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The evaluation of deformation reduction by geosynthetics sandwiched with gravel layers beneath an embankment during liquefaction of level 2 and level 1

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ABSTRACT: Roads are permitted to go through some deformation caused by a severe seismic event (so-called Level 2 such as 1996 Kobe and 2011 Tohoku) as long as they could be recovered quickly and easily. The authors have conducted to verify the effect of the countermeasure using geosynthetics sandwiched with gravel layers after a Level 2 seismic event through experiments and dynamic analyses. This countermeasure was found to be effective for maintaining the overall original shape of the embankment by suppressing the stretching of the toe of the embankment. It is legitimate for approach embankments near bridges and box culverts to be designed for a Level 2 seismic event. But because roads are extensive in the longitudinal direction, applying the Level 2 design for the rest of the embankment seems costly, thus Level 1 design approach seems feasible for these locations. Authors have verified the amount of settlement after a Level 1 seismic event (180 gal) by numerical simulations. The authors were able to summarize the settlement levels under various conditions that can be used as reference guidelines for designing embankments.

1 INTRODUCTION

Japan Road Association assigns the required performance for road structures, which are summarized in Table 1. Performance 2 design allows limited deformation that can be easily restored. The Level 1 seismic event is expected to occur once or twice during the service time of the structure (once in 100 years) while the Level 2 seismic event has a very low probability of being experienced by the structure (once in 1000 years).

Importance 1: Highway, national and prefectural roads, roads without alternative routes at the
event of disaster
Importance 2: Not as important as roads classified as Importance 1
Performance 1: Keeps sound condition
Performance 2: Allows limited deformation, easy to restore
Performance 3: Does not totally collapse

The authors conducted research on shallow ground reinforcement structures using geosynthetics. The purpose of this study is to confirm the deformation reduction effect of the embankment over the liquefied ground by the countermeasure. As a result, the effect of

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Table 1. Performance of earthwork structure.

Case	Importance 1	Importance 2
Static loading + traffic	Performance 1	Performance 1
Static loading + rainfall	Performance 1	Performance 1
Level 1 Seismic loading	Performance 1	Performance 2
Level 2 Seismic loading	Performance 2	Performance 3

suppressing settlement of the embankment crest by the countermeasure in this study was not sufficient as expected. However, the effect of suppressing the embankment shoulder and slope toe stretching by the countermeasure was demonstrated, and the effect of retaining the shape of the embankment was confirmed by experiment and reproduction, and predictive analysis.

The guideline of Japan Road Association assigns that important roads must sustain the same performance after a seismic event for structures such as bridges, embankments, box culverts, cut slopes and etc., in order to keep the roadability. Because roads are extensive in the longitudinal direction, applying Level 2 countermeasure for their entire span seems too expensive. Although approach embankments near bridges and other structures should consider severe seismic events, Level 1 design approach seems feasible for the remaining embankments. The authors conducted static numerical simulations of a Level 1 seismic event (180 gal) in order to verify the effectiveness of the countermeasure under various ground conditions.

2 DYNAMIC CENTRIFUGAL MODEL EXPERIMENT

2.1 *Experimental outlines*

A 50G dynamic centrifugal model experiment was conducted using a large-scale dynamic centrifugal load test apparatus at the Public Works Research Institute. The outline of the model of countermeasure is shown in Figure 1.

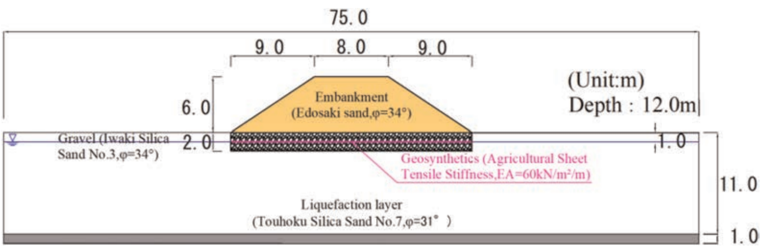

Figure 1. Outline of model ground.

2.2 *Material and seismic wave*

The liquefied layer was prepared by air-drop method using a sand hopper. The target relative density of the liquefied layer was Dr = 50%. A pore water pressure gauge and an accelerometer were set in the middle of the ground. The materials used in the experiment and their properties are shown in Figure 1. The Level 2 seismic wave (1995 Kobe, Japan) was used. The excitation time was 50 sec and the maximum acceleration was 557 gal.

2.3 *Results of dynamic centrifugal model experiment*

2.3.1 *Deformation of embankment*

The settlement of the embankment crest against time for each experiment is shown in Figure 2. The amounts of settlement at the center of the embankment crest and the embankment shoulder at 50 sec are 95 cm and 106 cm in Case 1 and 83 cm and 76 cm in Case 2, respectively. The settlement ratio of with/without the countermeasure is 87% at the center of the embankment crest and 72% at the embankment shoulder. The effect of suppressing settlement of the embankment crest by this method was lower compared to the previous study (Hla Aung 2021). The relation of excess pore water pressure ratio against time is shown in Figure 3. The negative excess pore water pressure ratio which is the same as positive dilatancy occurred during the first 5 sec to 15 sec for the case without the countermeasure, beneath the center of the embankment. This is because the shear deformation occurred at this location which is not compressive deformation by the liquefaction.

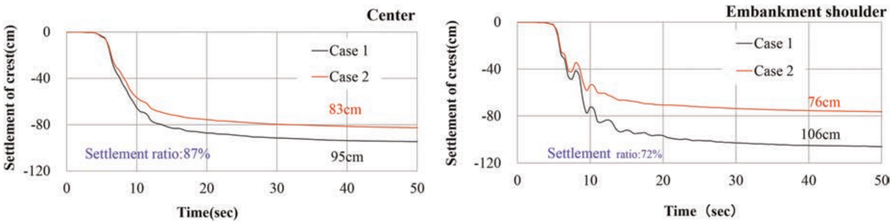

Figure 2. Relation of embankment crest settlement with times.

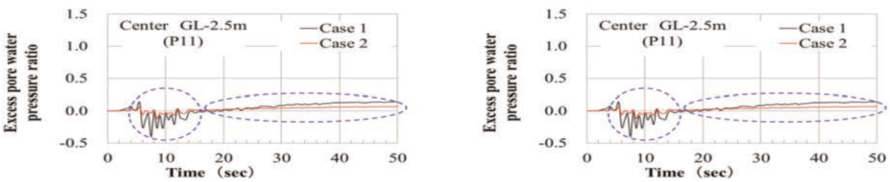

Figure 3. Relation of excess pore water pressure ratio against times.

2.3.2 *Factor analysis of embankment deformation*

The stretching amount of the embankment shoulders and toes was defined as the amount of widening in the horizontal direction. The lateral displacement of the liquefaction layer was defined as the maximum lateral displacement of the area directly under the embankment. The deformation of the embankment and liquefied ground after a seismic event are shown in

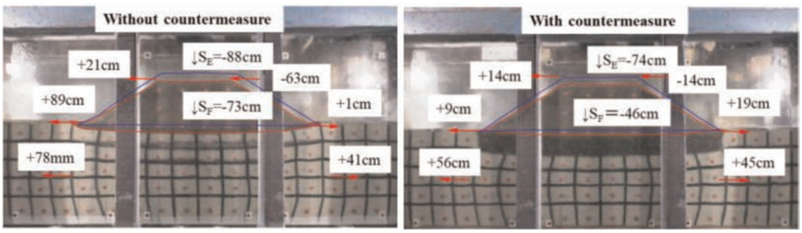

Photo 1. Deformation after seismic motion.

Photo 1. The stretching amounts of embankment shoulder without and with the countermeasure are -42 cm (21 cm, -63 cm) and 0 cm (14 cm, -14 cm), respectively. The stretching amount of the embankment toe without and with the countermeasure is 90 cm (89 cm, 1 cm) and 28 cm (9 cm, 19 cm), respectively. The embankment shoulder and toe stretching are greatly suppressed. It can be noted that the reduction of the liquefaction-induced deformation of the embankment by the countermeasure.

3 TWO-DIMENSIONAL DYNAMIC EFFECTIVE STRESS ANALYSIS

The 2D dynamic effective stress analysis program, LIQCA2D21, was used to reproduce the experimental results and predictive analyses under multiple conditions.

3.1 *Reproduction analysis*

LIQCA2D21 can reproduce the liquefaction of the ground and evaluate the excess pore water pressure, the deformation of the ground, and the embankment. A preliminary analysis was carried out for the purpose of reproducing the model experiment.

3.1.1 *Analysis conditions*

Analyses cases are Case 1 and Case 2 for without and with the countermeasures. The analysis mesh for Case 2 is shown in Figure 4. A drainage boundary was fixed at a depth of 1 m from the ground surface and the other surfaces are non-drainage boundaries. A 1m non-liquefaction layer was set around the crushed stones because the drainage effect of the crushed stone causes a smaller increase of excessive pore water pressure around the crushed stones and this was verified in the previous study (Hla Aung 2021). By setting the non-liquefaction layer, the analysis well replicated the experimental results.

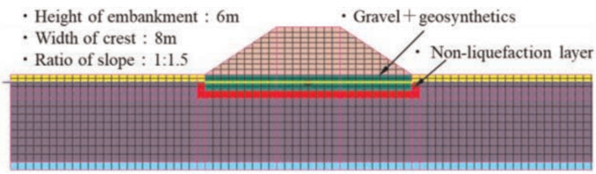

Figure 4. FEM model.

3.2 *Analysis results*

3.2.1 *Embankment crest settlement*

Figure 5 shows the settlement of the embankment crest against time. The final settlement at the center of the embankment crest shows a larger value than the experiment in Case 1. The

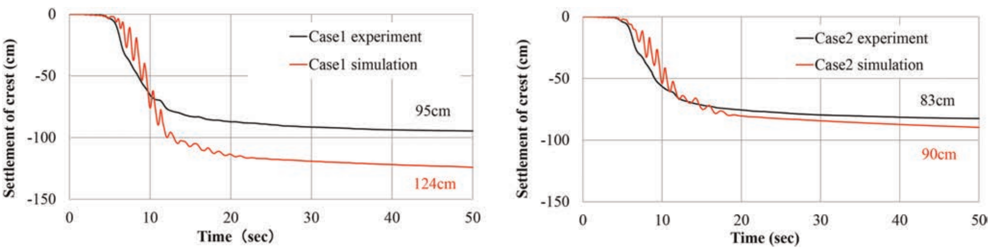

Figure 5. Relation of embankment settlement against times(Experiment · Simulation).

final settlement amount of the analysis of Case 1 is about 30% larger than the experimental value. Although the embankment settlement value obtained by the analysis is larger than the experimental value, the effect of settlement retention by the countermeasure can be expressed.

Figure 6 shows the relation of excess pore water pressure ratio against time. The excess pore water pressure ratio of the experiment and simulation of Case 1 is close to each other at the initial stage. After 5 sec, the analysis value of excess pore water pressure is about 7 times larger compared to the experiment. These results caused the settlement of analysis to enlarge compared to that of the experiment without the countermeasure shown in Figure 5.

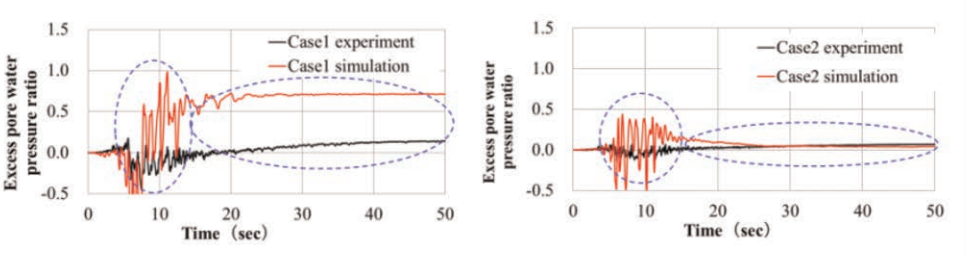

Figure 6. Relation of excess pore water pressure ratio against times(Experiment · Simulation).

3.2.2 *Deformation retention effect*

Figure 7 shows the deformation of the liquefied ground and embankment at the end of the vibration. The amount of stretching of the toe in Case 1 and Case 2 are 96 cm (57 cm, 39 cm) and 15 cm (10 cm, 5 cm) respectively. According to the above reproduced analysis results, it is possible to analytically confirm the effect of the countermeasures on the deformation reduction of the embankment.

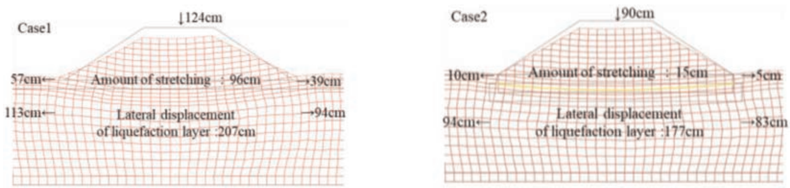

Figure 7. Deformation after seismic motion.

3.3 *Predictive analyses*

The predictive analyses were performed to verify the effects of the countermeasure under various conditions.

3.3.1 *Analysis conditions*

Analysis conditions are as follows: embankment heights of 2 m, 6 m, and 10 m, and liquefaction thicknesses of 5 m and 10 m. The embankment width and slope are 12 m and 1.5 m, respectively. The relative density of 50% and 70% of the liquefied ground and the Level 2 seismic motion are used in the predictive analysis.

3.3.2 *Analysis results*

The embankment crest settlements are shown in Figure 8. All the results are arranged at the excitation time of 50 sec.

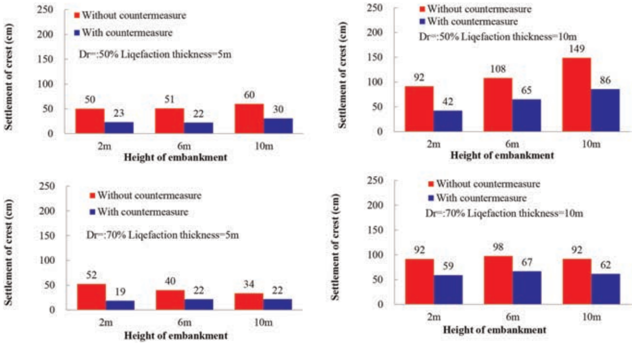

Figure 8. Settlement of embankment crest.

In the case of the relative density of 50%, the settlement of the embankment crest increases as the embankment height increases. On the other hand, in the case of the relative density of 70%, the amount of settlement does not necessarily increase with the height of the embankment. A height of more than 6 m reveals the phenomena of less settlement occurrence due to the effective stress influences.

Although the effect differs from case to case, the embankment crest settlement ratio (with/without the countermeasure) is 35% to 68%.

4 THE EFFECTIVENESS OF COUNTERMEASURE KEEPING EMBANKMENT SHAPE

The experiments and dynamic analysis show that the countermeasure refrains the embankment from spreading. It is similar to the deformation pattern IV in Figure 9, which appears in the guideline of road disaster countermeasure handbook published by Japan Road Association. The pattern illustrates the settlement without indifferential settlement and deformation while keeping the overall shape of the embankment. In this case, settlement below 50 cm is enough for a vehicle to pass. But it should be noted that the settlement of approach embankments, similar to Pattern V in Figure 9, must be below 20cm.

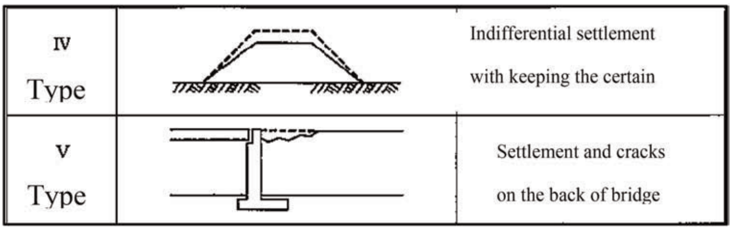

Figure 9. Classification damage patterns.

5 LEVEL 1 SEISMIC EVENT'S STATIC FINITE ELEMENT ANALYSIS

5.1 *Analysis condition and summarized simulation results*

The static finite element analysis program, ALID (Analysis for Liquefaction-Induced Deformation), is used to predict embankment settlement in Level 1 seismic. Analyses are conducted under various conditions of embankment heights (2 m, 6 m, 10 m), groundwater levels (GL-0 m, 1 m, 2 m), and liquefied ground thickness (3 m, 9 m,15 m).

5.2 *An example of estimation of settlement at the embankment crest*

An example of the estimation of settlements of the 5 m height embankment, under the condition of 1 m no liquefaction layer (groundwater level -1 m) and various liquefaction layers and $RL_{0.2}$, $RL_{0.25}$, are shown in Figure 10.

The settlement of the embankment at the crest of any thickness of liquefaction layers and RL values could be estimated using the two approximate equations shown in Figure 10.

The static finite element analyses results under Level 1 seismic condition (180 gal) simulate the amounts of the settlements. These results will be used as a reference guideline so that the road administrators could obtain the settlement of the embankment with a countermeasure without conducting a static finite element analysis.

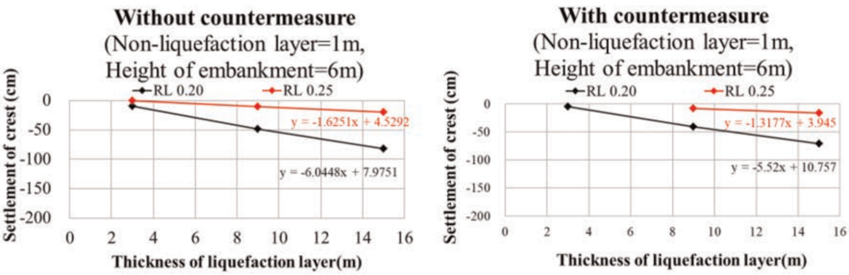

Figure 10. Settlement prediction for level 1 seismic.

6 CONCLUSIONS

In case of a severe seismic event, Level 2, and for a road that requires Performance 2, geosynthetics sandwiched with gravel layers have been proved as a potential countermeasure that tolerates some deformation that can be restored easily.

Experiments and dynamic finite element analysis show that the countermeasure prevents the stretching of the toe of the embankment.

The static finite element analyses results under Level 1 seismic event (180 gal) simulate the amounts of the settlements. These results will be used as a reference guideline so that the road administrators could obtain the settlement of the embankment with a countermeasure without conducting a static finite element analysis.

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