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Methods of improving survivability of steel beam/column connections in fire

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ABSTRACT

This paper reports the results of a series of numerical parametric studies on methods of improving survivability of steel beam/column endplate connections in fire using a detailed finite element model in ABAQUS. The parametric studies were performed on beam-column assemblies with realistic connection details and the main focus of this research is to investigate methods of improving connection design to enable the structure to survive very high temperatures. At very high temperatures, the beam of the structure experiences catenary action which may fracture the connections and exert additional forces on the columns. This paper investigates how different connection details (bolt diameter, bolt grade, endplate thickness, the use of fire resistance bolt and fire resistant steel for endplate) affect structural behavior and survivability at high temperatures. It is found that improving connection deformation capacity, in particular, using fire resistant bolts, will enable very high temperatures to be resisted.

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1. Introduction

In fire resistant design of a steel beam, the beam's limiting temperature is calculated based on the bending moment capacity of the beam. However, in realistic structures, axial restraints exist and as the beam deforms, axial forces develop in the beam. [12] provided a qualitative description of the behavior of axially restrained steel beams. When the beam's temperature is lower than its limiting temperature calculated without considering axial restraint, the axial force is compressive due to the beam's thermal expansion being restrained. At temperatures higher than the limiting temperature, the beam develops catenary action as the beam's axial shortening from large beam deflection becomes greater than the beam's thermal expansion.

This catenary action force is transmitted to the joints and the surrounding structure. [15–18] carried out a large number of parametric studies and concluded that if this catenary action force can be sustained by the joints, the beam can survive temperatures much greater than the beam's limiting temperature. This additional temperature above the beam's limiting temperature is essential to enable the structure to maintain stability in the event when the beam's limiting temperature is accidentally exceeded in fire attack. The objective of this paper is to investigate how joint design may be improved to survive high beam temperatures as possible.

Bolted connections are widely applied in steel structures, ranging from rigid connection to pin connection. Among bolted connections, extended endplate, flush endplate and fin plate connections are most popular. This research will investigate how their construction details may be improved to survive high temperatures.

In the previous study by the authors [1], the authors developed three simulation models based on ABAQUS, including the detailed finite element model in which the entire structure is modeled using solid elements, a simplified model (Beam Model) in which the beams and columns are represented by line elements and the joints by spring elements, and a Hybrid Model in which the beams and columns are simulated using detailed brick elements and line elements respectively, but using spring elements for the joints. The simulation procedures were validated by comparing the simulation results against relevant fire tests conducted by [13]. Although all three models can simulate global structural behavior, the detailed simulation method can faithfully represent very detailed structural behavior, particularly details of joint behavior, whereas the component based spring representation of joints may overlook some aspects of structural behavior, including column local behavior, interactions between joint forces in different directions, and thermal expansion of joint components. The aim of this paper is to use the validated detailed model to investigate methods of improving the survival temperatures of steel framed structures, focusing particularly on the effects of changing joint details.

2. Simulation methodology

[14] used computer programs to analyze global structural behavior of one complete frame and its associated subframes. It was concluded that subframe analysis is appropriate provided appropriate boundary conditions to the subframe are incorporated. Subframe analysis will be used in this research. Recently, [13] carried out 10 fire tests on subframes using five different types of connections (fin plate, web cleat, flexible endplate, flush endplate and extended endplate) and the simulation model of this study is similar to the test setup of [13] which is shown in Fig. 1, but the dimensions are different. The objectives of

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