Verification of combined sinusoidal load via cyclic tri-axial test and shaking table test

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ABSTRACT

Liquefaction studies have long been relied on laboratory dynamic tests using sinusoidal loads, and various liquefaction tests such as cyclic tri-axial tests and direct shear tests are frequently used for liquefaction assessment. Recently, several researchers in Korea have reported that sinusoidal load, which is mainly used for lab-test, does not accurately simulate the change of excess pore pressure causing liquefaction during the earthquake loading.

The purpose of this study is to develop a new loading model for earthquake that predicts the excess pore pressure behavior under seismic loads. For this purpose, we analyze the seismic records used in domestic seismic design and propose a new combined sinusoidal load. In order to verify the proposed combination sinusoidal load, the cyclic tri-axial tests and the shaking table tests using the laminar box were performed. The sinusoidal load and the combined sinusoidal load were used in the lab test under the same conditions. Additionally, numerical simulations using Finn model, which is an effective stress analysis model, was performed and compared with the shaking table test results. As a result, the proposed combined sinusoidal load more reliably simulates the behavior of the pore pressure caused by the earthquake than the conventional sinusoidal load.

Keywords: liquefaction, lab-test, sinusoidal load, combined sinusoidal load, shaking table test with laminal box

1 INTRODUCTION

On November 13, 2017, the Pohang Earthquake of 5.4 earthquakes occurred. At this time, a liquefaction phenomenon also occurred. The damage caused by liquefaction in the case of the Pohang earthquake did not directly affect the important facilities or building structures. However, most people want to make a countermeasure plan quickly due to the fear of liquefaction occurring in the strong seismic area.

Liquefaction is a phenomenon in which, when a sudden vibration load such as seismic load acts on a saturated sandy soil or a buried soil, the pore water in the soil develops excess pore water pressure in the undrained condition and the shear strength of the soil is lost and eventually acts like a liquid.

Cyclic tri-axial test, direct shear test, torsion shear test, ring shear test are typical examples of laboratory dynamic test are widely used in this liquefaction study. In these cases, sinusoidal load is mainly used. On the other hand, real earthquake records are used in the case of the shaking table test and centrifuge test.

The importance of experimental researches in the field of liquefaction study is also reflected in the research trends presented at PBD-III conference in Vancouver, Canada in 2017. The PBD-III International Conference is an academic event that mainly deals with the earthquake-resistant design of the ground vibration and soil field. Among the contents published in 2017, statistics on experimental papers relating to liquefaction are summarized as follows.

Table 1. Summary of PBD III papers' related to liquefaction

Total number of Presentation paper	Lab. Test (CTC, CSS, CTS)	Site Investigation	Shaking Table & Centrifuge
38	6	19	19

AS a result of the above, it can be seen that 20% of the total research is focused on experimental research. In detail, seismic simulation tests such as shaking table test and centrifuge test are performed more than laboratory dynamic tests. The more intensive studies on the cone penetration test and the field seismic exploration test were carried out than the standard penetration test.

In the case of Korea, laboratory dynamic test using sinusoidal load has mainly been performed, rather than shaking table test and centrifugal model test using real earthquake motion, in case that earthquake data is very lacking and vibration test equipment is not generalized.

In particular, the liquefaction assessment method in Korea is broadly divided into simplified assessment and detailed assessment. (EESK, 1997) Simplified assessment revised the method proposed by Seed and Idriss(1971) and introduced magnitude scaling factor(Youd and Noble, 1997). In this case, the earthquake magnitude 7.5 of the United States was revised to magnitude 6.5 for liquefaction potential assessment when applied to Korea. In addition, the detailed prediction uses the laboratory dynamic test, and it has been proposed to make a detailed assessment based on the cyclic tri-axial test using sinusoidal load considering the equipment construction status in domestic laboratories. (Kim et al, 2000)

In recent years, recent studies have shown that the sinusoidal load, which replaces seismic load, does not reflect the liquefaction behavior under real earthquake loading (Choi et al, 2007). Also, in 2018, research results on a new type of vibration load were also announced at the NCEE. (Kwan and Huaz, 2018)

In this study, we propose a combined sinusoidal load that can replace sinusoidal load, and perform cyclic tri-axial test and shaking table test to compare with sinusoidal load for feasibility study. In addition, numerical simulations are also carried out based on the effective stress analysis using Finn model which is well known in Korea.

2 EARTHQUAKE RECORDS USED IN KOREA

Fig. 1. shows the change in the standard response spectrum of Republic of Korea after the Gyeongju earthquake. This reflects the characteristics of the domestic geological features of the bedrock, which are located at relatively shallow depths and this spectrum is similar to the spectrum used in Australia. However, since there is not a lot of actual records satisfying the actual spectrum in republic of Korea therefore the earthquake records of large earthquake size are used in accordance with the standard response spectrum of Fig. 1. Recently, this spectrum matching has been proposed as a common application of seismic design criteria.

Fig. 2 is the result of Spectral Matching based on 0.154g of the 1000th reproduction cycle. In 2017, the Government of the Republic of Korea announced the Article 14 of the Earthquake and Hazardous Substances Countermeasures Act under the theme of common application of seismic design standards. In this context, it is mentioned that Spectral Matching is performed using the standard response spectrum of the rock ground in Fig. 1

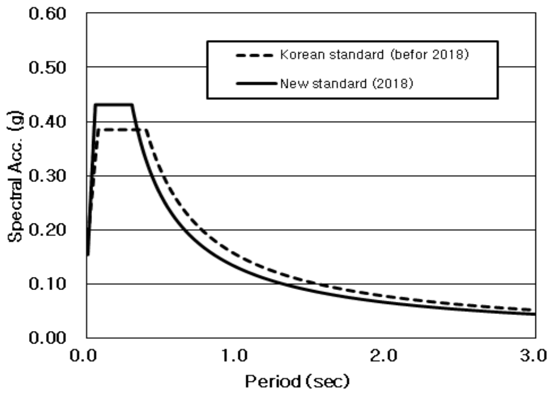
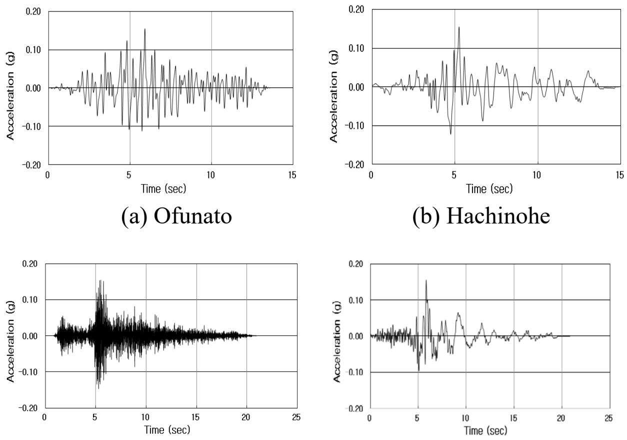


Fig. 1. New standard response spectrum (MOIS, 2018)



(a) Ofunato (b) Hachinohe

(c) Gyeongju (d) Pohang

Fig. 2. Representative earthquake records in Korea.

Fig. 2. shows that Ofunato and Gyeongju earthquake have short-period characteristics, while Hachinohe and Pohang earthquakes have long-period characteristics. Comparing the features of this earthquake record, the point at which the maximum acceleration is applied at 5~7 second of the vibration duration, whereas the vibration frequency (the number of times past 0) are about 10 times in Japan earthquakes, 20 times in Pohang, and 30 times in Gyeongju. The fact that the Pohang and Gyeongju earthquakes have relatively more vibration loads is due to the fact that earthquakes with relatively small earthquakes have been matched to large accelerations. Based on the above analytical result, we proposed the combined sine load as follows.

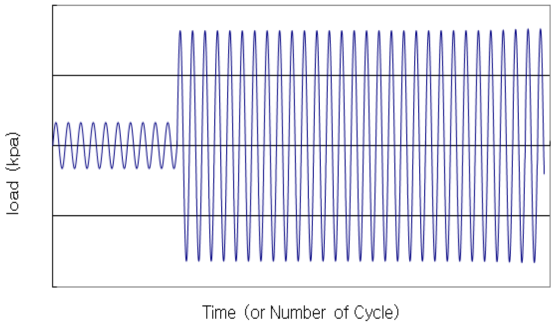


Fig. 3. New combined sinusoidal load

3 VERIFICATION

3.1 Cyclic tri-axial test

In this study, the combined sinusoidal load in Fig. 3 was compared with that of the conventional sinusoidal load. In this case, the specimen is composed of Jumujin sand. The remolded sample has a relative density of 40%, an effective confinement pressure of 100 kPa, and a vibration loading period of 1 Hz in the test. Test results are as follows.

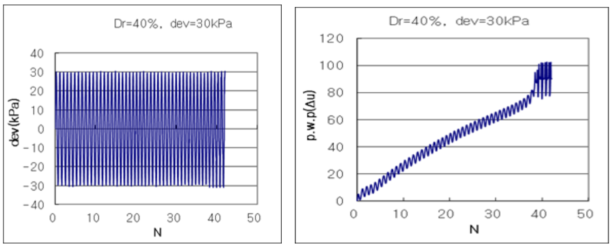


Fig. 4. Cyclic tri-axial test results (conventional sinusoidal load)

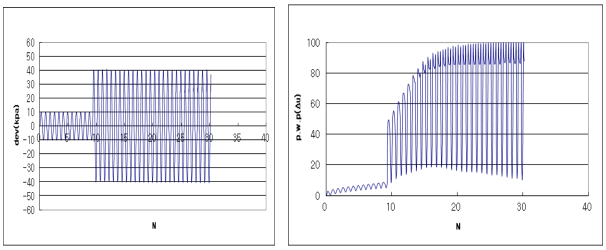


Fig. 5. Cyclic tri-axial test results (combined sinusoidal load)

As shown in Fig. 4 and 5, the sinusoidal load test progressively produces pore water pressure without rapid change of excess pore water pressure. On the other hand, the proposed combined sine-current load let the pore water pressure very large at the time of the second sinusoidal loading start. From these results, it can be confirmed that the combined sinusoidal load can replace the seismic load as a standard vibration load.

3.2 Shaking table test and numerical simulation

The shaking table test was carried out using a laminar box. The test conditions at this time were the same as in the vibration tri-axial test, but only the effective confining pressure was 60kPa. This is because, in the vibration tri-axial test, the effective restraining pressure can be freely applied through the air pressure, but it is reflected in the fact that there is a limit in increasing the confining pressure through the steel plate in the shaking table test. The test scene is as follows.

Fig. 6. Test Scene in Busan Earthquake Research Center

In this study, the shaking table tests are simulated using the Finn model installed in the FLAC program. The schematic diagram of the mesh and numerical analysis at the time of analysis is as follows.

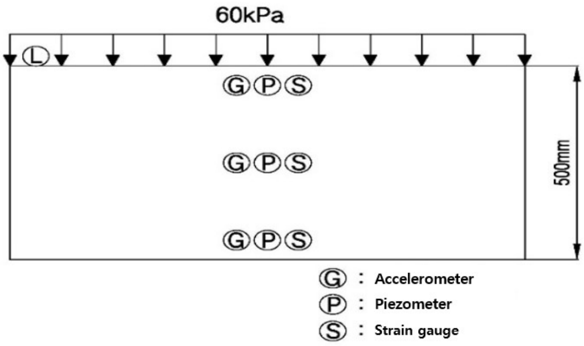


Fig. 7. Test condition and sensor's position

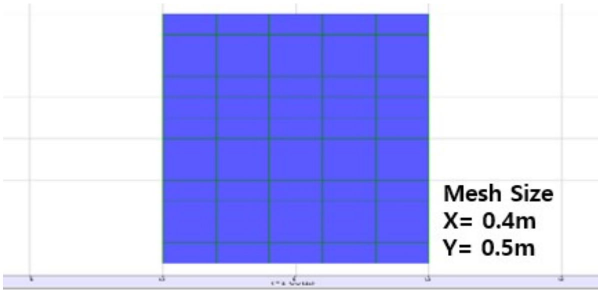


Fig. 8. Mesh for numerical simulation in FLAC

In the numerical simulation, the relative density of 40% in the test condition was regarded as the standard penetration resistance N-value 5. The actual shaking table test results and the numerical simulations results are as follows. The comparison position is the central part of the laminar box for the shaking table test, which takes into account the location of the accelerometer and pore water pressure sensor installed at the center of remolded soil.

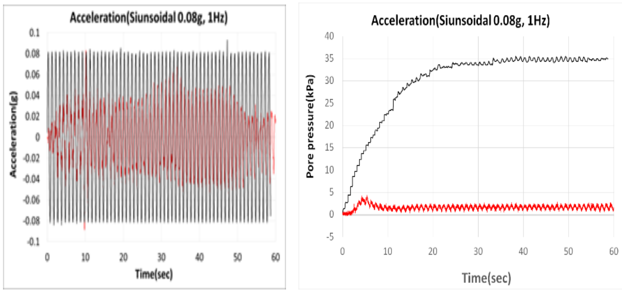


Fig. 9. Comparison for sinusoidal loading

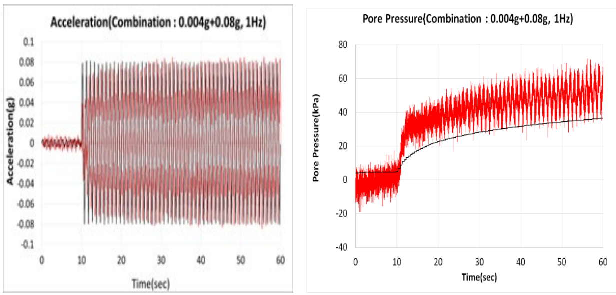


Fig. 10. Comparison for combined sinusoidal loading

In Fig. 9 and Fig. 10, the red line is the actual shaking table test result and the black line is the simulation result. As shown in the figures, in the case of the sinusoidal load test, the increase of the pore water pressure tended to be maintained, but in the combined load test, the pore water pressure rapidly build-up at the time of a relatively large sinusoidal load start, it is shown that the earthquake load is simulated well. In the case of numerical analysis, the experimental results were not predicted adequately and showed a large difference. In the two cases, the result when 0.08g sinusoidal load was applied, were similar. From this comparison, the new method for earthquake simulation will be necessary to predict the effective stress and pore water pressure reasonably. Conclusionally, the proposed standard dynamic load in this study is thought to be very helpful for the development of the analytical method of effective stress concept considering seismic load.

4 CONCLUSION

In this study, a new combined sinusoidal load was proposed to compensate for the fact that sinusoidal load does not simulate liquefaction behavior well under real earthquake load.

As a result of the study, it was confirmed that the proposed combined sinusoidal load had a good agreement in a sudden increase in excess pore water pressure over sinusoidal load. In other hand, numerical simulation based on existing effective stress analysis theory for shaking table test does not reflect change due to dynamic load, so it is necessary to develop analytical method to simulate the behavior under real earthquake loading. It can be thought that the combined sinusoidal load may be helpful in estimating the input parameters.

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