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# Hammer head beam solution for beam-to-column joints in seismic resistant building frames

Hoang Van-Long *, Jaspart Jean-Pierre, Demonceau Jean-François

*ArGEnCo Department, University of Liège, Belgium*

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ABSTRACT

This paper presents a research on an innovative stiffened extended end-plate joint, used to connect I-shaped beams to partially-encased composite wide flange columns. In the joint, T-shaped hammer heads cut from the same I-profiles than the beams are used, instead of using traditional haunches. At the joint level, the column web is strengthened by two lateral plates welded to the column flanges; these plates also reinforce the column flanges. This type of joint is proposed to use in the seismic resistance building frames, as a full-strength and a fully-rigid joint solution. Firstly, a test program carried out within a RFCS European project titled HSS-SERF "High Strength Steel in Seismic Resistant Building Frames", 2009–2013, will be presented. Then, analytical developments based on the component approach and aimed at predicting the joint response will be described; their validity will be demonstrated through comparisons with the tests. Moreover, a new design concept for full strength joint accounting for the actual position of the plastic hinge and the possible individual over-strength factors for each component is proposed, respecting the requirements of EN1998-1-1.



## 1. Introduction

In order to obtain a full-strength and a fully-rigid solution for bolted extended end-plate beam-to-column joints to be used in seismic resistant building frames, two directions are practically considered: (i) reducing the beam section near the joint (dog-bone beam) or (ii) using stiffeners to reinforce the end-plate parts outside the beam flanges. If the second solution is chosen, the haunches (with or without flanges) are generally used. Researches on the above joint types have been largely carried out in literature, and the design rules are also covered in Eurocodes.

In this paper, a new economical joint configuration is proposed to connect I-shaped beams to partially-encased composite wide flange columns (Fig. 1). In the proposed joint configuration, T-shaped hammer heads cut from the same I-profiles as the beams are used, instead of using the traditional haunches. At the joint level, the column is also strengthened by two lateral plates welded to the column flanges (Fig. 1); the use of these plates allows increasing the resistance of the column web components (in shear, tension or compression) but also the column flange in bending component.

In comparison with the joint solutions using haunches, the following advantages can be pointed out for the hammer head joint solution: (1) the use of hammer head allows a good load transfer from the beam to the joint zone and so avoids local compression in the beam web which appears with haunches (at the intersection between the haunch flange and the beam); (2) the use of hammer heads directly cut from the beam profile simplifies the fabrication procedure and leads to cost saving; (3) the capacity of the hammer head components can be multiplied by the over-strength factor as they are cut from the beam profile where the over-strength factor is applied, which will induce some economies in the design process. The observation reported in point (1) regarding the load transfer at the joint level has been demonstrated through the experimental tests conducted within the HSS-SERF project [1]; these tests will be presented in Section 2. Also, regarding the remark reported in point (2) on the economical fabrication process, a technical and economic evaluation was carried out for several types of joints in [1]: joint using long bolts, joint with external diaphragm, joint with rib stiffeners, and joint with hammer head beams. The conclusion was that the hammer head joint is the best solution. Finally, regarding point (3), detailed explanations will be given in Section 4 of the present paper.

However, the design of the proposed joint is not presently covered in Eurocodes and in literature, as the joint involves some new components. Therefore, analytical developments were realized in order to propose a full design procedure useful for practitioners and in full agreement with the component method which is the design method recommended in Eurocodes for the characterization of joints.

The present paper summarizes the researches on the proposed joint configuration, from the experimental tests to the development of the design procedure. In Section 2, the results of the tests on the proposed joint configuration will be reported. Section 3 will deal with the analytical development based on the component method. Section 4 is

* Corresponding author.
*E-mail addresses:* s.hoangvanlong@ulg.ac.be (H. Van-Long), jean-pierre.jaspart@ulg.ac.be (J. Jean-Pierre), jfdemonceau@ulg.ac.be (D. Jean-François).

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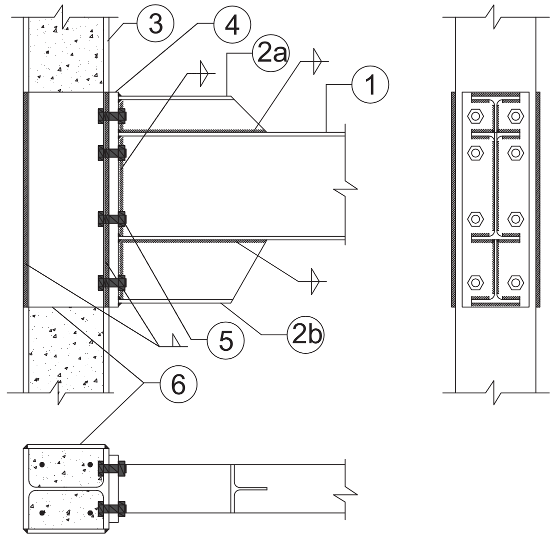


**Fig. 1.** Proposed joint configuration.

dedicated to the validation of the proposed models through comparisons to the experimental results. How to take into account for the actual position of the plastic hinges and individual component over-strength factors to satisfy the full-strength requirement from EN1998-1-8 dedicated to the seismic design of buildings will be the content of Section 5. Section 6 is finally devoted to the concluding remarks.

## 2. Experimental results

A test program was defined and performed on the proposed joint configuration within the HSS-SERF project; details about the performed tests and the obtained results can be found in [2]. All the joints were designed to be full strength ones, meaning that the plastic hinges should develop in the beam, more precisely in the cross-sections close to the hammer head ends. Within the test program, two categories of tests were defined: (1) prequalification tests for which the "actual" specimen configuration, i.e. the configuration which would be met in a building structure, were used and for which the plastic hinges occurred at the beam sections close to the hammer head ends; and (2) joint characterization tests for which the beams were strengthened so as to force the failure at the joint level and to obtain the complete behavior of the joint. Within the present paper, the joint characterization tests will be described as only these tests are used to validate the joint design procedure.

The specimen geometries and materials are presented in Table 1 and Fig. 2. Test A1 was defined to evaluate the resistance of the hammer head zone while tests A2 and B1 aim at characterizing the connection resistance under hogging and sagging moments respectively. Obviously, the elastic stiffness of the specimens can be recorded from the three tests. The HEB320 columns used for specimens A1 and A2 are made of S460 steel while the column HEB260 column in specimen B1 is made of high strength steel S690, to investigate the possibility of using high strength steel in seismic resistant building frames, but this aspect is not dealt with in the present paper.

The used testing set-up is presented in Fig. 3. A fixed hinge at the bottom and a hinge allowing a vertical displacement at the top are used at the column extremities. Possible displacements of the hinges have been anyway recorded during the tests. A vertical load is applied at the free end of the beam introducing a bending moment and a shear force in the joints. Lateral supports on the beam length have been placed to avoid the lateral torsional buckling of the beam during the tests.

**Table 1**
Description of the tested specimens (Fig. 2).

| Tests | Column | Beam | Lateral plates | Reinforcement degree | Loading type |
|---|---|---|---|---|---|
| A1 | HEB320 | IPE400 | 800 × 290 × 15 | Partial reinforcement (a = 350 mm—Fig. 2) | Hogging moment |
| A2 | HEB320 | IPE400 | 800 × 290 × 15 | full reinforcement (a = 50 mm—Fig. 2) | Hogging moment |
| B1 | HEB260 | IPE400 | 800 × 230 × 15 | full reinforcement (a = 50 mm—Fig. 2) | Sagging moment |

C30/37 concrete is used for all specimen; S355 steel is used for the beams and the end-plates; S460 steel is used for the HBE320 column and the associated lateral plates; S690 steel is used for the HEB260 column and the associated lateral plates; M30 10.9 bolts are used.
The filet welds of 5 mm is used to connect the hammer head web to the beams and the beam/hammer head webs to the end-plate, while the beam and the hammer head flanges are attached to the end-plate through filet welds of 8 mm.
The reinforcement degree is used to obtain the difference failure modes, aiming to characterize the difference components.