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An analytical method to calculate temperatures of components of reverse channel connection to concrete filled steel section under fire conditions

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ABSTRACT

The paper describes the development of an analytical model for calculating the temperatures of different components of reverse channel connections to concrete filled steel tubular sections. The proposed analytical model is based on the Lumped Capacitance Method and includes the calculation of the quantity of heat transferred at the interface between the steel tube and the concrete core. For unprotected connections, the connection is divided into two regions. One part of the connection is almost unaffected by the presence of the concrete core, on the contrary, temperature of the second part of the connection is significantly affected by the heat transfer at the steel/concrete interface. For protected connections, the entire connection is assumed to have the same temperature. Equivalent two-dimensional section factors are proposed for these connection parts. The analytical model is developed based on the results of extensive parametric studies under standard and different parametric fire conditions and validated against fire test results. The proposed analytical method is applicable to both fire protected and unprotected connections, including both the heating and cooling periods of the fire attack, and incorporating the effects of in-fill concrete.

1. Introduction

Research on the structural design of steel connections under fire conditions has been lagging behind that for steel structural members. For example, connections are not explicitly considered in fire safety design projects and there is a lack of design guidance in the current fire resistance design codes of practice [1,2]. This has been the result of the historical misconception that connections would perform better than the connected structural members because connections have a smaller surface to mass ratios (section factors) and hence would not increase in their temperatures as quickly as the connected members [3,4].

However, connections are the critical components of steel structures. In particular, connection failure has the potential of causing the dangerous consequence of progressive collapse. It is hardly surprising that since the World Trade Center building collapse on September 11th, 2001, the behaviour of connections in a fire has become an important focus of the international structural fire engineering research community, with the aims of understanding their fire performances and how they may be improved to enhance the robustness of structures in a fire, see [5–7]. As with other structural components in a fire, the first step of quantifying the connection behaviour is to calculate the connection temperatures. This is the aim of the paper.

Since the Component Based Method for quantifying connection behaviour [8], at both ambient and elevated temperatures, is favoured by the connection research and practice community owing to its flexibility and relative simplicity, temperature calculation methods should be developed for the connection components of different types of connections.

This paper will focus on a new type of connection: a reverse channel connection to a concrete filled steel tubular column. Fig. 1 shows a sketch of this connection type. This type of connection solves the problem of the inaccessibility to the inside of the steel tube. It has been the subject of study at ambient temperatures to obtain the bending moment – rotation curves [9], and in a fire to compare its performance against using other types of connections [10]. To help introduce this type of connection into practice, the RFCS COMPFIRE European project was carried out [11] to investigate the different aspects of fire performance of this type of connection in detail. One of the subjects of this project is the

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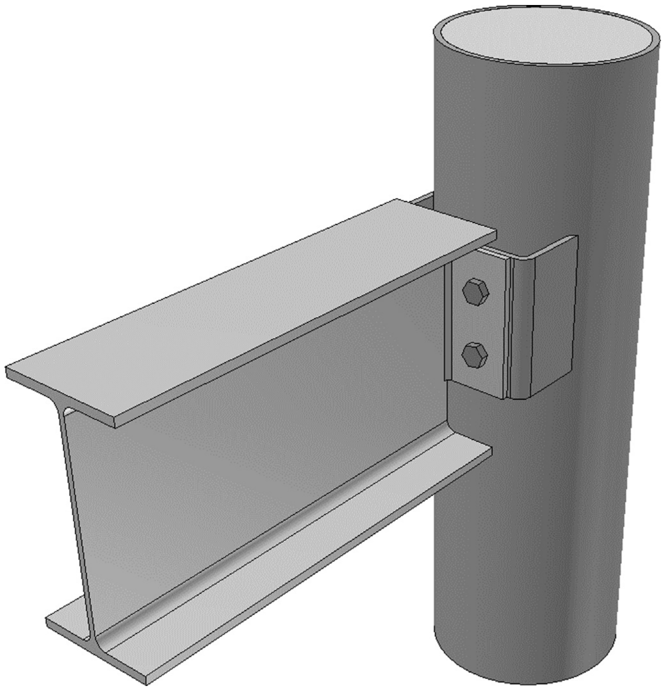

Fig. 1. Schematic of a reverse channel connection of a beam to a concrete-filled tubular column.

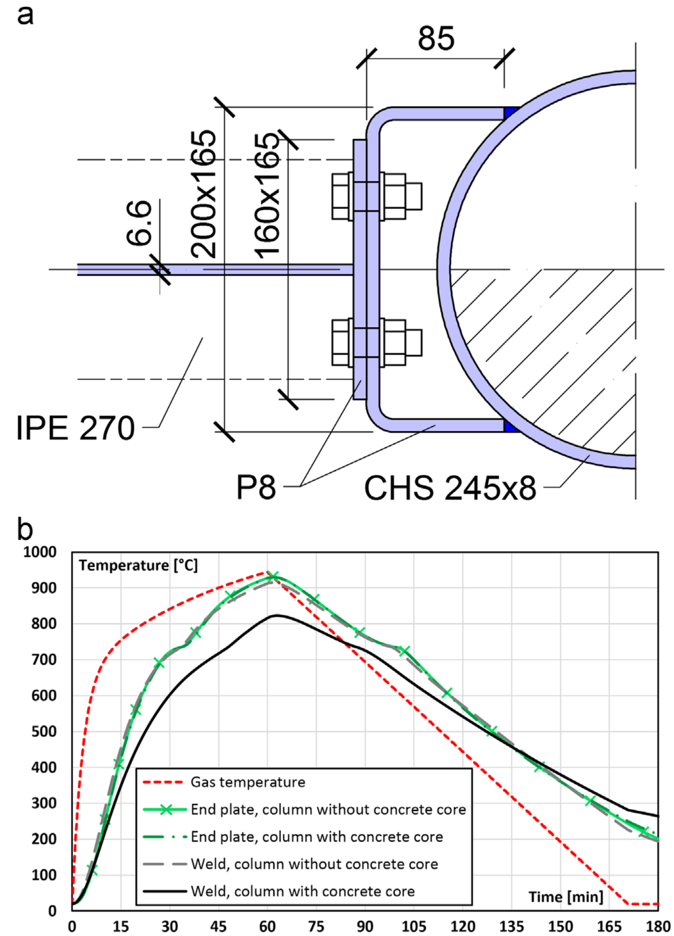

Fig. 2. Comparison of temperatures in an unprotected connection to a column with and without concrete infill: (a) arrangement of the connection; (b) component temperatures [12].

determination of the connection component temperature distribution during fire exposure. The authors have published a detailed paper presenting the experimental fire test results [12]. This paper develops an analytical method.

The component temperatures of a beam-to-column connection may be predicted by assuming reductions from the maximum temperature of the connected beam flange [13]. This is indeed the rather crude method in EN 1993-1-8 [1]. However, this method is based on very limited experimental data without any scientific basis. Both numerical [14] and experimental studies [3] have pointed out the inaccuracy of this method. Alternatively, the same equations for calculating steel section temperatures in EN 1993-1-2 [15] can be used, but the steel member section factor is replaced by the connection component section factor [16]. This has been implemented in [17] and [18,19]. This paper is based on the latter method as it has the scope of further development.

Previous studies [18,19] have considered connections to open sections; therefore, they are not directly applicable to reverse channel connections to concrete filled tubular columns. The research of Ding and Wang [17] is directly relevant; however, it has not addressed a number of issues that will be considered in this paper, including fire protected columns and cooling effects. Furthermore, in concrete filled tubular columns, the concrete infill helps to slow down the temperature rise in the connection. It is necessary to take into consideration this contribution from the infill concrete.

This paper will develop an accurate method for calculating the temperatures of different components of reverse channel connections to concrete filled tubes, for both fire protected and unprotected connections, including both the heating and cooling periods of the fire attack, and incorporating the effects of in-fill concrete.

2. General observations of temperature distributions in connection components

The authors have carried out fire tests and extensive numerical simulations of reverse channel connections to tubes, with and without fire protection to the connection, with and without concrete infill, and under standard and natural fire conditions, see [12]. Based on the results in [12], it is clear that the end plate, the reverse channel web and bolts have similar temperatures, but depending on whether there is fire protection to the connection, the temperatures of the reverse channel flanges and welds to the column tube may be different. Figs. 2 and 3 present how the temperatures of different components of unprotected and fire protected connections are affected by the presence of the concrete core in the column.

In the unprotected connection, the concrete core helps to significantly reduce the temperature in the area of the weld of the reverse channel flange to the column steel tube. On the contrary, the temperatures of the end plate, the reverse channel web and the bolts follow the fire temperature very closely. The different temperatures in different connection components occur because heat transfer to steel is the fact and temperature responses of different connection components are mainly affected by the local heating condition. For developing an analytical temperature calculation method, the connection may be divided into two connection regions: the end plate/bolts/reverse channel web, and the reverse channel flange/weld/column tube. The analytical model must include the heat sink effects of the concrete infill.

In the fire protected connection, the presence of the concrete core affects the temperatures of all the steel components because the heat transfer is slow and the heat sink effect of the concrete infill also influences the temperatures of the adjacent connection components not in direct contact with the concrete. For connection fire resistance design calculations, the different connection components may be treated as one part.