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THE FIRE SAFETY OF JOINTS IN COMPOSITE STRUCTURES

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INTRODUCTION

Both full-scale tests at Cardington (Newman *et al.* 2004) and real fires e.g. World Trade Center (NIST 2005, 2008) provide evidence that the connections of building frames are vulnerable to fracture in fire. Under fire exposure, the internal forces in the joints vary substantially during the course of the fire, even though the external forces applied to the structure may remain unchanged. This results from restraint to thermal deformations and degradation of the mechanical properties of the building materials at high temperature. Because current design methods for connection are solely based on ambient-temperature behaviour, the additional forces and rotations generated in fire are not taken into account. If at any stage of fire exposure the connection does not have sufficient resistance to accommodate the large rotations and co-existent forces, connection fracture will occur, which may lead to extensive damage or progressive failure of the structure. Against this background, the Structural Fire Engineering Research Group of the University of Sheffield has been researching the behaviour of steel and composite connections in fire for a number of years. The current emphasis in this work is on the robustness of connections in fire, and its influence on the avoidance of disproportionate collapse in framed structures. This paper presents the current research findings and reports an on-going project which extends the previous study on steel connections to the joint behaviours of composite frames.

ROBUSTNESS OF STEEL CONNECTIONS

From 2005 to 2008 the Universities of Sheffield and Manchester conducted a joint research project on the robustness of steel connections in fire (Yu *et al.* 2007, 2009). This included a test programme on four types of commonly used steel connections (54 tests in total), and development of component-based models. Flush endplate connections were the only semi-rigid type tested; the other three (flexible endplates, fin plates and web cleats) were typical of "simple" construction.

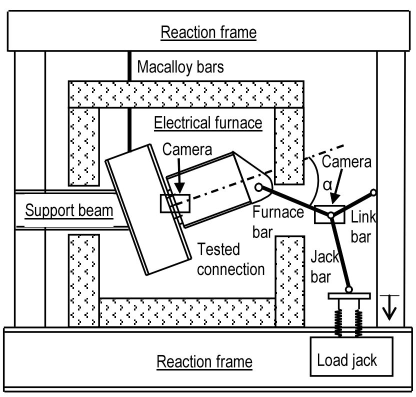

Figure 1. Test set-up.

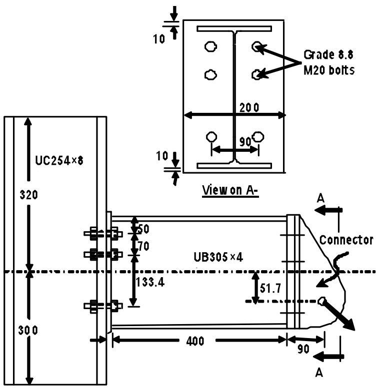

Figure 2. Typical flush endplate joint.

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This investigation adopted a test setup (Figure 1), in which the connections were subject to an inclined tying force, generating a combination of tension, shear and bending moment at the connections. The tests were performed in an electric furnace, in which the specimens were heated slowly to the specified temperature, and then loaded (under displacement control) to failure at constant temperature.

Figure 2 shows the details of a typical flush endplate connection. Three endplate thicknesses (8, 10 and 15mm) were tested. Most tests used three bolt rows, but for two tests the middle bolt row was removed. Connections were tested at three different combinations of shear and tying force, corresponding to different initial angles α (55°, 45° and 35°) between the axis of the steel beam and the furnace bar. The load angle has some effect on the overall connection resistance, but not on the failure mode. Figure 3 shows the main effect of endplate thickness; a thick endplate enhances resistance but significantly reduces ductility. The effect of removing one bolt row is shown in Figure 4. Removing the middle bolt row clearly reduces the resistance of the connection, but also reduces the ductility.

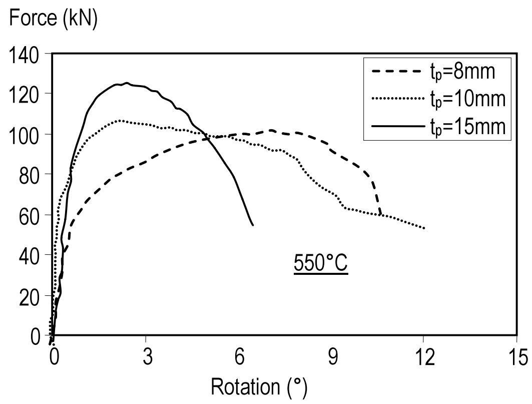

Figure 3. Effect of endplate thickness.

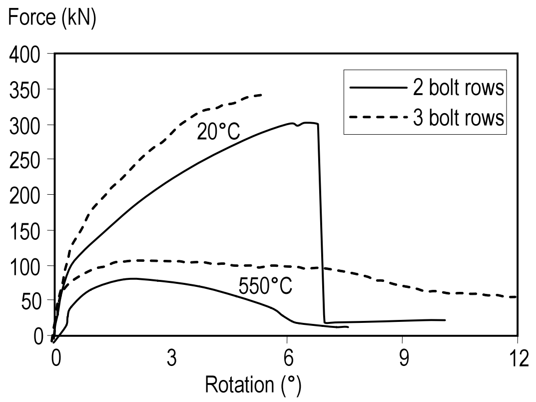

Figure 4. Effect of number of bolt rows.

Comparing with the other simple connections tested (Figure 5) the flush endplates clearly show higher rigidity (higher resistance and failure at lower rotation angles). All the flexible endplate connections tested show very low rotational capacity at high temperatures. The fin plate connections all failed by shear fracture of their bolts and their rotation capacity is only slightly better than that of the flexible endplates. The web cleat connections show significantly higher rotation capacity and ultimate resistance than the other simple connections.

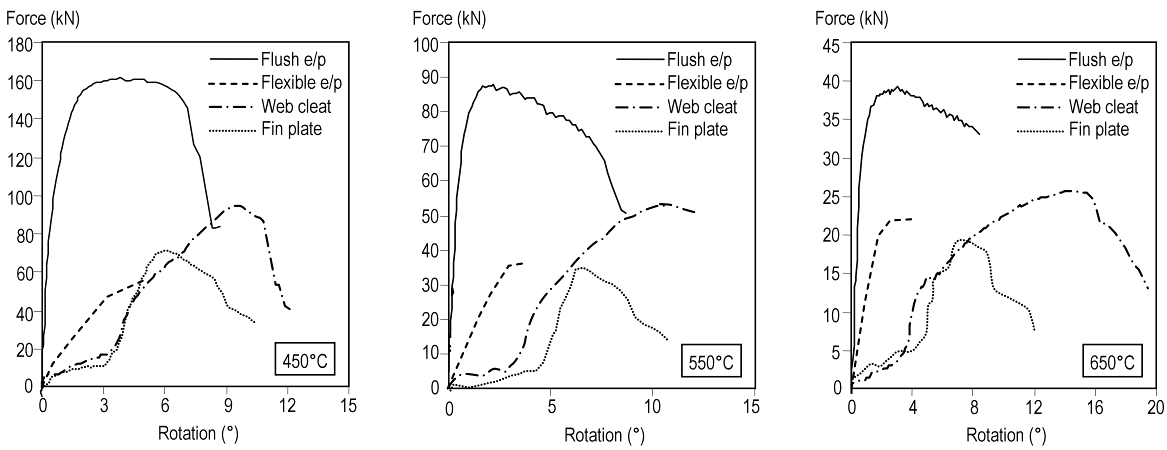

Figure 5. Behaviour of different connection types.

Component-based models have been developed for use in modelling the four types of connection studied in this project, and these have been shown to predict the connection behaviour with satisfactory accuracy. A few general conclusions may be drawn about the behaviour of these connections: 1. The rotational capacity of a connection depends on the deformational ductility of its components, together with the lever arm between the top bolt row and the compressive fulcrum; 2. For the connections, whose ductility relies on the bolts, the use of stronger bolts than are needed for ambient-temperature design is recommended; 3. For fin plate connections, using stronger bolts can considerably increase the rotational capacity; 4. For flush endplate connections, thin endplates should be used where ductility is required.

COMPFIRE PROJECT – CONNECTIONS TO COMPOSITE COLUMNS

This is a European-funded project in which the Sheffield group is collaborating with teams at Manchester, Coimbra, Lulea and Prague, as well as Corus Ltd. It concerns the behaviour and robustness in fire of practical connections between steel or composite beams and two types of composite columns - concrete-filled tubular (CFT) and partially-encased (PE) columns. The institutions involved will conduct tests at various scales, perform detailed FE modelling and develop a component-based approach. During the first year the Sheffield group will conduct a total of 20 tests, in a setup similar to that used for steel-to-steel connections (Figure 1), at ambient and elevated temperatures on flush endplate and reverse-channel connections to PE columns and on reverse-channel connection to both square and circular CFT columns. These tests will be used mainly to develop component-based connection models which will enable connection interaction to be modelled in whole-structure modelling software.

The test temperature (550°C, which is the average steel temperature) is the same for all tests but four cold tests and the load angle (α = 55°) is also the same for all tests, in order to sensibly examine the performance of the reverse channel. Beams are connected to reverse channels with a reasonably thick endplate (20mm) to ensure the reverse channel is the weakest component as desired.

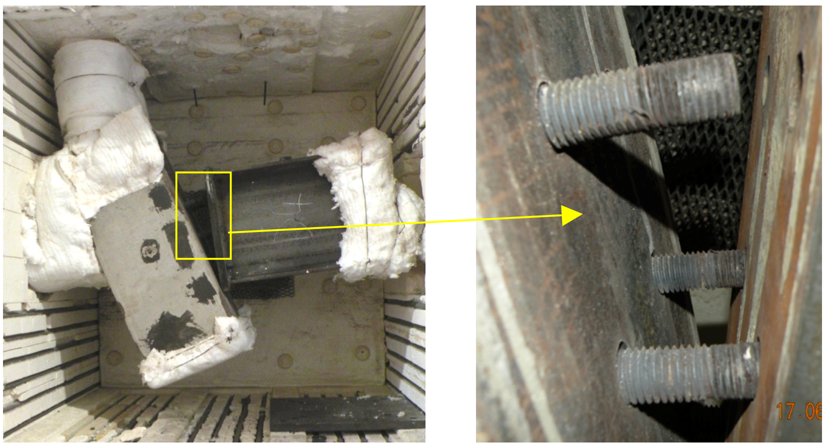

Figure 6. Failure of flush endplate connection to partially-encased column.

Figure 6 shows a flush endplate connection to PE column, which failed by nut stripping on all bolts while the other parts of the specimen barely deformed. To avoid this in the remaining tests, double nuts were used to bolt the beam endplate to the column or to the reverse channel. Seen from a few completed tests, the reverse-channel connections showed significantly higher rotation capacity and higher or comparable ultimate resistance than flush endplate connections. Its typical failure mode is shown in Figure 7. During testing, the reverse channel (mainly the face connecting to beam) deformed first, followed by the stretching and fracture of bolts row by row.

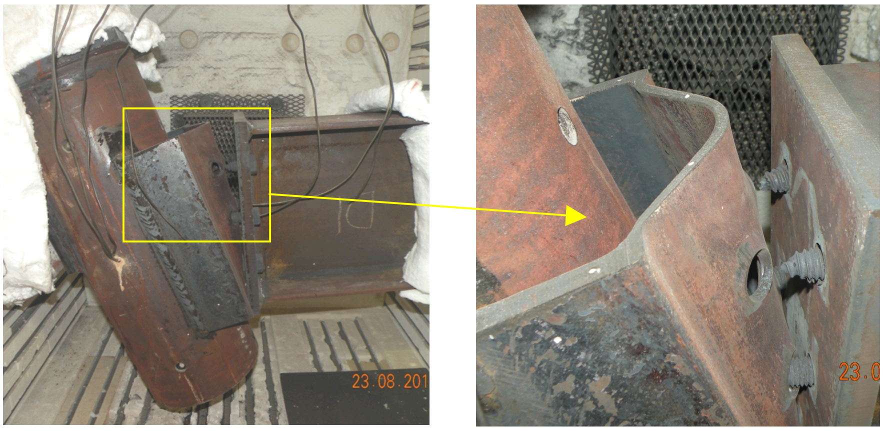

Figure 7. Typical failure of reverse-channel connection to CFT column.

The experiments will be followed by the development of a comprehensive component-based design methodology for composite joints against fire, which can be integrated into global modelling of frames. This will enable composite joints to be fire-engineered to the same level as the frame, offering substantial savings while maintaining safety levels.

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