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An experimental study on the contribution of geotextiles to bearing capacity of footings on weak clays

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ABSTRACT: Geotextile effects as a reinforcement material were studied through laboratory model tests of a strip footing on weak clays. The geotextile effects on bearing capacity and deformation of soil foundation were investigated in view of the distance of footing from geotextile layer and the footing embedment ratio. Tests were carried out under partially drainage condition in order to investigate closely bearing capacity, settlement and sliding length of geotextile. From the experiments, it has been found that the contribution of geotextile to the bearing capacity increase is high as the distance of footing from geotextile layer reduces, as the embedment depth of footing increases, and as the settlement of footing increases. And it has been also found that the ratio of sand layer depth to footing width, H/B, which gives the greatest geotextile effects falls between 0.5 and 1.0.

1 INTRODUCTION

The use of reinforcing materials to stabilize poor soil conditions predates the Romans. However, the use of geotextile as a reinforcement was not regularized before 1973 when a geotextile reinforcement was applied in a bridge construction in Sweden. Recently, the use of geotextile as a reinforcing element in soils has gained widespread use throughout the world. Many researches for geotextile effect on the bearing capacity of foundation soil were performed.

Sorlie(1977) and Gourc et al.(1982) reported the reinforcing effect of geotextile in unpaved road through laboratory model tests. Giroud and Noiray(1981) presented design charts for geotextile-reinforced unpaved road. Sellmeijer(1982) developed a analytical method for estimating the bearing capacity increase of road foundation due to geotextile reinforcement. Reinforced earth slabs have been studied by: Binquet and Lee(1975), Fragaszy and Lawton(1984) with a strip footing on sand and aluminum foil as the reinforcement; Akinmusuru et al(1982) with a square footing on sand and rope fiber as the reinforcement; Guido et al.(1985) with a square footing on sand and geotextile as the reinforcement. This paper includes the geotextile effects on bearing capacity and settlement through a series of laboratory bearing capacity tests of a strip footing on sand/clay layer reinforced with a geotextile.

2 EXPERIMENTAL WORK

2.1 Testing arrangement

Fig.1 shows the experimental set-up used in the tests. The experimental model has the plane dimension of 30cm x 110cm and the height of the model is 70cm. The wall of the model was made of 9mm thick Plexiglass in order to provide direct optical

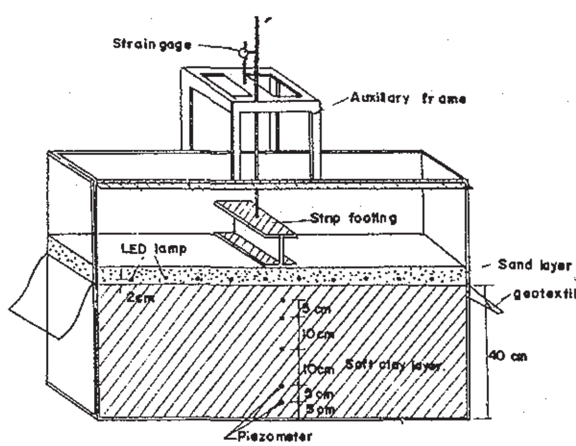


Fig.1. Experimental model set up

Table 1. Consolidation properties of clay

Before consolidation by self weight	water content, w(%)	60
	coefficient of consolidation, C_v(10^{-4}cm^2/sec)	7.4
	coefficient of permeability, k(10^{-8}cm/sec)	9.1
After consolidation by self weight	water content, w(%)	57
	initial void ratio	1.51
	compression index, C_c	0.305
	Cv in vertical direction (10^{-4}cm^2/sec)	4.73
	Cv in lateral direction (10^{-4}cm^2/sec)	5.12
	k in vertical direction (10^{-8}cm/sec)	6.70
	k in lateral direction (10^{-8}cm/sec)	7.35

observation of soil movement. Three numbers of steel strips were installed to reinforce the Plexiglass wall. Ten piezometers were installed symmetrically on both sides of the wall at different heights, 5, 10, 20, 30 and 35cm respectively from the bottom of the model.

Sample preparation was performed by placing a layer of geotextile over the 40cm deep clay layer, then sand was deposited until the desired level of height was achieved. The time dependent deformations were measured by utilizing a dial gauge on the footing and LED indicating lamps which had been inserted into the sand layer in a manner to form the square grid system of 10cm spacing. To simulate the rigid strip footing, a H-beam (10cmx30cm) was used and the vertical load was applied via loading plates. Dislocation of the model footing due to loading procedure was prevented by means of an auxiliary frame as shown in Fig. 1.

The clay used in all the tests has a liquid limit of 54% and a plasticity index of 21.9%.

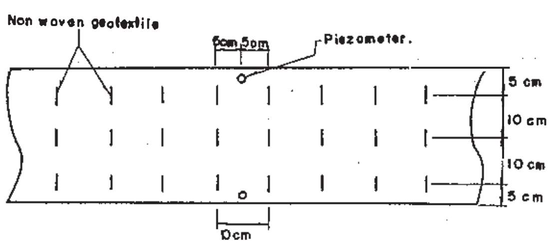


Fig.2. A plane view of inserted vertical drain

Table 2. Properties of geotextiles

Item \ Trade name	K/M 8401	Bidim U64
Structure	woven	non woven
Thickness(mm)	1.25	4.4
Weight (g/m^2)	350	550
Permeability (cm/sec : 0.02 bar)	2x10^{-2}	3x10^{-1}
Tensile strength (kg/cm)	90.6	-

The clay was mixed at slightly over the liquid limit, i.e water content of 58%-62% and smeared into the model box. On completion of each test the specimens were recovered for water content measurement and consolidation test. The consolidation properties of the clay are summarized in Table 1.

The sand used in all the tests has the mechanical properties of Gs=2.66, γ_{dmax}=1.65g/cm^3, γ_{dmin}=1.39g/cm^3 and has of uniform grain size ranging 0.59mm-2.0mm. The sand was placed above the clay layer and light compaction was applied manually by means of a wooden rod. Dry density of the sand layer was uniformly maintained between 1.47 g/cm^2 and 1.50 g/cm^2. The sand layer ranged in thickness up to 20cm. Geotextiles used in the experiments were a woven geotextile, K/M 8401 as reinforcement and a nonwoven geotextile, Bidim U64 as vertical drainage. The mechanical properties of geotextiles are shown in Table 2.

2.2 Vertical drain test using geotextile

Vertical drain test was performed before the bearing capacity test to investigate the effect of geotextile on consolidation. The nonwoven geotextile bands with a dimension of 43cm x 3.5cm were installed in the 40cm deep clay layer in square grid pattern to accelerate the consolidation. The spacing of them was 10cm. A plane view of inserted vertical drain is shown in Fig. 2.

The development and dissipation of the excess pore water pressure in the clay layer is shown in Fig. 3 when the overburden pressure from the 10cm deep sand was applied on the clay layer. Fig. 3 show that the primary consolidation of clay layer developed during one week owing to the geotextile effect.

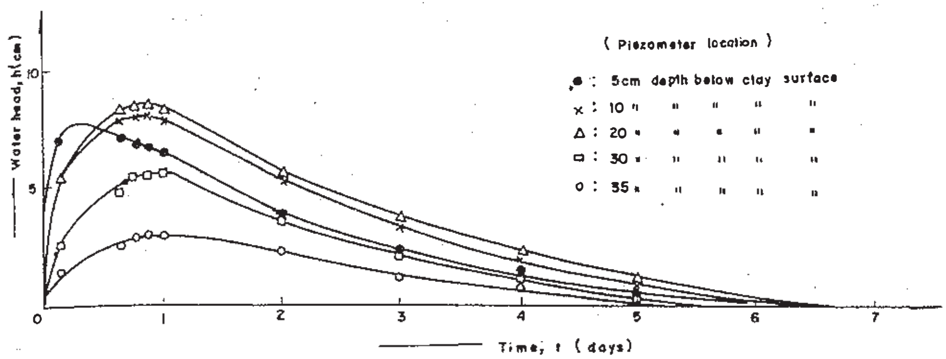


Fig.3. Development and dissipation of the excess pore water pressure

Therefore in this experiments, the bearing capacity tests were performed after one week under the condition of placing the sand layer on the clay layer with geotextile bands.

2.3 Bearing capacity test

The bearing capacity test was performed by acting loading plates on the strip footing placed on the sand/clay layer reinforced with a woven geotextile. Test loading is loaded incrementally by 0.1 kg/cm^2. The bearing capacity and settlement of foundation and sliding length of geotextile were investigated for each loading step.

Tests were carried out under the condition of partial drainage at 50 percent consolidation in order to investigate closely the geotextile effects on bearing capacity and settlement of foundation. Typical time dependent settlement is shown in Fig.4.

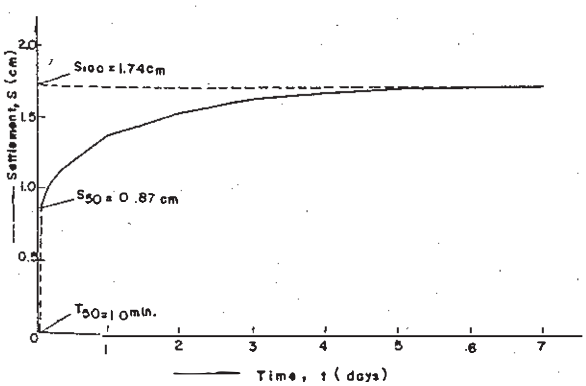


Fig.4. Time dependent settlement at the center of the sand surface for 0.144 kg/cm^2 of footing load

3. TEST RESULTS AND ANALYSIS

The bearing capacity of a strip footing on sand/clay layer reinforced with geotextile was studied in view of the following three parameters:

1. The depth below the footing of geotextile or the depth of sand layer, H. This was expressed as a dimensionless ratio H/B, where B is the width of the footing.
2. The embedment depth of footing, D. This was also expressed as D/B.
3. The settlement of footing, S.

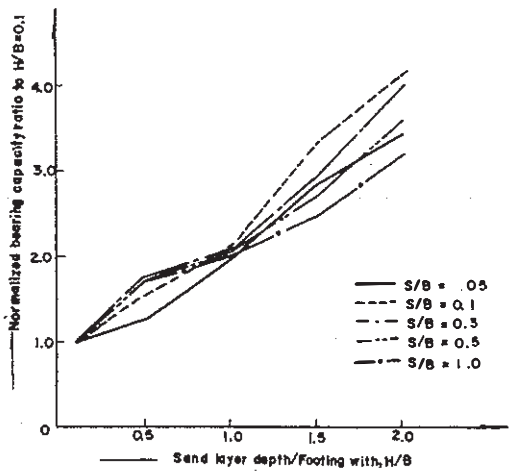
Geotextile effect on the deformation of foundation soil was also studied.

3.1 Effect of the depth below the footing of geotextile

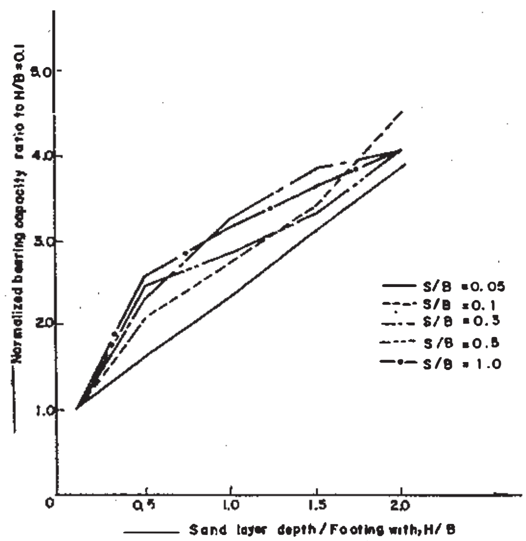
The bearing capacity tests were performed with various H/B ratios to investigate geotextile effect on the bearing capacity of surface footing. Fig.5 shows the normailzed bearing capacity ratios to H/B=0.1 for various H/B ratios in the cases with and without geotextile, respectively. Fig.5 indicates that the effect of the depth of sand layer on the bearing capacity of reinforced soil is greater than the unreinforced soil. And the increase of the normalized bearing capacity ratio resulting from the use of geotextile to various H/B ratios is shown in Fig.6. From Fig.6, it was found that the increase of bearing capacity due to geotextile is high as the settlement of footing increases. The rate of measured increase of 37%, 41%, 19% and 12% for H/B of 0.5, 1.0, 1.5 and 2.0, respectively in the range of S/B between 0.05 and 1.0 was observed.

Binquet and Lee(1975) introduced a term, bearing capacity ratio, BCR for convenience in expressing and comparing test data:

$$BCR=q/q_o$$



a) Case without geotextile



b) Case with geotextile

Fig.5. Normalized bearing capacity ratios for various H/B ratios

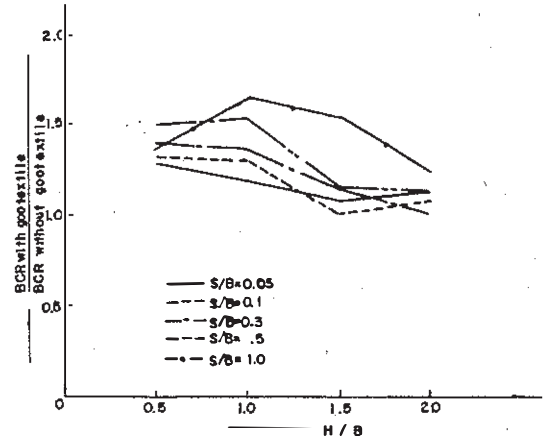


Fig.6. Increase of normalized bearing capacity ratio resulting from use of geotextile for various H/B ratios

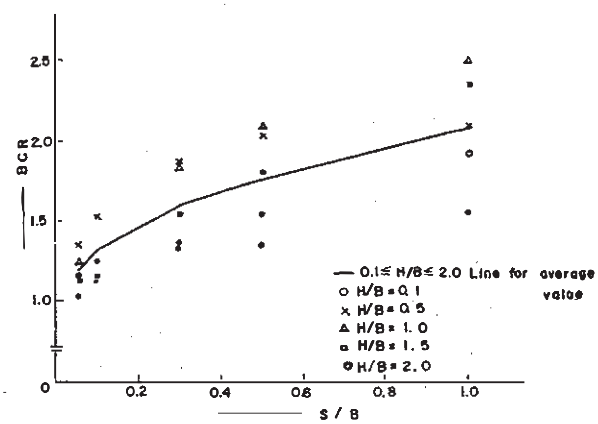


Fig.7. BCR-Settlement curves for various H/B ratios.

where q_o is the bearing pressure of the unreinforced soil and q is the bearing pressure of the reinforced soil, both measured at the same vertical settlement, S. Thus the BCR can be used to express the effect of geotextile for any desired settlement.

The BCR variation with settlement of footing for different values of H/B ratio is shown in Fig.7. It is found that the contribution of geotextile to the bearing capacity increase is high as the settlement of footing increases, for example the average value of BCR, BCR_{avg} is 1.186 for small settlement of S/B=0.05 and BCR_{avg}=2.088 for large settlement of S/B=1.0. As shown in Fig.7 the value of H/B which gives the greatest BCR is 0.5 for small settlements (S/B less than 0.3) and 1.0 for large settlement (S/B greater than 0.5). This indicates that H/B which gives the greatest geotextile effects falls between 0.5 and 1.0 for the settlements where S/B is less than 1.0.

From the experiments, it was found that when the depth of overlying sand layer is small, initial sliding of geotextile in sand/clay layer occurred at relatively low bearing pressure, which is due to small friction force between geotextile and soils. For this reason, the geotextile effect on the bearing capacity of strip footing is low for the small depths of sand layer where H/B is less than 0.5. In Table 3 are shown the bearing pressure for initial sliding and sliding length of geotextile with the variation of H/B ratios.

Table 3. Bearing pressure for initial sliding and sliding length with the variation of H/B ratios

H/B / Geotextile	0.1	0.5	1.0	1.5	2.0
Bearing pressure for initial sliding (kg/cm^2)	0.097	0.283	0.486	0.786	0.886
Sliding length (cm)	1.03	0.96	0.97	1.05	0.95

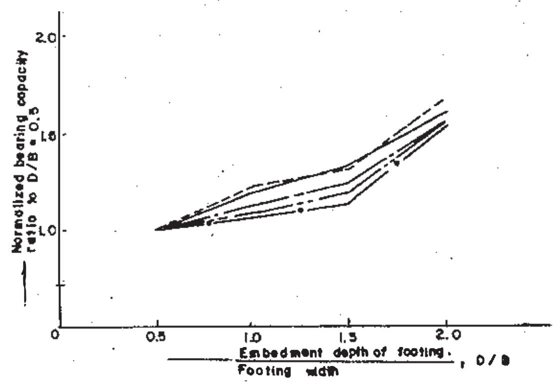
3.2 Effect of the embedment depth of footing

The bearing capacity tests were performed with various D/B ratios to investigate geotextile effect on the bearing capacity of strip footing under the condition of H/B=0.5. Fig.8 shows the normalized bearing capacity ratios to D/B=0.5 for various D/B ratios in the cases with and without geotextile, respectively. Fig.8 indicates that the increment rate of the normalized bearing capacity ratio varies in a similar fashion for the conditions with and without geotextile reinforcement.

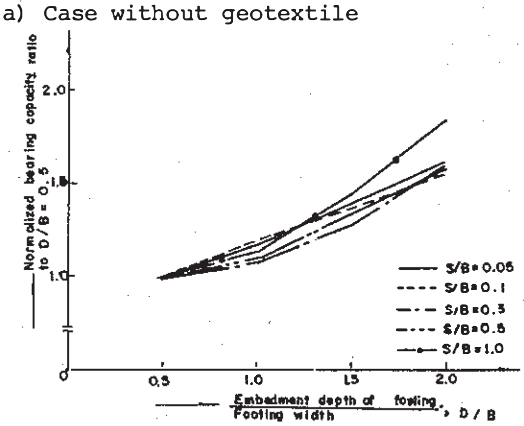
The BCR variation with settlement of footing for different values of D/B ratio is shown in Fig.9. It shows that the contribution of geotextile to the increase of bearing capacity becomes high as the settlement of footing increases for the condition of $0.5 \leq D/B \leq 2.0$. As shown in Fig.9 the value of D/B which gives the greatest BCR is 0.0 when S/B is less than 1.0. But the geotextile effects with regard to the embedment depth are similar in the range of $0.5 \leq D/B \leq 2.0$ while the effect differs greater as the settlement of footing increases.

3.3 Geotextile effect on the deformation of foundation soil

The time dependent deformations of foundation soil were measured by utilizing LED indicating lamps inserted in the sand layer for each loading steps of the bearing capacity test. As shown in Fig.10, LED lamp location is typically changed with regard to the increase of vertical footing load. It shows that the lateral deformation of foundation soil corresponding to the increase of vertical load occurred to the outward direction receding from the footing for the case without geotextile but to the inward direction being close to the footing for the case with geotextile. This indicates the geotextile response against the heaving and settlement of foundation soil. And the failure of the reinforced foundation soil occurred at high bearing pressure in a large deformation mode of circle due to the geotextile effect while the unreinforced foundation soil



a) Case without geotextile



b) Case with geotextile

Fig.8. Normalized bearing capacity ratios for various D/B ratios

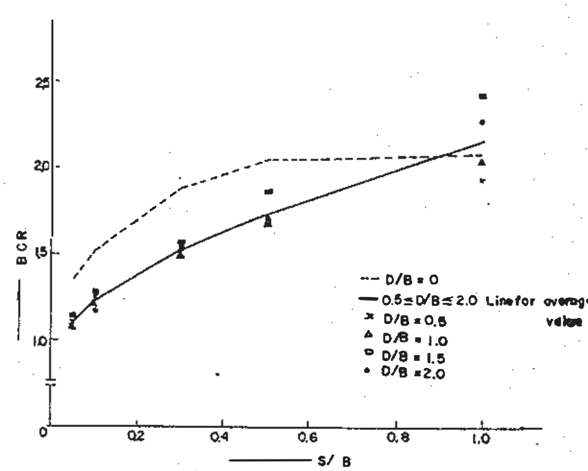
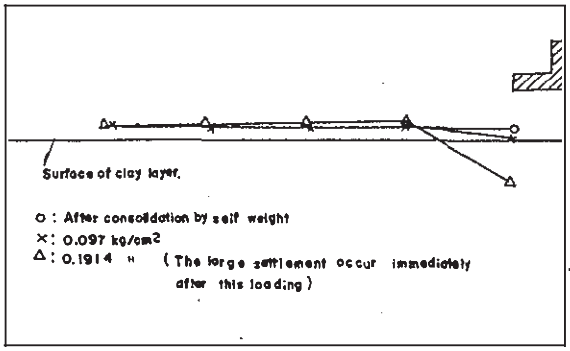
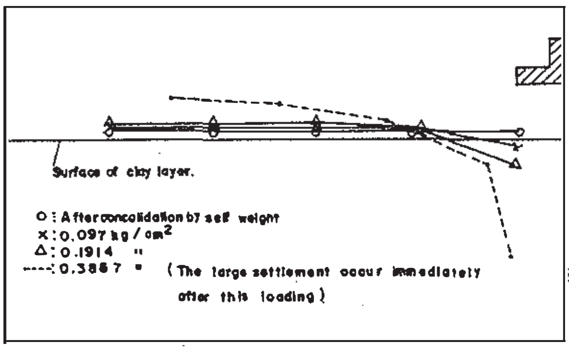


Fig.9. BCR variation with settlement of footing for different values of D/B ratio



a) Case without geotextile



b) Case with geotextile

Fig.10. Typical changes of LED lamp location with regard to the increase of vertical load (in the case of $H/B=0.5, D/B=0.0$)

failed in a small deformation mode at low bearing pressure. It was also found that the vertical and lateral deformation of foundation soil becomes small as the distance of footing from geotextile layer increases and the embedment depth of footing increases regardless of the geotextile reinforcement.

4. CONCLUSIONS

This paper has reported a series of laboratory bearing capacity tests of a strip footing on sand/clay layer with and/or without reinforcing geotextile. The results from the experiments are summarized as follows:

1) The contribution of geotextile to the increase of bearing capacity becomes high as the distance of footing from geotextile layer is reduced. It also becomes high as the footing depth and the footing settlement increases.

2) The ratio of sand layer depth to footing width, which gives the greatest geotextile effect, falls between 0.5 and 1.0 for the settlements where S/B is less than 1.0.

3) The ratio of embedment depth of footing to footing width, which gives the greatest geotextile effect, is 0.0 for the settlements of $S/B \leq 1.0$ but the geotextile effect with regard to the embedment depth where D/B is between 0.5 and 2.0 is similar for the settlements of $S/B \leq 0.5$.

4) Geotextile effect results in the bearing capacity increase over 100% for the conditions of $0.1 \leq H/B \leq 2.0$, $S/B \leq 1.0$ and $D/B \leq 2.0$.

5) The failure of the reinforced foundation soil occurred at high bearing pressure in a large deformation mode of circle due to the geotextile effect while the unreinforced foundation soil failed in a small deformation mode at low bearing pressure.

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