Application of stacked soil bags to repair and maintenance works of small earth dams

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1. Introduction:

Due to its specific natural conditions in terms of geographical location, topography, geology and climate, Japan is prone to periodical earthquakes, typhoons, intensive rain falls and volcanic eruptions, which often result into serious disaster. The devastation caused by these natural disasters is further aggravated often by serious damage to important civil engineering structures including earth dams. Hori (2005) reported that, among around 210,000 small irrigation earth dams (Fig. 1) exist in Japan, many have already been damaged and deteriorated by above mentioned disasters. To avoid a serious loss of human life and property in the future, there is a strong need for 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 earth dams. The essential requirements for the technology include a high construction speed and the use of only light construction equipment, because repair works should be as much as fast and are usually carried out in highly restricted and remote 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. To evaluate the strength and deformation characteristics of soil bags and to determine various design parameters, Lohani et al. (2004) and Aqil et al. (2006) carried out a series of strength and deformation tests (i.e., uni-axial compression and lateral shearing tests). The test results revealed that, although soil bags can exhibit high compressive strength against vertical load, the shear strength and stiffness when subjected to lateral shear load is relatively low. The latter fact is one of the major drawbacks preventing its wide use as a whole or part of a permanent critical civil engineering structure.

In view of the above, this study was carried out to devise a simple, practicable and cost-effective technique to alleviate the problem mentioned above. In addition the failure mechanism and deformation of soil bags when subjected to lateral shear at low and high normal stresses were evaluated.

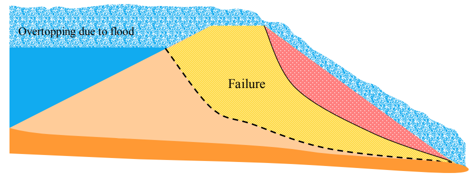

Fig. 1: Typical failure modes of small earth dams.

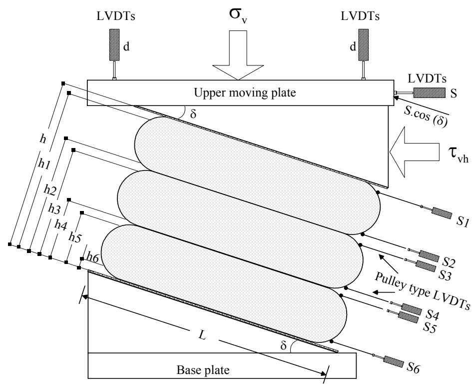

Fig. 2: Specimen with bedding planes at an angle of 18 degrees relative to the horizontal set in a lateral shearing apparatus.

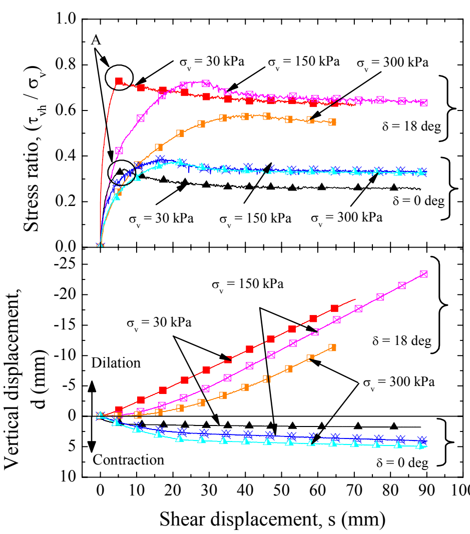

Fig. 3: Relationship among stress ratio, shear displacement and vertical displacement from tests at different σ_v values at δ = 0 & 18 degrees.

2. Testing method:

To increase the shear strength of a soil bag system, soil bags were arranged with an inclined interface between vertically adjacent bags. The angle, δ, of the direction of the interface relative to the horizontal (i.e., the direction of shearing) was set at 18 degrees as well as at 0 degrees for reference. To investigate the failure mechanism of a soil bag system, in particular to examine whether failure is caused by shear deformation of bags or by slippage at an interface between vertically adjacent soil bags, lateral displacements of soil bags were measured with a set of pulley type LVDTs: i.e., the end of a string extending from the respective LVDT was attached to the front side face of the stacked soil bags (Fig. 2). With the inclined soil bags, the pulley type LVDTs were arranged at δ =18 degrees.

The soil bags filled with 120 kg of air-dried Toyoura sand were placed on the horizontally placed base plate of the lateral shearing apparatus, where they were dynamically compacted using a vibratory compactor for 5 min. To prepare specimens for tests at δ =18 degrees, soil bags were placed on the base plate of the shear apparatus that had been set on a rotating table so the surface of soil bags remained horizontal during compaction. After compaction, the stack of dynamically compacted soil bags was moved carefully to be set in the shear loading system. They were then subjected to prescribed vertical stress, σ_v, before the start of lateral shearing at a constant displacement rate of 0.3 mm/min.

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3. Test results and discussions

Fig. 3 shows the relationship among the stress ratio, τ_{vh}/σ_v, the shear displacement, *s*, and the vertical displacement, *d*, both measured at the specimen top relative to the bottom, from six tests on a single pile of soil bags performed at different σ_v values at δ = 0 and 18 degrees. Figs. 4a & 4b show the distributions of lateral displacements along the specimen lateral face at different shear displacements at low and high σ_v values when δ = 18 degrees. From these figures the following trend of behavior may be seen:

a) Both peak τ_{vh}/σ_v value and pre-peak stiffness increased significantly by changing the angle δ from 0 to 18 degrees. The volumetric change also changed significantly from a contractive one to a dilative one. This is similar to a change from the behavior of loosely compacted granular material to that of densely compacted one, in which soil particles are forced to climb up those located in their immediately front when laterally sheared.

b) At low σ_v (i.e., 30 kPa), the slippage between soil bags controlled the shear strength of a soil bag system. The slippage started at the interface between the top and middle soil bags (Fig. 4a). When the slippage started at points *A* shown in Fig. 3, the τ_{vh}/σ_v value suddenly started dropping. It is very likely that, if slippage had not taken place, the peak stress ratio would have become much higher than observed.

c) At high σ_v (i.e., 300 kPa), the peak τ_{vh}/σ_v value was controlled by the shear failure of sand inside the soil bags. Slippage started taking place after the peak stress state (at *s*= around 50 mm, Fig. 4b). At smaller shear displacements, the distribution of shear deformation of soil bag system was uniform, as seen from a rather constant slope of the relation at *s*= 10 mm (Fig. 4b). Slippage between the upper moving plate and the top bag was not significant either at *s*= 10 mm.

It may be seen from the above that a soil bag system becomes very stable by simply being placed inclined so that the direction of the bedding planes of the soil bags becomes closer to the normal to the principal direction of applied compressive load. Fig. 5 shows the section of an earth dam constructed by a newly proposed technology using geosynthetics soil bags having a geogrid/geotextile tale. The geotextile tale attached to soil bags can provide additional safety against slippage. In addition, slippage at low normal stress, such as at the crest of earth dam, can be effectively prevented by connecting the geotextile tales of adjacent top soil bags (Fig. 5).`

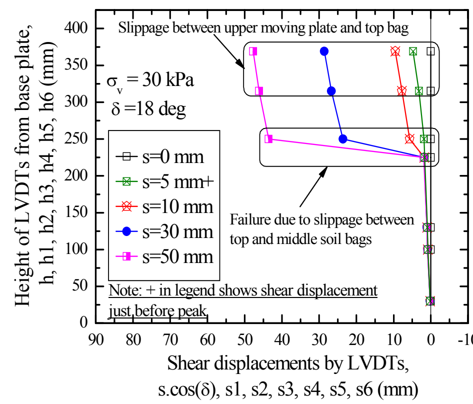

Fig. 4a: Distribution of lateral displacement of soil bags along height, at a low normal stress.

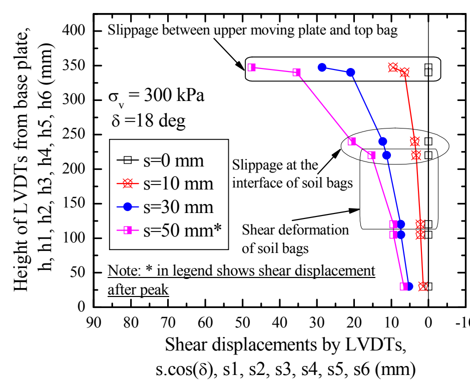

Fig. 4b: Distribution of lateral displacements of soil bags along height, at a high normal stress.

4. Conclusions:

1. The major potential problem of low shear strength and stiffness of a soil bag system when subjected to lateral shear load can be alleviated by placing them inclined so that the direction of the bedding planes of the soil bags becomes closer to the normal to the principal direction of applied compressive load.
2. At low normal stresses, slippage at an interface between adjacent soil bags controls the shear strength of a soil bag system subjected to lateral shear load. At high normal stress, the shear failure of the soil inside the soil bags controlled the shear strength.
3. The slippage failure of soil bags at low confining stress (normal stress), such as when used at the top crest of an earth dams, can be solved by connecting the top bags together with a geotextile tale.

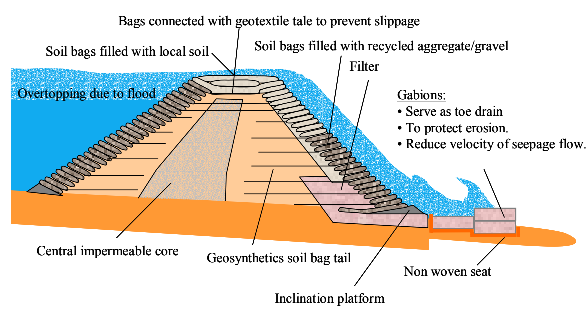

Fig. 5: Earth dam with inclined soil bags having a geotextile tale constructed by a newly proposed technology.

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