Numerical Simulation of Suspended Ceiling Collapse using ASI-Gauss Technique

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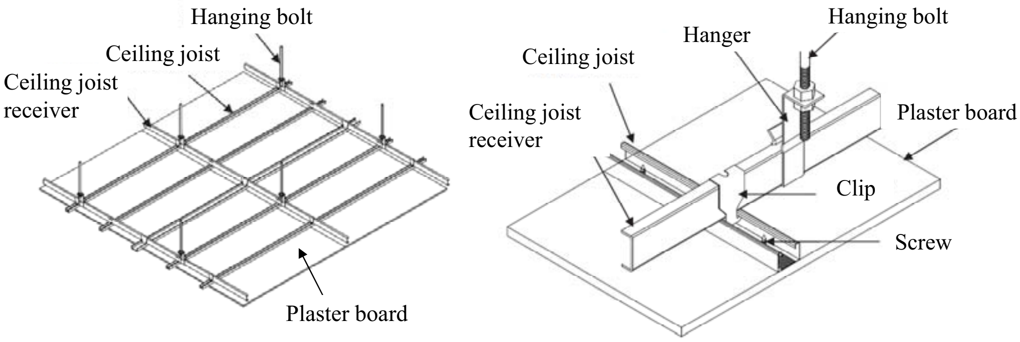
Abstract

Numerical simulation of suspended ceiling collapse caused by ground excitation is conducted in this research. Numerical model is a suspended ceiling, in which all members are modeled by the linear Timoshenko beam elements. The Adaptively Shifted Integration (ASI) - Gauss technique [1], which is utilized to shift the numerical integration point adaptively to an appropriate position, is applied to the nonlinear finite element procedure for structurally discontinuous problems. Nonlinear time-history analysis shows that insufficient attachment of ceiling joist and ceiling joist receiver due to poor execution of works on clip and hanger may trigger consecutive detachment of these elements and finally, resulting in ceiling collapse.

Introduction

Many accidents of ceiling collapse were observed in the 2011 Great East Japan earthquake and others in Japan. Typical configuration of suspended ceiling is illustrated in Figure 1. Plaster board is attached to ceiling joist with screw, ceiling joist is attached to ceiling joist receiver with clip, and ceiling joist receiver is attached to hanging bolt with hanger. In past earthquakes, many accidents of ceiling collapse were caused by the detachment of clip and/or hanger resulting in the fall-down of plaster board, ceiling joist and ceiling joist receiver. In this study, numerical simulation of ceiling collapse caused by earthquake ground motion is conducted.



(a) Global (b) Detail

Figure 1: Typical configuration of suspended ceiling (perspective)

Modeling and Analysis Method

Numerical model of a suspended ceiling is illustrated in Figure 2. Here, hanging bolt, ceiling joist receiver, clip, ceiling joist and plaster board are illustrated by black, blue, red, green, and gray lines, respectively. Ceiling size is 3600mm×3600mm and intervals of ceiling joist and ceiling joist receiver are 300mm and 900mm, respectively. Length of hanging bolt is 700mm and clip height is 50mm.

The Adaptively Shifted Integration (ASI) - Gauss technique [1], which is utilized to shift the numerical integration point adaptively to an appropriate position, is applied to the nonlinear finite element procedure. All members, including plaster board, are modeled by the linear Timoshenko beam element. The ASI – Gauss technique requires to model one member with only two elements to consider accurate plastic behavior of the member. For this reason, nodes are placed at the end and center points of all members. Total number of elements is 654 and total number of nodes is 547.

Numerical simulation of ceiling collapse involves structurally discontinuous problem. The updated Lagrangian formulation is utilized to consider geometric nonlinearity in incremental analysis. The detachments of ceiling joist and/or ceiling joist receiver are considered by setting sectional forces of clip and/or hanger to be zero once axial force acting on these members exceeds the maximum strength. The contact of members to the ground is also considered.

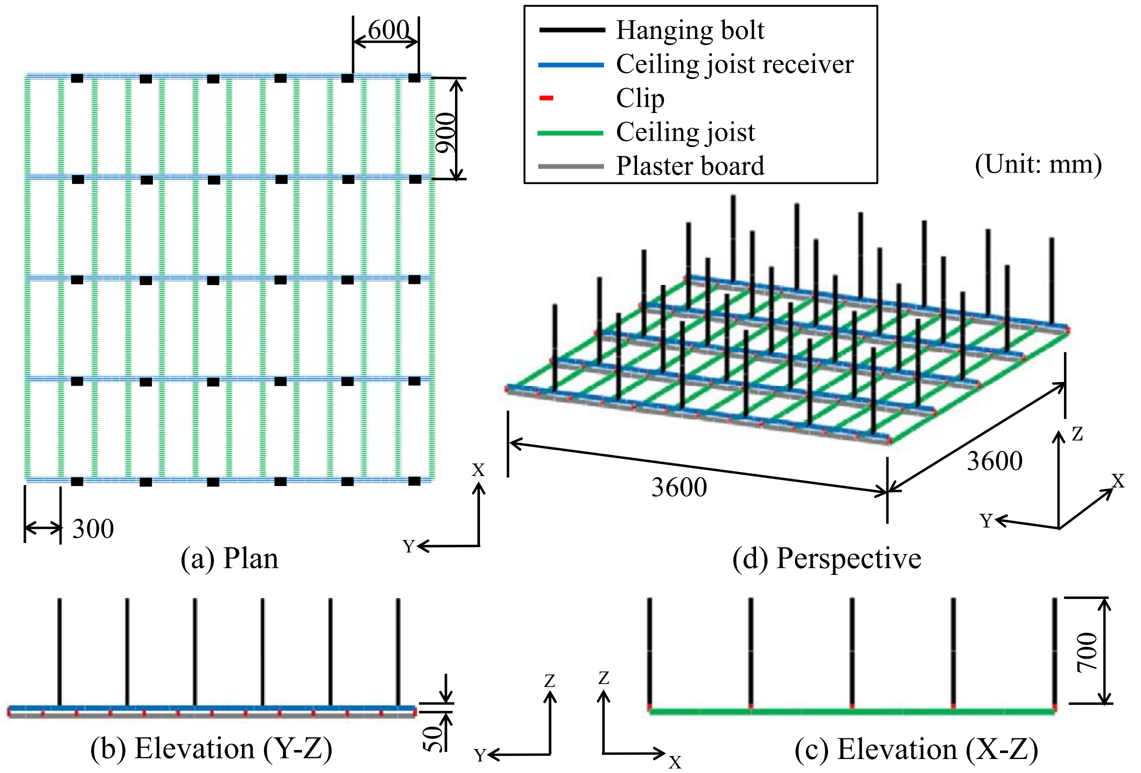


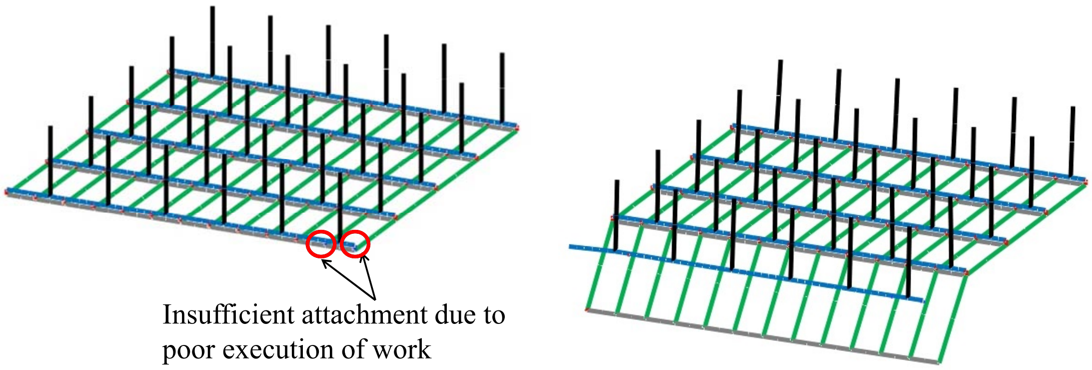
Figure 2: Model of suspended ceiling

Simulation Results

Nonlinear time-history analysis is conducted for numerical model in Figure 2, in which the ground motion acceleration, JR-Takatori record, is input at all nodes located at the upper end-point of hanging bolts. This assumes that a structure supporting the suspended ceiling is perfectly rigid and ground motion is directly induced to the ceiling.

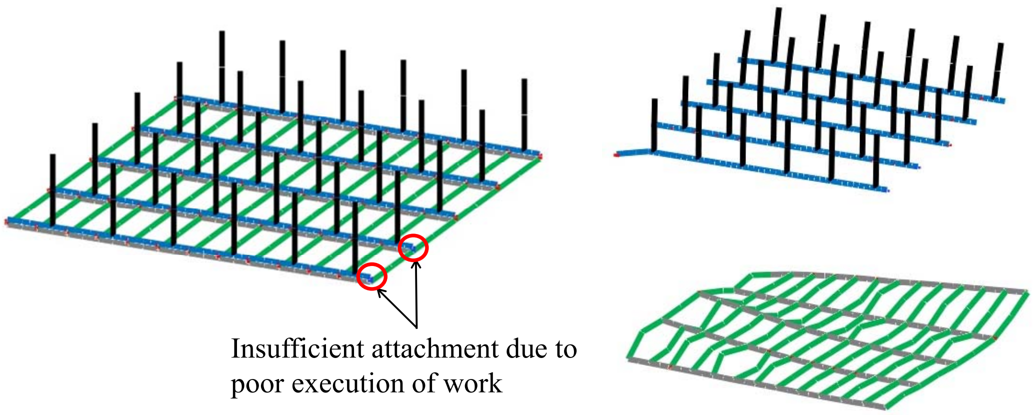
If all clips and hangers possess the maximum strength of 0.3kN and 2.8kN [2], respectively, any detachment of ceiling joist, ceiling joist receiver does not occur, resulting in simple oscillation of the suspended ceiling as a whole. However, if the maximum strength of two clips along the ceiling joist receiver is reduced to 0.05kN caused by poor execution of works on these clips as shown in Figure 3(a), partial detachment of ceiling joist occurs as shown in Figure 3(b). Further, if two clips along the ceiling joist possess the maximum strength of only 0.05kN shown in Figure 4(a), consecutive detachment of ceiling joist and ceiling joist receiver occurs and finally, resulting in ceiling falling-down, as shown in Figure 4(b).

Currently, simulation of suspended ceiling in large-space structure considering the interaction of their response is conducted to clarify the mechanism of ceiling collapse.



(a) Location of insufficient clips (b) Simulation result

Figure 3: Simulation of partially collapse



(a) Location of insufficient clips (b) Simulation result

Figure 4: Simulation of falling-down

Conclusions

Numerical simulation of suspended ceiling collapse is successfully conducted utilizing the Adaptively Shifted Integration (ASI) - Gauss technique. Analysis results show that insufficient attachment of ceiling joist and ceiling joist receiver may trigger consecutive detachment of these elements and further result in ceiling falling-down.

References

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