EXPERIMENTAL STUDY OF ISOLATED FLOOR SYSTEMS

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ABSTRACT :

To protect the nonstructural components in critical facilities (such as hospitals), focusing in particular on the key sensitive components in some rooms, a combined solution is proposed in which a structure is designed per a structural fuse philosophy and selected floors are isolated. This paper focuses on the experimental work related to the performance of isolated floor systems. Two types of isolated floor systems are considered: (i) a first proprietary system adopting special multi-directional spring units, and; (ii) an isolated system using concrete ball-in-cone isolation bearings with polyurethane balls as rolling balls. These systems were tested on 6-DOF shake table. The floor seismic excitation was obtained from nonlinear time history analysis of an SDOF frame designed as a structural fuse frame. The test results show that the isolated floor systems work well. The mechanical properties of these two isolated floor systems are also obtained in terms of acceleration-displacement relationship, which provides the foundation to better simulate these isolated floor systems in future parametric study of the combined solution.

KEYWORDS: Isolated floor, Seismic isolation, Nonstructural component, Earthquake engineering.

1. INTRODUCTION

Vargas and Bruneau (2006a, 2006b) presented a structural fuse concept where passive energy dissipation (PED) devices are designed such that all seismically induced damage is concentrated on the PED devices, allowing the primary structure to remain elastic during seismic events. The structures designed under this concept are stiff, leading to a decrease in drift demands on the nonstructural components. However, the acceleration demands on the nonstructural components can increase by using this system.

To protect the nonstructural components in critical facilities (such as hospitals), such as the key sensitive components on the floor of a room, a combined solution of stiffening the structure and isolating the floor is proposed. In order to study this design concept in terms of parametric analysis in commercial program, the mechanical properties (such as the force-displacement relationship) of the isolated floor system must first be obtained. It is also necessary to investigate the performance of the isolated floor systems, such as whether the system properties vary during response and whether the system is strong enough to carry the design gravity loads. Therefore, some tests were conducted on these isolated floor systems.

This paper presents the details of tests conducted on two types of isolated floor systems. The test results illustrate the mechanical properties in terms of acceleration-displacement relationship in this research. These tests also show that these two isolated floor systems work well.

2. TEST SETUP

2.1. Isolated Floor System I

First, a proprietary isolated floor system by Dynamic Isolation Systems (DIS) was tested. This kind of isolated floor system relies on two sets of multi-directional spring units (Figure1) and a platform on wheels to reduce the acceleration response of the nonstructural components sitting on top of the floor. This isolated floor system is called Isolated Floor System I here to distinguish it from the other isolated floor system considered in this research. The setup of Isolated Floor System I is shown in Figure 2. For the tests of the isolated floor system, the system was constructed on a concrete footing slab cast to provide a representative floor surface to be typically found in buildings. When setting up the specimen, the footing slab was first fixed down to the 6-DOF shake table in Structural Engineering and Earthquake Simulation Laboratory (SEESL) of University at Buffalo. Also, to simulate the real conditions of a room in real buildings, three layers of a surrounding concrete masonry wall were built on the concrete footing slab (about 610 mm (24 in) high in total, as shown in Figure 2). The inner area surrounded by the wall is 3454 mm x 3454 mm (136 in x 136 in), i.e. about the real size of a small room. Some steel plates were installed to cover the moat between the isolated floor and the surrounding wall, which is about 286 mm (11.25 in) wide, as would be required in a real application.

Figure 1 Multi-directional spring units

Figure 2 Setup of Isolated Floor System I

2.2. Isolated Floor System II

The other type of isolated floor system considered in this study adopted 12 sets of concrete ball-in-cone isolators, which are shown in Figure 3. This isolated floor system is denoted as Isolated Floor System II. This was a custom-made system, differing from other ball-in-cone systems in that polyurethane balls on a concrete rolling surface were used. The dimensions of the working surface of the concrete ball-in-cone isolators were similar to those used by Vargas and Bruneau (2006b). This kind of isolator is designed to limit horizontal accelerations to 0.1g. The setup of Isolated Floor System II is shown in Figure 4. Again, the concrete footing slab and surrounding wall were adopted for the tests of this isolated floor system. Some steel plates were also used to cover the moat between the isolated floor and the surrounding wall.

Figure 3 Concrete ball-in-cone isolators

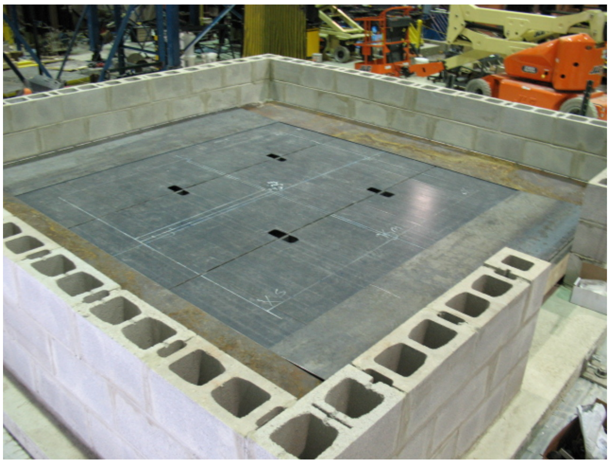

Figure 4 Setup of Isolated Floor System II

3. INPUT

An elastic response spectrum was first defined in accordance with the NEHRP Recommended Provisions for Seismic Regulations for New Buildings and other Structures (FEMA 2004) for Sherman Oaks, California, and site soil-type class B, the site of the Multidisciplinary Center for Earthquake Engineering Research (MCEER) Demonstration Hospital. The design spectral accelerations for this site are S_{DS}=1.3g, and S_{D1}=0.58g for 2% probability of exceedance in 50 years. For this spectrum, T_s is 0.45 s, and T_0 is 0.09 s. A response spectra compatible acceleration time histories was generated by using the Target Acceleration Response Spectra Compatible Time Histories (TARSCTHS) Code, by Papageorgiou et al. (1999). The comparison between the elastic response spectrum for 5% of critical damping corresponding to this response spectra compatible acceleration time histories and the target NEHRP 2003 elastic response spectrum is shown in Figure 5. Good agreement is noted. .

This response spectra compatible acceleration time histories was adopted as seismic input in SAP 2000 (Computers and Structures Inc. 2004) to analyze a single-degree-of-freedom (SDOF) structural fuse frame designed by Vargas and Bruneau (2006a). The mass of this frame is 0.35 kN$\cdot$s^2/mm (2 kip$\cdot$s^2/in). The initial lateral stiffness of the frame, K_{isf}, is 49.43 kN/mm (282.26 kip/in), and the yield strength, V_{ysf}, is 714.39 kN (160.61 kip). The natural vibration period of this SDOF frame is 0.53 s. The post yielding stiffness ratio is K_{psf}/K_{isf}=0.25, where K_{sfp} is the frame lateral stiffness after yielding of the metallic energy dissipating element. The equivalent linear viscous damping ratio of the frame is 5%. The lateral force-displacement relationship for the structural fuse frame is shown in Figure 6.

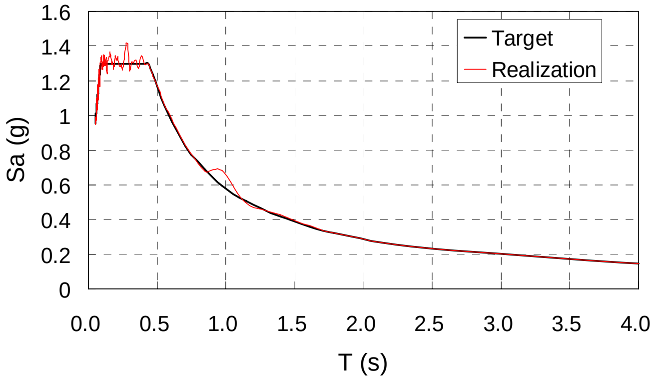

Figure 5 Elastic response spectrum of realization vs target response spectrum (ζ=5%)

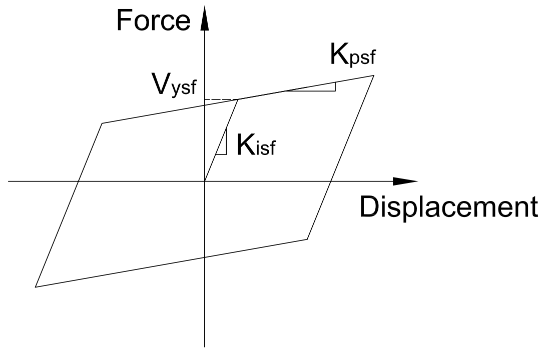

Figure 6 Lateral force-displacement relationship of SDOF structural fuse frame

4. LOADS AND INSTRUMENTATION

The office floor uniformly distributed design live load requirements in Minimum Design Loads for Buildings and Other Structures (ASCE 2005) is 2400 Pa (50 psf). Also, the load combination of 1.2D+L+1.0E was considered. The corresponding target symmetrical load value on top of the walking surface of the isolated floor systems is 2916 Kg (6422 lb). Some steel plates were deposited on top of the isolated floor to produce that gravity load. The actual weight of the steel plates used was 2805 Kg (6180 lb). For both shake table and the isolated floor, some accelerometers and string pots were adopted to measure the acceleration response and displacement response, respectively.

5. TEST RESULTS

During the tests, the two isolation systems performed as expected, each moving as a unit. After all the tests, there was no damage to the isolated floor systems. The isolated floor systems were also able to carry their design live loads during seismic events.

The force-displacement relationships of the isolated floor systems were also obtained during these tests. Here, the displacement of the isolated floor system means the relative displacement of the isolated floor with respect to the shake table/concrete footing slab. The force of the isolated floor system means the restoring force corresponding to each displacement value. Since the restoring force in value is equal to the reverse value of the total mass of the isolated floor system and the loads on top times of the absolute acceleration response of the isolated floor, the test results of Isolated Floor Systems I and II are illustrated in terms of acceleration-displacement relationships. They are shown in Figure 7 and Figure 8, respectively. The comparison of acceleration response between the shake table and the isolated floor is shown in Figure 9 and Figure 10, respectively.

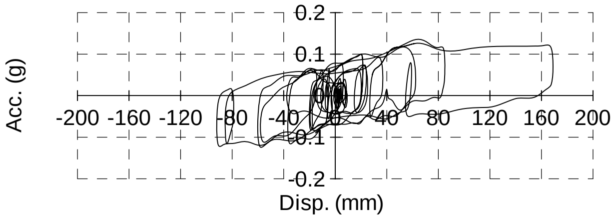

Figure 7 Acceleration-displacement relationship of Isolated Floor System I

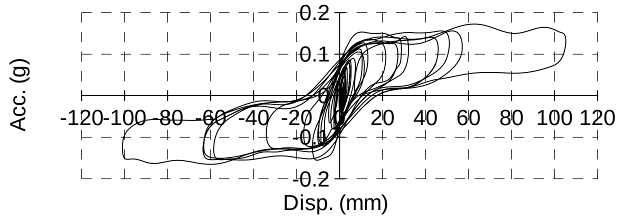

Figure 8 Acceleration-displacement relationship of Isolated Floor System II

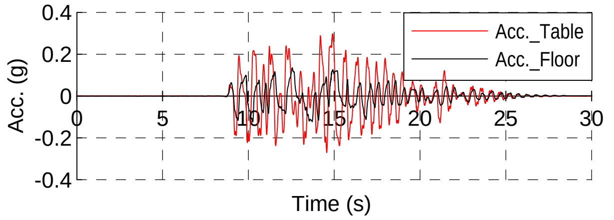

Figure 9 Acceleration response comparison of Isolated Floor System I test

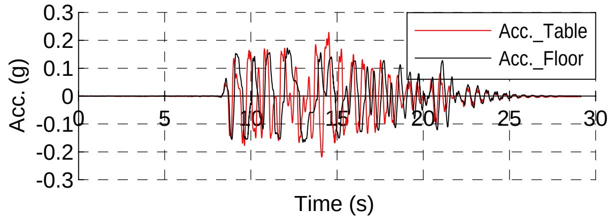

Figure 10 Acceleration response comparison of Isolated Floor System II test

From Figure 7 and Figure 8, it can be noted that, for both isolated floor systems, the acceleration-displacement relationship traces some hysteresis loops. The area of the loops is proportional to energy dissipation (since acceleration is directly related to the restoring force of the isolated floor system). From the mechanical behavior of ball-in-cone systems (Kemeny 2003, Vargas and Bruneau 2006b), the behavior of the ball-in-cone isolators should be bi-linear elastic if the friction between the rolling ball and the bearing plates is small and neglectable. However, the loops in Figure 8 show that the rolling friction between the polyurethane balls and the concrete bearing plates is significant and can not be neglected.

Figure 9 shows that the peak acceleration response of the isolated floor is significantly reduced, down to 0.14g, compared with the shake table response of 0.30g. Figure 10 shows that the peak acceleration response of the isolated floor is reduced down to 0.17g compared with the peak shake table response of 0.23g. Although the reduction of peak acceleration response in Isolated Floor system II is not as significant as for Isolated Floor System I, the peak acceleration response for both isolated floor systems should remain relatively constant, particularly for system II after the rolling balls between the two bearing plates reaches the conical surface of the bearing plates (as long as the rolling balls remain within the working surface) regardless of the input amplitude. This phenomenon is observed in Figure 8 that the peak acceleration response is almost a flat line, which means a constant acceleration value.

The above reports on the preliminary phase of this study. The observed mechanical behaviors of the two isolated floor systems considered remains to be compared with those predicted using physical models to be developed from this study. Each isolated floor system had its own model. Furthermore, in some cases, comparison between the mechanical behaviors of system components, isolators, and corresponding isolated floor systems will be necessary to provide the foundation for the development of a design procedure integrating structural system design and isolated floor system design.

6. CONCLUSIONS

In this research, two kinds of isolated floor systems were tested to check their seismic performance and to capture their hysteretic mechanical behaviors. In these tests, each of these two isolated floor systems worked as a whole system and provided satisfactory seismic performance in addition to carrying the required design live loads. Isolated Floor System I reduced the acceleration response of nonstructural components more significantly than Isolated Floor System II. However, Isolated Floor System II may limit the peak acceleration response of nonstructural components on top to a constant value (as long as the rolling balls are within working surface) regardless of the input amplitude. The test results in this study provide the foundation to better model the isolated floor systems through comparison with the mechanical behaviors of the corresponding isolators.

ACKNOWLEDGEMENT

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