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Advantageous features of the geo-composite learned from small-scaled model tests

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ABSTRACT: This paper presents some of the advantageous features learned from the laboratory model tests on geo-composite reinforced soils. The model tests were done in three categories: a) plate load bearing capacity tests for level ground of soft Ariake clay, b) stability tests on saturated embankment and level ground of Kanto loam, and c) stability of wrap-around geosynthetic revetment wall subjected to water waves. The test results reveal that the geo-composite is effective for increasing the stability of foundation and embankment due to high interface frictional force. Stiffness as well as bearing capacity of soft ground increases significantly when thin sand mat interlaced with geo-composite was used. In addition to this, sand mat maintained efficient drainage potentials, which prevented clogging due to intrusion of finer particles into the geo-composite.

1 INTRODUCTION

One of the shortcomings of nonwoven geosynthetics when applied to the reinforcement of soft unstable soils is its low tensile strength, weak interface friction bond and inefficient drainage potential. A geo-composite (Fig. 1), which consists of high strength woven fabric heat bonded between nonwoven fabrics, owns the higher tensile strength and stiffness than the nonwoven geosynthetic alone, and thus is enable to improve unstable soils. This type of geo-composite is highly permeable in both in-plane and cross-plane directions. The present paper describes the results obtained from model tests at laboratory for possible applications of this geo-composite for improving the bearing capacity of reclaimed soft clay, for increasing stability of marginal soil embankment and lastly for increasing stability of revetment wall at the waterfront under wave actions. The results prove that characteristics of the geo-composite are exerted enough to increase not only reinforcement but also the potential of filtration and drainage in soft soils.

2 PROPERTIES OF GEO-COMPOSITES

The geo-composite used in the present study has a structure with woven fabric sandwiched by nonwoven fabrics at both sides and it owns the advantageous properties for reinforcement of soft soils. For example, tensile strength and stiffness of the geo-composite are higher than a geogrid (Fig. 2). Tension tests on four different geosynthetics , e.g. woven, nonwoven, geogrid and geo-composite (also termed as composite fabric, Fig.2), envisage the wide differences in strength and stiffness. With higher tensile strength and stiffness, the geo-composite provides higher frictional force obtained from the simple friction testing devise (Hirao et al., 1992), in comparison to those of other geosynthetics. Besides, the high pullout resistance is also exhibited to both sand and clay (Nagashima et al, 2001;Yasuhara et al., 2001). This corresponds well to the characteristic feature of frictional force between soil and geosynthetics (Yasuhara et al., 1994).

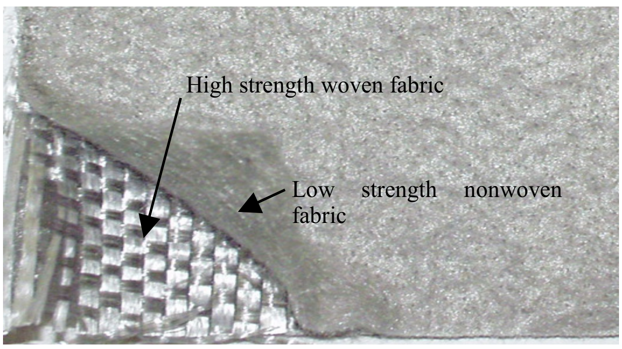


Figure 1. Geo-composite sample

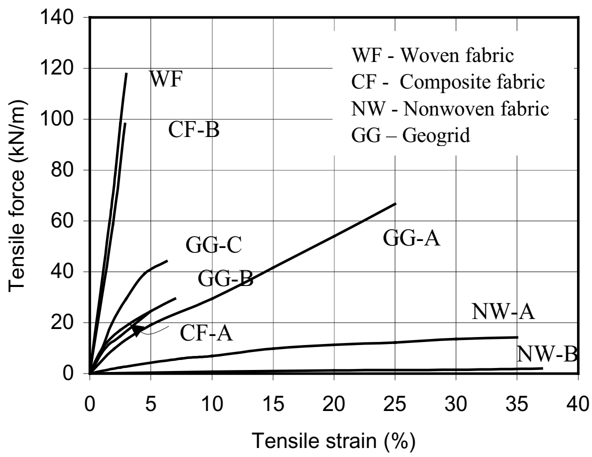


Figure 2. In-air tension tests on various geo-fabrics

3 GEO-COMPOSITES FOR IMPROVING BEARING CAPACITY OF RECLAIMED SOFT CLAY

In order to make sure of the advantage of geo-composites for reinforcement of unstable soils, a series of small-scaled model footing tests (box size-2m length, 0.5m wide and 1m depth) under the gravitational condition were carried out at the laboratory. Four kinds of geosynthetics (woven, nonwoven, geogrids-three types and geo-composites-two types) were used (Hirao et al., 1992; 1996). Reinforcement of soft soils requires both tensile strength of the material and frictional force at the interface. Judging from the results in which the frictional force against soft clay (γ_s = 16.2kN/m^3, w_n= 130%, w_L = 107%, I_p = 66) with τ_v = 0.491 kPa, obtained from vane shear tests is plotted to tensile force, it is indicated that geo-composites are moderately provided by two properties required for reinforcement of soft clay. This means that geo-composites are the most suitable for reinforcing soft soils as reclaimed land.

Fig. 3 shows a typical result of model footing tests, which compares the results of load vs. settlement curves from plate loading tests. Those tests were carried out to investigate what kind of geosynthetics among woven, nonwoven, geogrid and geo-composite is the most effective for reinforcement of soft clay when each one is placed on the surface of soft clay. It can be seen from Fig. 3 that bearing capacity indicated by inflection point in load vs. settlement curves (q vs. S curves) for the geo-composite fabric is largest among the cases with three geosynthetics and without any geosynthetics in the experiments.

Successive to this series of model tests, in order to increase the stability of soft soils more markedly, an attempt was made to combine the geo-composite with thin sand mat. The results in Fig. 4 indicate how this combination of geosynthetics with sand gives birth to increase in bearing capacity. This effect of increase in bearing capacity obtained by combining the sand mat with the geo-composite is caused by the fact that geo-composite becomes familiar not only with soft clay but also with sand. This is a kind of so called "structural sandwich effect" which was first coined by Yamanouchi (1967). On the other hand, when only the sand mat without any geosynthetics being combined is placed over the surface of soft clay, no reinforcement effect is observed in Fig. 4.

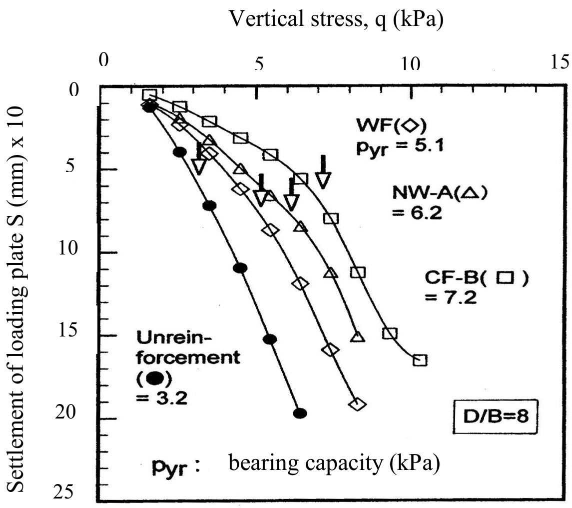


Figure 3. Plate load tests on Ariake clay reinforced with various geofabrics

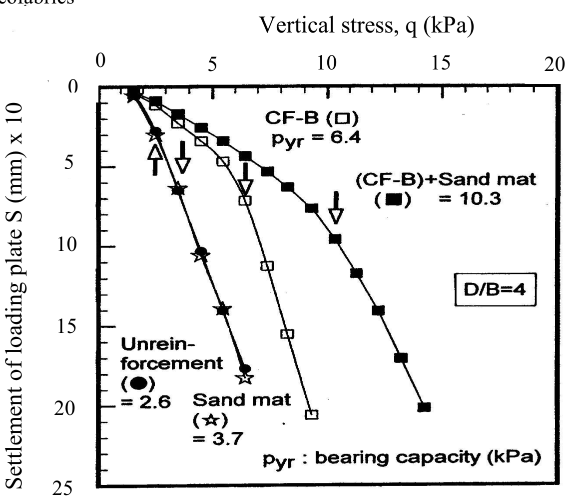


Figure 4. Plate load tests on Ariake clay with sand mat and geo-composite

4 GEO-COMPOSITE FOR THE IMPROVEMENT OF MARGINAL SOIL

Model tests on the Kanto loam embankment reinforced with three equally spaced planar geosynthetics (Nonwoven Geosynthetic-NW and Geo-composite-CF) layers are illustrated in Fig. 5. Kanto loam used for all the model tests is a volcanic-origin silty soil with γ_s= 16.6 kN/m^3, liquid limit (LL)=94% and I_p= 29. In test series for Case a (Fig. 5a), embankment was prepared by compacting the soil at 70% as optimum moisture content. A spacer block of required size was used while making the model embankment. On the other hand, embankment and level ground for Case b (Fig. 5b) 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. The size of model embankment (0.458 m base, 0.231 m top width, 0.378 m high, 0.10 m thick and 1V : 0.6H slope) were tested in acrylic box. Thin transparent rubber sheet with colored grid lines has been pasted with silicon grease at one face of the box for observing deformation of the soil during loading.

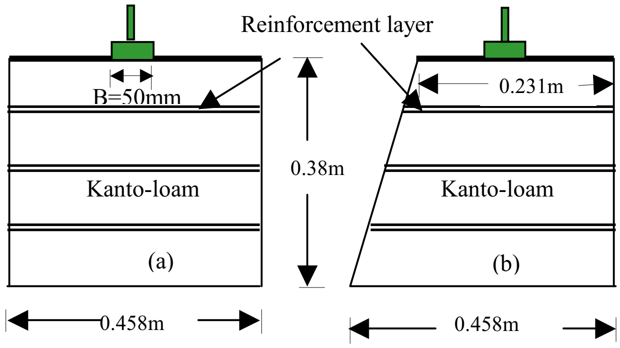


Figure 5. Details of model tests (a) Level ground, (b) Embankment

4.1 *Preloading of Kanto loam*

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. 6, most of pre-compression occurred within a day. Since the spacer block was present, less settlement

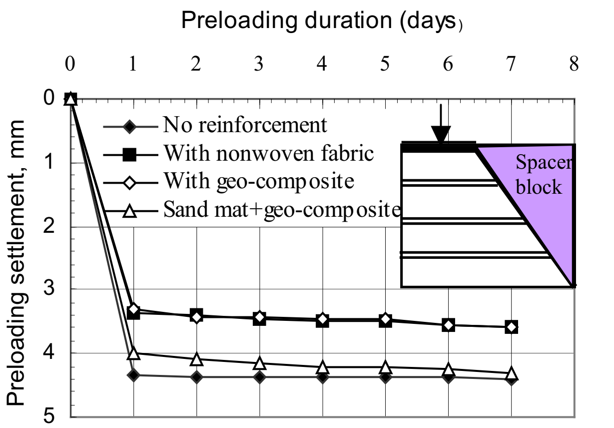


Figure 6. Pre-loading of model embankment with spacer block

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 block was removed and the top face of the embankment was loaded with a 50 mm strip footing under the constant rate of displacement. The top layer of reinforcement was placed at 74.5 mm 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. 6.

4.2 *Load-displacement relations*

Load tests on the model embankment were done with 50 mm wide footing. Position of the footing for Test series-A was near the tip and for the Series-B the footing it was placed at the center of top face. The sloped face of the embankment was made at 1V:0.6H, which is usually steep and it was kept unwrapped by reinforcement layers for all cases. Test results are presented in nondimensional units as shown in Fig. 6. There is significant increase in bearing capacity as well as stiffness of the reinforced embankment. With thin sand mat the improvement shoots up further. Since the Kanto-loam was compacted at OMC=70%, permeability and transmissivity characteristics could not be measured from these experiments. It will be shown in the later section.

In order to check the effectiveness of geo-composite, some tests have been performed with another nonwoven type (NW) geosynthetics. Tests results are shown in Fig. 7. It is envisaged that geo-composite is relatively more effective than nonwoven

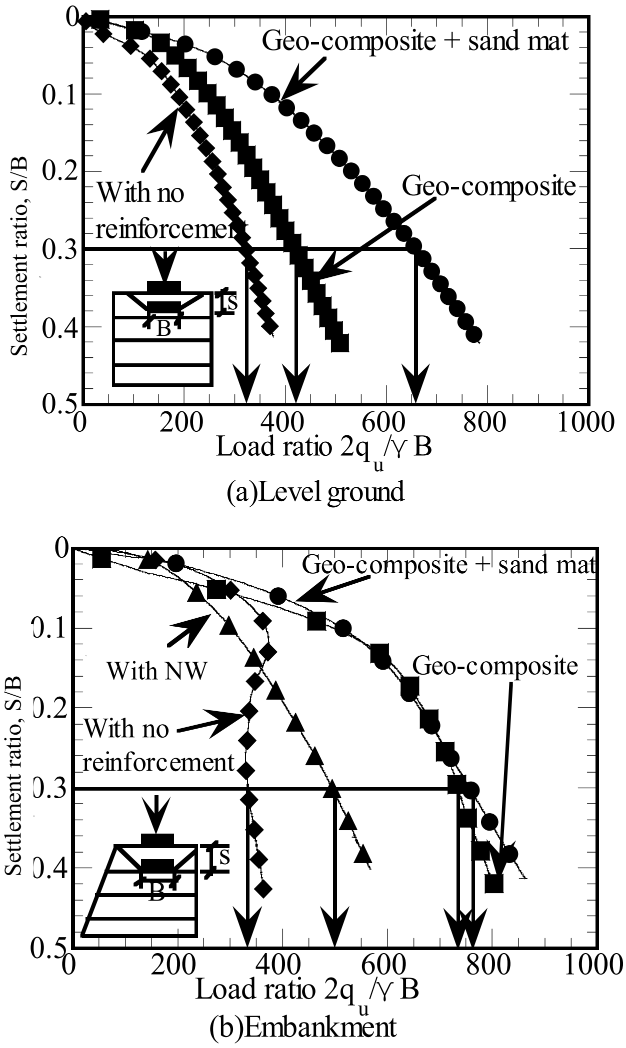


Figure 7. Normalised load vs. footing settlement response

geotextile. Even from these tests, no explanation is given on how geo-composite contributes to the effective drainage and preventing from clogging phenomena.

Kanto-loam was made into slurry form after mixing twice of it's LL (=94%) and this slurry was put inside the model box. Drainage valves were kept open for free drainage upto 7 days, then precompression was carried out which is already explained in Fig.2. Load tests results after precompression are shown in Fig.7. In the case of level ground, the reinforced clay sample is always at or near to saturated state and hence the role of sand mat and geo-composite is clearly distinguished. Compared to geo-composite alone, geo-composite-sand mat combination envisaged significant improvement in the bearing capacity (Fig. 7b). In the case of embankment, it was not feasible to keep it saturated all the while, as the sloped face was unprotected. In this case clear distinction between geo-composite and sand mat combination could not be obtained. The reason might be that the bond between sand and clay was not perfect. Moreover, the top surface of the embankment developed cracks at large footing settlement and it moved horizontally outward along the sand-clay interface.

4.3 *Permeability and transmissivity test*

Initially after each model test is terminated, then a piece with 100 mm wide and 250 mm length, was cut out from the geo-composite which was placed among modeled embankment and then was used for a relatively simplified testing equipment for investigating the changes in permeability and transmissibility of the material. The testing apparatus is shown in Fig. 8.

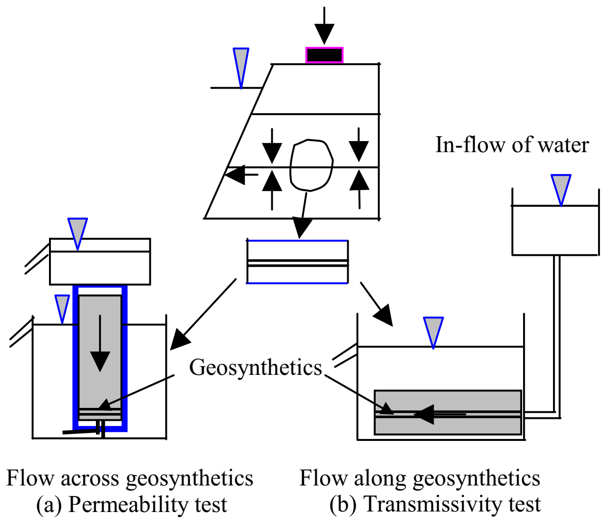


Figure 8. Schematics of permeability and transmissivity test

Usually geo-composite is endowed not only by reinforcement but also by drainage effects designated by permeability and transmissibility. Permeability and transmissibility are indices for drainage potentials through vertical and horizontal directions against the geo-composite, respectively. Potentials in those permeability and transmissibility of geo-composite are required to be retained during the life of embankment or ground. However, since geo-composite is normally sandwiched 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 particles into textures of geo-composite.

The difference of the above-stated clogging with and without sand mats is revealed in Fig. 9. This shows that a part of geo-composite gets stained after model tests are finished. When sand mat is used clogging has been reduced to a grater extent. In these tests separate measurements of drainage and pore pressures have not been done. However, simple permeability and transmitivity tests on the exhumed geo-composite samples brought out the effectiveness of sand mat in preventing clogging.

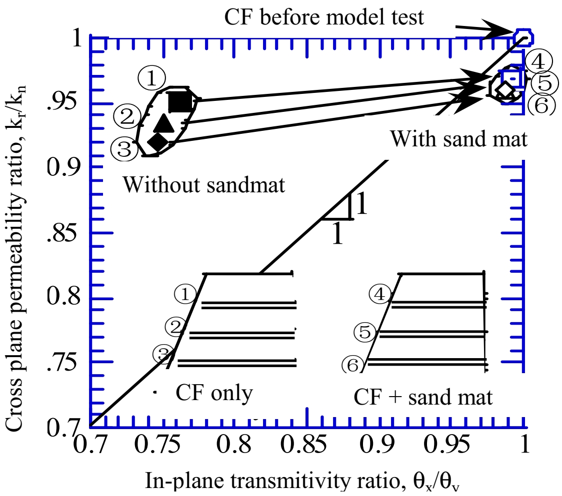


Figure 9. Normalised permeability vs. transmissibility plot

5 WRAP-AROUND GEOSYNTHETIC REVETMENT FOR COASTAL PROTECTION

Geosynthetic reinforced revetments have been applied successfully in developing countries. The advantages of using geocomposite in this application were investigated by means of a series of model tests. The purpose of these model tests is to compare the behaviour between embankments reinforced with a geocomposite and reinforced with nonwoven geotextile.

5.1 *Tests and apparatus conditions*

To simulate the revetment conditions model tests were conducted in a “wave-maker tank” (5m length, 0.40m wide and 0.60m height). Inside the tank, a wrap-around geosynthetic reinforced embankment (base 450 mm, height 480 mm, each layer with 120 mm height, width 400 mm, wrap around length of 120 mm and face angle of 60 degrees with the horizontal) was built and subjected to twot kinds of traveling waves.

Figure 10 and Figure 11 show the dimensions of the “wave-maker tank” and general layout of the revetment wall respectively. Two kinds of geosynthetics were used in order to compare the behavior of the reinforcement: a geo-composite (nonwoven geotextile combined with a woven geotextile in between) and a nonwoven geotextile. Table 2 shows the apparent friction angle and cohesion between Toyoura sand and the geosynthetics used in the model tests.

Measures of the embankment taken during the model tests were vertical displacement by means of a vertical extensometer and lateral deformation with the aid of transparent films. To measure the wave height and wave period a “wave-maker device” was used in all the model tests. This “wave-maker device” consists in a movable wave gauge that automatically records wave data at different points of the tank.

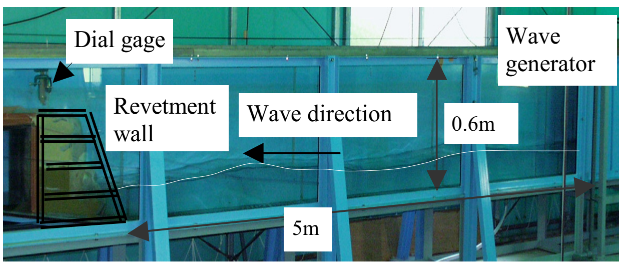


Figure 10. Layout of the wave-maker tank and embankment

Table 1. Properties of fill materials

Toyoura sand	values
Specific gravity	2.64
Average grain size, D_{50}	0.175 mm
Effective grain size D_{10}	0.129 mm
Uniformity coefficient, U_c	1.52
Max. void ratio, e_{max}	0.977
Min. void ratio, e_{min}	0.605
Angle of shearing resistance	40°
Cohesion intercept	0

Table 2. Interface friction properties of sand and geosynthetics

Friction state	Interface angle, deg	Cohesion, kN/m^2
Nonwoven and Toyoura sand	31.49	5.5
Geo-composite and Toyoura sand	34.08	9.4

Two kinds of standard traveling waves were used in the model tests, waves with 180 mm and 230 mm wave height. Wave period could not remained the same in all the model tests due to the limitation of the equipment, therefore, comparison was made only with embankments having the same wave conditions. Toyoura sand was used as the revetment fill material and its properties are shown in Table 1.

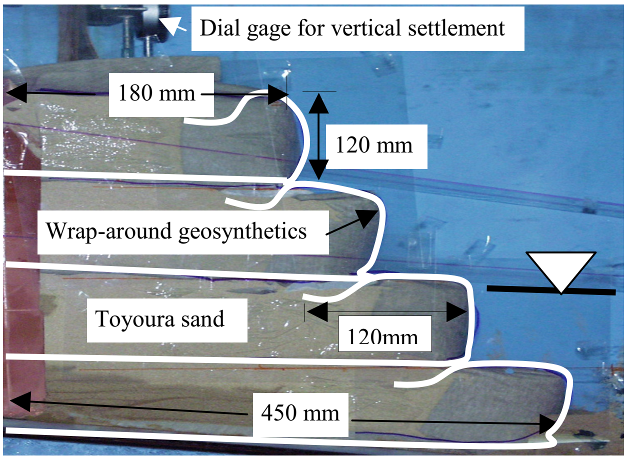


Figure 11. Dimensions of wrap-around geosynthetic revetment wall

5.2 *Layout of the Model Tests*

Figure 12 shows the layout of the model tests presented in this paper. The dimensions of the embankment remained the same during all the tests. The main objectives were to observe and compare the behavior of embankments made with loose and dense sands; compare embankments reinforced with a geocomposite and nonwoven geotextile and subjected to standard waves under two different of wave height.

One typical case of wave actions has been demonstrated in Figure 12. At the beginning the channel is filled with water at the level of 200mm and the revetment is protected by a thin plate till wave generator activates the water wave to desired height and frequency (in this case 230 mm at wave frequency of 0.96 sec). Then the waves are allowed to strike the wall till failure occurs. Vertical deformation of the wall is noted from the dial gage and complete deformations are noted from the side wall at different stages of wall behavior under continuous wave actions. In every experiment it is noted that wall experiences cavitations at the interface of 2nd and 3rd layer that leads to progressive failure.

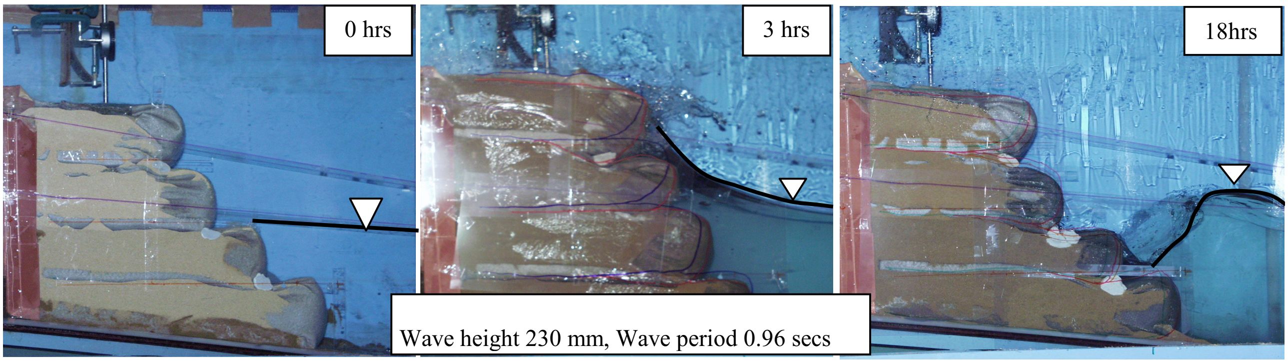


Figure 12. Various stages of wave actions and deformation of wrap-around geo-composite revetment wall

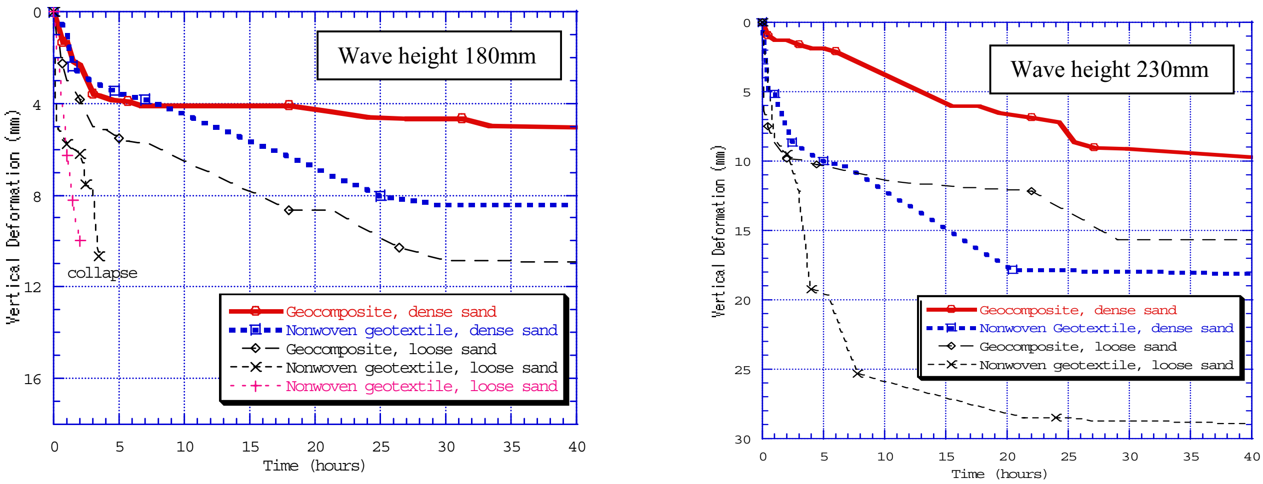


Figure 13. Comparison of vertical deformation measured during wave actions

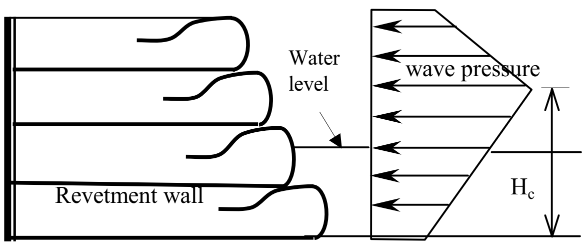
6 EXPERIMENTAL RESULTS

Figure 13 shows the comparison of vertical deformation versus time duration of wave attacks on the wall. Toyoura sand was made to fill at two workable states; loose and dense in combination with two varieties of geosynthetics; geo-composite and nonwoven. Geo-composite embankment suffered less deformation than the nonwoven ones. Dense sand embankments also showed more favorable behavior than loose sand ones. One of the reasons why geo-composite embankments behave better than nonwoven ones might be due to the higher tensile stiffness of the geo-composite (Table 1, Fig. 2).

On the other hand, loose sand with nonwoven geotextile reinforced embankments experienced larger deformations and when these embankments were subjected to waves with a wave height of 180mm, they collapsed within short period. It can be stated that the area where the biggest wave pressure struck also played important role in the deformation of the embankment.

The deeper layers of the embankment show the larger earth pressures and since all the embankments were restricted in the back wall of the apparatus; the critical situation occurred when the wave trough (pulling force) was attacking against the embankment. This explains why a smaller height of wave (180mm) attacking a lower layer caused more damage than a bigger wave (230 mm) attacking an upper layer. Compared to the model size and physical dimension of the set-up geo-composite appears to be dimensionally incompatible. Some more experiments have been done to study the effect of stitching of the reinforcement layers and cementing of sand at wrapping zone. The test results are encouraging while in a small scale, however, feasibility of these tests results for proper field applications are still under serious investigation.

Figure 14 shows the wave pressure of a wave with a wave height of 230 mm attacking the embankment. The main deformation of the embankments occurred where the biggest wave pressure acts (Dean & Dalrymple, 1998). Figure 15 shows that the deformation patterns of all the embankments were similar.



H_c : distance from bottom to max pressure

Figure 14. Maximum wave pressure on the embankment

The deformation of the embankment mainly occurred in the second layer from the top. Since the embankment behaves like a flexible structure, the second layer deforms independently of the other areas of the embankment. All the embankments that were

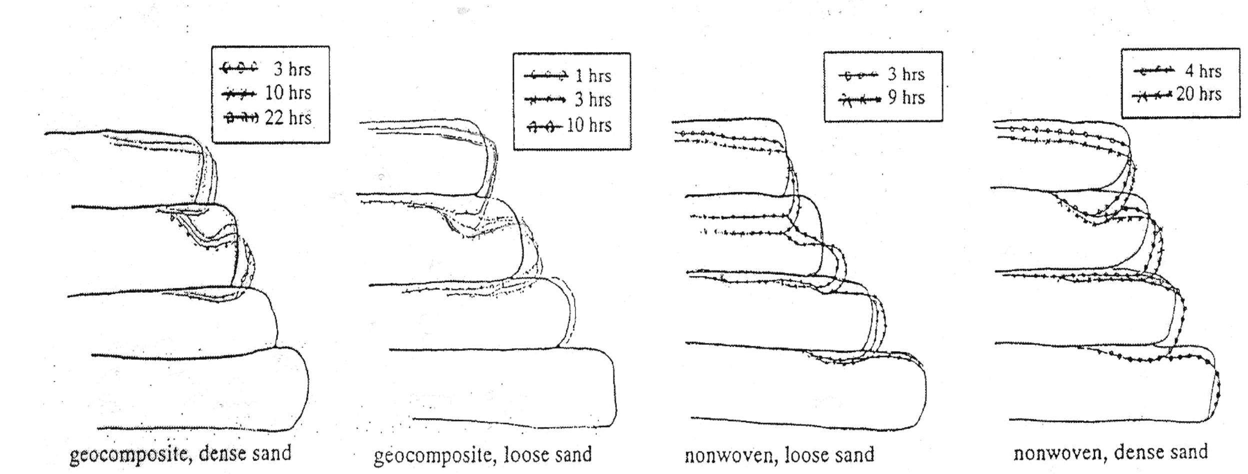


Figure 15. Comparison of deformation between cases with wave height of 230 mm

attacked by a wave with 230 mm height became stable after a reasonable time. This can be explained by stating that when the

inner sand re-accommodates completely, deformation stops and reaches a stable condition. Since the embankment is a flexible structure, dissipation of energy takes place at the frontal part of the embankment

Embankments with loose sand, reinforced with a nonwoven geotextile and subject to the attack of waves with a wave-height of 180 mm collapsed. The reason why geo-composite embankments were stable under the same wave conditions might be due to the fact that the interface friction angle of geo-composite against sand is higher than the same between sand and nonwoven geotextile. Further investigations have to be made to simulate progressive failure observed in the present model tests with the field conditions.

7 CONCLUSIONS

From the three test series following have been obtained respectively:

1) Reinforced soft clay: Geo-composite with sand mat showed as effective combination to improve bearing capacity of Ariake clay. Composite fabric caused maximum increase in bearing capacity due to its high interface friction with sand.
2) Saturated Kanto loam embankment and level ground: Geo-composite functioned well as effective drainage media in both directions and it's reinforcing effect enhanced with the use of thin sand mat. Clogging potential has been reduced with the use of thin sand mat.
3) Revetment wall: Geo-composite wrap-around wall behaved better than the same prepared with nonwoven geotextile. Dense sand performed better than loose ones. After uniform wave attacks, most of the deformation occurred during the first 6 hours. If the structure can support this first stage of deformation, then it stabilizes completely. The wave energy in the frontal part is dissipated, and no further deformation occurred.

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