学 位 論 文 内 容 の 要 旨

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学 位 論 文 題 名

Seismic Performance of Steel Moment-Resisting Frames with Spines Examined by Shake-Table Tests
(心棒を備えた鋼構造ラーメンの耐震性能を検証する振動台実験)

Seismic resisting multi-story building structures are expected to distribute the seismic demands evenly throughout the structure height, achieving the global mechanism and thus utilizing the full potential of the structure. However, soft story is still quite common in real constructions as observed in past large earthquakes. Such soft-story mechanism is difficult to avoid even if the structure is code compliant due to the stochastic nature of earthquakes.

The spine is introduced as a possible solution to the drift concentration at soft stories in conventional multi-story buildings. Spines are vertically continuous substructures with large lateral stiffness and strength. They are usually connected to the ground with a moment release connection (for example a mechanical pin) and remain essentially elastic under certain excitation levels. When connected to a base structure, the spines can distribute the demands uniformly in the system, coordinate the deformation of different stories and force a global deformation distribution via its large stiffness. Such systems have been successfully adopted in both retrofitting and new constructions and proved to be effective. For the interest of this project, the base structure is limited to Moment Resisting Frame (MRF), and the spines particularly refer to the pin-based form. The system is thus termed as MRF-Spine system.

Despite the effectiveness of the spine systems, it has been reported by various previous projects that there may be non-negligible higher mode responses in such systems compared to conventional seismic load resisting systems. Such higher mode contribution will lead to large story shear force and floor acceleration responses in the base structure, causing troubles in member design and cost control. Although some design methods considering higher mode contribution have been proposed, it still would be beneficial to control the higher mode demands in such systems to achieve a cost-effective design.

A possible solution to control the higher mode responses is to use deformable connections between the spines and the base structure, termed as Force-Limiting Connections (FLCs) in this research. Such connections can allow some relative motion between the spines and the base structure and hopefully reduce the higher mode responses. Besides, yielding of such connections is also expected to limit the force transferred from the base structure to the spines. Similar connections have been tested in an RC flat-slab rocking-wall system. But its application in an MRF-Spine system still requires real-world validation.

A series of full-scale shake table tests on the MRF-Spine system with FLCs were conducted in 2020 at E-Defense as a major Japan-US collaboration. The purpose of the tests was to provide real-world validation on MRF-Spine-FLC systems and to build confidence on such systems. During the test, two structural systems, with and without the FLCs, were tested. Two ground motions, one from the 1994 Northridge earthquake and the other from the 1995 Kobe earthquake, were selected to excite the

structure differently. Various structural responses were measured during the test and a comprehensive data analysis was conducted after the test to understand the behavior of the tested structural systems.
In addition to the conventional data analysis on the shake table tests, modal parameter identification and time-frequency analysis were also conducted to further understand the vibration properties of the MRF-Spine systems. The Auto-Regressive with eXtra input (ARX) method, the State-Space method and the Frequency Domain Decomposition (FDD) method were used to identify the modal parameters. The Synchro-Squeezed Wavelet Transform (SSWT) method was used to evaluate the time-frequency properties of the specimen. In addition, the Effective Modal Pseudo-Acceleration method was used to provide information from the response spectra point of view. Real world test data taken from several other shake table tests on other types of structural systems were used in addition to the MRF-Spine test. The supplementary tests were selected to provide comparisons on different possible influencing factors, including but not limited to the existence of spines, scale of the specimen, property of the excitation, proportion between the spine and the base structure, etc.
Results from the data analysis of the MRF-Spine shake table test and vibration property analysis proved the effectiveness of FLCs in controlling the higher mode acceleration and shear force responses in the structural systems. It was also confirmed that higher modes were relatively easier to be excited in the system with spines. Influence of other factors were also investigated. In the work reported here, confidence in the MRF-Spine-FLC systems was built from real-world data. The concept of such a structural system proved worth of further investigation.
Future work requires more comprehensive analysis on the specific design of the connection properties, as well as other influencing factors as above-mentioned. A series of detailed parametric study using numerical models carefully calibrated against the test results would be necessary to get a more systematic understanding of such systems. Code compliant design approaches on such systems also require more effort.