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Numerical analyses on steel beams with fin-plate connections subjected to impact loads

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ABSTRACT

This paper focuses on the dynamic behavior of steel beams subjected to falling floor impact loads, and fin-plate connection was used to connect beams and columns. ANSYS/LS-DYNA was employed to establish detailed 3D finite element models (FEM). The accuracy of finite element models was validated against experimental results. Simulation results indicate that the deflection angle of drop weight significantly affected maximum impact force. In addition, six groups of numerical simulations were conducted to study the influence of different parameters on dynamic behavior and impact resistance. The parameters included impact energy, impact location, strength of material, imposed load, distance of bolt holes and thickness of fin-plate. Energy dissipation, maximum displacement, distribution of plastic deformation and internal force at joints were compared in each numerical group. Parametric studies suggest that energy can be used to evaluate the structural resistance of steel beams in impact analyses. Steel beams show different dynamic behaviors under a certain impact energy but different impact masses and impact velocities. A higher impact velocity can slightly improve the energy dissipation rate. Steel beams develop different impact resistances while impact loads are applied at different locations. Besides, high-strength materials are beneficial to reduce the maximum displacement. Inertial effect plays an important role in dynamic behavior. Moreover, decreasing the distance between steel bolts and the thickness of fin-plate may cause premature failure of specimens under lower impact loads.

1. Introduction

With recent advance in structural engineering and material sciences, modern buildings become increasingly larger and taller. However, these structures are still threatened by abnormal loads due to accidents, faulty practice, terrorist attacks, etc. As early as 40 years ago, Leyendecker et al. [1,2] indicated the probability of occurrence of abnormal loads, and the building destroyed by abnormal loads due to accidents had happened many times. The partial collapse of the Ronan Point building in 1968 and the World Trade Center disaster in 2001 were two typical events in regard to structural failure under abnormal loading conditions. Since such events, engineer communities realized the importance of structural resistance to abnormal loads and have put more efforts to mitigate progressive collapse.

As a type of design methods against progressive collapse, alternative load path method (APM) incorporated in DoD [3] and GSA [4] has been widely used to analyze structural responses under various column removal scenarios. Fig. 1 shows a typical example of alternate load paths in adjacent structural members after the removal of an interior column.

In order to determine structural resistances against progressive collapse, many studies have been carried out on beam-column connections under static or dynamic loads. Yang and Tan conducted a series of experimental tests to investigate the behavior of steel bolted beam-column joints under a middle-column-removal scenario [5–7], and numerical models were developed and verified by test data [8]. Parametric studies were also conducted by the verified numerical models to quantify the rotation capacities of various types of joints under catenary action. Furthermore, a mechanical model based on a series of component tests was developed to predict the behavior of bolted-angle connections under pure tension [9,10].

In addition, dynamic column removal scenarios were also considered in experimental studies. Liu and Tan [11–13] conducted several tests on dynamic mechanical properties of steel beam-column joints subjected to sudden column removal scenarios. In the tests, uniformly distributed vertical loads were applied to bridging beams through steel plates and a quick release mechanism was employed to simulate the impact of sudden column removal. When the quick release mechanism was unlocked, the specimen underwent downward movement

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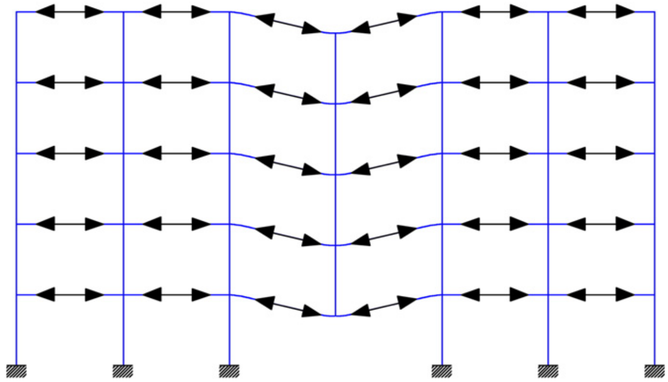

Fig. 1. Typical example of alternate load paths.

under gravity. Tyas and Stoddart [14–16] designed a set of experimental equipment, which could apply an axial tension load or a combination of moment and tension to a connection at high dynamic rates. The dynamic behavior and shear failure of web cleat connections were studied under dynamic loads. A modified component-based model was used to predict the dynamic behavior of connections and reasonable good accuracy was obtained. Huo [17–20] proposed a method to study the dynamic properties of steel beams and beam-column joints through drop weight tests. The drop-weight was lifted to a certain height and then released suddenly. Potential energy was transformed into kinetic energy, and the drop-weight struck the top of the column stub. Dynamic behavior of hot-rolled steel beams, welded flange and bolted web connections and fully-welded connections were tested under drop-weight impact loads.

It is worth mentioning that most studies related to progressive collapse were based on middle-column-removal scenarios. Another important scenario, under which structural members are subjected to falling floor impact, may cause progressive collapse of structures. Kaewkulchai [21] studied three possible impact scenarios induced by failed members. A model was proposed to calculate the impact process and to develop a computer program. Vlassis and Izzuddin [22] developed a simplified design-oriented methodology for multi-story buildings subject to impact loads from upper failed floor. This methodology was based on energy theory and considered the falling of failed floors as debris. Although the accuracy and applicability of the proposed

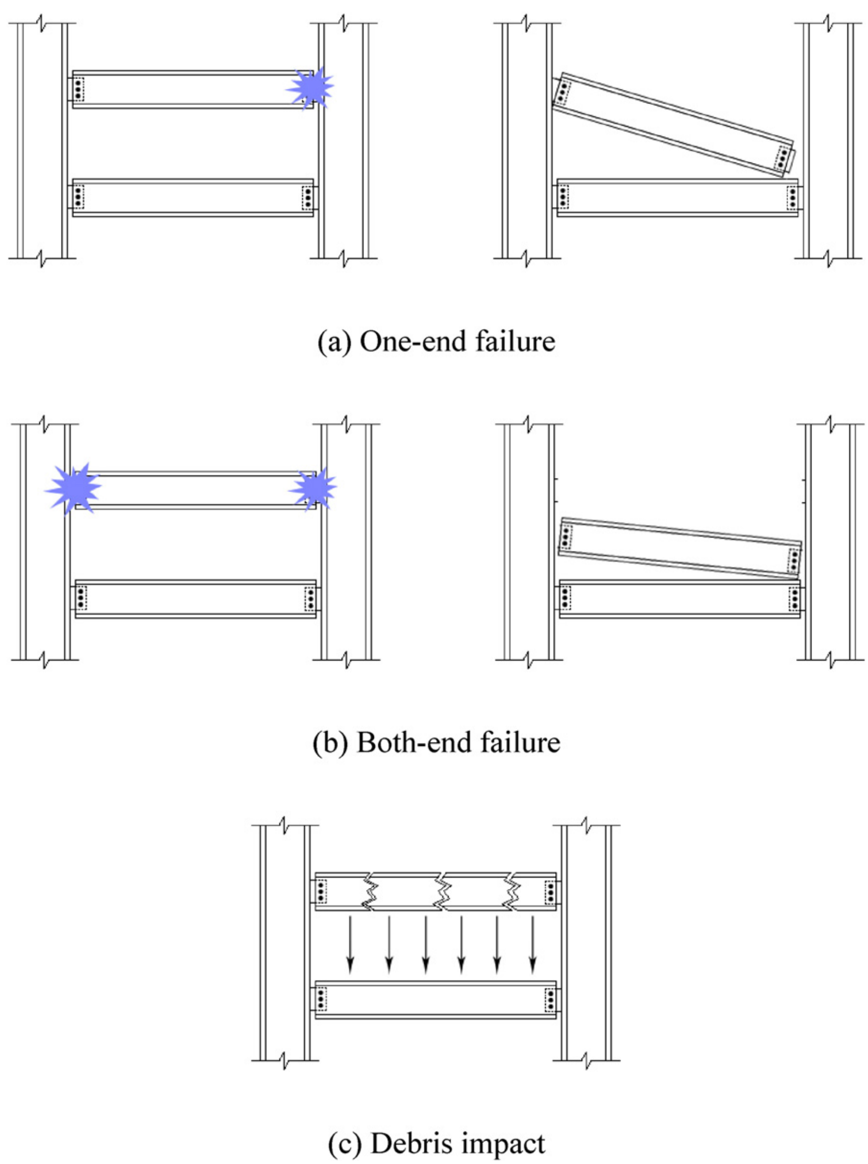

Fig. 2. Three possible conditions of falling floor impact scenario (a) One-end failure (b) Both-end failure (c) Debris impact.