CONNECTION BEHAVIOUR AND THE ROBUSTNESS OF STEEL-FRAMED STRUCTURES IN FIRE

Ian Burgess

Department of Civil & Structural Engineering, University of Sheffield, Mappin Street, Sheffield S1 3JD, UK.

Abstract

The full-scale fire tests at Cardington in the 1990s, and the collapse of at least one of the WTC buildings in 2001, illustrated that connections are potentially the most vulnerable parts of a structure in fire. Fracture of connections causes structural discontinuities and reduces the robustness provided by alternative load paths. An understanding of connection performance is essential to the assessment of structural robustness, and so to structural design against progressive collapse.

It has traditionally been assumed that steel beam-to-column connections have sufficient fire resistance, because of their lower temperatures and slower rate of heating, than the members to which they are attached. However, the forces and deformations to which they can be subjected during a fire differ significantly from those assumed in general design, either for the ambient-temperature Ultimate Limit State or for the Fire Limit State. The internal forces in connections generally start with moment and shear at ambient temperature, then superposing compression in the initial stages of a fire, which finally changes to catenary tension at high temperatures. If a connection does not have sufficient resistance or ductility to accommodate simultaneous large rotations and normal forces during a fire, then connections may fracture, leading to extensive damage or progressive collapse of the structure.

Practical assessment of the robustness of steel connections in fire will inevitably rely largely on numerical modelling, but this is unlikely to include general-purpose finite element modelling of large structural subframes, including details of the connections, because of the complexity of such models. The most promising alternative is the component method, a practical approach which can be included within global three-dimensional frame analysis. In this method the connection is represented by an assembly of individual components with known mechanical properties; it has been validated as an adequate, if not 100% accurate, representation of the behaviour of certain connection types in fire. For use in the context of robustness in fire, component characterization must include high-deflection elevated-temperature behaviour, and represent it up to fracture.

In reality a connection may either be able to regain its stability after the initial fracture of one (or a few) components, or the first failure may trigger a cascade of failures of other components, leading to complete detachment of the supported member. If connections are to be designed to avoid the possibility of complete detachment, then numerical modelling must be capable of predicting the sequence of failures of components, rather than considering the first loss of stability as signifying building failure. In order to model these effects it is necessary to use a dynamic analysis, so that loss of stability and re-stabilization can be tracked, including the movements of disengaging members and the load-sharing mechanisms which maintain integrity and stability within the remaining structure, until total collapse occurs.