Numerical Analysis of Progressive Collapse of RC Frame under Blast Loading

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Summary

In this paper, the effects of initial damage and non-zero initial conditions of the structure member on the progressive collapse of reinforced concrete frame under blast loading are studied, the results of which are compared with the benchmark results and the results from GSA method. Based on the comparison and observation, an improved GSA method used in the analysis of progressive collapse of reinforced concrete (RC) frame is proposed, which can be used in the design of progressive collapse resistant reinforced concrete structures.

Keywords: RC frame; blast load; progressive collapse; initial damage; non-zero initial condition

1. Introduction

For an economic and safe design of structures against progressive collapse to blast loading, a reliable progressive analysis is essential. Currently, two approaches to analyse structural progressive collapse, namely the US General Service Administration (GSA) method and the US Department of Defence (DoD) method are commonly used. However, Hao & Wu found that, both the two approaches underestimate the response of the structural member. In this paper, the effects of initial damage and non-zero initial conditions of the structure member on the progressive collapse of reinforced concrete frame under blast loading are studied, the results of which are compared with the benchmark results and the results from GSA method. Based on the comparison and observation, an improved GSA method used in the analysis of progressive collapse of RC frame is proposed, which can be used in the design of progressive collapse resistant reinforced concrete structures.

2. Numerical Model

Software LS-DYNA is utilized in this paper to set up the two-span and three-storey frame structure, as shown in Fig.1. The frame has three bays with a span of 6 m each in x direction, and has two bays with 3 m each in y direction. The storey is 3 m for all the storeys. The dimensions of all the columns are 300 mm × 300 mm, and the beams 200 mm × 300 mm, all with a 2% longitudinal reinforcement and ø10@200 mm hoop reinforcement. The slab is 150 mm thick with a dimension of 6 m × 3 m. Solid elements of 50 mm cube were used to model the column, beam and slab of the frame. Shell element is utilized to model the rigid ground. The material model MAT_72 is utilized to model the reinforced concrete. Material model MAT_20 is used to model the rigid ground. The contact between the structure members and rigid ground and the strain rate effect of the materials are also considered.

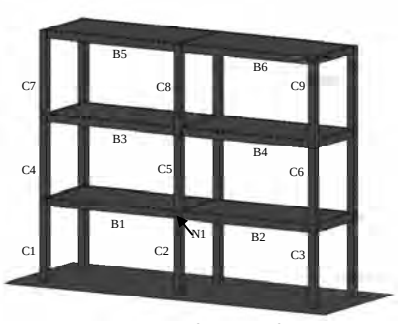

Fig. 1 Sketch of the RC frame

3. Benchmark analysis

In order to evaluate the effect of progressive analysis method for RC frame, a benchmark progressive analysis of the established RC frame is carried out. In the analysis, blast loads acting on the front face of the RC frame is directly applied to the structure. Detonation on ground surface at a

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distance 10 m from the centre column in front of the structure is considered. The critical charge weight that only knocks off the key column is calculated and selected to be 1000 kg. The analysis results shows that at t=100 ms the key column failed and then the whole frame collapse at t=900 ms.

4. GSA method

As mentioned above, GSA method is the guideline in analyzing progressive collapse released by the US General Service Administration. It includes both static and dynamic analysis. In this section, the GSA dynamic analysis method is used to carry out the progressive collapse analysis of the established RC frame. Results show that frame collapse at a longer time t=1200 ms. Comparison of the member response with the benchmark results obtained from the above mentioned benchmark analysis also shows that the GSA method is not good in predicting the RC frame collapse.

5. Improved GSA method

In this section, the approaches to consider the initial damage and initial condition of the adjacent members numerically are proposed. The results of the progressive analysis with consideration of initial damage, initial condition or not are compared with each other. Based on the observation and discussion, an improved GSA method is proposed.

The damage index D of the column could be obtained using the pressure-impulse diagram for RC column previously developed by the authors. Then the damaged strength and stiffness of the column could be approximately derived. In this paper, the initial damages of the adjacent columns (C1, C3, and C4-C6) are considered and obtained. (The positions of columns are shown in Fig.1).

The initial condition is used to take into account the initial velocity of the adjacent member at the time when the key column collapse, which is also the beginning of the progressive analysis in GSA and DoD guidelines. In this section, the initial velocities of column C1 to C6 are derived.

Progressive analysis are carried out using the GSA method with initial condition or initial damage, Results show that by considering the initial condition or initial damage of the adjacent columns, better prediction of the collapse procedure of the frame could be achieved.

Based on the above observation, an improved GSA method is proposed. The procedure is as following: (1) Establish the finite element model of the RC frame; (2) prior to the removal of the key element, bring the model to static equilibrium under the combination of dead loads and live loads as defined in GSA guideline; (3) select the considered blast scenarios, and define the key member that should be removed accordingly. (4) according to the blast scenarios, calculate the initial velocity and the initial damage of the adjacent structural member from the proposed approach; (5) with the model stabilized, remove the appropriate key element instantaneously. At the same time, apply the initial velocity and the initial damage to the adjacent structural member; (6) continue the dynamic analysis until the structure collapses or reaches a steady and stable condition.

6. Conclusion

The three dimensional model of frame structure with two spans and three storeys is set up with explicit dynamic analytical software LS-DYNA in this paper. Through the comparison of the analysis results it is found that the GSA method might give inaccurate collapse time and structure response when used in the progressive analysis. Based on the GSA method, the effects of considering initial damage or non-zero initial conditions of adjacent column on the results of progressive collapse analysis of RC frame under blast loading are studied, which shows that by considering the initial condition or initial damage of the adjacent columns, better prediction of the displacement, velocity and acceleration of structural member could be achieved, as well as the collapse process. An improved GSA method in the analysis of progressive collapse of RC frame is also proposed, which can be used in the design of progressive collapse resistant RC structures.

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