Basic Research Method and Progress of Progressive Collapse

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Abstract

In recent years, the structural progressive collapse caused by the earthquakes, terrorist attacks and other reasons frequently occurs. Domestic and foreign scholars have conducted a lot of research on the ground structure collapse. This paper summarized the research status of structural progressive collapse from three aspects: the concept of structural progressive collapse, analysis method of structural progressive collapse and anti-progressive collapse design, and forecasted the future research hotspots.

Keywords

Progressive Collapse; Numerical Simulation; Anti-Collapse Design.

1. Concept of progressive collapse

With the improvement of economic development level, people's requirement for safety has been increasingly higher; moreover, the building structures are developed in a large-scale and complex direction, so the structural progressive collapse has become a widely-concerned topic in the engineering sector. Since the gas explosion of Ronan Point Apartment in London in1968 to the collapse of two World Trade Center skyscrapers in New York in 2001 due to aircraft crash, the study on "progressive collapse" of architectural structure has been performed for more than 40 years. According to the definition in ASCE7-05 of ASCE [1], the structural progressive collapse refers to the local structural destruction caused by the sudden events under the regular service condition, which is transmitted from the initial failure position along the components, finally resulting in the entire building collapse or disproportionate collapse with the initial destruction. This paper summarized the research methods of anti-progressive collapse, systematically summarized the analysis methods and design methods and forecasted the future research direction.

2. Research on numerical analysis method of progressive collapse

Due to the complexity of structural collapse and limitation of test conditions, the structural collapse test is characterized by the great difficulty and high cost, so the numerical simulation becomes a feasible and effective research method. The complexity of progressive collapse problem makes it difficult to obtain the theoretical solutions and accurate experimental data. Therefore, numerical simulation has become an effective method, the most representative of which include the discrete element method and finite element method. The advantages of finite element method is that it can effectively and accurately calculate the mechanical behavior before the structural damage, but it has a low efficiency in calculating the motion and collision between the rigid bodies after the structural damage. On the contrary, the discrete element method is inferior to the finite element method in the calculation accuracy before the structural damage, but it has a high efficiency in calculating the motion and collision between the rigid bodies after the structural damage.

2.1 Finite element method

The finite element method is a kind of numerical analysis method to obtain the approximate solution of engineering problems. It replaces the real structure with the discrete finite element sets, and obtains the approximate solution of the entire structure through the element analysis. In the engineering design, such approximate solutions can meet the needs of projects with enough accuracy. The finite element method is the generalization of matrix displacement method of skeletal structures in the

structural mechanics, which is applied to two-dimensional and three-dimensional problems. At present, it has become a commonly-used method in the engineering sector for stimulating elasticity and elastic-plastic problems. However, the finite element method is based on the grid division technology, so it is difficult to simulate the serious element distortion, and its application in progressive collapse simulation is limited due to the complexity of element connection. The representative general finite element analysis software includes MSC-MARC, LS-DYNA and ABAQUS, etc. Kwasniewski [2] established the fine finite element model of 8-floor reinforced concrete structure using LS-DINA software to analyze the progressive collapse, analyzed the structural model after vertical load is added or key column is removed, study the influences of modeling parameters on calculation results and propose the method of reducing the uncertainty of calculation results. Lu Xinzheng et al. [3] developed the collapse simulation analysis program based on the finite element program MSC-MARC, analyzed the structural collapse under fire and earthquake, established the finite element model with fiber beam model analyzing the rod components and layered-shell model analyzing the wall structure, selected the appropriate element birth and death basis and element contact algorithm to simulate the whole process of structural collapse under the effect of abnormal loading. Jiang Xiaofeng et al. [4] used LS-DYNA program to simulate the progressive collapse process of large-span truss structure, and studied the dynamic effect of internal force redistribution and the main failure mode of structural progressive collapse.

2.2 Discrete element method

The discrete element method was a kind of numerical simulation method proposed by an American scholar, Cundll [5], in 1971, used to analyze the stability of fractured rock, which can simulate the whole process of rock cracking and collapse accurately. The discrete element adopts the spring stiffness to simulate the mechanical behavior of structure, which has obvious advantages in handling the rigid body displacement and contact and is suitable for stimulating the combination and collision of discrete bodies. Motohiko et al. [6] stimulated the collapse of concrete frame structure under the dynamic loading using the extended discrete element method, and the simulation results were well consistent with the actual seismic structural damage. Gu Xianglin et al. [7] proposed a theoretical model of structural collapse analysis based on the discrete element method, established the calculation models of concrete block under different collision forms combined with the experiment, established the spring force-displacement constitutive relation of new materials, and analyzed the collapse process of RC frame structure and masonry structure under earthquake; realizing the three-dimensional visualization of structural collapse process based on OpenGL technique. The comparisons between the simulation results, the experimental results and the engineering measurement results show that the discrete element method is suitable for the analysis of large structural deformation.

3. Design method

Different from traditional design of strength and stiffness stability, the anti-progressive collapse design focuses on the capacity of keeping the original shape of the entire structural system in case of local component failure, which considers generally from two perspectives: design based on the definite accidents; design with attention to the structural performance, instead of the accidents.

3.1 Conceptual design method

Conceptual design is mainly performed from the structural design concepts, such as the integrity, ductility, redundancy and structural measures, so as to improve the anti-progressive collapse capacity of structure. The importance of anti-progressive collapse conceptual design is emphasized in norms and design guidelines of each country. The conceptual design mainly consists of two parts: 1) The continuity and ductility of structure are ensured by structural measures, and ACI318-08 (ACI, 2008) is the most representative regarding the structural measures in the existing norms, which stipulates the structural measures ensuring the cast-in-place and assembly structural integrity in detail, so the progressive collapse can be avoided to a certain degree; 2) The reasonable structural design can ensure

the reserve of force transferring path and anti-progressive collapse bearing capacity, and it is suggested to avoid the structural arrangement in weak parts, improve the force transferring path of redundancy, block the structural division of progressive structure and consider the reverse load component design. The disadvantages of conceptual design include the difficult quantification, and the design effect depends heavily on the skills and experience of designers.

3.2 Tie force component method

Through rationally setting the existing components or connections, this method provides sufficient tie force strength. It is required that the force transferring path should be straight and continuous, and the main measures include setting the level and vertical longitudinal bars, and using effective connection anchorage. Horizontal tie includes the internal tie, surrounding tie, outer column (wall) tie and corner post tie, etc.; vertical tie mainly includes the setting in column and load-bearing walls. Good deformation and ductility in the components and joints can improve the integrity, help dissipate energy, and transfer the internal forces to other components, so as to give full play to the redundancy.

3.3 Alternate path method

When alternate path method is used, the key components in the structure are removed, and the finite element is used to simulate the failure mode of residual structure after the removal. It is needed to increase the strength of residual structure after the removal to avoid progressive collapse. In fact, this method increases the redundancy of structure and defines an effective alternative force transferring path, so it is also known as Alternate Path Method. In general, the vertical load-bearing components susceptible to accidental action are removed, including the periphery long and short center pillar and corner column in each layer, and the inner column at the bottom. At the same time, the designer can determine the size and location of removing components according to the specific needs. The calculation method used in removing components can be the linear static, linear dynamic, nonlinear static and nonlinear dynamic methods, respectively.

4. Conclusion and prospect

Due to the complexity of structural collapse, domestic and foreign scholars have performed a series of research on the structural collapse failure criterion, collapse numerical simulation, anti-collapse design and measures. But there is still a lot of work to do in order to analyze and design effectively, so we can consider from the following aspects:

1. To prevent the structural progressive collapse, it is needed to pay attention to the overall performance of structure (robustness) and the relevant redundancy characters, ductility, connection strength and structural measures ensuring the above performances.

2. To ensure the structural safety, it is needed to vigorously strengthen the study on "structural collapse", including the investigation of collapse structure in accidents and disasters, the study on accidental action, later structural loading experiment, collapse simulation and simulated calculation.

3. Reasonable failure criterion study: Structural collapse failure criterion is the key problem in the study on structural collapse, which has great significance in evaluating the collapse failure mechanism and safety redundancy of structure. At present, scholars have proposed a variety of collapse failure criterion, but it still needs further study.

4. The accurate numerical simulation method and simplified high-performance analysis method of structural progressive collapse are characterized in understanding the essence of collapses and collapse control design, and it needs to be studied further.

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