

Shaking Table Tests on a Deformation Mitigation Method for Existing Road Embankment during Liquefaction by Using Gravel and Geosynthetics

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Abstract. Small scale shaking table tests in a 1-g gravity field were carried out to evaluate effectiveness of a deformation mitigation method for an existing road embankment during liquefaction by using geosynthetics sandwiched between gravel layer and a gabion. The gravel layer could dissipate an excess pore water pressure during liquefaction immediately, and perform as a rigid plate below a slope of embankment. Furthermore, the gabion could confine the slope of embankment and restrain the lateral movement of slope. As a result, these functions could restrain the deformation of embankment, and keep the shape of embankment and flatness of crest.

1 Introduction

A settlement and deformation of road embankment was occurred due to soil liquefaction during earthquake. Because it brought a serious damage such as cracks and gap of road surface, even emergency vehicles such as ambulances and restoration work cars could not run through this road just after earthquake. Fig. 1 shows an example of road embankment damage during the 2016 Kumamoto earthquake in Japan [1]. Because the road embankment with a total length of about 30m collapsed at the Kyushu Expressway, it caused settlement and cracks to road surface, and this road was closed for 12 days after the earthquake. It was considered that the damage was caused by liquefaction of foundation under the embankment because this place was reclaimed land from the old river.

A liquefaction countermeasure technique for the embankment by using geosynthetics sandwiched between gravel had been proposed [2]. Because the gravel has high permeability, it will be able to dissipate excess pore water pressure rapidly. Furthermore, because the geosynthetics have high tension strength, the gravel layer with it will have high resistance against bending deformation due to overburden load of embankment. This method does not restrain the occurrence of liquefaction completely but mitigate the excessive deformation such as settlement and lateral movement. Its performance

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requirement is to secure a passable road for emergency cars and repair the road rapidly just after earthquake. It had been confirmed that this method has effectiveness for newly constructed embankment against liquefaction by a centrifuge model shaking test, a numerical analysis [2] and a shaking table test in a 1-g gravity field [3].

A liquefaction countermeasure technique for an existing embankment by using geosynthetics sandwiched between gravel under the slope and a gabion over the slope as a counterweight fill was proposed in this study. Fig. 2 shows the process of improvement to the existing embankment. Each step is as follows: (1) An embankment above liquefiable layer, (2) Excavating a part of slope surface, (3) Excavating a trench for gravel layer, (4) Installing gravel into the trenches and set a sheet of geosynthetics between gravels, (5) Reconstructing the slopes on the gravel layer, (6) Setting a gabion which filled with gravel on the slope surface.

Shaking table tests were conducted in a 1-g gravity field in order to evaluate the effectiveness of this method for the existing road embankment. As a result, this method could mitigate a lateral movement of slope, and a flatness of crest could be kept by this effect though the settlement of the slope increased due to the dead load of gabions.



Fig. 1. Damage of road embankment during the 2016 Kumamoto earthquake.

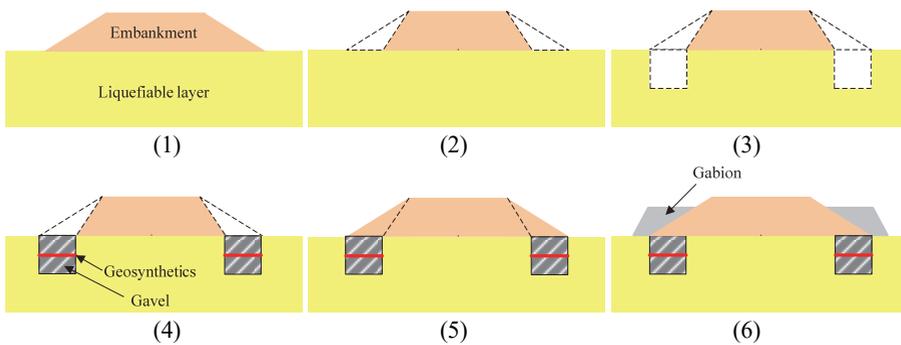


Fig. 2. Process of improvement to existing embankment.

2 Test procedures

Fig. 3 illustrates a cross section of top and side view of a model ground with a location of transducers. The model ground was set up in a rigid acrylic container whose size is 1200 mm long, 400 mm wide and 500 mm high. A liquefiable loose sand layer was formed under water by pouring silica sand No.7 ($\rho=2.66\text{g/cm}^3$, $D_{50}=0.17\text{mm}$, $k=4.79\times 10^{-3}\text{cm}$) through 2mm sieve to reduce the dropping velocity and to maintain it in the loosest state as possible. The relative density of this liquefiable sand layer was about 50%. A base layer which consists of dense sand was made by shaking the loose sand with acceleration of 100gal for 30 seconds, and then it came to about 90% relative density and 100mm depth. A liquefiable loose sand layer above the base was also formed by above method and its relative density came about 60% by shaking as mentioned above.

A gravel layer below the slope of embankment was 48mm x 390mm square and 50mm thickness, and a sheet of geosynthetics made by polyethylene was sandwiched between the gravel layers. No. 7 crushed stones ($\rho=2.72\text{g/cm}^3$, $D_{50}=3.55\text{mm}$, $k=1.09\times 10^{-1}\text{m/s}$) were used as the gravel. An embankment with 50mm height and 1:1.6 slope was built of clay mixed with silicone whose mass ration is 22%. Its target unit weight was 15kN/m^3 . The size of model embankment was scaled down one seventy-fifth of real embankment whose height was 4m and width of crest was 10m. A gabion with 35mm height and 1:0.5 slope consists of gravels which is placed into 2mm square wire mesh cage. It was set on the slope surface as a counterweight fill. Conditions of improvement are illustrated in Fig. 4.

An input wave used in tests was a sinusoidal wave with a frequency of 5Hz and peak magnitude of 140gal as shown in Fig. 5. At first, the duration time of 6 seconds was used as a first shaking, and then the duration time of 24 seconds was used as a second shaking after the measurement of ground deformation. Pore water pressure transducers, accelerometers and displacement meters were installed at the locations as shown in Fig. 3. A vertical displacement of the embankment was measured along three lines by using a point gauge.

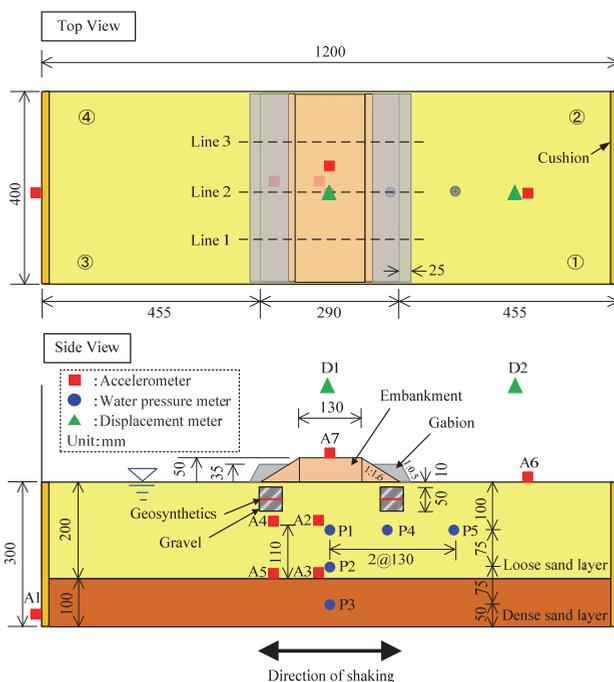


Fig. 3. General view of model ground.

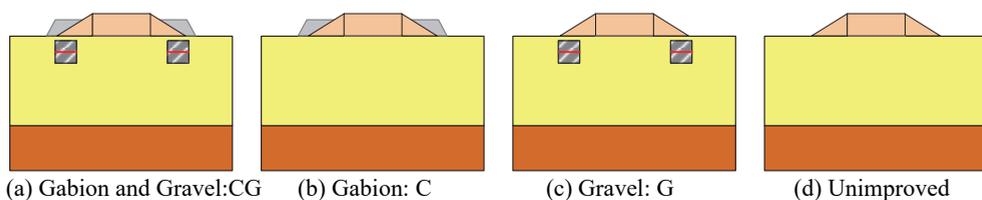


Fig. 4. Conditions of improvement.

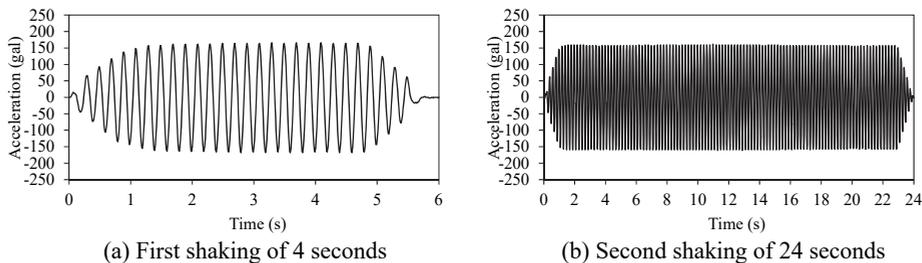


Fig. 5. Time history of input acceleration.

3 Test results and discussions

Fig. 6 shows a height of embankment from the surface of loose sand layer which were measured after first shaking of 6 seconds. It does not include the settlement of loose sand layer. This experiment focused on an effect by only occurrence of liquefaction. It can be seen that the embankment of cases CG and C which were with gabions sunk larger than case G without gabions. And also, the settlement of case CG was larger than case C without gravel layer. Therefore, it is considered that differences of settlement were influenced on the dead load of gabions and gravel layers, because of the embankment which lost bearing capacity. However, the shape of crest and the inclination of slopes in the case of improved were kept as compared with unimproved ground.

Fig. 7 shows a height of embankment from the surface of loose sand layer which were measured after the second shaking of 24 seconds. This experiment focused on an effect of continuous shaking. The settlement at the slopes was large due to the weight of gabions in the cases of CG and C. However, the settlement at the toe of slopes in the case of CG was smaller than case C. It suggests that the stiffness of gravel layers below the slopes can mitigate the lateral movement of slopes and settlement there. The embankment without gabions completely collapsed and its crest was deformed concavely because large lateral movement occurred at the slopes. Meanwhile, although a vertical displacement was large due to its weight in the case of unimproved, the shape of embankment and flatness of crest could be kept because the lateral movement was mitigated by gravel layers and gabions.

Fig. 8 shows time histories of excess pore water pressure ratio located at P4, 100 mm in depth from ground surface just under the slope of embankment during the second shaking of 24 seconds. These records were smoothed by using a moving average method. It is clear that maximum pressures of cases CG and G with gravel layer were restrained due to high permeability of gravel. However, it seems that the time of dissipation took a long time in the cases CG and C with gabions. It is considered that the permeability of gravel layer decreased because the gravel layers were deformed by the settlement due to the weight of gabions.

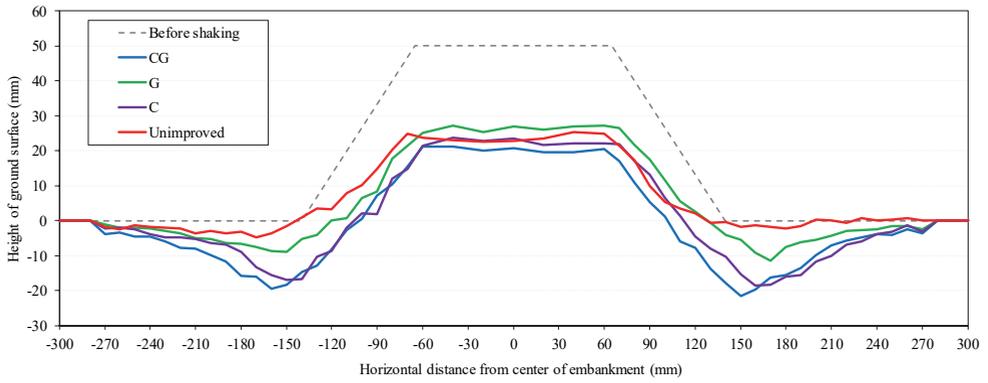


Fig. 6. Deformation of embankment after first shaking of 4 seconds.

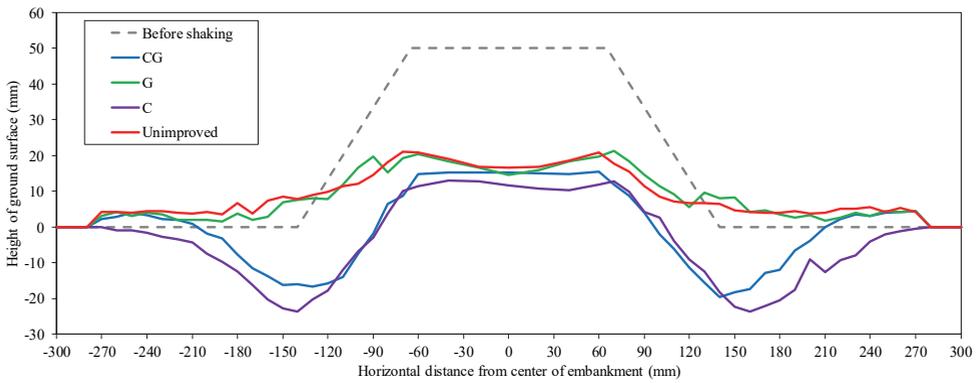


Fig. 7. Deformation of embankment after second shaking of 24 seconds.

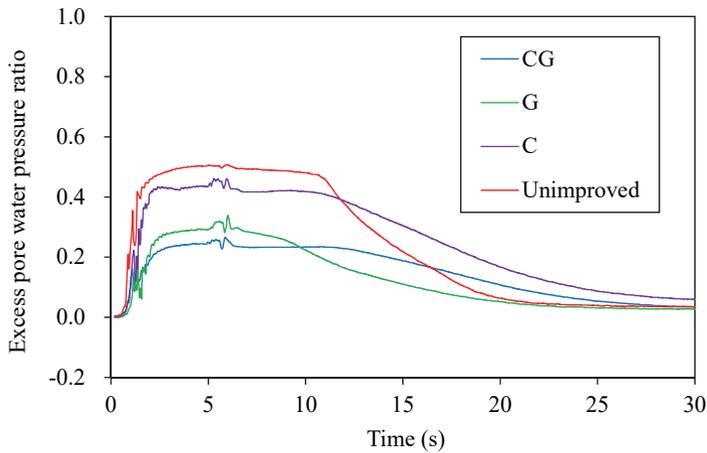


Fig. 8. Time histories of excess pore water pressure ratio at P4 during first shaking.

4 Conclusions

The liquefaction countermeasure technique for the existing embankment by using geosynthetics sandwiched between gravel layer under the slope and gabion over the slope as the counterweight fill was proposed in this study. Shaking table tests were conducted in a 1-g gravity field in order to evaluate the effectiveness of this method for existing road embankment. The following conclusions were obtained on the basis of the experimental study. Even if the bearing capacity of the foundation ground under embankment was decreased, the deformation of embankment could be mitigated due to confining the slopes by gabions, rigidity of gravel layers below the slopes and dissipation of excess pore water pressure by permeability of gravel layers. As a result, this method could mitigate the lateral movement of slopes, and this effect could keep the shape of embankment and flatness of crest though the settlement of crest increased due to the dead load of gabions.

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