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Effect of bending stiffness of geotextiles on bearing capacity improvement of soft clay

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ABSTRACT : In the previous papers, the authors have investigated the factors contributing to bearing capacity improvement of soft clay reinforced with geotextiles through the results from laboratory model tests. It was emphasized that the frictional characteristics exerted between clay and geotextile is most important for improvement of bearing capacity. However, it has not been made clear how the bending stiffness of geotextiles is correlated to bearing capacity improvement. In the present paper, therefore, the results from laboratory investigation into the effect of bending stiffness are discussed. The following conclusions are derived from the present study : (1) the bending stiffness of combined geotextiles with sand mat covering the soft ground which were determined directly by back-analysing the results from laboratory model tests is closely related to improvement of bearing capacity in soft clay. This back-calculation is based on the assumption that the combined sand mat with geotextiles on soft ground is considered the simple beam with partially distributed uniform loads supported by the elastic body and (2) the effect of sand mat overlaid on soft clay on bearing capacity improvement is most exerted in the combination with geogrid. In this case, increase in bearing capacity is largely contributed by increase in bending stiffness of geogrid combined with sand mat.

1 INTRODUCTION

The authors have carried out the small-scaled model tests at the laboratory for utilization of geotextiles for improvement of soft clays (Hirao et al., 1992). Based on the results from these tests, they have dealed of the mechanism, the geotextile characteristics and soil-geotextile interaction properties contributing to bearing capacity improvement.

Successively to these works, the present paper discusses on the advantageous effect of bending stiffness developed between soils and geotextiles when sand mat is laid over soft clay before construction of such earth structures as embankment. It is also detected on the results of model tests what kind of and how geotextiles should be combined with sand mat to exert the effect of bending stiffness in reinforcement of soft clay.

2 EXPERIMENTAL PROGRAMME

2.1 Outline of Model Tests

Soil tank with 2m width, 0.5m length and 1.0m depth, as illustrated in Fig. 1, was used for model tests to ensure the effect of geotextile application on improvement of soft clay (G_s = 2.62, W_L = 107%, I_p = 66). Details were described in the previous papers (Hirao et al., 1992). Soft clay mixed with water until w_i of 130% was attained was poured into soil tank to form 40 cm and 80 cm thickness of clay layer. Average vane shear strength of model clay layer after pouring is 0.005 kgf/cm^2 (0.5 kPa) which is almost constant against depth.

A layer of geotextile is firstly placed directly over whole the surface of clay layer with 2m width and 0.5 m length. Successively, sand mat with 3 cm thickness is laid onto geotextile. To obtain the load versus settlement curves, we carried out several kinds of model footing tests in which step loads are applied to soft clay reinforced with geotextile and sand mat. For comparison of the effect of reinforcement, a plate loading test on soft clay with sand mat and no geotextile is also conducted.

Vertical load with 0.01kgf/cm^2 (1.0 kPa) for every step is by step applied to the loaded plate with 10 cm width, 49 cm length and 4.9 kgf (48 Pa) weight. Loading duration of each step is 15 min. Loading is applied until clay layer is failed.

2.2 Properties of Geotextiles Used

Table 1 summarizes the mechanical properties of three kinds of geotextiles used in the present study. Those are (1) woven fabric, (2) composite geotextile in which woven fabric is sandwitched with unwoven fabric in both sides, and (3) geogrid. Bending stiffness of each geotextile described in Table 1 was determined from the following procedure.

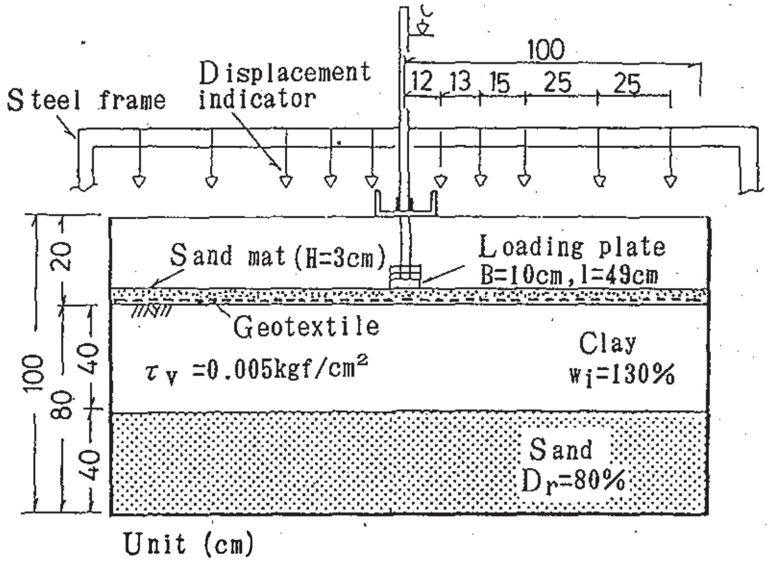

Fig. 1 Testing apparatus for modeltests

Table 1 Mechanical properties of geottextils used

MATERIAL	SYMBOL	THICKNESS or OPENING (mm)	B (gf·cm²)	l (cm)	DESCRIPTION
WOVEN FABRIC	WF	0.5	9.53×10^2	11.3	- - - - -
COMPOSITE FABRIC	CF-B	4.0	1.15×10^3	16.0	
GEOGRID	GG-A	9 x 9	2.36×10^3	33.9	———
	GG-B	28x40	1.32×10^4	75.3	—•—•—
	GG-C	28x33	1.89×10^4	85.3	—•—•—•

B : Bending stiffness , l : Stiffness

2.3 Bending Stiffness Test of Geotextile

The following two procedures were used for determining the bending stiffness of geotextile:

(i) Bending stiffness of geogrids, B, was determined from the deflection of geogrid, D, measured in the cantilever method as shown in Fig. 2. By using a proposal by the Geogrid Research Commiittee (1986), this is given by:

$$B = (w \times L_G^3) / (8 \times D) \qquad (1)$$

where B : bending stiffness (gf·cm^2), w : weight of geogrid (gf), L_G : length of grid (cm), and D : deflection of grid (cm).

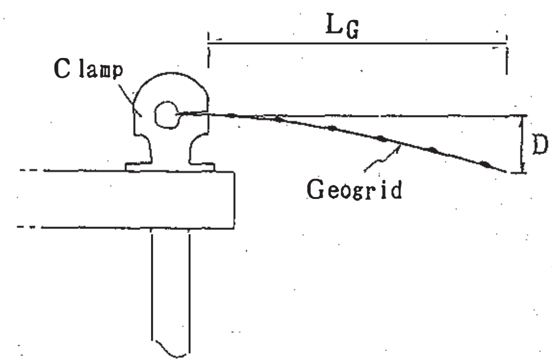

Fig. 2 Cantilevermethod for measurement of bendin; stiffness of geogrid

(ii) Stiffnesses of geogrids, woven and composite fabrics were obtained using the 45° cantilever method regulated by the testing method for general fabrics in JIS. In this test, as shown in Fig. 3, a shift length is measured as the fabric is slowly pushed towards theslope. Thus, the corresponding stiffness is defined as a shift length, l, of fabric when the edge of fabric touches the slope with 45°.

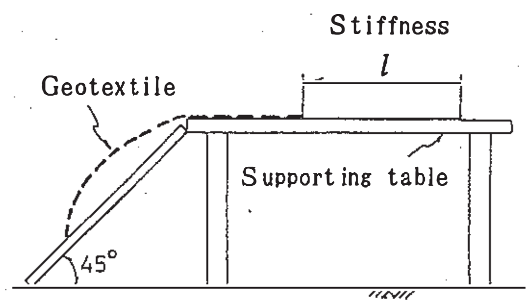

Fig. 3 Method for determining stiffness of geotextiles

Fig. 4 presents the relation between bending stiffness,B, and stiffness, l, in geogrids, indicating that the log scale of bending stiffness is linearly correlated to the stiffness. By extrapolating this linear relation for geogrids, the bending stiffness corresponding to the softness of woven and composite fabrics can be analogied. The values of B obtained in this way are given in Table 1. Values of B for woven and composite fabrics are low in comparison with that in geogrids. This fact is considered later in discussing the effect of bending stiffness of geotextiles on bearing capacity of soft clay.

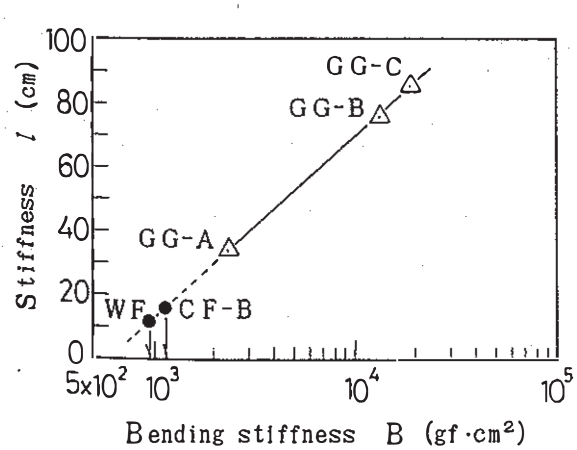

Fig. 4 Relation between stiffness and bending stiffness

3 EXPERIMENTAL RESULTS AND THEIR INTERPRETATION

3.1 Effect of Sand Mat on Improvement of Bearing Capacity

Fig. 5 shows the representative curves of load versus settlement relations measured in plate loading tests. The results in Fig. 5 indicate the following:

(i) Sand mat placed on soft clay has little influence on improvement of bearing capacity.

(ii) Sand mat contributes to the increase in bearing capacity due to combination with geogrid.

This positive feature of sand mat in the item (ii) is caused by : (i) Self-weight of sand mat acts as the counter balance, (ii) sand mat stops up the opening of meshes in geogrid and (iii) relative increase in stiffness of sand mat is endowed due to reinforcement by geogrid.

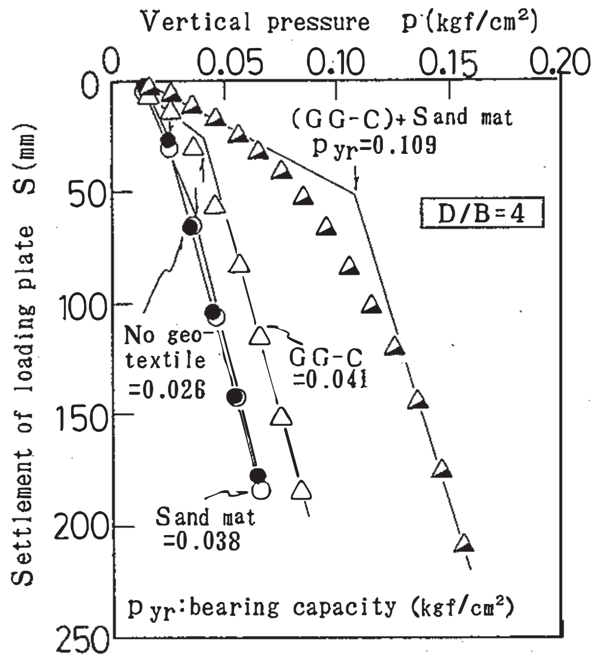

Fig. 5 Representative curves of settlement and vertical pressure obtained by model tests

3.2 Effects of Bending Stiffness and Softness on Bearing Capacity

The ratio of bearing capacity, p_{yr}, of soft clay increased by reinforcement with geotextile to that, p_{yn}, with no geotextile is designated by R_p. Fig. 6 and Fig. 7 show the effects of both the bending stiffness in the geogrids and stiffness in woven and composite geofabrics, respectively, on the value of this R_p for soft clay with reinforcement by geotextiles.

It is understood from these results in Figs. 6 and 7 that placement of geogrid owning the large bending stiffness does not necessarily increase the bearing capacity of soft clay, while bending stiffness in geogrid is larger than that in composite geofabric. This tendency is irrespective to the clay thickness. It is also pointed out from these figures that combination of sand mat with every geotextile can eminently increase the bearing capacity, independently of kind of geotextiles. It is concluded, therefore, that the placement of the single geotextile over soft clay has no close connection with the improvement of soft clay.

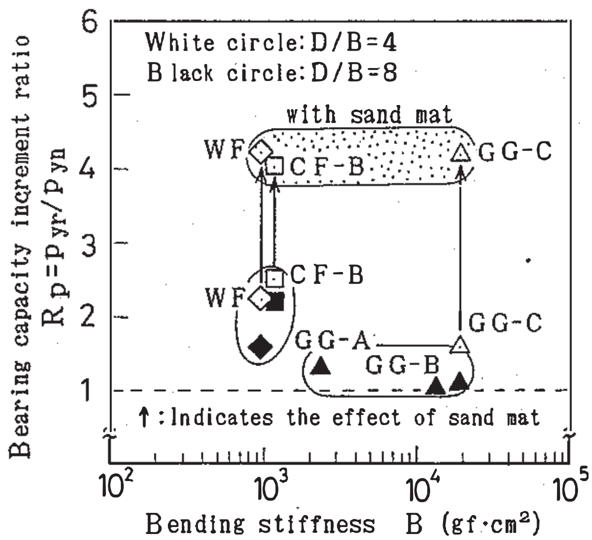

Fig. 6 Effect of bending stiffness on increase in bearing capacity of soft clay

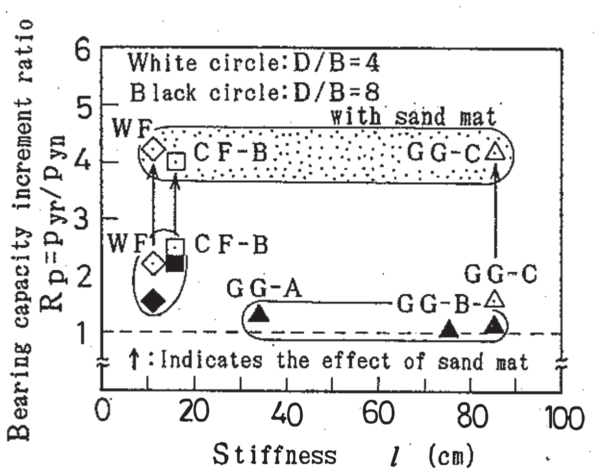

Fig. 7 Effect of stiffness on increase in bearing capacity of soft clay

3.3 Evaluation of the Effect of Sand Mat on Improvement of Bearing Capacity

Although the results from model tests at the laboratory indicate that the placement of geogrid combined with sand mat increases the bearing capcity, no quantitative explanation for this effect is done because of difficult determination of the mechanical parameter for sand mat with geotextile. Accordingly, an attempt to estimate the bending stiffness of the sand mat reinforced with geotextile which is regarded as a unified elastic body is performed to overcome this difficulty.

By assuming, as a first approximation, the loading condtion used in the present study as was shown in Fig. 1 to be the simple beam applied by the partially distributed load, the bending stiffness of the unified body is given from the characteristic equation by:

$$EI = \frac{x(4R_A L^3 - 4R_A L x^2 - qb^4)}{24yL} + \frac{q}{24y} \cdot \langle x-a \rangle^4 \quad (2)$$

where Ra : reaction force at falcurum, L : span distance, y : deflection and x : distance from falcurum. The settlement of the center of unified body is taken as a deflection, y, which is necessary to estimate EI using Eq. (2). The span distance is assumed to be a distance between two points at surface of clay showing the approximately zero settlement in Fig. 8.

Fig. 9 shows the relation between bearing capacity and bending stiffness of with and without sand mat. It is clear from Fig. 9 that the bearing capacity increases with increase in the initial bending stiffness which is caused by sand mat placement. Fig. 10 was obtained by rearranging the results in Fig. 9 into the bearing capacity increment ratio versus initial bending stiffness ratio relations. It can be said from both Fig. 9 and Fig. 10 that bearing capacity with every geotextile combined with sand mat increases twice as that without sand mat, with increasing the bending stiffness, EI. This tendency is particularly eminent in geogrid with sand mat. On the contrary, bearing capacity for only the sand mat placement with no geotextile is the almost the same as that with only the geogrid. Theferore, it can be said that the effect of sand mat is not exerted unless sand is restrained to some extent by geotextile. To sum up, it is concluded that increase in the bending stiffness due to placement of sand mat with geotextile significantly contributes to increase in bearing capacity of soft clay.

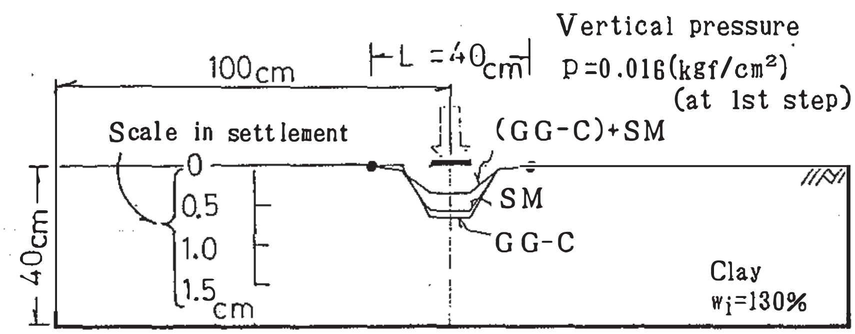

Fig. 8 Examples of the span distance taken from results observed in model tests

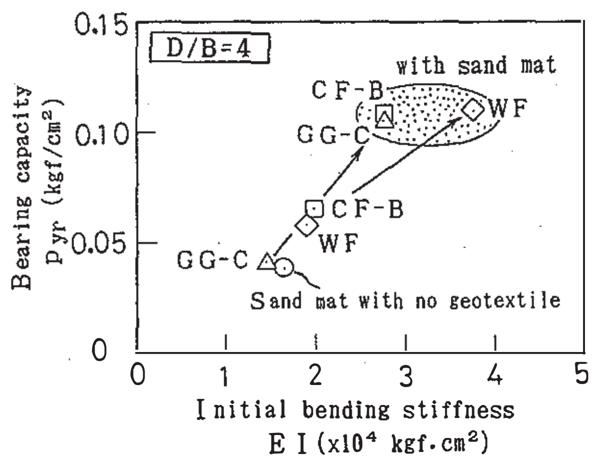

Fig. 9 Relation between initial bending stiffness and bearing capacity with and without sand mat

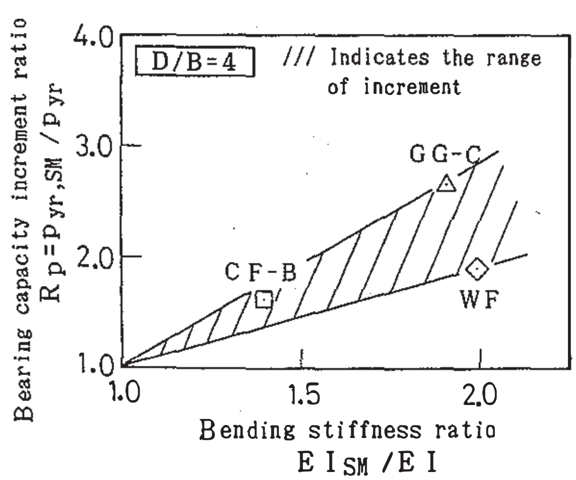

Fig. 10 Relation between bearing capacity and initial bending stiffness increment ratios

4. CONCLUSIONS

1) The bending stiffness owned by geotextiles has nothing to do with increase in bearing capacity of soft clay.

2) On the contrary, placement of sand mat with geotextile covering soft clay contributes to the improvement of bearing capacity of soft clay. In particular, this tendency is eminent in geogrids.

3) The apparent bending stiffness increased by restrainment effect of geotextiles against sand particles plays an important role in improvement of increased bearing capacity. Besides, this increased bending stiffness has a very close connection with the bearing capacity incremental ratio.

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