Experimental research in soil liquefaction inside an embankment resting on soft ground

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1. Introduction

The 2011 Tohoku earthquake occurred on 11th March 2011 led to catastrophic devastations including liquefactions underneath embankments which were located on the impermeable ground. Before 201, many researches have been focused on the liquefaction occurred in the ground. On the other hand, this huge earthquake led to the occurrence of liquefaction inside embankment, therefore the research focusing on the liquefaction inside embankment would be important for preparedness of the coming huge earthquakes but such few researches have been done at this moment. In terms of strength against liquefaction, many researchers, for instance, Tobita et al. (2005), have investigated the behaviors of embankments on liquefiable ground for which the liquefaction resistance affected by loading history, ground water level, and other factors were considered. However, few researches focusing on the liquefaction inside embankment have been conducted. Therefore, this study aims at the relationship between liquefaction and initial stress.

2. Outline of centrifuge test

The centrifugal acceleration up to 50G using the centrifuge apparatus at Kyoto University, Uji campus was applied for all cases of model test. After 50G, the viscous water, which was adjusted to maintain consistency with the scaling law, was supplied beneath the central zone of an embankment, following by the input excitation wave. The original excitation wave set by the frequency of 1 Hz and a time period of 30 seconds times a scale law n is shown in Figure 1. The maximum acceleration level of almost 200 gal measured at the central bottom of an embankment is shown in Figure 2 as a typical example of the propagation of acceleration due to this input wave. Since liquefaction occurs when the pore water pressure overcomes the earth pressure at the same point inside an embankment, earth pressure gauges (EP), pore water pressure gauges (PP), and acceleration gauges were embedded in an embankment model as shown on Figures 3-5 for observation. Table 1 shows the condition of each test regarding with the amount of input excitation and the scale of each excitation wave.

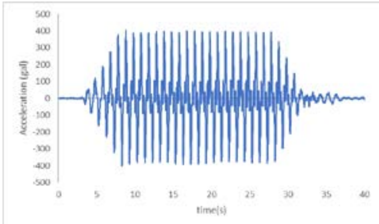

Figure 1 Original wave

Figure 1 Propagation of wave

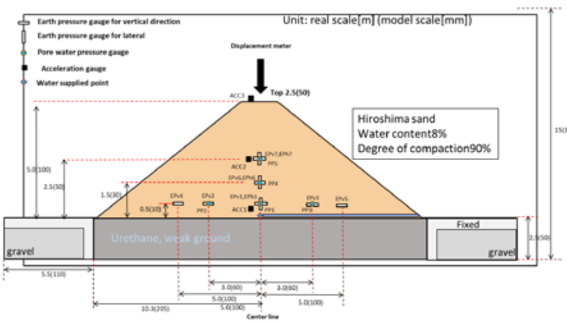

Figure 2 Layout of each gauge set for Case1 & 2

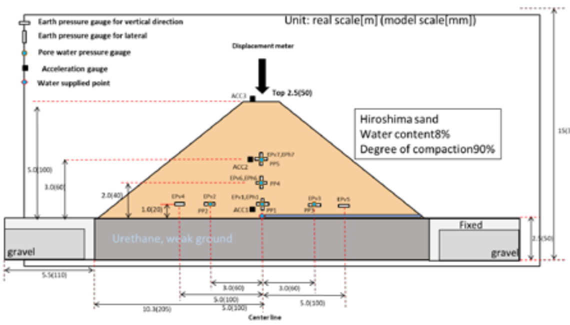

Figure 3 Layout of each gauge set for Case3~5

Table1 Condition of each test

Cases	Amount of excitation	Magnification and order of excitation wave
Case1	2	1→1
Case2	3	1→1→1
Case3	6	0.33→1→0.33→0.66→1→2
Case4	3	1→1→1
Case5	4	1→1→1→2
Case6	1	1

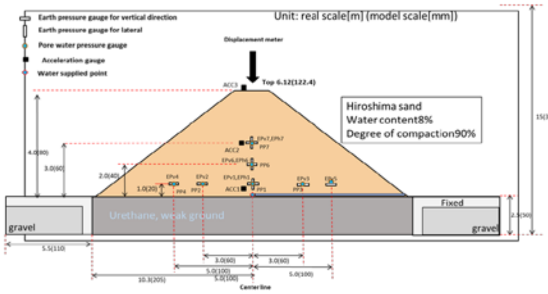

Figure 4 Layout of each gauge set for Case6

Keywords: Soil liquefaction, Reliquefaction, Soil arching, Embankment, Dynamic behavior
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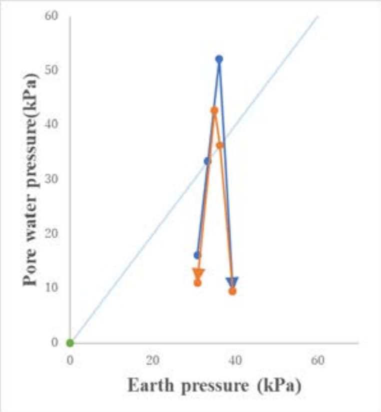

Figure 5 Stress transition at Case1

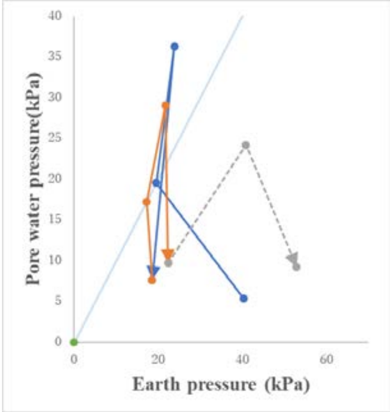

Figure 6 Stress transition at Case2

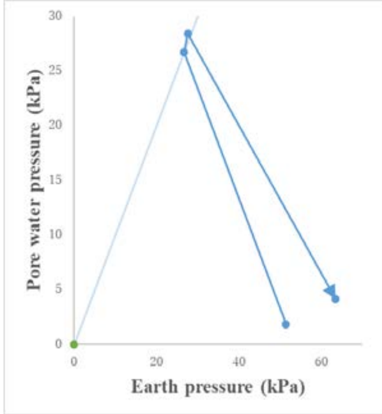

Figure 7 Stress transition at Case6

3. Results of experiment and consideration

As a result, the occurrences of liquefaction were observed at Case1, Case2 for each 1st and 2nd excitation and at Case 6 at the central bottom of an embankment, in addition, formations of soil arching at Case1, 2 and 6 was also observed. Due to the distribution of earth pressure inside the embankment like arch formation, the central bottom of an embankment is considered vulnerable to liquefaction. To evaluate the influence of the initial stress distribution on the behavior of embankment under earthquake occurrence, the transitions of earth pressure and pore water pressure during the excitation at the central bottom of an embankment are plotted in the Figure 5, 6, and 7. Results of each case using 4 points are connected by arrow lines. The 1st point represents the static condition before the excitation, the 2nd point exhibits the liquefaction occurrence, the 3rd point shows the peak pore water pressure due to the excitation, and the last one is the static condition after excitation (before the next excitation). In these figures, according to each result, from Case1 and 2, built-up pore water pressure induced by the second excitation was lower than that of the 1st one. In case2 and 3, the conditions of stress distribution might reach the situation in which liquefaction hardly occur. These results indicated that the series of excitation might lead to strengthen the liquefaction resistance inside an embankment. Under the same layout of instrumentation, while the height of an embankment for Case6 is lower than Case1&2, arching effect remained in Case1 and Case2, but did not remain in Case6 due to the excitation. Therefore, the height of embankment is considered as one of important factors for soil arching. Figure 8 shows the transition of each stress of other cases in which liquefaction did not occur due to the excitations which had the same scale of original wave. This figure shows that all points move away from the line of liquefaction, including the 3rd excitation at Case2 (Figure5, grey line) where the earth pressure is higher compared with that of the pore water pressure; so that liquefaction hardly occur. Focusing on the initial stress condition before the 1st excitation, when the earth pressure is higher than 50kPa, liquefaction is not expected to occur at the central bottom of an embankment.

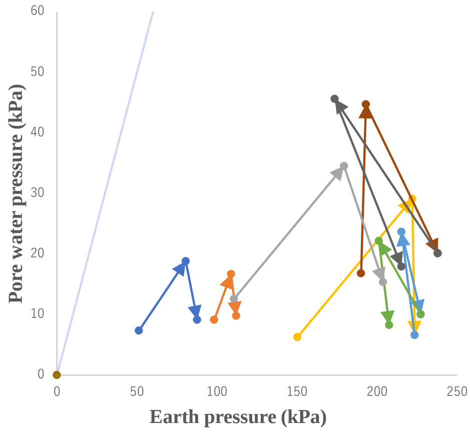

Figure 9 Stress transitions for Case3~5

4. Summary

In this research, centrifuge tests were conducted in order to evaluate the behavior of embankment under earthquake. As a result, under soil arching condition, liquefaction was easily occurred, and soil arching was hard to collapse. Moreover, the accumulation of earthquake seems to lead to the increase of liquefaction resistance regardless of existence of soil arching. In addition, the criteria for liquefaction occur or not, we can consider that the initial earth pressure at the central bottom of an embankment is higher than 50~60 kPa and this condition can indicate that the soil arching inside embankment exist or not. In this research, Urethane was utilized to model a flexible ground, but the experiments might not able to realize the actual ground condition.

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Reference

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