COST Action TU0904
Integrated Fire Engineering and Response

Institute for Sustainability and Innovation in Structural Engineering

BASELINE STUDY ON THE STRUCTURAL BEHAVIOUR OF COLD-FORMED STEEL ELEMENTS SUBJECTED TO FIRE

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OBJECTIVES

- Study the effect of local, distortional and global buckling on cold-formed steel elements under fire conditions.
- Therefore, a number of compressive and flexural strength tests on cold-formed steel elements with restrained thermal elongation subjected to fire have been undertaken at UC, with the purpose of assessing the failure modes, the fire resistance and the critical temperature of this kind of elements.
- These experimental tests will be the basis of a numerical research in order to provide a great amount of data for the elaboration of an analytical study for the development of simplified calculation methods for fire design of cold formed steel elements. It is noticed that most scientific investigations in this area are based on the structural behaviour of single elements at elevated temperatures, on short elements and essentially on studies of numerical nature.

EXPERIMENTAL INVESTIGATION

Test Specimens

- The specimens were made of one or more CFS profiles, namely, channel (U) and lipped channel (C) profiles. All these profiles were 2.5 mm thick and 43 mm wide. The inside bend radius and the length of the edge stiffeners of the C profiles measured respectively 2 and 15 mm.
- The cross-sections of the C profiles were 150 mm tall for the columns and 250 mm for the beams, whereas the U profiles were 155 mm tall for the columns and 255 mm for the beams, so that the C profiles could be placed between the flanges of the U profiles.

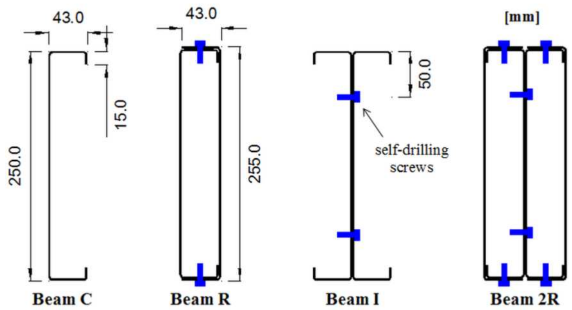

Figure 1. Scheme of the cross-sections of the tested beams

EXPERIMENTAL INVESTIGATION

Test Specimens

- The lipped I beams consisted of two C profiles, whereas the R beams consisted of one C and one U profile. At last, the 2R beams were made of two C and two U profiles. The connections between these profiles were materialized by means of steel self-drilling screws.
- Both types of elements were 3 m long and all profiles were made of S280GD+Z structural steel.

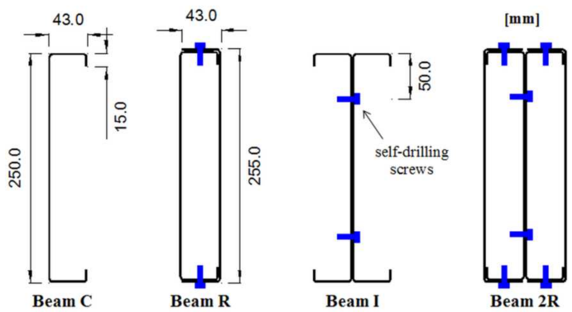

Figure 1. Scheme of the cross-sections of the tested beams

❖ EXPERIMENTAL INVESTIGATION

Test Method for Columns

Figure 2. Test set-up for CFS columns

- The 3D restraining frame was used to take into account the axial stiffness of the surrounding structure to the column. Different values of stiffness were provided by positioning the peripheral columns of the restraining frame in different positions.
- The loading was applied by a hydraulic jack, which was hung on a 2D reaction frame. Beneath this hydraulic jack a load cell was still mounted in order to monitor the applied load during the test.
- Additionally, the restraining forces generated in the columns due to the heating were measured by a load cell located inside a void cylinder of high stiffness. This cylinder was placed between the testing column and the restraining frame.

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❖ EXPERIMENTAL INVESTIGATION

Test Method for Beams

Figure 3. Test set-up for CFS beams

- A new test set-up for fire resistance tests of beams was performed to take into account not only the axial stiffness but also the rotational stiffness of the surrounding structure to the beam.
- The loading was applied by a hydraulic jack, which was hung on a 2D reaction frame and was controlled by a servo hydraulic central unit. Beneath this one a load cell was also mounted in order to monitor the applied load during the test.
- A spherical plain bearing and a spherical hinge were also assembled in the loading system in such a way that the load system could easily follow the lateral deformations of the beams during the tests.

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EXPERIMENTAL INVESTIGATION

Test Method

- The test set-up for beams also consisted of a roller and pinned support to provide a simply supported beam. On the other hand, the columns could be tested under pin- or fixed-end support conditions.
- Concerning the loading, the columns were axially loaded, whereas the beams were loaded at two points, 1.0 m from the supports of the beam in such a way that between the two loading points the beam was under pure bending state.
- During these tests, the load applied on the elements, the vertical and horizontal displacements of them, as well as, the temperatures in the furnace and at several points of the elements were measured.
- The specimens were heated with a modular electric furnace, which was capable to heat up to 1200 ºC.

EXPERIMENTAL INVESTIGATION

Test Procedure

- These fire resistance tests were performed in two stages: loading and heating stage.
- Firstly, the specimens were loaded up to the target force under load control at a rate of 0.1 kN/s. The load level applied on the elements was a percentage of the design value of buckling load of the respective element at ambient temperature.
- Finally, the heating stage was started after the desired load was reached. Thus, the specimens were heated according to the standard fire curve ISO 834. During this period of heating, the load was kept constant until the specimen buckled.

EXPERIMENTAL INVESTIGATION

Results

- There was a delay in the temperature increase in the closed built-up beams comparing with the open built-up beams, due to the presence of fresh air inside of the respective beams. This figure shows that the temperature in the C, lipped I, R and 2R beams increased at a rate about 67, 47, 43 and 34 ºC/min, respectively, after the sixth minute of test.

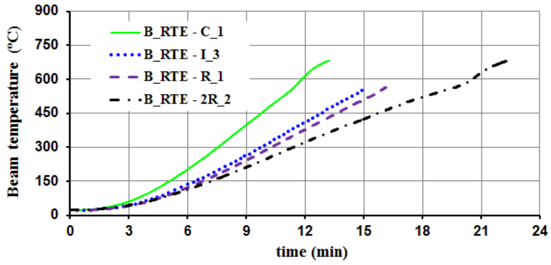

Figure 6. Evolution of the mean steel temperature in the different beams

EXPERIMENTAL INVESTIGATION

Results

- In relation to the restraining forces in beams with a 50% load level, it can be seen in these figures that the C, lipped I, R and 2R beams started to lose their strength after 7.5, 12, 13 and 20 minutes of test, respectively, corresponding to the following critical temperatures of 300, 411, 414 and 570 ºC.

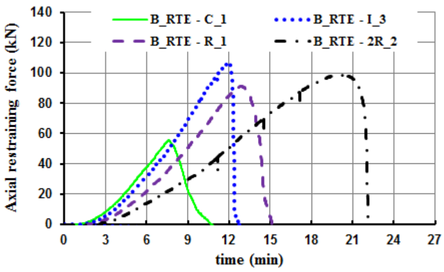

Figure 5. Evolution of restraining forces as a function of time in beams

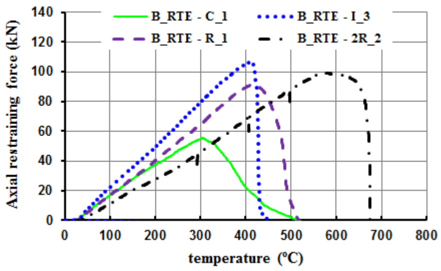

Figure 6. Evolution of restraining forces as a function of temperature in beams

❖ EXPERIMENTAL INVESTIGATION

↳ Results

- Regarding the restraining forces in columns with a 30% load level, it can be seen in these figures that the critical time of the C, lipped I, R and 2R columns was respectively about 9, 10, 12 and 16 minutes, corresponding to an average critical temperature around 450 ºC.

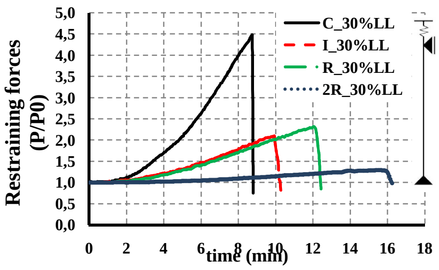

Figure 7. Evolution of restraining forces as a function of time in columns

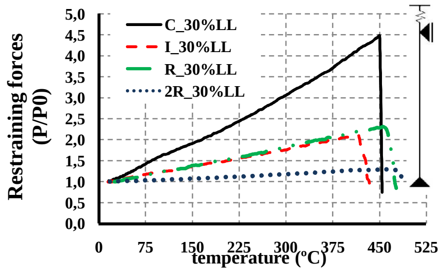

Figure 8. Evolution of restraining forces as a function of temperature in columns

❖ EXPERIMENTAL INVESTIGATION

↳ Failure Modes

- Since all fire resistance tests were performed inside a furnace, only the final shape of the column or the beam could be observed. It was possible to observe that the flexural buckling about the weak axis was the main failure mode responsible for the collapse of the pin-ended C and lipped I columns.

Figure 9. Configuration of the deformed C column after test

Figure 10. Configuration of the deformed lipped I column after test

❖ EXPERIMENTAL INVESTIGATION

↳ Failure Modes

- On the other hand, as an example, it was observed that both local, distortional buckling and lateral-torsional buckling were responsible for the collapse of the 2R beams.

Figure 11. Configuration of the deformed 2R beam after test

❖ CONCLUSIONS

- The results of this research study showed above all that cold-formed steel elements commonly used in this kind of buildings may have a quite low fire resistance, as it was expected. As well as that, they are very sensitive to local, distortional and global buckling and also their interactions.

- However, it was observed that the closed built-up sections showed an enhanced fire behaviour than the open sections. For example, the closed built-up beams had an increase about 50% in the fire resistance, comparing with the open beams.

- Other important conclusion to be drawn is that the temperature limit of 350 ºC indicated in the Eurocode 3 Part 1.2 might be too restrictive, since for temperatures higher than this one, the elements might still have load bearing capacity.

- Hence, in the near future it is going to do further experimental tests and perform parametric studies outside the bounds of the original experimental tests.

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Muito Obrigado

Many Thanks

Muchas Gracias

Viel Dank

Merci Beaucoup