Physical Modelling in Geotechnics

Geo-centrifuge experiment to investigate two functional effects on structure-soil-structure interactions

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ABSTRACT: Dynamic structure-soil-structure interaction (SSSI) between three structure are investigated using the dynamic geo-centrifuge experiment at KAIST, Korea. Three single-degree-of-freedom (SDOF) buildings are constructed with an aluminium named M, S1, and S2. A homogeneous ground formed by a silica sand with a relative density (D_r) of approximately 80% is prepared using an air pluviation method. Two motions included an artificial earthquake and a Hachinohe earthquake are applied to the soil base as an input excitation. The results indicate that the power spectral density (PSD) of M, which is the most massive building, decreases in series of tests with other sub-buildings, S1 and S2, compared to the reference result. However, SSSI increases the response of the S1 building, less massive one, regardless of distances between buildings and input motion. The rocking restriction from the relatively massive buildings affects significantly on SSSI between buildings.

Keywords: structure-soil-structure interaction, geo centrifuge, earthquake, rocking stiffness.

1 INTRODUCTION

In recent years, the problems of structure-soil-structure interaction (SSSI), where the seismic wave from vibrating structure could affect response of an adjacent structure during an earthquake, have been investigated in numerous studies (Ngo et al. 2019; Trombetta et al. 2014). The SSSI problems between two buildings have been studied indicating the several influential factors such as distance between buildings, relative height and mass ratio between them during an earthquake (Alexander et al. 2013; Wong and Trifunac 1975). The vibration of a more massive building could reduce under SSSI effects when comparing to the motion of an isolated building.

There is a considerable need for physical model to study SSSI effects between three buildings. In this study, five centrifugal tests were carried with three buildings named the main (M), and sub buildings (i.e., S1, and S2), which have different masses, heights, and fixed-base frequency to simulate the diversity of building in a city. The distance between buildings were varied in the test.

2 EXPERIMENTS

Geo-centrifuge facility located at KOCED Geotechnical Centrifuge Machine Center, Korea Advance Institute of Science and Technology, was used in this study with a centrifugal acceleration (N) of 45 *g*. The earthquake simulator used was an electro-hydraulic-servo, which can generate a maximum ground acceleration of 40 *g*. An equivalent shear beam (ESB) container was used, which has inner dimension of 490×490 mm and a 630 mm height.

2.1 Soil properties and building models

In centrifugal test, a silica sand was used as a ground material (Ngo et al. 2019). The raining system was used for silica sand to produce a homogeneous ground with relative density (D_r) of about 80% by using the air pluviation method. Dynamic properties of soil sample, such as shear modulus degradation and damping curves were estimated by performing resonant column test (RCT) on soil specimen at similar condition (Ngo et al. 2019).

An array with eight pairs of in-flight bender elements were installed in the soil to measure the shear wave velocity (V_s) of soil during the centrifugal acceleration, as indicated in Fig. 1.

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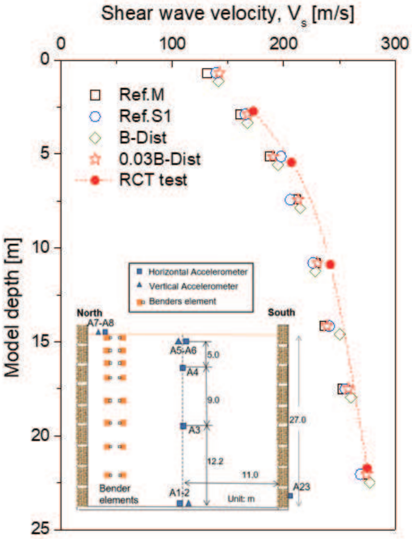


Fig. 1. Shear wave velocity profile of ground

Three single-degree-of-freedom (SDOF) building models (i.e., M, S1 and S2) were made of aluminium with different masses and heights. The fixed-base frequency of each building was defined by an impact hammer test, which was 2.19 Hz for M, 1.82 Hz for S1 and 7.05 Hz for S2 building, respectively. The sliding (f_S) and rocking frequency (f_R) were then defined and shown in Fig. 2 (Gazetas 1991).

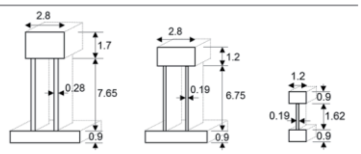
Quantity	Building		
	M (main)	S1 (Sub1)	S2 (Sub2)
Dimensions (m)			
Foundation dimensions (m): Width (B)×Length (L)×Thickness (T)	5.2×5.2×0.9	4.1×5.2×0.9	1.2×2.0×0.9
Effective height, h_{eff} (m)	9.4	8.25	2.97
Mass at 1g, m (kg)	1.89	1.25	0.13
f_n at 45 g, (Hz)	2.19	1.82	7.05
Sliding frequency, f_s (Hz)	5.89	6.72	11.16
Rocking frequency, f_r (Hz)	2.36	2.95	3.25

Fig. 2. Dimensions and properties of buildings.

2.2 Sensor location and data processing

To record motions of soil and structure during an earthquake, accelerometers were installed on the ESB container, in the soil (i.e., in a vertical array and at free-field as shown in Fig. 1), on the foundation, wall, and roof of building (Fig. 3). Three pairs of strain gauges were also attached on each wall of M and S1 buildings at three position, top, middle, and bottom (Fig. 3) to estimate bending moment of wall of buildings and overturning moment of the foundations during the seismic loading (Ngo et al. 2019).

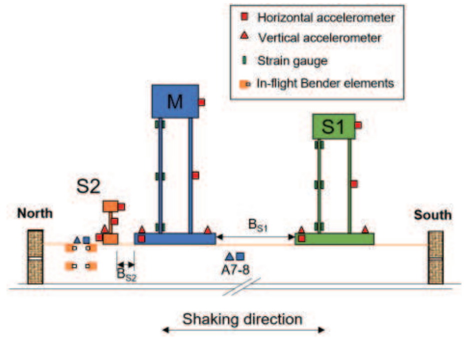


Fig. 3. Testing layout with three buildings (i.e., M, S1 and S2) at B-Dist.

2.3 Input motion and experimental layout

Two motions included an artificial earthquake, which is generated following the Korean standard for seismic designing of nuclear power plant (RG 1.60), and a Hachinohe earthquake (recorded at Tokachi Oki, Japan in 1968) were applied to the soil base as an input excitation in all tests. In addition, the base motion was scaled into three levels of peak accelerations (PGA_{BM}) as: low (PGA_{BM} = ~0.1g), medium (PGA_{BM} = ~0.2g), and high (PGA_{BM} = ~0.3g) intensities.

Two reference tests (i.e., Ref.M and Ref.S1) with single M or S1 building were performed to obtain reference response of each one. A series of experiments were performed with the installation of the three buildings (S1-M-S2) in an alignment at two inter-distances, to with B (B-Dist.), and 0.03B (0.03B-Dist.) where B is the width of smaller foundation.

3 RESULTS AND DISCUSSIONS

3.1 Response of M and S1 buildings

The power spectral density (PSD) of roof motion using Welch method with 1024 points Hamming-window was estimated and plotted in Fig. 4. It could be observed that in SSSI tests, PSD of S1 building increased while that of M building, the most massive one, decreased compared with those in the reference tests, regardless distances between buildings. Similar results were also obtained for the artificial input at three levels of earthquake, which show similar results with SSSI between two buildings (Ngo et al. 2019). Also, M and S1 buildings vibrated at a flexible-base frequency (the peak) smaller than fixed-base one (f_n). Details for the responses of soil ground and each building can be found in Ngo et al., (2019)

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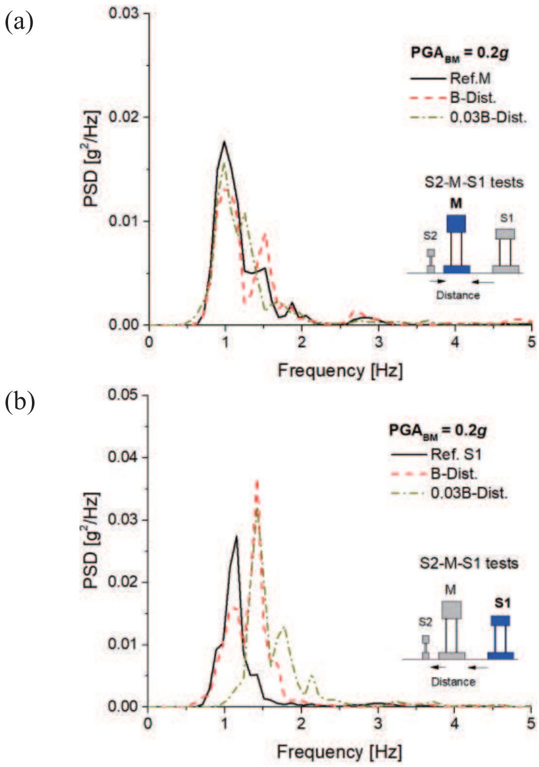

Fig. 4. Power Spectra Density (PSD) of (a) M and (b) S1 buildings with Hachinohe earthquake.

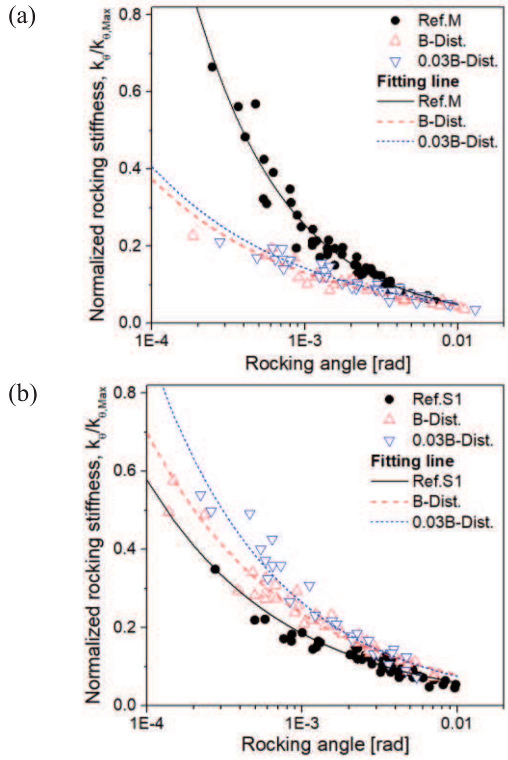

Fig. 5. Normalized rocking stiffness of (a) M and (b) S1 buildings with Hachinohe earthquake.

3.2 Nonlinear rocking stiffness

To explore SSSI effects on the rocking behaviour of building, the rocking stiffness ($\boldsymbol{k_\theta}$) of M and S1 building were explored from the overturning moment and rocking angle, which were estimated by attached strain gauges on the walls and vertical acceleration on foundation (Ngo et al. 2019), as shown in Fig. 5. The best fitting line was obtained for power equation for rocking angle ($\boldsymbol{\theta}$). It would be seen that k_θ of M building reduced in SSSI tests compared to those in the reference test, and an inverse trend for S1 building. It would be that, in SSSI with a smaller building, the rocking restriction induced an increment in rocking stiffness, and therefore, response of M building reduced during earthquake.

4 CONCLUSION

A series of centrifugal experiments were carried out to investigate SSSI effects at various distances between three buildings. The primary findings are as follows:

1. M and S1 buildings vibrate at a frequency smaller than its fixed-base frequency.
2. SSSI effects between three buildings cause a reduction in the energy of motion of the main building, while the energy of motion of less massive one increased during an earthquake, regardless distance and levels of earthquake.
3. Due to the restriction from adjacent building during earthquake, rocking stiffness of more massive building decreases, while that of less massive one increases, which could play a significant role in the modification of response of each building when they located adjacently.

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