Experimental Study on Silt Liquefaction by Shaking Table Test

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Abstract. Based on the shaking table test, the liquefaction of silt under earthquake load and the earthquake damage after liquefaction are studied. The test results show that the lower silt is relatively dense, the pore pressure increases slowly, and the pore pressure ratio cannot reach the initial liquefaction state. However, under the stronger earthquake action, the dense silt may also produce liquefaction, which indicates that the increase of pore water pressure has a great relationship with the compactness and earthquake intensity under the earthquake load. Because the permeability coefficient of silt is relatively low, the increase and dissipation of pore pressure are relatively slow. After the earthquake, the pore pressure of silt continues to rise, and the liquefaction will be further aggravated.

1. Introduction

Shaking table test is a large-scale indoor dynamic test initially used to study the liquefaction behavior of soil layer, which can simulate the stress conditions of natural soil layer with large samples. It can input a random wave or given harmonic vibration from the bottom to the ground, and can simulate the actual effect of seismic wave to the maximum extent. The large scale shaking table test can measure the law of pore water pressure growth and residual displacement during liquefaction, and can reproduce the macro process of soil liquefaction. The disadvantage of shaking table test is that undisturbed soil cannot be used, and the consolidation state of remolded soil is difficult to be the same as that of the field. Therefore, the liquefaction test of seismic simulation shaking table can only qualitatively or semi quantitatively simulate the liquefaction performance of the undisturbed soil on site[1].

Early studies on liquefaction focused on the evaluation of resistance and residual strength of sand triggered by liquefaction, while few studies on dynamic characteristics of saturated silt under earthquake action[2]. A series of dynamic triaxial liquefaction tests and triaxial shear tests were carried out on saturated silt after pore water pressure dissipated in different degrees. The results show that the anti liquefaction strength of saturated silt decreases with the increase of applied dynamic stress amplitude, the larger the dissipation degree of pore pressure, the greater the undrained shear strength and the smaller the tangent modulus[3]. Through cyclic torsional shear test by GDS hollow cylinder apparatus, the effect of initial shear stress on liquefaction characteristics of saturated silt was studied[4]. The purpose of this shaking table test is to test the liquefaction resistance of silt in the site by inputting the seismic time history of the site seismic risk analysis and simulating the seismic vibration according to certain similarity criteria, so as to obtain the visual data of seismic liquefaction of silt.
2. Model design and sensor arrangement
The size of the shaking table is 5×5 meters, the maximum bearing capacity is 30 tons, three directions of vibration load can be input at the same time. The maximum horizontal displacement of the table is 8 cm, and the maximum frequency of simulation is 50 Hz. The size of the test model box is 3.8×2×1.6 meters, and the model box and the vibration table are fixed with 8 bolts.

The two ends of the model box are thickened with sponge cushion of about 10 cm and sealed with impermeable membrane. The soil sample in the model box is formed by water sinking method, and 10 cm high clean water is added into the box. The crushed silt is evenly scattered into the water, and the water surface in the box is kept higher than the soil surface, so that a more uniform saturated silt layer can be obtained. When the soil sample reaches 130 cm high and the water level is about 10 cm high, the loading of soil is stopped. Keep for 2-3 days, let the residual air bubbles out of the soil, make the soil sample fully saturated, and then add silt to the height of 150 cm. The soil is pre vibrated by inputting about 50 gal seismic acceleration time history to accelerate the consolidation speed of soil samples. The pre vibrated soil samples are placed for another 4 days, and then the formal test is started. Table 1 shows the saturated bulk density of soil samples in three states.

15 pore pressure sensors, 8 acceleration sensors, 4 earth pressure sensors and 2 displacement sensors are used in this test. The 15 pore pressure gauges are buried in different positions in the soil. The acceleration sensors J01, J02 and J03 are buried near the same height of the pore pressure gauges K01, K02 and k03. The acceleration sensors G01 and G02 are placed on the soil surface. The acceleration sensors D02 and D03 are placed on the vibration table and the bottom surface of the model box. The acceleration sensor D01 is placed on the top surface of the model box. The displacement sensors w01 and W02 are placed outside the vibration table and the bottom of the box. The earth pressure gauge shall be buried near the same height of K01, K02 and K03. Figure 1 shows the location of the sensor. In Figure 1, 1 is the pore pressure sensor, 2 is the acceleration sensor, 3 is the displacement sensor, 4 is the sea cushion, and 5 is the vibration table.

![Figure 1. Schematic diagram of model box and some sensors](image1)

![Figure 2. Original ground motion time history curve of test](image2)
3. Test ground motion input
In this experiment, the ground motion was only input in one horizontal direction, the maximum amplitude of the ground motion is 0.12g, and the predominant frequency is about 1Hz. Figure 2 shows the time history curve of the ground motion. According to the similarity law, the duration of the selected input seismic wave is compressed to 7.2 seconds, and the maximum amplitude of the input acceleration is adjusted to 0.254g, which is called XZ1. The input wave whose maximum acceleration amplitude is adjusted to 0.32g is called XZ2. Four vibration tests were completed. The first test is carried out one week after the soil sample is formed, and the time of the last three tests is respectively 30 minutes and 48 hours after the first vibration and 30 minutes after the third vibration.

4. Macroscopic phenomenon of the test
In the first test, water precipitated from the soil surface, the model subsided about 2 cm, and there was a clear gushing near the edge of the box. About 20 minutes after the test, about 0.5 cm high water precipitated from the soil surface, and more eruptive mounds similar to volcanic mounds appeared on the soil surface. These phenomena indicate that the soil in the model box has been liquefied in the process of vibration and a short time after vibration.

In the second test, a large area of gushing water appeared, the soil subsided about 2 cm, and the silt was completely liquefied. About 3 hours after vibration, water about 5 cm deep precipitated from the soil surface. After the water on the soil surface is drained away, it is found that the soil surface is covered with water spray holes similar to craters, which are very consistent with the liquefaction phenomenon at the earthquake site, indicating that the silt has undergone serious liquefaction.

After 48 hours, the last two tests were carried out, and the test phenomenon was basically the same as before, except that the water yield was reduced after vibration, and the spray hole was not as large as before.

5. Experimental analysis
Figure 3 shows that the acceleration of vibration table and box bottom is consistent. Figure 4 shows that the displacement records of vibration table and box bottom are consistent, and there is no relative motion. According to the location of the piezometer, the effective overburden pressure of each layer can be calculated, which is 11.05kpa for the first layer, 7.38kpa for the second layer and 2.78kpa for the third layer.

![Figure 3. Acceleration record of vibration table and box bottom](image-url)

Figures 5 and 6 show three pore water pressure recording curves on the central plane of the model box along the vibration direction. With the increase of silt burial depth, the pore water pressure gradually increases, and when the pore water pressure reaches a stable state, the pore water pressure of each layer is approximately equal. The average pore water pressure of the first layer is 10.21kpa when it is stable, the average pore water pressure of the second layer is 7.06kpa, and the average pore water pressure of the third layer is 3.13kpa. Therefore, it can be calculated that the pore pressure ratio of the
first layer is 92.4%, that of the second layer is 95.6%, and that of the third layer is more than 1. Combined with the macroscopic phenomenon after vibration, it can be judged that the silt in the model box has been liquefied.

![Displacement record of top and bottom of shaking table](image1)

**Figure 4.** Displacement record of top and bottom of shaking table

![Time history curves of pore water pressure growth recorded by K01-K03](image2)

**Figure 5.** Time history curves of pore water pressure growth recorded by K01-K03

![Time history curves of pore water pressure growth recorded by K04-K06](image3)

**Figure 6.** Time history curves of pore water pressure growth recorded by K04-K06

### 6. Conclusion
Through this test, we can get the intuitive experience about whether the silt liquefaction under the earthquake load and the earthquake damage after liquefaction. Through the analysis of the test records,
the following conclusions are obtained:

(1) When the silt density is small, the whole saturated silt layer in the model box may liquefy. Under the same earthquake input, after pre vibration, the silt in the lower layer of the model box is relatively dense, the pore pressure increases slowly, and the pore pressure ratio can not reach the initial liquefaction state. However, under the stronger earthquake action, the dense silt layer may also produce liquefaction, which indicates that the increase of pore water pressure of silt layer under earthquake load has a great relationship with the compactness and earthquake intensity.

(2) It can be seen from the test results that liquefiable silt will not only liquefy during the earthquake, but also liquefy or aggravate the liquefaction due to the continuous increase of pore pressure after the earthquake. The liquefaction of silt will also produce serious water gushing phenomenon of sand blasting, and cause surface subsidence, resulting in foundation failure.

(3) The field conditions can not be fully simulated in the laboratory, so it is suggested to make a comprehensive analysis combined with the conclusions given by other methods.

References
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