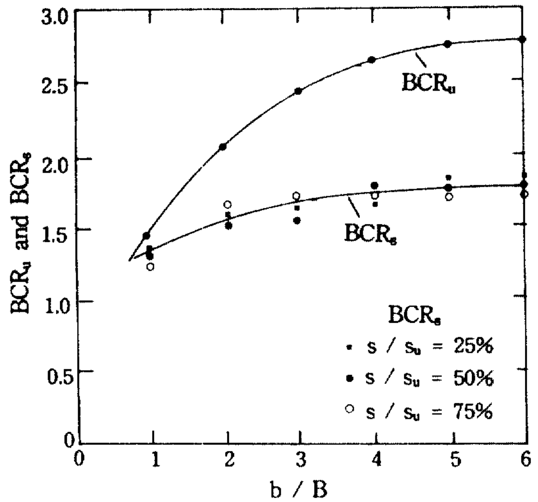

Fig. 8. Variation of BCR_u and BCR_s with d/B for Test Series C.

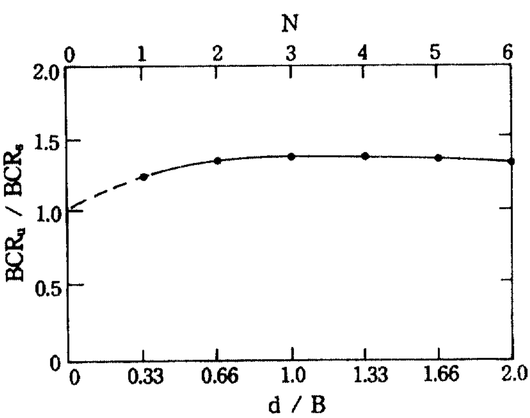

Fig. 7. Plot of BCR_u/BCR_s vs. N and d/B.

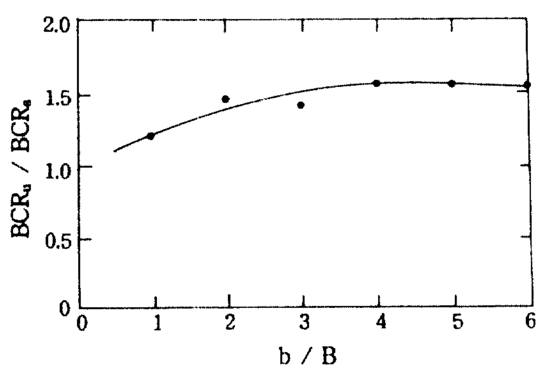

Fig. 9. Plot of BCR_u/BCR_s vs. b/B ($u/B=h/B=0.333$, $N=4$).

up to a maximum value of about 2.9 and remains constant thereafter. The magnitude of $d/B=(d/B)_{cr}$ at which BCR_u reaches a maximum value can be approximated to be 1.33 to 1.66. Guide *et al.*[5] determined $(d/B)_{cr}$ for square foundations to be about 1.25. Using the experimental q vs. s plots given in Fig. 4 and 5 and Eq. 2, the variation of BCRs at three settlement levels was obtained and plotted in Fig. 6. Although there is some scatter, a single curve for variation of BCR_s with d/B can be plotted as shown in Fig. 6. Based on the average curves of BCR_u and BCR_s shown, the experimental variation of BCR_u/BCR_s versus d/B has been plotted in Fig. 7 and shows that for similar values of d/B:

$$BCR_u=1.35\ BCR_s \tag{4}$$

3.3 Test Series C

Model Tests in this series were conducted to determine the optimum size (b×b) of the geogrid layer for mobilization of the maximum BCR. The magnitudes of u/B, h/B, and N were kept equal to 0.333, 0.333 and 4. The ratio b/B was varied as 1, 2, 3, 4, 5, and 6. The variation of BCR_u to BCR_s with b/B was obtained from the plots of q versus s in a manner similar to that discussed under Test Series B and is shown in Fig. 8. The nature of variations of BCR_u and BCR_s with b/B are practically similar in that they increase with b/B up to a maximum value at b/B=4. In the study of Guido *et al.*[5], the magnitude of the critical value of b/B was determined to be between 2.5 to 3. Based on the average curves shown in Fig. 8, the ratio of BCR_u to BCR_s for various values of b/B was calulated and shown in Fig. 9. The ratio increases from about 1.2 at b/B=1 to about 1.45 at b/B>3. Therefore, for practical purposes:

$$b/B=(b/B)_{cr}=4$$

and

$$BCR_u=1.55\ BCR_s$$

3.4 Test Series D

Binquet *et al.*[2] observed that, in order to obtain maximum benefit from the reinforcement, it is desirable that u/B be less than about 0.67. For larger u/B ratios, the failure surface in soil at ultimate load will be fully located above the top layer of reinforcement, and, in that case, the top layer of reinforcement will act as a semi-rigid surface. In bearing capacity tests with a square foundation supported by sand with geogrid reinforcement, Guido *et al.*[5] determined $u/B=(u/B)_{cr}$ to be about 0.75. In order to varify this fact, the present tests in this series were conducted with u/B as the variable parameter. For these tests, h/B, b/B, and N were kept constant at 0.333, 4, and 4, respectively. The experimently variation of BCR_u with u/B obtained from these tests is shown in Fig. 10. Based on Fig. 10, it appears that the variation of BCR_u with u/B can be approximated by two straight lines. The magnitude of u/B at the point of intersection of these two straight lines may be defined as $(u/B)_{cr}$. For the present test results, $(u/B)_{cr}$ is about 0.75 to 0.8. For $u/B>(u/B)_{cr}$, the straight line of the BCR_u versus u/B plots when extended gives a $BCR_u=1$ at u/B=2.5. Laboratory model tests on foundations supported by sand with a rigid rough base at a limited depth have shown similar results [Pfeifle *et al.*[8]]. As in the case of Test Series B and C, the variations of BCR_s at $s/s_u=25\%$, 50% and 75%, obtained from the load settlement curves, are also shown in Fig. 10. Fig. 11 shows the plot of BCR_u/BCR_s with u/B

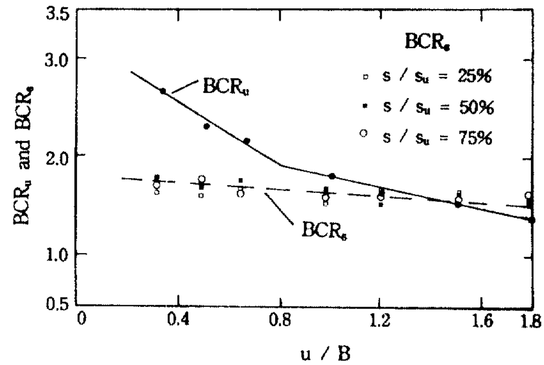

Fig. 10. Variation of BCR_u and BCR_s with u/B for Test Series D.

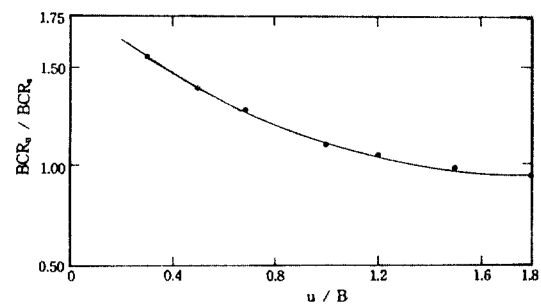

Fig. 11. Plot of BCR_u/BCR_s vs. u/B for Test Series D.

which was obtained by using the average curves shown in Fig. 10. The magnitude of BCR_u/BCR_s decreases from about 1.5 at u/B=0.333 to about 1 at u/B=1. For most reinforced earth foundation works, u/B is kept between 0.25 to 0.4. Hence, for practical purposes:

$$BCR_u=(1.4\ \text{to}\ 1.55)\ BCR_s$$

4. CONCLUSIONS

The results of a number of laboratory model tests to determine the bearing capacity of a shallow square foundation supported by sand reinforced by geogrid layers have been presented. Based on the model tests results, the following conclusions can be drawn.

1. For deriving the maximum benefit of soil reinforcement towards improving the bearing capacity, the optimum values for geogrid layers are as follows: $(d/B)_{cr}=1.33$ to 1.66, $(b/B)_{cr}=4$, and

u/B=0.75 to 0.8.

2. The BCR calculated on the basis of the ultimate bearing capacity is somewhat misleading for actual foundation design since most foundations are constructed on the basis of limited settlement. The magnitude of the BCR calculated on the basis of limited settlement is about 1.35 to 1.55 of BCR_u.

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