Bulletin of the *Transilvania* University of Braşov • Vol. 5 (54) - 2012
Series 1: Special Issue No. 1

STEEL JOINTS - COMPONENT METHOD APPLICATION

D. RADU[1]

Abstract: As long as the rotation joint stiffness is considered in the calculation, the steel structure joints can be made in semi-rigid version, i.e. no rigid or pinned. Thus, new modeling capabilities: semi-rigid / total resistance, semi-rigid / partial resistance. Eurocode 3 standard is considering these possibilities by introducing three types of modeling: simple (if pin-end), semi-continuous and continuous. *Terms of continuous, semi-continuous and nominally pinned are defined as follows: Continuous: the joint ensures perfect rotation continuity between connected elements; Semi-continuous: the joint ensures a partly rotation continuity between connected elements; Simple: the joint interrupts the rotational continuity between connected elements. Interpretation of these types of modeling should be done in accordance with the structural analysis type. In the case of a global elastic analysis, only the stiffness properties of joints are important for joints modeling. The semi-rigid connection is taken into account in the calculation model by means of a spring which is characterized by the elastic constant k.*

Key words: *Semi-rigid joints, Joints ductility*

1. Introduction

In current cases of analysis of a structure is not practical the separation of the joint deformability from the web panel of the column. Therefore, these deformations can be modeled by a single spring at the intersection of joint elements axes - modeling deformation behavior of a node takes into account the deformation of the panel from shear deformation of the web and rotation of the connections.

Nodes configuration should be design to resist to $M_{b1,Ed}$ and $M_{b2,Ed}$ bending moments, $N_{b1,Ed}$ and $N_{b2,Ed}$ axial forces, $V_{b1,Ed}$ and $V_{b2,Ed}$ share forces transmitted from the connected elements to the joint (Fig. 1).

The resulted share force $V_{wp,Ed}$ from the web panel, will be:

$$V_{wp,Ed} = \left(M_{b1,Ed} - M_{b2,Ed}\right)/z - \left(V_{c1,Ed} - V_{c2,Ed}\right)/2 \quad (1)$$

where z is the lever arm.

In order to model a node in order to reproduce correctly the expected behavior, the share web panel and each connection must be modeled separately, taking into account the bending moments and axial forces of each element which interfere at the edge of the web panel (Fig. 2 and Fig. 3).

As a simplified alternative to the presented above model, a unilateral node configuration can be modeled as a single node, and configuration of a double-side node can be modeled as two separate nodes which interact with each other. Therefore, configuring a beam to column double-side node has two moment-rotation characteristics, one for the right side of the

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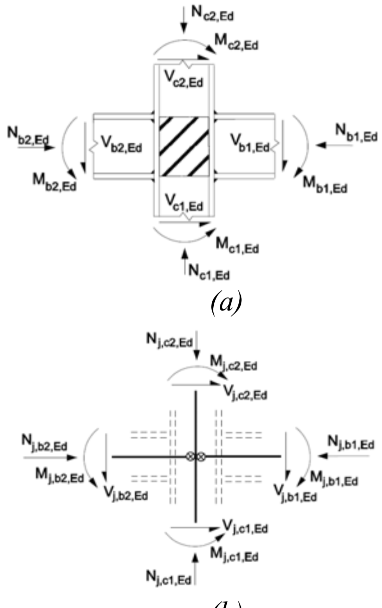
[1] Civil Engineering Faculty, *Transilvania* University of Braşov.

joint and the other for the left. In a bilateral beam to column node, each fixture is modeled with separate rotation points (Fig. 3), each end of the beam has a moment-rotation feature that takes into account the behavior of the shear web panel and the influence of the correct connection.

When determining the moment resistance and rotation stiffness for each node, the possible shear web panel influence will be taken into account according with β_1 and β_2 coefficients, where β_1 is the value of the transformation parameter β for the right side of the node and β_2 is the value of the transformation parameter β for the left side of the node.



(a)

(b)

Fig. 1. Forces and moments acting on the joint [5]: a. Values nearby the web panel; b. Values at the intersection of the elements center lines

The exact values of β_1 and β_2, based on the values of beam bending moments $M_{j,b1,Ed}$ and $M_{j,b2,Ed}$, from the intersection of the elements centers of gravity lines, can be determined using the simplified model shown in Fig. 1 (b) as follows:

$$\beta_1 = \left|1 - M_{j,b2,Ed} \big/ M_{j,b1,Ed}\right| \leq 2$$
$$\beta_2 = \left|1 - M_{j,b1,Ed} \big/ M_{j,b2,Ed}\right| \leq 2 \qquad (2)$$

where: $M_{j,b1,Ed}$ is the moment at the intersection from the right hand beam and $M_{j,b2,Ed}$ is the moment at the intersection from the left hand beam.

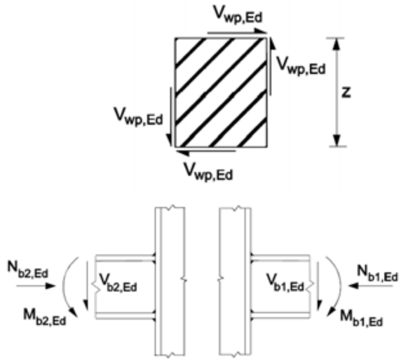


Fig. 2. Forces and moments acting on the web panel at the connections

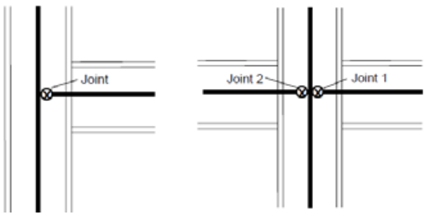
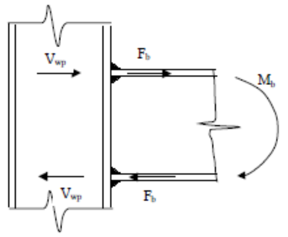


Fig. 3 Modeling the joint (1 – Node; 2 – Left Node; 3 – Right Node): Single sided and double-sided joint configuration

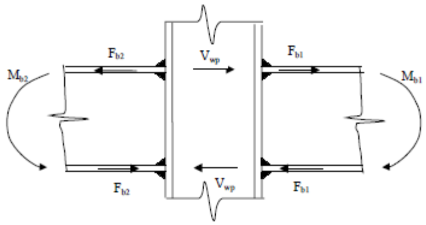
The transformation parameter β, puts in direct connection the web panel shear with tension and compression forces from the joint. Spring characteristic curve Mb - Φ which represents the joint behavior is shown in Fig. 5c; this results from summing the joint rotation (Φ c) with web panel rotation (γ).



Single sided joint

$$V_{wp} = \beta \cdot F_b$$

where $F_b = M_b / Z$,



Double-sided joint

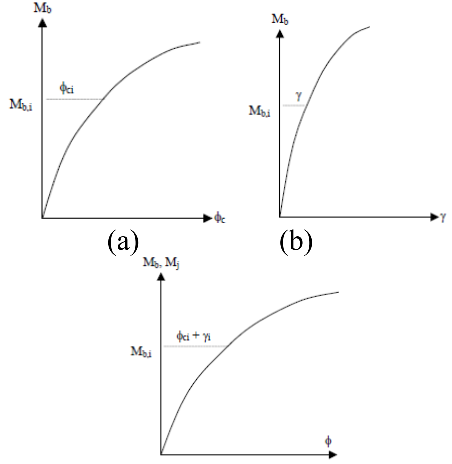
$$V_{wp} = \beta_1 \cdot F_{b1}$$

$$V_{wp} = \beta_2 \cdot F_{b2}$$

where $F_{b1} = M_{b1} / Z$, $F_{b2} = M_{b2} / Z$

Fig. 4. Definition of β - transformation parameter [5]

In case of a single sided joint, the deformability characteristic curve from column web panel share and rotation can be transformed in a $M_b - \gamma$ curve through β transformation parameter (Fig. 5).



(a) (b)

(c)

Fig. 5. The bending characteristic of the spring: a. joint; b. web panel; c. spring

Since the values of the transformation parameter β can be achieved only after determining the internal efforts distribution, its accurate determination can be made only through a cycles calculation. But for practical applications, these iterative methods are difficult to use, so it is necessary to provide conservative values for β. These values vary between β = 0, (double sided joint, equal moments equal and opposite directions, Fig. 6a) to β = 2, (double sided joint, equal moments equal and identical directions, Fig. 6b).

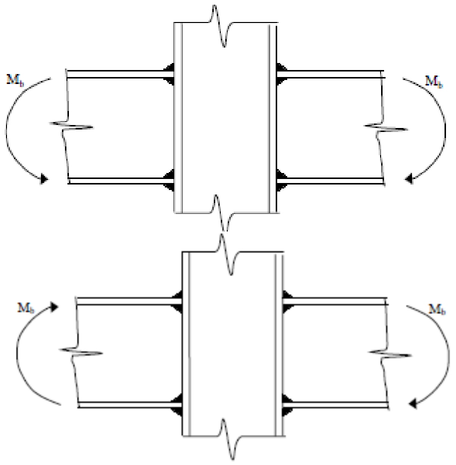


Fig. 6. Factor β limits: a. equal and opposite direction moments; b. equal and same direction moments

Nonlinear behavior of the joints, represented by springs with a certain rotation stiffness, it is quite difficult to use in current design practice. Therefore, the actual moment-rotation characteristic curve of the joint can be modeled without a significant loss in accuracy by an elastic - perfectly plastic characteristic curve (Fig. 7a). This representation has the advantage of being similar to the behavior characteristic curve of the bended elements. (Fig. 7b).

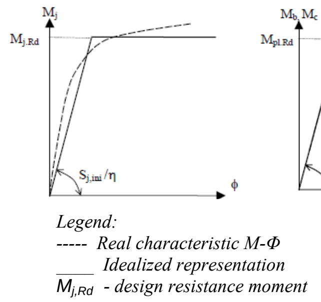


Fig. 7. Bilinear moment-rotation curves [8]: a. Joint; b. Element

There are neglected the effects of material cold straining. This explains the behavior differences between the idealized behavior of the joint and actual behavior.

Depending on the type of analysis, can be choose different modes of idealization of the characteristic M – Φ: elastic modeling for elastic analysis, rigid-plastic modeling for a rigid-plastic analysis (Fig. 8) and a nonlinear modeling for the elastic-plastic analysis (Fig. 9).

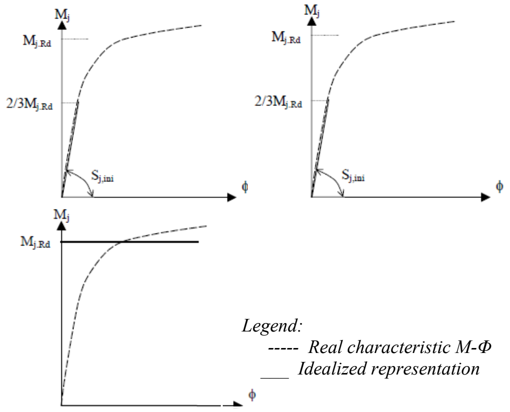


Fig.8 Moment-Rotation Rigid-Plastic representation [7]: a. Elastic checking; b. Plastic checking

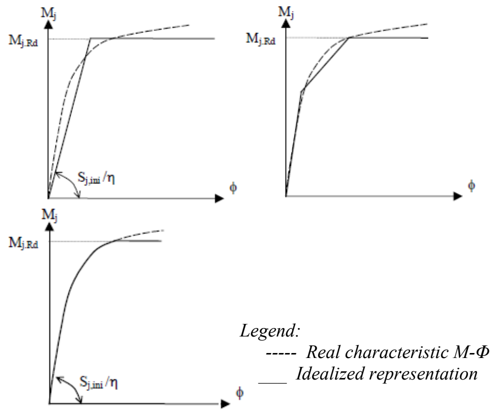


Fig. 9 Moment-Rotation characteristic nonlinear representation [7]: a.Bilinear representation; b.Trilinear representation; c. Nonlinear representation

The approximate M-Φ curve can be obtain through experimental testing or mathematical models based on the geometrical and mechanical properties of the joint. On scale experimental testing are the most reliable methods of description of the rotational behavior of the joints. These experiments are time consuming and expensive, thus cannot be regarded as a design procedure. Although during time a lot of experiments have been done and there were developed mathematical models for representation of the M- Φ curve. These mathematical models include: (i) curve fitting to test results by regression analysis, (ii) simplified analytical models, (iii) mechanical models that take into account the various sources of joint deformability and (iv) numerical models.

Current design practice adopts the Eurocode component method for the prediction of the rotational behavior of beam-to-column joints. Thus the joint can be subdivided into three different zones: tension, compression and shear. In each area, several sources of deformability can be identified, which are simple elemental parts (or “components”) that contribute to the overall response of the joint: (1) column web in shear, (2) column web in compression (3) column web in tension (4) column end plate in bending, (5) beam end plate in bending (6) beam web tensioned or compressed; (7) tensioned bolts (8) tensioned welding.

In principle, this methodology can be applied to any joint configuration and loading conditions provided that the basic components are properly characterized. Essentially, the method involves three basic steps: (1) identification of the active components for a given structural joint, (2) characterization of the individual component F-Δ response and (3) assembly of those elements into a mechanical model made up of extensional springs and rigid links. This spring assembly is treated as a structure, where F-Δ behavior is used to generate the M-Φ curve of the full joint.

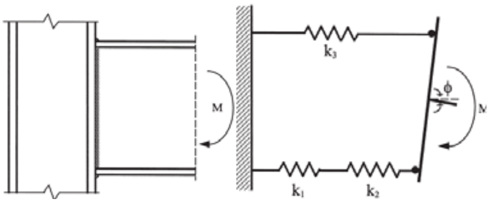


Fig. 9. Active components and mechanical model adopted by Eurocode 3 for characterization of the joint rotational stiffness – welded beam-column joint

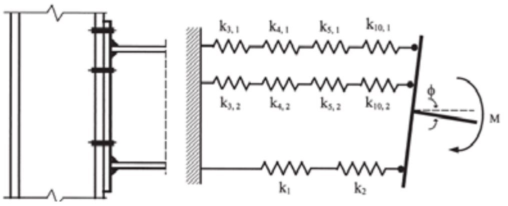


Fig. 10. Active components and mechanical model adopted by Eurocode 3 for characterization of the joint rotational stiffness – bolted beam-column joint

The basic joint components are modeled through means of nonlinear extensional springs (Fig. 11a; K: spring axial stiffness). The complex behavior of the joint can be approximated with simple relationships without significant loss of accuracy. The elastic-perfectly plastic response is one of the possible idealizations. Following the Eurocode 3 approach for idealization of the flexural joint spring nonlinear behavior, this response is characterized by a secant stiffness, k_e/η, and a full plastic resistance, F_{Rd} (Fig. 11b). k_e is the initial stiffness of the component and η is a stiffness modification coefficient. Eurocode 3 defines this coefficient for different types of connections. For a single component, similar values can be adopted. The post-limit stiffness, k_{p-l} is taken as zero, which means that strain hardening and geometric nonlinear effects are neglected. Regarding the component ductility, i.e. the extension of the plastic plateau, the code [5] presents some qualitative principles that are however insufficient. For instance, the component column web in shear has very high ductility and therefore the deformation capacity is taken as infinite; on the other hand, the bolts in tension are brittle components with no plastic plateau.

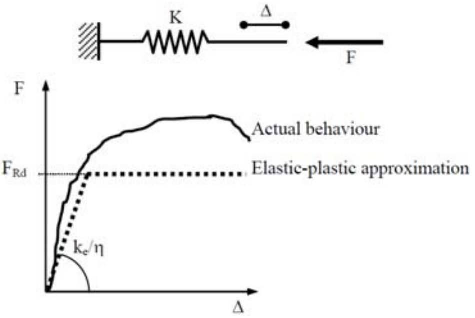


Fig. 11. Modeling a component subjected to compression: a. Extensional spring representing a generic component; b. Actual behavior and elastic-plastic response.

2. Application – beam to column joint FEM model

In order to evaluate the behavior of a rigid beam to column joint it is proposed a frequently used joint – bolted joint with extended beam endplate.

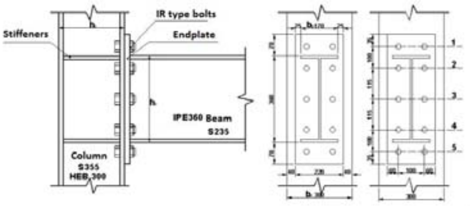


Fig. 12. Description of the joint

Following application of the Eurocode 3 and the Component Method, results the bending moment – rotation as represented in the figure 13. (the curve results for SteelCON joint design software).

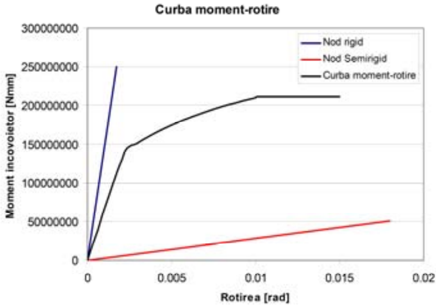


Fig. 13. Bending moment – rotation curve for the given joint

As expected the joint enters in the category of a semi-rigid type joint.

In order to compare the Eurocode 3 component method results with a FEM model, it was done a modeling and analysis of the joint with MSC SimExpert FEM software (fig. 13 and fig.14).

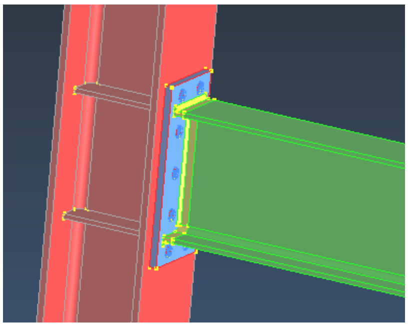


Fig. 14. Geometry of the beam to column joint

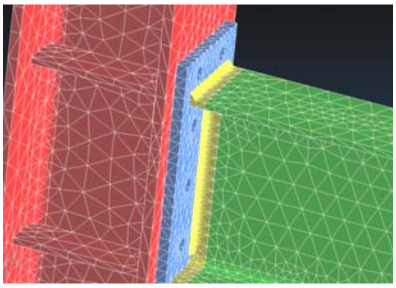
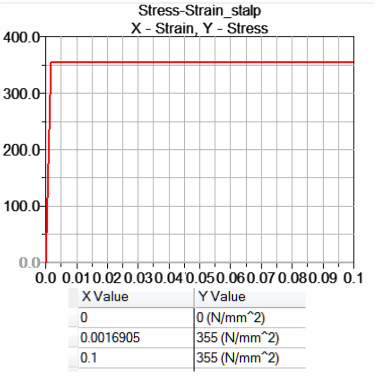


Fig. 15. FEM model – meshing of the components of the joint

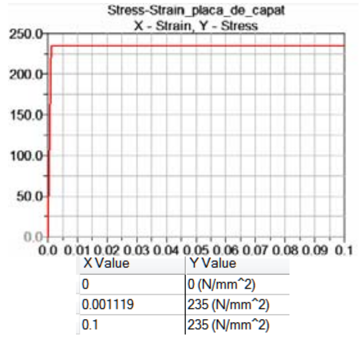
Thus it was created a material for each component and it was considered a bilinear type behavior for the materials (stress-strain curve).

After gradual applying of the bending moment onto the joint, it resulted the stress-strain diagrams presented for each component in the figures 16,17,18,19.



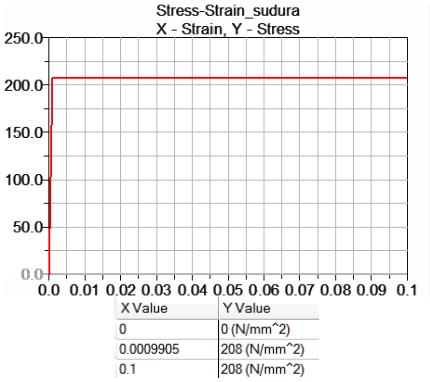
X Value	Y Value
0	0 (N/mm^2)
0.0016905	355 (N/mm^2)
0.1	355 (N/mm^2)

Fig. 16. Column Strain-stress diagram following a nonlinear plastic analysis



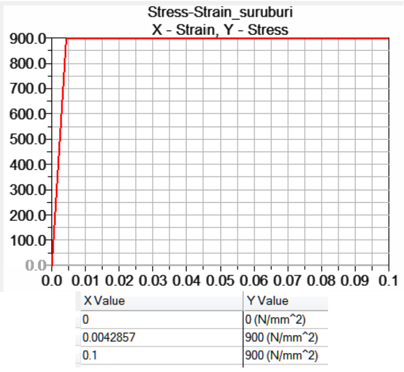
X Value	Y Value
0	0 (N/mm^2)
0.001119	235 (N/mm^2)
0.1	235 (N/mm^2)

Fig. 17. Beam Endplate Strain-stress diagram following a nonlinear plastic analysis



X Value	Y Value
0	0 (N/mm^2)
0.0009905	208 (N/mm^2)
0.1	208 (N/mm^2)

Fig. 18. Beam Endplate-Beam profile weld Strain-stress diagram following a nonlinear plastic analysis



X Value	Y Value
0	0 (N/mm^2)
0.0042857	900 (N/mm^2)
0.1	900 (N/mm^2)

Fig. 19. Joint bolts - Strain-stress diagram following a nonlinear plastic analysis

The resulted bending-rotation curve (Fig. 20) with the same approximate values with SteelCON curve, confirms the application of the Eurocode component method as being a practical and easy to use in the ordinary joints design problems.

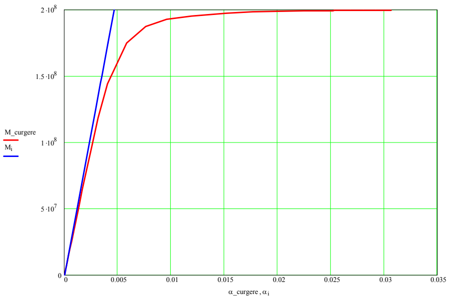


Fig. 20. Joint Bending-Rotation curve

2. Conclusions

In the current design is necessary to adopt the use of a wide range of types of joints.

The use of semi-rigid joints type, requires an assessment of ductility (rotation) in node and therefore an assessment of the entire nonlinear moment-rotation response of the joint.

The component method accepted by the standards it is used in current practice for a small type of joints range but can provide good and fast results without complex FEM type analysis.

Also the component method provides separate procedures to evaluate the initial strength and stiffness of steel and composite joints.

These procedures set out in Eurocode 3 and Eurocode 4 regulations, are reproducing these properties in a satisfactory manner with the possibility of ease calculation.

Ductility evaluation presents two difficulties when compared with the initial strength and stiffness: knowledge of the nonlinear force - deformation response of each component and knowledge of the nonlinear moment-rotation response of the joint.

The first problem is still insufficiently explored in the literature, most research is focused on assessing the strength and rigidity of structural components.

The second problem requires numerical iterative procedure, because of plasticization and instability phenomena.

Assuming known the nonlinear behavior of components, it is necessary to determine the total nonlinear moment-rotation response of the joint type and consequently determination of resistance, initial stiffness and maximum rotation of the joint. In this case a FEM analysis is necessary.

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