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Bearing capacity of sand foundation reinforced by geonet

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ABSTRACT: A series of bearing capacity tests were performed on reinforced sand using the strip footing. The sand was reinforced with geonet which has relatively weak tensile strength. Types of reinforcement were one layer, multi-layer, and mattress. In the case of the one layer type it presents the effective depth and length of geonet in relation to the increase of ultimate bearing capacity. In the case of multi-layer type the optimum layer number was investigated, and tests were performed on the unreinforced footing with the same depth as the maximum reinforcing depth. And in the case of mattress-type reinforcement the effects of the thickness and the length of mattress were investigated. Of the three reinforcing methods the greatest ultimate bearing capacity was obtained from multi-layer type and the optimum layer number was 4 and the ultimate bearing capacity ratio was 3.65.

1. INTRODUCTION

The methods of stabilizing the soft ground include ground improvement, rigid foundation, and earth reinforcement. Of them the earth reinforcement can be said to the beneficial method which reinforces the ground by using the reinforcing material such as geosynthetics. Since Vidal, H. introduced his study about earth reinforcement in 1963, the earth reinforcement has been used increasingly in geotechnical engineering. This is a study on the reinforcement of sandy soils under the strip footing. A model test apparatus was set up and various series of tests with a strip footing were performed with the reinforcing material called "geonet". Among reinforcing methods are one layer, multi-layer, and mattress-type reinforcement. From the test results, this study presents the effective way of reinforcing the sandy ground to improve the ultimate bearing capacity and settlement characteristics.

2. MODEL TEST

2.1 *Test apparatus*

In this study the multiple sieving pluviation apparatus was used to form the homogeneous model ground with a constant relative density. It is possible to get the required relative density by controlling the falling height between the lowest sieve and the model ground and also the diameter of hopper from which sand flows down. In these tests the falling height and the diameter of hopper were made to be 70cm and 40mm, respectively. As the result, the relative density of the model ground obtained was about 75%. And the size of model test apparatus is 1200mm wide, 300mm long and 700mm deep. The side wall of the bin consists of transparent plastic plates and rubber membrane. Silicon grease was used on both side plates of the bin to reduce the side friction. The force is applied on the ground surface by motor screw jack under the condition of 1mm/min of displacement speed.

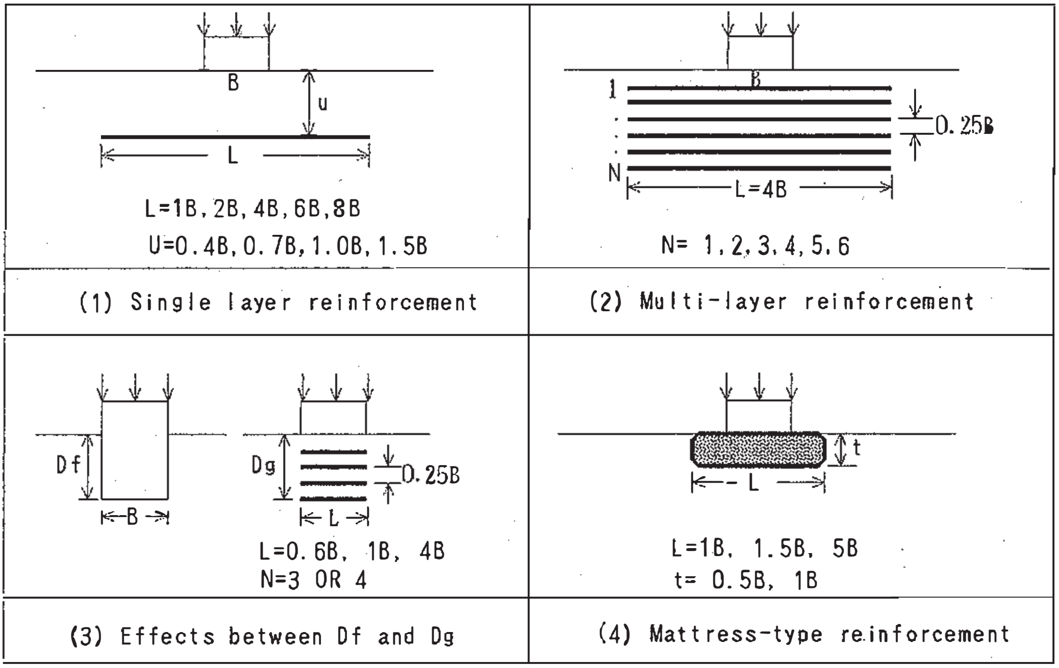

Fig. 1 Test groups (B= 10cm)

2.2 *Materials used in tests*

Dry Jumunjin sand called "the standard sand of Korea" with a particle size of 0.2-1.0mm was used as the soil of the model ground. Specific gravity of sand was 2.66. Model ground of about 450mm depth was made by means of the multiple sieving pluviation method and the average unit weight of ground is about 1.581 gf/cm^3 and the relative density is 75%. And fine gravel with a particle of 10-25mm was used as a material filled within the mattress.

Geonet used as the reinforcing material was made from polyethylene and the size of the net eye was 8mm x 6mm. It had a mass per unit area of 425g/m^2 and average thickness of 2.9mm. The maximum tensile strength was 2KN/m.

2.3 *Outline of the experimental methods*

Four groups of tests were performed and the outline is shown in fig. 1.

3. DEFINITION OF BEARING CAPACITY RATIO

For the analysis of experiment results, two types of bearing capacity ratios were considered as the judgement basis of reinforcing effects. One type called BCR is a ratio of ultimate bearing capacity at failure of the reinforced ground to the unreinforced ground. The other, called BCR$_s$, is a ratio of bearing capacity of the reinforced ground to the unreinforced ground at the same level of settlement. Namely BCR and BCR$_s$ can be defined as:

$$BCR = \frac{q_{ur}}{q_u} \tag{3.1}$$

$$BCR_s = \frac{q_{rs}}{q_s} \tag{3.2}$$

where, q_{ur} and q_u indicate ultimate bearing capacity of the foundation supported, respectively, by reinforced and unreinforced ground, and q_{rs} and q_s indicate bearing capacity of the foundation supported, respectively, by reinforced and unreinforced ground at the same level of settlement s.

4. TEST RESULTS

4.1 *Unreinforced sand*

The load-settlement behavior of unreinforced sand is shown as only solid line in fig. 2. From this figure it appears that the curve increases at the initial stage and shows the peak strength. The ultimate bearing capacity and the settlement at peak were 1.65 kgf/cm2 and 8.05mm, respectively. Back-analysis of the ultimate bearing capacity using the classical bearing capacity theory suggests that the angle of friction for unreinforced sand was 45°.

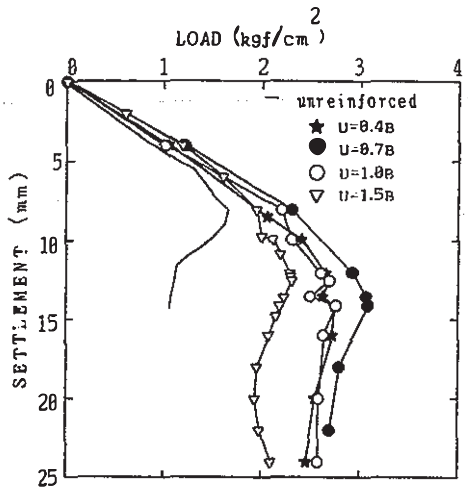

Fig. 2 Load-settlement according to the depth of reinforcing layer (L= 6B)

4.2 *One layer reinforcement*

4.2.1 *Load-settlement behavior*

A series of tests were carried out in exactly the same manner as on the sand only but with a one horizontal layer of geonet placed at different depths and lengths. The depths of the geonet layer in the tests, expressed as a fraction of footing width, were 0.0B (on the surface), 0.4B, 0.7B, 1.0B, and 1.5B. The lengths of the geonet layer were 1B, 2B, 4B, 6B, and 8B.

Fig. 2 shows the load-settlement behaviors according to the variation of the depths of reinforcement layer when the width of reinforcement layer is constant as 6B. From these curves it can be seen that:

(1) the peak bearing loads in the tests with geonet were achieved at much greater settlements than that of the unreinforced.

(2) the residual bearing loads in the tests with geonet showed only a little difference compared with the peak bearing capacities and also they sustained the constant values in spite of the continuing increase of settlements.

4.2.2 *The effects of the depth and the length of laying geonet*

Fig. 3 demonstrates the influence of the depth and the length of the geonet on the peak bearing loads in terms of BCR. It shows that the effective depth is about 0.7B independent of the size of geonet length. The values of BCR were greatest as 1.31, 1.48, 1.6, 1.7, and 1.87 in the depth of 0.7B, and smallest as 1.1, 1.22, 1.3, 1.39, and 1.41 in the depth of 1.5B. With respect to the length of geonet, fig. 3 also shows that as the geonet length L was increased, the values of BCR were increased. However the geonet length L greater than 6B had little influence on the increase of BCR. Therefore it is evident that the effective length is about 6 times more than the width of footing B.

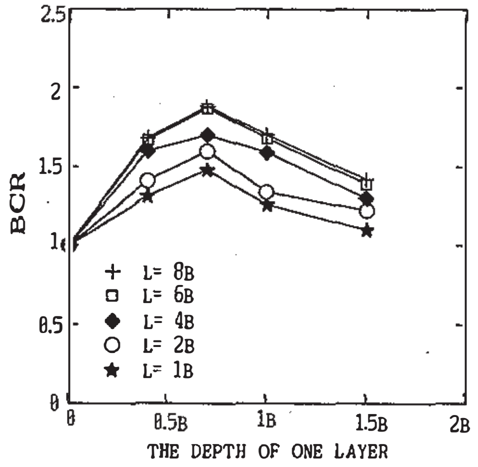

Fig. 3 Variation of BCR according to depth and length of reinforcing layer

4.2.3 *Effects of settlement restraint by reinforcement*

In the unreinforced model sand the ultimate bearing capacity and the settlement at peak were 1.65kgf/cm^2 and 8.05mm, respectively. In order to evaluate the effects of settlement restraint in case of one layer reinforcement, the settlement restraint ratio was defined as:

$$SCR=(Su-Sr)/Su \qquad (4.1)$$

where, Su indicates the settlement at the failure load, 1.65 kgf/cm^2 of unreinforced sand, and Sr indicates the settlement at 1.65 kgf/cm^2 of the load in case of one layer reinforced sand.

Fig. 4 shows the values of SCR according to the ultimate bearing capacity in case of one layer reinforcement. From this figure it appears that as the ultimate bearing capacities increase, the values of SCR increase ranging from 5% to 30%.

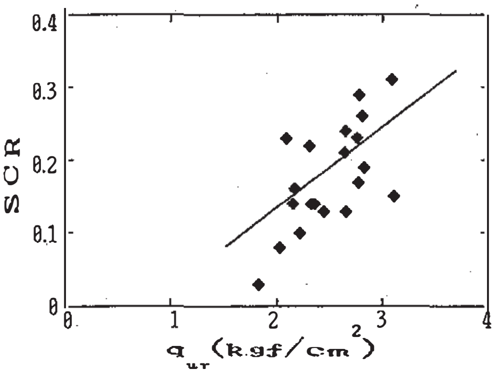

Fig. 4 Restraint effect of settlement due to one layer reinforcement

4.3 *Multi-layer reinforcement*

4.3.1 *Reinforcing effects of the number of geonet layers*

A series of tests as shown in fig. 1(2) were performed in order to investigate the effects of the number of geonet layers. The numbers of geonet layers (N) were 1, 2, 3, 4, 5, and 6, while the length of geonet used, L, was 6B. The vertical space between layers was 0.25B. Fig. 5 shows the variation of load-settlement behaviors with different numbers of geonet layers. The curves in fig. 5 show that there is little difference between peak loads and residual loads when N is more than 3. Hence it is evident that there is no sudden failure in spite of great deformation in case of reinforced ground.

Fig. 6 shows the variations of the ultimate bearing capacity ratio (BCR), the bearing capacity ratio at the same settlement (BCRs), and the settlement ratio at peak load (Sr/B), according to the increase of N. From this figure BCR begins to increase at constant speed, but when N is reached at 4, the speed of increase of BCR is remarkably reduced. Hence the optimum number of geonet layers is 4. This means that when the depth of reinforcement exceeds about 1.25B, no further significant effects of reinforcement can be obtained. In case of BCRs, the increase speed with N is very slow compared with that of BCR. In case of Sr/B , the settlement ratio at peak load, it is evident that the value of Sr/B is increased despite of increase of BCR due to the increase of N. Accordingly, it should be recognized that the use of the reinforcement method can be dangerous in the civil engineering works in which the magnitude of settlement is restrained in spite of high values of BCR.

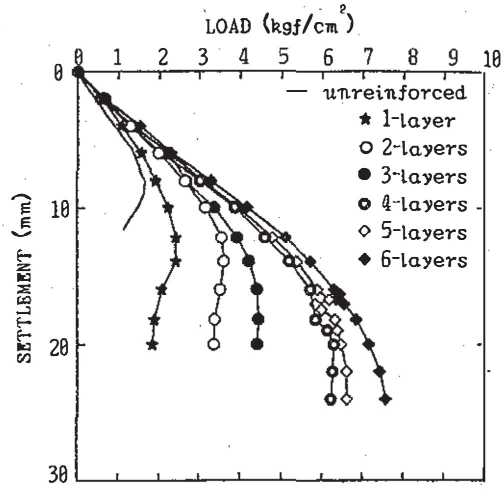

Fig. 5 Load-settlement according to the increase of reinforcing layer

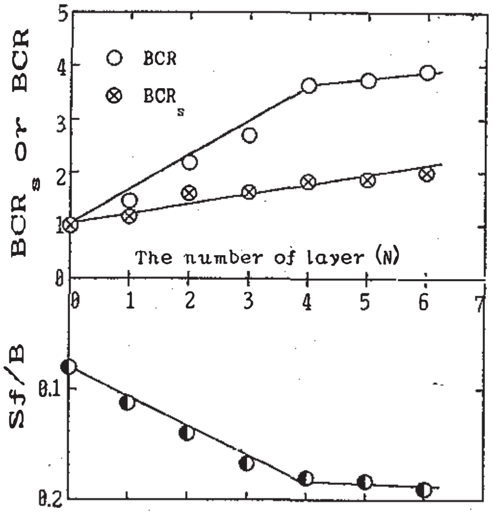

Fig. 6 BCR, BCRs and Sf/B according to the increase of reinforcing layer

4.3.2 *Effects of the length of reinforcement in case of three and four layers*

The outline of this series of tests is shown in fig. 1(3). The object of the tests is to study whether three and four layers with such short lengths as 0.6B and 1B can reinforce the ground effectively. It should be remarked that the length of reinforcement layers with L=0.6B, and 1B used in the tests is shorter than and similar to a footing B. Three tests with a footing depth Df=0, 0.75B, and 1B on unreinforced sand were performed as reference tests. Fig. 7 shows the variation of load-settlement behaviors between the footing unreinforced with Df=0 and 0.75B and the sand with Dg=0.75B, reinforced with three horizontal layers

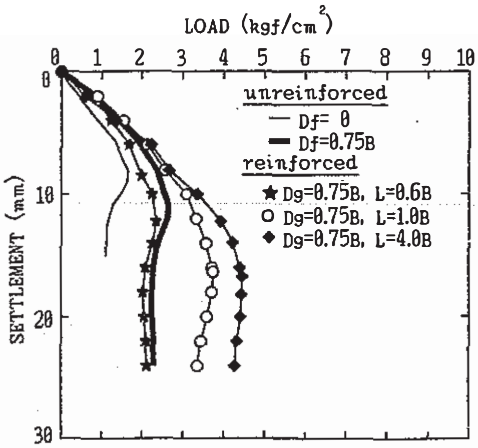

Fig. 7 Load-settlement in three layer reinforcement

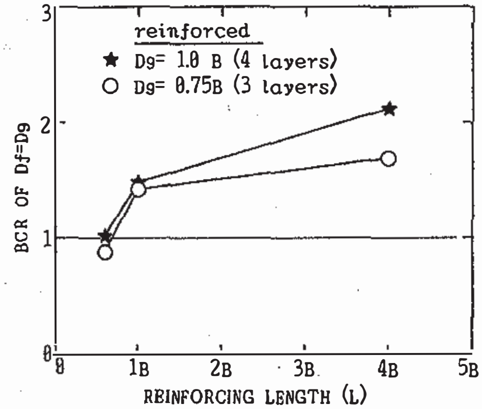

Fig. 8 Comparison of ultimate bearing capacity between the unreinforced footing with Df=Dg and the sand foundation reinforced by geonet with three or four layers

of geonet. From this figure it may be seen that even short reinforcement with L=0.6B can increase both the initial stiffness and the peak strength of ground.

Fig. 8 shows the $BCR_{(Df=Dg)}$ of the sand, with Dg=0.75B, and 1B, reinforced with three horizontal layers of geonet to the footing unreinforced with Df=0.75B,1B. Especially in case of L=B, it may also be seen that the bearing capacity for the sand reinforced to a depth of Dg=0.75B and 1B with three layers, loaded with a surface footing, is much greater than that of the unreinforced sand, loaded with a rigid deep footing having the same depth Df=Dg. The values of $BCR_{(Df=Dg)}$ increase as the length of layers L is increased. However it appears that the increase rate is reduced if L has a value greater than B.

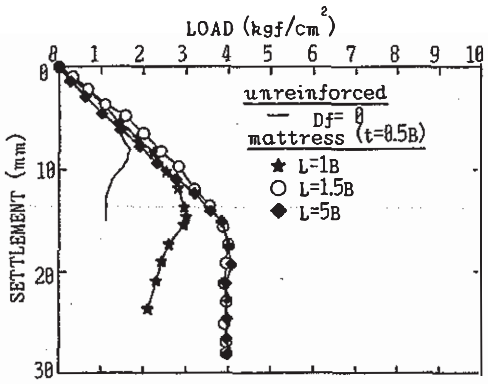

Fig.9 Load-settlement in mattress reinforcement

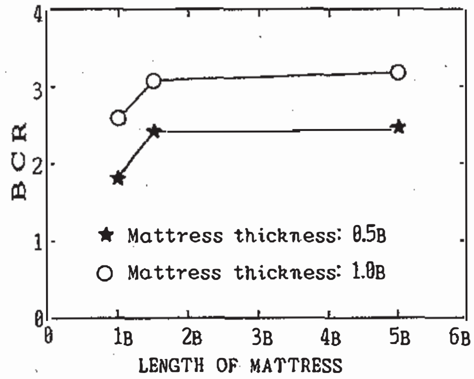

Fig. 10 BCR of geonet reinforced mattress on sandy ground

4.4 *Mattress reinforcement using geonet*

Mattress foundations using geogrid were often used to improve the supporting capability of a soft soil foundation. It is known that the vertical load applied on the geogrid-mattress foundation is transmitted to the supporting foundation of the wider area, thereby providing the foundation with greater supporting capability. The outline of this series of tests is like as shown in fig. 1(4), in which geonet was used as a reinforcing material instead of geogrid. The experiments were carried out with 0.5B, 1B thick geonet-mattress models on sand of 75% relative density, also changing the length of geonet mattress by 1B, 1.5B, 5B. Fine gravel was used as the internal material of mattress.

The specific gravity and dry density were respectively 2.63 and 1.64 gf/cm^3. Fig. 9 shows the variation of load-settlement behavior on the geonet-reinforced mattress with thickness t=0.5B. From this figure it may be seen that in case of mattress having the length more than 1.5B, it didn't show peak load. That is to say, it appears that peak loads are almost the same as residual loads in spite of the continual increase of settlement. Settlements were measured by about 40mm in the tests, but they showed the similar tendency.

Fig. 10 shows the values of BCR according to the mattress length and the mattress thickness in case of mattress-type reinforcement. From this figure it is evident that the mattress has the greater value of BCR as thickness or length of mattress is increased. But in case of mattress having the length more than 1.5B, the mattress length had little effect on the increase of BCR.

4.5 *Variation of BCR according to reinforcement methods*

Based on all the test results, the variations of BCR have been plotted in Fig. 11. The contents of x-coordinate mean (1) only sand of unreinforced case, (2) one layer reinforcement expressed as N=1, (3) multi-layer reinforcement expressed as N= 2, 3, 4, 5, 6 and (4)mattress-type reinforcement as MT=0.5B, 1B.

From this figure it is evident that the arrangement methods of reinforcement material can change the ultimate bearing capacity of reinforced sand. Of the three reinforcing methods the effective one was the multi-layer type. For example in six layer reinforcement the value of BCR was the greatest as about 3.9. And it is interesting that BCR of matress with the thickness of 1.0B was less than that of multi-layer reinforcement which the number of layers is equal to or greater than 4.

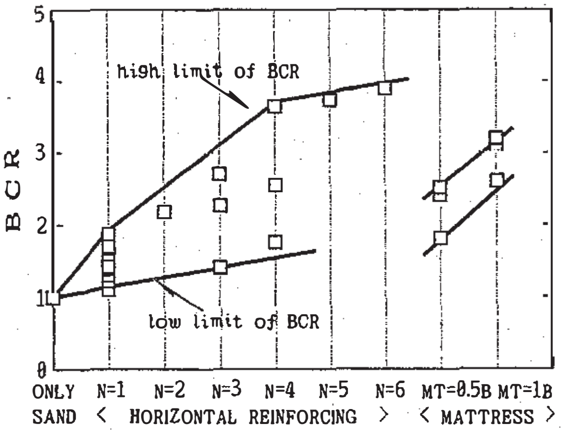

Fig. 11 Range of BCR according to reinforcing methods(N: the number of geonet layer, MT : mattress thickness)

5. CONCLUSIONS

This study was performed to find the most effective way of reinforcing the ground using the geotextiles called geonet. A series of plane strain model tests with a strip footing were performed. From the test results, in one-layer reinforcement the ultimate bearing capacity increased by 1.1 - 1.9 times as compared with the unreinforced ground, the optimum depth of the reinforcement layer below the footing was 0.7B, the optimum length of the reinforcement layer was considered to be about 6B, and the ratio of the settlement restraint was 5% - 30% under the bearing capacity of 1.65 kgf/cm^2.

In multi-layer reinforcement, with keeping the spacing of reinforcement U/B=d/B=0.25, the optimum number of reinforcement layers was 4 , and the value of BCR was 3.65 in the optimum condition. In three or four-layer reinforcement with the use of length of 1B , the effect of reinforcement was much greater than that of the unreinforced footing with the same depth as that of the lowest layer of reinforcement.

Mattress has the greater value of BCR as thickness or length of mattress is increased. But in the case of mattress having the length more than 1.5B, the mattress length had a little effect on the increase of BCR.

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