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Hybrid-sandwiched foundations reinforced with geosynthetics

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ABSTRACT: As one of promising field techniques for earth reinforcement, the hybrid sandwich earth structures reinforced with geosynthetics have been developed. The reinforcement in this technique is attained by enhancement of interaction between geosynthetics and thin sand layers which are placed above and beneath geosynthetics. This technique is usually adopted for reinforcing and improving soft or marginal soils which are not usually suitable for banking, backfill and foundation geomaterials. Among the advantageous aspects of sandwich-type reinforced earth structures combined with geocomposites and sand mat, toughness improvement as well as hydraulic conductivity improvement is highlighted in this paper.

1 INTRODUCTION

As one of promising field techniques for earth reinforcement, the hybrid sandwich earth structures reinforced with geosynthetics have been developed by the authors (1992; 2004). The reinforcement in this technique is attained by enhancement of interaction between geosynthetics and thin sand layer which is placed above and beneath geosynthetics. This technique is usually adopted for reinforcing and improving soft or marginal soils which are not usually suitable for banking geomaterials for motorways and railways. Advantageous aspects of sandwich-type reinforced earth structures combined with geocomposites and sand mat are highlighted in this paper. Those aspects were elucidated by two kinds of laboratory tests: (1) model footing tests on improvement of bearing capacity and deformation for reinforced earth structures; and (2) large consolidation tests for improvement of hydraulic conductivity, including both vertical permeability and horizontal transmissibility characteristics of geosynthetics.

2 SANDWICHED EARTH STRUCTURES

Foundations and embankment with placement of sand among soft soils, as shown in Fig. 1, have some advantages such as accelerating drainage and increasing stability. This type of placement is called “sandwich structure”. When this typical sandwich structure is combined with geosynthetics and chemical agents such as cement or quicklime, the sandwich effect in improving soft soils must be more marked. This can be called “hybrid reinforcement” in the present paper. The multiple-sandwich reinforcement using geosynthetics and quicklime pertains to this reinforcement. In reviewing this method that was proposed by Yamanouchi and Miura from the late of 1960’s through 1980’s (1982), it can be said that they had keen insight into reinforcement of earth structures made of soft clay by using geosynthetics.

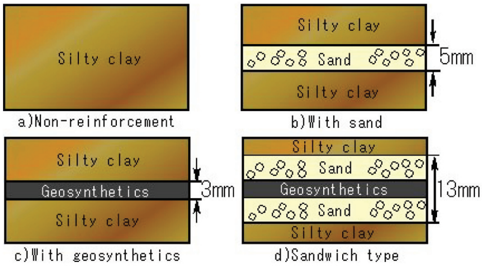

Figure 1. Key sketch for sandwich earth structures.

3 HYBRID DRAIN SYSTEM

Thick geosynthetics (GS) can be used as permeable layers for draining water expelled from the soil by the consolidation process. There are certainly economic as well as design limitations in manufacturing thicker GS. However, a combination of thin granular blanket covering the permeable GS might be a suitable alternative (Yasuhara et al. 2001a, 2001b). A series of steep-faced model embankment tests have been conducted on a thin sand mat combined with a high strength geocomposite (Yasuhara et al. 2001a, 2001b; Yasuhara 2002; Ghosh and Yasuhara, 2004). Their study highlights the importance of providing a thin sand mat to enhance stability by activating the reinforcement functions of the sandwich GS system. From the above studies, it is pointed out that the importance of the coupled functions of the sandwich system has been recognized, but no systematic experimentation for the quantification of drainage due to consolidation of the fine-grained soils has been done.

4 OUTLINES OF EXPERIMENTAL WORKS

Two kinds of model tests were carried out to ensure the availability of sandwiched earth structure in which the thin sand layer is placed both above and below the geosynthetics for attaining construction of more stable embankment and foundations than earth structures and foundations reinforced with geosynthetics only and without any reinforcement.

4.1 *Model footing tests*

Model footing tests for investigation of improvement for bearing capacity and stiffness of silty clay were carried out by using the soil tank with 50 cm height, 90 cm width and 19.4 cm length as shown in Fig. 2 in which displacement-controlled static loads can be applied to the loading platen with 10 cm width by connecting the loading motor and the gear shaft with the electro-magnetic clutch. The rate of displacement is 0.24 mm/min in every test.

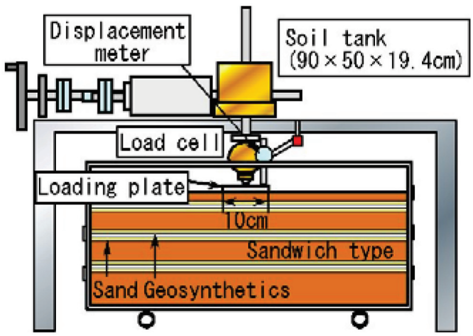

Figure 2. Model testing apparatus.

Two kinds of soils were used in experiments. To produce the level model ground for mode footing tests, Silty clay and Toyoura sand were used for forming foundation ground and for processing filtration and drainage as sand mat. The sand layers with 0.5 cm for the case without sand mat and 1.3 cm for the case with sand mat were placed above and beneath geosynthetics. Silty clay was mixed under the initial water content with three times as liquid limit (38% approximately) until achieving homogeneous slurry conditions and then was poured in the soil tank. Thereafter, slurry silty clay was preconsoli-dated stepwise by 20 kPa and 50 kPa, respectively, for 12 hr in both loading steps. This procedure was repeated until attaining model ground initially with 35 cm height. Index properties used are summarized in Table 1.

Table 1. Index properties of soils used.

Toyoura sand		Silty clay	
Soil particle density ρ_s	2.59 (g/cm^3)	Soil particle density ρ_s	2.58 (g/cm^3)
Maxmum void ratio e_{max}	0.977	Liquid limit w_L	37.7 (%)
Minimum void ratio e_{min}	0.605	Plastic limit W_P	16.4 (%)
Finer content	0 (%)	Plasticity index I_P	21.3

We adopted three types of geosynthetics, nonwoven geofabric (abbreviated by NW), geocomposite (GC) and geonet (GN) whose typical stress-strain curves in axial tension tests were shown in Fig. 3, indicating that GC owns highest tensile strength and stiffness in comparison with other two geosynthetics. Geosynthetics with the width and length was placed at locations in depth with D/B (D : depth of geosynthetic placement, B : breadth) equal to 0.2, 1.2 and 2.2. The reason of the top placement is based on the fact, which was obtained in the previous study by Ghosh (2002), that optimum depth suitable for reinforcement of model ground was around 0.2 through 0.5 of D/B. Placement of NW and GC at the lower locations with 1.2 and 2.2 of D/B plays a role in accelerating drainage of silty clay ground, while GN was not effective for it.

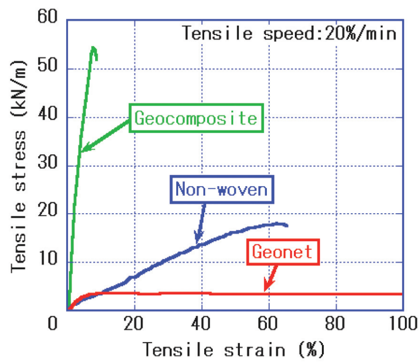

Figure 3. Stress vs. strain relations of geosynthetics in tensile tests.

4.2 *Tests for hydraulic conductivity*

We performed two kinds of hydraulic conductivity tests on permeable geosyntheics specimens (NW and GC) which were taken out and cut out to suit each size for hydraulic conductivity tests: rectangular shape with 120 mm length and 50 mm width for vertical permeability tests and circular shape with 50 mm diameter for in-plane transmissibity tests. The testing equipment which was designed and manufactured by Ghosh and Yasuhara (2004) is illustrated in Fig. 4 and testing condition using this apparatus is listed in Table 2. In this apparatus, the water head difference of 60 mm for vertical permeability tests and 120 cm for in-plane transmissibity tests, respectively, is produced by providing the air pressure into the distilled water container. Each test was conducted by the following procedure:

(i) In vertical permeability tests, circular five layers of GS specimen were set inside the apparatus with the filter layers at the top and bottom consisting of the iron mesh and glass beads, as shown in Fig. 4(a). Every test was conducted under a certain confining pressure shown in Table 2.
(ii) In in-plane transmittibity tests, one layer GS was contained by membrane with the flow direction open and then was placed within the apparatus.
(iii) The thickness of GS at each test was measured by the displacement meter attached at the top plate.
(iv) GS specimens used in every test were cut off for suitable sizes from GS samples after bearing capacity tests.

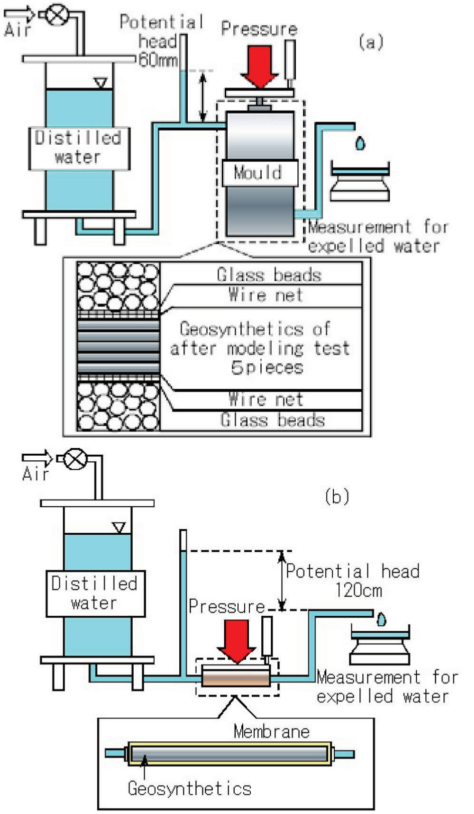

Figure 4. Hydraulic conductivity tests.

Table 2. Hydraulic conductivity testing scheme.

	Flow characteristics test	
	X-plane	In-plane
Used geosynthetics	Geocomposite, Non-woven	
Size	φ 50 mm	120 mm × 50 mm
Thickness	2.6 mm	3.5 mm
Potential head	60 mm	120 mm
Air pressure (kN/m^2)	4.7, 9.5, 19, 37, 75, 150, 300	14, 28, 56.5, 113, 226, 450, 900

5 IMPROVEMENT OF TOUGHNESS

In the previous studies (Yasuhara, et al., 2001a, b; Yasuhara, 2002; Yasuhara, et al., 2002a, b; Ghosh and Yasuhara, 2004) which have been carried out by the first author and his coworkers at Ibaraki University, Japan, the sandwiched-earth structures and foundations reinforced with geosynthetics together with sand blankets above and beneath geosynthetics improve the hydraulic conductivity as well as the bearing capacity and stiffness of soft and weak cohesive soils. This technique suggests the possibility that earth structures using marginal soils can be used for construction by means of the sandwiched structure. The authors have been exploring the additional possibility of this type of earth structures.

Since the 1995 Great Hanshin earthquake, toughness of earth structures as well as building structures has been required for maintaining the relations with and without geosynthetics and sand during life of infrastructures. Here, the toughness implies that the earth structures can resist against shear stress even when undergoing the large deformation. Although there have been several definitions of toughness in fracture mechanics or material mechanics, we use in the present paper the potential energy until the material and the structure reach failure and which is equivalent to the area in stress vs. strain or load vs. displacement curves until failure. The typical examples obtained from model tests using the apparatus as shown in Fig. 2 are shown in Fig. 5(a) with GS only and Fig. 5(b) with GS and sand layers.

This area can be rephrased to the energy absorption potential. However, since geo-materials do not always

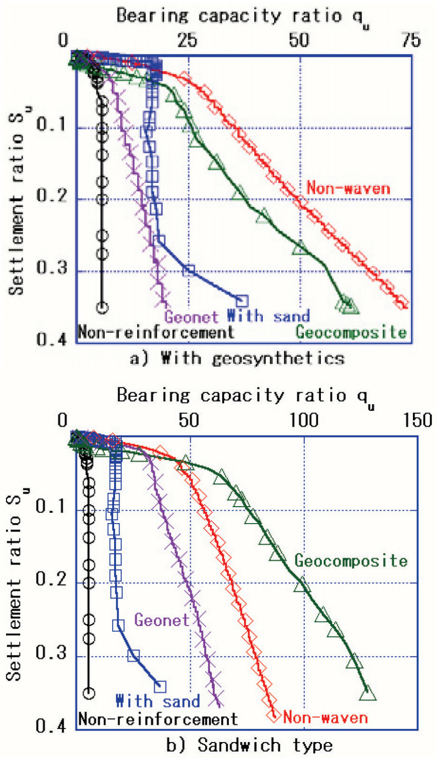

Figure 5. Vertical load ratio vs. settlement ratio relations (S_u = S/B).

exhibit the clear peak shear stress differently from metals, then we have to adopt as an equivalent failure a specific displacement such as the settlement ratio, S/B (S: settlement, B: width of loading plate) corresponding to 0.3, as schematically shown in Fig. 6, for the model tests carried out in this study.

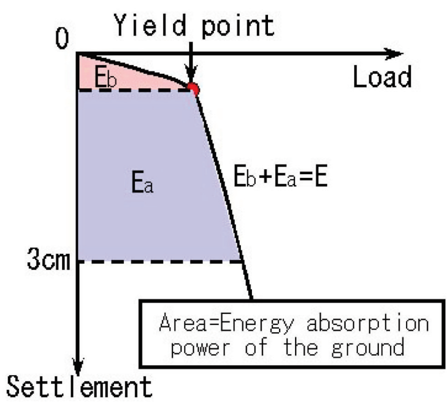

Figure 6. Key sketch for load vs. settlement relations.

This specific value of 0.3 for S/B is based on the testing standard for plate loading tests regulated by JIS (JGS 1521-1995). Following the definition as shown in Fig. 6, the toughness value, E, in this study is estimated by:

$$E = E_b + E_a \tag{1}$$

where E_b : area from the origin to yielding point and E_a : area from yielding point until equivalent failure. Each toughness value, E_b, E_a and E is obtained from the load vs. settlement curves as was previously shown in Fig. 5. These toughness indices, E_b and E_a are given by respectively:

$$E_b = \int_0^{S_y} p dS = \int_0^{S_f} f(S) dS \tag{2a}$$

$$E_a = \int_{S_y}^{S_f} p dS = \int_{S_y}^{S_f} f(S) dS \tag{2b}$$

where S_y and S_f are settlements corresponding to the yielding and equivalent failure, respectively. Since the width of the loading plate in all the tests is 10 cm, then the settlement corresponding to the equivalent failure is 3 cm. The toughness value obtained from Fig. 5 and calculated by Eq. (1) is plotted against the normalized bearing capacity improvement ratio, q^*, and the stiffness improvement ratio, K^*, respectively, in Fig. 7 and Fig. 8. It is indicated from both figures that the toughness increases with increasing the bearing capacity and stiffness ratios and in particular an increase of toughness in the case of the hybrid sandwiched foundation (HBS) is more eminent than that without HBS. In other words, the HBS reinforcement system improves not only the bearing capacity and the stiffness but also the toughness of foundations on soft soils. In addition, it can be said that the use of GC is more beneficial for improving the toughness of foundations.

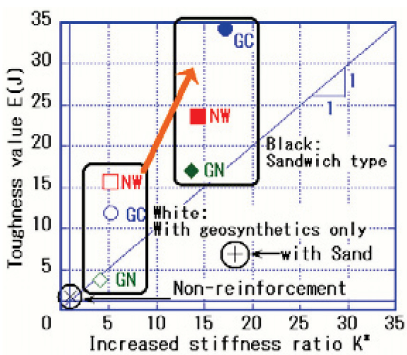

Figure 7. Toughness value plotted against bearing capacity ratio (E(J) : E_b + E_a, q^* : q_{ur}/q_{un}).

Let us here define the toughness ratio E_a^* given by E_{br}/E_{bn} (E_{br}, E_{bn}: toughness value with and without

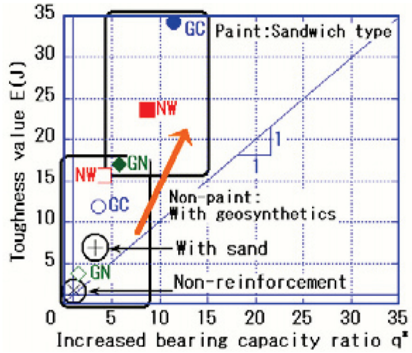

Figure 8. Toughness value plotted against stiffness ratio.

reinforcement by geosynthetics and granular material before the yielding point) and E_a^* given by E_{ar}/E_{an} (E_{ar}, E_{an}: toughness value with and without reinforcement by geosynthetics and granular material after the yielding point until the equivalent failure). Figure 9 illustrates the relation between E_b^* and E_a^* which were read out from Fig. 5. It can be seen from Fig. 7 through Fig. 9 that the HBS structure improves the toughness more markedly than those reinforced by only geosynthetics but without sand placement. It can also be emphasized that the toughness improvement ratio, E_a^*, in the region beyond the yielding point becomes marked as well as, E_b^*, in the region before the yielding is reached. Therefore, it is expected that the HBS reinforced system plays a role in prolonging the life of earth structures and foundations.

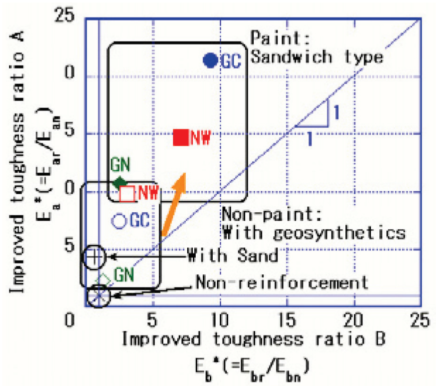

Figure 9. Two toughness ratios interrelationship.

6 CHANGE IN HYGRAULIC CONDUCTIVITY

Under confined state it is not possible to check cross-plane flow capacity of the drain specimen. Therefore, the exhumed specimen was tested in a separate apparatus developed for this purpose. In order to achieve a reliable accuracy in the measurements, five numbers of 50 mm diameter drain specimen were used. As thickness of the specimen reduces with applied pressure, flow capacity across the drain specimen was measured under the constant hydraulic heads of 60 mm, 120 mm and 180 mm, respectively. Figures 10(a) and (b) plots the transmissivity and permittivity vs. applied normal pressure, respectively, at hydraulic head of 60 mm. While clogged specimens showed significant reduction in the flow capacity, there was marked improvement in the flow capacity after hybrid sandwiched structures. In Fig. 10, the pressure dependency of flow capacity of exhumed drain specimens are described. With increasing pressure on the drain specimen there is marked reduction in the permittivity. The relative rate of flow capacity reduction in both directions is more or less found the same in silty clay. Evidently clogging has reduced cross-plane flow capacity. A comparison of the permittivity and transmissivity into ratio as presented in Fig. 11, envisage the beneficial effect of sandwiched earth structures.

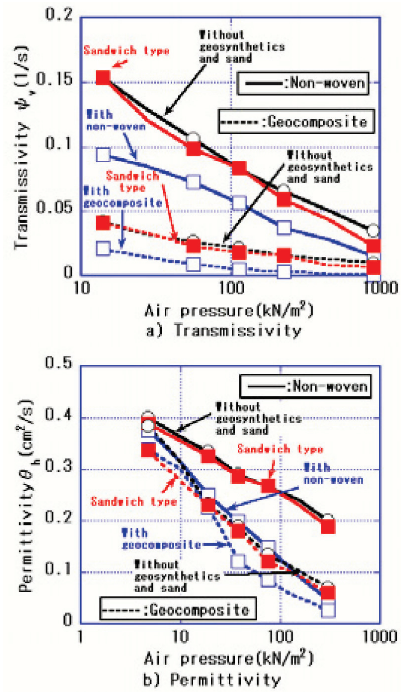

Figure 10. Variations of hydraulic conductivity.

This beneficial effect of sandwiched earth structures on toughness improvement must be correlated to the hydraulic conductivity because toughness improvement in terms of the permeable geosynthetics must be caused by both drainage and reinforcement effects. Thus, in order to make sure of this conjecture, an attempt was made to plot the toughness increase

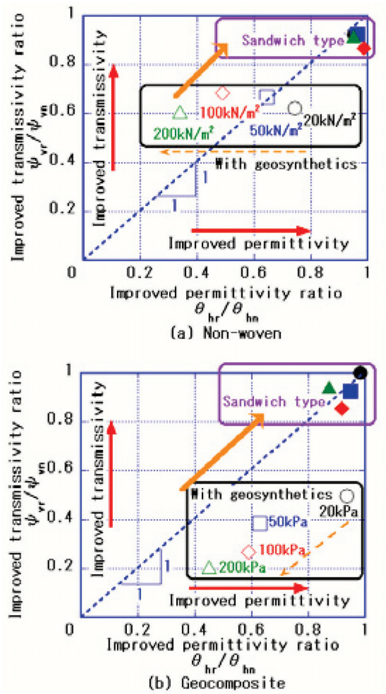

Figure 11. Hydraulic conductivity interrelationship for non-woven and composite geosynthetics.

against permeability improvement in Fig. 12. It is indicated from Fig. 12 that: (1) There is a good correspondence between permittivity and toughness improvements. Toughness of silty clay reinforced with geosynthetics is more marked depending on the improvement of hydraulic conductivity although Fig. 11 does not include the improvement of transmissivity. (2) In particular, toughness after yielding of ground becomes larger for the case with sandwiched reinforcement than the one without it. In other words, sandwiched reinforcement makes cohesive soils' foundation tenacious to applied loads.

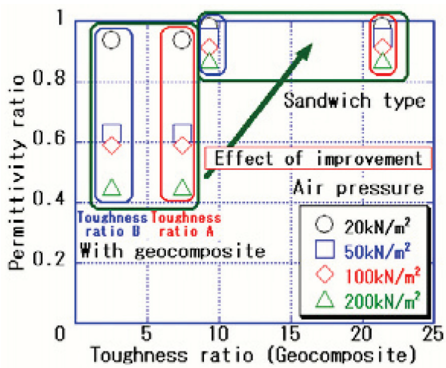

Figure 12. Relation between toughness ratio and hydraulic conductivity.

7 CONCLUSIONS

It is indicated from the results from both laboratory tests on sandwich-type earth reinforcement with geosynthetics and their interpretation that:
(1) Sandwich-type reinforcement combined with geosynthetics and sand mats increases stability and decreases deformation of earth structures. In particular, the sandwich structure is effective for providing toughness, which has remained an important issue for achieving infrastructure maintenance.
(2) Hydraulic conductivity of geosynthetics used for this type of earth reinforcement can be maintained for a long period of time. Such conductivity sometimes disappears, particularly because of clogging when geosynthetics are adopted in embankment construction using finegrained soils. This fact implies that the sand mats which are laid above and beneath geosynthetics play a salient role in preventing clogging of geosynthetics that occurs by intrusion of fines from cohesive soils.
(3) The hydraulic conductivity maintenance contributes not only to improvement of both mechanical properties of bearing capacity and stiffness but also to toughness of foundations consisting of cohesive soils.

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