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Investigation on Two-elevation Integrated Ceiling System Considering Interaction Effect around Equipment

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1. Introduction

Recent earthquakes such as the 2011 Tohoku earthquake and the 2016 Kumamoto earthquake have highlighted that buildings demonstrating relatively little structural damage still suffer from extensive damage and failure of nonstructural systems. The dropping and failure of nonstructural components can lead to lengthy functional disruptions, and substantial economic losses as well. Observations of the damage suffered by nonstructural components vary with the architectural style; nevertheless, the failure of suspended ceiling systems is among the most commonly reported damage. Typical damages of suspended ceiling systems are shown in Fig. 1.

(a) Collision (b) Panel dropdown

Fig. 1 Typical ceiling damage [1]

In recent years, existing researches have been mostly concentrated on the individual performance of suspended ceilings. Due to the different dynamic characteristics of ceiling panels and electric equipment, they interact with each other under earthquake excitations. Besides that, another critical issue is the seismic demand of the multi-elevation ceiling. Though the conventional construction method has been reported and implemented for the multi-elevation ceilings in practice, the real dynamic response of this unique system still lacks.

This paper reports the seismic damage observations of typical Japanese suspended ceiling, and highlights the important role of the reinforcing bars between the two ceiling elevations.

2. Typical ceiling configuration

Suspended ceiling systems are widely used in building structures, providing aesthetic appearance to conceal the overhead piping and mechanical systems. Typically, the electric equipment is installed and embedded into the ceiling panel blocks to meet the functional requirements.

For the Japanese suspended ceiling system, threaded rods rather than wires are preferred for the suspension of the constitutive grid. In general, a small gap of less than 5 mm exists between partitions and ceiling panels, filled by flexible sealing materials, to avoid any direct contact with the walls; and ceiling panels are fixed with the runners by screws instead of merely placing on the flange of runners. Fig. 2 illustrates a typical Japanese ceiling system.

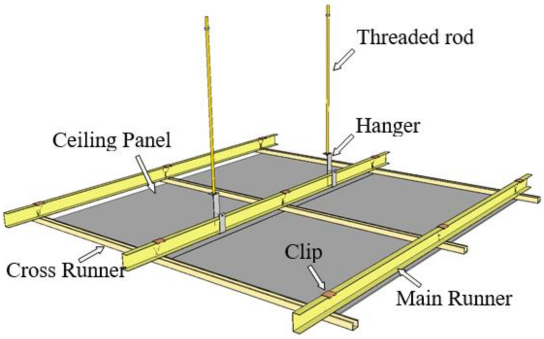


Fig. 2 Suspended ceiling configuration in Japan

3. Shake table tests

A series of shake table tests were conducted to evaluate the seismic performance of the Japanese two-elevation integrated ceiling system. JMA Kobe ground motion was scaled to three levels, i.e., PGV 25 cm/s (L1), PGV 50 cm/s (L2), PGV 80 cm/s (L3), and input the above motions into the overall structure. Totally 14 laser displacement transducers and 37 accelerometers were attached to different locations of the integrated system, including ceiling panels, ACs, Lightings, and even pipings to monitor the seismic responses. The on-site test configuration is displayed in Fig. 3.

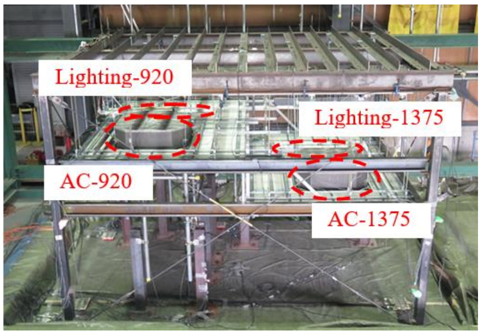
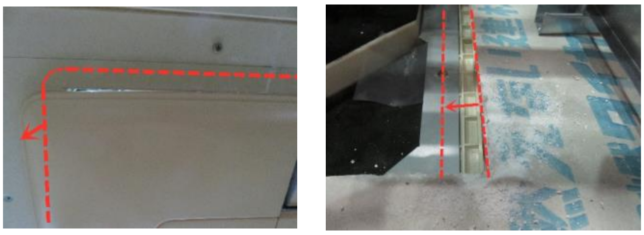


Fig. 3 Test overview

(a) Without reinforcing bar (b) With reinforcing bar

Fig. 4 Reinforcing bar

The reinforcing bars (Fig. 4) were analyzed in detail to see its influence on the seismic behavior of the integrated ceiling system. Under JMA Kobe L2, no apparent damage occurred, and the maximum relative drift (MRD) between two ceiling elevations was only 0.61%, indicating the great integrity of the ceiling system.



(a) Twisting of AC (b) AC movement

Fig. 5 Damage observations

Under JMA Kobe L3, The AC cover was stuck into the original clearance and certain twisting deformation existed (Fig. 5). MRD increased to 1.81% and relative residual deformation between the two elevations of 0.4 mm appeared. After removing the reinforcing bar, MRD under JMA Kobe L2 reached 3.9%, resulted in very large residual deformation of 4.2 mm, demonstrating the important role of the reinforcing bars. Besides, the lighting fixtures are very flexible to resist the input seismic force. Fig. 6 shows the drift variation between two ceiling elevations with different ground motion excitation.

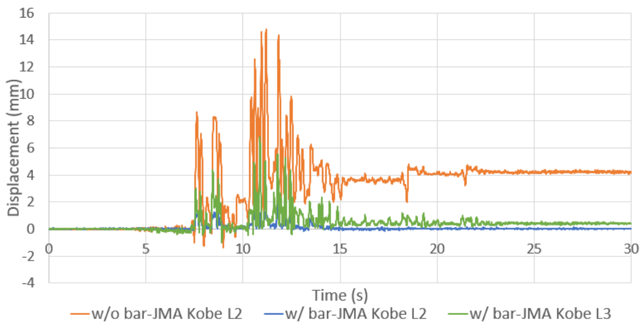


Fig. 6 Relative displacements of two elevations

4. Conclusions

The following conclusion can be addressed:

1. The Japanese integrated ceiling system has excellent seismic performance; most damage is concentrated at the boundary of the electric equipment and the ceiling panels.

2. The reinforcing bar connecting two ceiling elevations is beneficial to reduce the relative displacement and ensure the integrity of the integrated ceiling system.

3. Lighting fixtures are very flexible under earthquake excitation, and some reinforcements are needed.

Acknowledgments

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References

[1] Architectural Institute of Japan (AIJ), Preliminary reconnaissance report of the 2011 Tohoku-Chiho Taiheiyo-Oki Earthquake. Tokyo: Maruzen Publishing; 2012. (in Japanese)