Experimental Investigation of Soil-Structure Interaction Effect on Seismic Structural Response using Centrifuge Test

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1. Introduction

Soil-Structure Interaction (SSI) is a crucial factor to determine the seismic responses of structures such as a nuclear structure. The analysis of the SSI effect is routinely performed to safety assessment related to the nuclear structure and it is expanded to common civil structures, but, in many cases, this effect is assumed to be beneficial [1]. The SSI effect, however, can be manifested variously and sometimes show detrimental consequences due to the resonance between the soil-structure system and the input earthquake motion [2]. This uncertainty gives rise to the necessity of study for the SSI effects. In this study, the SSI effect on the seismic structural response was investigated using centrifuge model test.

2. Centrifuge Testing Program

The 20g centrifuge tests were performed in the 5 m radius, 240 g-ton capacity centrifuge facility at KAIST [3]. Unless otherwise noted, all values herein are presented in a prototype scale. The centrifuge test models are comprised of a soil layer, shallow foundations, and structures as depicted in Fig.1, and several experiments were conducted while changing the superstructure. Dry silica sand (Dr =80%) was used to construct a 12m of dry dense sand layer, and three different rectangular foundations were considered with the lengths of 1.4, 2.0, and 2.8 m, respectively. Simplified single-degree-of-freedom (SDOF) structures with flexible columns were designed with two thin plates and a lumped mass, and its natural period is about 0.26s. The four recorded earthquake motions were excited at the base of the model with increasing the earthquake intensity.

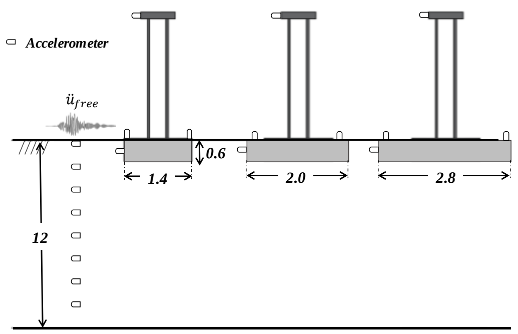

Fig. 1. Schematic diagram of the Centrifuge Model Tests in Prototype Scale (unit: m).

3. Test Results

3.1 Responses of SDOF Structure

To elucidate the SFSI effect on the structural seismic response, the net displacements of the SDOF structure on shallow foundation were compared with the calculated structural displacements based on the assumption of fixed-base condition using the recorded soil surface motion. Fig.2 shows the results when peak ground acceleration of soil surface motion is about 0.6g during the Kobe earthquake test. The net displacements of the calculated fixed base structure, which were determined by the input motion, showed similar responses regardless of foundation size, but the displacements of the flexible base structure decreased when the foundation lengths were 1.4m and 2.0m. However, the displacement of the flexible base structure for the largest foundation was still similar to that of the fixed base structure.

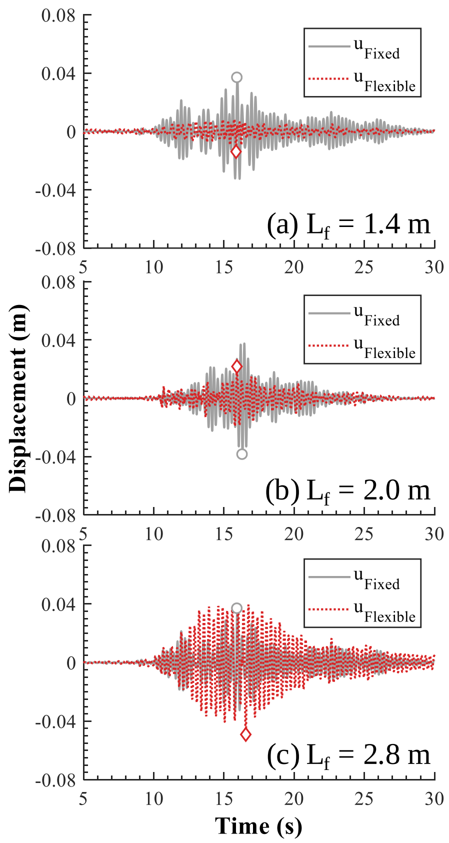

Fig. 2. Net Displacements of the Structure with the Fixed and the Flexible base

All peak values of the seismic loads of the structure from centrifuge tests are depicted as shown in Fig.3. As the fixed base motion increase, most of the flexible base motions turned into gradually smaller than the fixed base motion and converged to a limited value due to the foundation rocking behavior. On the other hands, some markers, appeared above the one-to-one line, indicate that the SFSI effect is not always positive as introduced in [2].

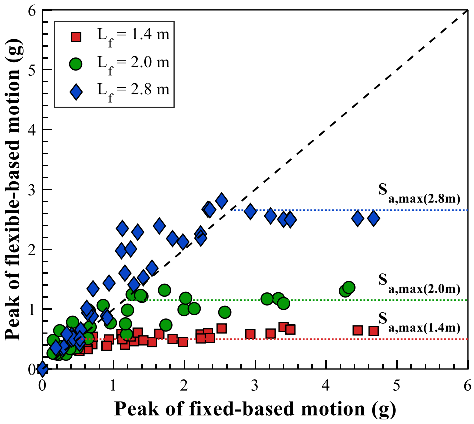

Fig. 3. Comparison of Peak Seismic Load of the Structure between the Fixed Base Motion and the Flexible Base Motion

3.2 Period Lengthening of the Soil-Structure System.

Fig.4 shows the transfer function of measured acceleration between the soil surface and the lumped mass of structure when the weak level shaking was applied. As a result of the inertial SSI effects [4], the natural periods of the flexible soil-structure systems were lengthened than the those of the fixed base structure, and the largest natural period of the flexible base system was observed in case of the smallest foundation.

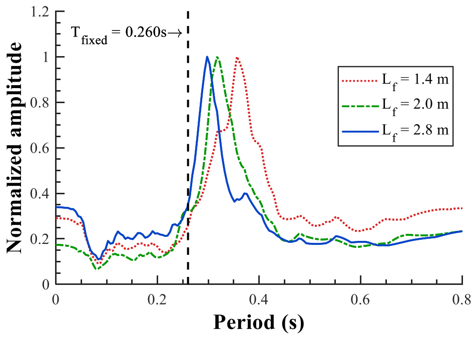

Fig. 4. Lengthening of the Natural Period of the Flexible Base System by Acceleration Transfer Function

In order to investigate the SSI effect mentioned previously, the comprehensive relationship between the soil surface motion mean period [5], the system natural period, and the system response is presented in Fig. 5. The test results are widely distributed along second and fourth quadrants. Notably, in case of quadrant 2, the more significant structural responses of the flexible base were induced, because the lengthened natural periods of the flexible soil-structure system were closer to the mean period of soil surface motion than the natural period of the fixed structure.

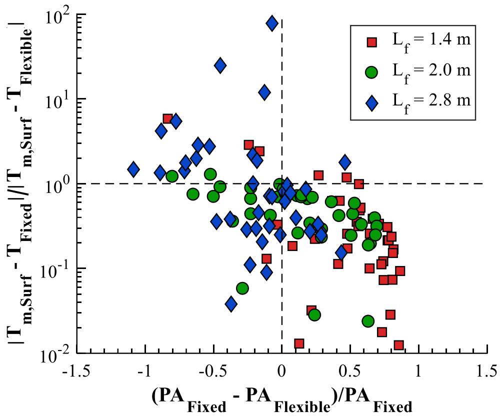

Fig. 5. Relationship between the Soil Surface Motion Mean Period, the System Natural Period, and the System Responses

4. Conclusions

The SSI effect on the seismic structural responses was experimentally investigated. From the centrifuge model test result, it is confirmed that when the lengthened natural periods of the system due to the SSI effect were closed to the soil surface motion mean period, the structural responses became larger than the calculated fixed base structural responses. And the consequence of the SSI effects was varied depending on the shallow foundation size.

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