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

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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 problem of determining the components comportment, is more complex, because the comportment of the components of the joint in 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. In the first one the major axis is loaded while the minor axis remains unloaded. In the second test, the minor axis is loaded and the load in the major axis is applied while the minor axis remains loaded, and then, the influence of the weak axis loading in the major axis stiffness is evaluated. Along this loading process, measurements of displacement sensors and load cells are carried out. In this work, the tests are conducted in the elastic range, in order to determine the global elastic stiffness of the strong axis. The moment-displacement curves for the major axis are shown, and the values of global initial stiffness in both tests are compared.
These results of the tests will be used in future works for calibrating the FEM model of the joint. This work will allow a parametric analysis with the aim of characterizing the different parameters that influence the interaction between major and minor axis in the 3D joints.

Key-Words: - 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 in the 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 those of all the constitutive components. In recent years, contributions to this research field have been continuous. Some research studies focus on determining the stiffness and resistance characteristics of the 3D joints [2-4], while other works focus on obtaining models to calculate the rotation and resistance characteristics of the T-stub [5-7] and the E-stub [8, 9].
Unfortunately, the component method established in the current version of EC3 does not allow the calculation of minor axis joints or three-dimensional joints such as that considered in this paper. Moreover, the formulations do not include the interaction between both axes.
This paper presents the experimental investigation carried out on two 3D joints, with the aim of evaluating the influence of the loading in minor axis on the global stiffness of the major axis.

2 Experimental research

2.1 Description of the test

This experimental investigation comprises two tests of the three-dimensional joint proposed in Fig. 1. The three-dimensional joint analyzed 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 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.

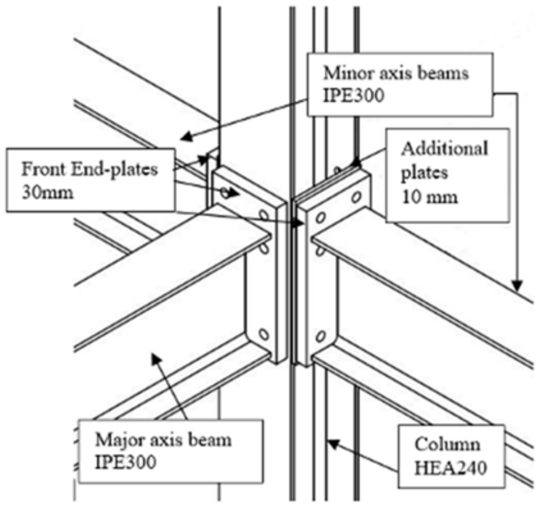

Figure 1. 3D joint configuration.

The specimen are based on IPE and HEA hot rolled sections. Both minor and major axis connections consist of IPE300 section beams connected to a HEA240 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 Fig. 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 Figs. 3 and 4 respectively.

Hot rolled sections and plates are specified in grade S275 steel. The material properties are shown in Table I.

Table 1. Elastic materials properties

specimen	E (N/mm^2)	Fy (N/mm^2)
HEA 240	208000	301
IPE300	208000	312
Additional plates	209000	296
Front plates	209000	287

Figure 2. Test arrangement of the external 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 external frame joint configuration shown in Fig. 2. Two test have been done. In the first test (T01), the major axis is loaded until a maximum load of 40 KN, without loading in the minor axis. In the second test (T02), firstly symmetrical loading (30 KN) is applied in both beams of the minor axis and then the load in the major beam 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 major axis initial global stiffness.

Figure 1. Detail of the displacement sensors

Figure 2. Detail of the load cells

2.2 Tests results

As explained above, two tests have been developed. In both tests, the important measures are the level of loading in both axis, and the vertical displacement of the major axis beam just under the loading point. These values have been obtained, and they are discussed in this section. The global initial stiffness values of the strong axis have been obtained by means of the moment-vertical displacement relationship.

Fig. 5 shows the moment-displacement curve of the mayor axis beam in the first test (T01), in which the minor axis remains unloaded. Fig. 6 shows the moment-displacement curve in the second test (T02), 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 II 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 17.7%. 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 FEM and a detail of the deformed shape and Von Misses stresses in the joint when both axis are loaded.

It is not possible to establish the comparison between the stiffness values obtained from tests and the theoretical values provided by EC3, because these latest ones do not take into account the stiffening effect due to the additional plates and the load acting on the minor axis.

Table 2. Stiffness comparison (KNm/mm)

	Sj, ini (T01)	Sj, ini (T02)	ΔSj, ini (%)
External frame	8.3318	8.8151	17.7

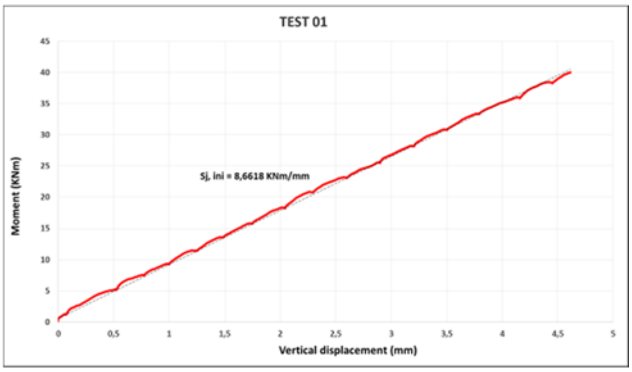

Figure 5. Moment-Displacement diagram for major axis with no loading in the minor axis

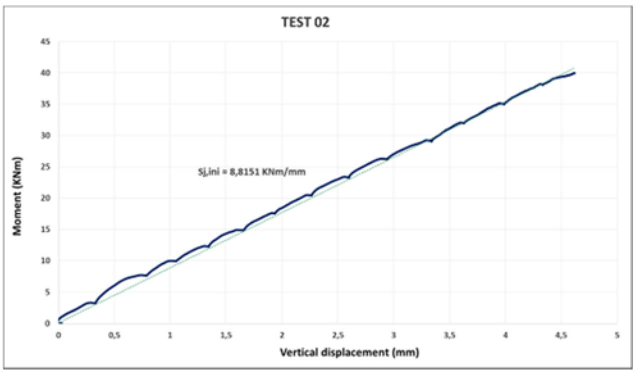

Figure 6. Moment-Displacement diagram for major axis with loading in the minor axis

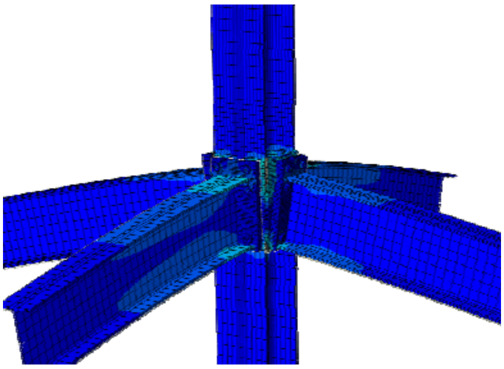

Figure 7. Complete FEM of the joint

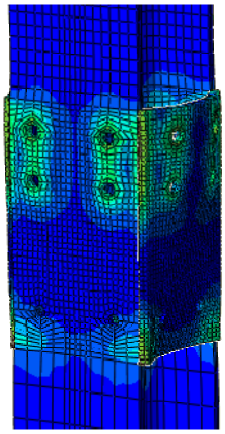

Figure 8. Detail of the deformed shape and Von Misses stresses in FE model of the joint

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