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Robustness of Steel Joints in Fire: An Experimental Study on Structural Behavior of Joints in Restrained Steel Frames in Fire

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1. Introduction

Joints are important members in steel framed structures and play a critical role in controlling progressive collapse of structure under fire attacks. Although previous research studies on steel-framed structures in fire have resulted in the development of fire engineering design methods that are currently being widely adopted in fire resistant design, gaps are still exist in understanding joint performance in fire. A research on robustness of steel framed structures, to understand the joint performance in fire and develop feasible methods to qualify joint behavior under complex loading conditions, has been carried out in the University of Manchester in collaboration with the University of Sheffield.

In total 10 fire tests were conducted in the fire testing laboratory at the university of Manchester. Each test used a fresh specimen specially designed in the form of "rugby-goalpost". One beam section, two column sections and five joint types were involved.

*S*ummary of specimen details

Test ID	Joint type	Connection component dimension (mm)	Column section	Beam section
Test-1	fin plate	150x130x10	UC 254x254x73	UB 178x102x19
Test-2	flexible endplate	150x130x8		
Test-3	flush endplate	150x200x8		
Test-4	web cleat	90x150x10 (depth: 130)		
Test-5	extended endplate	150x250x8		
Test-6	fin plate	150x130x10	UC152x152x23	
Test-7	flexible endplate	150x130x8		
Test-8	flush endplate	150x200x8		
Test-9	web cleat	90x150x10 (depth: 130)		
Test-10	extended endplate	150x250x8		

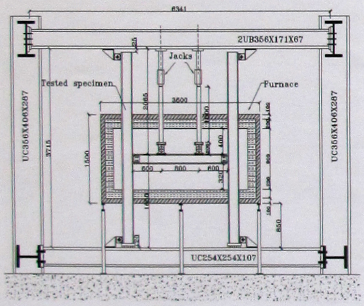


Fig.1: Elevation view of the test set up

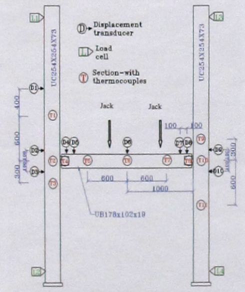


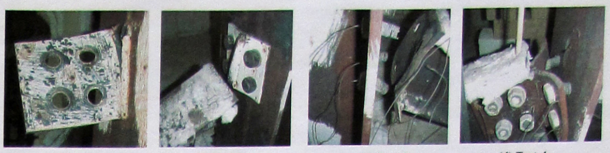
Fig.2: Arrangement of measurement devices on a specimen

2. Joint failure modes and structural deformation

The "failure" definition adopted here is to reflect the main object to provide an insight into joint behaviour in terms of its contribution in preventing progressive collapse of the steel frames in fire. Therefore as long as the structure was not physically detached from each other or fractured, it was assumed that the joint is still functioning or has not failed.

*S*ummary of specimen observation and failure modes

Test ID	Joint type	Main observations	Failure mode
Test-1	fin plate	Beam flange bearing against column flange, little column deformation	Weld fracture
Test-2	flexible endplate	Beam web fractured mainly in shear, complete detachment of beam from column, little column deformation	Beam web fracture & detachment
Test-3	flush endplate	Thread-stripping of bolts and nuts, complete detachment of beam from column, little column deformation	Bolt thread stripping & detachment
Test-4	web cleat	Web cleat large deformation, thread-stripping of bolts and nuts of top bolts but connection not detached, little column deformation	Some bolt thread stripping
Test-5	extended endplate	Classical end plate ductile deformation, compressive buckling in beam lower flange, little column deformation	-
Test-6	fin plate	Beam flange bearing against column flange, plastic hinges in column	Weld fracture
Test-7	flexible endplate	Large flexible end plate and column flange deformations	Slight weld fracture
Test-8	flush endplate	Large column flange deformations, moderate end plate deformation	-
Test-9	web cleat	Large web cleat and column flange deformations	-
Test-10	extended endplate	Moderate end plate deformation, large column flange deformations, plastic hinges in column flanges	-



(a) Test-1 (b) Test-2 (c) Test-3 (d) Test-4

Fig.3: Typical failure modes on joint components

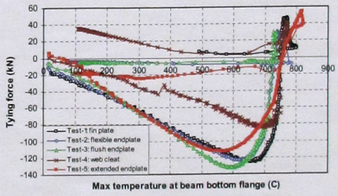
(a) Test-5, column: UC254x254x73; beam: UB178x102x19

(b) Test-10, column: UC152x152x23; beam: UB178x102x19

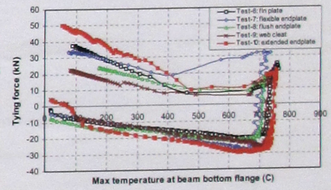
Fig.4: Comparison of joints with different column sections

3. Development of axial forces in joints and beam limiting temperature

The qualitative behaviour of an axially restrained beam is now well established. However there are many factors may influence the joint's ability. This research only focused on effects of two factors considered: joint type and column size.



(a) Column size: UC254x254x73



(b) Column size: UC152x152x23

Fig.4: Comparison of development of axial forces at joints

*S*ummary of beam limiting temperatures (with axial force=0)

Test ID	Test-1	Test-2	Test-3	Test-4	Test-5	Max temp difference by connection types (˚C)
Temperature (˚C)	748	728	728	750	753	25
Test ID	Test-6	Test-7	Test-8	Test-9	Test-10	
Temperature (˚C)	733	700	710	725	745	45
Max temp difference by column sizes (˚C)	15	28	18	25	8	

4. Conclusions

- The test data provided valuable insights in understanding joint behaviour and failure modes.
- The test beams were able to experience very large deflections (span/8 – span/6) even without fracture.
- If beam limiting temperature is calculated based on its bending moment resistance, using different joints has little effect with the changing in beam limiting temperature being less than 50 C. The effect of column size is even smaller, less than 30 C.
- Using different joint types had little effect on the beam's axial force in compression, but using different column sizes had great effect. However irrespective of the great effect of using different column sizes, the structure was able to sustain the applied load through the beam in compression phase.
- If catenary action in the beam is considered in fire resistant design (e.g. to consider structural robustness), the effect of column sizes and joint types should be considered.
- If using the ability of a joint to allow beam to develop catenary action without joint failure, flexible endplate connection performed the poorest, then followed by flush endplate, fin plate and web cleat connections. extended endplate connection was the strongest.

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