Collapse Simulation of Wide-Area Suspended Ceiling System Using the ASI-Gauss Code

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Many ceiling collapse damages were observed in wide-area structures such as gymnasiums during the 2011 Great East-Japan Earthquake [1] and the 2016 Kumamoto Earthquake [2]. The prevention of ceiling collapse phenomena is an important issue not only to save people's lives, but to keep these facilities to be safely used as shelters after earthquakes.

In this paper, a numerical analysis to simulate the ceiling collapse in a full-scale gymnasium specimen, which was tested at the E-Defense shaking table facility in 2014 [3,4], was conducted. A numerical model consisted of steel structural frames and suspended ceilings were constructed. All the members were modeled using linear Timoshenko beam elements and the adaptively shifted integration (ASI) - Gauss code [5] was applied. Hangers and hanging bolts were modeled in one piece. The plaster boards were assumed as rigid in out of plane direction and only the mass of rock wool boards was considered. Their strength were neglected. Clips and screws were modeled with minute, small elements. Each plaster board was modeled separately to consider local contact between plaster boards, which was simulated by modeling the screws slightly apart. Elasto-plastic buckling of braces and hanging bolts were considered by modeling them with eight beam elements each and two hinge elements on both ends. The clips connecting ceiling joists and ceiling joist receivers are small and delicate components that may be detached during repeated excitation. Once there is a local detachment of clips, a change in the load distribution may cause a chain reaction of detachments, which ends in a drop of plaster boards. Furthermore, the detachments of hanging bolts that are connected to the structural members composing the roof, and failure of screws on plaster boards are assumed to be other main causes of the ceiling collapse. The results of some preliminary tests [6-9] conducted to see the actual strength of these components are implemented in the analysis for criteria.

The numerical result was validated by the experimental result [3,4], which was performed at the E-Defense under an input of two continuous K-NET Sendai 50% waves. The acceleration responses, the spectrum and the displacement responses obtained on the roof matched well with the experimental result. According to the results, the plaster boards near walls pattered down occasionally at the first peak of the first wave. These were due to detachment of clips and screws caused by collisions to the walls. Then, the clips near roof top began to get loose due to buckling of hanging bolts caused by vertical excitation, which ends, at the first peak of the second wave, in drop of plaster boards in a wide range (Fig. 1). The numerical result had shown the collapse of the ceilings progressed owing to the detachment of clips that connected the ceiling joists to the ceiling joist receivers, which eventually led to a large-scale collapse of the ceilings.

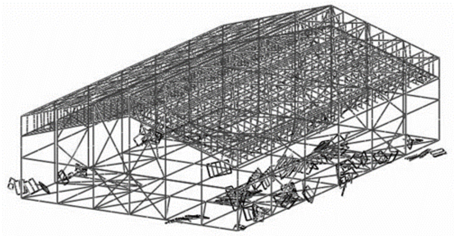

Fig. 1 Collapse of ceilings in a gymnasium during seismic excitation

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