Advanced FE models of stiffened cleat angle connections

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ABSTRACT

In this paper, the development of reliable 3D FE models of stiffened angle connections is dealt with. These advanced models will permit to obtain the assessment of the 3D deformational response of some future tests. *Abaqus®* finite element code was used to carry the 3D finite element analyses out. Symmetry was considered for these numerical analyses so a quarter of the geometry was modelled. The results obtained are compared with those from the analysis of the analogous specimens but without the top angle stiffener, showing an important increase in the initial connection stiffness. At the same time, the stress increment in the column panel zone due to the presence of the angle stiffener has been discussed.

Keywords: Finite Element, Numerical Model, Semi-rigid Connections, Steel Construction, Angle Connections

1. INTRODUCTION

It is a fact that all connections used in current steel construction possess stiffness which fall between the extreme cases of fully rigid or ideally pinned joints. The characterization of the real semi-rigid behavior of connections must be properly modeled in order to reliably predict the response of the frame. The use of bolted angle cleat connections is characterized by substantial economic benefits, essentially due to the ease in the erection process [1]. On the other hand, the analysis of the effects of some of the last devastating earthquakes have pointed this typology out as more suitable for seismic design than welded connections [2]. The initial stiffness of angle connections could be increased by introducing stiffeners in the joint design [3, 4, 5].

In this paper, the development of reliable 3D FE models of stiffened angle connections is dealt with. These advanced models will be used to obtain the assessment of the 3D deformational response of some angle connection tests which will be carry out in the future. On the other hand, the effect of the stiffener can be carefully observed in these numerical models and be included afterwards in analytical proposals [4].

2. SPECIMENS CONSIDERED IN THE STUDY

The specimens geometry was composed of a HEA 300 column, IPE 240 beams, L100x10 web angles, hand tightened grade 10.9 M20 bolts and, finally, top angles L120x90x8 with 8 mm-Stiffener (Model *TA8S8*), L120x90x8 with 10 mm-Stiffener (Model *TA8S10*), L120x90x10 with 8 mm-Stiffener (Model *TA10S8*) and L120x90x12 with 8 mm-Stiffener (Model *TA12S8*). The seat angles were made of the same profile as the top angles but without stiffener. A summary of the specimen characteristics can be observed In Table 1.

Table 1. Specimen Characteristics

Model	**Thickness (mm)**	
	Stiffener	**Angle**
TA8S8	8	8
TA8S10	10	8
TA10S8	8	10
TA12S8	8	12

3. FE MODEL DESCRIPTION

Abaqus® finite element code was used to carry the 3D finite element analyses out. Symmetry was considered for these numerical analyses so a quarter of the geometry was modelled. The models were discretized using C3D8I eight node brick elements with full integration, incompatible modes and second order accuracy. Contact between all parts was included with a friction coefficient of 0.3, by using the general contact algorithm of *Abaqus®*. The stiffener and the cleat angle were connected by means of tie constraints. The material properties introduced in the FE models are those provided by the manufacturer. Additionally, the washers were modelled as isolated elements, so that appropriate interactions between components may be developed. The bolts were modelled as elastic components in order to avoid convergence problems. To achieve the "snug tight" condition, little pretension has been applied to the bolts by means of a thermal load applied to the bolt shank. The thermal decrease is calculated by means of the next equation, which disregards the head bolt deformation:

$$\Delta T = \frac{1}{\alpha}\left[\varepsilon_{sh} - \frac{\sigma_p}{E}\right] \quad (1)$$

Where σ_p is the preloading tension in the bolt, α is the coefficient of thermal expansion, E is the modulus of elasticity and ε_{sh} is the bolt shank deformation that can be expressed as:

$$\varepsilon_{sh} = \frac{-A_{sh}\sigma_p}{EA_a} \quad (2)$$

Where A_a is the annulus area (the effective contact area between the bolt head and the plates), and A_{sh} is the bolt shank area:

$$A_a = \frac{\pi\left(d_{bh}^2 - d_{sh}^2\right)}{4} \quad (3)$$

$$A_{sh} = \frac{\pi d_{sh}^2}{4} \quad (4)$$

Where d_{bh} and d_{sh} are the bolt head diameter and the bolt shank diameter, respectively.
Considering that the unthreaded part of the bolt is generally larger than the threaded part, the nominal value of the bolt shank diameter will be introduced in Equations 3 and 4 in accordance with the bolt geometry related to the FE model.
A uniform prescribed displacement was applied to the model by means of a rigid surface connected to the beam end. The analyses were carried out through a quasi-static process using the explicit solver of *Abaqus®* package. Figure 1 shows a deformed configuration of *TA12S8* model with a representation of the vertical displacements field. The meshing of the different components can be observed in the detailed on the right side.

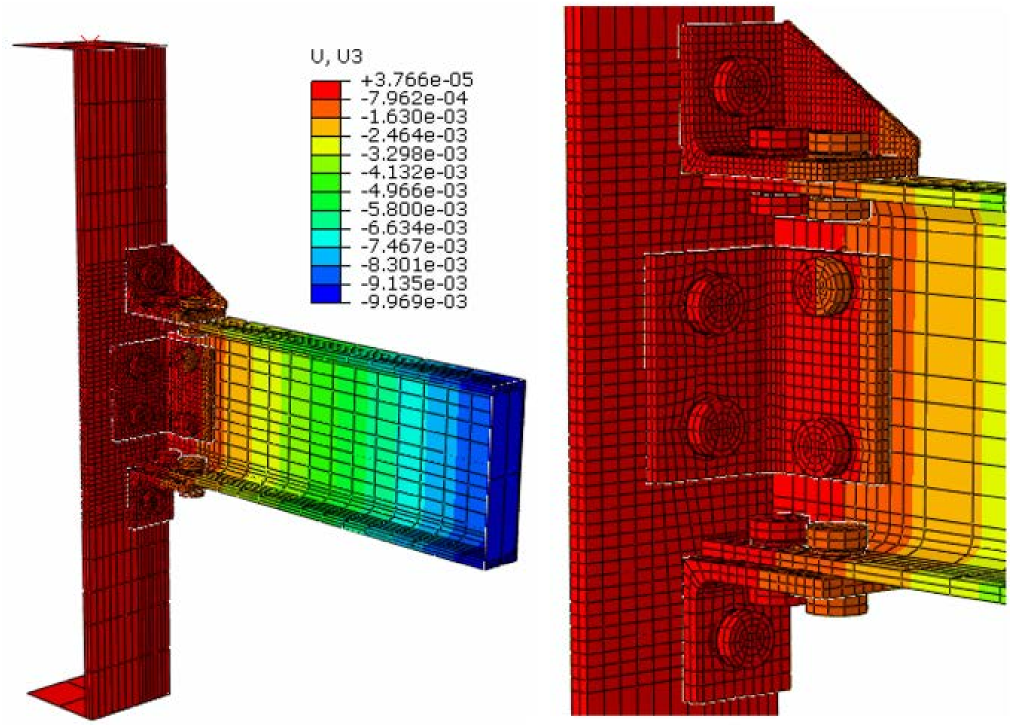

Figure 1. *Numerical results for vertical displacements in model TA12S8.*

4. FE RESULTS

Figures 2 to 4 show the Moment-Rotation results from the numerical study. The results for the specimen *TA8S10* are very close to the results of test *TA8S8*, so the effect of increasing the stiffener thickness has proved to be not relevant.

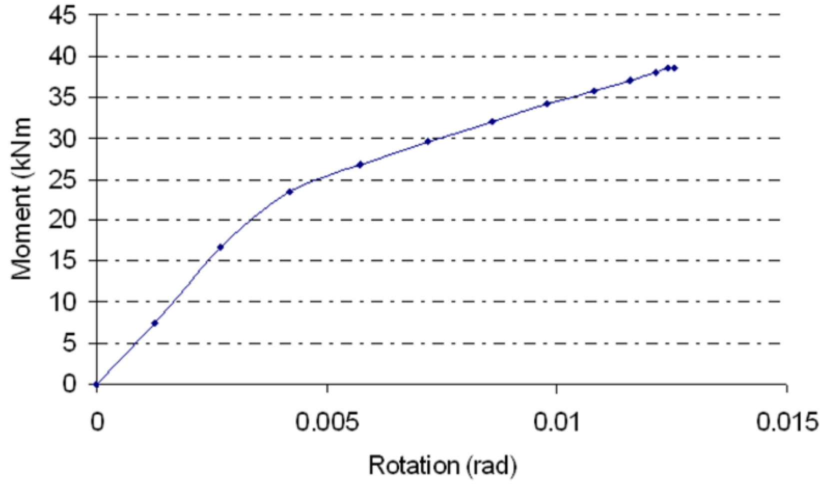

Figure 2. *Moment-Rotation curve for model TA8S8.*

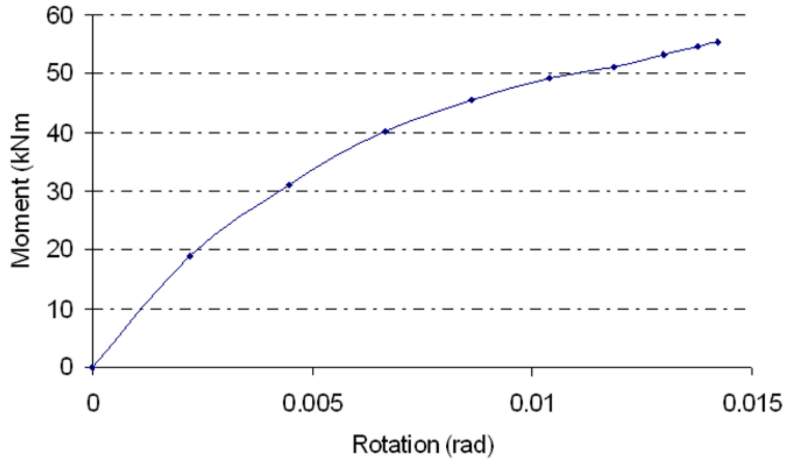

Figure 3. *Moment-Rotation curve for model TA10S8.*

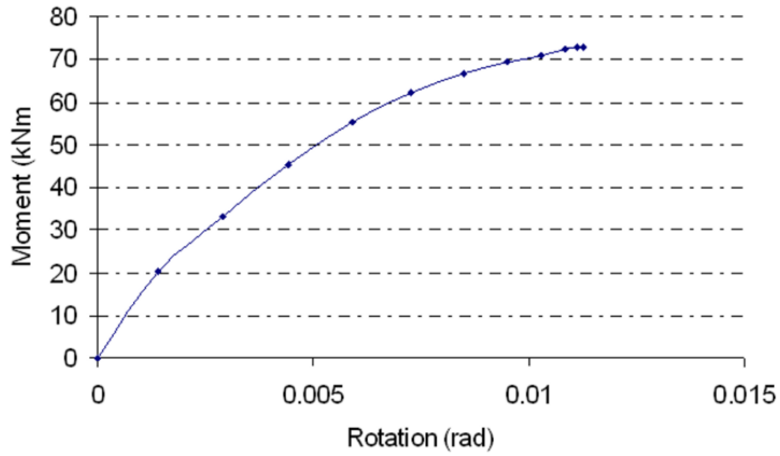

Figure 4. *Moment-Rotation curve for model TA12S8.*

In Figure 5 the sequence of yielding in the top angle can be observed for model *TA12S8*. Three plastic hinges can be easily identified: the first one is close to the filled of the cleat, the second one is located in the vicinity of the bolt hole, and the third one is a vertical yielding line close to the stiffener. The geometrical configuration of this yielding pattern is hugely important when a resistance model is considered in the sphere of the EC3 Component approach.

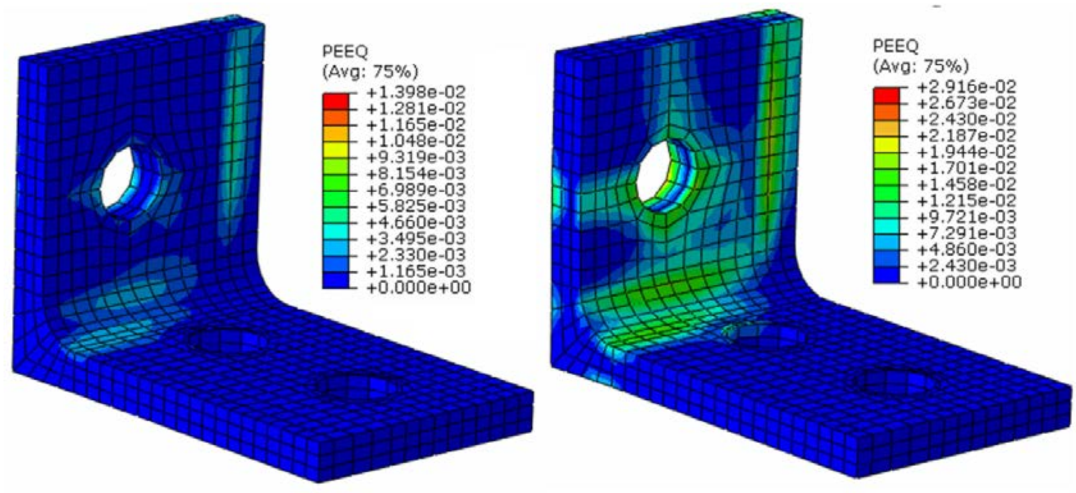

Figure 5. *Equivalent plastic strain sequence in the top angle for model TA12S8.*

5. COMPARISON BETWEEN STIFFENED AND UNSTIFFENED NUMERICAL SIMULATIONS

In this section a comparison has been developed between the numerical results of Moment-Rotation curves from the specimens with and without stiffener in the top cleat angle. The description of the numerical study on unstiffened angle connections can be looked up in [6]. The test set up consisted of a HEA 300 column profile with IPE 240 beams attached by means of L100x8 web angles and top and seat angles: L120x90x12 (Test1), L120x90x9 (Test2), L120x90x8 (Test3) and L120x90x10 (Test4).

As it can be observed in Figures 6 and 7, the increases in the joint resistance and rotational stiffness is very important, reaching values close to 100% in most cases.

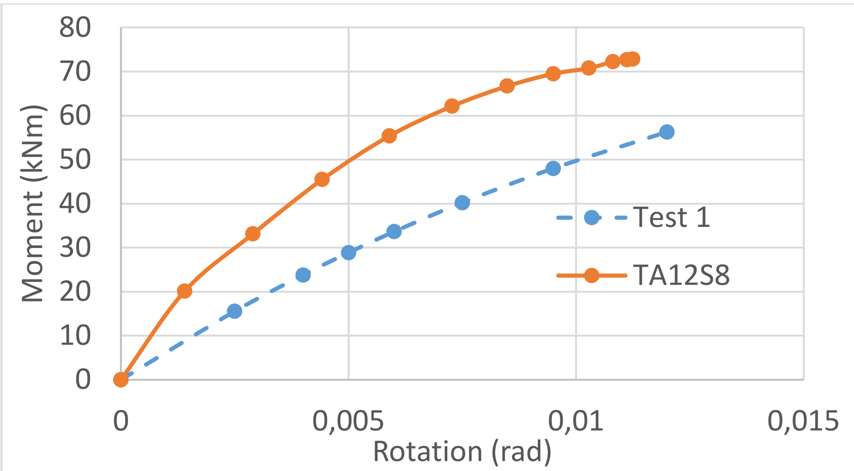

Figure 6. *Moment-Rotation numerical curves for model TA12S8 and Test1 model.*

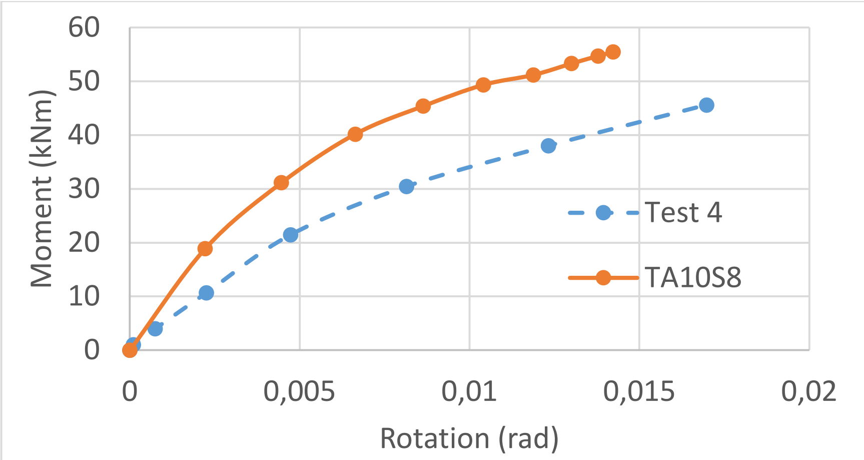

Figure 7. *Moment-Rotation numerical curves for model TA10S8 and Test4 model.*

This connection typology, including the stiffener in the top cleat angle is, therefore, closer to the design values of end plate connections but preserving the advantages of angle connections related to the ease of construction and deconstruction, as well as the economical benefits.

6. STIFFENER EFFECT ON THE PANEL ZONE

The effect of increasing the stiffness of the angle can change the behaviour of angle connections, since the column components will be more involved in the connection resistance. Therefore, the angles in bending could cease to be the critical components in some cases. Figure 8 shows Von Mises stress for model TA10S8 at the final loading step.

Besides, Figure 9 shows the stress field in the column web of *TA12S8* model and a graphical comparison with *Test 1* model when the first yielding appears in the top angle. It can be observed the increase in the tension stresses in the column web due to the angle stiffener effect. The Component Methodology of Eurocode 3 (EC3) can easily identify the weakest component and consider it in the design. In these cases, another methodologies based on simplifications must be discarded, since it is not possible to assure that the joint resistance is governed by the angles in bending.

On the other hand, in the evaluation of the stiffness of the column web in tension, it is customary the use of an effective width. The EC3 approximation is based on a reduction of the effective width used for calculating the joint flexural resistance. Nevertheless some authors [7] had recommended the use of an effective width for stiffness calculations which has proved to provide with better results in most cases.

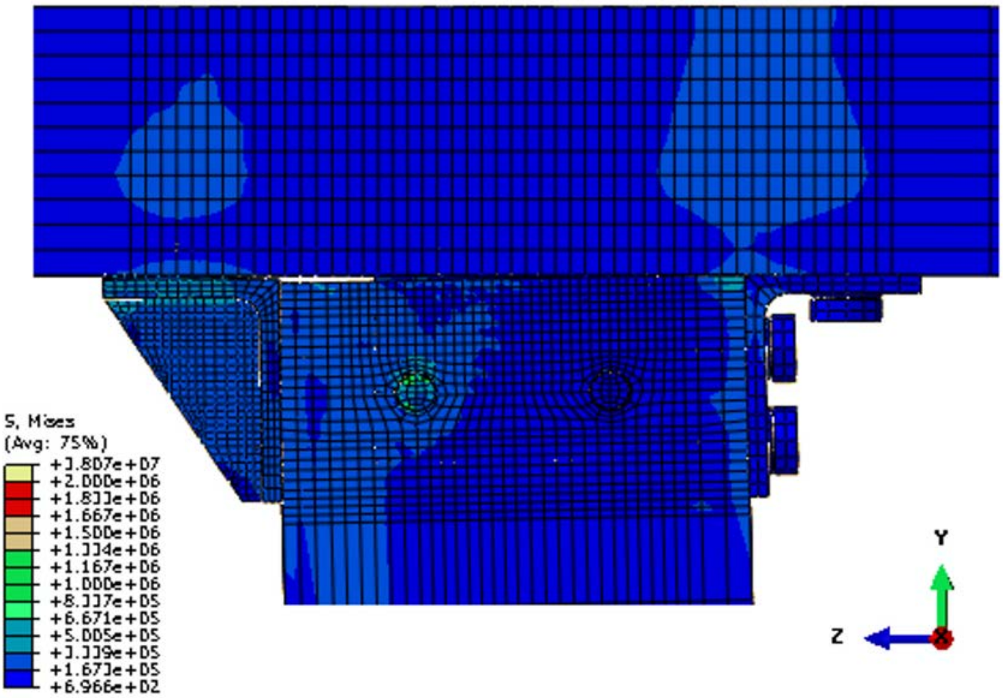

Figure 8. *Von Mises stress in the column web at the end load stage for model TA10S8.*

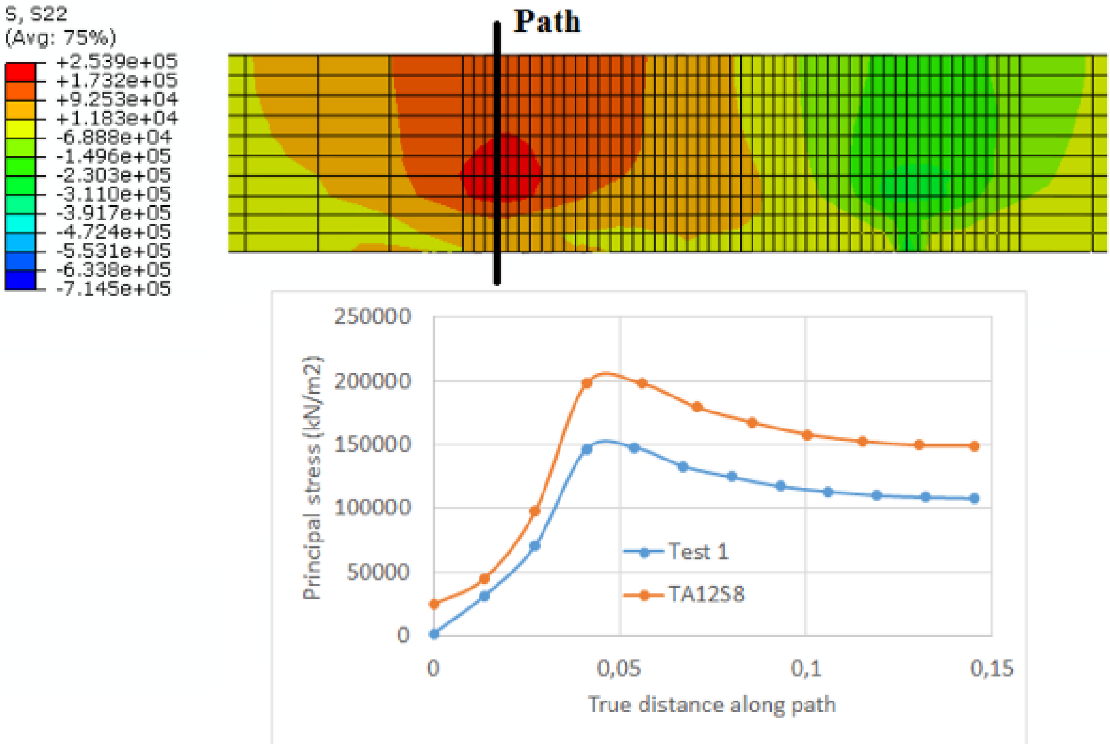

Figure 9. *Principal stress in the column web at first yielding stage for model TA12S8. Comparison with Test 1.*

7. CONCLUSIONS

- 3D FE models of stiffened top and seat angle connections with double web angles made up of rolled European profiles have been developed.
- The use of top angle stiffeners leads to important increments both in joint stiffness and resistance, in comparison with the analogous models without stiffening.
- A slight increment in the stiffener thickness has not a significant influence in the joint behaviour.
- The use of angle stiffeners can lead to stress increases in other joint components like the column web in tension. This situation is not a problem when the Component Methodology of EC3 is used. Nevertheless, simplified approaches must be avoided.
- These increases in stiffness and resistance, due to the presence of a stiffener, has shown the possibilities of angle connections in European steel construction as an alternative to other typologies.

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REFERENCES

[1] Reinosa J.M., Loureiro A., Gutierrez R., Lopez M. (2015). Analytical plate approach for the axial stiffness prediction of stiffened angle cleats. *Journal of Constructional Steel Research, 106: 77-88*.

[2] Reinosa J.M., Loureiro A., Gutierrez R., Lopez M. (2015). Analytical frame approach for the rotational stiffness prediction of beam-to-column angle connections. *Journal of Constructional Steel Research, 106: 67-76*.

[3] Schippers J.D., Ruffley D.J., Rassati G. A., Swanson J.A. (2012). A design procedure for bolted top-and-seat angle connections for use in seismic applications. In *7th International Workshop on connections in steel structures* (pp. 173-186). Timisorara: ECCS.

[4] Reinosa J.M., Loureiro A., Gutierrez R., Moreno A. (2008). Nonlinear elastic-plastic 3D Finite Element Modelling of Top and Seat Angle Connections with Double Web Angle. In *Eurosteel 2008* Volume A (pp. 501-506). Graz: ECCS.

[5] Skejic D., Dujmovic D., Beg D. (2014). Behaviour of stiffened flange cleat joints. *Journal of Constructional Steel Research, 103: 61-76*

[6] Reinosa J.M., Loureiro A., Gutierrez R., Lopez M. (2014). Experimental and numerical study of angle connections assembled with European profiles. *Informes de la construcción, 66; Extra 1.*

[7] Faella C., Piluso V., Rizzano G. (2000) Structural Steel Semirigid Connections. CRC Press LLC.