New Horizons in Earth Reinforcement – Otani, Miyata & Mukunoki (eds)

Toughness improvement of hybrid sandwiched foundations and embankment reinforced with geosynthetics

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ABSTRACT: We have developed a new construction technique called Hybrid Sandwiched Reinforcement (HBS) method in which thin sand layers are placed above and beneath the geosynthetic fabric to increase the mechanical potential of cohesive soil embankment and foundations. This reinforcement method offers advantages of reinforcement improvement and maintenance of hydraulic conductivity. Successive to the authors' previous works, this paper describes small-scale model tests on embankments with and without reinforcement and a sand layer.

Results from model tests are interpreted with emphasis on improved toughness of HBS-reinforced embankments. Results clarified that HBS not only controls embankment deformation; it also improves the toughness using placement of geosynthetics in an embankment comprising cohesive soils such as Kanto loam of volcanic-ash origin. As an important finding related to toughness improvement of HBS earth structures, the model test results show that the improved toughness of foundations and embankments are independent of the sand layer thickness, which implies that the sand thickness in sandwich-type earth structures is sufficient for maintaining the HBS structures' hydraulic conductivity and avoiding clogging of the geosynthetics.

1 INTRODUCTION

Great demand has arisen for effective utilization of high-water-content viscosity soil because of a lack of good soil and difficulty securing construction sites. For those reasons, we have developed a new construction technique called Hybrid Sandwiched Reinforcement (HBS) method, by which thin sand layers are placed over and beneath the geosynthetic fabric (GS) to increase the mechanical potential of cohesive soil embankments and foundations. The HBS method is used together with sand layer not only for protection of non-woven clogging but also for a new function: toughness improvement. This reinforcement method is advantageous for reinforcement improvement and retention of hydraulic conductivity. Both are greater than in cases of reinforcement without the sand layer. Successive to the authors' previous works, for this study, we performed small-scale model tests on embankments with and without reinforcement, and with and without the sand layer. This report specifically addresses toughness improvement. We executed model tests to assess reinforced conditions with sand and GS.

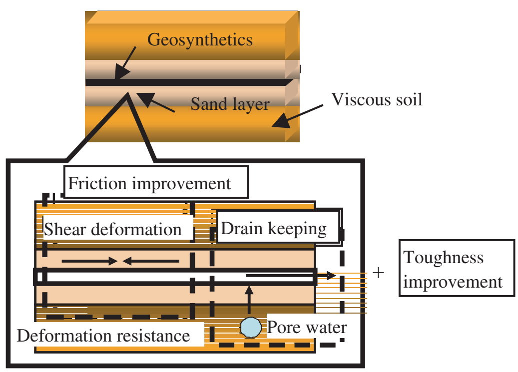
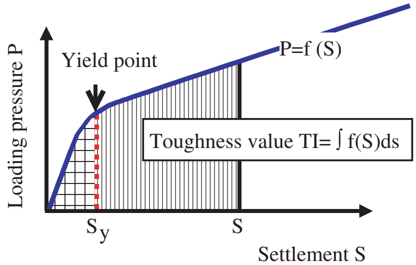


Figure 1.1. Outline of HBS method.

2 TOUGHNESS AND TOUGHNESS VALUE CALCULATION

We define toughness as that which is not prone to incidence of sliding and movement. Figure 2.1 shows the toughness value calculation method. We estimated the



Toughness value to yield point: $TI_y = \int_0^{s_y} f(S)ds$

Toughness value to settlement: $TI_s = \int_0^{s} f(S)ds$

Increase rate of toughness: $E_s = TI_s / TI_y$

Figure 2.1. Toughness value calculation method.

HBS method toughness value (TI) from the loading pressure-settlement curve to involve shear deformation. We defined the area from the original to the yield point as TI_y and from the original to each certain settlement point as TI_s. We calculated the reinforcement toughness values as TI_{ysr}, TI_{ssr} and no-reinforcement toughness values as TI_{ysn}, TI_{ssn}. Concretely, we estimated the rate of toughness improvement (E_{sr}/E_{sn}) using (1).

$$E_{sr}/E_{sn} = \frac{TI_{ssr}/TI_{ysr}}{TI_{ssn}/TI_{ysn}} = \frac{\int f(S)_{sr}ds \Big/ \int_0^{y} f(S)_{sr}ds}{\int f(S)_{sn}ds \Big/ \int_0^{y} f(S)_{sn}ds} \quad (1)$$

E_{sr}: increase rate of toughness in reinforcement
E_{sn}: increase rate of toughness in non-reinforcement
TI_{ssr}, TI_{ysr}, toughness value in reinforcement
TI_{ssn}, TI_{ysn}: and non-reinforcement

3 OUTLINE OF MODEL TEST

3.1 *Test system and measurement method*

This 50-cm-high and 19.5-cm-deep model had a slope gradient of 1 : 0.6. Kanto loam (64.5% initial water content, 0.83 g/cm^3 dry density, 2.77 void ratio, 77.4% degree of saturation) soil was used. The soil was spread, then compacted using a hand vibrator; the slope was reset with a pallet. In addition, Toyoura sand was used in HBS method case as the sand layer with geosynthetics. The loading plate width was 10 cm and the loading speed was 0.2 mm/min. Figure 3.1 shows an outline of a model test. Loading pressure, settlement and slope displacement were measured. Furthermore, the slope displacement was recorded using a video camera. Measured positions were at 20 cm, 25 cm, 30 cm, 35 cm, and 40 cm.

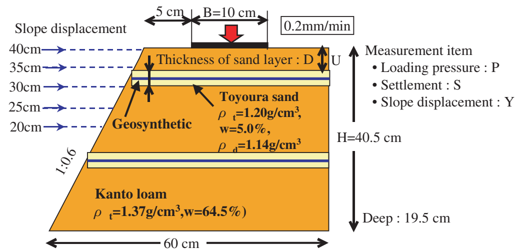


Figure 3.1. Outline of model test.

Table 3.1. Material data of Toyoura sand and Kanto loam.

Toyoura sand		Kanto loam	
Soil particle density	2.64 g/cm^3	Soil particle density	2.72 g/cm^3
Maximum void ratio	0.977	Natural water content	68.7%
Minimum void ratio	0.605	Liquid limit	84.5%
Fine-grained soil content	0%	Plastic limit	61.1%
		Plasticity index	23.4%

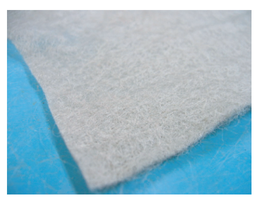


Photo 3.1. Non-woven

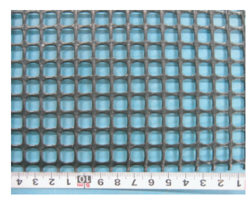


Photo 3.2 Geonet

3.2 *Material of soil and geosynthetics*

3.2.1 *Soil*

We used volcanic Kanto loam as the embankment material and Toyoura sand as the sand layer, for which data are shown in Table 3.1.

3.2.2 *Geosynthetics*

We used two types of GS. One is non-woven (Photo 3.1), with tensile strength of 5.8 kN/m (strain is 110%). Another is Geonet (Photo 3.2), with tensile strength of 3.6 kN/m (strain is 10.6%). Table 3.2 shows GS characteristics.

3.3 *Model test case*

We tested reinforcement effects and toughness improvement effects of the HBS method. Table 3.3

Table 3.2. Characteristics of GS materials.

	Tensile strength	Strain	Coefficient of permeability Vertical	Horizontal	Space	Material
Non-woven	5.8 kN/m	110%	5×10^{-1} cm/s	4×10^{0} cm/s	–	PP
Geonet	3.6 kN/m	10.6%	–	–	10 mm	PE

Table 3.3. Model test case.

Case	Reinforced method	Geosynthetics	Sand thickness	layer	Single layer depth
1	Non-reinforcement	–	–	–	–
2	Non-woven + sand	Non-woven	1 cm	1 (top)	2 cm
3	Non-woven + sand	Non-woven	1 cm	1 (top)	4.5 cm
4	Non-woven + sand	Non-woven	1 cm	1 (top)	7 cm
5	Sand	–	1 cm	1 (top)	4.5 cm
6	Non-woven	Non-woven	–	1 (top)	4.5 cm
7	Sand	–	3 cm	1 (top)	4.5 cm
8	Non-woven + sand	Non-woven	3 cm	1 (top)	4.5 cm
9	Geonets	Geonets	–	1 (top)	4.5 cm
10	Geonets + sand	Geonets	3 cm	1 (top)	4.5 cm
11	Non-woven + sand	Non-woven	1 cm	2	4.5 cm
12	Non-woven + sand	Non-woven	1 cm	3	4.5 cm

shows the test case. As Fig 3.2 shows, we devoted particular attention to effects of: (a) HBS method, (b) one layer's GS position, (c) sand thickness, (d) the GS type, and (e) a reinforced layer.

4 RESULTS AND DISCUSSION

4.1 *Effect of HBS method*

We confirmed the HBS method effects. Fig 4.1 shows settlement of the embankment with loading pressure in cases 1, 6, 7, and 8. Fig 4.2 shows changes in rate of toughness improvement with each settlement. These results show that case 8 of HBS method (non-woven + sand) offers the most rigidity and most rate of toughness improvement. Especially, the rate of toughness improvement in case 8 was 1.8, which contrasts to case 1, with 1.0, in 40 mm settlement. The rate of toughness improvement was about 2 times by using HBS method. These results verify that HBS method

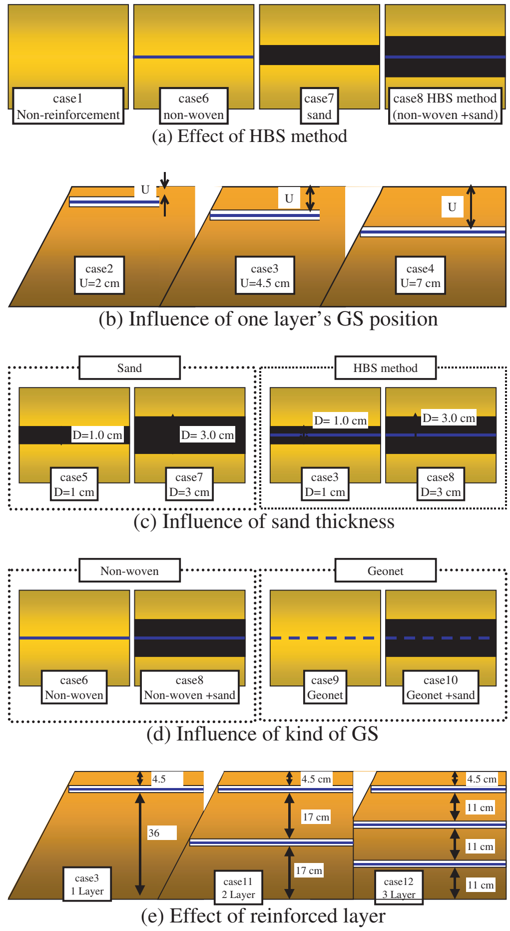


Figure 3.2. Test Case.

prevents clogging of the GS and increases toughness. Fig 4.3 shows slope displacement that occurs with loading pressure in cases 1, 6, 7, and 8. In addition, we calculated the experimental displacement two times to show the difference of displacement. The top of the slope showed large deformation in case 1 (non-reinforced): maximum displacement was about 3 cm. Moreover, the maximum displacement was about 1 cm in case 8 (non-woven + sand). Results confirmed that conditions in case 8 improved rigidity and deformation, in addition to toughness, using HBS method.

4.2 *Influential factors on HBS method toughness improvement*

4.2.1 *Influence of one layer's GS position*

We confirmed the influence of one layer's GS position on toughness improvement. Fig 4.4 shows

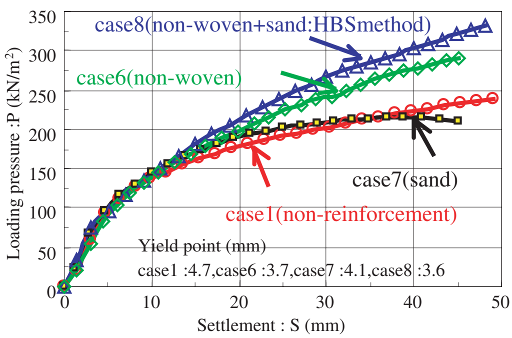


Figure 4.1. Settlement of loading position and loading pressure.

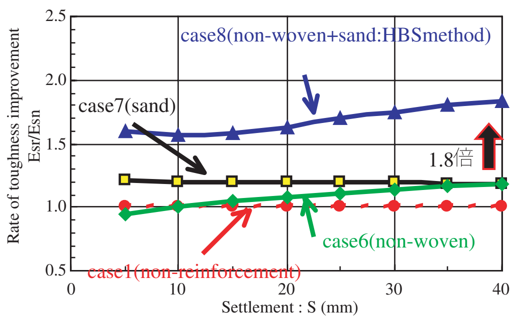


Figure 4.2. Rate of toughness improvement (effect of HBS method).

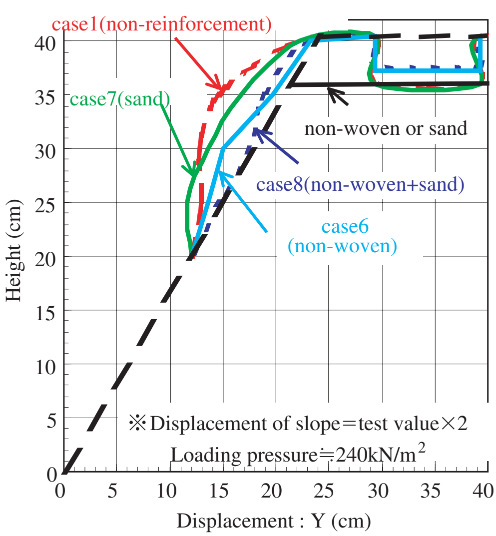


Figure 4.3. Slope displacement (effect of HBS method).

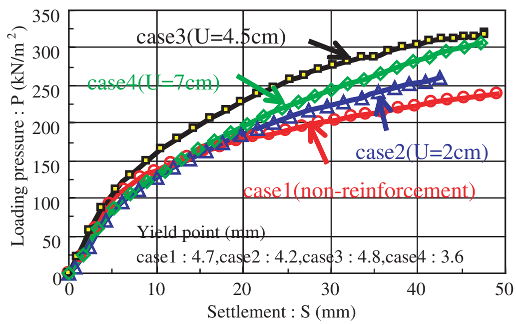


Figure 4.4. Settlement of loading position and loading pressure.

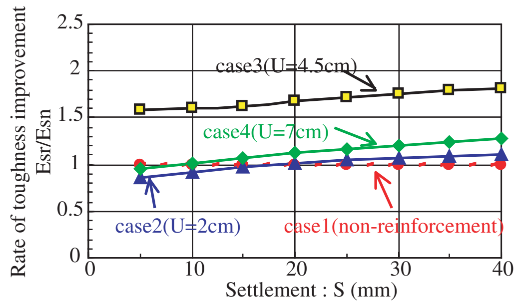


Figure 4.5. Rate of toughness improvement (influence of one layer's GS position).

embankment settlement with loading pressure in cases 2, 3, and 4. Fig 4.5 shows changes in rate of toughness improvement with each settlement. These results show case 3 (4.5 cm reinforcement layer position) as the most rigid and largest effect of toughness improvement. The GS pressure was confirmed as weak in case 2 (2.0 cm reinforcement layer position) because the GS tensile force was not sufficiently secured. We considered that the embankment underwent slope failure above the reinforcement layer position in case 4 (7.0 cm reinforcement layer position).

Fig 4.6 shows slope displacement with loading pressure in cases 1–4. From that result, in case 2 ($U = 2.0$ cm), the maximum displacement was 2.0 cm. The top of the slope shows large deformation that is comparable to those of cases 3 and 4; the GS of case 2 did not control slope deformation. Furthermore, we confirmed 1 cm displacement above the reinforcement layer position in case 4 ($U = 7.0$ cm). However, displacement of case 4 was less than the displacement of case 1 (non-reinforcement). There were reinforcement effects of GS and HBS method in case 3 ($U = 4.5$ cm) where GS is lain in a deep position. Fig. 4.4 demonstrates the effectiveness of HBS method because the rigidity of case 4 actually increased with settlement.

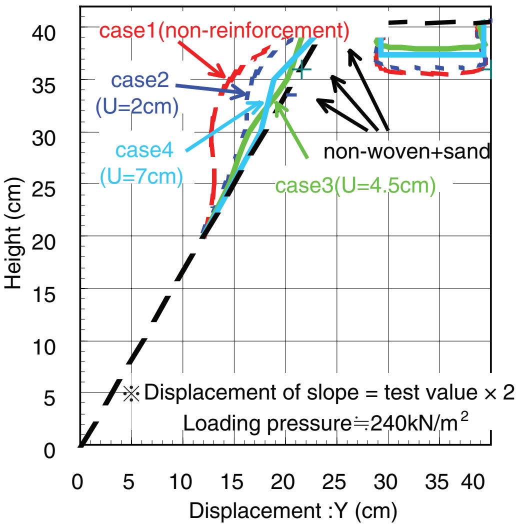


Figure 4.6. Slope displacement (influence of one layer's GS position).

4.2.2 *Influence of sand thickness*

We confirmed the influence of sand thickness on toughness improvement. Fig 4.7 shows embankment settlement with loading pressure in cases 3, 5, 7, and 8. Fig 4.8 shows changes in toughness improvement with each settlement. Cases 3 and 8 use HBS method (non-woven + sand), cases 5 and 7 use only sand. In addition, sand thickness of cases 3 and 5 are 1 cm, sand thickness of cases 8 and 7 is 3 cm. Comparison of sand thickness of 1 cm (cases 3 and 5) to sand thickness of 3 cm (cases 7 and 8) shows that rigidity and toughness improvement rate were equivalent. Therefore, sand thickness showed no difference: if the lay area of GS and sand are equal, the friction characteristic is independent of the sand thickness. However, to maintain drainage characteristics of non-woven GS (clogging prevention), we must distinguish the sand layer thickness from the drainage characteristics.

Fig 4.9 shows the slope displacement with loading pressure in cases 3, 7, and 8. Displacement for case 5 could not be measured because of a measurement error. From this result, the maximum displacement was 0.5 cm in case 3 (sand thickness $D = 3.0$ cm) and 1.0 cm in case 8 (sand thickness $D = 3.0$ cm), implying that displacement was determined by sand thickness. Especially, case 8 showed large displacement at the nearby reinforced layer. This test differs from actual behavior because of the low confining pressure model test. For a thick sand layer ($D = 3.0$ cm), Kanto loam and Toyoura sand were not identical; embankment slip failure might have occurred because of sand layer weakness.

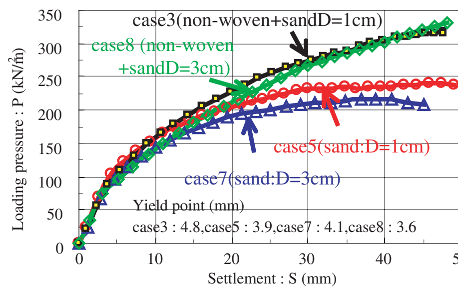


Figure 4.7. Settlement of loading position and loading pressure.

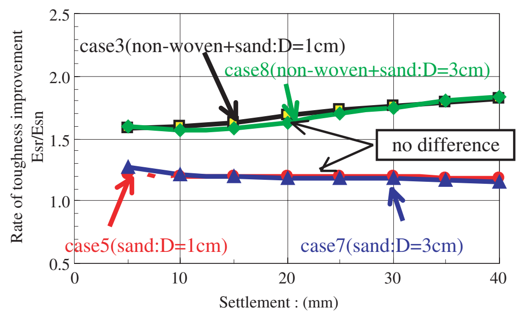


Figure 4.8. Rate of toughness improvement (influence of sand thickness).

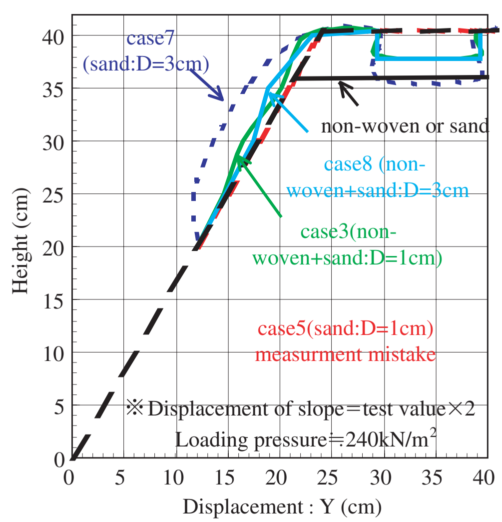


Figure 4.9. Slope displacement (influence of sand thickness).

4.2.3 *Influence of kind of GS*

We confirmed that the GS type influences toughness improvement. Fig 4.10 shows settlement of the

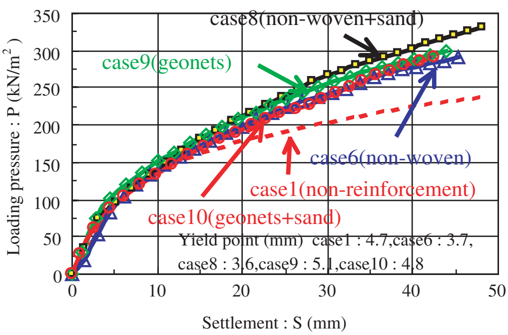


Figure 4.10. Settlement of loading position and loading pressure.

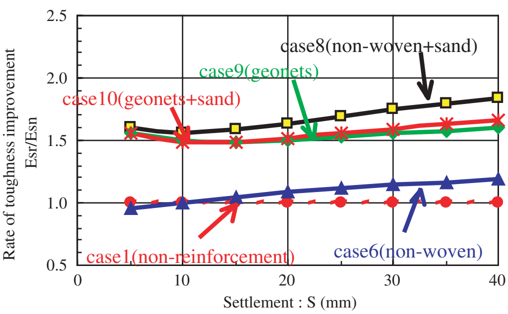


Figure 4.11. Rate of toughness improvement (influence of kind of GS).

embankment with loading pressure in cases 6 and 8–10. Fig 4.11 displays changes of toughness improvement for each settlement. These results show no clear difference of non-woven (cases 6 and 8) and Geonet (cases 9 and 10) for rigidity. However, cases 6, 8–10 have high rigidity compared to case 1 (non-reinforced). Furthermore, toughness improvement of case 8 (non-woven + sand) in 40 mm settlement was 1.8, in contrast to that of case 10 (Geonet + sand) in 40 mm settlement, which was 1.6. Case 8 (non-woven + sand) exhibits a large effect of toughness improvement.

Fig 4.12 shows slope displacement with loading pressure in cases 6, 8–10. The maximum displacement was 2.0 cm in case 10 (Geonet), and the maximum displacement was 3.5 cm in case 1 (non-reinforced). Consequently, embankment displacement was controlled using Geonet. However, because the maximum displacement was 1.0 cm in case 8 (non-woven + sand), we confirmed that using non-woven is most effective for displacement control. This test showed that the interaction effect of sand and GS was superior to that of Geonet, but the possibility exists that Geonet can have a larger carrying capacity using a different kind of sand. This test used effective high-content viscosity soil to advance consolidation and increase strength.

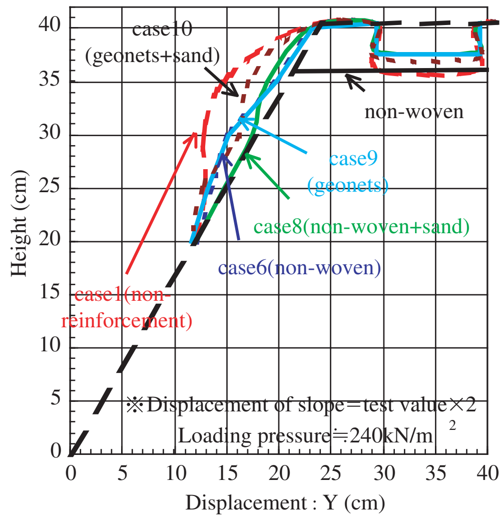


Figure 4.12. Slope displacement (influence of kind of GS).

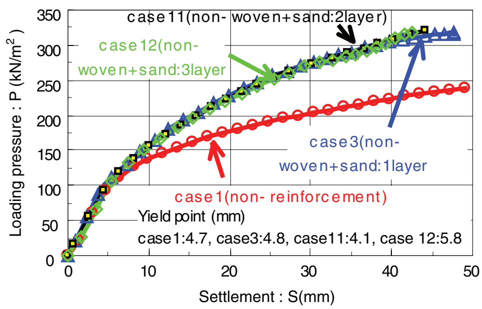


Figure 4.13. Settlement of loading position and loading pressure.

Therefore, we considered that using non-woven and Geonet GS is suitable.

4.2.4 *Effect of reinforced layer*

Results of 4.1 effect of HBS method confirmed the effect of HBS method. Next, we studied the number of reinforced layers' influence on toughness improvement. Fig 4.13 shows embankment settlement of with loading pressure in cases 1, 3, 11, and 12. Fig 4.14 shows changes of toughness improvement with each settlement. Rigidity is nearly equal and toughness improvement is nearly equal in cases 3, 11, and 12. There was no increase of rigidity and toughness value (carrying capacity) by changing the reinforced layer. Fig 4.15 shows slope displacement with loading pressure in cases 1, 3, 11, and 12 because slope displacement of cases 3, 11, and 12 was smaller than that of case 1 (non-reinforced).

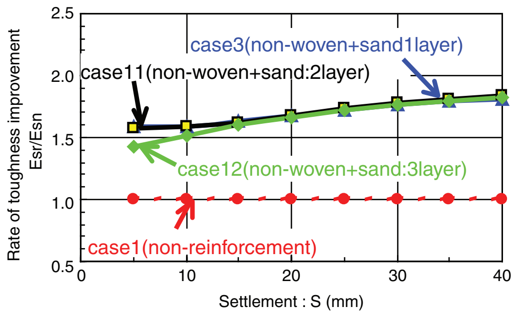


Figure 4.14. Rate of toughness improvement (effect of reinforced layer).

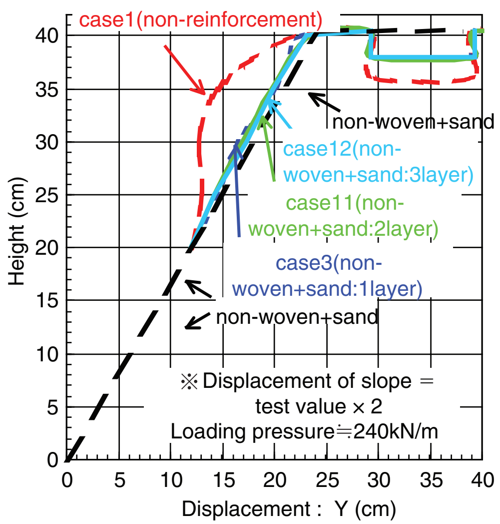


Figure 4.15. Slope displacement (effect of reinforced layer).

Results show that deformation was controlled, but no difference was apparent from changing the reinforced layer. From Fig 4.16, we considered the position of the sliding surface was less than that of the second layer. Therefore, we must explore numerous reinforcement layers and positions of reinforcement layer in reinforcement function (carrying capacity) and drain function in future studies.

5 CONCLUSION

From the results described in this paper, the following are concluded.

(1) Results clarified that HBS improves toughness more markedly than conventionally adopted placement GS in clay embankments.

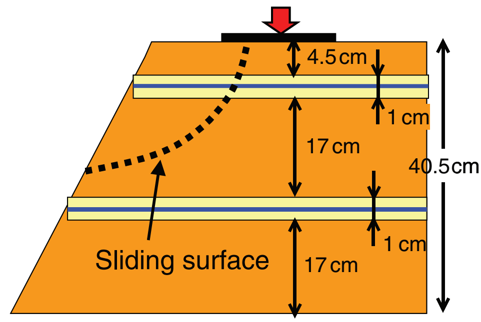


Figure 4.16. Sliding surface (case 11).

(2) Effects of toughness improvement did not depend on sand thickness in these model tests. It is an important subject to decide sand thickness not to decrease drain characteristics of non-woven materials.

(3) Embankment material and friction of sand and GS exert a large influence.

(4) These results are inferred to be applicable to conditions at many sites.

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