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Experimental evaluation of 3D steel joint with loading in both axis

Loureiro, Alfonso[1]; López, Manuel[2]; Reinosa, José Manuel[3]; Gutiérrez, Ruth[4];

ABSTRACT

The current European standard of steel structures (Eurocode 3) establishes the necessity of taking into account the rigidity and resistance of joints in the overall calculation of the structure. This normative uses the method of the components for obtaining the elastic characteristics of the joints, as rigidity and resistance. In the case of 3D joints the comportment of one of the axis is influenced by the loads in the other one. The level of stress in the minor axis influences the rigidity of the major axis, and vice versa.

In the present work, two tests of an external 3D joint with additional plates in the weak axis is conducted, and the influence of the weak axis loading in the major axis stiffness is evaluated. The moment-displacement curves for the major axis are shown, and the values of global initial stiffness in both tests are compared.

Keywords: 3D joints, experimental evaluation, interaction between minor and major axis.

1. INTRODUCTION

Conventional design of steel frameworks is usually carried out under the assumption that joints are either fully rigid or ideally pinned. Modern design codes recognise the concept that the actual joints exhibit a behaviour that is intermediate between these two extreme cases. Eurocode 3 (EC3) [1] includes procedures and formulations to define both the stiffness and resistance of the semi-rigid joints starting from their geometrical and mechanical properties.

The rotational behaviour of the joint can be described by means of the in-plane moment-rotation curve. This curve defines three main properties: rotational stiffness, moment resistance and rotation capacity. Many studies are aimed at obtaining these moment-rotation curves or the associated properties so that they can be incorporated into the global frame analysis. Three main approaches may be followed: experimental, numerical and analytical.

EC3 provides an analytical procedure, called component method, which allows one to evaluate the stiffness and resistance characteristics of the joint by assembling all the constitutive components. In recent years, contributions to this research field have been continuous, but this method is not applicable for characterizing the comportment of three dimensional joints, and so, the effort in this new research field is growing. Cabrero and Bayo [2, 3] have studied the comportment of 3D joins under proportional loading. Loureiro et al. [4] have presented experimental and numerical results of 3D joints under non-proportional loading. The stiffness and resistance of E-stubs in 3D joints have been analysed

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by Loureiro et al. [5, 6]. Gibbons et al. [7] have presented the results of experimental results of 3D semirigid steel joints, and Costa et al. [8] have made experimental tests of 3D joints with beam to column bolted connections.

Unfortunately, all the works in the 3D researching leads to the conclusion that the component method established in the current version of EC3 is not able to have account for the interaction between the loading level in both axes in the case of 3D joints as those studied in this work. So, with the aim of evaluating the influence of the loading in minor axis on the global stiffness of the major axis, this paper presents the results of the experimental tests of two 3D joints with additional plates in the weak axis. The paper shows the influence of the loading in the minor axis of the joint on the stiffness of the major axis, by means of the moment-displacement curves.

2. EXPERIMENTAL RESEARCH

2.1. Description of the tests

This experimental investigation comprises two tests of the three-dimensional joint proposed in Figure 1. The three-dimensional joint analysed in this paper is characterized by the presence of the additional plates in the weak axis. The additional plates act as stiffeners for the major axis joint and contributes to the resistance of the column web in tension, compression and shear. As it can be observed, the major and minor axis connections consist of extended end-plates. The minor axis connections are bolted to the additional plates welded to the column flanges.

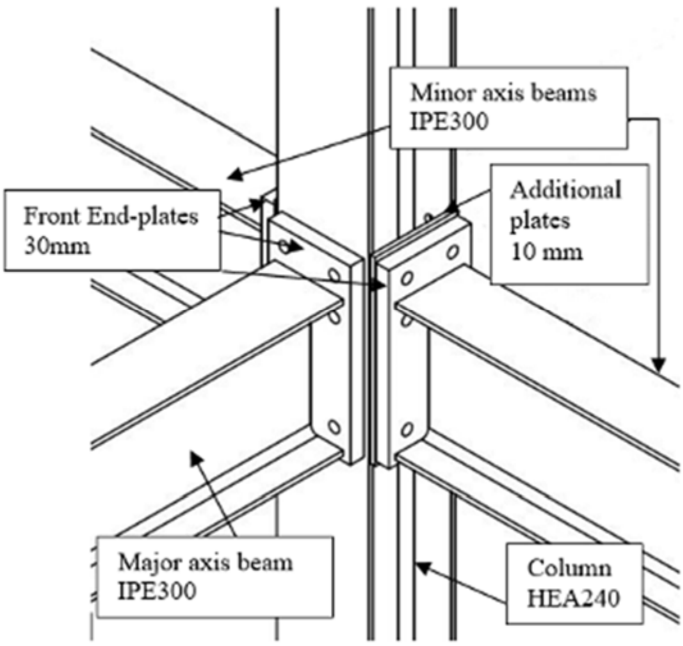

Figure 1. *3D joint configuration.*

The specimen are based on IPE and HEA hot rolled sections. Both minor and major axis connections consist of IPE 300 section beams connected to a HEA 240 column using extended end-plates and two tensile bolt rows. The additional plates of the minor axis are 10 mm thick. End-plates of the beams are 30 mm thick in all cases, with the objective of assure that they have a very high stiffness. TR16 bolts of quality 10.9 in clearance holes are employed. The bolts are designed as bearing type, category D in EC3; thus, they are hand-tightened up to a torque value of 125 Nm (approximately 30% of that required for preloaded bolts) to ensure the snug-tight condition.

The geometry of the tested frame is shown in Figure 2. The column is fixed supported at both ends and the load is applied to the free end of each beam. The distance between the loading point in the beams and the column is 1 meter. The instrumentation comprises displacement sensors and load cells with the aim of evaluate the global moment-displacement relationship of the major axis of the frame. The displacement sensors are located exactly under the loading points. All instrumentation is connected to a System 7000 data acquisition equipment controlled by StrainSmart® software. A detail of the displacement sensors and load cells can be seen in Figures 3 and 4 respectively.

Hot rolled sections and plates are specified in grade S275 steel. The material properties of the different elements of the tested frame are shown in Table 1.

Table 1. Mechanical characterization of materials

element	E(N/mm^2)	f_y(N/mm^2)
HEA240	208000	301
IPE300	208000	312
Additional plates	209000	296
Front plates	209000	287

Figure 2. *Test arrangement of the joint*

The aim of the tests is to see the influence of the minor axis loading in the behaviour of the global major axis stiffness for the joint configuration shown in Figure 2. Two test have been done. In the first one (Test 01), the major axis is loaded until a maximum load of 40 KN, without loading in the minor axis. In the second one (Test 02), firstly symmetrical loading (30 KN) is applied in both beams of the minor axis and then the load in the major beams is increased again until 40 KN, while the minor axis remains loaded. These values of loading in both axis have been evaluated from the results provided by a previously developed numerical model, with the aim of assuring that both axis remains in the elastic zone, and no plastic deformations appear in the joint. As said before, this loading procedure allows us to determine the influence of the minor axis load in the initial global stiffness of the major axis.

Figure 3. *Detail of the displacement sensors.*

Figure 4. *Detail of the load cells.*

2.2. Tests results

As explained above, two tests have been developed. In both tests, the important measurements are the level of loading in both axis, and the vertical displacement of the major axis beam just under the loading points. The tests are symmetrically loaded and so the mean value of both displacements of the beams has been calculated. The hydraulic cylinders have exactly the same internal pressure, and so, the lectures of their loading forces are the same. The global initial stiffness values of the strong axis have been obtained by means of the moment-vertical displacement relationship.

Figure 5 shows the moment-displacement curve of the mayor axis beam in the Test 01, in which the minor axis remains unloaded. Figure 6 shows the moment-displacement curve in the Test 02, when the minor axis has been previously loaded until 30 KNm. The graphics show the initial stiffness values, Sj,ini, obtained through linear regression analysis of the curves.

Table 2 shows the initial stiffness values of the major axis in both tests, and the relation between them. It can be seen that the rigidity of the strong axis increases when the minor axis is loaded. In this case, the increment of the major axis stiffness is about 1.77 %. From previous FEM analysis, it can be said that this stiffening effect is primarily due to the tensioning effect of the column flanges by the load acting on the minor axis. Figures 7 and 8 show the complete finite element model of the frame and a detail of the deformed shape and Von Misses stresses in the joint when both axis are loaded.

Table 2. Stiffness comparison

	Sj,ini (KNm/mm) Test 01	Sj,ini (KNm/mm) Test 02	Δ Sj,ini (%)
External frame	8.6618	8.8151	1.77

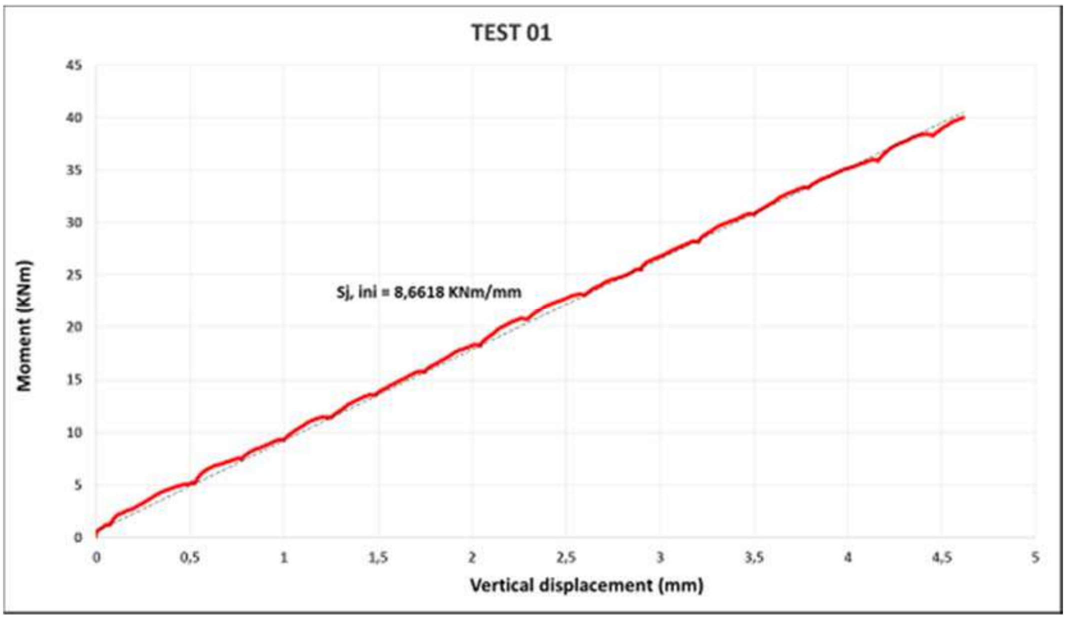

Figure 5. *Moment-Displacement diagram for major axis without loading in the minor axis.*

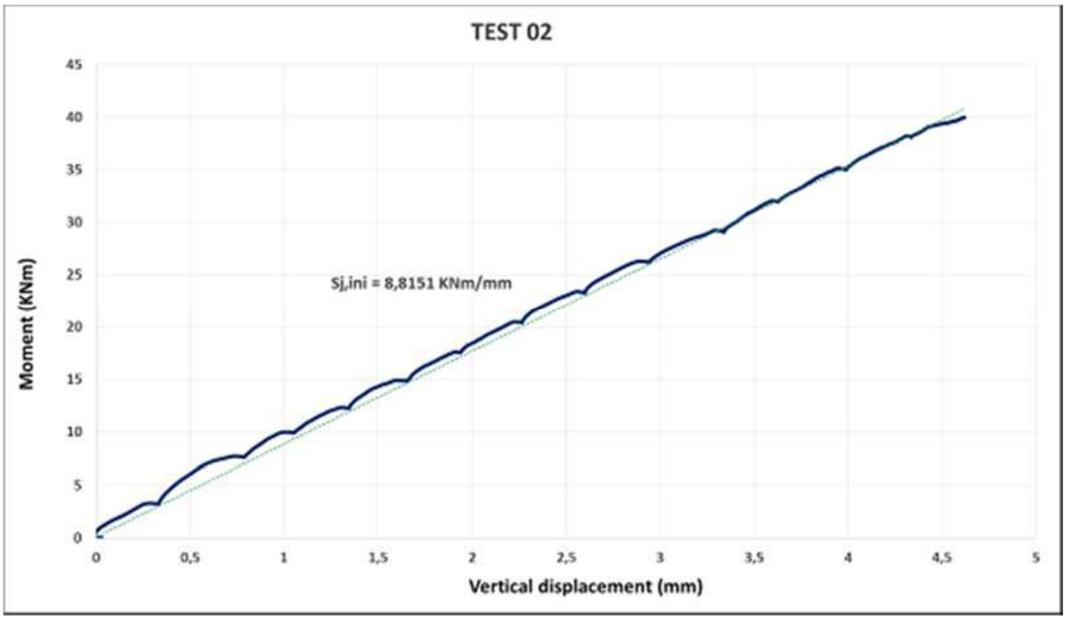

Figure 6. *Moment-Displacement diagram for major axis with loading in the minor axis.*

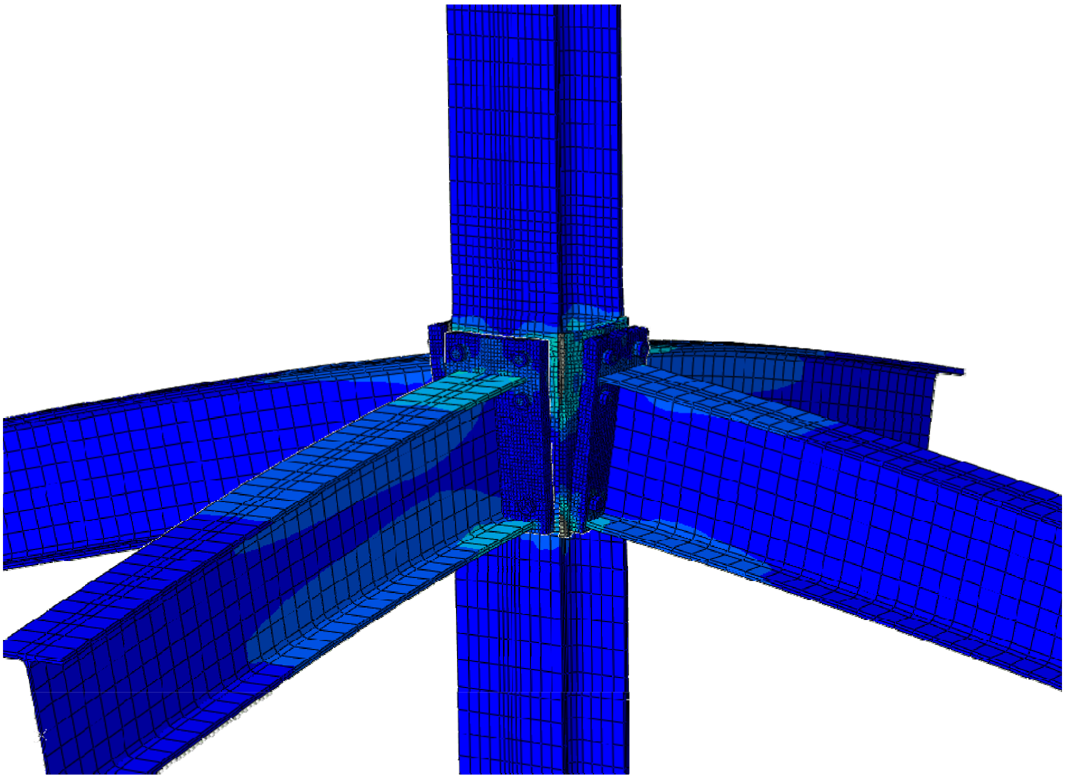

Figure 7. *Complete FEM of the joint.*

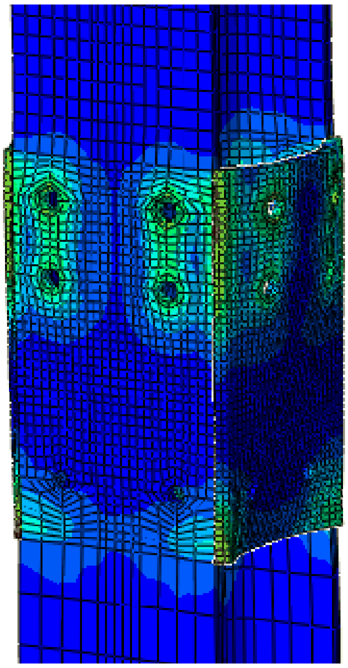

Figure 8. *Detail of the deformed shape and Von Misses stresses in FE model of the joint.*

3. CONCLUSIONS

This paper focuses on the experimental study of a type of three-dimensional node with semi-rigid joints in both axes. Both the major and minor axis connections consist of extended end-plates, and the connection of the weak axis is made by additional plates welded to the flanges of the column.

The proposed joint has been studied by means of experimental tests in order to analyse the behaviour of an internal frame configuration, as well as to assess the interaction between minor and major axes; that is, the effect of the minor axis load on the initial global stiffness of the major axis of the joint.

Experimental results show coupling effects between the major and minor axis joints. The minor axis load stiffens the column flanges in bending and the additional plates in tension. This results in an increase of the initial stiffness of the major axis joint that should be accounted for in the global analysis of the structures. But further research is needed with the aim of quantify the increment of the major axis stiffness versus the level of loading in the minor axis. The objective is to obtaining calibrated FEM with the aim of carrying out a parametric study with the aim of including the stiffening effect due to the additional plates and the interaction of both axis for components like the column flange in bending and the system formed by the column web and the additional plates in tension, compression and shear. The results of this study will be used for a posterior metamodeling of the joints by means of Kriging method and/or Neuronal networks.

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