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Methods of improving the survival temperature in fire of steel beam connected to CFT column using reverse channel connection

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ABSTRACT

This paper presents the results of a numerical study, using ABAQUS, of the behaviour and methods of improving the survival temperatures in fire of steel beams to concrete filled tubular (CFT) columns using reverse channel connection. The beams are axially restrained by the connected columns and develop catenary action so their survival temperatures are primarily controlled by the joint tensile resistance and deformation capacity. Therefore, improving the beam survival temperature mainly relies on improving the joint performance. This study investigates five different joint types of reverse channel connection: extended endplate, flush endplate, flexible endplate, hybrid flush/flexible endplate and hybrid extended/flexible endplate. The connection details investigated include reverse channel web thickness, bolt diameter and grade, using fire-resistant (FR) steel for different joint components (reverse channel, end plate and bolts) and joint temperature control. The effects of changing the applied beam and column loads are also considered. It is concluded that by adopting some of the joint details to improve the joint tensile strength and deformation capacity, it is possible for the beams to develop substantial catenary action to survive very high temperatures. However, it is important that the additional catenary force in the beam is resisted by the connected columns.

1. Introduction

Concrete filled tubular (CFT) columns have a number of advantages including attractive appearance, high structural load carrying capacity and high fire resistance. However, the use of CFT columns has to overcome the problem of making connections due to difficult access from within the steel tube. As a result, the reverse channel connection has been developed. In this method, the two legs of a channel are welded to the tubular column face and the channel web is connected to a conventional endplate on the beam side. Fig. 1 shows a sketch of reverse channel connection. Detailed studies of reverse channel connection performance in fire were first reported by Ding and Wang [1] who carried out fire tests and reported that using reverse channel connection could allow the beam to develop substantial fire resistance. The authors [2] undertook detailed numerical simulations of the fire tests by Ding and Wang to validate their numerical simulation model. The validated numerical model is used to conduct the parametric studies reported in this paper.

Although making use of joint bending moment resistance can enhance fire resistance of the connected beam under bending, the emphasis of this paper is on the development of catenary action in the steel beam under fire attack. As a response to the collapse of the World Trade Center buildings on September 11, 2001, developing methods of controlling fire-induced progressive structural failure is now one of the most important aspects of the structural fire engineering research agenda and catenary action has now been identified as a feasible method [3].

Catenary action in a beam occurs when the beam's temperature is above its conventional limiting temperature, which refers to the temperature at which the beam's bending resistance is reached [4]. Catenary action has been investigated by a number of researchers, including Yin and Wang [5–7], Guo and Li [8], Yu [9]. The results of numerical studies by Yin and Wang [5–7] suggest that if the joints have sufficient tensile resistance and rotational capacity, the connected steel beam can survive very high temperatures without failure. As with other numerical studies, Yin and Wang [5] assumed infinite joint deformation capacity. The results of recent research studies on realistic joints to open section columns [10,11,17,18] indicate that conventional realistic joints have limited deformation capacities. Furthermore, the fire test results of Ding and Wang [1] on restrained beam–CFT column assemblies also confirm that conventional connections to CFT columns would not have sufficient strength or deformation capacity to allow substantial catenary action to develop in the beams. The main objective of the research reported in this paper is to find ways of enhancing the strength and deformational capacities of reverse channel connections to CFT

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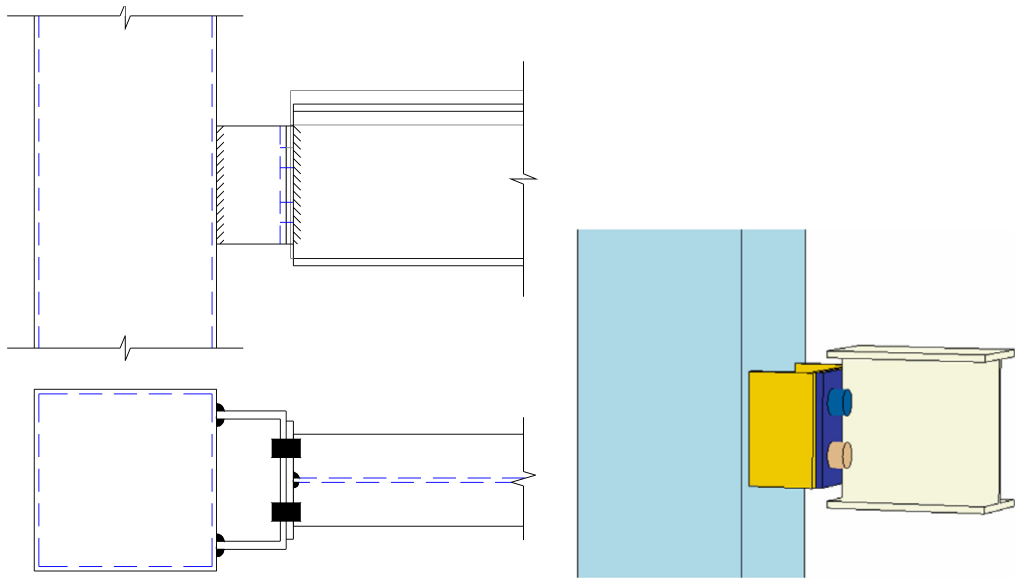

Fig. 1. Typical a reverse channel connection using a flexible endplate.

columns to prolong the development of catenary action in the connected beam.

To achieve the above objective, this paper will investigate the feasibility of the following methods:

1. Using hybrid connections.
2. Using fire-resistant steel in joint components.
3. Fire protection of joint components.
4. Joint detailing.

Whilst some of the methods investigated in this paper may not be immediately feasible, it is important to identify the potential solutions to aid future developments for practical use.

2. Simulation methodology

Fig. 2 shows the structural arrangement to be simulated in this research. It represents a steel beam connected to two concrete filled tubular (CFT) columns. The top and bottom of the columns

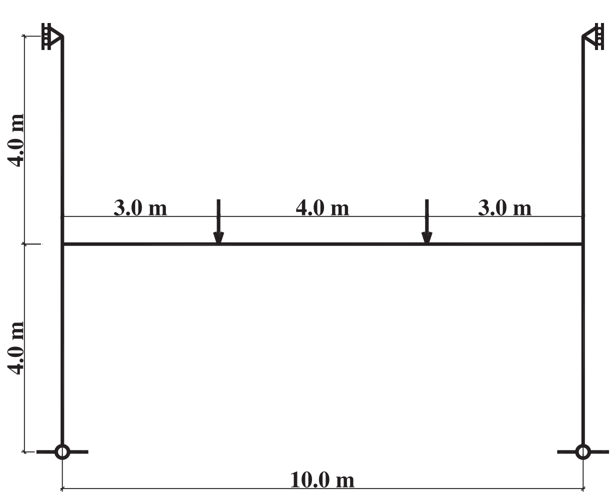

Fig. 2. Dimensions and boundary condition of structure assembly.

are rotationally unrestrained but are horizontally restrained to simulate the lateral stability system in a real structure. This structural arrangement is the same as used in the fire tests of Ding and Wang [1]. The simulation methodology to be summarised below has been validated by the authors [2] by comparison against the fire test results of Ding and Wang [1].

- Three-dimensional solid elements (C3D8) were used to model the main structural members (beam, steel tube, concrete fill, connection components).
- Boundary conditions: half of the structure was modelled due to symmetry. The bottom of the columns was pinned in all three directions and the top of the columns was pinned in two directions but movement along the column axis was allowed; because half of the structure was modelled due to symmetry, all nodes at the beam mid-section were fixed in the axial direction, which effectively prevented rotation about the two principal axes of the beam cross-section, but allowed the beam to twist about its longitudinal axis. To represent the effect of the concrete slab, the beam was assumed to be fully restrained in the lateral direction;
- To reduce the number of elements and nodes in the FE model, the column was divided into three parts and only the central part connected by the joint (90 cm) was actually modelled using the solid elements. The other two parts away from the joint zone were modelled using general beam elements with "box" cross section for the steel tube and "rectangular" cross section for the concrete infill. The ABAQUS "Coupling" function was used to join the three column parts [12].
- The reduction factors for strength and elastic modulus of carbon steel at elevated temperatures were the same as in EC3 (EN 1993-1-2) [13].
- The ABAQUS contact function was used to simulate interactions between many contact pairs, including the interface between the wall of the SHS and the concrete fill, between the bolt head and the web of the reverse channel, between the bolt nuts and endplate, between the bolt shanks and the web of the reverse channel, between the bolt shanks and the endplate, and between the web of the reverse channel and the endplate. In order to reduce computational cost, a contact was defined as