Development of a new aseismic reinforced construction method by using soil-bag stacks at the toe section of the embankment

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ABSTRACT

The authors have proposed an aseismic reinforcement method for a road embankment by using soil bags that can reuse local embankment materials. In the results so far, it is confirmed that when the pre-stress pressure of 75 kN/m^2 or more is applied to the soil-bag stacking, deformation due to subsequent excitation is suppressed. In this study, shaking table test of a full-scale earth embankment was conducted in order to examine the reinforcing effect of the soil-bag structure when introduced at the toe section of the existing embankment. Both stability analysis and test results confirmed the effect of soil-bag stacks in increasing the overall seismic resistance of the embankment.

Keywords: new aseismic reinforced construction method; soil-bag stacks; honeycomb structure

1 INTRODUCTION

Many of the existing embankments spread across Japan require drastic maintenance, because their earthquake resistance is considerably questionable due to the poor quality of the embankment materials used and insufficient compaction. The collapse of the Tomei highway embankment, damaged by the Suruga-bay earthquake in 2009, is a typical case example that shows the need of serious attention. It is therefore, an urgent task for researchers/engineers to develop technologies capable of quickly and accurately judge the vulnerable parts of these risky existing embankments that are also viable to be implemented efficiently and economically.

The authors have recently proposed an aseismic reinforcement method for a road embankment by using soil bags that is cost-effective, easier to construct and can reuse local embankment materials (Shibuya et al., 2016). Fig. 1 shows the proposed model of a new aseismic reinforced construction method. The construction steps can be listed as: i) excavate the limited area of the toe section of the embankment, ii) stack a tightly compacted pillow type soil-bags (n.b., thickness about 20 cm) in the form of a honeycomb, and iii) anchor the soil-bag structure by anchor bolts. By installing such stiff structure at the toe section of the embankment, the overall stability of the cited embankment increases, hence, the damages by rainfall and earthquakes may also be minimized.

In order to understand the effect of soil-bag structure on the earthquake protection of the embankment, static loading tests were performed in the past on soil-bag stacks. The results concluded that the rigidity of the soil-bag stacks could be expected by stacking the soil-bag on the honeycomb structure and applying the prestress load (Fig. 2). In addition, tests were also performed on soil-bag stacks by considering the lateral pressure from the embankment. The result confirmed that when the prestress load of 50 kN/m^2 or more is applied on the soil-bag stacks, deformation due to subsequent excitation is suppressed appreciable, as shown by Fig. 3 (Kuda et al. 2017). By considering the results so far, a shaking test of a full-scale embankment was performed in this study on the machine owned by National Research Institute for Earth Science and Disaster Resilience (NIED) and the usefulness of the soil-bag stacks as a new aseismic reinforced construction method was examined.

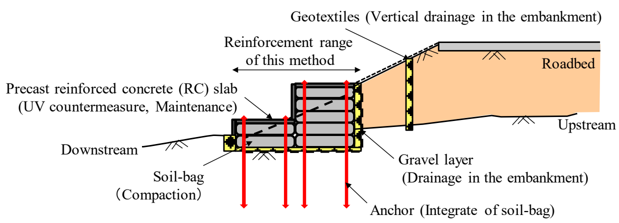

Fig. 1. Proposed model of a new aseismic reinforced construction method.

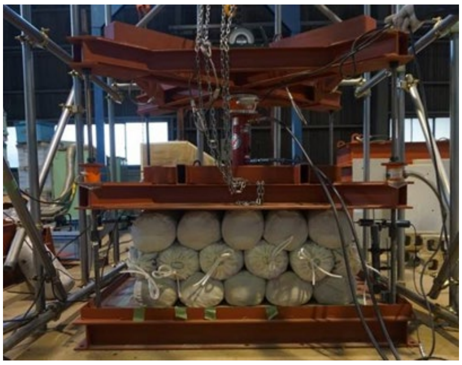

Fig. 2. Static loading test of the soil-bag stacks.

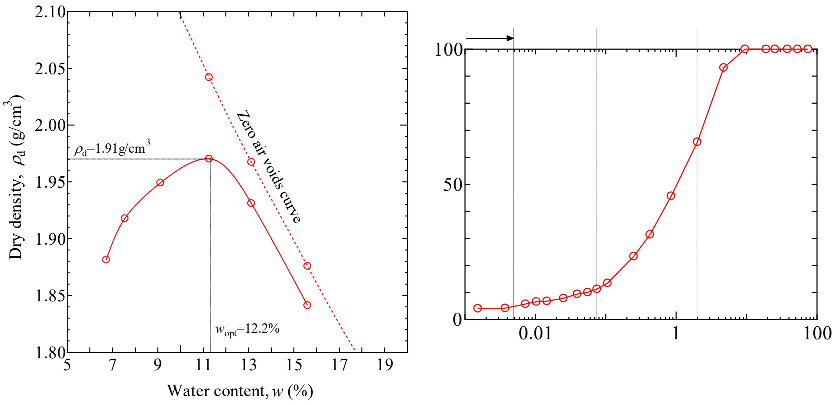

Fig. 4. Compaction curve (left) and grain size distribution curve (right) of test material

Fig. 3. Shaking test of soil-bag stacks considering the lateral pressure from the embankment.

Fig. 5. Pillow type soil-bag.

2 TEST METHOD

The compaction curve and grain size distribution curve of the soil used in this experiment are shown in Fig. 4. In the tests, embankments without (Case 1) and with reinforcing soil bag stacks at the toe section (Case 2) were constructed at the same water content and dry density. The pillow type soil-bags (20 cm in diameter, 50 cm in length) used in the toe section of the embankment were compacted by dropping them 10 times from the height of 30 cm, as shown in Fig. 5.

For the shaking test, a large shaking table apparatus owned by NIED was employed. The size of the shaking table was 15 m × 4.5 m. The embankment was constructed inside the container (11.6 m in length, 4.0 m in depth and 5.0 m in height) installed on the shaking table. Fig. 6 shows schematic diagrams of the two experimental embankments (Case 1 and 2). The degree of compaction and the water content of the soil used for both embankments are almost same, as shown in Fig. 7. In case of Case 2 embankment, soil-bag stacks were installed at the toe section up to one-third of the embankment height. The height of the soil-bag stacks was obtained from the result of preliminary numerical analysis by considering the earthquake resistance of test embankment (Kato et al., 2016). Fig. 8 shows details of the soil-bag stacks. The soil-bags were loaded to form a honeycomb structure to resist deformation from the side. After that, soil-bag stacking was prestressed vertically to 75 kN/m^2 by using six anchor bolts before applying the seismic load.

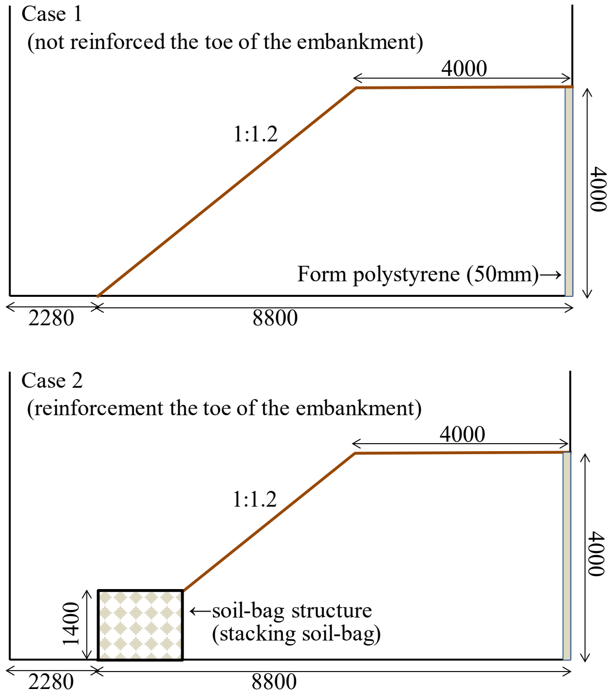

Fig. 6. Outlines of Case 1 and Case 2 embankments.

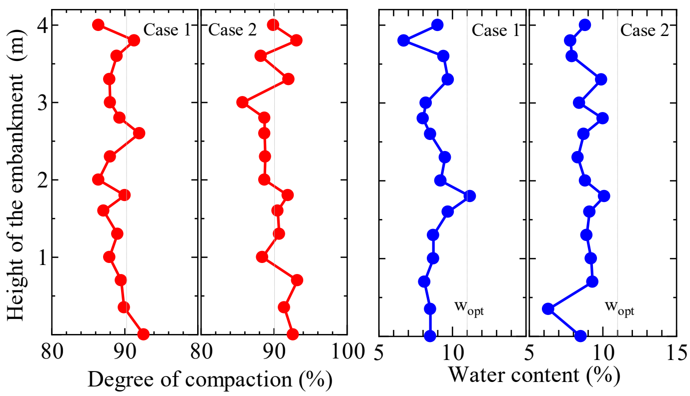

Fig. 7. Degree of compaction and water content at both embankments

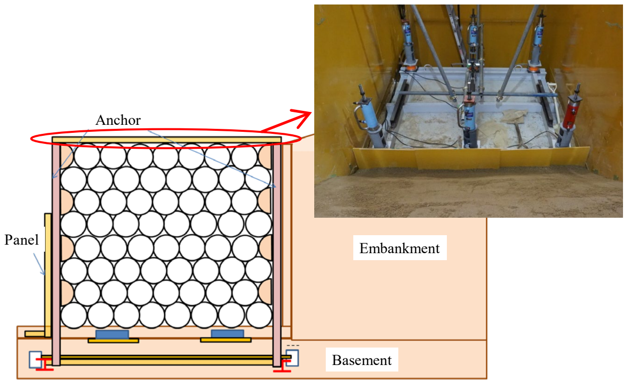

Fig. 8. Outline of the soil-bag stacks.

Regarding the input excitation, the acceleration of sine wave waveform of 2 Hz frequency was varied as 100, 250 and 750 Gal. Strain gages and accelerometers were installed inside both test embankments, at every 1.0 m interval from the toe section.

3 SIMPLE CIRCULAR SLIP STABILITY ANALYSIS OF THE SLOPE

A circular arc slip stability analysis was carried out with COSTANA and by using the physical properties of the embankment materials, as shown in Table 1. Here, the parameters of the soil-bag stacks were calculated from the constant pressure direct shear test (Ishida et al., 2017), and the soil-bag stacks were considered as a rigid body for the analysis.

Fig. 9 shows the result of analyses for the Level 2 earthquake excitations. From these two figures, factor of safety (F_s), slightly smaller than unity in Case 1 and more than unity in Case 2 is easily noted. Therefore, the seismic reinforcement method using the soil-bag stacks can be expected to promptly restore when the embankment collapses.

4 RESULTS AND DISCUSSION

Both cases of embankment collapsed with an extremely high input acceleration of 750 Gal. When the embankment collapsed, the maximum output acceleration measured on the shaking table for Case 1

Table 1. Parameters used for stability analysis

	Embankment	Soil-bag stacks
γ_{sat} (kN/m^3)	20.29	20.0
γ_t (kN/m^3)	18.53	19.0
c (kN/m^2)	27.0	80.0
ϕ (°)	36.0	34.0

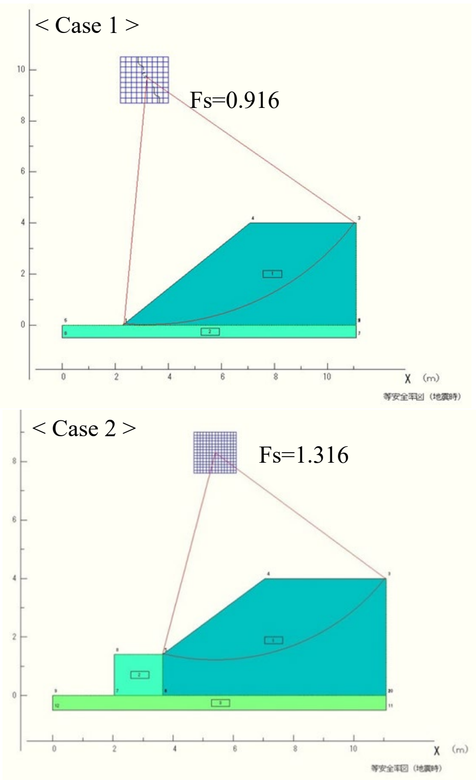

Fig. 9. Result of the analysis (Level 2 earthquake motion).

was 750 Gal whereas, for Case 2, it was 800 Gal. In the following paragraph, we discuss on both embankments collapse conditions.

Fig. 10 shows the deformation of test embankments before and after the excitation surveyed by 3D. It is clear that the scale of embankment damage was notably decreased due to the installation of soil-bag structure. Calculating the amount of soil movement in both embankments before and after excitation, the amount of soil discharged in Case 2 was less than half the amount of Case 1. It was also confirmed that there was no shear deformation of sliding of the soil-bag stacks during 750 Gal excitation in Case 2. In addition, from the Fig. 11, it was confirmed that the soil-bags maintained the honeycomb structure. Therefore, it is plausible to write here that deformation due to vibration did not occur due to stable prestress given to the soil structure.

Fig.12 shows the penetration resistance before and after the excitation at the crest of the embankments. This test was performed by lightweight dynamic cone penetration test apparatus. From these results, it can be

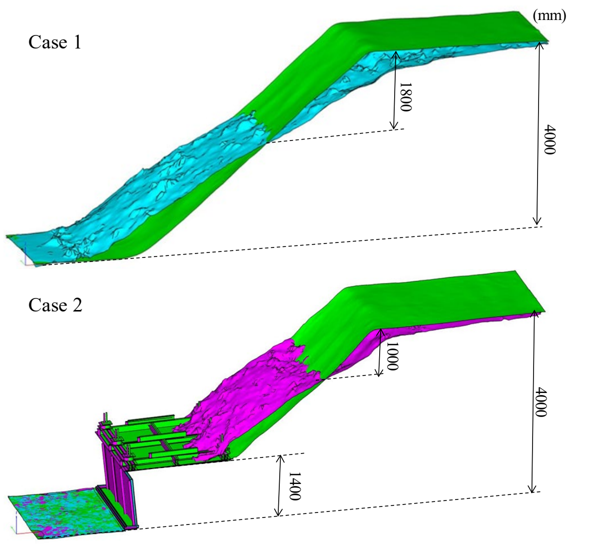

Fig. 10. The deformation of the embankment before and after the excitation.

Fig. 11. Soil-bag stacks after the shaking test (750Gal).

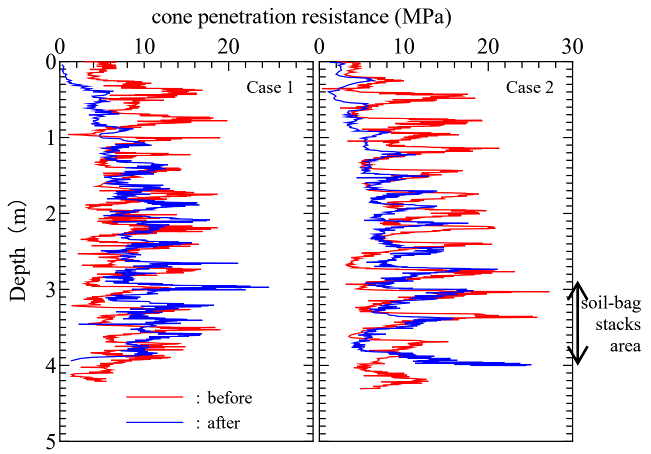

Fig. 12. Cone penetration test results measured by lightweight dynamic cone penetration test.

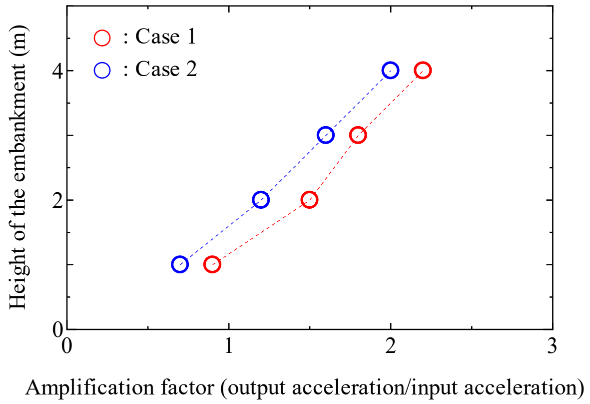

Fig. 13. Comparison of acceleration amplification.

understood that both embankments have lower strength after excitation than those before shaking. In addition, the intensity after the excitation tended to be slightly lower in Case 1 than in Case 2. Case 1 bottom section seems to have increased the resistance and also convincing because of large soil movements. In addition, as shown in Fig.11, the soil bag state might not have changed in Case 2 even when subjected to the large acceleration of 750 Gal.

Fig. 13 shows the amplification amount of input acceleration inside the embankment. As the amplification factor (i.e., the ratio of measured acceleration to that of input wave) of Case 2 is noticeably lower than Case 1, the earthquake resistant effect of the soil bag structure was validated.

5 CONCLUDING REMARKS

Based on the results obtained by using the large shaking table test, the effect of soil-bag stacks in increasing the overall seismic resistance of embankment was confirmed. Although the simple circular slip failure analysis produces larger factor of safety, the test data showed the failure in both cases due to a large input acceleration of 750 Gal. Inclusion of limited earth movement in the analysis, such as observed in the test cases, is expected to produce the better correlations between the two. With the test data, it is also expected that if the embankment reinforced by the soil-bag structure is damaged by a large earthquake, the amount of deformation would be limited.

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REFERENCES

Kato, T., Shibuya, S., Nakanishi, N., Katayama, M., Yui, H., Toshito, S., Ito, S. and Ishida, M. (2016). A seismic reinforcement at the toe of embankment using sandbag-structure Part4: A trial design for a collapsed road embankment, 51th Japan National Conference on Geotechnical Engineering, 1135-1136 (in Japanese).

Shibuya, S., Tani, K., Beak, J.M. and Jeong K.B. (2016). Aseismic reinforcement at the toe of embankment using sandbag-structure -Part1: Basic idea, 51st Japan National Conference on Geotechnical Engineering, 1129-1130 (in Japanese).

Ishida, M., Shibuya, S. Kataoka, S., Nakanishi, N., Kato, T., Toshito, S. and Ito, S. (2017). Direct box shear test of soil – Bag materials in use for reinforcing the toe of the existing embankment, Geosynthetics Engineering Journal, 32, 203-208 (in Japanese).

Kuda, T., Shibuya, S., Kataoka, S., Tajima, R., Moriyoshi, Y., Moriguchi, Y. and Nakazawa, H. (2017). Enhancing aseismic stability of road embankment by reinforcing the toe with soil-bag structure, Geosynthetics Engineering Journal, 32, 175-182 (in Japanese).