Characterisation of beam-to-column steel-concrete composite joints beyond current Eurocode provisions

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Abstract

In EN 1994-1-1, design rules are given for the evaluation of the mechanical properties of structural steel-concrete composite joints (rotational stiffness, resistance and ductility). The proposed rules are based on the component method as recommended in EN 1993-1-8 and, in particular, rules for components specific to composite joints are provided in EN 1994-1-1. The main weakness of the rules as presently proposed is that they are only covering cases where composite joints are subjected to shear forces and hogging moments while, in practice, such joints can be subjected to other loading conditions such as sagging bending moments, cyclic loadings, combined bending moments and axial loads, elevated temperatures etc. It is the reason why, during the last decades, researches have been conducted in this field with the objective of improving/extending the rules presently recommended in the Eurocodes.

The present paper highlights the main outcomes from part of these researches conducted at Liège University and at University Politehnica Timisoara which could be seen as proposals for future improvements of the beam-to-column provisions in Eurocodes in general and of Eurocode 4 in particular.

Keywords (max 10): composite joints, component method, static loading, cyclic loading, exceptional loading, robustness, seismic loading.

1. Introduction

Nowadays, the component method is a widely recognised procedure for the prediction of the design properties of structural joints. This method is the one recommended in the Eurocodes for the characterisation of structural joints and applies to any type of steel or composite joints, whatever the geometrical configuration, the type of loading (axial force and/or bending moment...) and the type of member sections.

This method considers any joint as a set of individual basic components modelled as springs – see Fig. 1. Each of these components possesses its own strength and stiffness either in tension or in compression or in shear. The column web is subject to coincident compression, tension and shear. This coexistence of several internal forces within the same joint element can obviously lead to stress interactions that are likely to decrease the resistance of the individual basic components; the latter is taken into account within the method.

The application of the component method requires the following steps: (i) identification of the active components in the joint being considered; (ii) evaluation of the mechanical properties for each individual basic component in terms of specific characteristics: initial stiffness, design resistance etc. or the whole deformability curve and; (iii) assembly of all the components and evaluation of the mechanical properties of the whole joint in specific characteristics: initial stiffness, design resistance etc. leading to a final moment-rotation design curve.

The application of the component method requires a sufficient knowledge of the behaviour of the basic components. Those covered by Eurocode 3 for steel joints are listed in Table 1 (components 1 to 12); those covered by Eurocode 4 for composite joints are identical to the steel joints by considering two additional components also presented in Table 1 (components 13 and 14). Also, Eurocode 4 covers components which are reinforced by the presence of concrete (column web panel in shear or column web in compression in a composite column). The combination of these components allows to cover a wide range of steel and steel-concrete composite joint configurations. However, the rules as presently reported in the Eurocodes only cover the situations for composite joints subjected to shear forces and hogging moments. It is the reason why, during the last decades, researches have been conducted on the behaviour of composite joints subjected to different kind of actions such as sagging bending moments, cyclic loadings, combined bending moments and axial loads, elevated temperatures etc. with the objective of improving/extending the recommendations presently proposed in the Eurocodes.

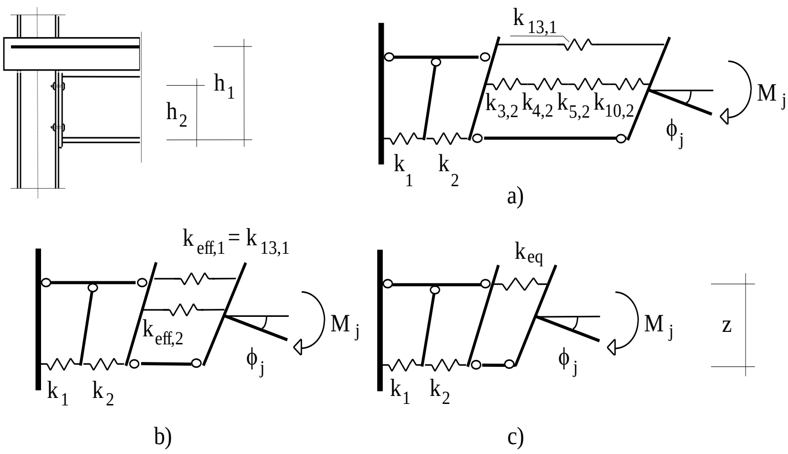

Figure 1. Example of a spring model for a composite flush end-plate connection [1]

N°	Components
1	Column web panel in shear
2	Column web in compression
3	Beam flange and web in compression
4	Column flange in bending
5	Column web in tension
6	End-plate in bending
7	Beam web in tension
8	Flange cleat in bending
9	Bolts in tension
10	Bolts in shear
11	Bolts in bearing
12	Plate in tension or compression
13	Longitudinal steel rebars in tension
14	Steel contact plate in compression

Table 1. Components covered by Eurocode 3 and Eurocode 4.

Next sections summarise main outcomes of recent researches conducted at Liege University and at University Politehnica Timisoara which could be seen as background information for a possible future improvement of the beam-to-column joint provisions in Eurocodes in general and in Eurocode 4 in particular. Section 2 will first reflect recent developments performed on the behaviour of composite joints subjected to static loading and, in particular to sagging moment and combined bending moments and axial loads. Then Section 3 summarise a recent study on the behaviour of composite joint subjected to elevated temperature. Finally, the behaviour of joints subjected seismic actions and, in particular, to cyclic loadings is considered in Section 4.

2. Composite joints under static loading

As previously mentioned, the present draft of the Eurocodes already allows covering and characterising composite joints but are still limited on different aspects.

Particularly, only composite joints under hogging moments are covered while, in practice, such joints could also be subjected to sagging bending moments and/or to axial forces. It is for instance the case when considering (i) the behaviour of composite sway frames ([2] and [3]) in which sagging moments at the extremities of the composite beams may occur or (ii) the behaviour of composite structures subjected to exceptional events such as the loss of a column ([4] to [6]), scenario in which the beam extremities are subjected to combined hogging or sagging bending and tensile loads (membrane forces). In the next sections, the behaviour of beam-to-column composite joints under sagging moment and under M-N loading is under consideration.

2.1. Composite joints under sagging moments

As previously mentioned, the component method can be applied to a huge range of joint configurations subjected to different loading conditions but it is required to have at his disposal the required rules to characterise the mechanical properties of the activated components. Considering the component method as presently proposed in the Eurocodes, it is not yet possible to predict the properties of composite joints subjected to sagging moments as no rule is available to predict the properties of one of the activated components under such loading which is the component “concrete slab in compression”.

In recent researches, methods to characterise this component in term of « resistance » are proposed. Their aim is to define a rectangular cross-section of concrete (with an effective width $b_{eff,conn}$ and a height z) participating to the joint resistance (similar approach that the one adopted to predict the resistance of composite beams). The procedure which is described and recommended in this section combines two approaches proposed respectively by F. Ferrario [7] and by J.Y.R. Liew [8]. The combination of these two approaches allows reflecting in a more appropriate way the physic of the observed phenomena and, in particular, how the concrete resists to the applied load in the vicinity of the joint as demonstrated in details in [9] and [10] and briefly addressed here below.

For the definition of the effective width of concrete $b_{eff,conn}$ to be adopted for the joint characterisation, the proposal of Ferrario [7] is adopted:

$$b_{eff,conn} = b_c + 0,7h_c \leq b_{eff} \qquad (1)$$

where b_c is the width of the column profile flange, h_c the height of the column profile cross section and b_{eff}, the effective width of the concrete/composite slab to be considered for the beam in the vicinity of the joint; b_c represents the contribution of the concrete directly in contact with the column flange while $0,7.h_c$ is the contribution of the developed concrete rods in the "strut-and-tie" behaviour (see Figure 2).

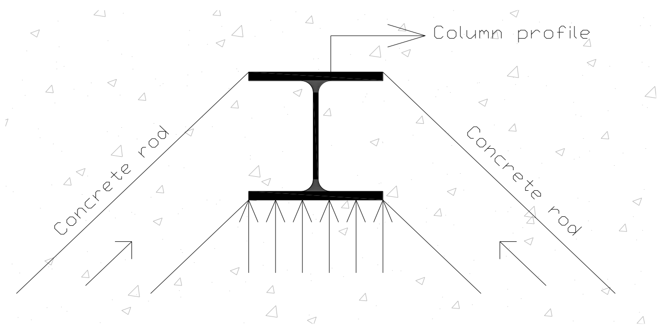

Figure 2. Plane view of the slab in the vicinity of the joint - development of concrete rods in compression under sagging moment [9]

For the definition of the height z of the component "concrete slab in compression", the method proposed by Liew [8] is preferred to the one proposed by Ferrario [7] (i.e. to consider that the full thickness of the concrete slab or of the concrete above the ribs in case of composite floor is activated):

- the characterisation of the joint components in tension and eventually in shear is performed respecting the rules recommended in the Eurocodes;
- then, the height of the concrete/composite slab contributing to the joint behaviour is computed by expressing the equilibrium of the load developing in the concrete/composite slab in compression with the components activated in tension or in shear and assuming a rectangular stress distribution in the concrete (equal to 0,85 f_{ck}/γ_c in a design as recommended in Eurocode 4):

$$z = \frac{\sum_i F_{Rd,i}}{b_{eff,conn}.(0{,}85.f_{ck} / \gamma_c)} \leq h_{concrete} \qquad (2)$$

  where $h_{concrete}$ is the total height of the concrete slab (in case of a composite slab, $h_{concrete}$ is equal to the concrete above the ribs), f_{ck} is the characteristic strength of the concrete, γ_c is the safety coefficient to be applied to the concrete material and $F_{Rd,i}$ is the tensile resistance of bolt row *i*;
- finally, the characterisation of the joint is performed assuming that the centre of compression is located at the middle of the height of the contributing part of the concrete slab (*z*).

Ferrario [7] and Liew [8] only deal with the characterisation of the component "concrete slab in compression" in term of resistance but no procedure is proposed to predict the stiffness of this component; however, this property is requested in order to be able to predict the initial stiffness of the whole joint (and so to define the moment-rotation behaviour law).

If reference is made to [11] related to the characterisation of column bases, a formula is proposed to estimate the stiffness of a concrete block against a rigid plate. In the present case, the steel column encased in the concrete slab can be considered as a rigid plate; so, the formula proposed in [11] can be extended to the present situation to compute the stiffness of the component under consideration:

$$k_{\mathrm{csc}} = \frac{E_{cm} \cdot \sqrt{b_{eff,conn} \cdot z}}{1{,}275.E_a} \qquad (3)$$

where E_{Cm} is the secant Young modulus for the concrete, E_a, the elastic Young modulus for the steel and k_{CSC}, the stiffness of the component "concrete slab in compression" to be used in the component method.

In [9], the so-defined analytical approach is validated through comparisons with results from experimental tests performed on composite joints in isolation. An example of such comparison is reported in Figure 3 where the analytical prediction is compared to results obtained at Trento University [12] through experimental tests conducted on external composite joints in the framework of a European RFCS project named PRECIOUS.

In Figure 3, it can be seen that two experimental curves are drawn. They differ from the configuration of the slab met in the tested specimens: TEST 2 joint is made of a composite slab while TEST 3 one is made of a concrete slab. It can be observed, from the comparison reported in Figure 3, that a very good agreement is obtained between the analytical prediction and the experimental results. For TEST 2, a loss of resistance in the joint is observed at a rotation of 29 mrad which is not reflected by the analytical prediction. In fact, this loss of resistance during the test is associated to a lack of ductility of the concrete at the connection level, phenomenon not yet implemented in the proposed analytical apporach. However, as the objective with the analytical model is to predict the plastic resistant moment (point A on Figure 3) which is reached before this lack of ductility, this phenomenon does not call into question the validity of the model.

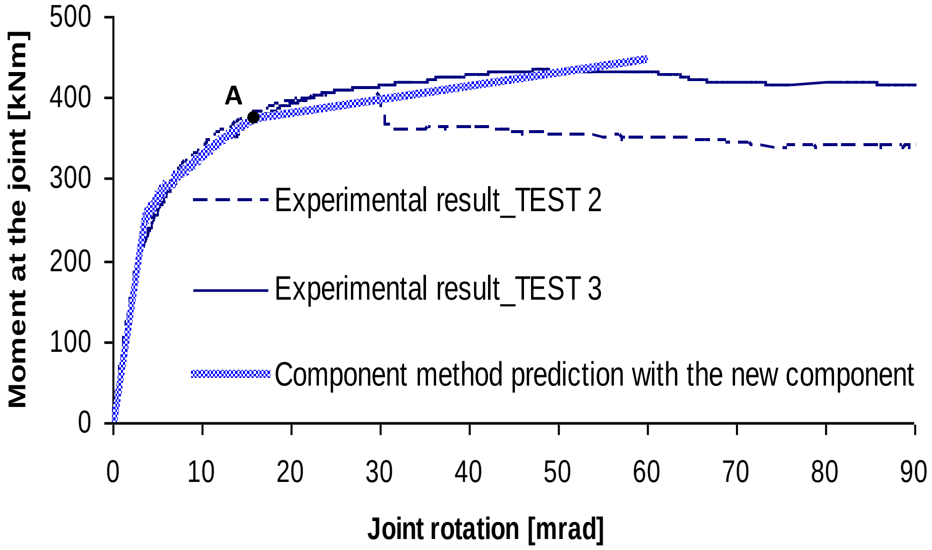

Figure 3. Joints under sagging moments - Comparisons analytical prediction vs. experimental results [9]

2.2. Composite joints under M-N

In the Eurocodes, the proposed design recommendations are mainly devoted to the characterization of joints subjected to bending moments and shear forces. In particular, in Part 1.8 of Eurocode 3 dealing with the design of steel joints, the field of application is restricted to joints in which the force N_{Ed}, acting in the joint, remains lower than 5% of the axial plastic design resistance $N_{pl,Rd}$ of the connected beam (and not of the joint itself what is quite questionable as far as the influence of the applied axial load on the joint properties is of concern).

Under this limit, it is assumed that the bending response of the joints is not significantly influenced by the axial forces. It has however to be mentioned that this value is a fully arbitrary one and is not at all scientifically justified. However, in some situations, these joints can be subjected to combined bending moments and axial loads, e.g. at the extremities of inclined roof beams or in frames subjected to an exceptional event leading to the loss of a column, situation where significant tying forces may develop in the structural beams above the lost column.

If the above-mentioned criterion allowing neglecting the effect of the axial load is not satisfied, Eurocode 3, Part 1-8, recommend to check the resistance by referring to “M-N” interaction resistance diagram defined by the polygon linking the four points corresponding respectively to the hogging and sagging bending resistances in absence of axial forces and to the tension and compression axial resistances in absence of bending.

The PhD thesis of Cerfontaine [13] demonstrates that the recommended method is questionable and is even unsafe in many situations which is not acceptable. In consequence an improved design analytical procedure, fully compatible with the component method concept, was (i) developed by Cerfontaine [13] to predict the response of ductile and non-ductile steel joints subjected to combined bending moments and axial loads and (ii) extended to composite joints in [9] (see also [14]). The model, including a worked example is fully described in [9].

The validity of the analytical approach was checked through comparisons to experimental results of tests performed in Stuttgart in the framework of an RFCS project entitled “Robust structures by joint dutility” [15]. Figure 4 reflects the comparison between the analytically predicted resistance curves and the experimentally obtained ones. On this figure two analytically predicted curves are reported:

- One named “plastic resistance curve” which is computed using the actual elastic strengths of the materials and;
- One named “ultimate resistance curve” which is computed using the actual ultimate strengths of the materials.

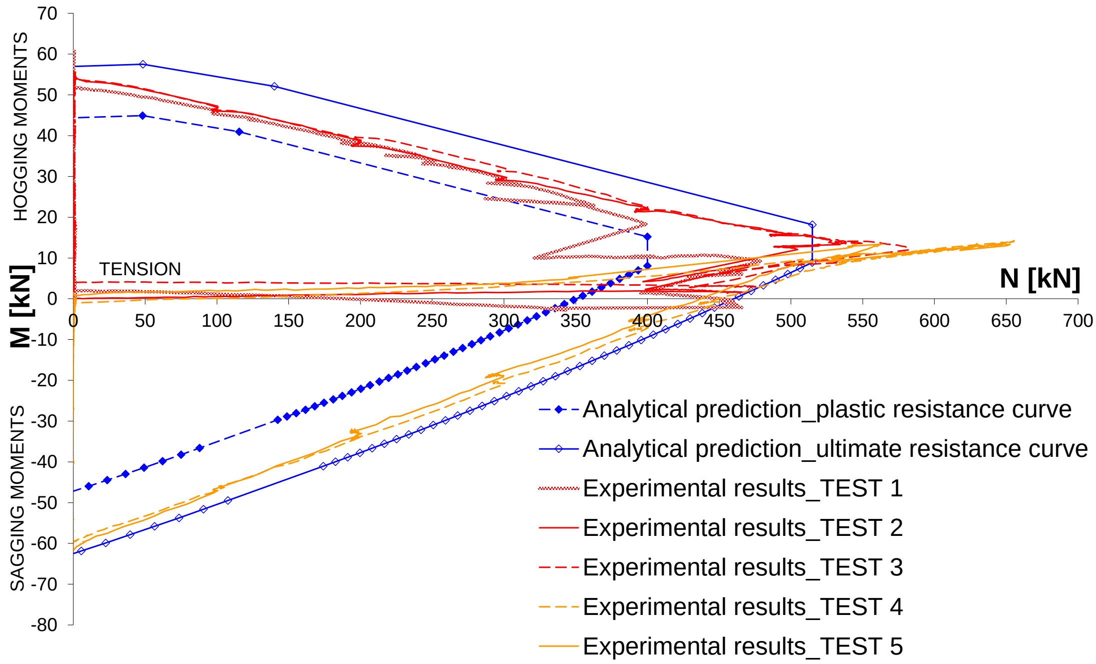

Figure 4. Comparison of the resistance interaction curves [9]

Looking to Figure 4, it is observed that the analytical curves fit appropriately with the experimental results. Indeed, the reported experimental curves are between the plastic and ultimate analytical resistance curves, which is in agreement with the loading sequence used during the tests as detailed in [9].

3. Composite joints at elevated temperatures

In case of fire, the beam-to-column joints play a key role in the global structural response. These joints, initially loaded in bending, may be subjected to elevated temperatures associated to combined bending moment and axial load. Within the RFCS project ROBUSTFIRE, an approach to estimate the mechanical response of bolted composite beam-to-column joints at elevated temperatures under M-N has been developed and validated ([16] and [17]).

This methodology is founded on the approach addressed in the previous section and is in full agreement with the component method recommended in the Eurocodes for the joint characterisation.

The procedure described in the previous section can be applied at elevated temperature provided the knowledge of the temperature distribution in the joint and, in particular, in the different joint components. Each component resistance is then simply estimated using the material resistance at its given temperature.

The validation of the proposed approach has been realised through comparisons to experimental results obtained from six fire tests performed at the University of Coimbra on a composite steel-concrete beam-to-column frame. The tested composite frame was subject to mechanical (bending and axial forces) and thermal actions (constant temperature equal to 500ºC or 700ºC). The objective of the conducted experiments was to observe the evolution of the combined bending moments and axial loads in the heated joint when catenary action develops in the frame during a column loss due to a localized fire.

An example of such comparison is reported in Figure 5. In this figure, it is observed that a very good agreement is obtained between the analytical estimations and the experimental results. Similar safe agreements were observed through comparisons to other tests results.

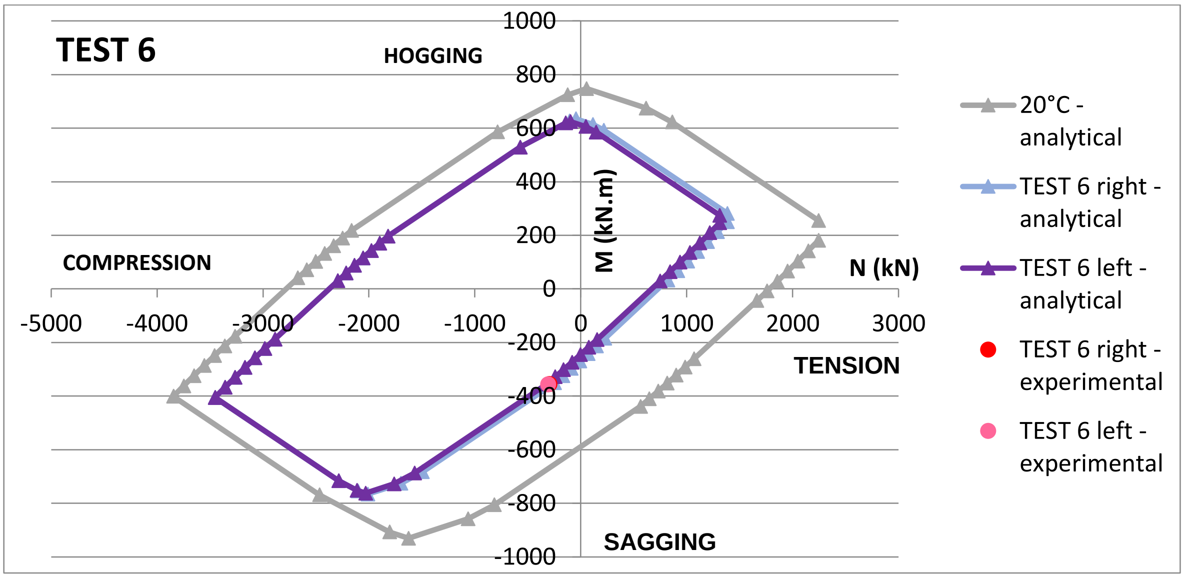

Figure 5. Comparison of the experimental resistances to the analytical curve for TEST 6 (composite joint at 700°C) [17]

Accordingly, if the temperatures at the level of the different joint components are known, the analytical model is able to predict accurately the joint resistance for any M-N couples. A perspective to the presented study is the development of a full analytical procedure by including in the developed approach an analytical estimation of the component temperatures, considering what is already proposed for a specific joint configuration in [18] as, in current evaluations, a 3D thermal FEM analysis is still required to predict these temperatures in practice.

4. Composite joints under cyclic loading

In many situations the structures are subjected to alternate lateral loading, such is the case of seismic load or high wind loads. In these cases, the composite joints can be subjected to alternating moments, changing from hogging to sagging and consequently the behaviour under cyclic loading plays a crucial role in the overall structural behaviour.

For seismic design, the Section 7 of EN 1998-1 contains additional requirements for seismic-resistant steel and concrete composite buildings.

In a general manner, the cyclic behaviour is dependent on the connection typology and the characteristics of its constitutive components in terms of resistance, stiffness and ductility. In accordance with the seismic design norm EN 1998-1, the designer can chose to (i) guide the plastic hinge formation in the connected element (e.g. the beam), this leading in most of the cases to haunched or reinforced joints or (ii) to assure the plastic hinge formation within the joint, case in which the ductility of the joint must be proven by testing evidence. However, the last possibility is not really considered by seismic designers as the experimental tests delay the execution time of the building. Also, EN 1998-1 constrains the shear design force of the column web panel to $0.8.V_{wp,Rd}$ (clause 7.5.4) and limits its cyclic deformation to maximum 30% of the joint rotation (clause 6.6.4).

4.1. Global cyclic behaviour

The global behaviour of composite joints is directed influenced by the cyclic loading as shown by various studies ([19] – [31]) by general degradation of strength and stiffness in successive load cycles.

In one of the early testing of composite joints, Lee and Lu [23] have proven that the composite beam-to-column joint behaviour presents stable hysteretic loops, based largely on the steel elements of the connection. The connections were realised by direct welding of the beam on the column flange or to connecting plates. Considering the global behaviour presented in section 2, the cyclic response of joints remains highly unsymmetrical due to the presence of the concrete slab.

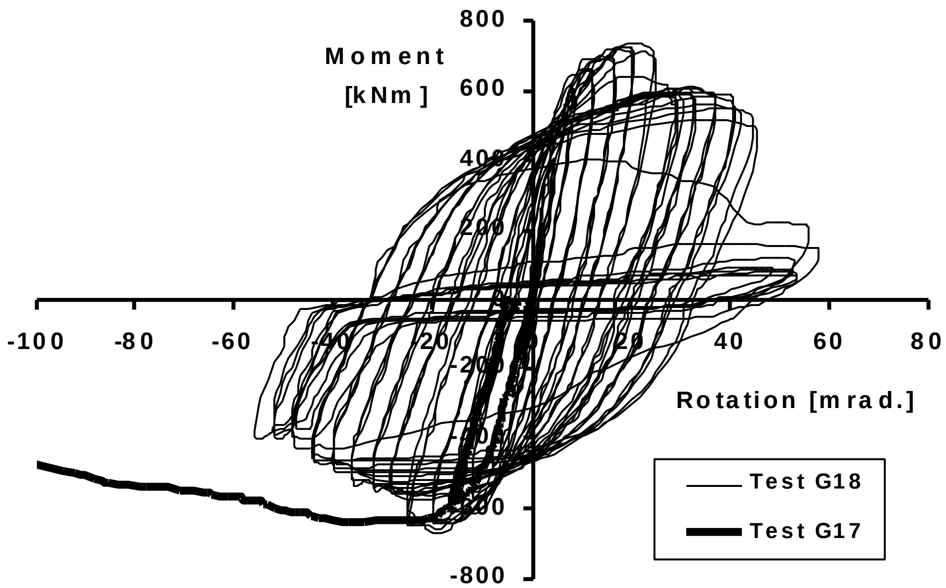

Figure 6. Unsymmetrical behaviour of composite joints [19].

Figure 6 presents the cyclic response (G18) of an external composite continuous joint (T joint) in comparison with a monotonic loaded specimen (G17). In a general manner, the cyclic loading introduces an important reduction of joint ductility, which could be accompanied by a reduction of the maximum resistance of the joint. However, in case of internal joints loaded to produce anti-symmetrical bending moments, the overall joint response becomes symmetrical by diagonal alternation of the tension and compression components and amplified shear of the column web panel [19].

The numerical simulation of cyclic behaviour of composite joints represents a very difficult task, as the cycles present some particularities in comparison with the symmetrical behaviour of pure steel or concrete joints:

- the composite joints can present important dissymmetric behaviour in sagging and hogging, by the employment of the concrete slab, respectively the reinforcement;

- in consecutive cycles, the slip can become important under the effect of cracking of concrete in consecutive cycles;

- the failure is different in hogging and sagging: while the first employs the tensile reinforcement and upper part of the connection, leading generally to a ductile behaviour, the latter can involve high stresses in bottom parts, leading to brittle failure of bolts, welds or heat-affected zones as revealed by various scientists.

Starting from a generic model proposed by Mazzolani [24], Rui and Da Silva [25] presents a model able to simulate the global behaviour of a composite beam-to-columns composite joint. The original model of Mazzolani is based on the classic Ramberg-Osgood model and allows the mathematical simulation of hysteretic behaviour with slippage (or so-called pinching effect), where the cycles have the shape shown in Figure 7. The modified Mazzolani model defines two branches for each cycle, ascending and descending, allowing two distinct slippages for the branches.

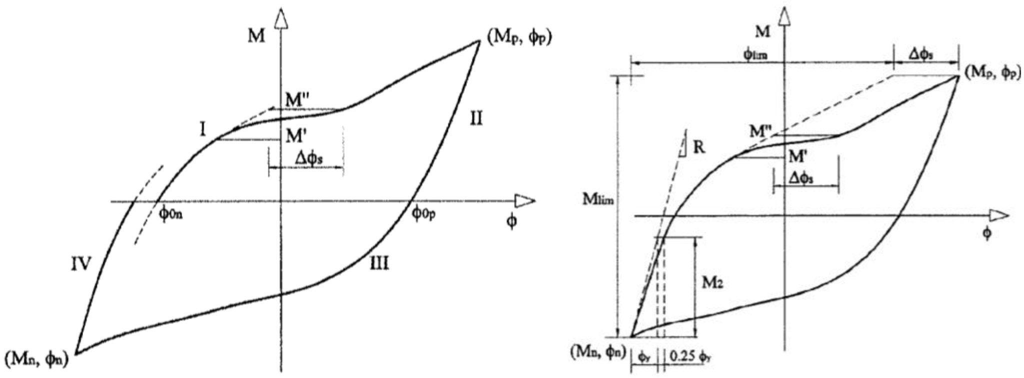

Figure 7. Original [24] and modified [25] Mazzolani model for cyclic behaviour of composite joints.

4.2. Influence of concrete slab in cyclic response of composite joints

The presence of the concrete slab on pure steel joints can induce a dissymmetry in response, as shown by various authors, contrary to the modern design norms which advise to disconnect steel and concrete elements in areas where the plastic hinge is expected to develop, and to consider a symmetric plastic behaviour for the beam, as for the steel section alone.

In case of **pure steel joints** The Northridge 1994 earthquake revealed that the usual welded connections of steel moment-resisting frames have been damaged by brittle fractures at or near the complete penetration groove welds connecting the bottom girder flange to the column [25]. The brittle failures initiated at very low levels of plastic demand, and in some cases even in elastic state of the structure. The fractures then progress along a number of different paths, depending on the individual joint conditions [26]. Besides other factors, there have been two reasons identified for the premature fracture of the welds, as discovered by site investigations and then proved by laboratory tests: (i) detailing practice in the weld access hole area that often leaded to large stress concentrations in the bottom beam flange weld which proved to be a metallurgically complex area and (ii) the presence of a floor slab at the girder top flange which tends to shift the neutral axis of the beam towards the top flange. This results in larger tensile deformation demands on the bottom flange than on the top. The presence of the slab tends to greatly reduce the chance of local buckling of the top flange. The bottom flange, however, being less restrained can experience buckling relatively easily.

In order to observe the influence of the composite beam on **simple joints**, Liu and Astaneh [27] tested a series of internal joints subjected to cyclic asymmetrical loading, conceived as simple steel connections with/without composite floor slab. The test results show that there are major differences in cyclic behaviour between steel and composite specimens as the maximum bending capacity as well as the initial stiffness of the joint is almost double in composite joints although at a drift angle of 40 mrad the contribution of the slab is almost entirely lost, due to severe damage to concrete slab. Also, the failure mode changed with the shift of the neutral axis from the symmetrical fracture of the shear tab in case of steel specimens to cracking of concrete and later fracture of the shear tab only in the bottom part.

As proved by experimental investigation on cyclically loaded **semi-continuous joints**, the main influence of the slab consists in increased strains in bottom connection components and limitation of rotation capacity. Ciutina et al. [28] and Lachal et al [29] investigated a series of internal (T configuration) semi-rigid and partial strength bolted end-plate beam-to-column joints. The difference between the G13-S15 steel specimen and the G14 and G15 composite specimens is the missing bolt in the extended upper part of the end-plate and the presence of the concrete slab. In the case of composite joints, the slab was composite by considering a 60 mm corrugated sheeting and a single layer of reinforcement with 12 bars Φ10 disposed over the effective width. Transversal reinforcement meet the EN 1998-1 Annex C requirements for seismic re-bars.

The comparison of the cyclic response curves (see Figure 8) show a clear reduction in the ultimate rotations between the steel (G13-S15) and the composite (G15) cyclic specimen. This fact is due to the increased level arm acting in sagging which finally leads to early failures in the connection. However, the other parameters such as resistance and stiffness are higher in case of composite joints. The synthetic comparison of experimental results is given in Table 2. The reduction in ductility between he composite monotonic loaded specimen (G14) and the cyclic one (G15) is drastic.

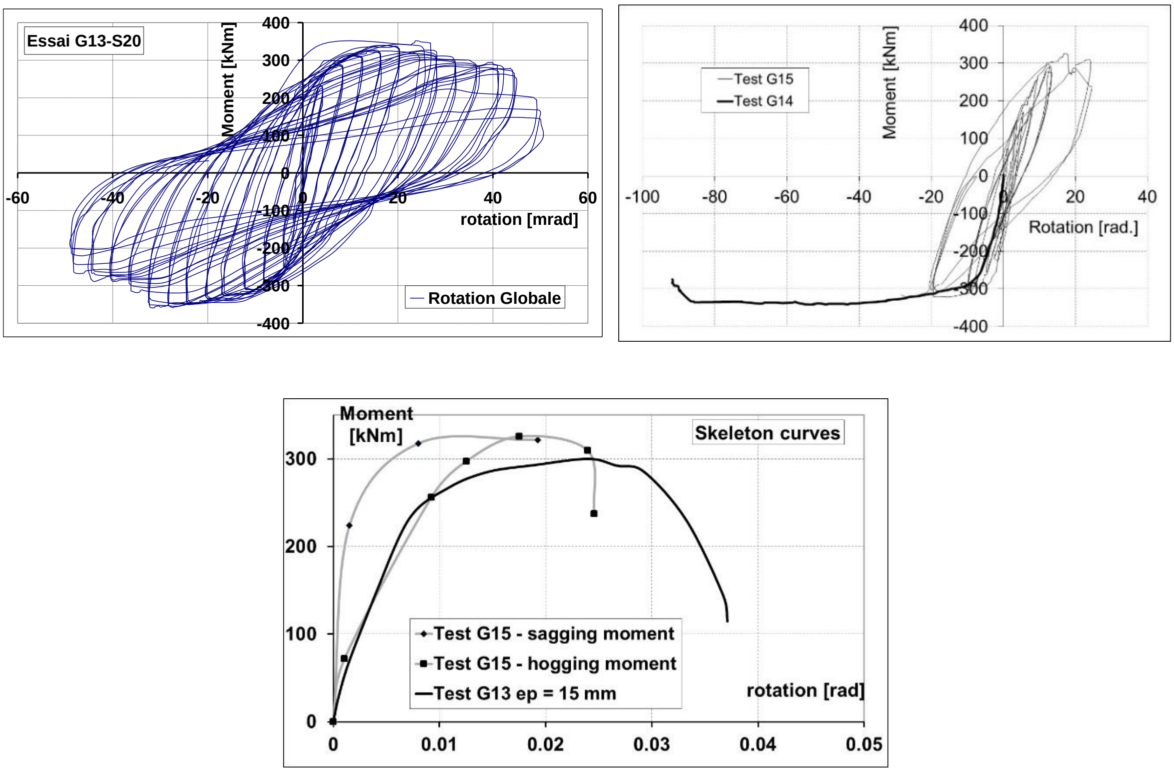

Figure 8. Moment-rotation cyclic curves and comparison of envelope curves for G13, G14 and G15.

Test name	Loading	$S^{+}_{j,ini}$ [kNm/rad]	$S^{-}_{j,ini}$ [kNm/rad]	$M^{+}_{\max}$ [kNm]	$M^{-}_{\max}$ [kNm]	$\Phi^{+}_{\max}$ [mrad]	$\Phi^{-}_{\max}$ [mrad]
G13-S15*	Cyclic	32400		313		31.5	
Essai G14	Monotonic (hogging)	----	49900	----	342	----	91,8
Essai G15	Cyclic	41098	53630	326	340	24	68

* - mean values

Table 2. Main characteristics of the G13, G14 and G15 joints [29].

In case of **continuous joints** it is expected to shift the plastic hinge formation in the connected element, namely in the beam. According to modern seismic rules, the non-dissipative connection should possess sufficient over-strength in order to comply this rule. The EN 1998-1 clause 6.5.5 for steel and reprised in chapter 7 for composite steel and concrete joints conditions that:

$$R_d \geq 1.1 \cdot \gamma_{ov} \cdot R_{fy} \qquad (4)$$

where:

R_d is the is the resistance of the connection

R_{fy} is the plastic resistance of the connected dissipative member based on the design yield stress of the material

γ_{ov} is the overstrength factor, usually taken in design as 1.25.

Accordingly, the usual requirement for full-strength joints is that $R_d \geq 1.375 \cdot R_{fy}$. As the dissipative member is expected to be the beam, practically the connection resistance should be 1.375 times higher than that of the composite beam. As in hogging bending the reinforcement increases the steel beam resistance by 10 to 20%, the main problem in case of composite beam-to-column joints is in sagging, case for which the usual steel beam resistance is increased 2 to 2.5 times. For this reason, the majority of continuous composite joints are highly strengthened.

As demonstrated by Ciutina et al. [28], composite joints with haunches should force the plastic hinge formation in beams if adequate design and detailing measures are considered in design. Based on the beam ductility, important rotation capacities could be attained in cyclic loading, without significant reductions in the resistance. However, the rotation capacity of the beam is reduced in case of cyclically loaded specimens, both in hogging and sagging. For all these cases the failure mode was by the formation of plastic hinges in beams.

In the same series of tests, the Specimen G16 was a pure steel connection test with extended end-plate connection and haunch. The comparison of testing results between G16 (steel) and G18 (composite), both cyclically loaded, lead to the following behaviours – see the response envelope curves in Figure 9:

- the composite specimen shown a higher stiffness and resistance in both sagging and hogging bending;

- for both joints the failure was by plastic hinge formation in the beams with only elastic rotations recorded in the connections and column panel. The concrete slab prevented the local buckling of the upper flange in sagging bending, leading to a non-symmetrical hinge in the beam – see Figure 9 (right);
- after the cracking of the concrete slab in first plastic cycles the moment drops to values characteristic to steel specimen;
- the presence of the slab influences the ultimate beam hinge rotations – computed for a 20% drop of the maximum moment on the discharging branch - by important amounts: from 60/51 mrad (hogging/sagging) for steel specimen to 40/32 in case of composite specimen.

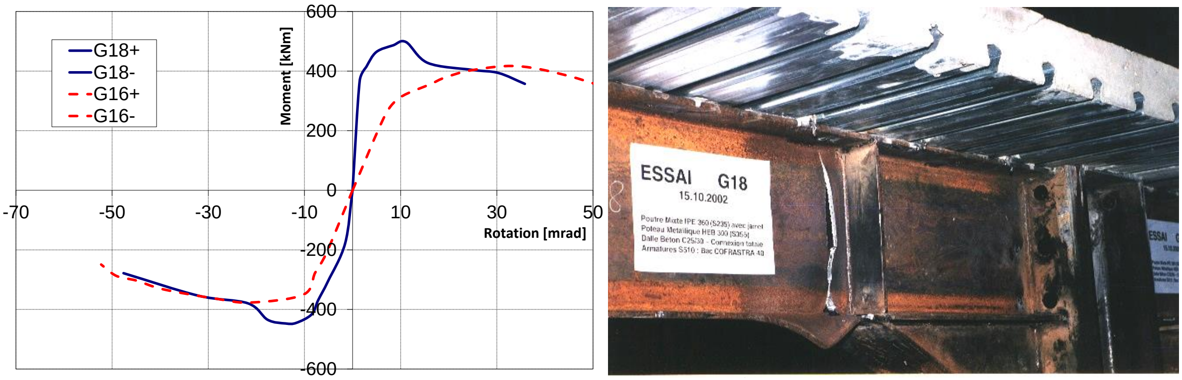

Figure 9. Envelope response curves for steel (G16) and composite (G18) specimens: non-symmetric failure of the G18 specimen (Ciutina et al., 2004).

The RBS could be an alternative in shifting the plastic hinge from the joint to the beam, in most of the case to lead to a ductile behaviour. The cut lengths and cut-depths of the beam flanges controls the moment resistance of the RBS. For static loads, Huang et al. [30] proposed analytical formulation of the mechanical performance and an amplification factor for considering the slab contribution to the plastic moment of the beam section at the column face. The cyclic ability of composite joints with RBS to dissipate energy was proved by testing.

4.3. Design recommendations and avoidance of brittle failure in cyclic loading

As proven by various researchers, the cyclic behaviour of composite beam-to-column joints in buildings is mainly different from the behaviour of similar steel joints due to the presence of concrete and its constitutive elements such as reinforcement, profiled sheeting, connectors etc. Although offering a good resistance and stiffness in compression, concrete is generally degraded by cyclic loading through cracking and crushing, thus the initial benefits of the presence of concrete could be lost in subsequent plastic cycles.

Table 3 presents a series of components that are characteristic to composite joints and their effect in the cyclic response, as they have been reported in literature.

Component	Impact on cyclic behaviour of joint	Further studies can be investigate:
Presence of concrete slab	- shifts the neutral axis towards the top flange; - hogging: noticeable increase of bending resistance; ductile behaviour; - sagging: important increase in bending resistance; higher tensile strains recorded in bottom flange; possible brittle failure - the form of the weld access hole influences the initiation of cracking;	- the complete disconnection of the slab from the column that can limit the slab influence;
Presence of composite beam	- in case of simple joints the composite beam can increase the moment resistance up to values characteristic to semi-continuous joints; - in semi-continuous joints, the composite beam increases both the resistance and stiffness in regard to steel solution; the cyclic rotation is smaller than in the case of steel joints; - for continuous joints the behaviour is fully dependent on the beam capacities: in general the stiffness and resistance is greater than in the similar steel solution but the rotation capacity is limited;	- participation width in sagging/hogging of joints; - possibilities to realise simple joints with composite beams; - possibilities to realise discrete cracking of concrete; - continuous or semi-continuous joints for slim-floor solutions

	- in plastic cycles, after cracking of concrete, the contribution of the slab is lost; - the failure mode consists of alteration of concrete slab by cracking/crushing in tension/compression and failure of the bottom steel components.	
Presence of profiled sheeting	- hogging: no influence if the troughs are transversal to the beam: the joint behaviour and analytic characteristics should only consider the full concrete slab; the parallel disposition of the troughs could be considered as additional reinforcement in tension if proper anchored; - sagging: no influence: the joint behaviour and analytic characteristics should only consider the full concrete slab.	- the parallel disposition of profiled sheeting in semi-continuous and continuous joints; - the effective width of the profiled sheeting.
Cyclic behaviour of connectors	- the alternate cyclic load on connectors significantly reduces the characteristic resistance (up to 40%) and significantly limits the steel-concrete slip; - the cyclic load on connectors remain a very hard condition, not actually proved in cyclic joint tests.	- the direct correlation between the alternance of bending moments at the beam end and the solicitation on composite beam connectors.
Partial interaction of the slab	- there is not recorded a noticeable influence on the cyclic response of joints.	- design guidelines of composite joints with partial connection of the slab.
Column web encasement	- for the component CWP in shear the concrete encasement brings an increase in resistance and stiffness; - the component remains ductile with important strain-hardening stiffness; - in joints loaded to cyclic loading with CWP employed in the plastic mechanism, its encasement improves the resistance and stiffness of the joint up to concrete cracking without further influence.	- the difference in cyclic response of joints with partial and full encasement of the column; - different detailing of encasement and reinforcing in the presence/absence of column horizontal stiffeners.

Partially encased beams	- delays the local buckling failure of steel beam if the failure is in the beam.	- a proper investigation of cyclic behaviour of composite beam-to-column joints with partially encased beams as this could reveal the real benefits of the system; - the detailing of connection of reinforcement as it could be important in the formation of the plastic mechanism.

Table 3. Characteristic composite components in joints and their effect on cyclic loading.

In addition to these parameters, in order to achieve an adequate behaviour under cyclic loading and to avoid the brittle failure of cyclically loaded joints, design measures should be considered in order to:

- consider an over-resistance of brittle components such as bolts and welds, including the heat affected zone;
- avoid joint components that can induce a slip (so-called the “pinching” effect) in the cyclic behaviour of joints and thus minimizing the dissipated energy, e.g. the cleat angles;
- avoid the massive cracking and fracturing of concrete by a discrete disposition of reinforcement; however, the designer should consider that the concrete components are the first degrading under cyclical loading;
- include the high-ductility of the CWP in the plastic mechanism of the joint, in accordance with the allowable limits (30% according to EN 1998-1);
- consider a balanced design under sagging and hogging, in accordance with the design demands. Although desirable, the symmetry in response is very hard to obtain

5. Conclusions

During the last decades, researches have been conducted on the behaviour of composite joints subjected to different kind of actions, not covered by current EN1994-1 provisions such as:

- joints under sagging bending moments;
- influence of cyclic loadings;
- joints under combined bending moments and axial loads;
- joints under elevated temperatures etc.

with the objective of improving/extending the rules presently proposed in the Eurocodes design rules.

Within the present paper, outcomes of some of these researches are briefly addressed. Some of the presented results could be considered as background information for possible improvement of the Eurocode recommendations.

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