DYNAMIC CENTRIFUGE MODEL TEST ON THE APPLICATION OF DRAIN METHOD TO PREVENT SAND BOIL DUE TO LIQUEFACTION

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1. INTRODUCTION

The effectiveness of drain method on preventing sand boil was proved by previous studies (Nguyen *et al.*, 2019; Sassa *et al.*, 2017) by using static seepage centrifuge tests, while in this study a series of dynamic model tests are conducted, to reproduce sand boil due to liquefaction and to determine the performance of drain method on suppressing this behavior.

2. CENTRIFUGE MODEL TEST

A soil model test was prepared in a centrifuge box with an inner dimension of 600 mm length x 500 mm height x 200 mm width. The model ground as shown in Fig. 1 consists of a loose sand layer with an 8.5 m thickness on the prototype scale made of Tohoku sand No. 7. This layer was made by air pluviation method to attain a specific density of 40 % (ρ_d = 1.353 g/cm^3, ρ_{sat} = 1.925 g/cm^3) while colored sand was also used to make black lines with a pitch of 1 m at the front face of the ground model (Fig. 2 and Fig. 3). To enhance sand boil, an 80 mm thick impermeable layer made of bentonite (ρ_t = 1.220 g/cm^3) was placed on top of the sand layer. The water table was then set to 0.5 m below the sand layer's surface on the prototype scale. In this experiment, a viscosity fluid (γ_w=1.170 g/cm^3), a mixture of glycerin and water to achieve a viscosity of about 20 times the viscosity of water (centrifugal force of 20G was applied), was used to simulate the prototype permeability of the soil. Accelerometers and pore water gauges were installed during model preparation to measure the acceleration and pore water pressure of model ground during the experiment. Importantly, the pore water pressure gauges were set at various depths to observe the dissipation path of water pressure. Detail of model ground including cross-section and plan view, as well the position of gauges and accelerometers is presented in Fig.1.

To identify the effectiveness of the drain method, 2 test cases were conducted including the unimproved soil and the improved soil with drain material. The improvement pattern of drain materials was decided based on the previous studies (Nguyen *et al.*, 2019), where the drains (diameter of 10 mm in model scale) were applied with a spacing of 1.3 m as shown in Fig.1. The drains were installed to the depth of 3 m below the water table, while their tops were extended to the ground surface allowing the water to flow-out. The model ground was prepared at laboratory-floor and saturated at 20G centrifuge condition by injecting the viscosity fluid from the bottom. The initial water table was confirmed by pore water pressure gauges and visual checks. The centrifuge was then stopped to remove the fluid tank before starting the main experiment. The model ground was liquefied by a ground motion with an acceleration of 300 Gal in 50 seconds (frequency of 3 Hz). To enhance sand boil, the model ground was subjected 3 times of motions with a gap of about 1500 seconds applied between seismic events, allowing exceed pore water pressure to dissipate. High-speed cameras were also used to observe the front face and the top view of the model ground.

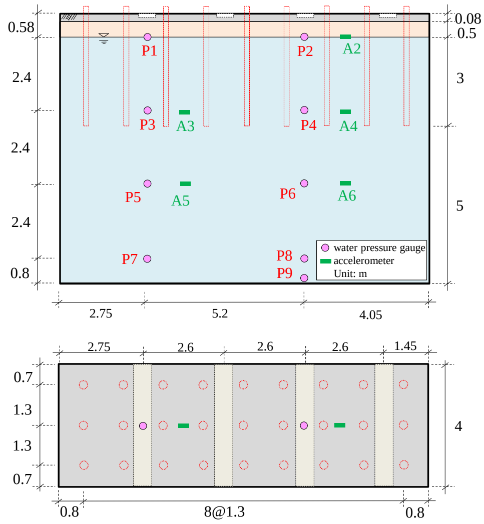

Fig. 1 Soil model (prototype scale)

3. EXPERIMENT RESULT AND DISCUSSION

3.1 Unimproved soil

The front face of model ground before and after motions taken from a recorded video is shown in Fig. 2, while the changes of pore water pressure and the exceed pore water pressure ratio (E.P.W.R) with time are presented in Fig. 4. The pore water pressure increases significantly in all areas of model ground due to motions, causing the liquefaction of soil. The increasing pore water pressure tends to dissipate to the ground surface, resulting in saturation of the dry sand layer above the water surface. The dissipation of pore water pressure furthermore lifts the impermeable layer where a thin layer of water appears between the sand and the impermeable surface layers. These behaviors were observed from the front view camera during the experiment. Also, according to the top view camera, there are several cracks appear in the lifted-up surface layer due to the accumulation of pore water pressure

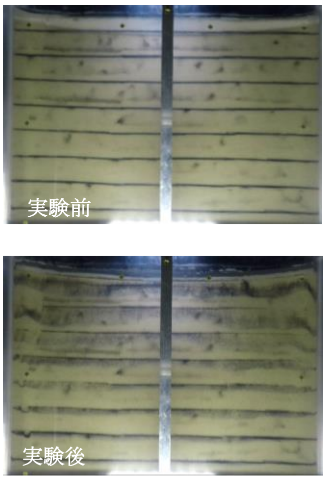

Fig. 2 Unimproved soil

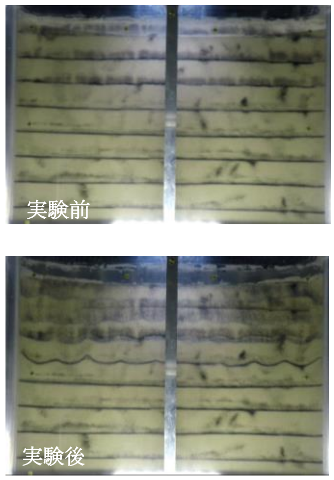

Fig. 3 Improved soil

during its dissipation after the second motion. The upward dissipation of water pressure is also confirmed from the time history of pore water pressure in Fig. 4. The pore water pressure at the depth portion (P7, P8, P9) starts to decrease right after the seismic event, while at lower depths the pressure continuously increases. The lower the depth is the longer the water pressure increases. For example, water pressure at P1 and P2 is increasing for further 600 seconds after the motion. As a result, the E.P.W.R. at shallow depths becomes greater than 1 as shown in Fig. 4. Although sand is not ejected to the ground surface, the upward dissipation of water pressure, the uplift of the surface accompanying cracks, and the discharge of water can be considered as the main features of boiling phenomena.

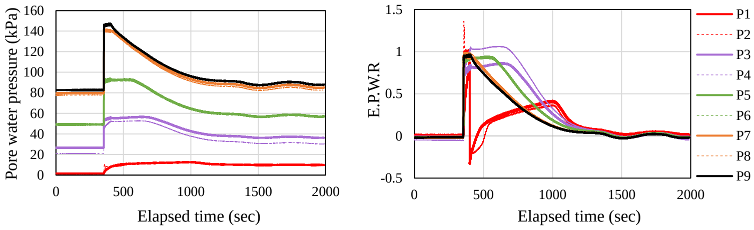

Fig. 4 Unimproved soil (the first motion)

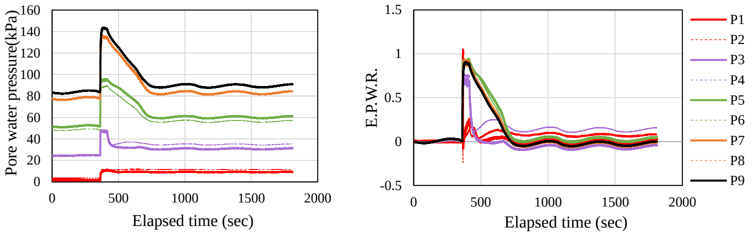

Fig. 5 Improved soil (the first motion)

3.2 Improved soil

By turning to the model ground with drain improvement, the deformation of the model ground and the measured pore water pressure are presented in Fig. 3 and Fig. 5 respectively. The model ground liquefied due to the motion where the E.P.W.R increases to 1 during vibration as shown in Fig. 5. The increase of pore water pressure and its upward dissipation are almost the same as that of the unimproved soil. However, a close examination of the observed soil behavior tells us that excess pore pressures at/above the bottom of the drains were lower than those at the same depths in the unimproved soil. Also, irrespective of the depth, the increasing water pressure starts decreasing soon at the end of the motion. Especially, the dissipation suddenly takes place and almost finishes right after the vibration at shallow depth with drain improvement, while at deeper portions (P5 to P9) without drain the dissipation takes a longer time to finish. It is proved that the effectiveness of drain improvement on enhancing the permeability of improved ground resulting in a fast dissipation of excess water pressure. From the front-view camera, the uplift of the impermeable layer, observed in the test with unimproved soil, is not found in this case where the dissipating water does not accumulate below this layer. On the other hand, from the top-view camera during the experiment, water starts dissipating directly to the ground surface at the time of vibration. By contrast, it takes more than 500 seconds after the motion for water to well up to the surface in the unimproved soil. The enhancement of water dissipation by using drain is also confirmed with a large amount of water welling out from the soil, resulting in a large settlement of model ground (Fig. 3). The settlement strongly occurs at the drain-improved portion with large compaction as shown in Fig. 3. The settlement of the ground surface is also measured by using a laser transducer at the end of the experiment. A settlement of 0.65 m is confirmed in the case with drain improvement, compared to a 0.4 m settlement in the unimproved soil. A comparison of the time history of pore water pressure between two test cases is presented in Fig. 6. In general, the excess pore water pressure starts to decrease earlier with drain improvement irrespective of the depth. The use of drain material also prevents the continuous increase of water pressure after motion which happens in the unimproved soil. Consequently, the drain method can also prevent sand boil caused by the accumulation of dissipating water pressure. Besides, by enhancing the soil permeability with drain, the process of water dissipation (P3, P4) completes soon after vibration, resulting in a quick recovery of the soil strength that is reduced by the increase of water pressure. In unimproved soil, this process takes more than 700 seconds (at P3, P4) after vibration, which remains the soil in an unstable condition in such duration. The effectiveness of drain material is obviously proved by the prevention of sand boil and the quick recovery of improved soil strength.

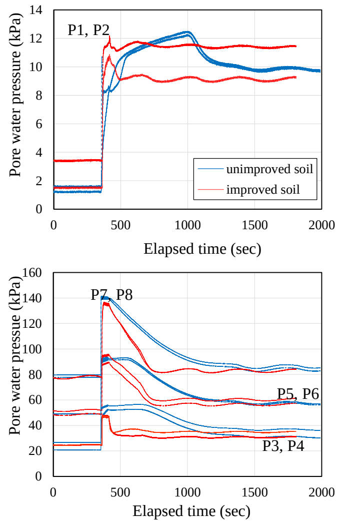

Fig. 6 Comparison between 2 cases

4. CONCLUSION

Dynamic centrifuge model tests are successfully conducted to reproduce sand boil behavior and to evaluate the effectiveness of the drain method in preventing sand boil. By applying the drain material to the shallow portion of a loose sand layer, the pore water pressure generated during earthquakes can instantly dissipate, preventing the accumulation of pore water pressure and boiling as well. On the topic of boiling prevention using drain material, the design procedure and field trial test will be further considered to bring the method for practical application.

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