Failure mechanism and effect of sheet pile countermeasure for embankment liquefaction

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1. Introduction

River dikes at more than 2000 locations were damaged due to Off the Pacific Coast of Tohoku Earthquake in March 2011, of which main causes were not only foundation soil liquefaction but also liquefaction of embankment soil. Sheet pile as a countermeasure had been widely used to reduce damage due to the foundation liquefaction. For cases of embankment liquefaction, more research works are needed for the better understanding the failure mechanisms and effects of countermeasure technique. In this study, centrifuge tests were conducted to investigate the failure mechanisms of embankment with and without sheet pile.

2. Centrifuge Testing Program

Centrifuge tests were conducted to simulate the liquefaction of embankment with and without sheet piles at toes of embankments. A total of 4 tests were conducted including one benchmark model and three countermeasure models as shown in Figure 1. Two countermeasure models had the different sheet pile length, 2 m (prototype) for model B and 1 m (prototype) for model C. All models were constructed in a rigid container with internal dimensions of 43 cm long, 12 cm wide and 22.7 cm deep with transparent one side wall. Testing was performed in 50 g centrifugal acceleration. 5 cm (prototype) thick Aluminum plates were used as model sheet piles. The models consisted of a 1 m deep drainage layer, a 2 m deep dense foundation soil (Toyoura Sand, Dr=95%) and a 4 m height loose sand embankment. The embankment soil was silica sand no.8 with the mean grain size D_{50}=0.1 mm. This soil was prepared at a water content of 19.2% and compacted in a wooden mold of a trapezoidal shape to a dry density of 90% the maximum dry density (D_c=90%). The model was fully saturated with a 2% Metolose solution in the vacuum chamber. The model was set on the centrifuge and excess water was drained at 50 g until the water level in the embankment was 1 m above the base of

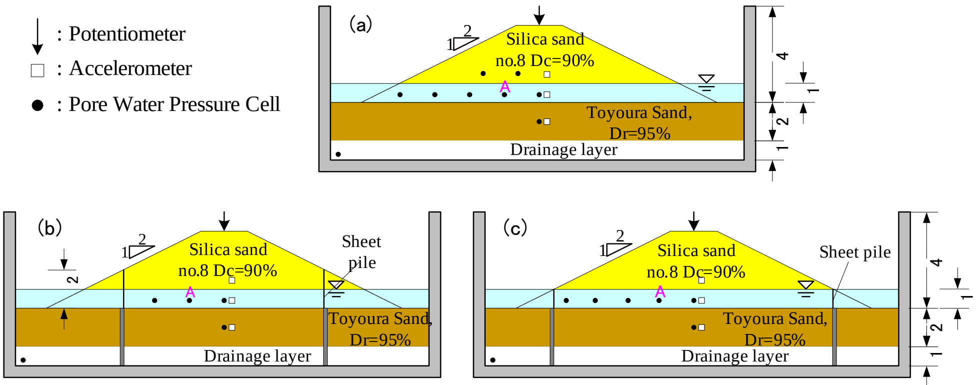

Figure 1. Model configuration, (a) Benchmark model; (b) Sheet pile 2 m height; (c) Sheet pile 1 m height

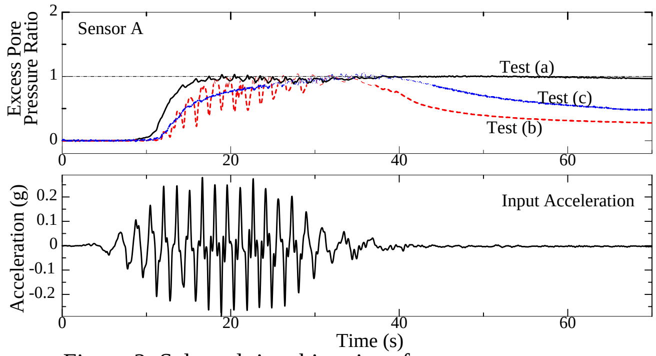

Figure 2. Selected time histories of excess pore pressures of 0.28 g shaking event

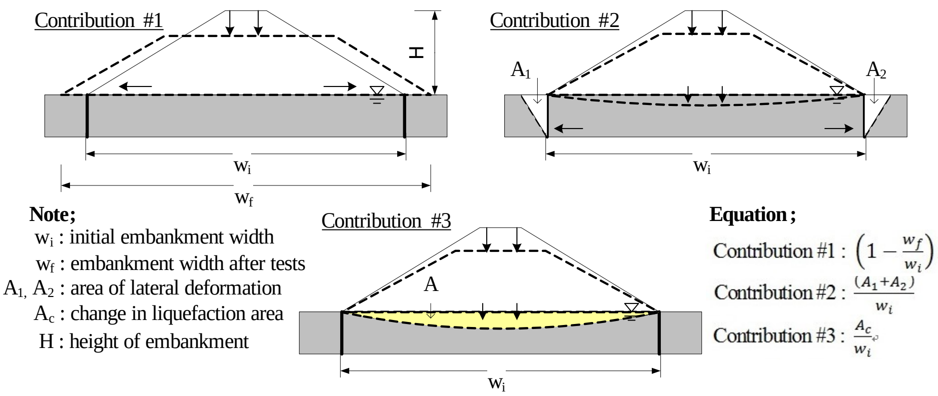

Figure 3. Guideline to measure the contribution factor for crest settlement

embankment. Two shaking event were imparted to all the models with input peak acceleration A_{max}=0.16 g and 0.28 g.

3. Analysis

Figure 2 represents acceleration and excess pore pressure ratio (EPPR) of A_{max}=0.28 shaking events. The excess pore pressure ratio of all models reached unity in several cycles. Effective overburden pressure used to calculate EPPR was estimated simply from the thickness of the soil just above the sensor location. Okamura (2002) described three contributions category to determined dominant factor that affect the liquefaction failure as shown in Figure 3. Contribution #1 is crest settlement due to shear deformation of embankment, contribution #2 is crest settlement due to lateral deformation of foundation soil, and contribution #3 is crest settlement due to volume change of foundation soil. These three contributions are estimated based on the photographs taken after the tests. Three contributions for the crest settlement analyzed above were shown in figure 4. It was found that major mechanism of crest settlement of the benchmark model was shear deformation of embankment (contribution #1). For model B and C, the sheet piles effectively constrained shear deformation. Figure 5 shows the photo of model A before the test. The red line and red dots in the figure represents the surface of the embankment and lattice points after the test. Figure 6 indicates displacement vector and maximum shear strain contours of the three models. Benchmark model (model A) deform from crest and spreading to toe of embankment. This also suggests that shear deformation was major mechanism for this model. However, shear deformation decrease due to existence of sheet pile in model B and C. It was also observed that the sheet piles improved integrity of embankment. Significant cracks and fissures were observed for the benchmark model but no such degradation was found for models B and C.

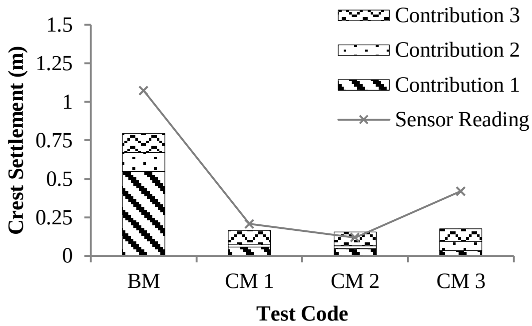

Figure 4. Contribution factor of embankment to crest

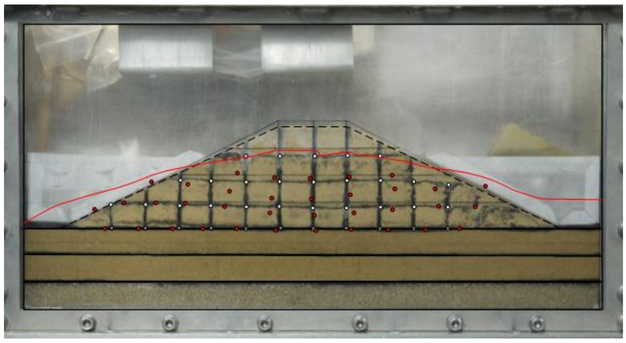

Figure 5. Shear deformation and failure pattern guideline

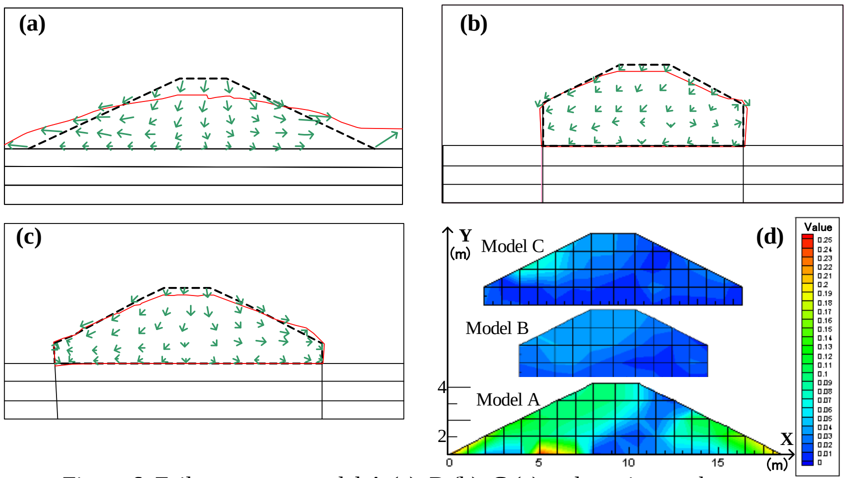

Figure 6. Failure pattern model A (a), B (b), C (c) and maximum shear strain distribution all models

4. Conclusion

Three centrifuge tests of embankment model with and without sheet piles at toes were conducted to look into deformation mechanism due to embankment liquefaction. It was found that the major mechanism of crest settlement is the shear deformation of embankment. Sheet pile as countermeasure greatly assisted to reduce the shear deformation and thus, crest settlement of the embankment.

References

(1) Okamura, M., Matsuo, O. (2002): “Effects of remedial measures for mitigating embankment settlement due to foundation liquefaction,” Int. Journal of Physical Modelling in Geotechnics 2, pp. 01-12. **(2)** Okamura M, Tamamura S, Yamamoto R (2013): Seismic stability of embankments subjected to pre-deformation due to foundation consolidation. Soil and Foundation 53(1):11-22.