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Study on mechanical characteristics and safety evaluation method of steel frame structure after fire

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Abstract Mechanical characterization of steel frame structure after fire are analyzed based on fire dynamics, heat transfer theory, structural mechanics, and finite element theory. We study the temperature characteristics and mechanical properties of steel frame structure under different fire locations and propose a safety evaluation method. We also analyze damage level of main frame components, maximum temperature of fire, thermal characteristics of frame components, firing duration, etc. to provide useful information for fire resistance design of the steel frame structure and post-disaster safety evaluation.
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Keywords fire, steel frame, mechanical characteristics, safety level, safety evaluation

Safety evaluation and reinforcement in the reinforced concrete structure and steel structure are widely applied nowadays. However, it lacks of systematic research. Only site visit combining with technical data in related references and surface damage level of material are considered in currently safety evaluation. Appraisal conclusion depends largely on the evaluator's experience, and such kind of evaluation does not match the modern design theory and detection technology. Few researches[1–9] can be found on how to systematically evaluate the safety level of steel frame structure after fire. This study proposes a safety evaluation method for steel frame structure and provides some guidance information for fire resistance design and safety assessment post-disaster.

Temperature field of steel frame in the building is normally assumed to has a uniform or linear distribution in the thermal analysis. However, temperature distributions of frame components can be quite different under elevated temperature in a fire. In this paper, thermal analysis of a plane frame is performed using ANSYS software and the standard time-temperature curve (ISO-834 Curve) selected for the fire modeling.

At elevated temperature, failure criterion of steel frame's bearing capacity can be analyzed from two aspects: local damage of frame component and general failure of steel frame. Steel frame structure is deemed to have failed when one of the following criteria, divided into these two aspects, is exceeded.[10,11]

Criterion I Deforming rate of frame component exceeds $\mathrm{d}\delta/\mathrm{d}t \geqslant l^2/(15h)$ (component loses its stability bearing capacity).

Criterion II Deformation of frame component exceeds $\delta \geqslant l/20$ (component loses its stability bearing capacity). Here δ is maximum deflection of component, l is length of component, h is

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height of component's cross section, and t is time of combustion.

Criterion III Integral deformation of steel frame exceeds $\delta/h \leqslant 1/30$ (structure loses its general stability). Here δ is inter-story drift and l is height of the overall framework.

In this work, a plane frame fixed on the ground and having 4 layers and 3 spans (as shown in Fig. 1) is studied, and its height is 15.3 m and has a column spacing of 6 m. Lateral supports are provided to all columns of the frame on both left side and right side. Concentrated load is assumed to be imposed on the top of column, and the outside load and inside load of lateral column are 80 and 160 kN. A uniform load of 27 kN/m is imposed to all beams. Beam and column all have an I-shaped cross-section and their sizes are listed in Table 1.

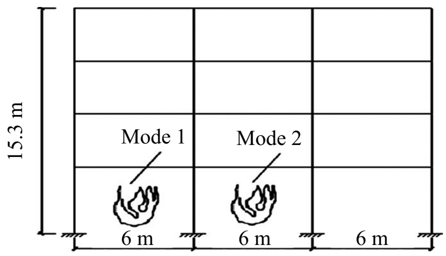

Fig. 1. Schematic of steel frame model under fire.

Table 1. Beam and column size of steel frame.

	High/mm	Wide/mm	Flange/mm	Web/mm
Beam	600	300	20	12
Column	500	360	20	14

The fire is supposed to happen in a fireproof compartment (Mode 1 or Mode 2 as shown in Fig. 1) and the fire duration is 15 min. In both modes, beam and column are heated directly except the top flange of beam and outside edge of column. We also assume the fireproof compartment is capable to prevent the fire spreading to other rooms, even without the coating effects of steel frame surface.

Temperature and displacement of the plane frame are analyzed using ANSYS software based on the engineering condition described above (Mode 1 and Mode 2 in Fig. 1). Figure 2 shows that displacement in X direction at the beginning ($t = 0$, so-call static displacement) is small and in the safe range. With heating growing, steel component gradually loses its strength and lateral displacement becomes larger and larger with plastic hinge coming out and rapid dropping of lateral rigidity.

Comparing to other parts of beam and column, displacements of beam-column joints in X direction (Fig. 3) show great different thermal characteristics due to the temperature variation. This makes beam-column joints the weakness of steel frame.

Static displacement of beam-column joint in Y direction (as shown in Fig. 4) is also small and in the safe range. When the heating grows, stiffness and bearing capacity of steel component decrease gradually and deflection becomes larger and larger.

Figure 5 shows that deforming rate of beam is low before 600 s. Due to the continuous