砂の堆積方向を考慮した振動台による液状化試験

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1. Introduction

Liquefaction, as stated by Bardet (2003) and the United States Geological Survey, is a phenomenon where saturated loose sands lose their strength through strong ground vibrations because of increase of pore water pressure. Figure 1 shows how liquefaction affects to the structure.

Figure 1. Liquefaction phenomenon and its effects on structures.

When liquefaction occurs beneath buildings and other structures, heavy damage occurs during earthquakes. Therefore, study of liquefaction was conducted in the field of Geotechnical Engineering.

One of the most notable examples of liquefaction, as mentioned by Sana (2021) is caused during the 1964 Niigata Earthquake as shown in Fig. 2, in which 3,534 houses were destroyed and another 11,000 were damaged. This level of damage was induced by liquefaction caused in the poor sub-soil conditions.

Figure 2. liquefaction damage caused by the 1964 Niigata Earthquake

In the Geotechnical Engineering Laboratory, the shaking table tests were conducted to study the liquefaction process using model ground with a certain deposition angle of sand. The results obtained from the experiment can help determine when the liquefaction start to occur and how the starting time is changed by the deposition angle of the sand particles.

The main objective of this study is to evaluate the effects of sand deposition angle on the liquefaction resistance using the shaking table test, in which accelerations and pore water pressures are measured. Moreover, microscopy measurements were conducted to estimate soil's particle orientation.

2. Experiment

2.1 Tools used in experiment

For the experiment, we used the shaking table (Fig. 3) with a container (Fig. 4), which has dimensions of 50 cm in length, 20 cm in width and 40 cm in height. Model ground was created with a height of 28 cm.

Figure 3. Shaking table

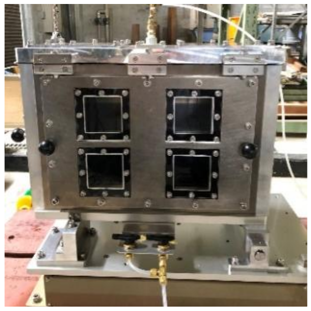

Figure 4. Soil container

In the model ground, 2 types of sensors are placed as shown in Fig.5: one is an accelerometer to calculate the cyclic stress during shaking, the other is pore water pressure meter to determine liquefaction from the excess pore water pressure ratio.

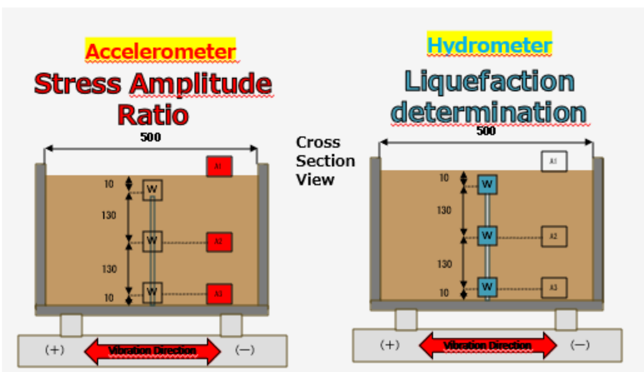

Figure 3. positions of sensors in model ground

2.2 Experimental Procedure

The container was inclined according to the target depositional angel (0, 45 or 90 degrees) as shown in Fig. 6. In this manner, the sand is then poured into the mold with a certain height to obtain the desired relative density.

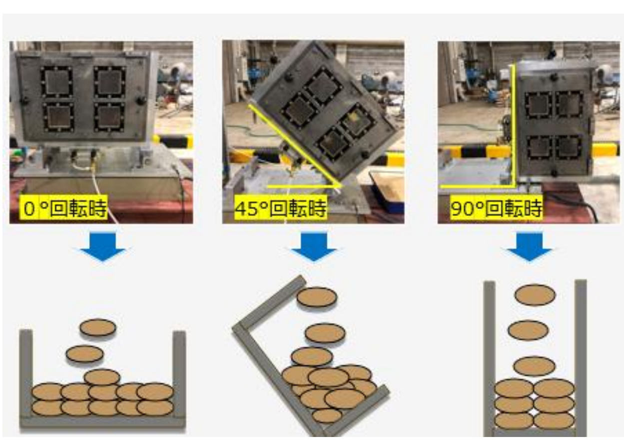

Figure 4.Setting for inclined container

After the sand was sedimented, the container was set in horizontal direction. Then degassed water was supplied from the bottom of the container under full vacuum condition. After saturation of the ground, the vacuum was released. Then the cyclic acceleration was applied to the container to generate liquefaction. After the liquefaction tests, microscopic pictures were taken in the front face of the model ground to measure the orientation angle of the soil particles (Fig 7).

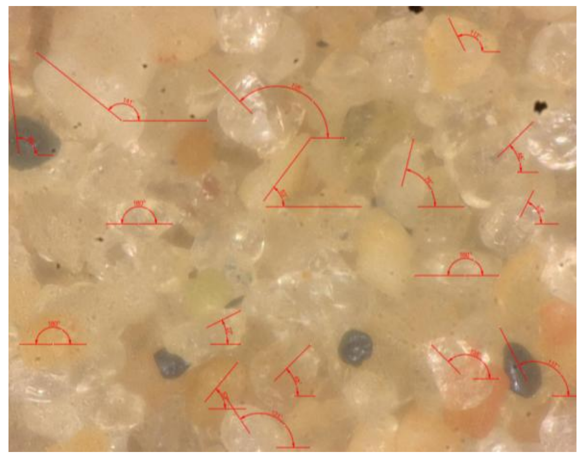

Figure 5. Microscopic picture of the sand particles (with their orientation angles)

2.3 Testing cases

For this research, 3 different depositional angles and 2 different densities were considered as shown in Tables 1 and 2:

Initial Sand Deposition Angle (°)	0, 45, 90
Relative Density (%)	60%
Sample Weight (kg)	42
Vibration Acceleration (gal)	350
Frequency of vibrations (Hz)	5
Cycle (Times)	20

Table 1 Experimentation Parameters for Case 1

Initial Sand Deposition Angle (°)	0, 45, 90
Relative Density (%)	30%
Sample Weight (kg)	43.5
Vibration Acceleration (gal)	200
Frequency of vibrations (Hz)	5
Cycle (Times)	20

Table 2 Experimentation Parameters for Case 2

3. Results

Figures 8 and 9 present the relations between excess pore water pressure ratio and number of cycles induced by shaking from the excess pore water pressure data obtained at middle and bottom part of the ground, respectively.

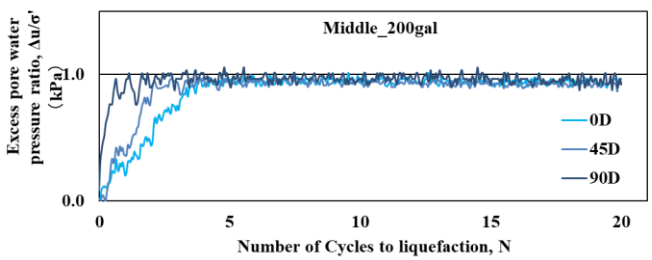

Figure 8. Relations between excess pore water pressure ratio and number of cycles (first liquefaction, middle part of the ground)

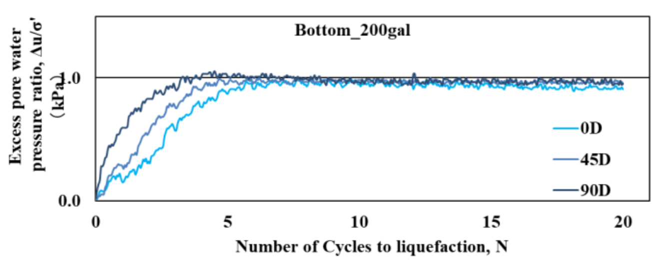

Figure 9. Relations between excess pore water pressure ratio and number of cycles (first liquefaction, bottom part of the ground)

Reliquefaction test followed the first liquefaction test. The results are shown in Figs. 10 and 11 in the same manner with liquefaction test.

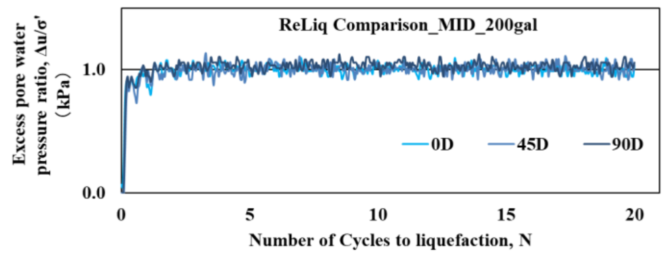

Figure 10. Relations between excess pore water pressure ratio and number of cycles (reliquefaction, middle part of the ground)

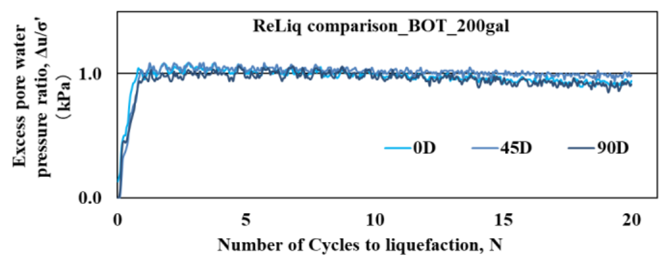

Figure 11. Relations between excess pore water pressure ratio and number of cycles (reliquefaction, bottom part of the ground)

Then, the particle orientation angles were measured in the model grounds before and after liquefaction with the help of microscopic photography images, as shown in Figs. 12 and 13.

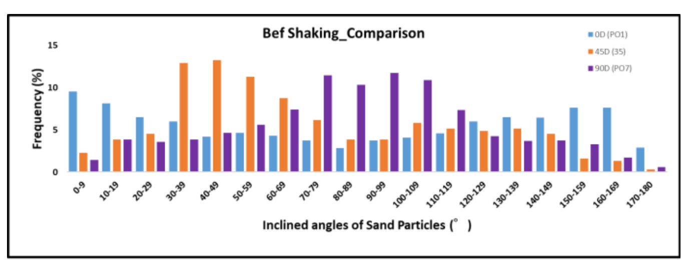

Figure 12. Particle orientational angles (pre-liquefaction)

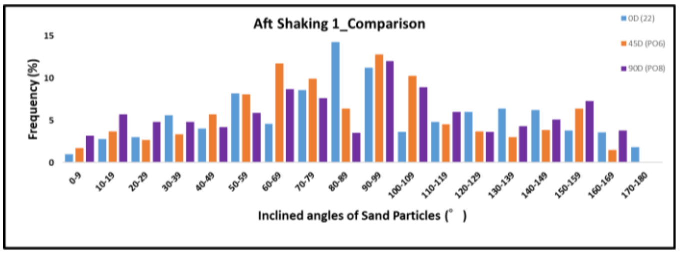

Figure 13. Particle orientational angles (post-liquefaction)

3.1 Results analysis and considerations

- Excess pore water pressure ratio:
    - From the liquefaction tests, the ground with 0-degree need the greatest number of cycles to liquefaction, while the 90-degree ground need the smallest number of cycles to reach first liquefaction. Those results indicate as the particle orientation angle increases, the liquefaction strength decreases.
    - From the reliquefaction tests, the difference in generation of pore water pressure becomes indistinct. Moreover, the generation of pore water pressure becomes faster than that in first liquefaction test.
- Particle orientation angle distribution
  Figure 12: In the ground before liquefaction, the angle distribution seems to be in accordance to the initial deposition angle.
  Figure 13: In the ground after liquefaction, the angle distribution tends to concentrate in around 90-degree in all cases.

4. Conclusions

The initial deposition angle of sand particles significantly influences their liquefaction behavior. From the comparison of three cases (0, 45, and 90-degree), the greatest liquefaction resistance appears in 0-degree ground, the second was 45-degree, and the third was 90-degree. Therefore, 90-degreee ground is most susceptible to the liquefaction.

Particle orientation measurement revealed that sand particles tend to concentrate their angles to around 90-degree.

Therefore, reliquefaction strength will be decreased comparing with liquefaction strength from the view of particle orientation. If the densification of the ground induced by liquefaction is comparatively small, the ground will be easily liquefied again. This fact matches with the repeated reports of liquefaction in the same ground.

5. References

- Bardet, J.-P. (2003). International Handbook of Earthquake and Engineering Seismology, Part B.
- Sana, H. (2021). Liquefaction as a seismic hazard: scales, examples, and analysis.
- USGS. (s.f.). What is liquefaction? Obtenido de USGS: https://www.usgs.gov/faqs/what-liquefaction