New Horizons in Earth Reinforcement – Otani, Miyata & Mukunoki (eds)

Displacement and failure characteristics of model geogrid-reinforced structure subjected to impact load

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ABSTRACT: In order to clarify the failure mechanism of geogrid-reinforced structure affected by earthquake, the failure mode of reinforced structures are carefully investigated when it was subjected to the impact load, based on the pictures shot by the high speed camera. It is observed that as the acceleration increases, the sliding surface of the geogrid reinforced structure first appears from the back of the sliding surface predicted by Coulomb's active earth pressure. The fixing length of reinforcement is important to improve the deformation characteristics of the reinforced structure during the impact load.

1 INTRODUCTION

On March 20, 2005, an earthquake of magnitude 7.0, which was named as the 2005 Fukuoka-ken Seiho-oki Earthquake, occurred in the northwest part of Fukuoka City. A large number of retaining walls and houses in Genkai island located at 9km far from the epicenter had a huge damage under the predicted seismic intensity scale of 6 upper due to the earthquake (see Kobayashi et al., 2006). Two old geogrid reinforcement steep embankments existed which were constructed in 1980's survived with a little damage such as the clacks of top part of the embankments and the small forward displacement with the cutting of the front part of the geogrids. However, the degree of the damage inside of the reinforced embankment was not so clear. Thus, in order to properly judge what level of repairs are needed, it is important to clarify the effects of the damage mentioned above on the subsequent durability and resistance against the earthquake. It is desired to indicate the basic idea for judging the most suitable repair's method of the damaged reinforcement structures. In this study, as a first step of this object, the characteristics of the failure and deformation patters of the earth reinforcement embankment subjected to an impact load were experimentally investigated through the monitoring of the behaviours by using a high speed camera. It is noted that the discussion below is limited to be a qualitative one.

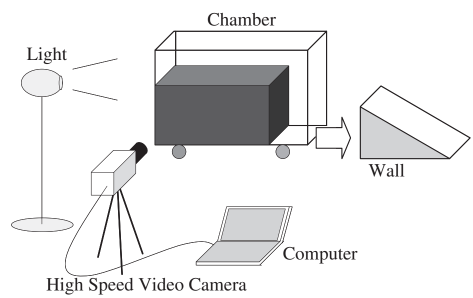
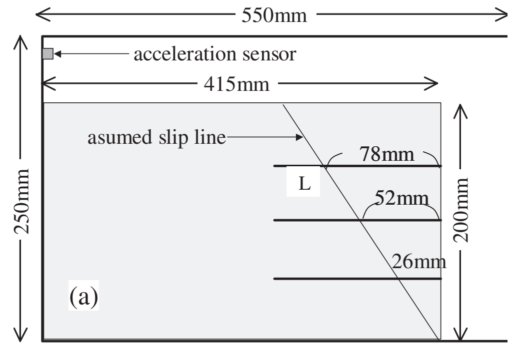


Figure 1. Outline of experimental system.

2 OUTLINE OF EXPERIMENTS

2.1 *Model apparatus used*

A model chamber with casters is used, where an impact load is applied by manually dashing the chamber against a wall. The model ground consists of the length with 41.5 cm, the height with 20 cm and the width with 10 cm, in which its side is made of an acryl plate to observe the movement of the ground during the test using a high speed digital video camera as schematically shown in Figure 1. This camera (Phantom V4.2; Vision research co. ltd.) can take 2024 scenes for 2 seconds with 512*512 pixel. A typical model reinforced ground is shown in Figure 2, together with the photo.



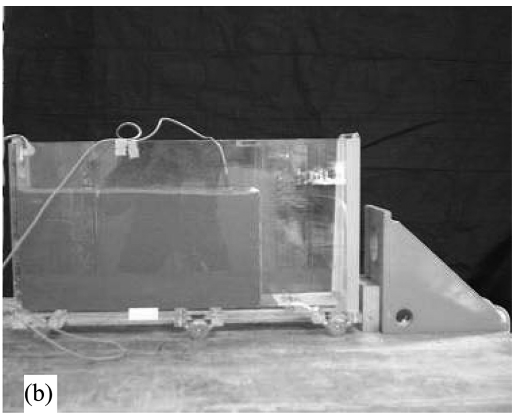


Figure 2. Earth reinforcement mode ground.

The magnitude of the impact load was evaluated by the acceleration sensor mounted in the top part of the chamber. As shown in this figure, each reinforcement material was horizontally laid in the ground with an equal vertical space. Length of the reinforcement material was determined based on the expected slip surface from the Coulomb's active earth pressure theory. In this study, three different embodiment lengths of the earth reinforcement materials were prepared, whose lengths were 67 mm and 33.5 mm longer, and 10 mm shorter than the length from the front of the ground to the slip line shown in Figure 2, where ΔL is the embodiment length defined.

2.2 *Earth reinforcement and geomaterial used*

A graph paper was selected as a model reinforced material, whose merits are to be easy to install in the ground and to adjust its length. A decomposed granite sandy soil called as "Masado" with $D_{50} = 0.5$ mm and $U_c = 30$ was used for making a model ground. The maximum size of the particle diameter was controlled to be less than 2 mm. The model ground were made by the compaction of Masado with the optimum water contents, which consists of four layers of Masado. Each layer is compacted to be 1.44 g/cm^3. A series of drained direct shear box tests of Masado with same sample conditions of the model ground were conducted under the constant normal stresses to obtain the strength parameters of this materials. As a result, the internal friction angle and cohesion are determined as around 39degrees and 4 kPa, respectively, which seems to reflect an well compacted model ground.

Table 1. Test condition.

Case1	Earth reinforcement with embodiment length ΔL of 67 mm
Case2	Earth reinforcement with embodiment length, ΔL of 33.5 mm
Case3	Earth reinforcement with embodiment length, ΔL of -10 mm
Case4	No earth reinforcement

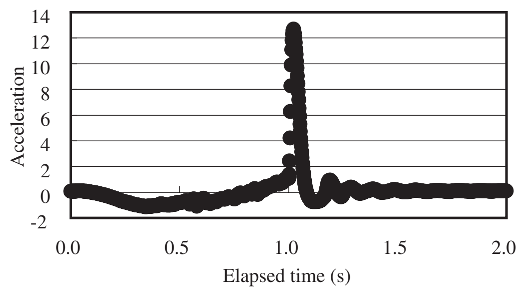


Figure 3. Typical acceleration time history.

2.3 *Experimental procedure and conditions*

A impact load is applied to the model ground by using an inertia force mobilized when the chamber strikes against a fixed wall (see Figure 1). The deformation and failure pattern of the ground are carefully observed by high speed video camera and then analyzed by PIV method through the test. The magnitude of the impact loads are relatively evaluated by the values of an acceleration sensor. The measured acceleration varies widely, and thus two or three tests were conducted under the same initial test conditions. Test cases conducted are summarized in Table 1, where the earth reinforcement materials with three layers are installed in the Cases from 1 to 3, whose differences are the length of the materials. On the other hand, for comparison, Case 4 is prepared, which treats the ground without any earth reinforcement materials. Figure 3 indicates a typical acceleration time history obtained.

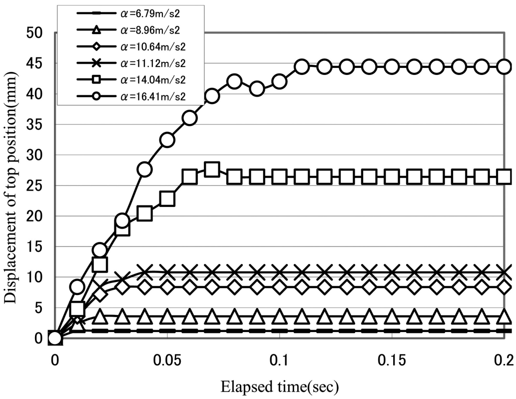


Figure 4. Displacement of earth reinforcement at top position against elapsed time.

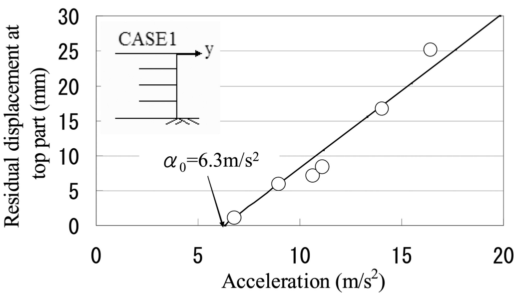


Figure 5. Residual displacement at top part of the ground against accelerations.

3 RESULTS AND DISCUSSIONS

3.1 *Displacement and failure properties of reinforced ground*

Figure 4 shows the displacements of the top of the ground in Case 1 against the elapsed times under the various acceleration conditions. The displacement begins to occur at the moment once an impact load is applied and proportionally increases with the increasing elapsed time. After that, the displacement for each case converges to a certain value being dependent on the magnitude of acceleration. Figure 5 indicates the relationship between the residual displacements at the top of the ground and the acceleration values in Case 1. It is found that the residual displacement begins to occur when the acceleration becomes greater than around 6.3 m/s^2 in this model earth reinforcement ground and then increases with the increasing acceleration. When the acceleration exceeds a certain value, it is observed that even if the inside of the earth reinforcement area has no damage, there is a case the slip layer can be formed behind the reinforcement area and the ground often reaches the failure. Therefore, the embodiment length of the earth reinforcement material seems to be important to increase the potential safety of the reinforcement ground. Figure 6 shows the typical failure patterns from Case 1 to Case 4 under the acceleration around 14.5 m/s^2 when the elapsed time reaches to 0.1 seconds. From the high speed video observation, the following behaviours can be seen. In Case 4 without any earth reinforcement and Case 3 in which there is no sufficient embodiment length for all the earth reinforcement materials, a clear clack such as a slip line first appears behind a Coulomb's slip surface. Many clacks inside of soil mass within the clear slip line are then presented and the length of clacks becomes longer and longer with the elapsed times. Finally the embankment in both cases reaches to a catastrophic failure. On the other hand, in Case 1, which has a sufficient embodiment length for all the earth reinforcement materials, a clear crack first appears which seems to be similar to the Case 1. After that, although the soil mass ahead of the clack moves forward, a catastrophic failure does not occur due to the earth reinforcement effects. The number in Case 1 (see Figure 6(a)) means the order of which the clack appears during the tests. It is found that the first clack appears fairly behind the theoretical Coulomb's slip line and each reinforcement material prevents the progress of the clack.

3.2 *Effect of embodiment length on the displacement behaviours*

Figure 7 shows the horizontal displacement at the top of the ground normalized by the wall length against the elapsed time with every 0.15 seconds after the impact load is applied under the acceleration of around 14.5 m/s^2. The typical results in Case 1, Case 3 and Case 4 are compared here. It is clear that the results in Case 3 and Case 4 have a same trend. It means that little reinforcement effect can be found in the case that the embodiment length is not sufficient. Figure 8 shows the horizontal displacements of the ground at depth of 50 mm, 100 mm and 150 mm from the bottom in the Case 1 and Case 2, paying attention to the accelerations normalized by α_0 defined in Fig. 5. It is noted that the embodiment length in Case 2 is half comparing with that in Case 1. When α/α_0 is relatively small, there is little difference of the displacement in each case. And then, when the normalized acceleration becomes larger, the displacement in Case 2 gradually becomes greater, comparing with that in Case 1. Such tendency tends to be remarkable for increasing acceleration. It is conformed that the embodiment length works well to reduce the horizontal displacement of the earth reinforcement structure when subjected to relatively large impact loads.

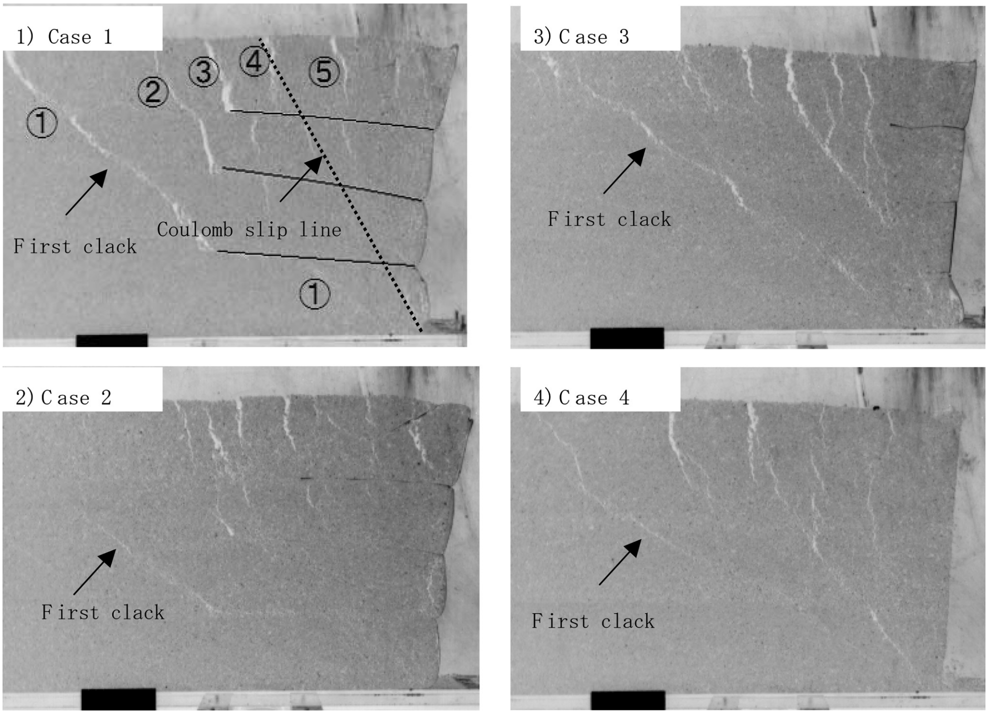


Figure 6. Typical failure patterns of each case at 0.1 seconds after subjected to an impact load.

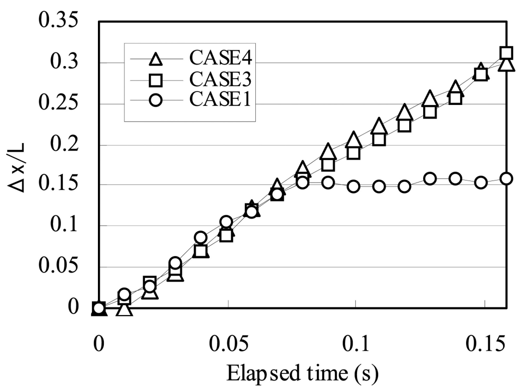


Figure 7. Normalized horizontal displacement at top of the ground against elapsed time for three cases with different embodiment length.

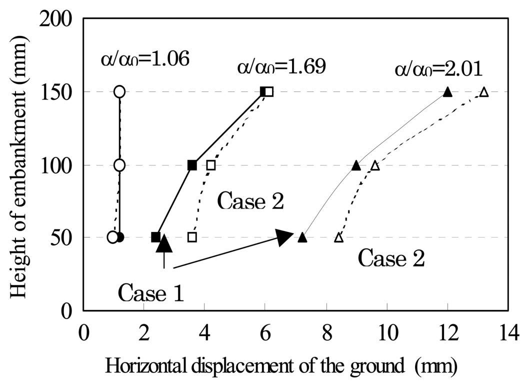


Figure 8. Comparison of horizontal displacement in Case 1 with those in Case 2 paying attention to the magnitude of the acceleration.

3.3 *Visualization of the movements of earth reinforcement ground*

Figure 9 indicates the displacement vectors of the earth reinforcement ground in Case 1 in the period of 0.006 seconds from 0.05 second just after subjecting the impact load. The displacement vectors tend to increase with approaching to the upper part of the ground and also to the earth reinforcement wall. A slip surface, which is first observed, is also depicted in this figure. It is confirmed that the soil mass inside of the slip surface mainly moves forward.

4 CONCLUSIONS

Failure and deformation patters of the earth reinforcement embankment subjected to an impact load were

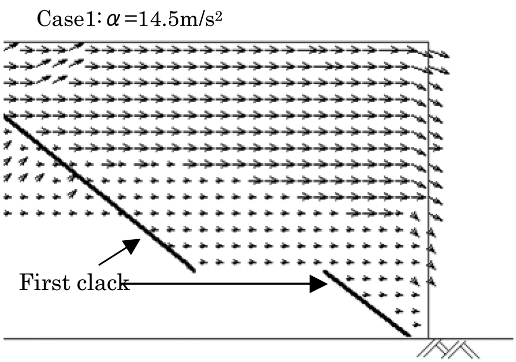


Figure 9. Typical displacement vectors of the ground in Case 1.

experimentally investigated through the monitoring by using a high speed camera. The following main conclusions are obtained in this study.

1) When the acceleration exceeds a certain value, even if the inside of the earth reinforcement area has no damage, there was a case that the slip layer can be found behind the reinforcement area.
2) Irrespective of the reinforcement condition, every time the first clack due to an impact load appeared fairly behind the active area by the Coulomb's theory. After the first clack appeared, many clacks were produced in the active area inside of the first clack within a very short elapsed time.

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