Shake Table Tests on Mitigation of Liquefaction Lateral Spreading by Using Gravel and Geosynthetics

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Liquefaction-induced lateral spreading has imposed damages to structures during past earthquakes. This paper presents experimental results of a series of large scale 1 g shake table tests on mitigation measures for models reinforced with gravel and geosynthetics and subjected to liquefaction-induced lateral spreading. Firstly, observations linked with the mechanism of lateral spreading based on the test without remedial measures is presented, followed by the results based on tests with remedial techniques by using gravel only and then gravel combined with geosynthetics as well. General test results including time-histories of accelerations, pore water pressures and displacements are presented and discussed in this paper. The results indicated that by applying the proposed mitigation measures, the seismic performance of the soil models can be improved by reducing excess pore water pressure and ground lateral displacement.

Key words : liquefaction, lateral spreading, geosynthetics, gravel, shaking table test

1. INTRODUCTION

During past earthquakes, many important structures have been subjected to severe damages due to lateral displacements of liquefied ground named as lateral spreading. Lateral spreading is the term used to refer to the development of large horizontal ground displacements due to earthquake-induced liquefaction, in the case of even small free ground surface inclination or small topographic irregularities, e.g. river and lake banks (Valsamis et. al., 2010). As described by Bartlett and Youd (1992), it occurs on mild slopes of 0.3-5% underlain by loose sands where a shallow water table is present. Such soil deposits are prone to excess pore water pressure generation, liquefaction and consequently large lateral displacement during seismic excitations. Recent earthquakes have highlighted the fact that lateral movement becomes more known and important for civil engineering structures since it inflicts considerable lateral loads and may lead to widespread failures, one of the examples can be seen in **Fig. 1**.

As time goes through, it appears that many methods could be applied as countermeasure for liquefaction, e.g. by using gravel and geosynthetics. Gravel, or also called crushed stone, due to its high friction and drainage properties, is the effective technique as well to be used as liquefaction countermeasure. Morikawa et. al. (2014) presented that liquefaction of the ground can be reduced by using crushed tiles. Furthermore, Geosynthetics have been used world widely in many fields due to their merits such as its high tension strength in order to improve the problematic soils, for instance, liquefiable soil.

Fig.1 Lateral Spreading during 2016 Kumamoto Earthquake.

The use of a mix of gravel and geosynthetics will be a good technique to mitigate liquefiable soil problems. In accordance with this, Murakami et. al. (2010) presented unification between geosynthetics with gravel in order to restrain liquefaction for embankment. They concluded that the use of geosynthetics sandwiched between gravel will have high resistance against bending deformation due to overburden load of the embankment. Even though this method does not overcome the occurrence of liquefaction completely, but it alleviates the excessive deformation such as settlement and lateral movement.

The objective of this paper is to study the influence of geosynthetics and gravel reinforcement on horizontal displacement of liquefiable soils with mildly sloping ground. Large 1-g gravity field shaking table tests have been conducted in order to investigate the influence of the reinforced soil on liquefaction-induced lateral displacement of liquefied soil.

2. SHAKING TABLE TEST

A series of models were constructed and tested at the Earthquake Engineering Laboratory of Kanazawa University.

The sand container used has dimensions of 150 cm length, 75 cm width, and 75 cm height. The box size was selected in order to provide enough space for the soil to move laterally towards the downslope. The sand box was built from galvanized steel and acrylic/plexiglas.

Liquefiable loose sand layer was designed by pouring the sand through the sieve into the water. The sand that used in this research was silica sand No. 7 with index properties ρ=2.66g/cm^3, D_{50}=0.17mm and k=4.79x10^{-3}cm. The relative density of this liquefiable soil was around 50%.

The remedial measures used in this study were gravel and geosynthetics. The first method, crushed stone No. 5 (ρ=2.56g/cm^3, D_{50}=3.55mm and k=10.9cm) were used as the gravel to formed a gravel layer with 6 cm thick. Furthermore, a sheet of geosynthetic made by ofelin sandwiched between the gravel layer used as a second technique.

Fig. 2 shows the schematic cross section and plan view of the physical model along with the layout of accelerometers, water pressure meter, and displacement meters. As can be seen in this figure, the ground in the model consisted of a liquefiable sand layer with a relative density of 50 % and mildly sloping ground (approximately 4^o).

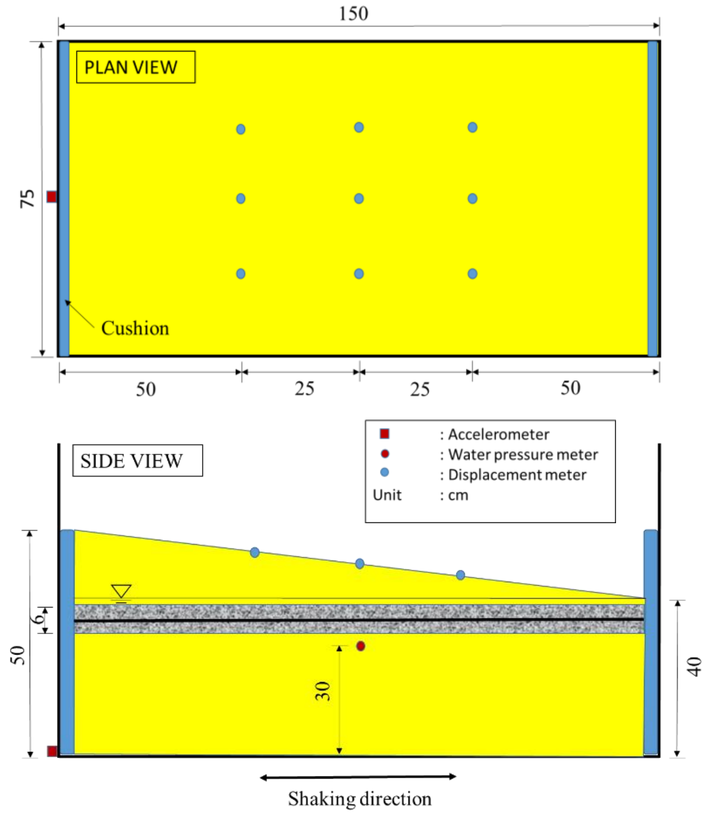

Fig.2 Schematic cross section and plan view of the physical model and installed instruments.

3. TEST RESULTS AND DISCUSSIONS

In this part, a summary of the main data measured during the shaking table test such as acceleration, water pressure, and lateral spreading is presented and discussed.

(1) Acceleration

As can be seen in **Fig. 3** an input wave used in the test was a sinusoidal wave with a frequency of 3 Hz, peak magnitude of 50 gal and shaking time duration was 15 seconds.

(2) Excess pore water pressure

Pore water pressure monitored in three different conditions; firstly sand with no remedial measure, secondly used gravel only, and last remedial by using gravel and geosynthetics. Water pressure meter situated in the center of the sand box in-depth about 30 cm from the bottom of the container. **Fig. 4** displays sample recorded water pressure time histories for three different conditions as mentioned before.

As seen in the graph, the presence of the reinforcing materials tend to reduce the pore water pressure. Pore water pressure measurement shows that the best result in order to lower pore water pressure obtained from remedial method by using gravel and geosynthetic.The model with gravel and geosynthetic managed to reduce pore water pressure up to 25% compared with a model without countermeasure. This good result exhibits the ability of the hybrid of geosynthetic and gravel layer in dissipation of excess pore water pressure developed during the shaking time.

(3) Lateral displacement

Fig. 5, **Fig. 6** and **Fig. 7** display lateral displacement measured through 9 points at the sand surface in three different states; no countermeasure, gravel only, and geosynthetic sandwiched between gravel, respectively.

Based on the test results, as can be perceived on the pictures, generally, the amount of the movement is reduced with the presence of the remediation measure materials.

As seen in these figures, the value of the lateral displacement varies for every different model. By comparing the three figures, it can be determined that the lowest amount of lateral spreading obtained from model reinforced with gravel and geosynthetic.

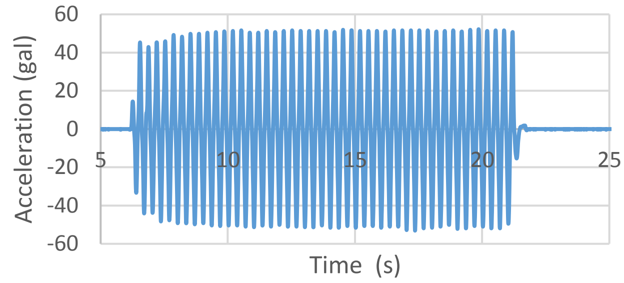

Fig.3 Acceleration time histories.

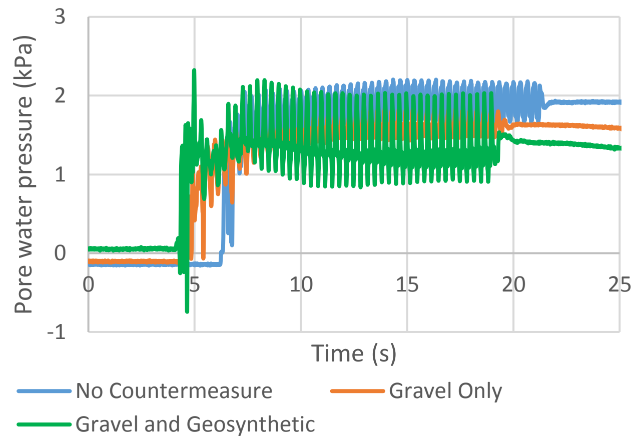

Fig.4 Sample excees pore water pressure time histories

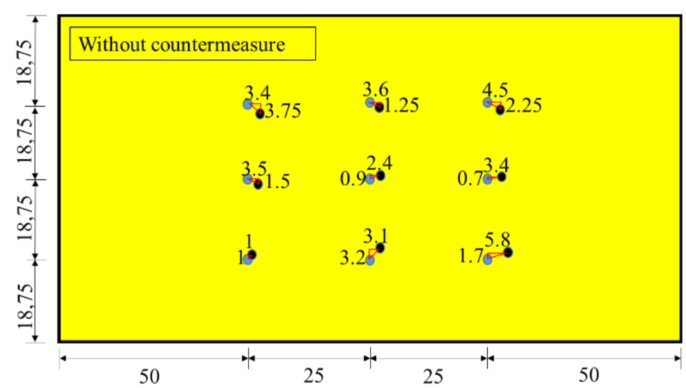

Fig.5 Lateral soil displacement of model without remedial measure

The coherence of gravel layer with its high permeability and high tensile strength provided by geosynthetic considered as the main reason for this best result. By comparing the lateral displacement of all points between no measure model and model with geosynthetic sandwiched between gravel, the highest amount of lateral displacement reaches around 70%.

Even though results showed some irregularities on lateral displacement amount, particularly in gravel only remediation, it can still be judged that the using of gravel and geosynthetics is one of the solutions that can be recommended to be used in order to reduce liquefaction-induced lateral spreading.

4. CONCLUSIONS

In order to measure the effectiveness of gravel and geosynthetics remediation to reduce the liquefaction-induced lateral spreading of liquefiable soils, shaking table tests were performed. Following conclusions can be noted as the main outcomes of this study :

(1) The excess pore water pressure measurement showed that the existence of gravel with its high porousness generates shorter time in water pressure dissipation.

(2) Merged with geosynthetic which furnished with high tensile strength, this method could perform as an inflexible stratum with high permeability, which considered contributed to reduce excess pore water pressure as well up to maximum reach around 25%.

(3) Model improved with gravel and geosynthetic correspondingly gives good results in order to degrade the amount of liquefaction-induced lateral spreading which the maximum result obtained is that this method can minimize the lateral displacement up to 70% compared to non-reinforced model.

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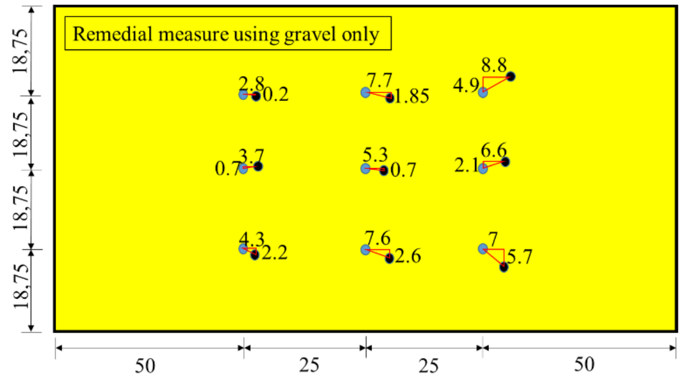

Fig.6 Lateral soil displacement of model with gravel remediation

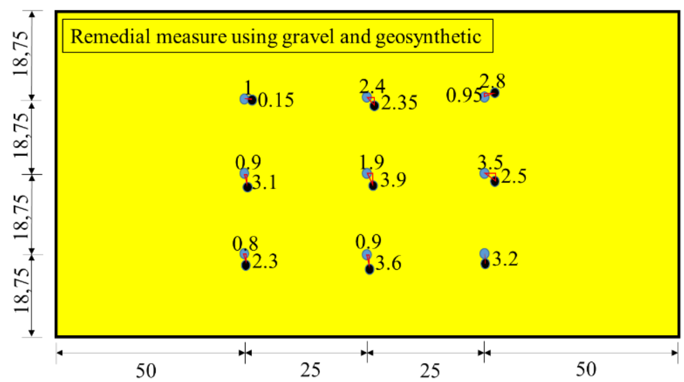

Fig.7 Lateral soil displacement of model with gravel and geosynthetic remediation

REFERENCES

1) Valsamis, A. I., Bouckovalas, G. D., Papadimitriou, A. G.: Parametric investigation of lateral spreading of gently sloping liquefied ground, *Soil Dynamics and Earthquake Engineering* 30, pp. 490-508, 2010.
2) Bartlett, S. F., Youd, T. L. : Empirical analysis f horizontal ground displacement generated by liquefaction-induced lateral spreads, Technical Report, NCEER-92-0021, National Center for Earthquake Engineering Research, 1992.
3) Morikawa Y., Maeda K., and ZHANG F. : Effectiveness of Crushed Tile in Countermeasure Against Liquefaction, *Journal of GEOMATE*, Vol. 7 No. 1 (S1. No. 13), pp. 1003-1008, 2014.
4) Murakami, K., Kubo, M., Matsumoto, T. and Okochi, Y. : Study on the effect of deformation control embankment during liquefaction by using geosynthetic sandwiched between gravel, *Geosynthetics Engineering Journal*, Vol. 25, pp. 133-140, 2010.