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Experimental Research and Finite Element Modeling of 3-D Semi-Rigid Composite Joints under Proportional Loads

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Abstract

The behaviour of 2-D composite semi-rigid joints has been researched since the seventies, including experimental work, numerical models, analytical models and practical methods of analysis. However, one of the areas where research is still needed is in the three-dimensional behaviour of semi-rigid composite joints, that is, columns with beams attached to both axes (major and minor axis).

This paper describes the details and the results of an experimental program consisting in a test of a 3D composite semi-rigid joint. The design of major axis connection is made with a bolted flush end plate connection while that of the minor axis is done by means of an additional plate welded to the column flanges, rather than attach it to the column web. The specimen is subjected to proportional loads, and further research will be done with non-proportional loads.

A finite element (FE) model is developed and validated using the experimental results. The FE model will be used to perform a parametric study for three-dimensional semi-rigid composite joints subjected to proportional and non-proportional loads in a future research.

Keywords: three-dimensional semi-rigid composite joints, experimental, FEM

1. Introduction and objectives

The behavior of semi-rigid joints is being widely investigated, especially in the context of the Eurocodes 3 for steel joints and Eurocode 4 for composite joints. These codes do not provide either rules or information on the behaviour of 3D semi-rigid joints and/or the connections of beams to columns in the weak axis. Regarding this issue, some authors have done research on minor axis steel joints directly attached to the column web (Costa Neves et al. (2003), Costa Neves et al. (2005)). Recently, Cabrero & Bayo (2007a,Cabrero & Bayo (2007b) have proposed a new solution for minor axis steel joints, investigated and tested the three dimensional behaviour of coupled 3D steel joints. Regarding the composite joints, Green et al. (2004) have tested and presented results on some full scale three-dimensional partially-restrained composite joints under dynamic loads. Rassati et al. (2004) have presented some discussions about the modeling of these joints in the companion paper.

The aim of this paper is to provide more insight into the three-dimensional behaviour or semi-rigid composite joints. For this purpose, a 3D semi-rigid composite joint is proposed and tested. The results obtained are presented and then used to validate a FE model which will be used in a parametric study and also to develop analytical expressions to define the 3D behaviour.

2. Prototype description

The experimental program consists on one test on three-dimensional semi-rigid composite joint subjected to proportional loads. Further research will be carried out on joints subjected to non-proportional loads. The choice of geometry and materials has been made in accordance with Eurocodes 2, 3 and 4 (CEN (2002), CEN (2003), CEN (2004)).

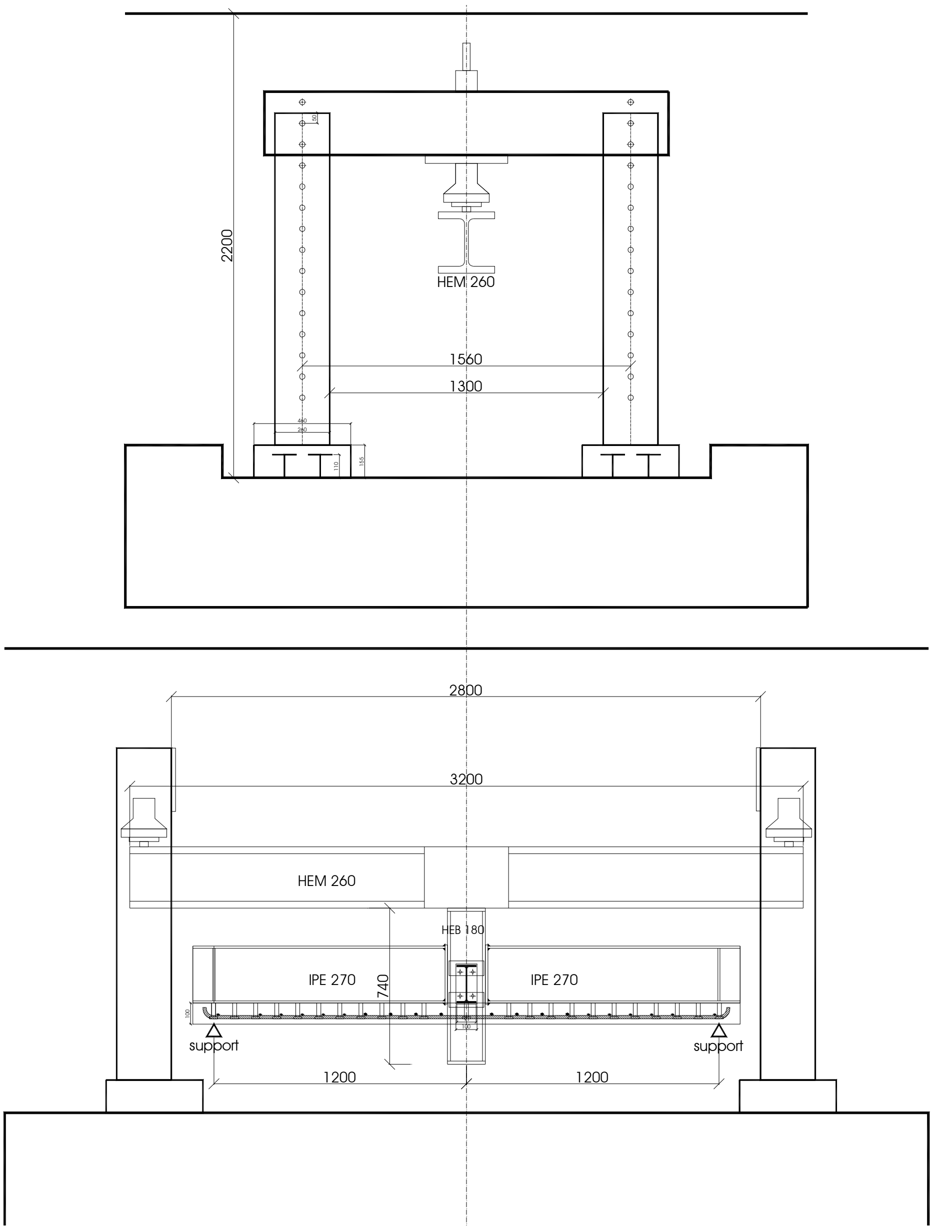

Figure 1: Test Configuration

The specimen consists on a 3D semi-rigid composite joint, that is, a column with composite beams attached to both the strong and the weak axis. The strong axis connection is carried out by means of a bolted flush end plate with the central rebars of the slab passing through the column flange as explained in Gil & Bayo (2008a), Gil & Bayo (2008b). The weak axis connection is materialized by means of an additional plate welded to the column flanges, rather than attaching the beam to the column web. This system was previously developed and tested in Cabrero & Bayo (2007a) for steel joints.

The loading pattern and test configuration are shown in Figure 1. The specimen is placed face down and the load is applied to the top of the column. The end of each beam is supported on a load cell that measures the corresponding reaction in that support. Since the length of the beams in every axis is the same, the specimen is symmetric and the applied loads are proportional.

Regarding the instrumentation, the load is introduced in the top of the column by means of two hydraulic jacks that feature 400 kN each. The reactions in the beams are measured with load cells with a limit of 200 kN. Two inclinometers are placed in the weak axis beams, close to the column; the third is placed in one of the strong axis beam and the fourth in the column web. A displacement transducer is used to measure the deflection at the bottom of the column and finally, strain gages are placed in the relevant components of the joint in order to obtain qualitative information on the sequence of the yielding process.

The load is applied in two stages. In the first one, the column is loaded progressively up to 200 kN and then is completely unloaded. In the second stage, the specimen is loaded progressively until failure.

3. Experimental results

The tested joint shows a nonlinear behavior at early loading stages, as it is shown in the column load- deflection curve of Figure 2. This is due to the small tensile strength of the concrete whose cracks spread and grow with increased loading. The total load applied in the column is greater than 500 kN and the column deflection reaches almost 60 mm.

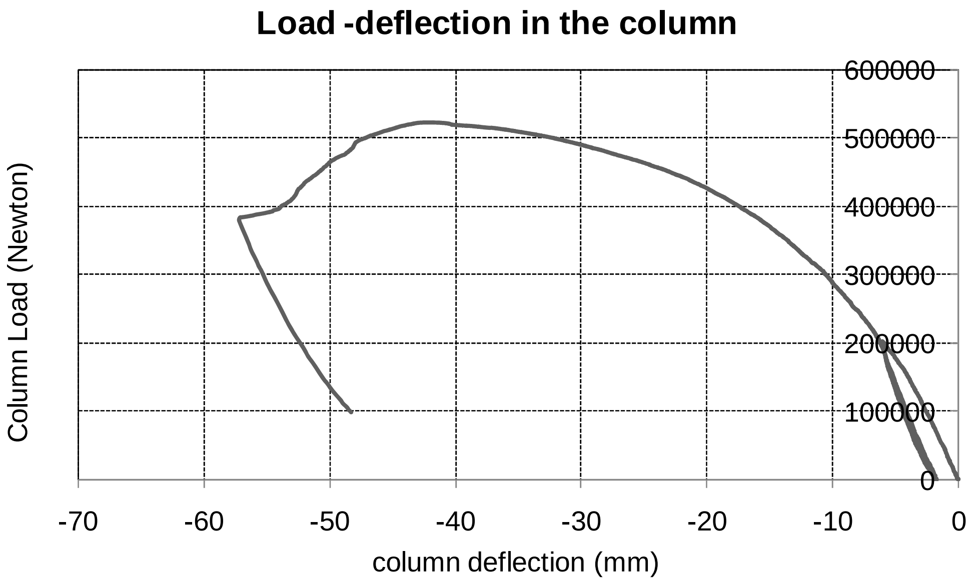

Figure 2: Column Load-deflection curve

Figure 3 shows the moment-rotation curve for a major axis joint and the minor axis ones. It can be seen that the maximum moment in the major axis joint is around 150 kNm and the maximum rotation reached 30 mrad. There are several steps at the end of the curve, due to the yielding of the components. The complete collapse of the joint is produced when suddenly a shear stud is broken due to the longitudinal shear. Previously, the additional plate in compression, the column web in compression and the rebars of both, the strong and weak axis, have yielded. The minor axis joints reach a moment of around 40 kNm and a rotation of 50 mrad, thus showing a quite ductile behavior.

When the specimen fails, there are two components in the minor axis which have yielded: the additional plate in compression and the reinforcement. The rest of the components in this axis remain in an elastic range.

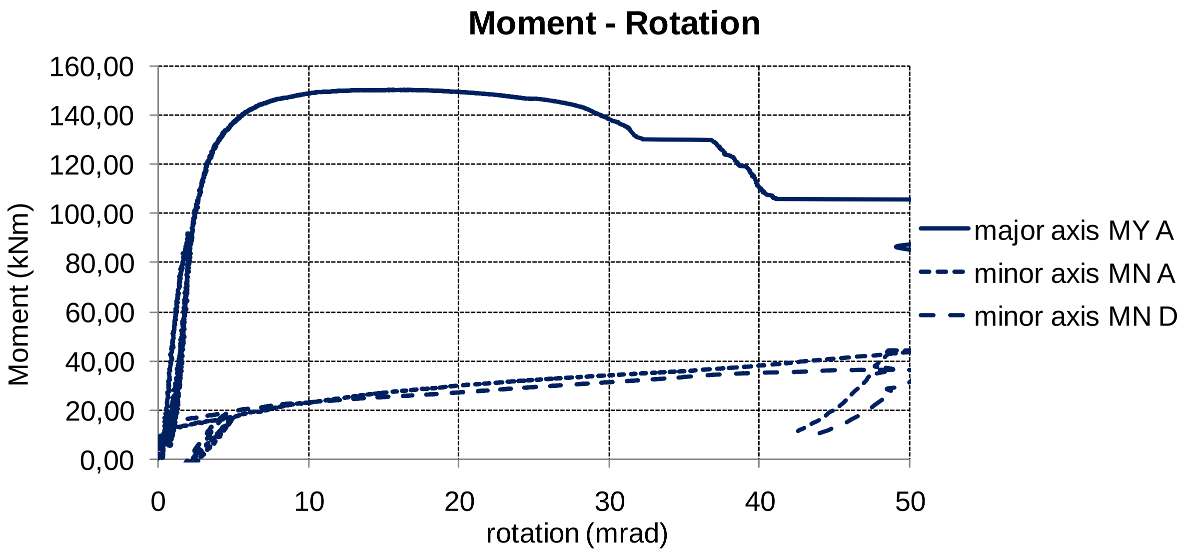

Figure 3: Moment-Rotation curves

4. Finite element model

4.1 Geometry and definition of the elements

A finite element model is developed by means of the ABAQUS program (2008).The three-dimensional FE model (Figure 4) has the configuration and dimensions of the tested specimen. The specimen has been modeled without the use of symmetry because it will be more useful to have the complete model for a future parametric study with non-proportional loading.

The concrete slab, the slab reinforcement, the steel beams and column, the bolts and even the shear studs are modeled with 8-node solid elements with incompatible modes (C3D8I).

4.2 Interactions, boundary conditions, materials and analysis

The interactions between the different materials are modelled in the following way:

The reinforcement and the shear studs are embedded in the slab. This technique eliminates the translational degrees of freedom of the embedded nodes and makes them correspond with those of the host element.

Surface to surface contact interactions are defined between the end plate and the column flange. The bolt head and the nut are tied to the plates to simplify the interaction between them, since those parts are not going to separate.

The materials chosen for the finite element model are the same as those in the specimen: S275 for structural sections and plates, B500SD for reinforcement, C30 for the concrete, and the shear studs with strength of 450 N/mm2.

A non-linear analysis is carried out using the arc length method (Riks) for the loading increments, which allows us to monitor possible drops in the load displacement and stress-strain curves.

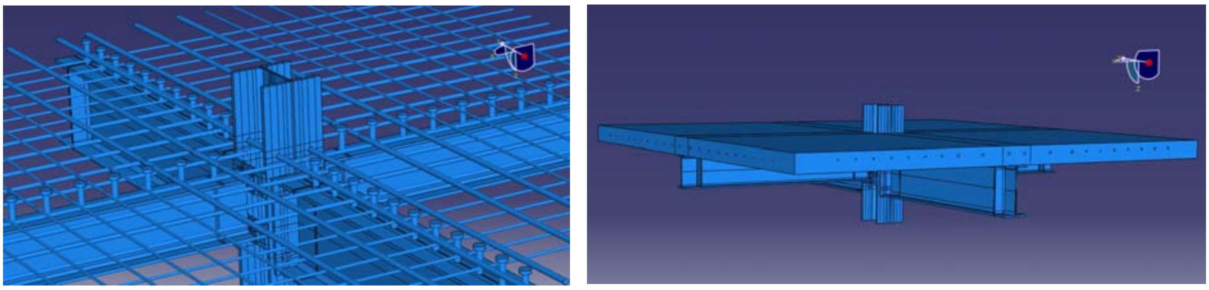

Figure 4: Finite element model

4.5 Comparison with experimental results and model validation

Figure 5 shows the comparison between the column load-deflection curve obtained with the FE model and that obtained from the test. The FE model predicts with good accuracy the behaviour (stiffness and strength) of the 3D composite joint, except for the rotation capacity. Thus, it will be used in the parametric study which will help to develop analytical models to determine the main characteristics (stiffness and strength) of this type of joint.

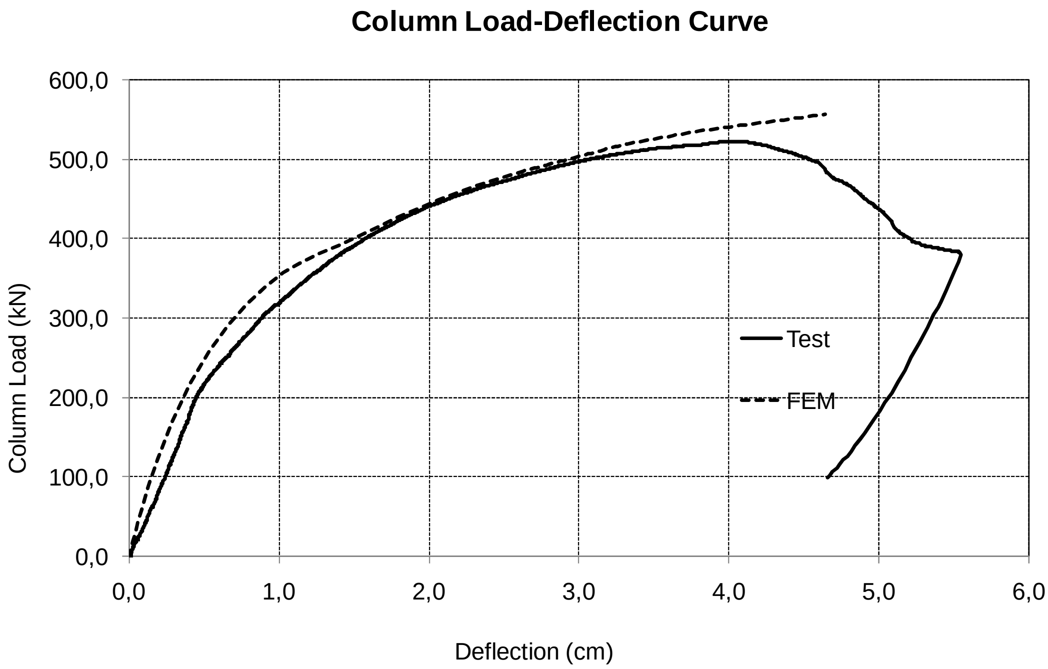

Figure5: Comparison between the FE model and the test

5. Conclusions

A design for three-dimensional semi-rigid composite joint is proposed and tested under proportional loads. The strong axis connection of the proposed joint is carried out by means of a bolted flush end plate with the central rebars of the slab passing through the column flange. The weak axis connection is materialized by means of an additional plate welded to the column flanges, rather than attaching the beam to the column web. The results obtained are analyzed and shown. The proposed joint shows a good behaviour which satisfies the EC3 rotation requirement of 30 mrad.

The experimental results are used to validate the complete FE model that represents the tested joint. The moment-rotation curve which is obtained is adjusted with quite accuracy to that of the tests, except for the rotation capacity, due to the fact that the FE model is not capable of capturing the concrete failure properly. Despite of this, the FE model is still valid to predict the stiffness and strength of this type of joint, and it will be used eventually in a parametric study and to further research the characteristics of these joints.

6. Acknowledgements

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