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# A diagrammatic evaluation of geo-composites for reinforcing cohesive soils

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ABSTRACT: Two diagrams are proposed to ensure the advantageous features of geo-composite on improvement of stability, stiffness and permeability of cohesive soils. The one is to plot the increase ratio in bearing capacity against the one in ground reaction coefficient, which was obtained from the results of model footing tests in the laboratory. The other is to correlate the change in permeability with the one in transmissibity in geo-composite before and after model footing tests. It is emphasized from two diagrams that placement of thin sand layers above and under geocomposites enables to maintain permeability and transmissibity of geo-composite as well as gives rise to marked improvement of stability of cohesive soil embankment.

## 1 INTRODUCTION

Among the recently developed geo-composites, a geo-composite with a non-woven fabric combined with a vvoven fabric in-between has been used for reinforcing marginal or cohesive soils (Hirao et al., 1992 ; Hirao et al., 1996 : Tanabashi et al., 1998 ; 2000 : Yasuhara et al., 1999). This kind of geo-composite is characterized by having the potentials not only of high tensile and frictional resistance but also of vertical and horizontal drainage potential. Those are very beneficial in reinforcing the marginal soils which are not suitable for constituting ground or embankment with no improvement.

In order to confirm the serviceability of the geo-composite for reinforcement of embankment made of Kanto loam which is a typical volcanic-origin silty soil in Japan, a family of small-scaled model tests was carried out.

The current paper describes the results from these model tests with interpretation for possible application to fields. The two diagrams are proposed from the test results to ensure the advantageous features of geo-composite on improvement of stability, stiffness and permeability of cohesive soils. The one is to plot the increase ratio in bearing capacity against the one in ground reaction coefficient, which can be obtained from the results of model footing tests in the laboratory. The other is to correlate the change in permeability with the one in transmissibity in geo-composite before and after model footing tests. It is emphasized from two diagrams that placement of thin sand layers above and under geo-composites enables to maintain drainage potential defined by permeability and transmissibity of geocomposite as well as gives rise to marked improvement of stability of cohesive soil embankment.

## 2 OUTLINE AND SCHEME OF EXPERIMENTS

Key sketches for laboratory small-scaled model tests on the Kanto loam embankment reinforced with two or three planar geosynthetics (unwoven geosynthetic (UG) and geo-composite (GC)) layers are illustrated in Fig. 1. Kanto loam used for all the model tests is a volcanic-origin silty soil with 2.69 kN/m3 for specific density of solid particle, 94% for liquid limit (LL) and 29 for plasticity index ($I_P$). In test series for Case A, embankment was prepared by tamping compaction of this Kanto loam with 40 to 50% as initial water content. On the other hand, embankment and level ground for Case B were made by consolidating slurry of Kanto loam with twice of LL as initial water content in order to make sure of the drainage effect for geosynthetic more clearly. Water content of Kanto loam in these tests was about 72% on the average. In one case among the test series for both Cases A and B, sand mat was placed above and beneath geosynthetics to increase the effects of reinforcement and to avoid clogging due to intrusion of finer into the texture of geo-composite. Model embankments (Case A : 21.8 cm base, 11 cm top width, 18 cm high, 10 cm thick and 1V : 0.6H slope, Case B : 45.8 cm base, 23.1 cm top width, 37.8 cm high, 10 cm thick and 1V : 0.6H slope) encased in acrylic box was prepared with help of a spacer block. For comparison with those effects in embankment, as shown in Fig. 1, model tests on level ground (Series B-2) were also included in the test series for Case B as B-2.

The sample for embankment for Case A series was left for saturation for about one week, followed by pre-compression up to 9.8 kPa. As is seen in Fig. 2, most of pre-compression occurred within a day. Since the spacer block was present, less settlement took place. However, presence of a nonwoven geosynthetic and a geo-composite combined without sand mat on embankment made lesser pre-compression settlement than that for unreinforced embankment. This may be mainly attributed to the reinforcement effect. On the contrary, presence of sand mat along with geo-composite has led to comparatively larger settlements. This may be due to the drainage effect and/or faster dissipation of excess pore pressures resulting in consolidation. Exact nature of such phenomena cannot be ascertained from the present test results, because the embankment was left for free drainage after one week for saturation. After the pre-compression was completed, the spacer disk was removed and the top face of the embankment was loaded with a 5cm strip footing under the constant rate of displacement. The top layer of reinforcement was placed at 9.45cm depth for Case B series of tests. As there was not so much pre-compression settlement, which was mainly due to the presence of the spacer block as shown in Fig. 2.

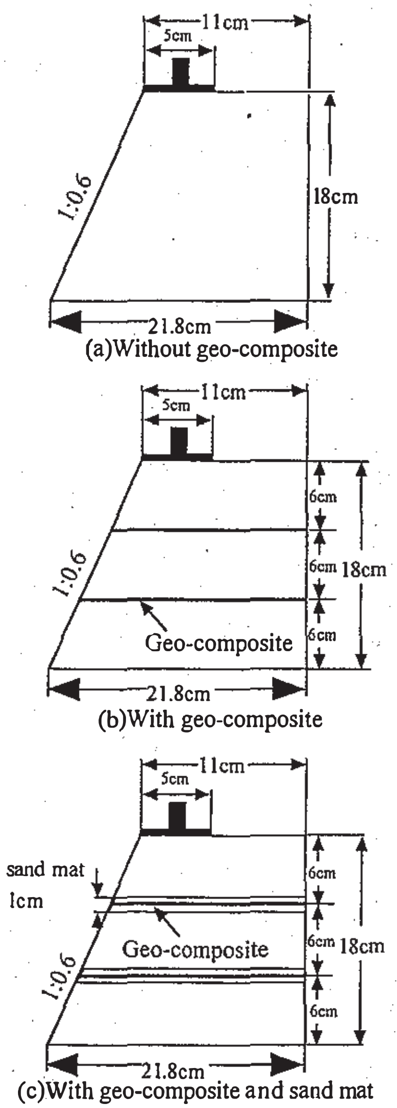



Figure 1a. Model tests (Series A).

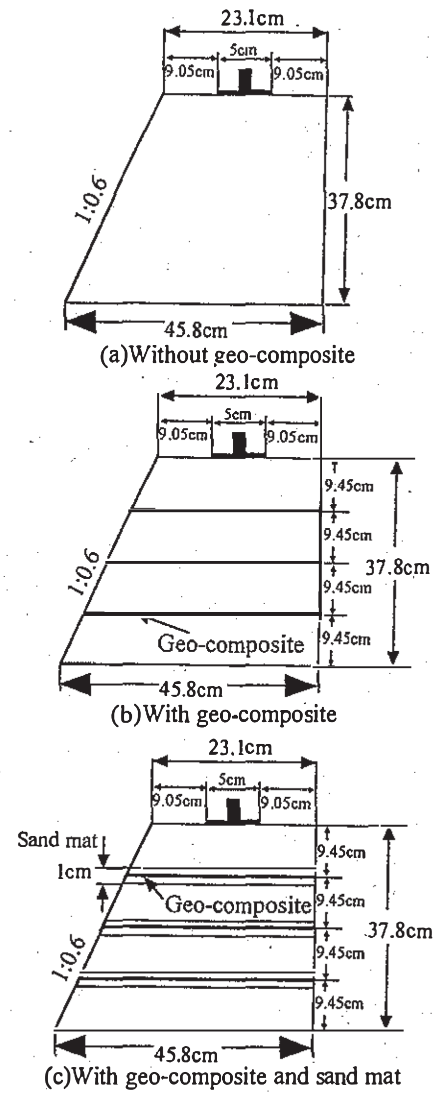



Figure 1b. Model tests (Series B-1).

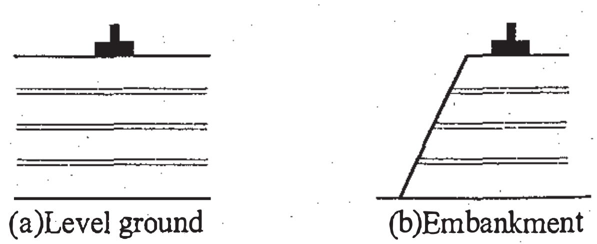



Figure 1c. Model tests (Series B-2).

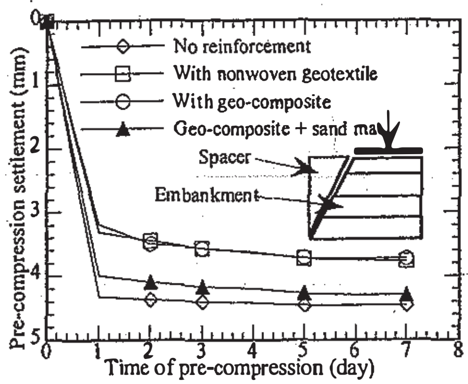



Figure 2. Time vs pre-compression settlement of embankment with spacer block.

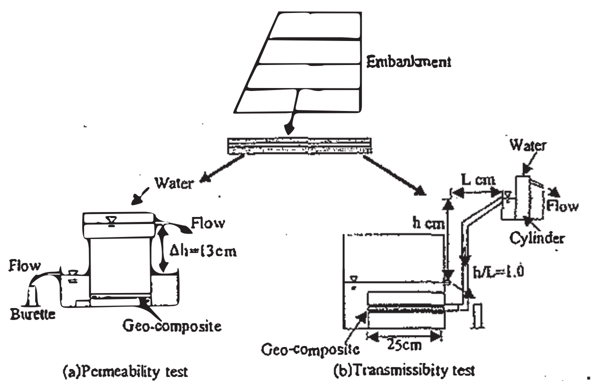



Figure 3. Simple laboratory tests for permeability.

This tendency must be helpful for understanding the results of loaded tests after precompression which will be later described.

After each model test is terminated, then a piece with 10 cm width and 25 cm length, was cut out from the geo-composite which was placed among modeled embankment and then was used for relatively simplified testing equipment for investigating the changes in permeability and transmissibity of the material. The testing apparatus is shown in Fig. 3.

# 3 EVALUATION OF ADVANTAGEOUS FEATURES IN GEOCOMPOSITE FROM MODEL TESTS

## 3.1 *Evaluation of bearing capacity and stiffness*

Fig. 4 schematically illustrates the vertical load versus settlement relation which is obtained from model footing tests from simulated level ground and/or embankment at laboratory with and without reinforcement using geosynthetics. Note that the vertical axis for settlement and the horizontal axis for load are given by normalizing S and q by B and $(1/2)\gamma B$, respectively, where B is width of loading plate and $\gamma$ is unit volume weight of soil used. The following two parameters which designate the improvement ratio for bearing capacity and stiffness can be defined from Fig. 4:

Bearing capacity index : $R_q = q_{ur}/q_{un}$ (1)

Stiffness improvement index : $R_k = K_{ir}/K_{in}$ (2)

where $q_{ur}$ and $q_{un}$ are bearing capacities with and without reinforcement which correspond to S/B equal to 0.3. Although this value of 0.3 is arbitrarily selected for the sake of convenience, this procedure is used consistently through the present study for determining bearing capacity in any case where the determining bearing capacity in any case where the peak value of q is not observed in load versus settlement curves as is shown in Fig. 5 through Fig. 7. $K_{ir}$ and $K_{in}$ in Eq. (2) are ground reaction force coefficients with and without reinforcement.

The results determined from S/B versus $2q/\gamma B$ curves (Fig. 5 to Fig. 7) in model tests for two cases on embankment with and without reinforcement are plotted in the form of the relation between $K_{ir}/K_{in}$ and $q_{ur}/q_{un}$ in Fig. 8 for Cases A and B-1, and Fig. 9 for Case B-2. It is indicated from both figures that:

1) Geocomposite contributes to larger improvement for both bearing capacity and stiffness of embankment than unwoven geosynthetic does.
2) Placement of sand mats above and beneath geocomposite increases both bearing capacity and stiffness. However, less increase is observed in the case of adopting the unwoven geosynthetic. This advantage in geo-composite may be attributed to the fact that the pull-out resistance force of geo-composite against sand is much higher than that against Kanto loam as is shown in Fig. 10. In addition, regarding this benefit in geo-compoiste, it can be also envisaged that the bending stiffness of the geo-composite is larger than that of unwoven geosynthetic. This effect should work out more markedly due to combination with sand.

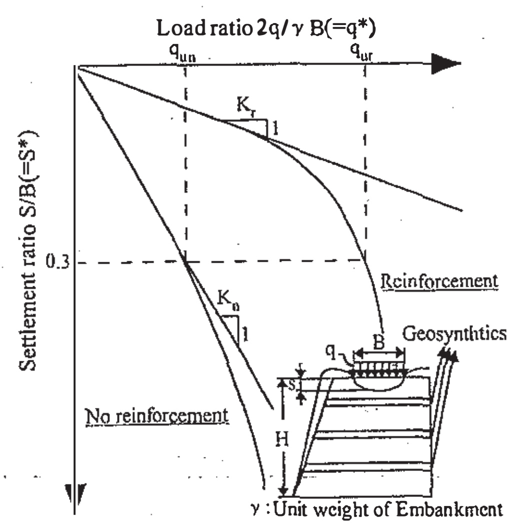



Figure 4. Key sketch for load versus settlement curve.

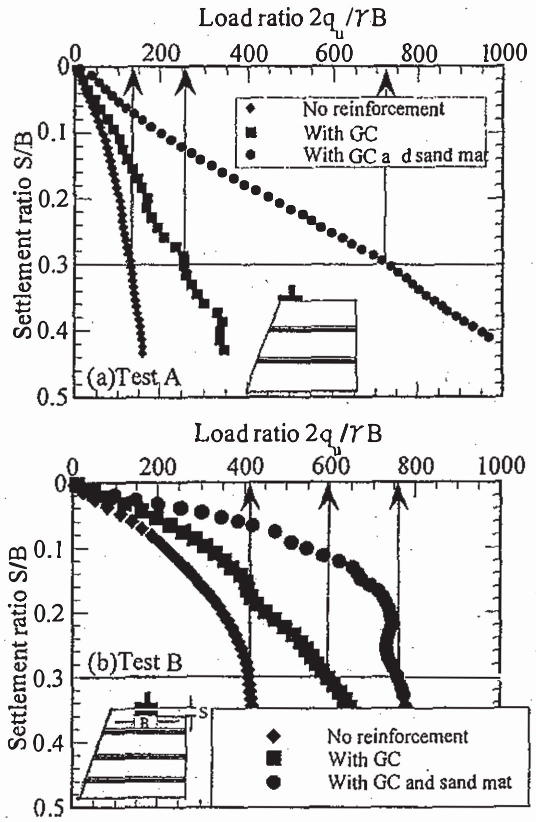



Figure 5. Effect of sand mat on reinforcement.

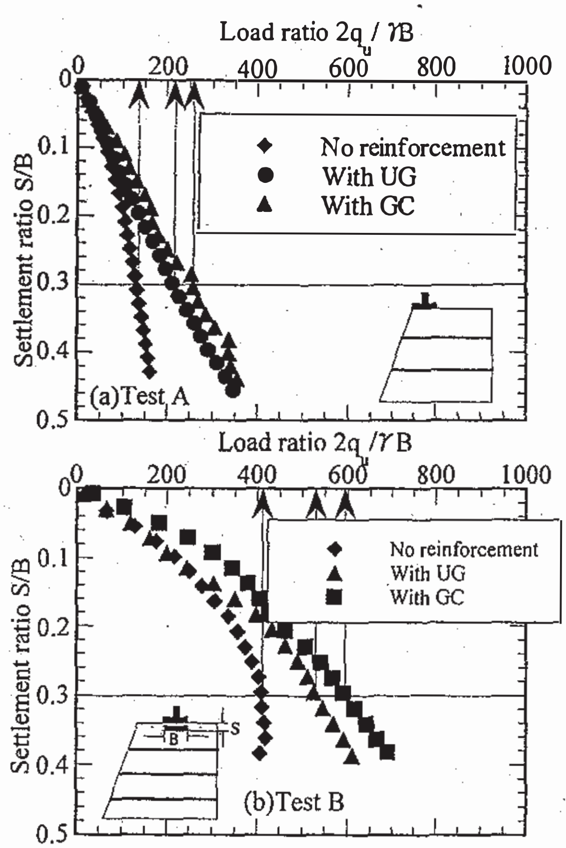



Figure 6. Effect of geosynthetic on load-settlement curve.

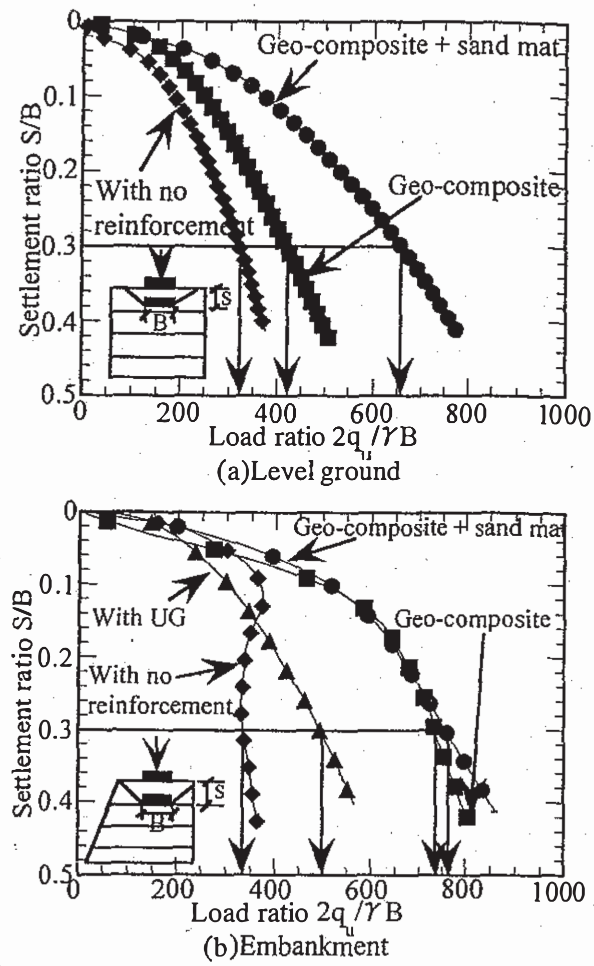



Figure 7. Effect of geo-composite on reinforcement to embankment and level ground.

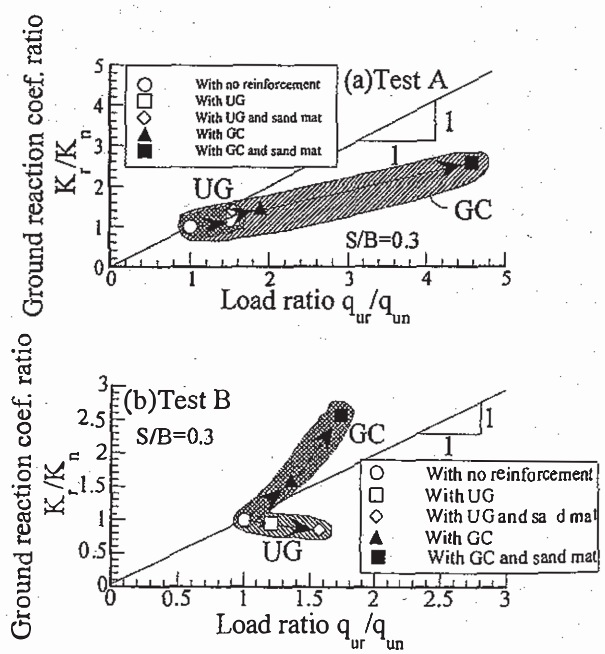



Figure 8. Bearing capacity ratio versus stiffness ratio relation (A,B-1).

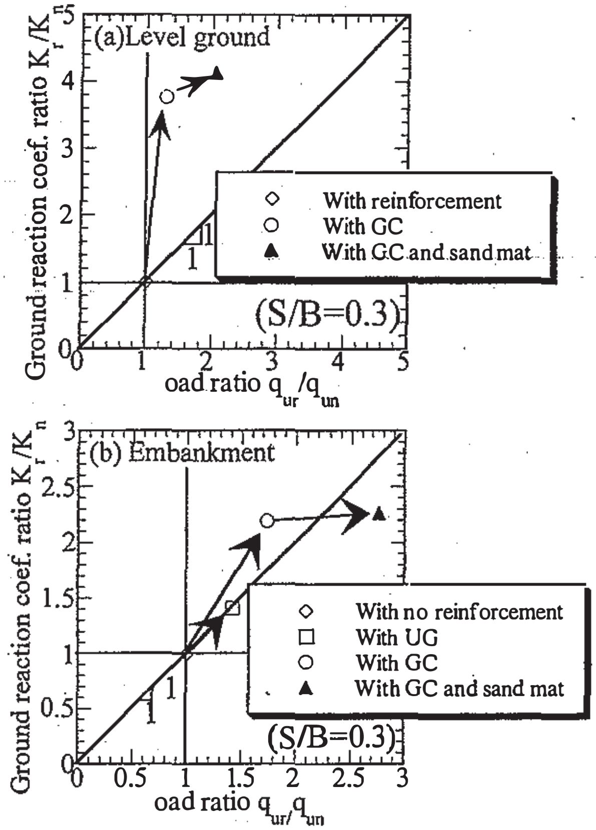



Figure 9. Bearing capacity ratio versus stiffness ratio relation (B-2).

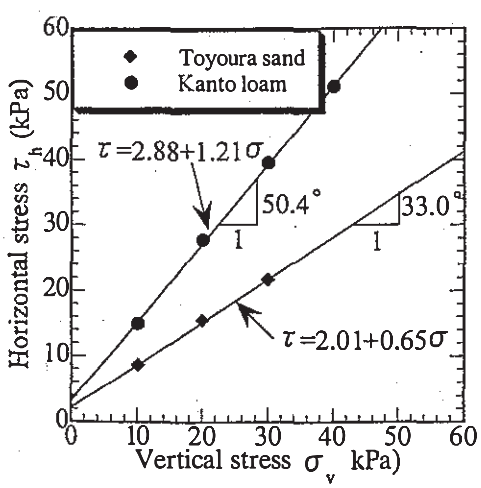



Figure 10. Results from pull-out tests.

3) On the other hand, as well as for compacted embankment, geo-composite plays a role in marked improvement, particularly in stiffness of Kanto loam embankment prepared by pre-consolidating from slurry condition. However, placement of sand mat produces an increase in bearing capacity than in stiffness. The difference of the sand mat effect on improvement observed between Fig. 2 and Fig. 9 may be ascribed to insufficient pre-consolidation in slurry Kanto loam. This tendency should be interpreted together with the results in pre-compression characteristics as is shown in Fig. 2. In other words, this implies that acceleration of consolidation must be a key for increasing reinforcement effects in the case of marginal soils with high water content.
4) In comparison with both cases of level ground and embankment included in Case B-2, reinforcement effect in stiffness using geo-composite is more marked than that of embankment using unwoven geosynthetic. This effect is more clear in level ground than that in embankment. This advantageous feature of geo-composite is probably caused by the higher bending stiffness than that of unwoven geosynthetic.

### 3.2 *Evaluation of drainage potential*

It is expected that geo-composite is endowed not only by reinforcement but also by drainage effects designated by permeability and transmissibity. Permeability and transmissibity are indices for drainage potentials through vertical and horizontal directions against the geo-composite, respectively. Potentials in those permeability and transmissibity of geocomposite are required to be retained during the life of embankment or ground. However, since geocomposite is normally sandwitched in the horizontal direction by soils in embankment, these potentials are deteriorated from time to time, mainly due to clogging which is caused by intrusion of finer into textures of geocomposite. As an attempt to avoid this inconvenience, sand mats are placed at both sides above and beneath the geocomposite as was shown in Fig. 1.

For characteristic evaluation of clogging effect, the horizontal permeability coefficient as well as the vertical permeability coefficient before and after model tests were investigated using the simple devise shown in Fig. 3. The results from both investigation are demonstrated in Fig. 11 which is plotted in the coordinate by the ratios of both coefficients designated by $k_r/k_n$ and $\theta_r/\theta_n$, respectively. Fig. 11 points out that:

1) clogging of the geo-composite without thin sand mat (indicated by 1, 2 and 3 in the figure) is significant while the same with it (indicated by 4, 5 and 6) is insignificant.
2) the in-plane permeability of geocomposite is reduced more markedly than the cross-plane permeability, which means that clogging should affect transmissibity of geo-composite.

The difference of the above-stated clogging with and without sand mats is recognized in Photo 1 which evidences that a part of geo-composite gets stained after model tests are finished, in comparison with that before model tests. In other words, this is no more than the existence of finer of Kanto loam being intruded into geo-composite. Such a diagram as in

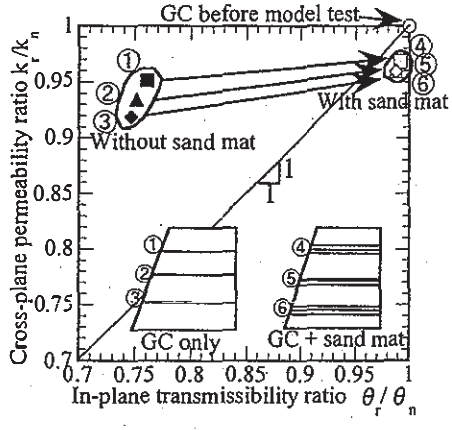
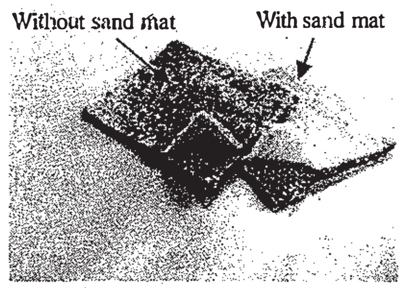
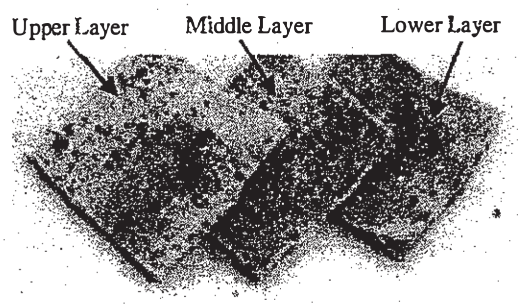



Figure 11. Clogging effect of exhumed geocomposite.




(a) Staining condition of geo-composite with and without sand mat




(b) Staining condition of geo-composite in each layer of embankment without sand mat

Figure 12. Difference of stain in geo-composite.

Fig. 11 that plots both the ratios of cross-plane permeability and in-plane transmissibity of geo-composite before and after model tests is helpful for understanding the advantage of geo-composite in permeability potential and for exploring the way how to maintain the drainage potential of geo-composite.

## 4 CONCLUSION

1) Two diagrams are proposed to ensure the advantageous features of geocomposite on improvement of stability, stiffness and permeability of cohesive soils based on the results from laboratory model tests for embankment and level ground.
2) It is emphasized from two diagrams that placement of thin sand layers above and under geocomposites enables to maintain permeability and transmissibity of geo-composite as well as gives rise to marked improvement of stability of cohesive soil embankment.
3) In order that the use of geo-composite is successful in increasing stability and saving costs, the couple effect of geo-composite reinforced fine-grained soils needs elaborate investigation and numerical analysis. Besides, more specific experimental techniques are required to obtain the interaction parameters between soils and geocomposite.

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