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Lateral shearing tests on geosynthetic soil bags

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ABSTRACT: A series of full-scale lateral shear tests were carried out on a stacked soil bag system to evaluate its strength and deformation characteristics when used in maintenance and repair works of small earth dams. The infilling materials were crushed concrete aggregate and natural sand. Lateral displacements at the front face of the stacked bags were measured. A stacked soil bag system exhibited significantly low peak shear strength and pre-peak stiffness when sheared laterally. This low performance was due partly to slippage at the interface between vertically adjacent soil bags because of the relatively smooth surface of geotextile material of soil bag and partly to highly anisotropic strength of the stacked soil bag system. The former factor could be eliminated by placing a geogrid layer at the respective interface between vertically adjacent soil bags. The latter factor could be eliminated by placing the soil bags in an inclined position by which the respective soil bag should climb up the bag in its immediately front when laterally sheared.

1 INTRODUCTION

Situated in the world's hazard belt, Japan is often subjected to typhoons, earthquakes, floods, land slides, etc. The major natural disasters that occur periodically in the country are climatic and seismic ones. The devastation caused by these natural hazards is further aggravated when they cause serious damage to important civil engineering structures such as earth dams. Hori (2005) reported that around 210,000 small earth dams exist in Japan, many of which have already been damaged and deteriorated by above mentioned hazards. To avoid loss of human life and property in the future, there is a strong need for very effective and highly cost-effective solutions to this problem. To this end, a research project was started aiming at the development of a new construction technology for not only the repair of damaged sections but also the maintenance of existing dams. The essential requirements for the technology also include a high construction speed and the use of only light construction equipment, because repair works should be as much as fast and may be carried out in highly restricted areas. To meet these requirements and considering the validated high performance and high cost-effectiveness of geosynthetic-soil structures (e.g., Tatsuoka et al. 1997), it was decided to employ geosynthetic reinforcement in the closed form (i.e., soil bags) in this project. Another important feature of the project is the use of crushed concrete aggregate, which has been over-supplied from massive demolition works of steel-reinforced concrete structures in mega-cities, as the backfill material for the soil bags.

Lohani et al. (2004) evaluated the strength and deformation characteristics of a stacked geotextile soil bag system by performing a series of full-scale vertical uni-axial compression tests. On the other hand, stacked soil bag systems may be subjected to lateral shear loading, in which the global direction of compressive load is largely inclined from the vertical direction, in seismic events. The strength and deformation characteristics in that case, which are essential for a reliable seismic design, are not known. It is likely that the strength when sheared laterally is largely different from, perhaps largely smaller than, the one when compressed vertically due to a highly anisotropic structure of stacked soil bags. In view of the above, a series of full-scale lateral shear tests were performed on a stacked soil bag system, and effective measures to increase the strength when sheared laterally were devised.

2 MATERIAL AND TESTING PROCEDURE

Two types of granular materials were used as the infilling material (Fig. 1). The first one was a well-

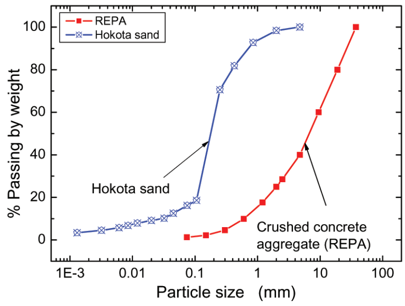

Figure 1. Gradation curves of infilling materials.

graded crushed concrete aggregate (named REPA) obtained by crushing concrete electricity poles. A relatively fine sand (Hokota sand) was also used to evaluate the effects of infilling material type on the strength and deformation characteristics of stacked soil bags. Soil bags made of a woven polypropylene geotextile, which is widely used in agriculture works, were used. The tensile rupture strength of the geotextile from tensile tests at a strain rate of 1.0%/min was 14.5 kN/m (Lohani et al. 2004). The weight of the moist backfill packed in the respective soil bag was 39 kgf. Before stacking, each soil bag was compacted using a vibratory compactor on the base plate of the shear apparatus. The stacked soil bags were first compressed to the prescribed vertical stress, σ_v, before the start of lateral shearing at a constant shear displacement rate of 0.3 mm/min.

Figure 2 shows the lateral shear apparatus used in the present study. Steel meshes were installed at the interfaces between the top and bottom soil bags and the upper and base steel plates of the apparatus to prevent slippage. To evaluate the shear deformation of stacked soil bags and to detect possible slippage between vertically adjacent bags, lateral displacements at the upper moving plate and the front side face of the stacked soil bags were measured with a set of horizontal LVDTs.

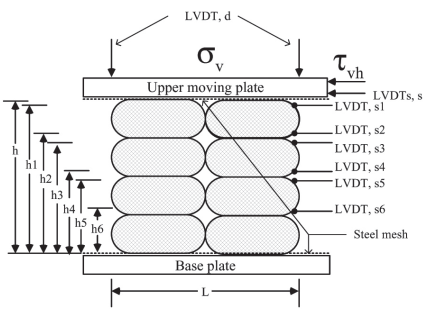

Figure 2. Schematic diagram of the experimental setup.

3 TEST RESULTS AND DISCUSSIONS

3.1 *Strength and stiffness of stacked soil bags*

Figure 3 shows the relationship among the shear stress, τ_{vh}, the shear displacement at the top of specimen, *s*, and the vertical displacement, *d*, obtained from six tests performed at different normal stresses, σ_v on soil bags of Hokota sand and REPA (see Table 1). Figure 4 shows the distributions of lateral displacement at the specimen lateral face along the specimen height at different shear displacements obtained from a typical test on REPA (case 7). From Figs. 3 and 4 and Table 1, it may be seen that the stacked soil bags, filled with either Hokota sand or REPA, exhibited significantly low peak shear strength and pre-peak stiffness with large shear displacements at peak shear stress. This performance is significantly lower when compared with the one when compressed vertically

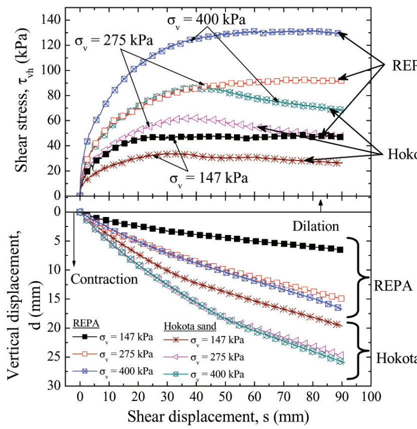

Figure 3. Relationships among shear stress, shear displacement and vertical displacement at different normal stresses for two types of filling material.

Table 1. Test conditions and part of test results.

Test case	Infill material	σ_v(kPa)	Use of geogrid layer	τ_{peak} (kPa)	*s* at τ_{peak} (mm)
1	Hokota	147	No	34.10	30.66
2	Hokota	275	No	66.55	38.28
3	Hokota	400	No	86.40	41.10
4	Hokota	147	Yes	31.75*	20
5	REPA	147	No	52.33*	20
6	REPA	275	No	72.05*	20
7	REPA	400	No	109.6*	20
8	REPA	147	Yes	50.72*	20
9+	REPA	147	No	74.60*	20

*shear stress at a shear displacement of 20 mm
+sheared laterally in an inclined position.

(Lohani et al. 2004). The possible reasons for the above can be summarized as follows:

(a) The interface between vertically adjacent soil bags was relatively smooth having a relatively low friction angle, which might have resulted in some slipping at the interface, as seen from a discontinuity in the slope of the relationship between the shear displacements at the top of specimen and the specimen height (Fig. 4).
(b) The shear stress that worked at the vertical interfaces between horizontally adjacent bags was very small or essentially zero, which resulted into a very small global complementary shear stress working inside the stacked soil bag system (Fig. 5). This stress condition, which is different from the one in simple shear, should have resulted into a very low shear strength of the stacked soil bag system when sheared laterally.
(c) The strength of the stacked soil bag system is highly anisotropic with the maximum compressive strength when compressed vertically, resulting from a laterally spreading cross-section of the soil bags.

These trends of behavior described above should be accounted for when using a stacked soil bag system as part of a geotechnical engineering structure which may be sheared laterally, typically under seismic loading conditions.

It may also be seen from Fig. 3 that the initial stiffness and pre-peak overall stiffness as well as the peak shear strength of the REPA bags are noticeably higher than the Hokota sand bags. This trend may be due likely to higher stiffness and strength of REPA than Hokota sand under otherwise the same conditions (Aqil et al. 2005). Moreover, the Hokota sand bags showed a larger degree of post-peak strain-softening. This trend can be attributed to a smaller particle size of Hokota sand, which results into a smaller thickness of shear band with a more degree of strain softening for the same global shear deformation. Lastly, both Hokota sand and REPA bags showed contractive behavior when sheared laterally, with a higher contraction rate with the Hokota sand bags. This trend of behavior may result into a reduction of strength when sheared laterally under constant height conditions.

3.2 *Effect of placing a geogrid layer*

Figures 6 and 7 show the effects of placing a geogrid layer at the respective interface between vertically adjacent soil bags. Although this arrangement showed no effect on the pre-peak stiffness, the shear strength

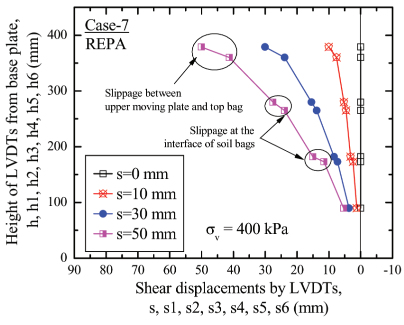

Figure 4. Distributions of lateral deformation of soil bags along the height (test case 7).

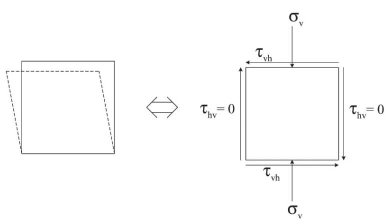

Figure 5. Global stress conditions of stacked soil bag system when sheared laterally.

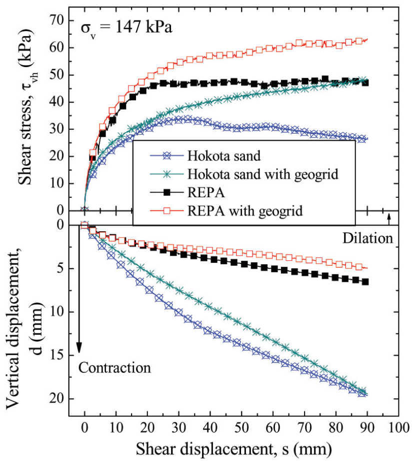

Figure 6. Effects of a geogrid layer at the interface between soil bags on the strength and deformation.

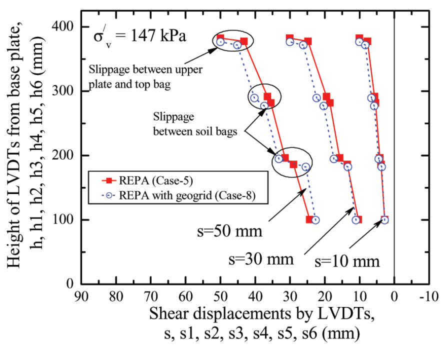

Figure 7. Effect of a geogrid layer at the interface between soil bags on the shear deformation.

increased noticeably with the increase becoming larger with an increase in the shear displacement. This change in the behavior was due likely to an increase in the friction angle by arranging a geogrid layer at the interface between vertically adjacent soil bags. The slipping at the interface for the same shear displacement did decrease by this arrangement, showing that the interface was still the weakest part of a stacked soil bag system.

3.3 *Effect of placing the soil bags in an inclined position*

To increase the shearing strength of a stacked soil bag system, a shear test was carried out on soil bags arranged with the interfaces between vertically adjacent bags inclined at an angle of 18 degrees relative to the horizontal (i.e., the direction of shear loading) (Fig. 8). Soil bags were compacted while placed horizontal on a table, which was later rotated to the prescribed angle relative to the horizontal. Subsequently, they were moved very carefully and placed in the lateral shear apparatus. Fig. 9 shows

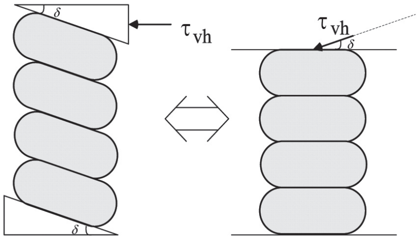

Figure 8. Soil bags placed inclined relative to the horizontal.

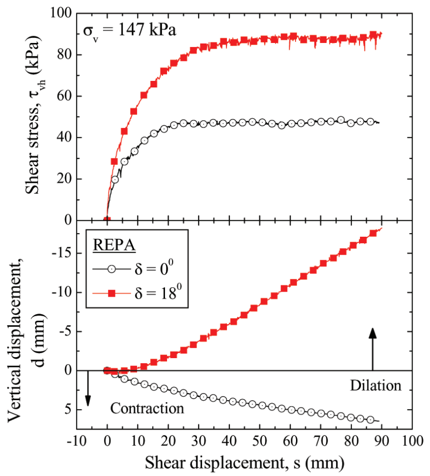

Figure 9. Effects of placing the soil bags in an inclined position on the strength and deformation.

the relationships among τ_{vh}, s, and d, from the test on the inclined soil bag system. It may be seen that, by this arrangement, both peak strength and pre-peak stiffness increased significantly and the volume change characteristics became significantly dilative. These trends of behavior are similar to those of densely compacted granular material, with which particles are forced to climb up those located in their immediately front when laterally sheared. This test result shows how to arrange soil bags as part of a geotechnical structure for a known direction of major applied load.

4 CONCLUSIONS

The following conclusions can be derived from the test results presented above:

(1) Due to its specific anisotropic structure, a stacked soil bag system exhibited low strength and stiffness when sheared laterally, much lower than those when compressed vertically.
(2) The interface between vertically adjacent soil bags was the weakest part of the soil bag system when sheared laterally. An increase in the friction angle by placing a geogrid layer at the interface resulted in an increase in the strength at large shear displacements without increasing pre-peak stiffness.
(3) The strength and stiffness of stacked soil bag system increased significantly by placing soil bags with the interfaces between vertically adjacent soil bags inclined relative to the horizontal (i.e., the direction of lateral shearing) so that soil bags are forced to climb up those in their immediate front.

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