Shaking-table test on seismic motion compressed characteristics in a liquefied soil

Chengshun Xu\textsuperscript{1a*}, Pengfei Dou\textsuperscript{1b}, Su Chen\textsuperscript{2c}, Liucheng Gao\textsuperscript{1d}, Xiuli Du\textsuperscript{1e}

\textsuperscript{1}College of Architecture and Civil Engineering Beijing University of Technology
\textsuperscript{2}Institute of Geophysics China Earthquake Administration
\textsuperscript{a}e-mail: xuchengshun@bjut.edu.cn, \textsuperscript{b}e-mail: bjutdoudou1991@outlook.com, \textsuperscript{c}e-mail: chensuchina@126.com, \textsuperscript{d}e-mail: 1273520962@qq.com, \textsuperscript{e}e-mail: duxiuli@bjut.edu.cn

Abstract—The seismic motion compressed characteristic is a key issue on liquefied soil-structure shaking table model test. A series of shaking table tests were performed to study the seismic motion duration compression characteristics on the dynamic response of liquefied soil. Macroscopic phenomena and dynamic pore water pressure were measured and analyzed. Experimental results showed that the intensity and frequency of seismic motion had a significant influence on the dynamic response of the liquefied soil. Meanwhile, the phenomenon of soil liquefaction and the frequency filtering effects were obvious when inputting longer duration seismic motion. The liquefied soil was more sensitive to the seismic motion, which was compressed according to the predominant frequency of the foundation. In addition, it is suggested that the uncompressed seismic motion was more appropriate on the liquefied soil-structure model in 1g shaking table tests.

1. INTRODUCTION

Shaking table model tests are performed to predict the soil and soil-structure interaction behavior under seismic loadings. There are two types of shaking table tests: the centrifuge shaking table test which can simulate in-situ confining stress in the model ground by using the centrifugal force; and the 1-g shaking table test which is performed in a 1-g condition. In general, 1-g shaking table tests are more convenient than centrifuge tests in preparing the model structure, controlling the relative density of the model ground, installing instrumentation, and performing tests. However, 1-g tests are generally performed to analyze the qualitative rather than quantitative behavior of a prototype structure because it is difficult to reproduce in-situ confining stress in the model ground. In the last decade, the study on proper similitude law, which links the model with the prototype geotechnical structures on a quantitative basis, has been performed to improve the applicability of 1-g tests. Iai et al. (1989, 1999) \cite{1,2} suggested a series of similitude laws to interpret the results of 1-g shaking table model tests quantitatively. Hwang (2004) \cite{3} performed 1-g shaking table model tests of a gravity quay wall and pile-supported wharf applying the Iai’s similitude law to reproduce the dynamic behavior of a harbor substructure which was damaged during an earthquake. As a result, the residual displacement of the 1-g model varied from one third to...
two thirds that of the prototype. The discrepancy might be attributed to the insufficient duration of earthquake input motion to observe the proper soil-pile dynamic interaction. Kim et al. (2006) [4] performed the centrifuge tests and 1-g shaking table tests simultaneously on saturated loose sands to verify Iai’s similitude law. They showed that the excess pore pressure in liquefiable ground can be simulated with the 1-g shaking table tests by applying the steady state concept and Iai’s law for the model test. Ozkahrman and Wartman (2007) [5] verified the applicability of Iai’s similitude law for the static behavior of a slope by using the modeling of the model technique. These results indicate that the 1-g model test results can be influenced by the variation of the natural frequency according to the size of model and amplitude & duration of input ground motion, which may not be incorporated into the similitude law.

In this study, a series of shaking table tests were performed to study the seismic motion duration compression characteristics on the dynamic response of liquefied soil. To achieve this, three different duration compression ratios were applied, and the behaviors of model soil-structures were measured.

2. SHAKING-TABLE TEST

Model soil consists of two layers with a top clay layer 30mm thick and a bottom saturated fine sand layer 450mm thick. During preparation, the soil was placed in the shear box layer by layer. Each layer was tamped backfill approximately 50mm thick. The water sedimentation method was used to saturate the model soil. After preparation, the model soil was allowed to stand for 2 days in its natural state in the laboratory. Before the test, the soil characteristics of the clay and fine sand used in the shaking table test were measured by conventional soil tests. The grain-size distribution of the fine sand is shown in Figure 1. The purpose of the series of shaking table tests is to study the seismic motion compressed characteristics in a liquefied soil. Using the Wolong ground record as reference waves, the intensity of the input motion was equal to 0.1g, 0.2g and 0.4g, respectively, by adjusting the peak acceleration of the original ground motion. The acceleration time histories and Fourier spectra of the input motions are shown in Figure 2. The Wolong ground motion was recorded during the Ms8.0 WenChuan earthquake on 12 May 2008 in Sichuan Province, China. The test cases are shown in Figure 3. Because dissipation of the excess pore pressure of the model soil was slow, each test was required to stand for at least 1.5-2 hours until the excess pore pressure dissipated completely. Many sensors were deployed to record various parameters throughout the series of shaking table tests, such as acceleration, excess pore pressure, earthquake-induced ground settlement and dynamic soil pressure. The layout of sensors in the model structure are shown in Figure 4, which includes 6 accelerometers, 6 pore pressure transducers, 2 displacement transducers, 5 soil pressure transducers, denoted as A, W, J, P, respectively. Based on the calibration for the accelerometers, pore pressure and soil pressure transducers, the measurement accuracy of the sensors was better than 0.5% F.S.

![Figure 1. Material property of model soil](image-url)
Figure 2. Wolong record in this series of experiments: a) the acceleration time histories; b) the corresponding response spectrum; c) partial enlarged drawing of the response spectrum

Figure 3. The loading condition
3. RESULTS AND INTERPRETATIONS

3.1. Dynamic characteristics of the soil-structure system
Model foundation predominant frequencies when inputting different compression ratios ground motion were shown in Figure 5, the predominant frequencies of foundations vary in different degrees under different ground motion excited (compression ratios: 1/1, 1/2, 1/5). There are great differences in liquefaction characteristics of subsoil when inputting different compression ratios ground motion. After exciting the 1:1 and the 1:2 compression ratio ground motion, the phenomenon of sand blasting and water pumping shows that the foundation soil was obviously liquefied. But when inputting 1:2 compression ratio ground motion, the model foundation showed more remarkable high frequency vibration characteristics. On balance, comparing with the test termination condition of the superstructure, attention should be given to the macroscopic phenomena of model foundation in the 1-g shaking table test for liquefiable foundation-structure system.

3.2. Peak pore water pressure
Pore water pressure peak at discrete locations of model soil under different ground motion excited was showed in Figure 6. As we can be clear from Figure 6, the peak pore water pressure of soil decreases with the decrease of compression ratio. When the creative ground motion excited, pore water pressure peak of model soil is maximum and this is related to the input energy of the ground motion. Thus, if the experiment will pay more attention to the nonlinear problem of the saturated soil in the shaking table experimental study on seismic response of liquefiable site, the difference of pore pressure under different compression ratios should be taken into account as a correction in the design of similitude ratio. Data of soil top measure point (W1) are normalized, then we can find that the peak time of pore pressure will be shifted back and the platform section will last for a long time on the decrease of the
similitude ratio. When the compression ratio of 1/5 ground motion was imputed, dissipation rate of soil is obviously faster than that of the original ground motion reflected in the data of measuring point W3. From the figure of space distribution of pore pressure ratio in model foundation (Figure 8), the design of similarity ratio has significant influence on the pore water pressure distribution. In general, the pore pressure ratio at the same location increases with the increase of the compression ratio and the pore pressure distribution of the model foundation shows more pronounced regularity. Based on the above analysis, if the purpose of the experiment of shaking table test for liquefiable foundation-structure system was to pay more attention to the site seismic response, the influence of the otherness of liquefaction characteristics of foundation soil on the dynamic characteristics of the system should be considered. In order to facilitate foundation liquefaction, it is best to choose ground motion without compression or less compression ratio.

Figure 6. Peak pore water pressure under different similitude ratio

Figure 7. Pore pressure development model for 0.2g Wolong record at measuring points: a) W1; b) W3

Figure 8. Space distribution of pore pressure ratio in model foundation for different compressed ratio: a) 1:1; b) 1:2; c) 1:5
4. CONCLUSION
A series of shaking table tests were performed to study the seismic motion duration compression characteristics on the dynamic response of liquefied soil. Experimental results showed that the intensity and frequency of seismic motion had a significant influence on the dynamic response of the liquefied soil. Meanwhile, the phenomenon of soil liquefaction and the frequency filtering effects were obvious when inputting longer duration seismic motion. The main conclusions are listed in detail as following:

1) After shocking for ground motion with different compressed duration ratio, the dynamic characteristics of model soil have changed obviously for the uncompressed seismic motion, and prominent frequency of soil decreased slightly for the 1:5 compression ratio.

2) For the test cases with the compressed seismic motions, the pore water pressure in saturated sand layer increased slowly and the pore pressure ratios were all small. In addition, the model soil liquefied significantly in the test case with uncompressed seismic motion.

According to the results from this series of experiments, it is suggested that the uncompressed seismic motion was more appropriate on the liquefied soil-structure model in 1g shaking table tests.

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