Investigation of the structure-soil-structure interaction between two structures in centrifuge test

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ABSTRACT: Dynamic soil-structure interaction and structure-soil-structure interaction (SSSI) between two structures were investigated using the dynamic geo-centrifuge machine at KAIST, South Korea. A homogeneous ground silica sand with a relative density of 80% was prepared using air pluviation method. In-flight shear wave velocity profile of the soil was measured using an array of bender elements during the test. A Hachinohe earthquake (recorded at Tokachi Oki, Japan in 1968) was applied to the soil base as input excitation. Two single-degree-of-freedom structures were constructed with aluminum named B1 and B2. The results indicate that total power spectral density of B1, which is a more massive structure, decreased in series of test with the B2 structure compared to those in reference tests. However, SSSI effects increased response of the B2 structure, regardless of distance between the two structures. The mass ratio and distance between two structures were important parameters controlling SSSI effects.

1. INTRODUCTION

In recent earthquakes like Kobe (1995), Izmit (1999), Iwate (2008), and Pohang (2016), serious damages of structures were recorded which shows the importance of study on structure response during an earthquake. Numerous studies have been performed to figure out modifications in structure motion due to soil foundation structure interaction (SFSI) because it is a crucial step in seismic design (Ghosh & Madabhushi, 2007; Ha et al., 2014). It is generally known that SFSI could be described by two mechanisms: kinematic interaction and inertial interaction (Stewart et al., 1999; Mylonakis et al., 2006).

Interaction between adjacent buildings in urban areas and cities during an earthquake is generally referred to structure-soil-structure interaction (SSSI) (Lee & Wesley, 1973; Lou et al., 2011; Trombetta et al., 2014). Luco and Contesse (1973), Lee and Wesley (1973), and Wong and Trifunac (1975) found SSSI effects in the low-frequency range in the vicinity of resonance frequency of soil-structures system. They also found that the distance between structures and relative mass ratio between two structures are the dominant parameters controlling SSSI effects. Amplitude response of the structure of interest, which is smaller and lighter than its neighbours, may become larger compared to response of an isolated structure. Analytical investigation performed by Alexander et al. (2013) and Aldaikh et al. (2016) indicated similar effects of relative mass ratio on SSSI between two structures.

Based on the discussion above, there is a considerable need for physical model, especially centrifugal test, to study SSSI effects and to provide experimental evidence so as to augment the limited knowledge of the problem (Lou et al., 2011). In the present study, five centrifugal tests

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were carried out to investigate SSSI effects of two structures named B1 and B2. The two structures were of different masses, height, and fixed-base frequencies to simulate the diversity of buildings in the city. The distance between structures was varied during the test.

2. SOIL-STRUCTURE MODEL AND TESTING LAYOUT

2.1 Geo-Centrifuge facility

Geo-centrifuge facility located at KOCED Geotechnical Centrifuge Machine Center, KAIST, Korea was used in this study with a centrifugal acceleration (N) of 45 g. The centrifuge machine has a rotational radius of 5.0 m and a maximum payload capacity of 2400 kg at 100 g acceleration. The earthquake simulator used was an electro-hydraulic-servo, which can generate a maximum ground acceleration of 40 g (Kim et al., 2013). To minimize boundary effects on dynamic response of soil during earthquake, an equivalent shear beam (ESB) container was used, which has inner dimension of 490×490 mm and a 630 mm height (Lee et al., 2013).

2.2 Structural model

Two building models (i.e., B1 and B2) were made of aluminum with different masses and heights. Building models composed of two thin walls and a top mass, which could vibrate at single-degree-of-freedom (SDOF) structure during an earthquake. The dimensions of structures at prototype scale are shown in **Error! Reference source not found.**. Foundation equivalent radius ($r_f = (BL/\pi)^{0.5}$) was defined from foundation width, B, and length, L. Height (h, from bottom to center of the lumped mass) was 9.4 m and 8.25 m for B1 and B2 structures, respectively.

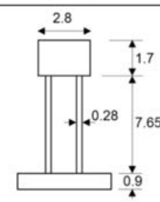
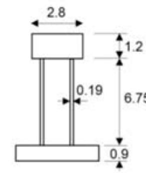
Structures	B1	B2
Dimensions (m)		
Foundation dimensions: Width (B)×Length (L)× Thickness (T) (m)	5.2×5.2×0.9	4.1×5.2×0.9
r_f (m)	2.95	2.61
Height, h (m)	9.4	8.25
Mass at 1g, m (kg)	1.89	1.25
f_n at 45 g, (Hz)	2.19	1.82

Figure 1. Dimensions and properties of structures. Dimensions are in prototype scale

The height ratio between B1 and B2 structure ($\chi_{1\text{-}2} = h_{B1}/h_{B2}$) was 1.14. Structure B1 has a higher mass than B2 with a mass ratio ($\psi_{1\text{-}2} = m_{B1}/m_{B2}$) of 1.5.

Fixed-base natural frequency (f_n) of the model structure was defined by performing impact hammer test on the small-scale structure. By considering the scaling law (Schofield, 1980), it was estimated to be 2.19 and 1.82 Hz for B1 and B2 structures, respectively.

2.3 Soil modeling

A soil model was prepared in ESB container by using poorly-graded silica sand (G_s = 2.65 and D_{50} = 0.51 mm). Table 1 shows the index properties of the silica sand. A 27 m (at the prototype scale) homogeneous ground with relative density (D_r) of approximately 80% was prepared using air-pluviation method (Figure 2).

An array of pairs of in-flight bender element were installed in the soil (Figure 2) to measure shear wave velocity (V_s) of soil during the centrifugal acceleration. **Error! Reference source not found.** shows a variation of measured V_s with depth.

Table 1. Properties of soil modeling in centrifuge test

Properties	Value
Specific gravity, G_s [-]	2.65
Fine contents passing #200 [%]	0.9
Maximum void ratio, e_{max} [-]	1.137
Minimum void ratio, e_{min} [-]	0.616
Uniformity coefficient, C_u [-]	1.6
Soil classification, USCS	SP
Relative density, D_r [%]	80
Dry density [t/m^3]	1.54