Post–Earthquake Fire Tests – Part 1: Report

Tudor Petrina

1 UTCN - 15 C. Daicoviciu Str., Cluj-Napoca, Romania

E-mail address: tudor.petrina@mecon.utcluj.ro

Abstract. Immediately after an earthquake, fire is the most probable accidental action on buildings. Beam-to-column steel connections are parts of the structure that need to have sufficient fire resistance in order for occupants to exit the building and firemen to intervene. Fire and post-earthquake fire tests on steel connections were made at the Technical University of Cluj-Napoca, Romania. Real scale specimens were created and some of them were subjected to cyclic action following a special procedure. After the cyclic action, the deteriorated specimens were immediately subjected to fire. New connections were also tested for fire action in order to find differences to the deteriorated case. In this paper, a short description of the specimen, test stand and equipment, the reports of all tests and immediate conclusions of each test are presented.

1. Introduction

The testing programme that was developed at the Technical University of Cluj-Napoca, Romania, Faculty of Civil Engineering Testing Facility, was aimed at finding the behavior of steel beam to column end-plate bolted connections under service loading during fire and also during post-earthquake fire. After majority of earthquakes, fire occurs especially in the urban areas due to pipes and other installations fracture.

During seismic motions, the connections are parts of structure that may have permanent damage, changing their strength and stiffness. For this reason, during a post seismic fire, they will work in a different manner, having a different fire resistance. With the help of tests, we want to find the effect of the seismic damage on the fire behavior of the structure. Similar results were obtained by other authors by means of numerical methods, for example, in Yassin [1].

2. Specimen, stand and furnace characteristics

The specimen was a steel beam to column end-plate connection designed like in figure 1. The column is made up by an H type compound profile having the flanges of 15mm thickness and the web of 10mm thickness and the beam is of I type compound profile with the thickness of the flanges of 15mm and the web of 8mm thickness. The bolts are of type 10.9 with controlled tense according to the European design code EN 1993 [2]. The connection is a steel beam-to-column bolted connection. The column is 3.0m high and the cantilever beam has a length of 2.0m. The type of the material used is structural steel S235JR as presented in Petrina [3]. There are 12 M20 bolts for each connection, having the length of 70mm. The column is stiffened by 15mm and 20mm steel plates.
The stand was designed according to Petrina and Muntean [4]. It has the following main objectives: to assure a pinned fitting of the column’s ends, to block the dilatation of the column, to block possible out-of-plane translations. According to Petrina and Muntean [4], these characteristics assure the conditions inside a steel structure made of 3D frames. Inside the Facility, the stand was arranged like in figure 2 below. The mechanic action was introduced by one press with two cylinders. The equipment for data acquisition was: thermocouple, displacement and force translators, equipment HBM – Quantum C – MX 1615 with Catman software.

The furnace was designed around the node to have the possibility to apply fire directly on the connection. Furnace’s main characteristics were: to have sufficient power, a good thermal insulation, to be constructible around the node, to permit beam movement up and down, to be removable after each test. The gas burner was of type Weishaupt having a power of 155kW, but only a quarter of that was used.

3. Directions and Procedure
At the tests conception stage the following main directions were decided: to find the behavior of the specimen at 20°C, 400°C, 500°C, 600°C under increasing force after introducing a cyclic loading history on the specimen equivalent to a seismic action, according to the European Convention for Constructional
Steelwork, Technical Working Group 1.3. in “Recommended Testing Procedure for Assessing the behavior of Structural Steel Elements under Cyclic Loads”, document no. 45, which “is a reference way to carry out and interpret tests, intending to cover the lack of such reference in European countries and most of other countries” [5]. The procedure is intended to produce a “unified way to carry out tests” [5]. The author adapted the above mentioned recommendations for the studied sub-assemblages, resulting in the following: two preliminary classical monotonic tests were performed on the specimen in order to find the yield loads in the positive/negative force range and absolute values of displacements in the positive/negative distance range; the third test was a cyclic test with increase of displacement; the fourth test consisted in starting of the furnace and taking the temperature of the specimen to the tested values (see the following report); next, tests three and four were repeated by testing the specimen at different temperatures; fire tests were also done on new specimens (not cyclical acted upon).

4. Reports of all tests
During the first test, according to the programme, the finding of $F_y^+$ and $e_y^+$ was aimed. From this, $F_y^+$ was deduced having the value of 185 kN and $e_y^+$ the value of 80 mm. The second test was aimed to find $F_y^-$, $e_y^-$. The time – force actually obtained curve is given in figure 3. This test consisted in introducing an increasing vertical force on the free end of the cantilever, upwards, until failure of the connection occurs.

![Figure 3. Time – force curve corresponding to second test.](image_url)

The yield load in the negative force range, $F_y^-$ was equal to 196 kN and $e_y^-$ was computed according to the curve from figure 4, its value was equal to 106 mm. The complete failure of the connection at second test is shown in figure 5.

![Figure 4. Displacement – force curve corresponding to second test](image_url)
According to the procedure, with the help of the third test, a cyclic loading history is applied on the specimen. The force is introduced increasingly, the displacement of the free end of the cantilever being controlled to pass through decided cycles. After that, the second part of the third test continued with the introduction of an increasing force downwards, at a steel temperature of 20°C. The deteriorated connection by the cyclic loading and the complete failure of the connection after the second part of the third test is shown in figure 6.

During test four, we followed the introduction of a cyclic loading history on the specimen, deteriorating the connection, after that, heat the connection to 600°C and break the connection by introducing a downwards force on the free end of the cantilever. During the first part, the connection was deteriorated by introducing cyclic loading according to the above mentioned procedure. The displacement – force curve that was obtained is shown in figure 7.
After that, the connection was heated to 600°C and the force was applied downwards until complete failure of the connection occurred (see figure 8).

The displacement – force curve corresponding to the failure of the deteriorated connection, at 600 °C is shown in figure 9.
The fifth test consisted in heating the specimen to 600°C and keeping the temperature constant, introduce an increasing force, downwards, on the free end of the cantilever, until complete failure of the connection. The response of the specimen (that was not previously deteriorated) is shown in figure 10.

![Displacement-force curve for fifth test](image)

**Figure 10.** Displacement-force curve for fifth test

During the sixth test the connection was first deteriorated by cyclic loads. The second part of this test consisted in heating the connection until a steel temperature of 400°C. At that point, keeping temperature constant, an increasing downwards force was applied on the free end of the cantilever until complete failure of the connection (see figure 12). The response of the connection in terms of displacement-force curve is shown in figure 11.

![Displacement – force curve corresponding to test 6 (post-earthquake fire)](image)

**Figure 11.** Displacement – force curve corresponding to test 6 (post-earthquake fire)
The seventh test consisted in heating the connection to a 400 °C temperature of the steel. An increasing downwards force was then applied on the free end of the cantilever until complete failure of the connection. The response of the connection during this test is shown in figure 13.

5. Conclusions
The complexity of modelling the fire behaviour of nodes has concerned a great number of researchers in the last years, as for example Faggiano and Mazzolani [6], Bursi [7] or Puccinotti et al. [8]. Their experimental results referred mainly about moment-rotation relations. All experimental test results and behavior were in accordance with similar tests realized worldwide: in [7,8] post-earthquake fire tests on steel connections that were performed at University of Trento (Italy) (the cyclic actions on the specimen) followed by fire tests at BRE (UK) were presented. In our case, after cyclic action, fire action was immediately applied on the specimen. The results were also in accordance with initial numerical simulations and initial computation following prescriptions of the European design code EN 1993 [2].

References
[1] M. H. Yassin. Post-earthquake fire performance of building structures. Ph.D. Thesis, Concordia University, Quebec, Canada, 2010 (in English)
[2] EN 1993:2005. Design of Steel Structures
[3] T. Petrina, Numerical and experimental analysis regarding fire resistance of structures – PhD Thesis, UT Press, Romania, 2014 (in Romanian);

[4] T. Petrina, D. Muntean, Setting up a test stand for steel beam-to-column connections behavior under post-earthquake fire. Proceedings of the Second international conference for PhD students in Civil Engineering. UT Press, ISSN 2392 – 9693, 2014, pp. 29-38;

[5] ECCS, T.G.W. 1.3, (1985). Recommended testing procedure for assessing the behavior of structural steel elements under cyclic loads

[6] B. Faggiano, F.M. Mazzolani. Methodology for robustness assessment of structures subjected to fire following earthquake through a performance base approach. COST TU0904, 2010

[7] Bursi, O.S., (2008). Prefabricated composite beam-to-concrete filled tube or partially reinforced concrete encased column connections for severe seismic and fire loadings – Final Report RFSCR-03034

[8] Puccinotti, R., Bursi, O.S., Franssen, J.M., Lennon, T., (2011). Seismic-induced fire resistance of composite welded beam-to-column joints with concrete filled tubes. Fire Safety Journal 46:335-347