Journal of Constructional Steel Research 99 (2014) 18–34

Contents lists available at ScienceDirect

Journal of Constructional Steel Research

Modelling partial end-plate connections under fire conditions

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ARTICLE INFO

Article history:
Received 13 November 2013
Accepted 23 March 2014
Available online xxxx

Keywords:
Partial end-plate connection
Fire resistance
Steel structure
Finite element modelling

ABSTRACT

This paper presents a simplified robust 2-noded connection element for modelling the behaviour of partial end-plate connections under fire conditions. In this new model the partial end-plate connection is modelled as a 2-noded nonlinear spring element. The characteristics of the spring – such as stiffness, tension, compression, shear strengths and bending moment resistance – are determined based on each component of the connection. It is well known that the rotational response of a partial end-plate connection comprises of two stages, due to the shift of the compression centre of the connection from the end of the endplate to the centre of the beam bottom flange at large rotation. This two stage behaviour is considered in the model proposed. Compared to normal component-based models the most significant of the current model is that this simplified model has very good numerical stability under static solver condition. The model also retains the advantages of both simple and component-based models. Fourteen tests of partial end-plate connection previously conducted by other researchers were used to validate the proposed model. It is evident that the model is capable to predict the behaviour of flexible end-plate connections under fire conditions. In order to investigate the influences of the connections on the behaviour of steel structures, a series of numerical studies has been conducted on a 2D steel frame, subjected to ISO834 Fire and Natural Fire. It is clear that the model can be used to represent the partial end-plate connections in performance-based fire resistance design of steel-framed composite buildings.

1. Introduction

The robustness of structures under fire conditions is a major consideration for structural engineers and architects. To improve the survival time of structures, and minimize the loss of life and property, extensive research has been devoted to the performance of steel-framed composite buildings under fire conditions [1–6]. Previous results show that the behaviour of connections has a significant effect on the fire resistance of composite buildings [7]. For structural fire engineering design, the connections between steel beams and columns are conventionally assumed to be "pinned" or "rigid", according to the rotational stiffness. However, a "semi-rigid" assumption better describes the behaviour of connection in reality [8]. At present, partial end-plate connections, which have higher flexibility and larger rotational capacity, are commonly used in steel-framed composite buildings in the UK. A popular form of this connection consists of a rectangular plate, which is symmetrically welded into the supported beam web, and bolted to the supported column flange. Such partial end-plate connections are of great popularity for their construction efficiency. They are easy to fabricate, can be assembled and erected on site, and have been widely used in the construction of braced multi-storey steel framed buildings in the UK.

In recent years, a variety of experimental and analytical research has been conducted on the behaviour of partial end-plate connections at elevated temperatures. In general, three main approaches have been pursued for modelling the behaviour of connections, at both ambient and elevated temperatures:

1) Using curve-fitting equations to represent the moment–rotation characteristics of the connection [9];
2) Applying detail finite element analysis to simulate the non-linear 3D response of the connection [10];
3) Using component-based models to predict the behaviour of the connection [11].

The first approach is the simplest one. However, these curve-fitting equations can only be used for connections that possess similar geometrical and mechanical properties to those investigated experimentally. The second approach can be adopted by using general commercial software, such as ABAQUS or ANSYS. This approach is however computationally expensive, especially for modelling large-scale complex global structures or sub-structures. In recent years, component-based models (also known as spring-stiffness models) have been widely applied to simulate the behaviour of beam-to-column connections under fire conditions. This approach was initially developed following a proposal by Zoetemeijer [12], and further developments are now included as part of Eurocode 3 Part 1.8 [13]. The basic concept of the component-based model is to treat a connection as a combination of several basic components (see Fig. 1). Each component is represented as a spring, possessing its own stiffness and strength in tension, compression and shear. The overall behaviour of the connections is modelled as an assembly of those individual springs.

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http://dx.doi.org/10.1016/j.jcsr.2014.03.007
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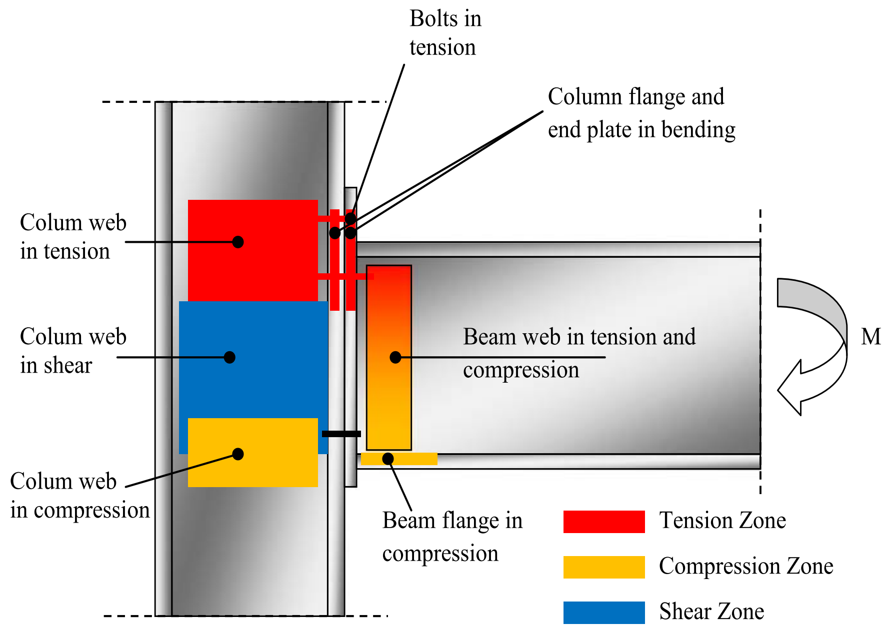

Fig. 1. Components within a bolted end-plate joint.

At present, a number of component-based models have been developed for the analysis of partial end-plate connections at elevated temperatures. For instance, Al-Jabri et al. [14] conducted a series of experimental tests on partial end-plate connections under fire conditions, and proposed a component-based model as well. In their component-based model, only the behaviour of partial end-plate connection at the first stage, before the bottom flange of beam contacts the column flange, can be simulated. In 2008, Hu et al. [15] carried out a series of elevated temperature tests on partial end-plate connections. They also developed a component-based model, which can predict the two stage behaviours of partial end-plate connections at elevated temperatures. In this model, the connection is regarded as a series of non-linear springs connected together using a rigid bar at each bolt row position. The performance of the connection is dependent on the force–displacement characteristics of these springs.

One significant problem for using component-based model is that under a static solver condition, if one of the springs within the connection fails, then the numerical illness may be generated within the stiffness matrix of connection element. Those illnesses may initiate numerical singularity for whole structures analysed and the analysis will stop. However, one spring failure within the connection doesn't mean the failure of the whole connection. In order to overcome this problem dynamic solvers are needed [16]. It is well known that using dynamic solver can significantly reduce the computational efficiency of the model.

Huang [17] recently proposed a robust 2-noded connection element, for modelling flush and extended end-plate connection between steel beam and column under fire conditions. This model has good numerical stability under a static solver condition, and also retains the advantages of both the simple and component-based models. In this model the connection is represented as a 2-noded non-linear spring element, and the characteristics of the spring (such as stiffness, tension, compression, shear strengths and bending moment resistance) determined based on a component-based approach. In this paper Huang's model will be used as the basis for the development of current simplified model to predict the behaviour of partial end-plate connections at elevated temperatures. The two stage behaviours of partial end-plate connections will be considered in the model presented here.

2. Development of the non-linear procedure

The main frame of Huang's 2-noded connection element [17] is extended here, to simulate the response of partial end-plate connections under fire conditions. In Huang's original model, the connection is specialized as a two-noded spring element which has no physical length (see Fig. 2). Each

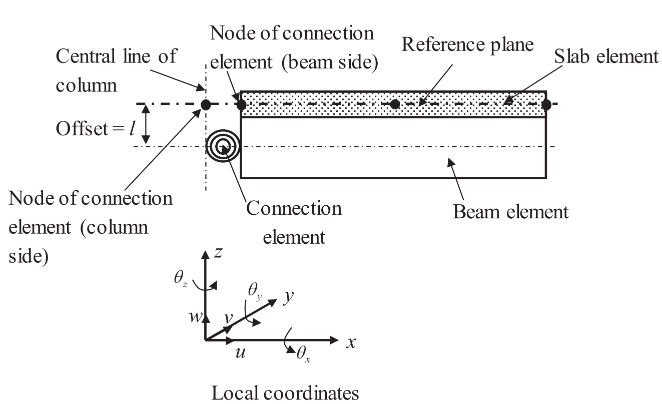

Fig. 2. Two-noded connection element.