Text of Presentation

Connection Design for Fire Safety - Cardington Structural Integrity Fire Test

1 Fire safety of structures may be increased by structural design for the exceptional loading condition created by fire. The level of safety which can be achieved has been shown by a fire test on a real structure at Cardington, which was conducted in order to improve knowledge about structural integrity in fire.

2 This lesson introduces connection design for fire safety: distribution of temperature, thermal properties, and component method. The preparation, execution and major results of the structural integrity test in the Cardington laboratory are shown. At the end is the connection design is summarised.

3 The modelling of the structure involves three stages. The first stage is to model the fire scenario to determine the heat energy released from the fire and the resulting atmospheric temperatures within the building. The second stage is to model the heat transfer between the atmosphere and the structure. The third stage is to determine the response of the structure. The definition of fire resistance is the ability of a building or its elements to satisfy for a stated period of time agreed criteria of load bearing capacity, integrity and insulation. The design of connections for fire safety involves calculation of the heat transfer to them and a determination of the response of the structural elements of the connections.

4 The design for high temperatures takes into account both the degradation of material properties and elongation of the heated elements, as well as the contraction of elements in cooling.
In the connections, because of the presence of concentrations of material, the temperature variation lags behind the corresponding temperature variation for the connected steel members.

5 The basis of connection design in fire is the temperature distribution in its elements.

6 The fire safety part of the European standard for the design of steel structures includes an Annex which gives rules to evaluate the behaviour of welds and bolts at high temperatures.

7 In line with the cold design of steel joints, the component method is applicable to the design of connections at high temperatures. The first step is to divide the connection into its components.

8 The resistance of each component is reduced at high temperature and this is expressed by a strength reduction factor. The deformation of the component is controlled by a reduction of its modulus
of elasticity.

9 The connection behaviour may be described on the basis of its component behaviour and temperature distribution.

10 An example of change in the behaviour of an and-plate connection with temperature.

11 The large-scale building test laboratory is housed in a former airship hangar at Cardington.

12 The laboratory has a uniquely large space of 48 m x 65 m x 250 in which to conduct experiments.

13 Three multi-storey buildings were built at full scale. In front is situated the six-floor timber-framed building. The figures on the right shows a fire test of timber stairs and the test of structural integrity by impact of vehicle.

14 In the centre of laboratory are located the seven-floor concrete framed building. The photos on the right are showing fire load by timber ribs in the fire compartment and the column as well as concrete slab after fire test.

15 The composite steel and concrete building was finished in 1994.

16 The structure is made of open sections and simple connections. The composite slab was cast onto corrugated metal decking.

17 Seven large fire tests have been performed on different levels of the composite frame.

18 The major objective of tests No. 1 and No. 2 was to study element performance in a real structure. Natural gas was used for heating in these tests.

19 Tests No 3 to No 6 were designed to study composite slab behaviour in fire. Timber cribs were burned to simulate the fire load in the office building.

20 For a composite multi-storey building it is desirable to fire-protect the compression members and to leave unprotected members in bending. The importance of protection of members in compression was demonstrated in the second test, where a part of the column was not protected.

21 Test No 7 was designed to study the structural integrity of the structure in the wake of the collapse of the World Trade Centre towers on September 11, 2001. The work is part of project CV 5535 of the European Union Fifth Framework programme. The objectives of the test were to study temperatures in elements and joints, the internal forces in the connections, and the behaviour of the composite slab.

22 The fire compartment was built on the third floor. The walls were constructed of three layers of gypsum plasterboard attached to thin-walled profiles. The window opening was designed to allow good but controlled ventilation during the fire.

23 The columns were fire insulated by 15 mm of Cafco300 vermiculite-cement spray. External joints were protected together with 1 m of the attached primary beams.The compartment was instrumented with 148 thermocouples, 57 regular-temperature strain gauges and 10 high-temperature strain gauges.

25 27 vertical and 10 horizontal deformations were measured.

26 Ten video cameras and two thermal imaging cameras recorded the fire and smoke development, the deformations and temperature development.

27 Sand bags represent the mechanical loadings; 100% of permanent actions, 100% of variable permanent actions and 56% of live actions.

28 Cribs of 50 x 50 mm timber produced a fire load of 40 kg/m^2.

29 The fire test was performed on January 16, 2003, after four months of preparation under
the supervision of the Bedford Fire Department. The burning was smooth from ignition, developing towards flashover and finally cooling. The smoke development was limited by the design of the openings. The time is shown on the graph of the gas temperature development. We may see
the bending of the primary beam during the fire trough the window of the compartment.

30 The slab reached 1220 mm maximum deflection during heating, which recovered to 925 mm of residual deflection on cooling. The time is shown on the graph of the gas temperature development. The deflection is shown from readings on secondary beam in the centre of the compartment.

31 The cracks in the plate opened in 53rd minute of the test.

32 The thermal imaging cameras give a visual representation of the temperature of the structure by colours over areas of about 24 to 24 millimetres. The fin plate connection of the secondary beam to the primary beam was observed. Local buckling of the lower flanges of beams is visible after 23 min of heating. The animation of thermographs shows the delay in the heating and cooling of the connections.

33 The development of the temperature in the compartment was predicted accurately. The graph shows the prediction of the gas temperature and the measured gas temperature. The highest temperature was reached at the back of the compartment. The maximum predicted temperature was 1078 °C at 53 min., whereas the actual maximum was 1108°C at 55th min.

34 The lower flange of the secondary beam achieved the highest temperature of any part of the structure. Its predicted maximum temperature was 1067 °C at 54th min, compared with the actual maximum of 1088 °C at 57th min.

35 The thermocouple measurements compare the temperatures in the components of the fin plate connection to the temperature of the lower flange of the connected secondary beam.

36 The beam to column header plate connection reached about 250°C less than the lower flange of the connected secondary beam.

37 After the fire only ashes remained from the timber ribs in the compartment.

38 Due to compression the beam webs buckle locally at elevated temperatures. The local buckling is located in zones of negative bending close to connections or colder parts of the beam.

39 The bearing of the fin plate on the beam web allows ductile deformation of the fin plate connection.

40 The header plate fractures in the heat affected zone of its weld on one side of the connection during the cooling phase. The connection continues to transfer the shear forces through the remaining part.

41 Connections are loaded in compression during heating and in tension during cooling. Reduction of the stresses due to local buckling may be observed.

42 The column flange exhibits some local buckling.

43 Shear buckling takes place in the beam web.

44 We may conclude based on the test that collapse of structure was not reached for the fire load of 40 kg/m^2, which well represents the fire load in a typical office building, together with a mechanical load greater than standard approved cases. The structure showed good structural integrity. The test results supported the concept of unprotected beams and protected columns as a viable system for composite floors.

45 Local buckling of the lower flanges of beams was observed after 23rd minute of heating. The fracture of end plates occurred under cooling in the heat affected zones of welds without losing the shear capacity of the connections. The well-designed fin plate connections behaved in ductile fashion due to elongation of holes in bearing.

46 The connections were exposed to different forces compared to those at room temperature because of their exceptional loading by fire. The good design of connections leads to robust behaviour. Connections in a structure are relatively cool compared to their connected elements due to their concentration of mass. There is no need for special checking and no need for local thermal insulation of normal connections. If there are beam splices within a beam span exposed to fire a component method gives a good prediction of the behaviour.

47

48 The experiment was carried out with the support of the EU Fifth Framework project No. CV 5535 “Tensile membrane action and robustness of structural steel joints under natural fire”.

49 The authors would like to thank to all members of the European project team who worked at the Cardington laboratory on the test.

50 The Czech Technical University in Prague has produced this lesson as part of the project “Continuing Education in Structural Connections” which was supported by the European Community under the Leonardo da Vinci Programme.