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A discussion on reinforced embankment structures having high earthquake resistance

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ABSTRACT: The authors have demonstrated in previous model experiments that embankments reinforced with geotextiles have abundant earthquake resistance. In addition, as a result of conducting new seris of experiments were performed,taking the structure of slope faces into consideration. It was ultimately faund that these effects can be further enhanced if the shear deformation of the soil is constrained to a certain extent, and those constrained materials are made to be more lightweight. This report discusses the superiority of the antiseismic by presenting those experimental results.performance of embankments reinforced by geotextiles having a lightweight slope face.

1. INTRODUCTION

Initiated in the Terre-Armmée method, the placement of geotextiles within embankments has become popular as embankment reinforcing methods for improving embankment stability in recent years. In countries such as Japan in particular, a large portion of the land is comprised of steep mountainous and hilly regions, leaving little room for residential and industrial areas. Earth reinforcement methods are therefor considered a very effective means of efficient utilization of land since they allow the usable surface area of land to be effectively increased through the construction of embankments having steep slope faces. In addition, as there are many earthquakes in Japan, these method are also considered effective because they does require heavy retaining walls. They are known to have an outstanding resistance against earthquakes because of their tensile resistance in the embankments under seismic loading. Accordingly, the authors attempted to demonstrate this. Moreover, conduct a study of methods to increase stability with respect to earthquakes. As a result, it was found effective to employ to improve the stability of reinforced embankments at the time of an earthquake a relatively rigid structure for the slope face, to minimize the shear deformation of the sand used for the embankment material, and to reduce the weight of the retaining blocks. This report attempts to clarify the effectiveness of embankments having a high degree of earthquake resistance along with those structures employed, by presenting experimental results focusing on the dynamic behavior of reinforced embankments and reinforced embankments having high earthquake resistance.

2. SUMMARY OF PREVIOUS EXPERIMENTAL RESULTS

The experiments to date mainly consist of miniature model experiments, centrigugal experiments, and large-scale experiments, and large-scale experiments. They are outlined in the following paragraphs. At the outset of this research, a small model experiment was conducted using sand and reinforcing material(Tisse paper, Nylon non-woven fabric, Polyethylene) in order to investigate the behavor of reinforced embankments. The law of similarity was not taken into consideration at that time, with respect to the scale of the experiment, The experiment with a miniature model embankment measuring 300 mm high, 500 mm in long and 200 mm wide was performed,varying the length of the reinforcing material, the number of layers, strength of the reinforcing material and the gradient of the slope face. A horizontal sine wave was then applied to

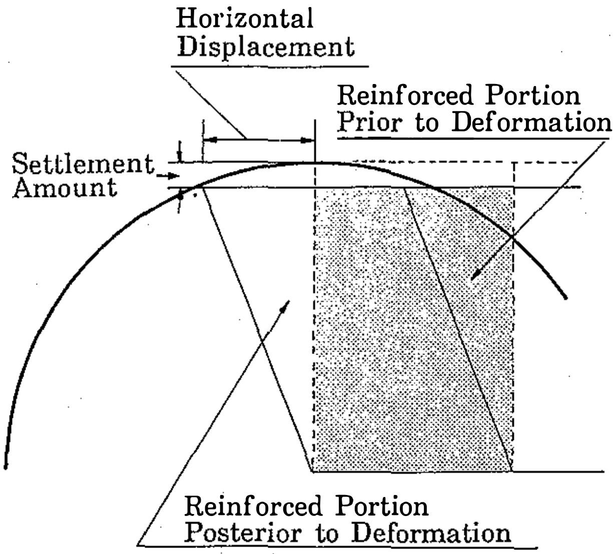
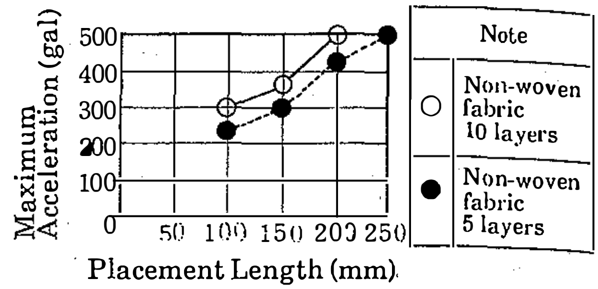
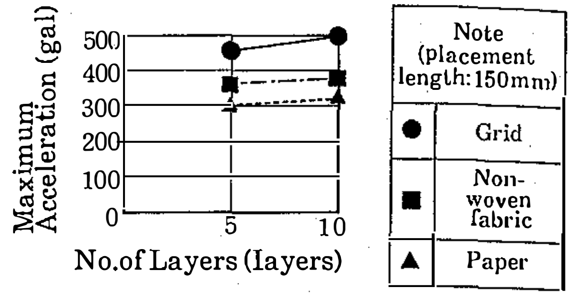


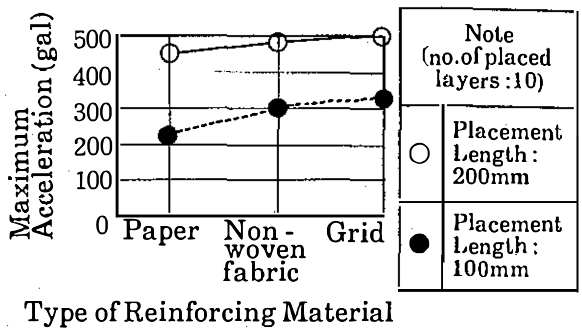
Fig.1 Relationship Between Settlement Amount and Horizontal Displacement of the Embankment



(a) Placement Length



(b) No. of Placed Layers



(c) Type of Reinforcing Material

Fig.2 Comparison with several Reinforcement and Maximum acceleration.

investigate the behavior of the model embankment up to the time of its collapse along with the acceleration of the destructive vibrations.The results of this experiments indicated that at the time of slipping collapse, there was no occurrence of a slip surface over the range in which the reinforcing materials were placed. As shown in Fig.1, the embankment behaved as a single unit in the manner of a conventional retaining wall. Furthermore,the deformation caused by horizontal seismic motion was transformed into shear deformation of the reinforced portions. The results are comparied in Fig. 2. Accordingly it was found that the higher gynamic stability can be obtained when reinforcing materials are placed over a longer distance with more layers of reinforcing materials, greater reinforcing material strength and a gentler gradient for the slope face.

Next, The reinforced embankments discussed here the earthquake resistance of embankments having conventional retaining walls was compared with being by performing a model experiment with the centrifuge testing apparatus of the Public Works Research Institute (Fig.3). The law of similarity is valid in this experiment. This experiment was performed with aminiature model embankment measuring 150 mm high, 250 mm in long and 150 mm wide varying, the length of the reinforcing material, the number of layers placed, the strength of the reinforcing material and the gradient of the slope face. Firstly, centrifugal force was applied to create a gravitational field of 30gal, followed by the application of a horizontal sine wave. As a result, the degree of deformation and collapse of embankments having heavy slope faces of concrete was large, while those of the embankments reinforced with geotextiles occurred at a greater acceleration than that for other types of embankments. It may therefor be concluded that reinforced embankments using geotextiles have a higher degree of earthquake resistance than conventional embankments.

In addition, a large-scale experiment was conducted in order to approximate actual con ditions more closely . As a result, factors that were unable to be examined in the miniature experiment could be clarified e.g., acceleration

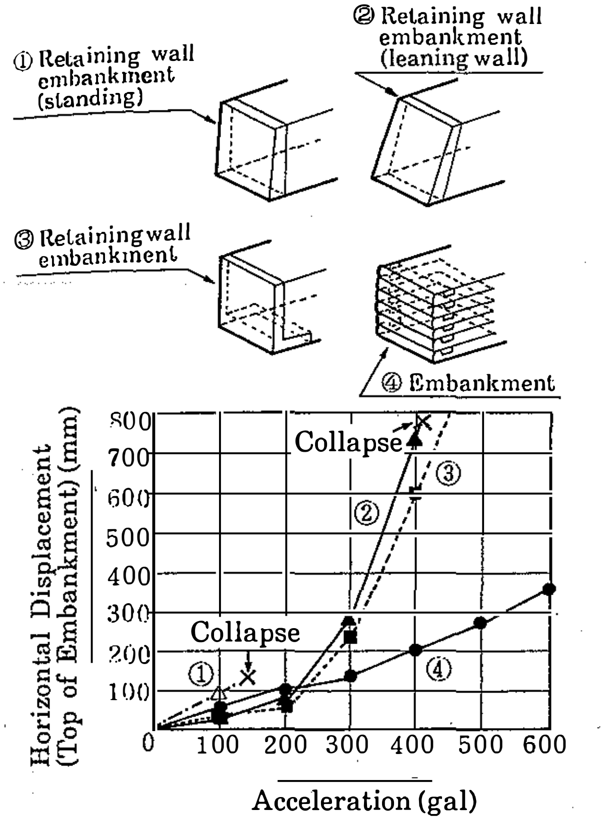


Fig.3 Estimated Displacement of Actual-Size (6m)Embankments and Comparison with Retaining Walls Using a Centrifuge Test

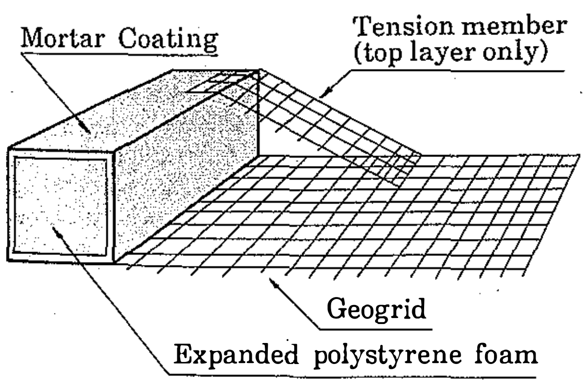


Fig.4 Slope Face Forming Block and Reinforcing Material (Geogrid) of Reinforced Embankments

at which yield is reached. A discussion of these results is provided in the following section.

3. REINFORCING STRUCTURE

As indicated in Fig. 4, the reinforcing structure comprises the mounting of a thin concrete panel on the front of a lightweight ex-

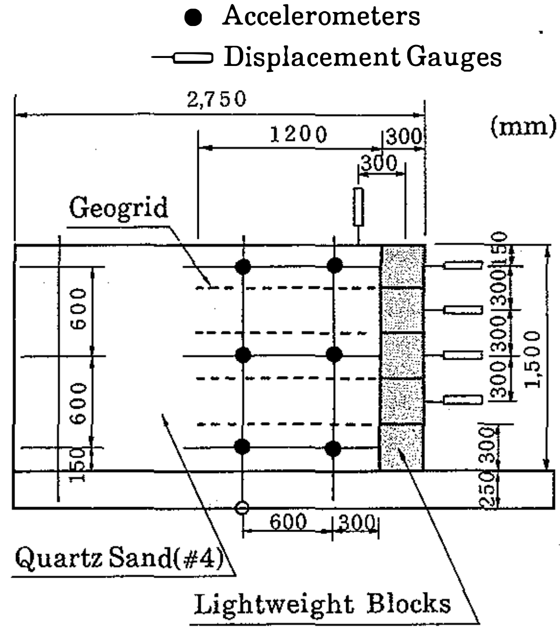


Fig.5 Configuration of Experimental Model and Instrument Installation Locations

panded polystyrene foam rectangular block. In addition, the other five surfaces of the rectangular block were wrapped with a geotextile and coated with mortar to improve weather resistance followed by the attachment of a geogrid. In the past several types of forms have been attempted: The form in which the soil is wrapped directly in geotextile; that where sandbags are wrapped in geotextile and blocks are wrapped in geotextile. It was able to confirm this time that,when the slope face is securely anchored, a higher degree of effectiveness in earthquake resistance rather than employing a method wherein only geotextiles are wrapped.

4. EXPERIMENTAL METHOD

Behavior of the embankments were observed after installing displacement gauges for measuring the displacement of the slope face, accelerometers in the embankment, and making gauge marks for observing displacement on the transparent surface of the soil container at the location of the cross section of the embankment. The arangement of the testpiece and the locations of the instruments are shown in Fig. 5. Vibrations using method were horizontal sine wave (Frequency 4Hz, Application time 5sec). Furthermore, vibrations were applied in stages of 40 gal each, up to a maximum of 640 gal.

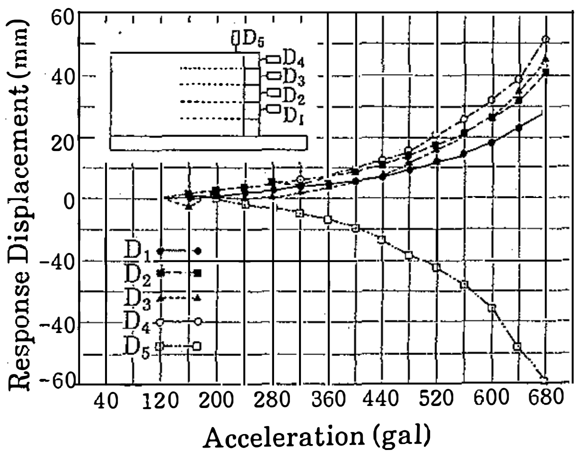


Fig.6 Maximum Residual Displacement at esch Vibration Stage

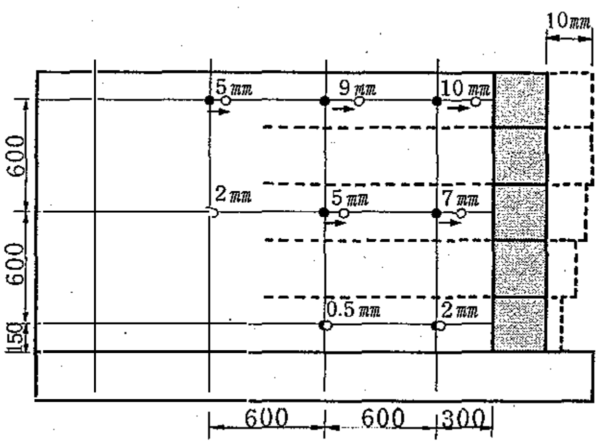


Fig.7 Horizontal Displacement at each Point within the Embankment During an Accelration of 400 gal

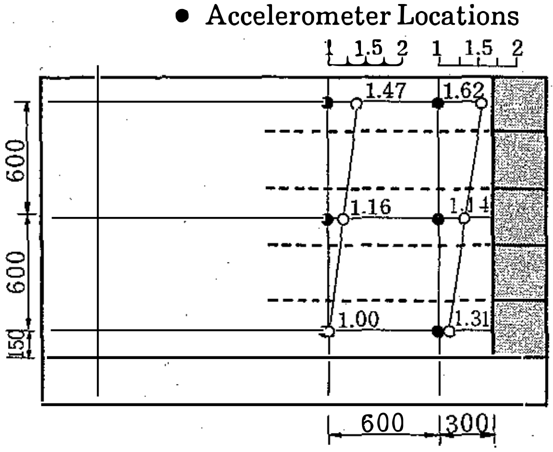


Fig.8 Accelration Response at Each Point within the Embankment During a Acceleration of 400gal

Vibration was returned to 0 gal for each stage at which time residual displacement and other measurements were made.

5. EXPERIMENT RESULTS

Firstly, the maximum residual displacements at each position for each of the vibration stages are shown in Fig. 6. Because the sand was compacted by the applied vibration,the amount of subsidence at the top of the embankment was greater than the predicted value. In addition, Fig.7 shown the results with respect to the amounts of displacement at each of the points within the cross section of the embankment at a acceleration of 400 gal.

The response of the acceleration at that time is illustrated by the state in Fig. 8, which closely corresponds with the displacement re sults in Fig. 7. There was no major destruction observed up to the maximum acceleration of the experiment of 680 gal. However, the progress of displacement appeared to increase slightly starting at 440 gal.

6. COMPARISON WITH CONVENTIONAL STRUCTURALLYREINFORCED EMBANKMENTS

By examining the experimental results,the effectivness of the reinforcing material has become more apparent for the horizontal displacement of the top of the embankment, the relationship between vibrational acceleration and horizontal displacement of the top of the embankment is indicated in Fig. 9.

It may be seen in these results, that the displacement pattern differs greatly,depending upon the reinforcing structure, used and slope faces. Case 6 in particular, the subject of this experiment, has the lowest amount of displacement, indicating a high degree of earthquake resistance. In addition, the relationship between acceleration and horizontal displacement at the top of the embankment is shown in Fig.10, using the logarithm of acceleration. There is a clear structural difference in the elastic range . It can be seen that in comparison to the other cases, Case 6 demonstrates elastic behavior up to a considerably higher acceleration level.

The primary reasons for this difference is obvions: in comparison to the other cases, the blocks are of lighter weight in Case 6, the blocks and reinforcing material are securely jointed together, and the reinforcing material

Note		
CASE 1	Geotextile* (wrapped) 10 layers, 1m, T=0.1t	×⋯⋯⋯
CASE 2	Geotextile* (wrapped) 5 layers, 1m, T=0.2t	----
CASE 3	Geotextile* (Expanded polystyrene foam) 5 layers, 1m, T=0.2t	△-·-·-·-
CASE 4	Geotextile* (earth blocks) 5 layers, 1m, T=0.2t	○——
CASE 5	Geotextile* (Expanded polystyrene foam) 10 layers, 1m, T=0.2t	□⋯⋯⋯
CASE 6	Geogrid (Expanded polystyrene foam + mortar) 5 layers, 1m, T=0.4t	●——

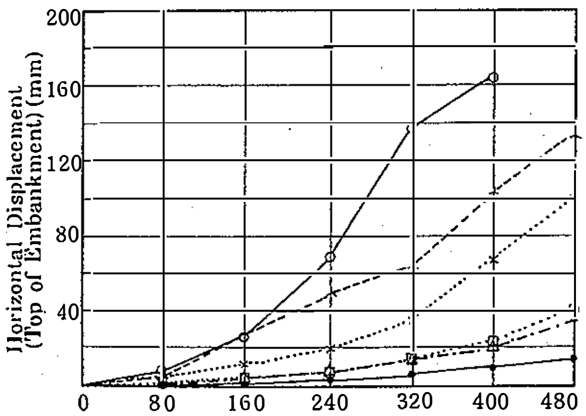


Fig.9 Relationship Between Acceleration and Horizontal Displacement of Top of Embankment for each of the Experimental Patterns

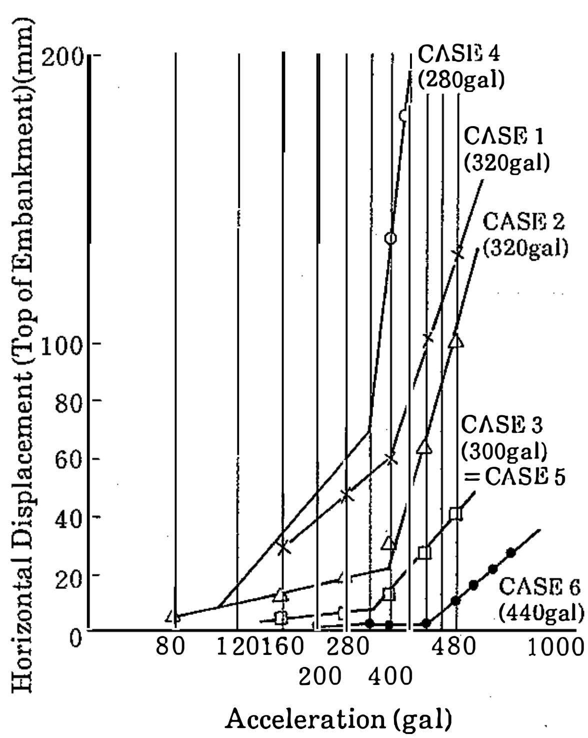


Fig.10 Relationship Between Acceleration and the Range of Elastic Behavior for each of the Experimental Patterns

has a higher strength. These factors are believed to have contributed to the increase in resistance in Case 6.

7. DISCUSSION ON STRUCTURAL EARTHQUAKE RESISTANCE

As has been reported previously, it has become clear that the degree of antiseismic performance of reinforced embankments is governed by the number of reinforcing materials placed, the length over which they are placed and the strength of the reinforcing material. A similar trend is also observed with respect to static stability. However, in the experiments conducted thus far, the effects of the construction method employed at the surface of the slope face on resistance had not been taken into consideration. It became apparent through a study of previons experiments,that there were cases in which the abovementioned qualitative performance was not followed according to the construction method employed for the slope face. It was felt that the resistance may be affected by the shape of portions which compose the slope face, nearby structures and other factors. Accordingly, past experiments were reviewed to focus on the shape of the slope face, and experiments were conducted by modifying structures in the vicinity of the slope in the manner of the experimental arangement discussed here. As a result, it was found that antiseismic performance will be improved. If the front surface blocks be lightweight, the reinforcing material is anchored to those blocks, and the strength of the reinforcing material is increased. Furthermore, as one of the resulting effects, the displacement of the entire embankment decreases, when shear deformation of the sand is minimized and displacement in the vicinity of the embankment slope face is reduced. In this case, it is desirable that the wall which composes the slope face not only be lightweight, but that it also be in the form of blocks and have a somewhat flexible structure in order to prevent it from collapsing.

8. CONCLUSIONS

As has been described above, in order to minimize the movement of soil in the vicinity of the slope face of embankments, the slope face should be held with blocks and the blocks and geotextile should be securely anchored. In addition, it also became clear that in order to reduce the force of inertia, the use of lightweight blocks and so forth is an important factor in increasing the earthquake resistance of reinforced embankments. For the future, we would like to proceed with further analysis in an attempt to perfect design methods.

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