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A PROPOSAL FOR THE MECHANICAL CLASSIFICATION OF BEAM-TO-COLUMN JOINTS FOR TIMBER STRUCTURES

Giacomo Iovane, Celeste Noviello, Federico M. Mazzolani, Raffaele Landolfo, Beatrice Faggiano

ABSTRACT: The performance of timber structures is greatly influenced by the capacity of the connections, in terms of both strength and stiffness, as well as ductility. Reliable estimations of the structural behaviour of timber buildings is possible through a full understanding of the joint behaviour. At present there is not a standard method that allows to identify the mechanical behaviour of timber connections. To fill this gap, in this paper, a procedure for the classification in terms of strength and stiffness of beam-to-column joints in timber structures is presented. The method is inspired to that one related to steel connections according to Eurocode 3. Then, with reference to a number of experimental studies available in the scientific literature on several timber beam-to-column joints, the proposed classification method is applied on typical configurations, evidencing that common joints can be classified as pinned or semi-rigid.

KEYWORDS: Timber structures, moment resisting frames, beam-to-column joints, joint mechanical classification.

1 INTRODUCTION

In timber constructions, joints have great influence on both local and global structural behaviours. Indeed they realize the constraints and restraints conditions of the structural systems, which the structural models for a reliable estimation of the internal forces and deformations are based on. Therefore a full understanding of the joint mechanical properties, such as strength, stiffness and also ductility, is essential. It is also worth to notice that timber members sizes can be determined by the number and type of connectors rather than by the strength requirements for members.

With regards to Moment Resisting Frames (MRF), several experimental studies have been recently carried out on common timber beam-to-column joints, aimed at evaluating the strength and stiffness capabilities [1-9].

However, both in national and international standards, there is not a method that allows to identify the mechanical behaviour of timber connections. To this purpose the moment-rotation relationship should be characterized.

In this paper, a procedure for the classification in terms of strength and stiffness of beam-to-column joints for timber structures is presented. The method is inspired by the classification procedure for steel connections, consolidated and well described in the Eurocode 3 part 1.8 [10], conveniently adapted according to timber connections characteristics. Then, with reference to several experimental studies available in the scientific literature, common configurations of timber beam-to-column connections, whose experimental moment rotation curves were available, have been classified in terms of stiffness by means of the proposed method.

Giacomo Iovane, giacomo.iovane@unina.it; Celeste Noviello, ce.noviello@gmail.com; Federico M. Mazzolani, fmm@unina.it; Raffaele Landolfo, landolfo@unina.it; Beatrice Faggiano, faggiano@unina.it; University of Naples Federico II, Department of Structure for Engineering and Architecture, Via Claudio 21, 80125, Naples, Italy

2 JOINT MECHANICAL CLASSIFICATION ACCORDING TO EUROCODE 3

As indicated in section 6.1 of EC3 part 1-8 [10] for steel constructions, the mechanical model of a joint may be represented by a rotational spring joining the centre lines of the connected members at the point of intersection, for a single-sided beam-to-column joint configuration. The properties of the spring can be expressed in terms of moment-rotation (M-θ) characteristic that describes the relationship between the bending moment $M_{j,Ed}$ applied to the joint and the corresponding rotation θ_{jEd} between the connected members (referring to the j-th member).

The design moment-rotation characteristic should define the following three main structural properties:

- bending moment resistance ($M_{j,Rd}$);
- rotational stiffness (S_j);
- rotational capacity ($\theta_{j,}$).

The complex mechanical behaviour of joints in terms of strength, stiffness and rotational capacity can be determined through the component method (section 6.1, [10]). The joint is analysed as an assembly of components, whose mechanical behaviour is studied separately, and the design resistance of the joint is assumed as the resistance of the weakest joint component, with reference to all the possible collapse modes.

According to Eurocode 3, part: 1-8 [10], in order to identify the effects of joint behaviour on the global structural analysis, three simplified joint models can be distinguished (Tab. 1): 1) *simple joints*, the joint may be assumed not to transfer bending moments; 2) *continuous*

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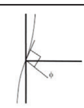
joint, the joint may be assumed to transfer the bending moments; 3) *semi-continuous joints*, the joint transfers the bending moments in some extents according to the joint rotational stiffness.

***Table 1**: Type of joint model [10].*

Method of analysis	Classification of joint		
Elastic	Nominally pinned	Rigid	Semi-rigid
Rigid-plastic		Full-strength	Partial-strength
Elastic-plastic		Rigid and full-strength	Semi-rigid and partial-strength; Semi-rigid and full-strength; Rigid and partial-strength
	Simple	*Continuous*	*Semi-continuous*
Type of joint model			

With reference to the Moment-rotation (M-θ) relationship, beam-to-column connections can be classified considering three different methods of structural analysis:

a) *elastic analysis*, based on a linear Moment-rotation (M-θ) relationship, where joints are classified according to rotational stiffness S_j (Fig. 1a);
b) *rigid-plastic analysis*, where joints are classified according to strength, provided that they are able to develop suitable plastic rotation (Fig. 1b);
c) *elastic-plastic analysis*, based on a bi-linear M-θ relationship, in which joints are classified according to both stiffness and strength, considering also the rotational capacity (Fig. 1c).

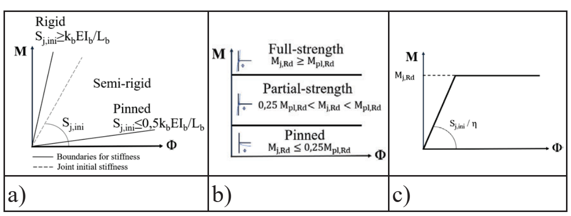


***Figure 1:** The EC3 joint classification in terms of a) stiffness, b) strength and c) stiffness and strength.*

It is worth noted that the stiffness of the connection should be compared to the stiffness of the connected members. Therefore the joint classification by stiffness can be expressed in terms of a non-dimensional stiffness parameter $\bar{k}$ (eq. 1), depending on the ratio between the initial joint rotational stiffness $S_{j,ini}$ and the bending stiffness of the connected beam (Fig. 1a):

$$\bar{k} = \frac{S_{j,ini}}{\left(\frac{E_S \cdot I_b}{L_b}\right)} \tag{1}$$

where $S_{j,ini}$ corresponds to the elastic bending moment $M_{j,el}$, not exceeding 2/3 $M_{j,Rd}$ ($M_{j,Rd}$ being the design bending strength of the joint), and to the rotation at the elastic limit $\theta_{j,el}$, L_b is the beam span, E_s is the steel elastic modulus and I_b is the beam cross-section moment of inertia. Therefore a joint can be classified as nominally pinned if $\bar{k} \leq 0.5$; semi-rigid if $0.5 < \bar{k} < k_b$; rigid if $\bar{k} \geq k_b$, with $k_b = 8$ for braced frames and $k_b = 25$ for moment resisting frames (Tab. 1). A nominally pinned joint shall be capable of allowing rotations due to design loads and transmitting internal forces, without developing significant bending moments; a rigid joint shall be capable of having a sufficient rotational stiffness to assume the continuity; a joint which does not meet the criteria for a rigid or a nominally pinned joint should be classified as a semi-rigid joint (Fig. 1a).
A joint is classified by strength (rigid-plastic analysis), depending on the ratio between the bending strength $M_{j,Rd}$ of the joint and the bending strength of the connected beam $M_{b,Rd}$ (Fig. 1b; eq. 2), namely the non-dimensional moment resistance parameter (eq. 2):

$$\bar{m} = \frac{M_{j,Rd}}{M_{b,Rd}} \tag{2}$$

Therefore, a joint can be classified as nominally pinned if $M_{j,Rd} \leq 0.25\ M_{b,Rd}$, partial strength if $0.25\ M_{b,Rd} < M_{j,Rd} < M_{b,Rd}$ ($0.25 < \bar{m} < 1$), full strength if $M_{j,Rd} \geq M_{b,Rd}$ ($\bar{m} \geq 1$, Tab. 1).
In a joint classification according to both stiffness and strength (elastic-plastic analysis), as a simplification of the non-linear moment-rotation behaviour, a bi-linear design moment-rotation characteristic may be adopted (Fig. 1c). Therefore, a joint can be classified as semi-rigid and partial-strength; semi-rigid and full-strength or rigid and partial-strength (Tab. 1). As a simplification, the rotational stiffness can be evaluated as $S_{j,ini}/\eta$ (Table 5.2, section 5.1.2 [10]), where η is a coefficient reliant on the connection type.

3 CLASSIFICATION BY STIFFNESS OF TYPICAL TIMBER BEAM-TO-COLUMN JOINTS

3.1 PROPOSED CLASSIFICATION METHOD FOR TIMBER BEAM-TO-COLUMN JOINTS

For the classification of timber joints, it is possible to apply the same method used for steel connections, conveniently modified to consider the timber material characteristics. In particular, the extension of the EC3 classification to timber joints is based on considering the elastic bending strength of the timber beam, $M_{b,el}$, and the timber elastic modulus, E_T.
The steel EC3 formulations for the joint classification in terms of stiffness ($S_{j,ini}$) and strength ($M_{j,el}$) can be suitably revised, by defining the non-dimensional stiffness and strength parameters $\bar{k}$ and $\bar{m}$, as it follows (Eq. 3, 4):

$$\bar{k} = \frac{S_{j,ini} \cdot L_b}{E_T \cdot I_b} \tag{3}$$

$$\bar{m} = \frac{M_{j,Rd}}{M_{b,el}} \tag{4}$$

where $S_{j,ini}$, $M_{j,el}$, $M_{j,Rd}$, $M_{b,el}$ and L_b have been previously defined, E_T is the timber elastic modulus, I_b is the timber beam cross-section moment of inertia.

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3.2 APPLICATION OF THE PROPOSED CLASSIFICATION METHOD TO LITERATURE TIMBER BEAM-TO-COLUMN JOINTS

3.2.1 Case studies of beam-to-column joints

From the literature review on experimental campaigns, four recurring types of timber beam-to-column joints can be identified (Fig. 2, 3, 4):

Type 1. Connection with internal or lateral vertical steel plate (rectangular- or T-shaped) and connectors (generally bolts, screws or pins; [3-5, 11-14])

Type 2. Connection with circular arrangement of connectors (generally bolts or screws; [5, 15]);

Type 3. Connection with top and bottom plates or brackets and connectors (generally bolts or screws; [1, 16]);

Type 4. Timber joint equipped with steel link [2, 17, 18].

A total of 46 joints are examined. In particular, for each joint type, the specimens are represented in Figures 2-4 and the number of tests carried out for each type, as well as the beam and column members sizes are provided in Table 2.

Among Type 1 joints, Wang et al. [4] have studied a beam to column joint with internal T-shaped 9.5mm thick steel plate (S235 steel grade) and bolts (M20, 8.8 steel grade), as base specimen S1, specimen S2 reinforced with screws orthogonal to the grains of the beam and column; specimen S3 locally made with cross-laminated glulam timber. The S2 and S3 specimens show increased stiffness and strength as respect to S1. A similar beam to column joint with internal T-shaped 10mm thick steel plate (S235 steel grade) and M16 bolt (8.8 grade), is studied by He and Liu [3], as base specimen S1, specimen S2 reinforced with bars, specimen S3 reinforced with self-tapping screws, in both cases arranged orthogonal to the grains of beam and column. The stiffnesses result quite similar. He et al. [12] analysed the same joint reinforced with hollow PVC tubes in the holes of the timber elements and with screws orthogonal to the grains. These reinforcements led to an increase in strength and stiffness as respect to the non-reinforced specimen. Beltran [5] tested a beam to column joint configuration with internal T-shaped 6.35mm thick steel plate (ASTM A36 steel grade) and connected bolts in a rectangular arrangement (M12, ASTM A325 steel grade). Salem and Petrycki [13] studied a beam to column joint with two external steel plates for evaluating the influence of the number of bolts (M20, ASTM A325 steel grade) and of the edge distance on the strength and stiffness. In particular, four different types of connection have been tested: edge distance equal to 4ϕ (where ϕ is the bolt diameter) and 3x4 bolts (in a rectangular arrangement); edge distance equal to 4ϕ and 3x6 bolts; edge distance equal to 5ϕ and 3x4 bolts; edge distance equal to 5ϕ and 3x6 bolts. The same specimens are tested by using a T-shaped steel plate by Salem [14]. The variation of the edge distance from 4 to 5 ϕ provides a larger increase of bending moment resistance than the variation of the bolts number from 4 to 6. The reverse happens with the internal steel plate. However, in general, from the test results, a low variation of stiffness among the specimen can be observed.

Wang et al. [11] have studied a post-tensioned (PT) energy dissipating beam to column joint, to provide self-centering capacity, connected with a T-shaped steel plate and bolts (M16-20). In particular, two specimens are tested, by varying the post-tensioned force applied to the steel strand (S1=40kN; S2=60kN). The joints shown similar stiffnesses (Fig. 2).

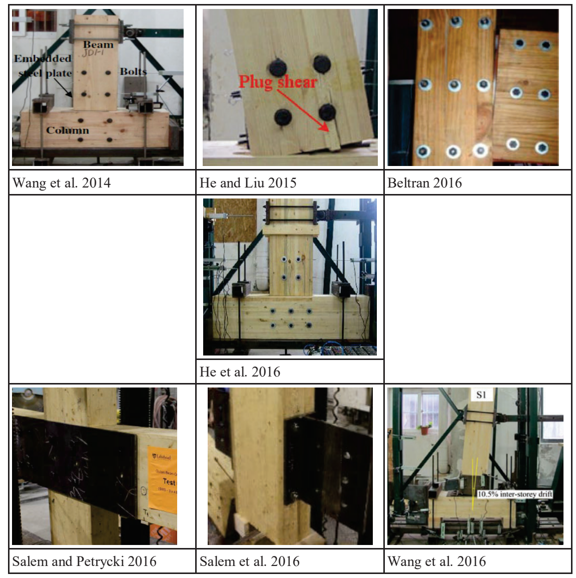

Figure 2: *Type 1 literature beam-to-column testing joints .*

Among Type 2 joints, Polastri [15] have tested different types of connection: beam to column joint configuration connected with pins (M12, 14, 16) in single (T01) and double (T08, T09) circular arrangements, with glued bars in single (T06) and double (T10) circular arrangements, as well as with a glued connection between timber members (T07). As a result, the glued connections (T06, T10) show higher stiffness and strength as respect to the other connection types. Beltran [5] have tested a beam-to-column joint with two different types of connection: bolts in a circular arrangement (M9, ASTM A307 steel grade); internal T-shaped 6.35mm thick steel plate (ASTM A36 steel grade) connected with bolts with different diameter, steel grade and arrangement (Fig. 3).

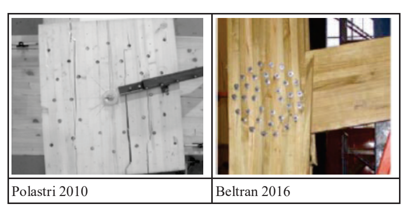

Figure 3: *Type 2 literature beam-to-column testing joints.*

Among Type 3 joints, Kasal et al. [1, 16] have tested a beam to column joint with two L-shaped aluminium angles located at the beam end top and bottom, connected to the beam through inclined self-tapping screws and to the column with horizontal self-tapping screws (Φ6.5-12mm), and a beam to column joint with two timber

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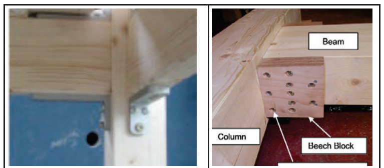
rectangular-shaped plates connected to the beam end top and bottom through inclined self-tapping screws and to the column with horizontal self-tapping screws (Φ6.5-12mm). Both the connections have shown good values of stiffness and strength (Fig. 4).



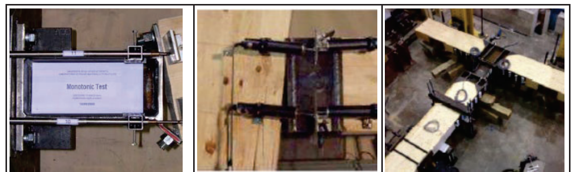
Kasal et al. 2010 | Kasal et al. 2014

Figure 4: *Type 3 literature beam-to-column testing joints .*

Table 2: *Study joints geometrical features.*

Reference studies	Number of tests	Timber member size B x H x L [mm]	
		Beam	Column
Type 1			
Wang et al. 2014	3	130x305x830	272x305x1000
He and Liu 2015	3	200x300x850	250x300x1100
Beltran et al. 2016	2	135x400x1300	200x270x2900
He et al. 2016	3	150x384x1000	240x384x1400
Salem and Petrycki 2016	4	137x318x1541	137x318x1541
Salem 2016	4		
Wang et al. 2016	2	200x300x1500	250x250x1000
Type 2			
Polastri 2010	6	120x600x3410	160x600x3410
Beltran et al. 2016	2	140x400x1300	100x400x3000
Type 3			
Kasal et al. 2010	1	40x120x800	80x80x800
Kasal et al. 2014	1	160x360x1500	200x200x2200
Type 4			
Andreolli 2011	8	120x230x2500	/
Nakatani et al. 2012	3	120x270x1200	120x270x1900
Gohlich and Erochko 2016	4	184x457x2000	184x457x1500
B: Base; H: Height; L: Length			

Type 4 joints have been conceived for seismic dissipative structures to delegate the dissipation capacity to the steel link, avoiding the failure of connections and timber members, which should remain in elastic field in case of earthquake. By integrating the timber technology with steel devices, some authors have proposed different solutions. Andreolli [17] have focused on 8 beam to column joint assemblages equipped with steel link (HE120B profile) connected to the beam by means of 4 glued threaded bars (M16, 6.8 grade, 540mm long), for investigating the joint behaviour with variable end-plate thicknesses (6-8-10-15-20mm). At the end of the tests, joints with large thickness of steel plate have reached higher stiffness and dissipative capacity through the plastic combined tensile-bending deformation of the bars and the bending deformation of the end-plate. Nakatani et al. [2] have tested a beam to column joint equipped with a box steel link connected by means of lag-screw-bolts embedded into the beam parallel to the grain and into the column in 3 different configurations: perpendicular to the grain; perpendicular and with a skew angle as respect to the grain; with a skew angle as respect to the grain. Joints with greater connector inclination have exhibited increased stiffness and strength, with a bolts pull-out failure. Gohlich and Erochko [18] have studied a beam to column joint equipped with steel link connected to the timber members by means of inclined screws, also varying the link profile and the inclination of connectors: dog-bone W250x28 steel profile with 45° inclination screws (Φ10,12mm SWG ASSY); dog-bone W250x28 steel profile with 30° inclination double screws; W200x25 steel profile with 45° inclination screws; W200x25 steel profile with 30° inclination double screws . The joints with dog-bone profile have shown a better performance in terms of both stiffness and ductility than the other connection types (Fig. 5).



Andreolli 2011 | Nakatani et al. 2012 | Gohlich, and Erochko 2016

Figure 5: *Type 4 literature beam-to-column testing joints .*

3.2.2 Classification of the joint case studies

For the study joints, the initial rotational stiffness ($S_{j,ini}$), the joint elastic bending moment ($M_{j,el}$) and the corresponding rotation ($\theta_{j,el}$) are evaluated starting from the Moment-rotation (M-θ) experimental curves from literature, according to the proposed method. The mechanical parameters are indicated in Table 3.

Moreover, the reference initial rotational stiffnesses for a pinned joint $S_{j,pinned}$ (eq. 5) and a rigid joint $S_{j,rigid}$ of a moment resisting frames (eq. 6) are calculated as it follows and given in Table 3:

$$S_{j,pinned} = \frac{0.5 E_T I_b}{L_b} \tag{5}$$

$$S_{j,rigid} = \frac{25 E_T I_b}{L_b} \tag{6}$$

Therefore, a joint can be classified by comparing the initial rotational stiffness of the joint with the reference ones as it follows:

$S_{j,ini} \leq S_{j,pinned}$ Nominally pinned;

$S_{j,pinned} < S_{j,ini} < S_{j,rigid}$ Semi-rigid;

$S_{j,ini} \geq S_{j,rigid}$ Rigid.

The joint classification by stiffness is also presented in terms of non-dimensional parameters, through the Moment-rotation ($\bar{m}$-$\bar{\theta}$) curves, which are defined based on the following equations (eq. 7, 8):

$$\bar{m} = \frac{M_{j,Rd}}{M_{b,el}} \tag{7}$$

$$\bar{\theta} = \theta_{j,Rd} \frac{E_T \cdot I_b}{L_b \cdot M_{b,el}} \tag{8}$$

where $\theta_{j,Rd}$ is the joint rotation corresponding to $M_{j,Rd}$, evaluated as $M_{j,Rd}/S_{j,ini}$.

The results of the proposed joints classification by stiffness in terms of $\bar{m}$-$\bar{\theta}$ curves are reported in Figure 6.

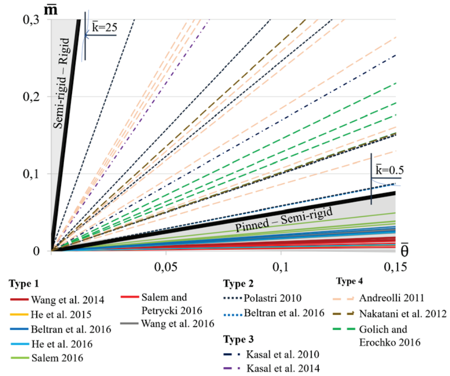


Figure 6: *Classification by stiffness of study joints.*

Table 3: *Classification by stiffness of study joints.*

Reference studies	$S_{j,pinned}$	$S_{j,rigid}$	$M_{j,el}$	$\theta_{j,el}$	$S_{j,ini}$
	[kNm/rad]		[kNm]	[rad]	[kNm/rad]
Type 1					
Wang et al. 2014	1759	87953	57.8	0.141	404.1
			35.6	0.101	334.5
			33.9	0.101	329.4
He and Liu 2015	2552	127602	22.2	0.092	256.2
			14.7	0.081	257.4
			27.1	0.113	276.3
Beltrán 2016	2215	110769	42.0	0.040	934.4
	1859	92985	89.6	0.041	2149.7
He et al. 2016	3362	168099	20.0	0.052	382.2
			20.0	0.012	1637.8
			20.0	0.012	1637.8
Salem and Petrycki 2016	1561	78024	19.0	0.198	95.9
			22.4	0.157	142.5
			20.6	0.101	206.5
			24.0	0.092	260.8
			29.5	0.041	737.5
Salem 2016			16.8	0.021	800.0
			18.6	0.023	810.8
			10.3	0.010	1030.0
Wang et al. 2016	1826	91312	38.3	0.056	677.8
			36.9	0.063	585.7
Type 2					
Polastri 2010	3674	183695	61.4	0.014	4297.0
			80.1	0.004	18033.0
			134.2	0.002	60912.0
			105.7	0.014	7379.0
			134.1	0.018	7345.0
			128.4	0.006	23103.0
Beltrán 2016	2297	114871	55.2	0.072	796.8
	2303	115158	44.0	0.050	905.7
Type 3					
Kasal et al. 2010	43	2160	1.9	0.013	146.15
Kasal et al. 2014	2405	120269	90.2	0.004	20976.7
Type 4					
Andreolli 2011	401	20045	11.1	0.007	1480.0
			8.3	0.012	691.6
			15.08	0.008	1885.0
			10.3	0.011	936.4
			14.8	0.004	3700.0
			18.65	0.009	2072.2
			23.2	0.006	3858.3
			32.3	0.008	4036.3
Nakatani et al. 2012	985	49208	16.0	0.003	5333.3
			16.0	0.008	2000.0
			16.0	0.008	2000.0
Gohlich and Erochko 2016	4792	239643	86.0	0.008	9772.7
			99.1	0.008	11261.4
			110.2	0.009	12244.4
			125.0	0.009	13888.9

Pinned joint
Semi-rigid joint

3.3 ANALYSIS OF JOINTS CLASSIFICATION

As a result of the classification, for a total of 46 joints examined, 22 are pinned, while 24 are semi-rigid.

Among Type 1 joints, most connections are classified as pinned joints [3-5, 11-14], except one specimen [5], characterized by an internal T-shaped steel plate connected to the beam with a circular arrangement of screws and to the column with a rectangular arrangement of bolts, which is classified as semi-rigid joint.

Among Type 2 joints, the connections tested by Polastri [15], characterized by beam with double column and a circular arrangement of pins, or glued bars, or glued connection between timber members, are classified as semi-rigid joints, while the two specimens tested by Beltran [5], characterized by beam with double column and a circular arrangement of bolts, are classified as pinned joint.

Among Type 3 joints, the connection tested by Kasal et al. [1], characterized by two aluminium L-shaped plates and screws, as well as the connection tested by Kasal et al. [16], characterized by two timber rectangular-shaped plates and screws, are both classified as semi-rigid joints.

All timber joints equipped with steel link (Type 4) are classified as semi-rigid joints [2, 17, 18].

In particular, among the semirigid category, for Type 1, the beam-to-column joint tested by Beltran [5] with internal steel plate connected at the beam with a circular arrangement of screws and at the column with a rectangular arrangement of bolts is the only semi-rigid joint. It is worth noticed that it shows the lowest initial stiffness ($S_{C,ini}$=2149.7kNm/rad) than all the other studied semi-rigid joints. For Type 2, the joint with the greatest initial stiffness is the T07 specimen ($S_{T07,ini}$=60912kNm/rad) tested by Polastri [15], which is configured as a glued joint, characterized by the complete gluing of the timber members, confirming the lower deformation of the glued joints compared to the traditional ones. For Type 3, the joint specimen tested by Kasal et al. [16], which has two timber rectangular-shaped plates connected to the beam end top and bottom, shows a higher initial stiffness ($S_{A,ini}$=20976.7kNm/rad) than the joint specimen tested by Kasal et al. [1], which has angles located at the beam end top and bottom ($S_{A,ini}$=146.15kNm/rad). For Type 4, the joint with the greatest initial stiffness is the P20, followed by the P15-10 ($S_{P20,ini}$=4036.3kNm/rad; $S_{P15,ini}$= 3858.3kNm/rad; $S_{P10,ini}$=3700kNm/rad) beam-to-column joints equipped with steel link tested by Andreolli [17], with steel end-plate thicknesses equal to 20-15-10mm respectively and the connecting threaded bars glued in the beam. Next, the beam-to-column joints tested by Nakatani et al. [2], which have a box steel link connected to the timber beam and column with glued threaded rods, follows in the stiffness classification (S_{ini}=2000.0kNm/rad). At last, all beam-to-column joints equipped with steel link profile and dog-bone profile, tested by Golich and Erochko [18] ($S_{MC-1A,ini}$=13888.9; $S_{MC-1B,ini}$=12244.4kNm/rad), are classified as semi-rigid joints, showing high initial stiffness values.

4 CONCLUSIVE REMARKS

The paper focuses on the proposal of a method for the

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mechanical classification of timber beam-to-column joints. In particular, the procedure for the mechanical classification of beam-to-column joints in timber MR framed structures is a suitable and efficient adaptation of that one related to steel joints presented in the Eurocode 3 part: 1-8, taking into account the timber structural features. The classification procedure, in terms of stiffness, has been applied to 46 joints studied through experimental tests in the scientific literature. Specifically, four types of joints have been identified: connection with internal or lateral vertical steel plate and connectors (Type 1); connection with connectors in circular arrangement (Type 2); connection with top and bottom plates or brackets and connectors (Type 3); timber joint equipped with steel link (Type 4). The classification of the joints in terms of stiffness has evidenced that 48% of the joints can be classified as pinned joints, while 52% of the joints can be classified as semi-rigid joints.

In particular, in semirigid joints category, beam-to-column joints with glued connection, such as the beam-to-column joint with glued connection between timber members tested by Polastri [15] and the beam-to-column joint equipped with steel link by means of 4 glued threaded bars tested by Andreolli [17], show higher stiffness values than the other joints tested:.

The study is in progress toward the application of the classification method to other beam-to-column joint types and configurations, whose moment-rotation curves have been achieved through experimental tests or even numerical investigations on well refined models, selected from the scientific literature. Moreover where the joints descriptions are completed of every mechanical details, the component method will be applied to better understand the contribution of the connection components features on the mechanical properties of the joints.

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