Prediction of Deformation of Geotextile Reinforced Walls subjected to Earthquakes

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ABSTRACT: It is necessary to accurately estimate the settlement caused by earthquakes so that more stable retaining structures can be designed and constructed. The authors had carried out dynamic loading model tests by employing a centrifuge apparatus. Based on a series of small scale model tests subjected to dynamic forces a method for predicting the deformation of retaining walls is proposed. The effect of the strength, length and the number of reinforcement on the strength and deformation of the wall is evaluated. It is found that the stiffness of the reinforced wall can be expressed well in terms of these three parameters.

1. INTRODUCTION

This research was carried out in order to examine the dynamic deformational characteristics of the geotextile reinforced embankment which had high resistance to vibration. It was found that resistance of the reinforced embankment was improved, and the deformation of the embankment decreased due to reinforcement (geotextile) and light-weight rigid facing wall. The light-weight rigid facing wall helped reducing the inertial force acting on the embankment. These results were presented in the previous reports [1), 2)]. Finally, for that the deformation of the embankment can be predicted, a series of dynamic loading model tests were carried out using the centrifuge apparatus. The length and strength of geotextile were treated as test parameters. The results of these tests indicated that properties of geotextile had direct influences on the displacement of embankment during vibration. Based on those observation, a tool for prediction of displacement for designer was proposed.

2. EXPERIMENT

In order to model an actual embankment of height 4.5m using 30g acceleration, the model embankment which dimensions were 15cm in height, 35cm in width and 15cm in depth was constructed in a 40cm height, 50cm width and 15cm depth container. Three types of geotextiles (Non-woven A : thickness (t) =0.09mm, tensile strength (Tmax)=1.8kg/5cm ; Non-woven B : t=0.11mm, Tmax=2.8kg/5cm ; Non-woven C : t=0.14mm, Tmax=4.6kg/5cm) were used. The lengths of geotextile in the reinforced embankment were 15cm, 10cm and 5cm and 5 layers of geotextile were embedded in the model embankment. Dried Toyoura sand was used as tested material. The sample was prepared to have a dry density (ρ_d) of about 1.5g/cm^3. The rigid facing wall was made of light weight blocks. This model embankment was placed on the shaking table which in terns was fixed to the centrifuge apparatus. The model embankment was, then, subjected to an acceleration of 30g. Sine wave vibration applied at frequency of 100Hz was, first, imposed by the shaking table to previde energy of 1G. This was applied for 25 cycles, then, shaking was stopped. Next step was to apply a similar sine wave to provide energy of 2G for 25 cycles. This process was continued until the vibratory energy reached 12G (0-1-0-2-0-3-0-4-0-5-0-10-0-12). The displacement of the rigid facing, strain in the reinforcement and the response acceleration of the embankment were measured. The location of transducers is shown in Fig.1.

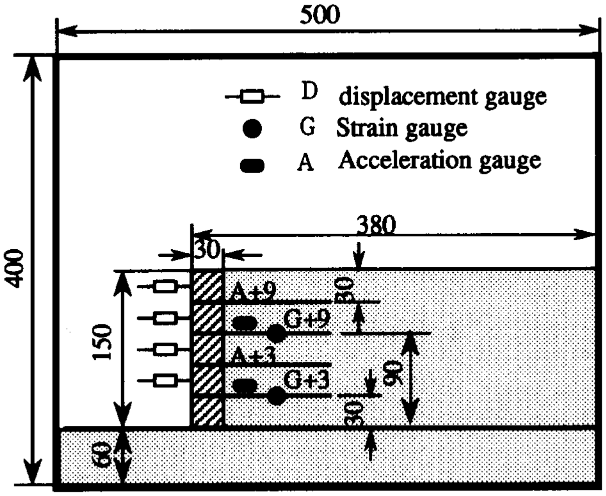

Fig.1 Layout of the transducers

3. EXPERIMENTAL RESULTS AND DISCUSSIONS

A similar tendency as observed in the previous research[1),2)] was also found from the present study. For each step of vibration, the magnification factor was larger near the top end of the embankment. For each step of vibration, the horizontal displacement of rigid wall was larger when the applied acceleration became large. Larger horizontal displacement of the rigid wall was observed near the top end. For the measurement of strain, the strain amplitude was larger near the top end. The amount of residual strain depended on the overburden pressure ; the residual strain was larger at location where larger overburden pressure was applied.

The strain taken place in the reinforcement as the centrifugal gravitational field was raised to 30g is shown in Fig.2. It should be noted that values of strain shown in Fig.2 is those determined in the centrifuge test. It can be seen from the figure that tensile force acting on the reinforcement became larger when the overburden pressure (depth) increases. However, it was observed that the displacement of the block at this stage was very small. By computing tensile force using actual scale, the tensile forces are 560kg/m (overburden pressure of 5.58t/m^2) and 305kg/m (overburden pressure of 2.79t/m^2) at location G+3 and G+9, respectively (Fig.1). It is clear that tensile force at G+3 location is higher than that measured at G+9 location. This is due to the effect of overburden pressure.

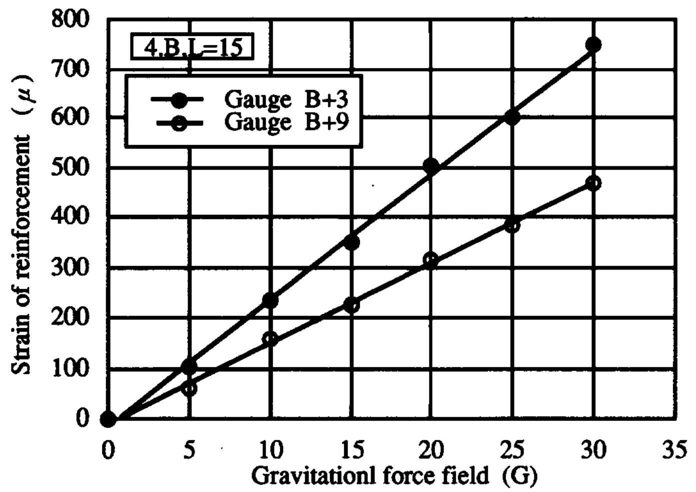

Fig.2 Strain in reinforcement during of centrifugal gravitationl force field

The effect of length of the reinforcement is shown in Fig.3. The displacements measured at uppermost block are plotted against the input vibration. Similar plots are also shown in Fig.4 and 5. It is clear that the longer the reinforcement is, the smaller the displacement of the embankment. However, the effect of length of geotextile becomes smaller when the geotextile is longer than 10cm. This can also be seen in Fig.6.

The effects of strength of geotextile on the uppermost block displacement is shown in Fig.4. It is found that stronger geotextile gives smaller displacement. Nevertheless, the reduction in displacement is not much when compares to the amount of increase in strength. Moreover, there is a limit at which its effectiveness becomes negligible.

The effects of density of sand on the uppermost block displacement are shown in Fig.5. The dry density used in the tests varied from about 1.48g/cm^3～1.59g/cm^3. It is clear from the figure that the denser the sand in the model embankment is, the smaller the displacement takes place throughout the test.

As the centrifugal acceleration increases the stress in the reinforcement increases. This is similar to the stress applied to the reinforcement during actual construction. Therefore, the consideration of this tensile stress in design stage is necessary. Based on the results shown in Fig.3, the optimal length of the reinforcement can be estimated. If the length of reinforcement is about 1/3H, large displacement takes place. It is found that the most economical length of geotextile lies between 3/3H to 2/3H.

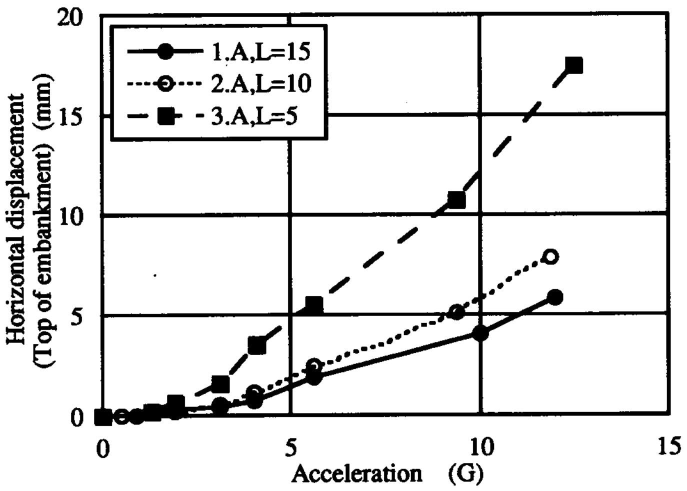

Fig.3 Effects of length of geotextile

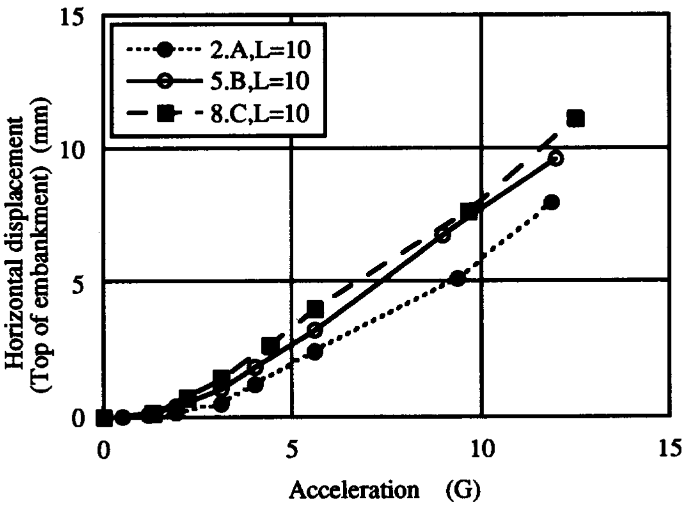

Fig.4 Effects of strength of geotextile

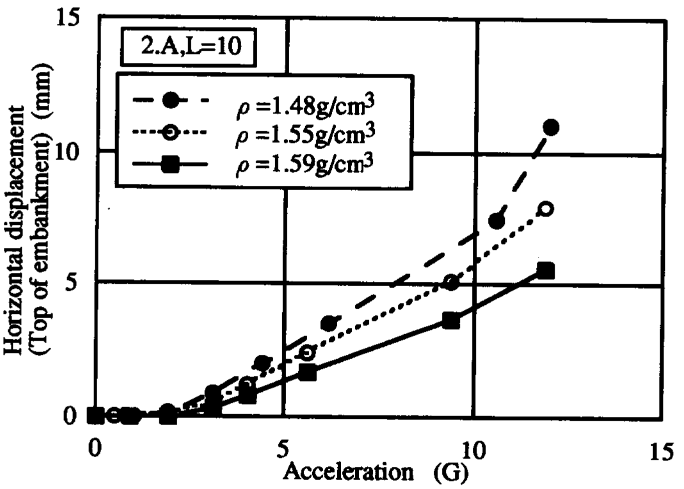

Fig.5 Effects of dencity of sand

As mentioned above, the strength of geotextile has little effect on the improvement of embankment subjected to both large and small vibrations. It is even believed that this is due mostly to the friction between geotextile and sand. The density of soil used for construction can alter the stiffness of the reinforced embankment, therefore, the quality of compaction during construction becomes one of the most important factor in centrolling the performance of the reinforced embankment. In summary, the length of the reinforcement becomes one of the most important factor in suppressing displacement of embankment during earthquake.

4. PREDICTION OF DISPLACEMENT

It is very difficult to predict the displacement taken place in a soil-structure system, especially, when soil starts plastic flow which corporates with large deformation. As stated before, geotextile, which has very low stiffness comparing to other metal reinforcement, deforms under static loading. Therefore, during construction, one could pre-apply the predicted amount of strain to the geotextile to prevent the deformation. However, it is difficult to make any correction after completion of construction. The most important stage is to predict the allowable displacement and try to make the displacement bounded in this allowable range. This will provide the most economical design.

The authors intend to give a guideline for prediction of deformation of a reinforced embankment during earthquake. There is several evidence showing that the geotextile reinforced embankments are so strong that there is no report of failure of the reinforced embankment due to earthquake. Even for a small amount of geotextile reinforced in the embankment will stabilize the embankment so that, to cause the slip failure, the input vibration needs to be considerable large. Therefore, determination of deformation that causes failure is the first task of designer. Any excess deformation indicates failure of embankment. The research for prediction of deformation of reinforced embankment is performed in this way.

Based on the experimental results, several factors have influences on the deformation characteristic of the geotextile reinforced embankment subjected to earthquake;i,e,length of reinforcement,strength of reinforcement and etc.

The idealize prediction technique is to take into account all of these factors, however, in the present study, there is no enough information to formulate such criteria. In this paper, only the length and strength of reinforcement will be considered in constructing the prediction criteria. This criteria proposed based on the results of the above stated centrifugal tests.

First, the effect of length of geotextile reinforcement which depends on the displacement and the horizontal input vibration is evaluated. Assuming that the ratio between length of reinforcement to height of the embankment is α, and the ratio between displacement at top end to height of embankment is $\beta(\delta/H)$, the relation ships between the ratios α and β of a reinforcement having strength of 2.76t/m obtained at different values of input vibration are shown in Fig. 6.

Next, the effect of strength of reinforcement is considered. Similarly, its effects depends on the stages of displacement and vibration. Assuming that strength of geotextile is expressed on actual scale as tensile strength T(t/m) per 1m width, the relation ships between T and β of a 10cm (α=0.667) length reinforcement obtained at different levels of vibration are shown in Fig.7. From these figures, it can be concluded that the effects of both length and strength of the reinforcement on the reinforced embankment increase until some certain levels which their effects become constant.

In order to predict the displacement, either Fig.6 or Fig.7 will be used to construct a monograph. For example, if similar graphs obtained for different values α (α=0.333, α=1.0) are plotted into Fig.7, the monograph for design can be constructed. Therefore, if the length of reinforcement, and allowable displacement are determined, the strength can be obtained from the figure. Alternatively, if similar graphs of different strengths are plotted in Fig.6, the design monograph on length of reinforcement can be constructed. Based on these methods, the rigid wall displacement during earthquake of an embankment reinforced with 5 layers of geotextile at 3～6m interval can be evaluated.

In the present study, the counter moment provided by a light weight block which holds the geotextile is relatively large when small vibrations of 1G～2G are applied, therefore, very small displacement could be observed. In design process, the counter moment should be neglected. Moreover, the confinement of back-filled soil due to the light-weight blocks causes displacement and this is included in the measured values. Therefore, low stiffness wall will result in large displacement. This can be seen in Fig.9 of Sakaguchi et al (1993) which showed that the displacement depends on the unit weight of the wall.

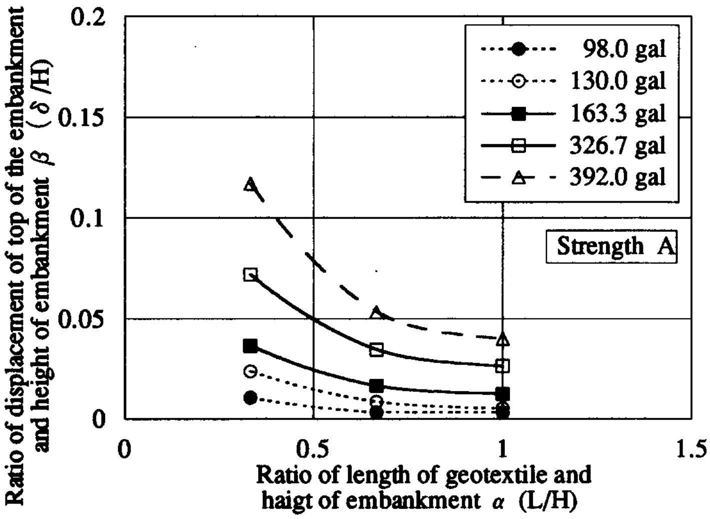

Fig.6 Relationships between ratios α and β at different levels of vibration

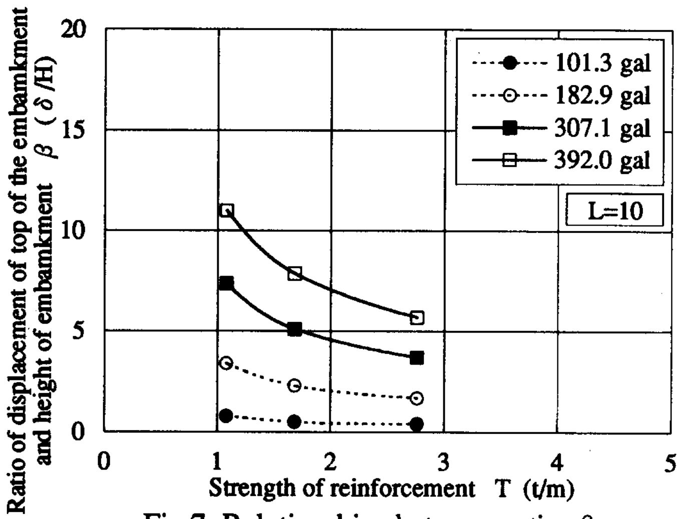

Fig.7 Relationships between ratio β and T at different levels of vibration

5. CONCLUSIONS

The first step for prediction of displacement during earthquake has been finished. The basic concepts, test result have been presented. In the next step, the height of embankment, layers of geotextile and slope of the wall will be treated as parameters in prediction.

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