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Procedia Engineering 210 (2017) 537–543

Procedia Engineering

www.elsevier.com/locate/procedia

6th International Workshop on Performance, Protection & Strengthening of Structures under Extreme Loading, PROTECT2017, 11-12 December 2017, Guangzhou (Canton), China

Fire-induced Progressive Collapse of 3D Steel Portal Frames

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Abstract

This paper presents experimental and numerical investigations on progressive collapse of 3D steel portal frames exposed to fire. A natural fire test was carried out on a 36m×12m full-scale steel portal frame. A finite element model is established and validated against the test results. The experimental results show that the frame collapses after 15 mins of heating due to the buckling of the heated columns. It is found that the adjacent frame column at mid-span moves outward, compared to the inward movement of columns at corner. The numerical results show that the fire protection had significant effect on the collapse mode. The protected portal frames show a lateral drift collapse mode, compared to a downward collapse mode for unprotected frames. A higher level of fire protection leads to longer buffer time to delay the collapse of frames.

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Peer-review under responsibility of the scientific committee of the 6th International Workshop on Performance, Protection & Strengthening of Structures under Extreme Loading

Keywords: 3D portal frame; progressive collapse; fire; natural fire test; numerical model; fire protection

1. Introduction

Steel portal frames, as one of the most common structural systems, have been widely used in industrial or warehouse buildings. As a type of long-span structures, steel portal frames have a high possibility of fire occurrence and suffer from rapid fire spread due to the large spacing without fire compartmentation. Steel material will loss most of its stiffness and strength at about 600°C. A number of recent fires in industrial structures have drawn

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Peer-review under responsibility of the scientific committee of the 6th International Workshop on Performance, Protection & Strengthening of Structures under Extreme Loading.
10.1016/j.proeng.2017.11.111

attention to a current lack of understanding about the progressive collapse of steel portal frames under fire conditions (Fig. 1). The progressive collapse is defined as "the spread of an initial local failure from element to element, eventually resulting in the collapse of an entire structure or a disproportionately large part of it" [1]. This indicates that failure of individual structural members is acceptable provided that structural collapse is prevented. However, there are few studies on the progressive collapse behavior of long-span structures exposed to fire. Moss et al. [2] studied the influence of support conditions, axial restraints, fire severities on the collapse mode of steel portal frames in fire. It was found that some level of base fixity should be provided to ensure a favorable inward collapse mode. EI-Heweity [3] investigated the failure temperature of steel portal frames exposed to fire. Garcia et al. [4] studied the behavior of steel portal frames with fire-resistant steel and intumescent coatings. The results showed that a combination of these two methods was the best choice from both economic and structural views.

This paper investigated progressive collapse resistance of 3D steel portal frames, both experimentally and numerically. A natural fire test was conducted on a full-scale steel portal frame with a span of 36m. Finite element models were created and validated against the test results. The effect of fire protections on the collapse resistance of portal frames was numerically studied.

2. Natural fire test

2.1. Test setup

A natural fire test was carried out on a 36m×12m steel portal frame, as shown in Fig. 1. A fire compartment of 4m×6m was setup in the mid-span of the frame, surrounded by fire walls. A pile of wood was used to simulate the fire load, as shown in Fig. 2. The design of the portal frame was in accordance with a Chinese code [5]. The cross-sections of the frame columns and frame beams were H500×200×6×10 and H580×200×6×8, respectively.

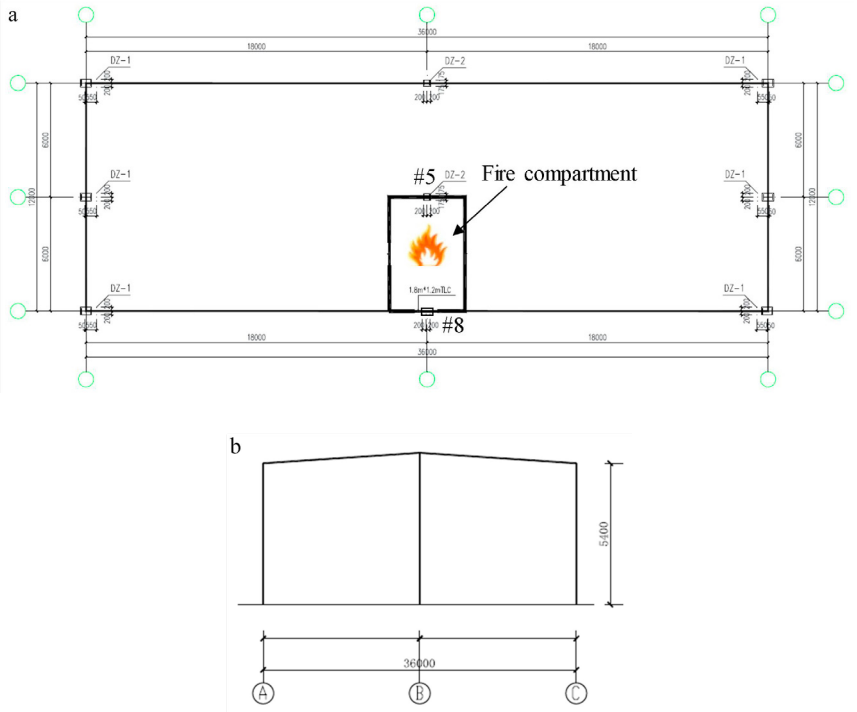

Fig. 1. Schematic of the tested steel portal frame: (a) plan view; (b) elevation view.

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