Component-Based Approach for Steel Joints in Fire

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**ABSTRACT**

This paper discusses on a component-based model for steel connections that has been developed to study the robustness of simple beam-to-column connections at elevated temperatures. The new model represents the realistic behavior of such connections under the influence of combined forces, together with the high rotations which can occur at the ends of beams, during building fires. Modeling of the connections using component-based models may provide a progressive picture of their internal forces and prediction of their local and overall behavior during a particular fire event. This method is capable of capturing the key features within overall connection interaction in realistic manner, based on underlying mechanical properties, coupled with evidence from experimental data.

**INTRODUCTION**

The structural response of the framing systems in fire conditions has been intensively researched for the past 30 years. These activities have largely been motivated by accumulated evidence of disastrous structural failures which have caused casualties and economic losses. Large deformations are expected under fire exposure, and these can lead to local collapse of supported beams and floor systems. The fire resistance of a building component concerns its ability to withstand exposure to fire without loss of its load-bearing function, or (in appropriate cases) its ability to act as a barrier against fire spread, or both. When a structural member is exposed to fire, its load-bearing properties change dramatically due to its declining strength and stiffness with increased temperature. However, this loss of load capacity can be compensated for by a logical assessment of the interactions between different structural members due to the continuity of the whole structure in the real situation.

In current design practice, joints are required to be protected to the same level as the more protected of the connected members. This is intended to ensure that the joints are not the critical parts of the structural assembly. Nonetheless, a major redistribution of internal forces in joints is liable to happen, making them more vulnerable during the sequence of heating and cooling [1]. The behaviour of connections is usually defined in terms of their moment-rotation characteristics at ambient temperature, including their rotational stiffness, moment capacity and ductility. At high temperature, it is desirable for joints to be designed to provide robustness, retaining their structural integrity despite large rotations and tying deformations. The whole process of heating and cooling are equally important, in the sense that, even if no fracture of the connection occurs during the heating phase, the connection may still be subject to fracture during cooling, which may endanger fire service personnel or lead to progressive collapse.

**Component-based method:**

In searching for alternative methods to compensate for the impracticality of conducting sufficient high-temperature tests over a wide range of joint types and assemblies, it is most beneficial to study complex joints using component-based method. The application of this approach was also detailed by Tschemmernegg et al [2] at the University of Innsbruck, Austria, focusing on the elastic-plastic behavior of connection design for semi-rigid construction. The behaviour of a connection is subdivided into that of simpler zones with distinct structural functions, represented by non-linear translational springs, either in parallel or series where appropriate. These
arrangements directly lead to a so-called ‘component-based model’. A general spring model was introduced with reference to the test loading arrangement which consisted of three major springs, namely: the load introduction spring, the shear spring and the connection spring (Fig. 1).

Application of component method at elevated temperatures:

Over the past decade, the component model has been further developed for different types of connection, with further scientific refinements to take account of axial force, bending and shear interaction, for most common types of connections. According to Jaspart [3], in order to integrate the actual joint response in a more consistent approach, the joint representation can be carried out in four successive steps; joint characterisation, classification, modelling and idealisation.

(i) Identification of the active components:

The active components of a joint consist of the elements that directly contribute to the deformation or limit its strength [4]. Evaluation of the key components can be made by describing their idealised load-transfer mechanisms. Take for example the failure of fin-plate connections at high temperatures which involves their response to a combination of beam end-shear and normal forces, and large rotations. Preliminary investigation of a fin-plate connection can be carried out by representing the shear connection as a lap-joint, which transfers the force across the connection via sheared bolts (Figure 2). Rex and Easterling [5] modelled the behaviour of single-bolt lap-joints as a combination of three fundamental behaviours; plate friction, plate bearing and bolt shear. Additional components are introduced at large rotations at high temperature, which are positioned at the lower beam flange. Another modification effectively assesses the influence of larger bolt holes.

(ii) Specification of component characteristics:

Comprehensive understanding of the overall behaviour of steel structures is crucial to guaranteeing their fire-resistance, and so the alternative of using analytical tools may further improve design efficiency by providing a rational representation of the behaviour. The accuracy of prediction of overall connection behaviour largely depends on the interpretation of individual component characteristics. The characterisation of these
components can be represented through their force-displacement curves. The effect of weakening of steel at elevated temperature can be applied at this stage, using high-temperature material properties, or by developing an elevated-temperature model predicting the capacities of the components. Simplified characterisations of the components are possible whenever only the resistance, or the initial stiffnesses, of the joints are required, without significant loss of accuracy (Figure 3).

Fig. 3: Idealisation of component characteristics [4]

(iii) Assembly of the components:

Assembly of connection components is based on the distribution of the internal forces within the joint. The overall applied forces are distributed at each loading step between the individual components according to the instantaneous stiffness and resistance of each component [2]. The component-based model assembly comprises zero-length extensional springs representing components, and rigid links. In general, for all types of connection, analytical prediction of the response of steel joints requires a continuous change of the mechanical properties with temperature.

Validation:

A comparison of the generated component model (indicated by CM) against the experimental result is given in Figure 4.

Fig. 4: Force-displacement comparison curves.

The force-displacement relationship of a bolted single plate indicates good agreement, with a slight discrepancy in the elastic range. The overall capacity of the component model suggests a more conservative response, being slightly lower than the analytical model by a mere 4.3%. In other research, Hu [7] also created a 3D finite element model using Abaqus, which provided good agreement with test results. The displacement of the component model, however, requires to be shifted in line with the free slip present in order to illustrate the actual behaviour of the bolted joint. The active response of the bolted joint is only established after positive contact between the bolt and the bolt hole walls.
Summary:  
In a framed structure during fire, a beam-to-column connection experiences changing combinations of axial forces and bending moments. In order to respond correctly to such load reversals, a load-reversal approach needs to be defined for each connection element at elevated temperature. This is partly due to the likely occurrence of large displacements, but is also due to the thermal effects and their transient character.

The component-based model is applicable to a broad spectrum of connection parameters and types. The versatility of this method allows unrestricted application, provided that the fundamental behaviour of one generic connection type can be realistically represented either empirically or experimentally. Since the generation of the component model has been described in the previous chapters, it is now necessary to investigate the applicability of the component model to real connection response. The assessment will provide an improved understanding of overall connection performance, including consideration of the structural interaction within simple isolated joints and global structural frames. In this article, the developed model is validated against available experimental results, and is subsequently extended to parametric studies on the influence of connection behaviour.

REFERENCES


