Risk Estimation for Progressive Collapse of Buildings Using Key Element Index

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In the case of an emergency such as an intense fire or the collision of an object with a building, there is a risk of progressive collapse [1]. This was the phenomenon that occurred at the World Trade Center (WTC) towers during the 9.11 terrorist attacks. The official statements released by the Federal Emergency Management Agency (FEMA) in 2002 [2] and the National Institute of Standards and Technology (NIST) in 2005 [3] and 2008 [4] concluded that the details of the failure process after the decisive initial trigger that set the upper part in motion were very complicated and their clarification would require large computer simulations. Among the various papers published after the incident, the one published by Bazant et al. [5] has become a milestone for numerous other works concerning the progressive collapse of buildings. By defining an overload ratio, the ratio of the elastic strength of the lower structure to the total weight of the upper, falling structure, they explained that the force applied to the lower structure by the upper overwhelmingly exceeded the design vertical load, and consequently, it would be practically impossible to design a high-rise tower to avoid a progressive collapse such as that which occurred in the case of the twin towers. On the other hand, they also admitted that numerous computer simulations should be carried out to clarify the collapse process, because their estimations were performed without considering the tilting of the upper structure, member fracture, and other details.

In this study, the collapse behaviors of steel-framed buildings were simulated to investigate the relation between a key element index [6-7] and the damage due to progressive collapse. The key element index is a parameter which indicates the contribution of a structural column to the vertical capacity of the structure. The collapse behaviors of steel framed buildings were simulated using the ASI (Adaptively Shifted Integration) -Gauss code [8], which can explicitly express member fracture and element contact in the collapse process. The progressive collapse phenomena were initiated by removing specific columns from the models. The total potential energy values of structural members after the collapse were used to estimate the damage of the buildings.

For the progressive collapse analysis, a ten-story, three-span steel framed building model was constructed. The columns were subdivided with two linear Timoshenko beam elements per member, and the beams and floors were subdivided with four elements. Several models designed based upon different axial force ratios were prepared to determine the effects of various structural strengths on the collapse scale of a building. The locations of removed columns were restricted to a single floor, and some patterns of removed columns were investigated. An example of the collapse sequence is shown in Figure 1.

By evaluating the numerical results using the key element index, it is found that the larger the integrated values of key element index, which are calculated by summing up all the key element index values for the removed columns, the risk of progressive collapse tends to increase; however, some peculiar tendencies are observed in the cases of removed columns with extremely symmetrical or asymmetrical locations. The threshold of the integrated value of key element index to cause a large-scale progressive collapse tends to depend on the strengths of models, and it cannot be generally decided. This is due to the fact that the key element index is a parameter which does not relate to the strength of the building itself. Therefore, the key element index may only be used to predict and compare the risks of progressive collapse in the same building, but this may be done even when various locations for the removed columns are assumed.

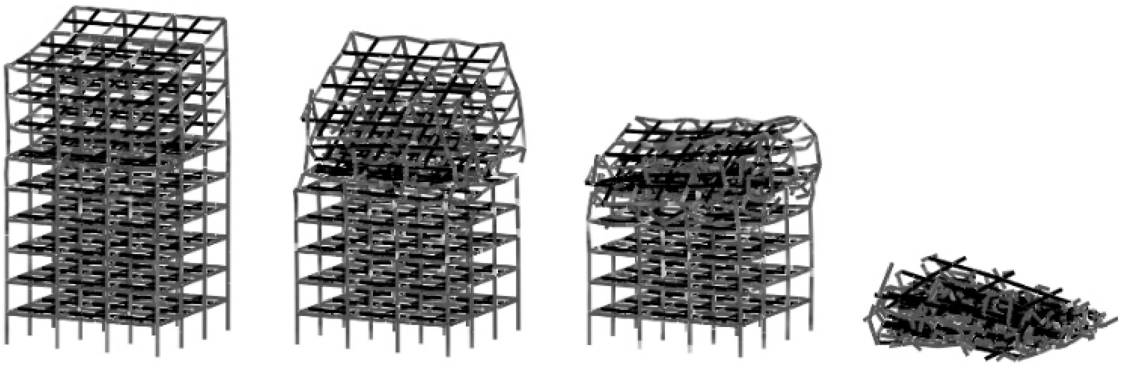

Fig. 1 Progressive collapse sequence of a ten-story, three-span steel framed building

References

[1] B.R. Ellingwood et al.: Best practices for reducing the potential for progressive collapse in buildings, National Institute of Standards and Technology (NIST), 2006.
[2] FEMA/ ASCE: World Trade Center Building Performance Study: Data Collection, Preliminary Observations, and Recommendations, 2002.
[3] NIST NCSTAR 1: Building and Fire Safety Investigation of the World Trade Center Disaster: Final Report on the Collapse of the World Trade Center Towers, National Institute of Standards and Technology (NIST), 2005.
[4] NIST NCSTAR 1A: Final Report on the Collapse of World Trade Center Building 7, National Institute of Standards and Technology (NIST), 2008.
[5] Z.P. Bazant and Y. Zhou: Why Did the World Trade Center Collapse? –Simple Analysis, *Journal of Engineering Mechanics*, pp. 2-6, 2002.
[6] D. Isobe: An Analysis Code and a Planning Tool Based on a Key Element Index for Controlled Explosive Demolition, *International Journal of High-Rise Buildings*, Vol. 3, No. 4, pp. 243-254, 2014.
[7] K. Oi and D. Isobe: Collapse Risk Prediction of Buildings on Fire Using Key Element Index, *Journal of Structural and Construction Engineering (Transactions of AIJ)*, Vol. 82, No. 738, 2017, to be published, in Japanese.
[8] K.M. Lynn and D. Isobe: Finite Element Code for Impact Collapse Problems of Framed Structures, *International Journal for Numerical Methods in Engineering*, Vol. 69, No. 12, pp. 2538-2563, 2007.