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Post-fire behaviour of high strength steel endplate connections — Part 2: Numerical study

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ABSTRACT

In this paper and its companion paper, a perspective of using high strength steels to take place of mild steels in structural design of endplate connections is proposed and investigated. The endplate is made of high strength steels while the beam and the column are made of mild steels. This paper presents a numerical study conducted using ABAQUS on high strength steel endplate connections after cooling down from fire, to reveal more information and better understanding on the post-fire behaviour of high strength steel endplate connections. The validation of this numerical modelling against all representative experimental results was performed on moment–rotation relationship, failure mode and yield line pattern of endplate connections, where it is found that good agreements exist. Hence this numerical analysis method can be employed with reasonable accuracy to predict the behaviour of high strength steel endplate connections after cooling down from fire. This finite element analysis provides an efficient, economical, and accurate tool to investigate the post-fire performance of high strength steel endplate connections, which can be further developed for the parametric study and post-fire evaluation of an entire steel structure with high strength steel members. This study offers a basis for structural engineers to perform accurate evaluation and safe reuse of structures with members made of high strength steels after fire.

1. Introduction

As we know, structural steels have excellent mechanical properties at ambient temperature; however like other materials, their strength and stiffness lose with elevated temperature. But structural steels can regain their mechanical properties after cooling down from fire temperatures below 600 °C, even for the quenched and tempered high strength steels (HSS) up to S960 [1,2], which is very promising for the reuse of steel structures after fire hazards.

Due to the fact that numerous unpredictable fire hazards happen almost every day all over the world, structural fire safety is currently one of the critical considerations in the design of high-rise buildings which are usually made of steels. In recent years, high strength steels have been more and more popular in high-rise buildings and landmark constructions. In practice, reliable evaluations on the reuse possibility of steel structures after exposure to fire are urgently needed. However, in the leading design standards of steel structures all over the world, only the former British Standard 5950: Part 8 [3] has a suggestion about the reuse of structural steels after fire. According to it, hot finished steels and cast steel can be reused after fire if the distortions remain within the tolerances for straightness and shape. As for mild steel S235 and S275, it is said that they can be assumed to be able to regain at least 90% of their mechanical properties. Similarly, for S355, it is suggested that it can be assumed at least 75% of the strength is regained after cooling from temperatures above 600 °C. But no assumption or suggestion is given for high strength steels in any current design standard of steel structures all over the world. In literatures, the available researches on post-fire performance of building structures are very few and mainly focus on steel–concrete composite joints [4], concrete-filled steel tubular columns [5,6], and mild steel frames [7,8]. By now, no research report on post-fire performance of high strength steel structures is available in literature. Therefore, the rising popularity of high strength steel structures and the low research level call for more researches on post-fire performance of high strength steel structures. Since connections are extremely important components of steel framed structures, an experimental and numerical investigation has been proposed and carried out on the post-fire performance of typical beam-to-column connections, endplate connections, made of high strength steels. The aim of this research is to reveal more understanding on their post-fire behaviour as well as to offer basic information for the recommendations of current design standards on the evaluation of high strength steel structures after fire.

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This paper presents a numerical study on high strength steel endplate connections after fire carried out using the commercial package ABAQUS 6.8 [9]. For comparison, the post-fire behaviour of mild steel endplate connections has been modelled as well. The endplate connections modelled herein are exactly the same with those in the experimental study presented in the companion paper [10]. The final deformation state, moment–rotation characteristics and stress distribution of endplate connections after fire are obtained from the numerical modelling. Furthermore, the accuracy of this numerical modelling is validated against the experimental results described in the companion paper [10].

2. Finite element model

The finite element software package ABAQUS 6.8 [9] was employed to numerically simulate the behaviour of high strength steel endplate connections after fire. The analysis type conducted herein was static.

2.1. Geometric details

The geometric details of all connections' components modelled in FEM are the same with those of the test specimens presented in the companion paper [10]. Because the geometric details, load, temperature distribution and boundary conditions of the endplate connection are symmetric, half of the endplate connection was modelled, to reduce computer costs and computing time. The components of this FE model are shown in Fig. 1, including beam, column, endplate, bolt shanks and nuts.

2.2. Mesh generation and element type

There are 7 surface-to-surface contact interactions and 7 tie interactions in this FE model, and the materials are endowed with non-linear properties. These configurations make this analysis sensitive to mesh, so the mesh should be fine enough in this model. To capture accurate stress distribution in the region around bolt holes where yielding would likely to initiate, an intensive mesh was created in the vicinity of bolt holes, as shown in Fig. 2(c). The whole connection was modelled using C3D8I element, because of its excellence in simulating contact interactions, non-linear material properties and stress concentrations. The detailed description of C3D8I element has been introduced in [11]. The mesh generation of this FE model is presented in Fig. 2.

2.3. Contact interaction and analysis process

The contact pairs in this numerical model comprise the bolts-to-column flange, column flange-to-endplate, endplate-to-nuts and bolt shanks-to-bolt holes, as shown in Fig. 3. The nuts were tied to the corresponding bolt shanks, see Fig. 4. Surface-to-surface contact, with a small sliding option, was employed for all contact surfaces to fully transfer load. The penalty friction with friction coefficient 0.44 was employed in the contact interaction property. To handle contact interaction

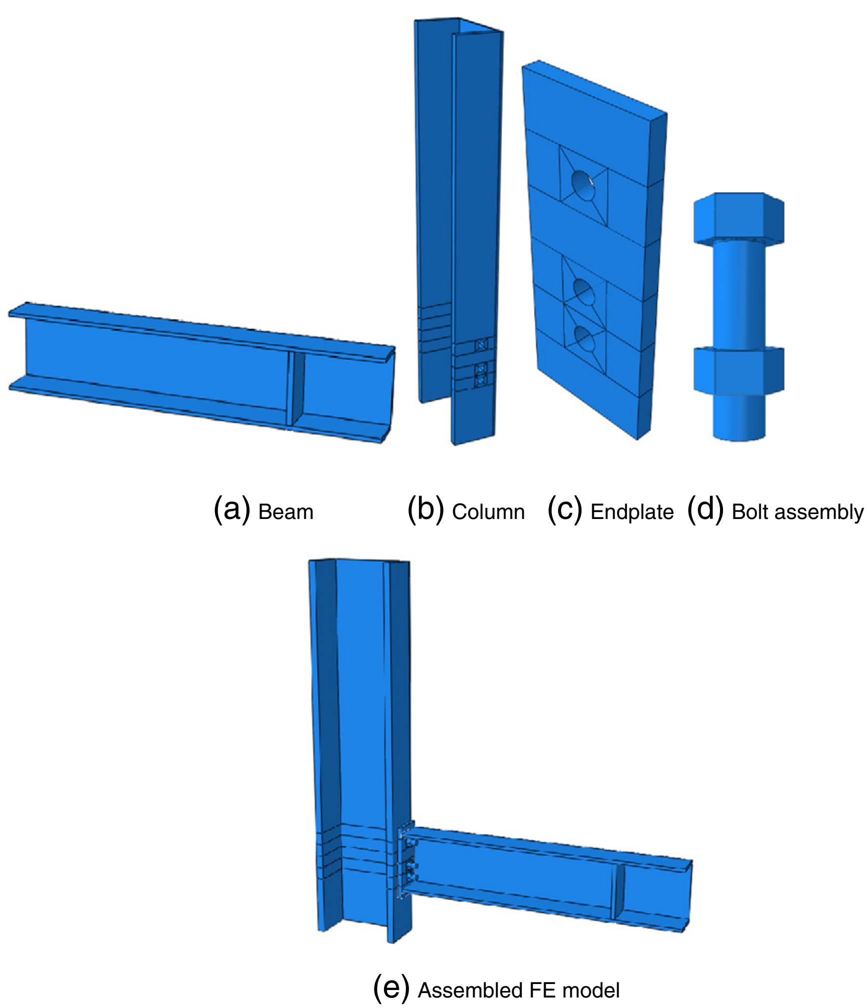

Fig. 1. FE model.