PREDICTION OF CYCLIC MOMENT-ROTATION BEHAVIOUR FOR TOP AND SEAT & WEB ANGLE CONNECTIONS BY MECHANICAL MODEL

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Received: 13 July 2005; Revised: 19 November 2006; Accepted: 24 November 2006

ABSTRACT: In this paper, a simplified mechanical model of the joint with relative moment-rotation characteristics for use in analytical modelling of MRSF systems is presented. The experimental moment-rotation behaviour of full-scale connections is first considered followed by the development of a finite element model for them. The inelastic moment-rotation predictions of the finite element model are compared with available experimental data. Experimental results of full-scale connections are also compared with the mechanical model proposed by the Eurocode 3. Based on the results of this comparison, a simplified mechanical model of the connection is developed. This proposed simplified mechanical model still adopts the same "component method" approach of the Eurocode 3, but introduces a more refined criteria for the modelling of the unilateral contact between the cleat and the column flange, and a different expression for the evaluation of the joint capacity. An extensive parametric analysis is then conducted to assess the inelastic moment-rotation behaviour and the results are compared with finite element analyses and with available experimental data. The moment-rotation predictions of the simplified mechanical model are in good agreement with experimental tests and with finite element analyses. The simplified mechanical model also gives more consistent initial stiffness and nonlinear relative moment-rotation estimates if compared to the model proposed by the Eurocode 3. The results of the conducted analyses show that the simplified mechanical model gives results that are in reasonable agreement with experimental data and are more accurate than the results of the Eurocode 3-Annex J model.

Keywords: Semi-rigid joints, steel structures, bolted connections, mechanical model, Eurocode 3, Annex J, finite element model, partial strength

1. INTRODUCTION

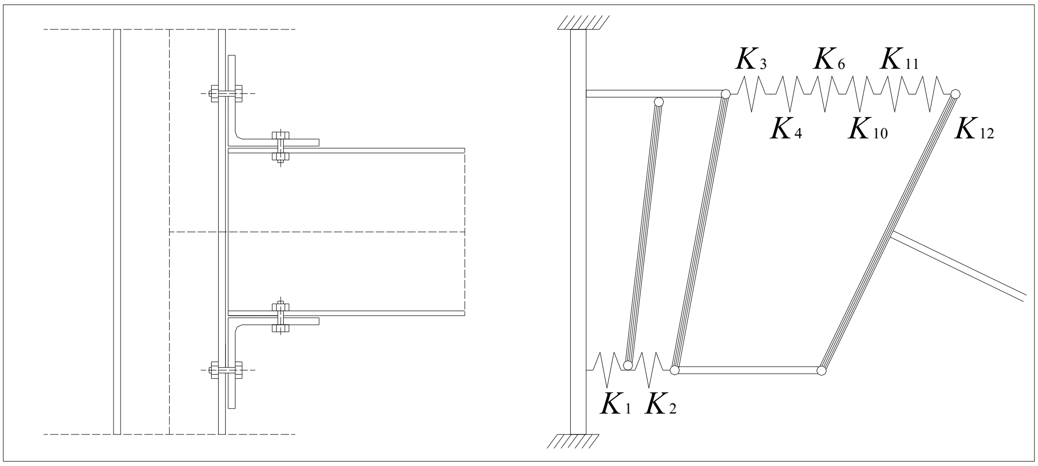
Conventional analysis of frames is usually performed under the assumption that a connection joining beam to column is either infinitely rigid or perfectly pinned. However, experimental test results on full scale joint sub-assemblages (Bernuzzi et al. [1], Calado and Pucinotti [2]) clearly show that the actual response of joints is far from the above idealisation. All connections transmit some moments and exhibit certain degree of flexibility. The unintended modelling error introduces flexibility in the frames and may considerably influence their static and dynamic responses. The concept of semi-rigid connections has been acknowledged by researches several years already. Nowadays, it is well known that all connections are semi-rigid. The concept of semi-rigid or flexible connections is recognized by the Eurocode 3 as well by several national codes for steel structures (for example the U.S.A. codes). But the theoretical knowledge did not actually have an immediate impact on practice. In this paper, the prediction of the cyclic moment-rotation behaviour of top and seat & web angle connections through a simplified mechanical model is presented. Many mechanical models were proposed in the past by the researchers to simulate both monotonic and cyclic behaviour (Kishi and Chen [3], De Stefano et al. [4], Pucinotti [5], Pucinotti [6], Ballio et al. [7] - De Stefano, A. and De Luca [8], De Stefano et al. [4], Bernuzzi et al. [1], Bernuzzi [9], Bernuzzi et al. [10]).

The proposed simplified mechanical model is based on the same "component approach" introduced by the Eurocode 3 with an introduction of a more refined modelling of the cleat-to-column interface and a different expression for the evaluation of the moment capacity of the joint, which takes into account for the effect of the d/t_a ("d" is the diameter of the bolt connecting the angle to the column flange, "t_a" is the angle thickness) and r_a/t_a ("r_a" is the groove fillet radius). Finally, the comparison among the experimental curves (Exp.), the Mechanical model (MecMod), the Eurocode 3 Annex J and the "modified" Eurocode 3 Annex J is considered to put in evidence based on their degree of accuracy.

2. THE EUROCODE 3-ANNEX J MODEL

The moment-rotation relationships of the connection are non-linear over the entire range of loading for almost all types of joints (Pucinotti, [11]). Different mathematical models have been proposed for the analysis of the inelastic connections behaviour under monotonic loading and under fully reversed cyclic loading (De Stefano and De Luca [8], De Stefano et al. [12], Bernuzzi [13], Bernuzzi et al. [1], Pucinotti [5]).

The Annex J of the Eurocode 3 addresses the issue of the analysis and design of beam-to-column joints in building frames subjected to predominantly static loading by the introduction of a mechanical model that simulates the connection behaviour by a series of different *components.* Each *component is* being modelled as an elastic spring with a specific stiffness and strength (De Luca et al. [14]). The appropriate coupling of these springs in a parallel-series fashion gives the global stiffness and strength of the connection. Figure 1 shows an example of Annex J model for Top and Seat angle connections. For each type of joint, the component model requires the preliminary identification of the basic components of the joint. Components stiffness coefficients, K_i, and resistant design forces ($F_{rd,i}$) are then evaluated. Finally, the joint initial rotational stiffness ($S_{j,ini}$) and its design moment capacity ($M_{j,Rd}$) can be computed. In the case of top and seat angle connections, the EC3 model considers the following components (figure 1b): the stiffness coefficients of the column web panel in: shear (k_1), compression (k_2) and tension (k_3); the column flange flexural stiffness (k_4) and the flange cleat flexural stiffness (k_6); The bolts tensile stiffness (k_{10}), and, for non-preloaded bolts, their shear stiffness (k_{11}) and their bearing stiffness (k_{12}).



a) b)

Figure 1. Example of Annex J model for Top and Seat Angle Connections

The initial stiffness of the connection is given by the formula:

$$S_{j,ini} = \frac{Ez^2}{\sum_{i=1}^{n} 1/K_i} \tag{1}$$

where:
E is the Young's modules,
K_i is the stiffness coefficient of the i-th component;
n is the number of basic joint components;
z is the distance from the mid-thickness of the leg of the angle cleat on the compression flange and the bolt-row in tension (figure 1b).

In the EC3 model, the joint resistance coincides with the resistance of the most weakest component; the flexural joint resistance, $M_{j,Rd}$ is computed as:

$$M_{j,Rd} = F_{Rd} z \tag{2}$$

where:

$$F_{Rd} = \min[F_{Rd1}, F_{Rd2}, ..., F_{Rdn}] \tag{3}$$

In EC3-Annex J, the moment-rotation response is described by a linear elastic relationship, Eqn. 4, if the moment $M_{j,Sd}$ is lower than the elastic one, M_e ($M_e=2/3M_{j,Rd}$), followed by a non linear part, Eqn. 5, up to the attainment of $M_{j,Rd}$, which provides the plateau of the *M-F* curve up to the ultimate rotation Φ_{Cd} (figure 2).

$$\varphi = \frac{M_{j,Sd}}{S_{j,ini}} \quad \text{if } M_{j,Sd} < 2/3 M_{j,Rd} \tag{4}$$

$$\varphi = \frac{(1.5 M_{j,Sd} / M_{j,Rd})^{\Psi}}{S_{j,ini}} \quad \text{if } 2/3 M_{j,Rd} < M_{j,Sd} < M_{j,Rd} \tag{5}$$

where:
$M_{j,Rd}$ is the design moment resistance of the connection;
$M_{j,Sd}$ is that applied;
Ψ is the shape factor;
$S_{j,ini}$ is the initial stiffens of the connection.

The parameter *y* depends on the joint type (it assumes the value of 3.1 in the case of bolted angle cleats).

The Annex J does not include a mechanical model for top-and-seat with web angle connections.

An extension of Annex J at this type of connections was presented in ([Pucinotti [5]) (see the curve indicate with EC3 –web in figure 3), where the limitation on the resistance moment was neglected and the validity of Eqn. 5 was extended also to the cases of $M>M_{j,Rd}$ (indicate with EC3-web+Hr in figure 3):

$$\varphi = \frac{M_{j,Sd}}{S_{j,ini}} \quad \text{if } M_{j,Sd} < 2/3 M_{j,Rd} \tag{6}$$

$$\varphi = \frac{(1.5 M_{j,Sd} / M_{j,Rd})^{\Psi}}{S_{j,ini}} \quad \text{if } M_{j,Sd} > 2/3 M_{j,Rd} \tag{7}$$

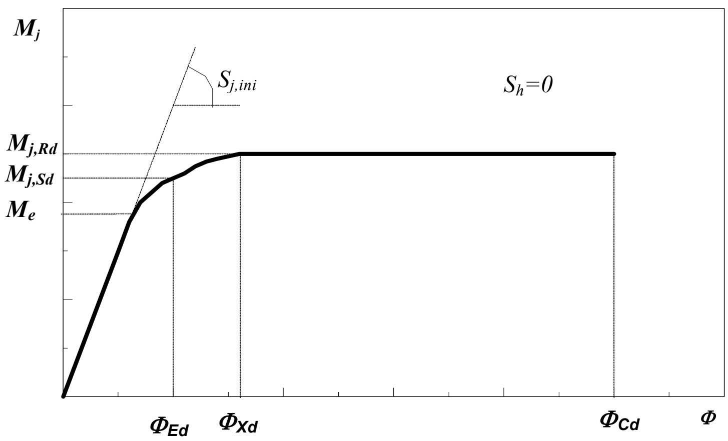


Figure 2. EC3-Annex J Model: Curve M-Φ

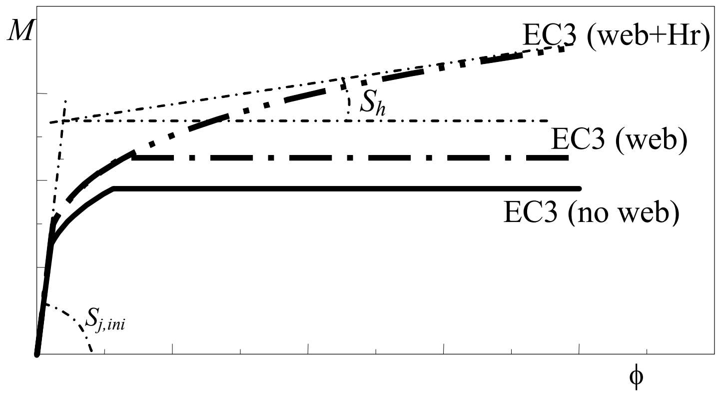


Figure 3. Extension of EC3-Annex J Model: Curves M-Φ

3. THE FINITE ELEMENT MODEL

To understand the actual behaviour of the available experimental results of this type of connections under monotonic and cyclic loading (Bernuzzi et al. [1]), a finite element model of the test setup has been developed (figure 4). The most relevant parameters influencing the nonlinear response of the joint have been considered in the finite element model. The unilateral contact between the column flange and the angular cleat was modelled with a set of discrete gap elements whose initial stiffness, K_t, was estimated by the following expression (Wales & Rossow [15]) :

$$K_t = \frac{t_{wc} E}{\ln(1 + H_c)} B_a \tag{8}$$

where

- t_{wc} is column flange thickness;
- E is Young modulus;
- H_c is column height;
- B_a is angle base size.

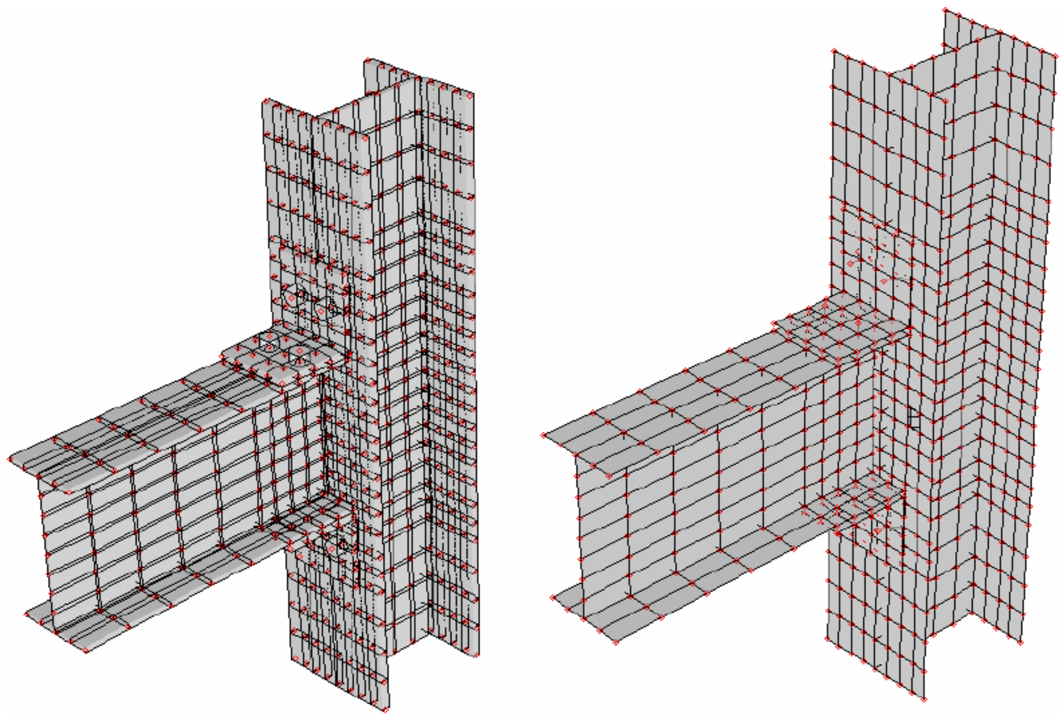


Figure 4. Finite Element Model

In figure 5, the finite element model and the Eurocode 3 Annex J model results have been compared with the experimental curves. The same figure 5 shows this comparison with reference to experimental "Bernuzzi" data (Bernuzzi [13]).

The results of this comparison (figure 5) show that the finite element moment-rotational predictions are in good agreement with experimental data.

The Eurocode 3 model, instead, gives a reasonable estimate of the initial stiffness, but largely underestimates the joint capacity (even including the strain hardening effect).

Afterwards, a parametric analysis was developed to understand the influence of most important parameters, in which moment-rotation curves were derived for various values of the varying parameter "d/t_a" (where "d" is the diameter of the bolt connecting the angle to the column flange and "t_a" is the angle thickness).

In figure 6, the results of the finite element model were compared with the inelastic moment-rotation predictions obtained by applying the Eurocode 3-Annex J model.

The results of this comparison confirm that the Eurocode 3 underestimates the joint capacity predicted by the finite element model over the entire range of variation of the investigated parameter d/t_a. It is possible to see that the EC3, which does not take into account for the effect of the d/t_a ratio on the joint capacity, gives inaccurate and conservative results.

They confirm that the EC3 model is not accurate enough to assess the inelastic rotation demand of actual connections.

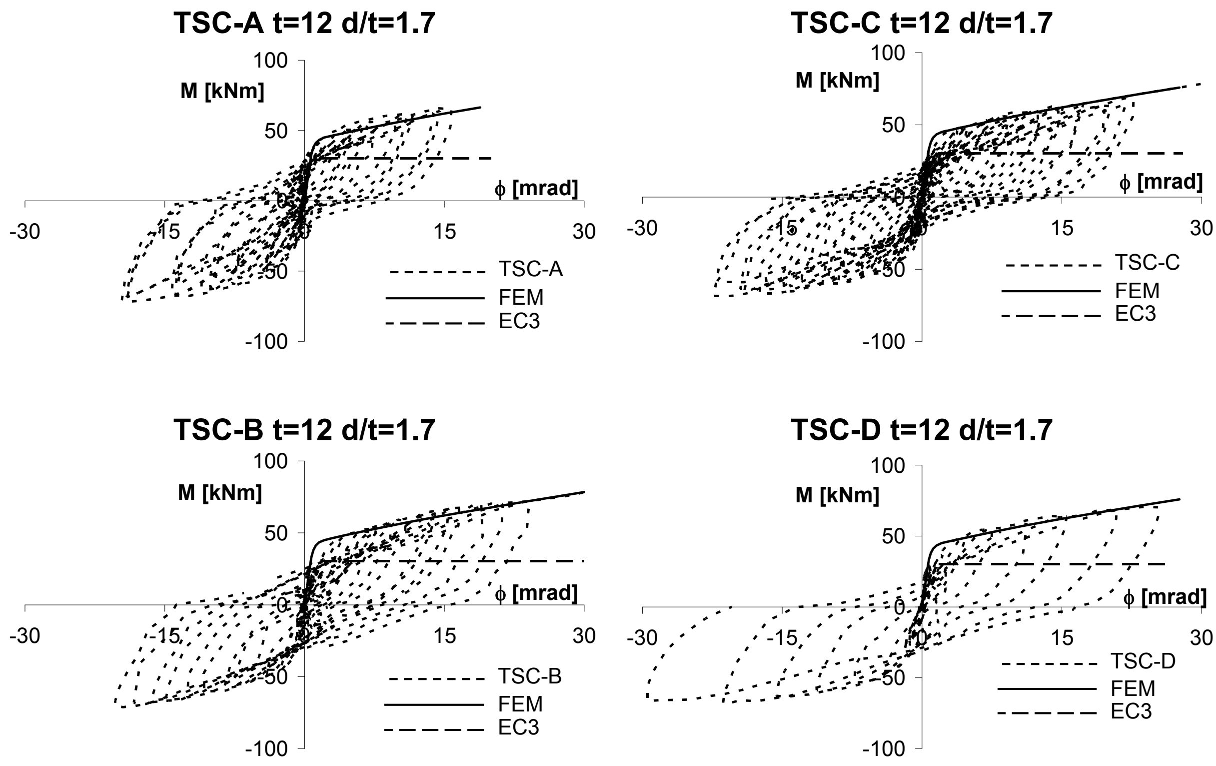


Figure 5. Comparison among EC3-Annex J model, F.E.M. Model and Experimental "Bernuzzi" Data

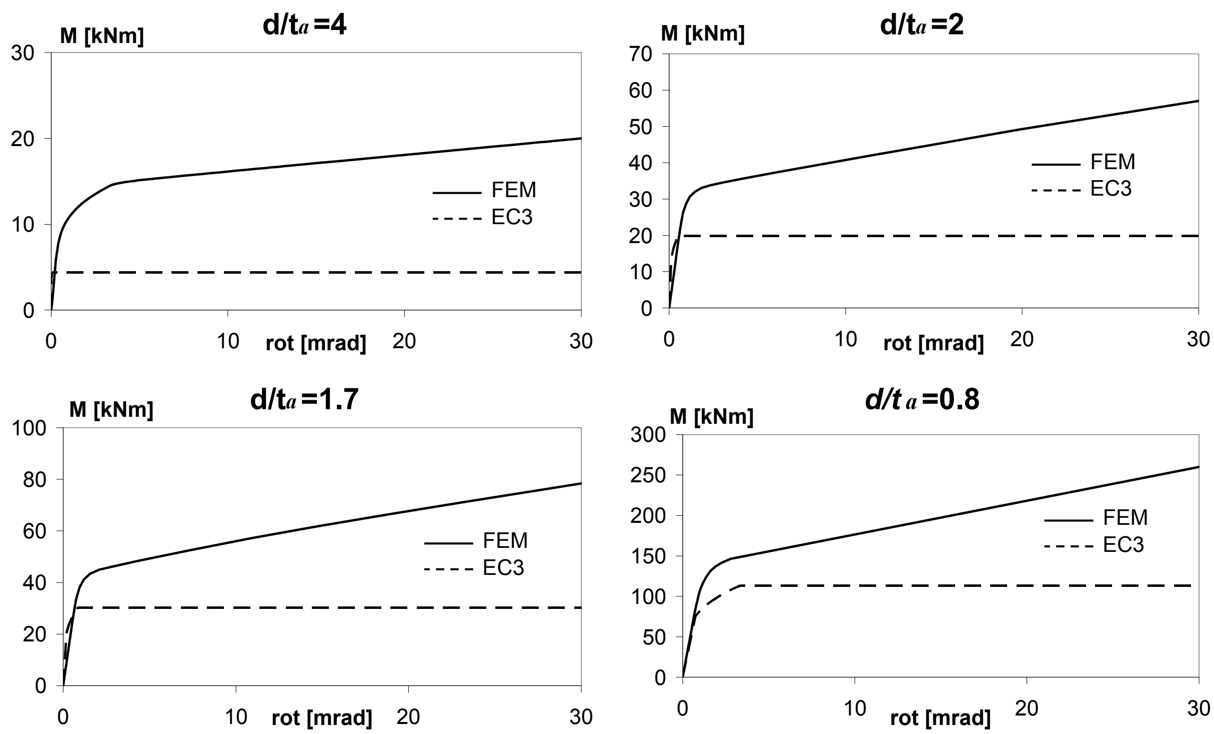


Figure 6. Parametric Analysis and Comparison Among F.E.M. Model and EC3-Annex J Model

4. THE PROPOSED MECHANICAL MODEL

A modified model is proposed in order to improve the inelastic relative moment-rotation predictions of the Eurocode 3. It is still based on the same "component" approach adopted by the Eurocode 3.

Using the experimental data and the results of the previous parametric analyses, the model was modified with the introduction of a different expression for the evaluation of the lever arm that modifies the joint capacity. This model is an extension of a previously model (Pucinotti [5]) where the effect of the unilateral contact between the angle cleat and the column flange was already included. The joint is modelled by two rigid bars connected by two non-linear springs (figures 7, 8) that represent the axial response of the angles. The rigid bars AB and CD (figure 7), respectively represent the column and the beam.

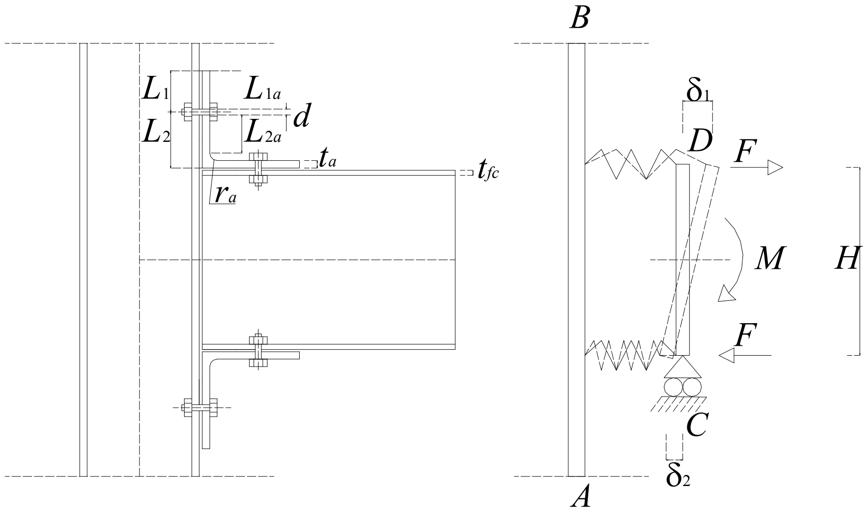


Figure 7. Top and Seat Angle Connections: Mechanical Model

The AC beam, as shown in figure 8, simulates the flexural response of the outstanding leg of angle and the spring BE (figure 8) is introduced to model the bolt behaviour. The AB part of the beam is modelled as an elastic beam supported by a discrete set of independent springs representing the stiffness, K_t , of the column web, Eqn. 8. The segment BC of the beam is modelled as an inelastic beam with linear strain hardening, while the BE segment is modelled as an elastic-perfectly-plastic spring.

The end C of the outstanding leg is free to translate vertically, but its rotation is constrained to the value: $\varphi_C = \delta_C / H_b$, were δ_C is the vertical translation and H_b is the height of the connected beam.

To obtain δ_C , it is possible to apply the principle of virtual forces (figure 9), considering a virtual unit load condition applied in C and orthogonal to the beam, which gives the moment distribution *M'(z)*:

$$\delta_C = \int_0^{L_{2a}} M'(z)\chi(z)dz + N'_{BE}\frac{N_{BE}}{K_b} + M'_B\frac{M_B}{K_\phi} \tag{9}$$

where:

- χ = curvature of the part BC of the beam;
- N'_{BE} =axial load;

K_b = axial stiffness of the bolts = $\dfrac{E\pi d^2/4}{t_a + t_{fc}}$

t_a = thickness of the angle;
t_{fc} = thickness of the flange column.

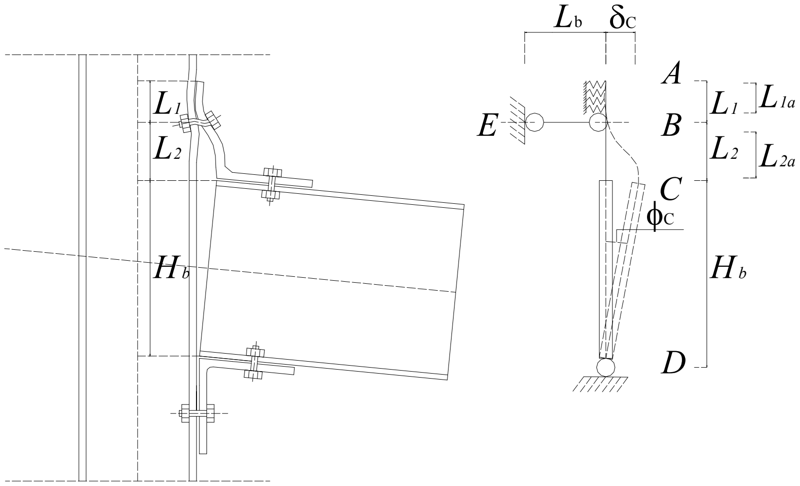


Figure 8. Top and Seat Angle Connections: Mechanical Model

A modified expression for the evaluation of "$L=L_{2a}$" is hereby proposed (figure 8) in order to take into account for the effect of the investigated d/t_a ratio and r_a/t_a ratio (r_a=root fillet radius) on the joint capacity:

$$L_{1a} = L_1 - d/2 \quad (10)$$

$$L_{2a} = L_2 - t_a - \alpha r_a - \beta d \quad (11)$$

where: L_2, t_a r_a and d, are shown in figure 7,

$$\alpha = -2.019\left(\frac{r_a + t_a}{t_a}\right)^3 + 9.574\left(\frac{r_a + t_a}{t_a}\right)^2 - 10.837\left(\frac{r_a + t_a}{t_a}\right) \quad (12)$$

and

$$\beta = 0 \qquad \text{if } d/t_a < 1$$

$$\beta = \sqrt{-(d/t_a)^2 + 3(d/t_a) - 8/4} \qquad \text{if } 1 \le d/t_a \le 1.5 \quad (13)$$

$$\beta = 1/2 \qquad \text{if } d/t_a \ge 1.5$$

The solution of the following fourth order differential equation applied at the part AB of the outstanding leg (figure 8) agrees with the valuation of the rotational stiffness K_ϕ ?of the spring B:

$$K_\phi = 2EI\alpha^2[E_1(A_1C - A_2S) - E_2(A_3C - A_4S) \quad (14)$$

where:

$$I = B_a t_a^3 / 12, \qquad \alpha = \left(\frac{K_t}{4EI} \right)^{(1/4)}, \qquad E_1 = \exp(\alpha L_{1a}), \tag{15}$$

$$E_2 = \exp(-\alpha L_{1a}), \qquad C = \cos(\alpha L_{1a}), \qquad S = \sin(\alpha L_{1a}), \tag{16}$$

in which, A_1, A_2, A_3 and A_4, have been carried out by means the boundary conditions:

- bending moment, $M_{(A)}=0$;
- shear, $V_{(A)}=0$;
- horizontal displacement of B, $v_{(B)} = -V_{(B)}/K_b$;
- rotation of B, $\varphi_{(B)} = 1$

still:

$$A_1 = A_3 = \frac{1}{(c - a/bd)}, \qquad A_2 = 2A_1 + A_4, \qquad A_4 = -A_1 a/b, \tag{17}$$

where:

$$a = E_1 S + 2E_1 C + E_2 S \qquad b = E_1 C + E_2 C \tag{18}$$

$$c = 3\alpha E_1 (C - S) + 2\alpha E_2 (C - S) \qquad d = \alpha E_1 (C - S) - 2\alpha E_2 (C + S) \tag{19}$$

In figure 10, the monotonic non-linear F-δ_C relationship is reported.

On the basis of previous experimental study (Bernuzzi [1,9,10,13]), the response of the outstanding leg in the cyclic case could be defined by the following phases (figure 11):

- unloading phase
  BC: linear elastic relationship of breadth $2F_e$ and stiffness S_i;
  CD: post-elastic behaviour with stiffness S_h;
  DE: contact between the outstanding leg and the column flange;
- reloading phase
  ED: reloading with contact between the outstanding leg and the column flange;
  DG: elastic linear relationship of breadth $2F_e$ and stiffness S_i;
  GH: post-elastic behaviour with stiffness S_h;

The mechanical model in the case of top and seat with web angle connections, presents a number of additional components equal to bolt-rows of the web cleat (figure 12).

The stiffness K_{tai} of the column web (Wales and Rossow [16]) in correspondence of the i-th bolt row is given by the formula:

$$K_{twi} = \frac{t_{wc} E}{\ln(1 + H_c)} B_{awi} \tag{21}$$

in which:

t_{wc} = thickness of the web column;

E = Young's modulus;

H_c = height of the beam;

B_{awi} = width of the portion of outstanding leg of web angles (figure 12).

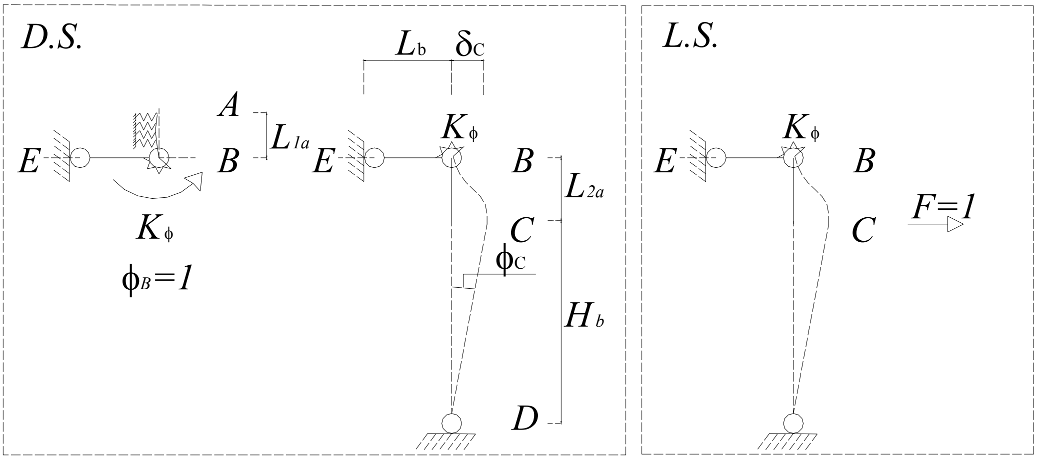


Figure 9. Application of the Principle of Virtual Forces

In this case, the extreme C of portion of the outstanding leg of web angle is free to translate horizontally but its rotation $\varphi_{Cwi} = 0$.

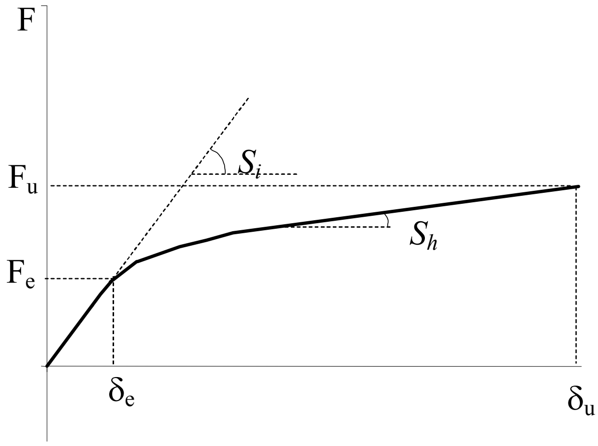


Figure 10. Elasto-plastic Relationship with Linear Strain Hardening

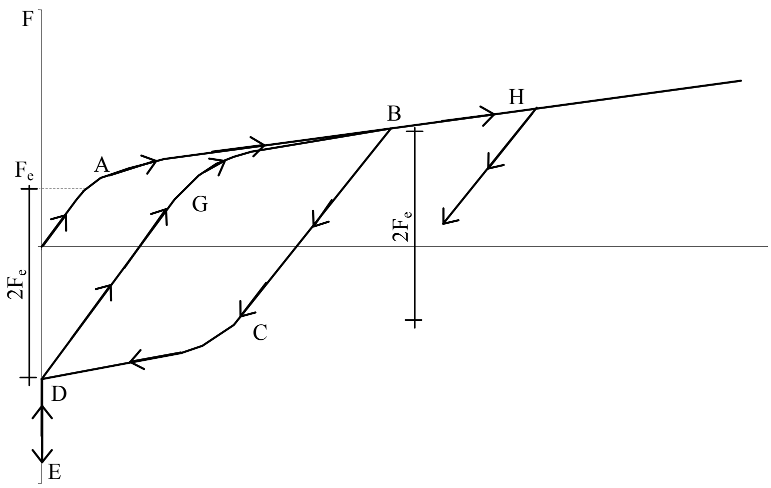


Figure 11. Extension at the Cyclic Case

δ_{Cwi} is obtained by the application of the principle of virtual forces:

$$\delta_{Cwi} = \int_0^{2L_{2awi}} M^{'}(z)\chi(z)dz + N^{'}_{BE}\frac{N_{BE}}{K_{bwi}} + M^{'}_{B}\frac{M_B}{K_{\phi wi}} \tag{22}$$

where:

χ = curvature of the part BC of the beam;
N'_{BE} = axial load;
K_{bwi} = axial stiffness of the bolts = $\dfrac{E\pi d^2/4}{t_{aw}+t_{fc}}$
t_{aw} = thickness of the web angle;
t_{fc} = thickness of the flange column. $K_{\phi wi}$ = rotational stiffness

and:

$$L_{1awi} = L_{1wi} - dw/2 \tag{23}$$

$$L_{2ai} = L_{2wi} - t_{aw} - \alpha w r_{aw} - \beta_w d_w \tag{24}$$

where: L_{1wi} and L_{2wi} are depicted in figure 12, while r_{aw} is the root fillet radius of web angle and d_w is the diameter of web bolts.

$$\alpha_w = -2.019\left(\frac{r_{aw}+t_{aw}}{t_{aw}}\right)^3 + 9.574\left(\frac{r_{aw}+t_{aw}}{t_{aw}}\right)^2 - 10.837\left(\frac{r_{aw}+t_{aw}}{t_{aw}}\right) \tag{25}$$

$$\beta_w = 0 \qquad \text{if } d_w/t_{aw} < 1$$

$$\beta_w = \sqrt{-(d_w/t_{aw})^2 + 3(d_w/t_{aw}) - 8/4} \qquad \text{if } 1 \le d_w/t_{aw} \le 1.5 \tag{26}$$

$$\beta_w = 1/2 \qquad \text{if } d_w/t_{aw} \ge 1.5$$

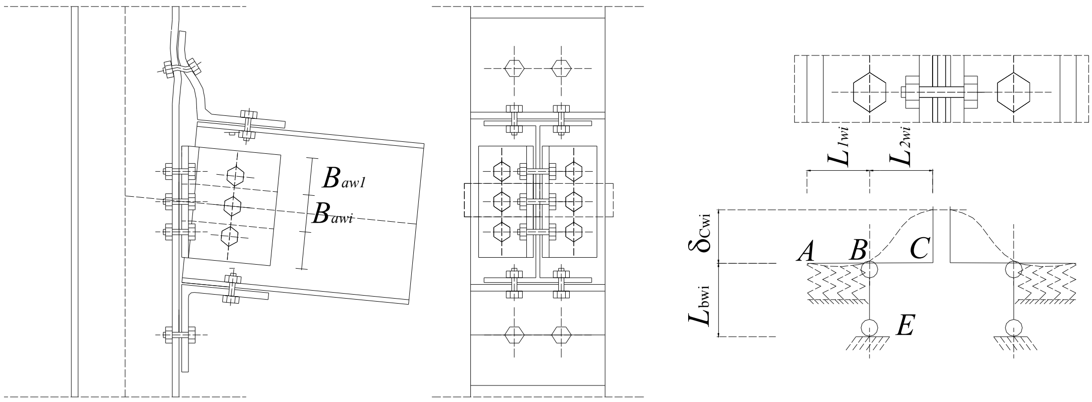


Figure 12. Mechanical Model with the Addition of the Web Angles

5. COMPARISON

Figures 13 and 14 show the moment-rotation curves obtained by the application of the proposed model, the finite element model and the EC3 model (with and without hardening).

The results show that the inelastic rotational predictions of the proposed model are really close to the finite element model.

The predictions of the proposed model are more consistent, over the entire range of variation of the investigated parameter "*d/t*"(0.8÷4), while the results of the Eurocode 3, which do not take into account the effect of the d/t_a and r/t_a ratios in the evaluation of the lever arm, represent an error. Here, the proposed model is applied to the experimental curves content in the Sericon data bank (Weynand [16]) and to the Bernuzzi experimental tests (Bernuzzi et al. [1]). Figure 15 shows the schemes of the different types of top and seat connections being considered (type A, B and C).

Joint type A does not include web angles while joint type B and type C include single web angle connection.

The geometric characteristics and the mechanical property of the studied connections are shown in the tables 1, 2 and 3.

Table 1. Bernuzzi: Geometrical and Mechanical Characteristics of the Joints

TEST	Type of joint	Beam	Column	Flange Angle Web Angle	Type of Bolt	f_{ya} [MPa] f_{ua}[MPa]	f_{yfc}[MPa] f_{ufc}[MPa]	f_{yfb}[MPa] f_{ufb}[MPa]
TSC-A	Type A	HE600B	IPE300	L120X120X12 /	M20 8.8	313.20 459.20	/ /	/ /
TSC-B	Type A	HE600B	IPE300	L120X120X12 /	M20 8.8	313.20 459.20	/ /	/ /
TSC-C	Type A	HE600B	IPE300	L120X120X12 /	M20 8.8	313.20 459.20	/ /	/ /
TSC-B	Type A	HE600B	IPE300	L120X120X12 /	M20 8.8	313.20 459.20	/ /	/ /

f_{ya} = Yield stress of flange Cleats f_{yfc} = Yield stress of Column flange f_{yfb} = Yield stress of Beam flange
f_{ua} = Ultimate stress of flange Cleats f_{ufc} = Ultimate stress of Column flange f_{ufb} = Ultimate stress of Beam flange

Table 2. “Sericon” Data Bank: Geometrical and Mechanical Characteristics of the Joints

TEST	Type of joint	Beam	Column	Flange Angle Web Angle	Type of Bolt	f_{ya} [MPa] f_{ua}[MPa]	f_{yfc}[MPa] f_{ufc}[MPa]	f_{yfb}[MPa] f_{ufb}[MPa]
101003	Type A	IPE 200	HE160B	L150x90x15 /	M16 -	/ /	280.0 422.3	351.0 456.0
101006	Type A	IPE 200	HE160B	L150x90x15 /	M16 10.9	/ /	280.0 422.3	351.0 456.0
101012	Type A	IPE 300	HE160B	L150x90x15 /	M16 10.9	/ /	280.0 422.3	303.0 447.0

Table 3. “Sericon” Data Bank: Geometrical and Mechanical Characteristics of the Joints

TEST	Type of joint	Beam	Column	Flange Angle Web Angle	Type of Bolt	f_{ya}[MPa] f_{ua}[MPa]	f_{yfc}[MPa] f_{ufc}[MPa]	f_{yfb}[MPa] f_{ufb}[MPa]
103001	Type B	HE200B	IPE 240	L150x90x10 L150x90x10	M16 8.8	298.0 478.5	274.0 419.0	291.0 420.0
103002	Type B	HE200B	IPE 240	L150x90x10 L150x90x10	M16 8.8	240.5 392.0	274.0 419.0	291.0 420.0
103003	Type B	HE200B	IPE 300	L150x90x10 L150x90x10	M20 8.8	298.0 478.5	274.0 419.0	279.0 419.0
103004	Type B	HE200B	IPE 300	L150x90x13 L150x90x13	M20 8.8	240.5 392.0	274.0 419.0	279.0 419.0
103005	Type B	HE200B	IPE 360	L150x90x10 L150x90x10	M24 8.8	298.0 478.5	274.0 419.0	279.5 418.0
103006	Type B	HE200B	IPE 360	L150x90x13 L150x90x13	M24 8.8	240.5 392.0	274.0 419.0	279.5 418.0
103045	Type C	HE200B	IPE 240	L150x90x10 L150x90x10	M16 8.8	298.0 478.5	274.0 419.0	291.0 420.0
103046	Type C	HE200B	IPE 240	L150x90x13 L150x90x13	M16 8.8	240.5 392.0	274.0 419.0	291.0 420.0
103047	Type C	HE200B	IPE 300	L150x90x10 L150x90x10	M20 8.8	298.0 478.5	274.0 419.0	279.0 419.5
103048	Type C	HE200B	IPE 300	L150x90x13 L150x90x13	M20 8.8	240.5 392.0	274.0 419.0	279.0 419.5
103049	Type C	HE200B	IPE 360	L150x90x10 L150x90x10	M24 8.8	298.0 478.5	274.0 419.0	279.5 418.0
103050	Type C	HE200B	IPE 360	L150x90x13 L150x90x13	M24 8.8	240.0 392.0	274.0 419.0	279.5 418.0

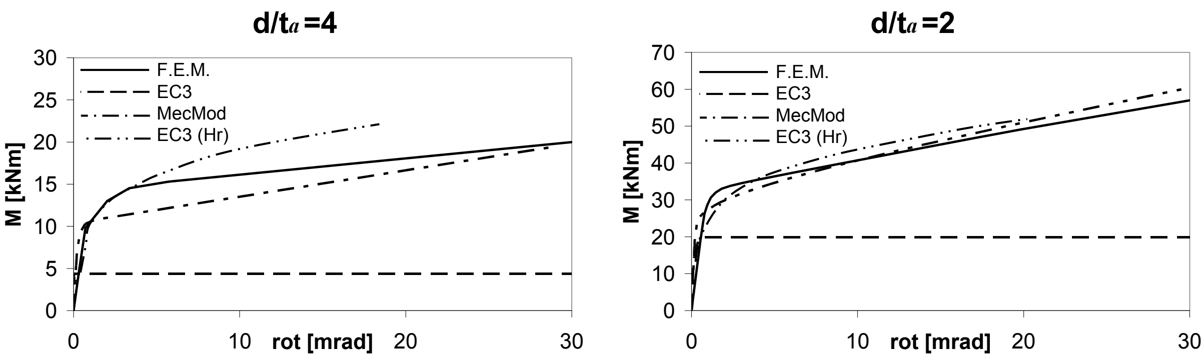


Figure 13. Comparison among F.E.M. Model, EC3-Annex J Model, Modified EC3- Annex J Model and Mechanical Model

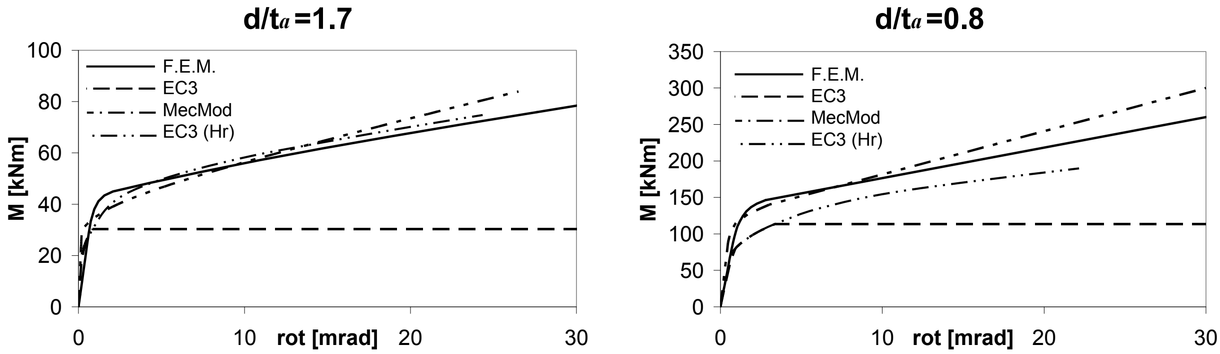


Figure 14. Comparison among F.E.M. Model, EC3-Annex J Model, Modified EC3- Annex J model and Mechanical Model

Figures from 16 to 20 show the comparisons among:

- the experimental curves (Exp.);
- the Mechanical model (MecMod);
- the Eurocode 3 Annex J (EC3(no web));
- the "modified" Eurocode 3 Annex J (EC3(web) that take in account of the contribution for web angles;
- the "modified" EC3(web+Hr) for top and seat & web angles plus hardening.

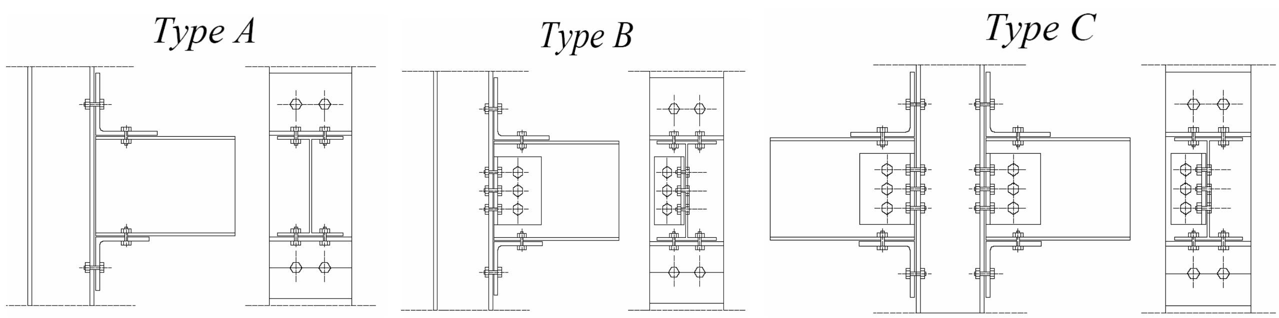


Figure15. Type of Investigated Connections

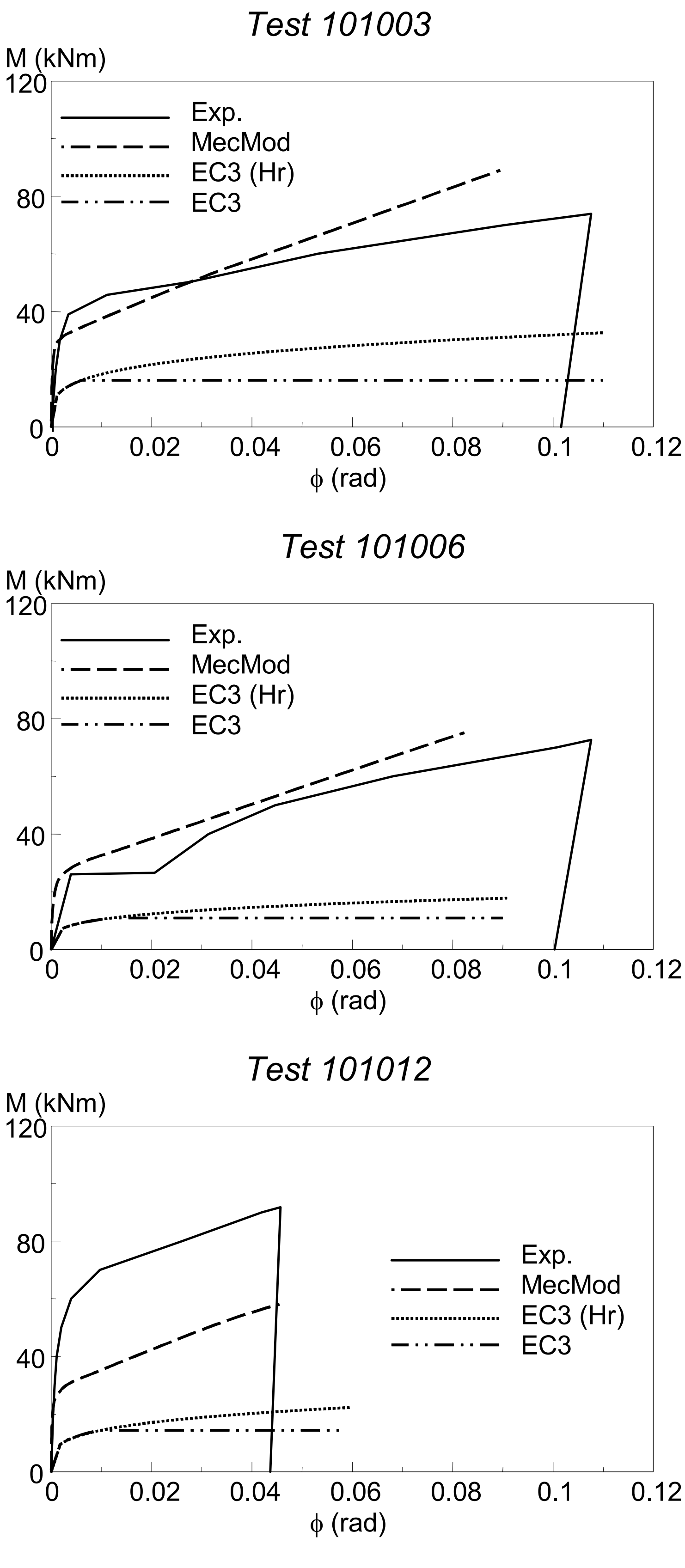


Figure 16. Comparison among Annex J, M.S.M. and Experimental “Sericon” Data

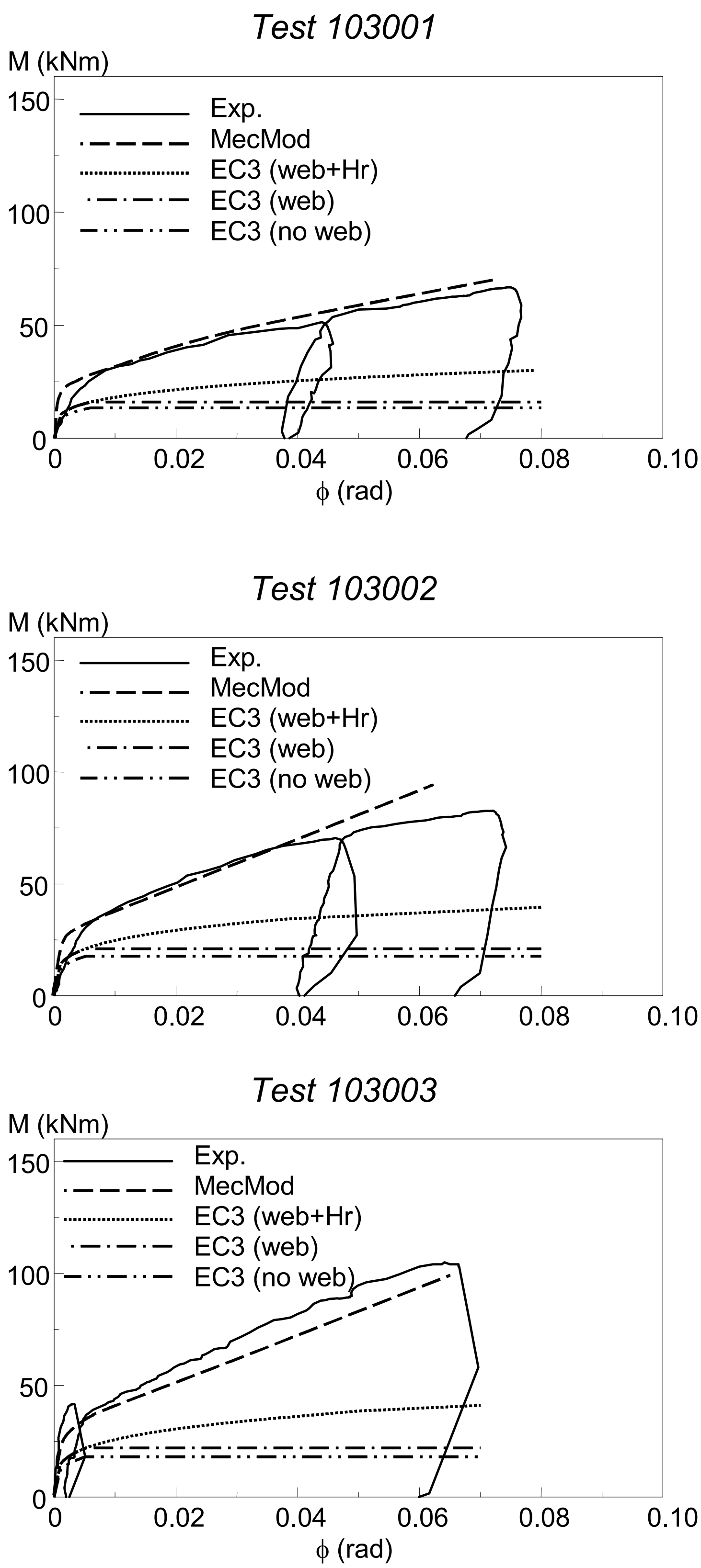


Figure 17. Comparison among Annex J, M.S.M. and Experimental “Sericon” Data

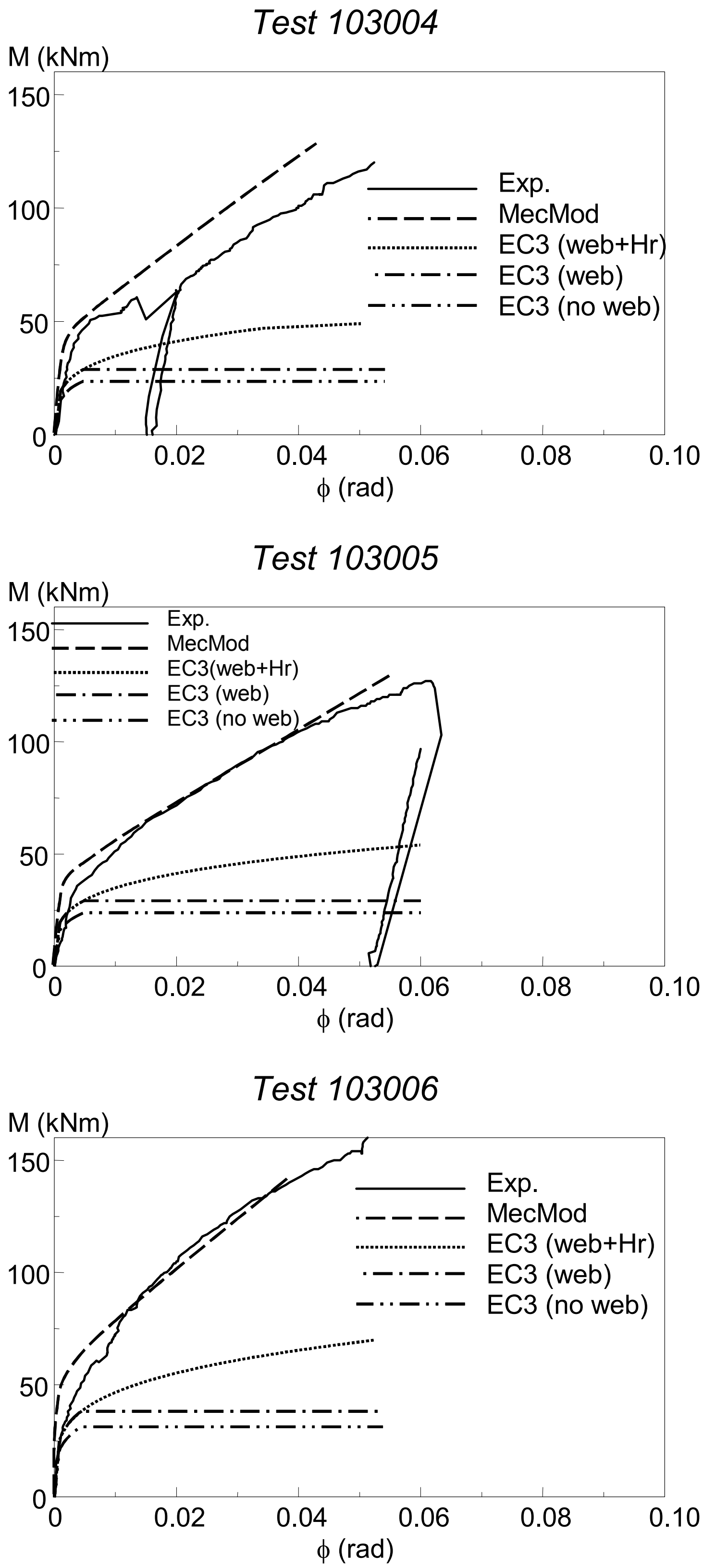


Figure 18. Comparison among Annex J, M.S.M. and Experimental “Sericon” Data

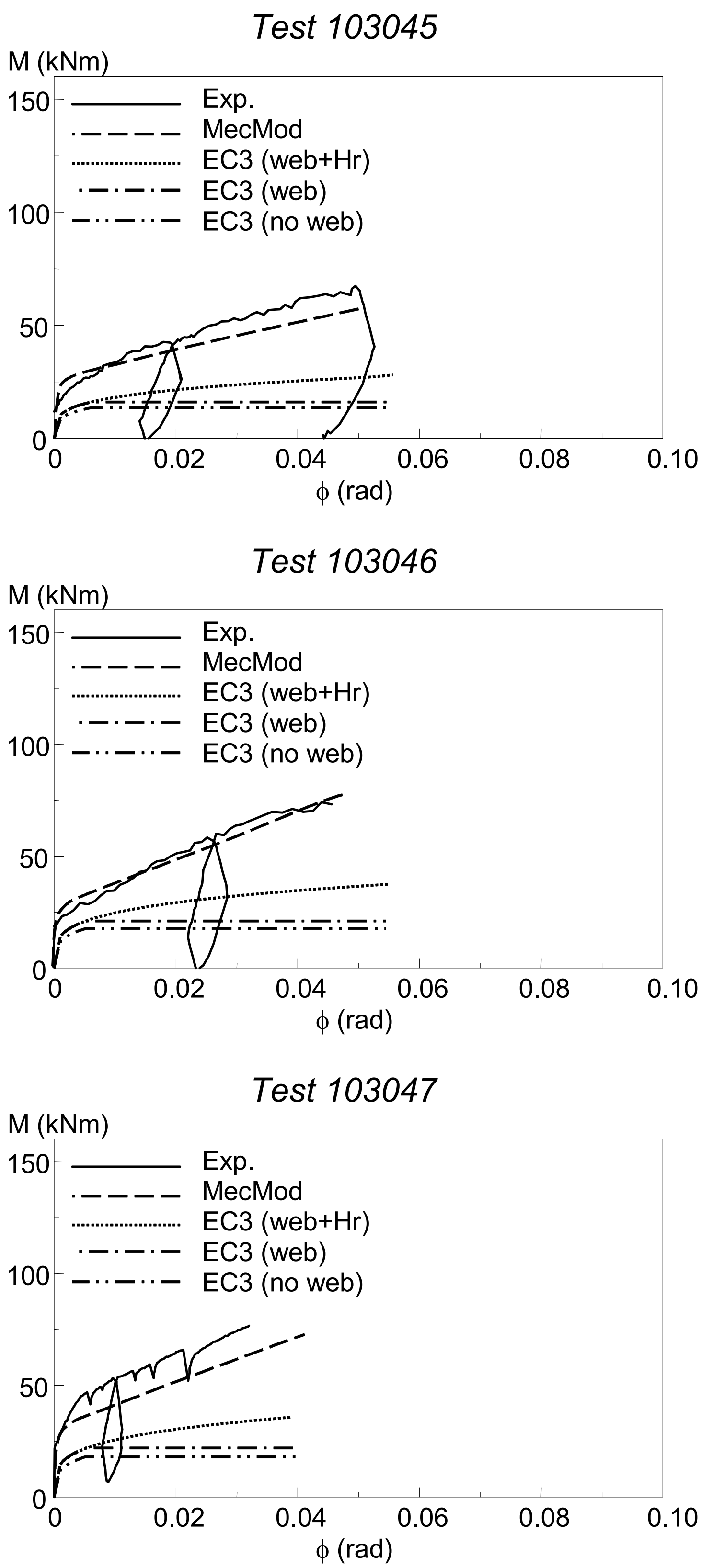


Figure 19. Comparison among Annex J, M.S.M. and Experimental “Sericon” Data

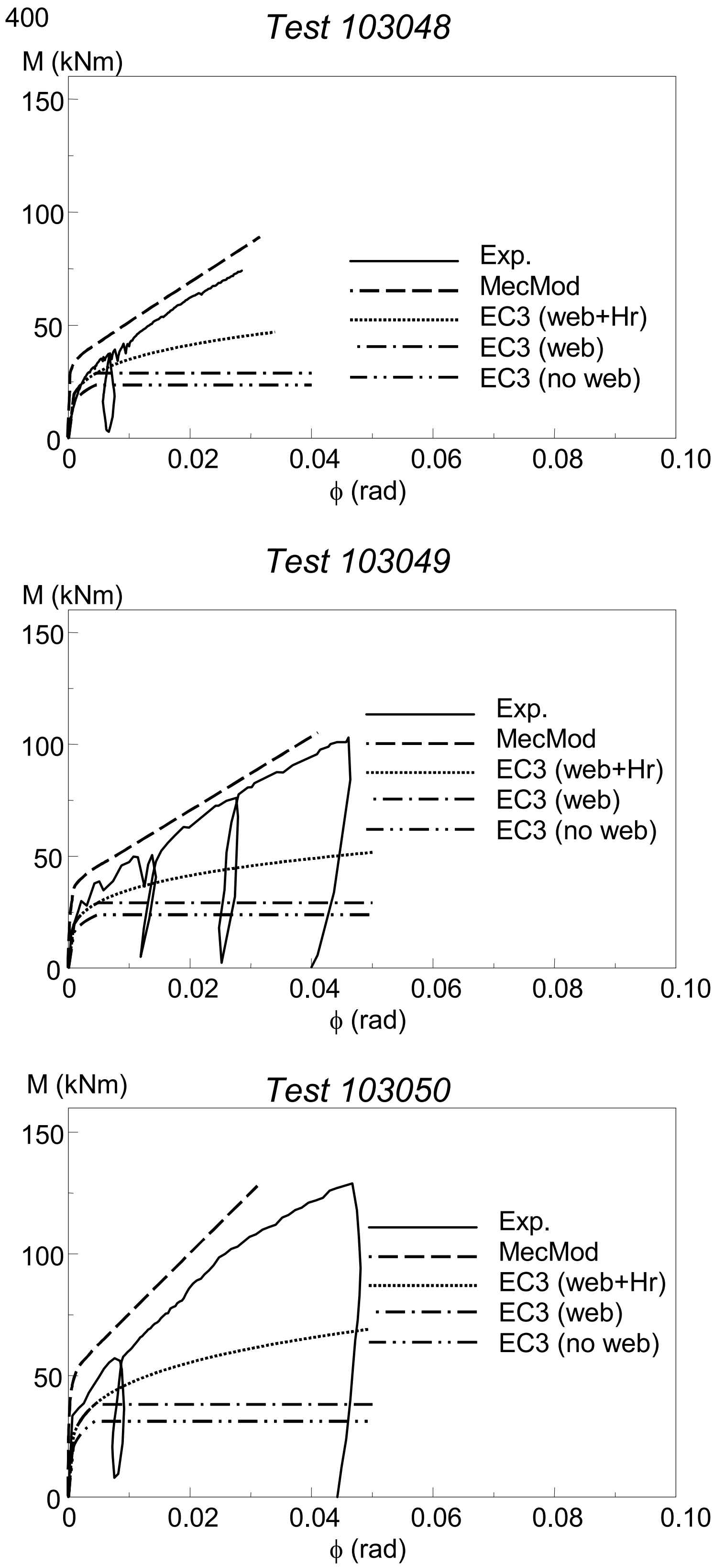


Figure 20. Comparison among Annex J, M.S.M. and Experimental “Sericon” Data

The "modified" Eurocode 3 application (top and seat & web cleats, top and seat & web cleats plus hardening) has shown a better accuracy, but it underestimates the resistance and sometimes it overestimates the stiffness. The web cleat's contribution, in the EC3, produces an increment of the strength about of 10 to 20%. The application of the Eurocode 3, by considering the web cleat plus hardening, shows a better assessment of the actual behaviour of the connections. The mechanical model (MecMod) shows a better evaluation of actual behaviour of the connections, especially on what concerns the prediction of the design moment resistance. The MecMod is able to predict the actual behaviour of different type of connections. The comparison between the moment-rotation curves of mechanical model and the Bernuzzi experimental curves (figures 21, 22, 23 and 24) show a good capability of MecMod on simulating the actual cyclic behaviour of this type of connection. The MecMod, in this first stage, does not take into account the phenomena of stiffness and resistance degradation.

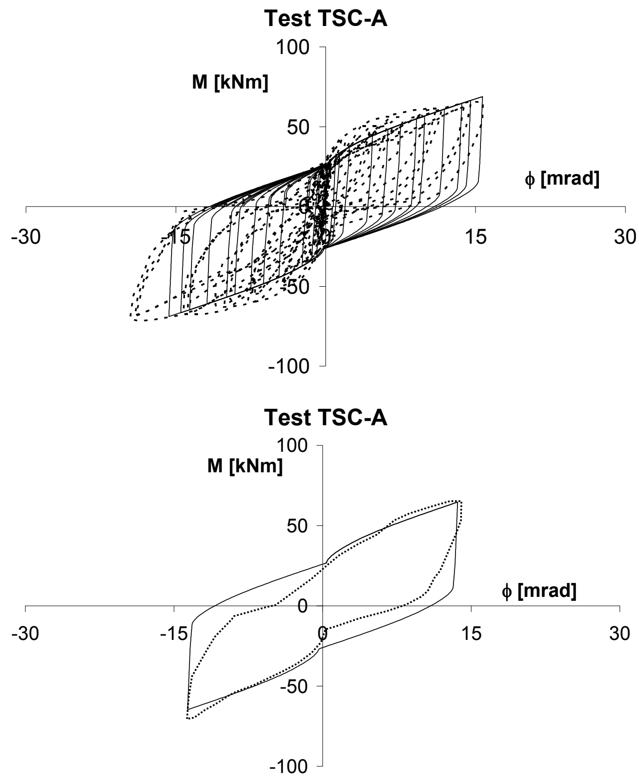


Figure 21. Comparison among Annex J, MecMod. and Experimental "Bernuzzi" Curve

In the same figures, a cycle of mechanical model is compared with an experimental one. It is possible to see the capacity of the model predicting the actual design moment resistance of the investigated connections.

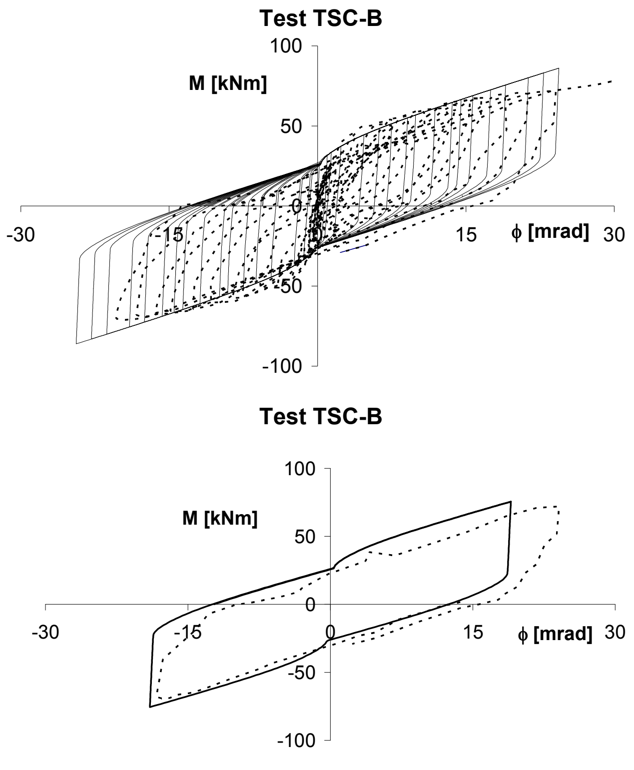


Figure 22. Comparison among Annex J, MecMod. and Experimental “Bernuzzi” Curve

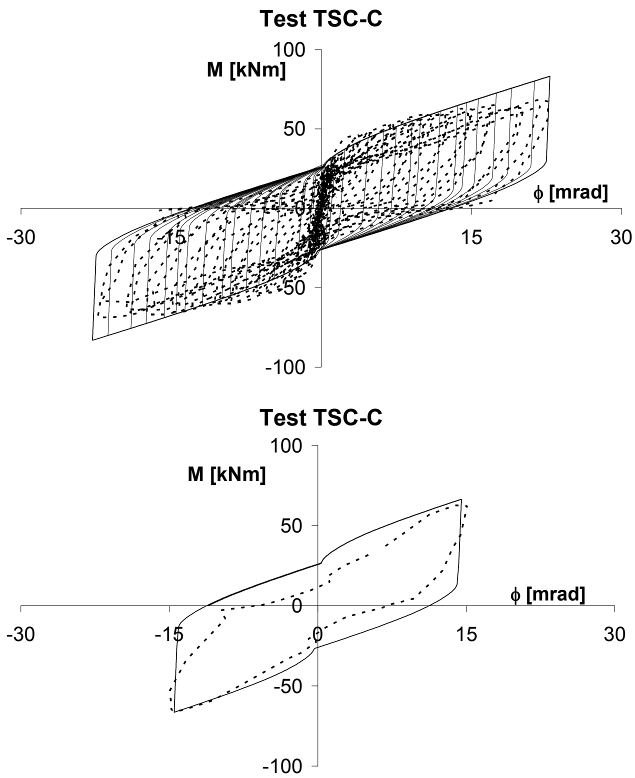


Figure 23. Comparison among Annex J, MecMod. and Experimental “Bernuzzi” Curve

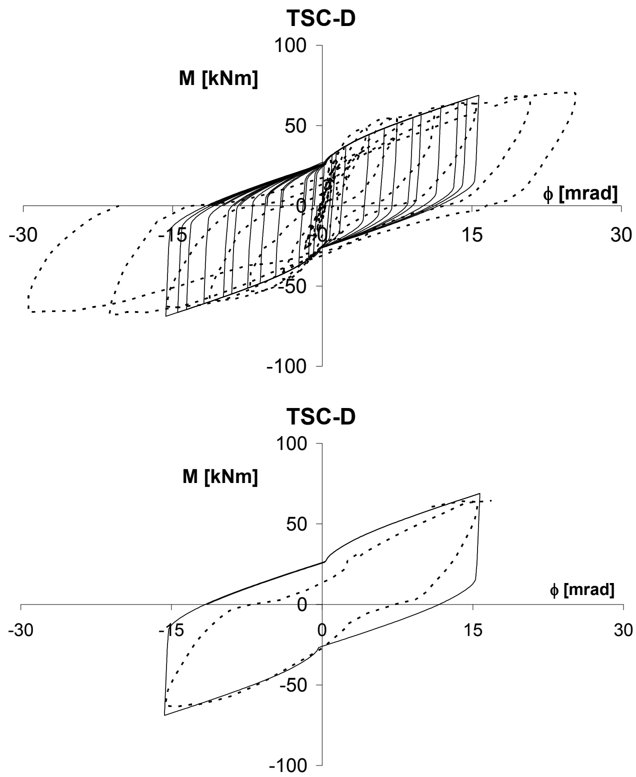


Figure 24. Comparison among Annex J, MecMod. and Experimental "Bernuzzi" Curve

6. CONCLUSIONS

The mechanical model for the inelastic analysis of semi-rigid and partial-strength top and seat angle bolted connections presented was based on the same "component approach" introduced by the Eurocode 3. The Eurocode 3 approach is still maintained, but has been introduced a more refined modelling of the cleat-to-column interface and a different expression for the evaluation of the moment capacity of the joint. It takes into account the effect of d/t_a and d/t_a ratios. The proposed mechanical model can be included into existing code for the analysis of MRSF, which includes joint types. These conducted analyses yield results in agreement to the experimental data and they are more accurate than the results obtained by the Eurocode 3-Annex J model.

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