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Structural Collapse Analyses of Buildings Using an Adaptive Finite Element Code

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Summary: An adaptive finite element code based upon the ASI (Adaptively Shifted Integration)-Gauss technique is applied on various collapse problems of buildings. The code provides higher computational efficiency than the conventional code in such problems, and enables us to cope with dynamic behavior with strong nonlinearities including phenomena such as member fracture and elemental contact. Contact release and re-contact algorithms are also developed and implemented in the code to realize complex behaviors of structural members during collapse sequence. An outline of the numerical code is described and some numerical examples are shown in this paper.

Key Words *: Structural collapse analysis, FEM, ASI-Gauss technique*

1. INTRODUCTION

Catastrophic disasters of large-scale buildings occurred recently are mainly caused by sudden, extreme external loads such as aircraft collision, explosion, large seismic excitation, and fire. In numerical research area, dynamic codes are generally used to investigate such phenomena. However, strong nonlinearity in the deformation of structures and rapidness of the external loads often generate higher hurdle in the analyses. The author and his collaborators have developed an adaptive finite element code with the use of an ASI (Adaptively Shifted Integration)-Gauss technique, which provides higher computational efficiency than the conventional code in such problems, and enables us to cope with dynamic behavior with strong nonlinearities including phenomena such as member fracture and elemental contact. Contact release and re-contact algorithms are also developed and implemented in the code to realize complex behaviors of structural members during collapse sequence. In this paper, an outline of the ASI-Gauss technique is described and several numerical results on collapse problems of large-scale buildings are shown.

2. NUMERICAL CODE

Toi and Isobe first developed an adaptive finite element code called the Adaptively Shifted Integration (ASI) technique [1]. The code can be easily implemented into the existing finite element codes using linear Timoshenko beam elements. In this technique, the numerical integration point is shifted immediately after the occurrence of a fully plastic section in the element so that a plastic hinge is formed exactly at that section. The relationship between the locations of the plastic hinges and the numerical integration points used in the shifting process was first found by Toi [2], and it was obtained by considering the equivalence condition between the strain energy approximation of the finite element and a physical model, the rigid bodies-spring model (RBSM). The technique provided higher computational efficiency than the conventional finite element scheme and was able to cope with dynamic behavior with strong nonlinearities including phenomena such as member fracture [3, 4]. However, it lacked accuracy in the elastic range when the number of elements per member was small due to the low-order displacement function of the linear Timoshenko beam elements. The technique was thus modified into the ASI-Gauss technique [5], to improve its accuracy, particularly in the elastic range. The numerical accuracy was increased by placing the numerical integration points of two consecutive elements forming an elastically deformed member in such a way that the stresses and strains are evaluated at the Gaussian integration points of the two-element member, where the accuracy of bending deformation is mathematically guaranteed for two-point integration. This technique gives results with high accuracy at a very low computational cost, even compared with the ASI technique, and is efficient in applications to the dynamic collapse analysis of large-scale buildings.

Fracture of member joints are considered by examining bending strains, axial tensile strain and shear strains in a member. The critical strain values used in the analyses are the values actually obtained from some experiments concerning the joint bolts.

Contact determination is done by examining the distance between two colliding elements using geometrical relations of the four nodes. Once determined to be in contact, the two elements are bound with a total of four gap elements. The gap elements are automatically eliminated after some time of contact, when the mean value of deformations of gap elements is decreased to a certain ratio.

3. NUMERICAL EXAMPLES

One of the various collapse analyses carried out recently is a fire-induced collapse analysis of a high-rise tower, which presents important role in an investigation seeking for the true cause of the total collapse of New York World Trade Center (WTC) towers in 9/11. Figure 1 shows the collapse sequence of the tower model exposed under symmetric fire pattern. The results clearly show the effect of the weak member joints, which were reported to be 20 to 30 % of the strength of the members in WTC towers, as well as the effect of the strength reduction due to elevated temperatures. It is also confirmed that the collapse initiation times can be affected by the strengths of outrigger trusses and member joints of overall structure, as shown in Fig. 2. C_m in the figure denotes the ratio of member joint strength against the member strength itself. In general, the models with outrigger truss systems withstand longer in time by catenary action under the condition that their load paths are protected.

Blast demolition analysis is also carried out on a high-rise tower as shown in Fig. 3. The explosives are set on 5th to 8th floors of the tower, which is carefully planned, in this case, to make the whole building fall sideways. Collision of neighboring buildings under long-period seismic excitation is also a big issue. We focused on a specific apartment house with three same type buildings consecutively built with very narrow gaps in between, of which two out of the three collapsed totally in 1985 Mexican Earthquake. According to the numerical results such as in Fig. 4, collision of buildings may well be generated by the difference of natural periods between neighboring buildings. The difference was actually observed in the same type buildings, due to be caused by the damages made in the past earthquakes. In this case, we set the natural period of one building to be 25% longer than the others.

4. CONCLUSION

The adaptive finite element code with the ASI-Gauss technique gives highly accurate solutions with small mesh subdivisions, and requires little calculation time. The shifting of the numerical integration points enables us to express a fractured section in a member, which is the main reason why the code can be effectively applied to collapse problems.

REFFERENCES

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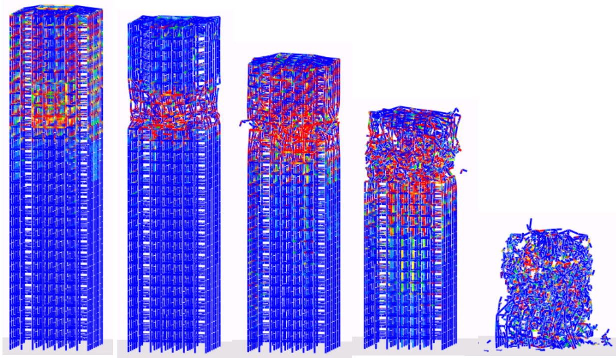

Fig.1 Fire-induced collapse analysis of a high-rise tower

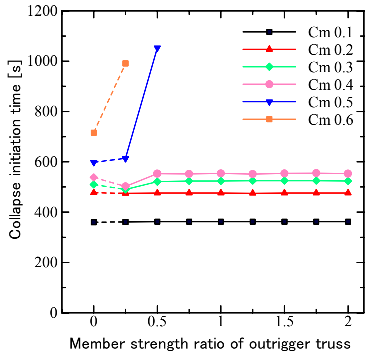

Fig.2 Influence of structural parameters on collapse initiation time under symmetric fire pattern

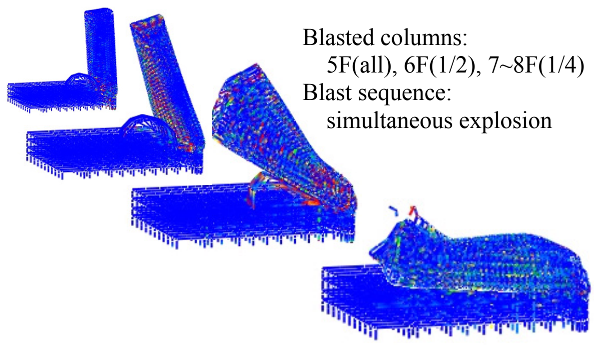

Fig.3 Blast demolition analysis of a high-rise tower

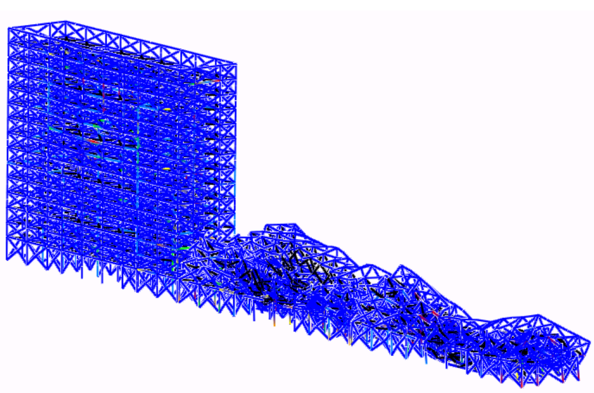

Fig.4 Collapse analysis of neighboring buildings under long-period seismic excitation