STRENGTH OF JOINTS SUBJECTED TO COMBINED ACTION OF BENDING MOMENTS AND AXIAL FORCES

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Keywords: Structural joints, component method, combined axial and bending forces, mechanical model, simplified calculation procedure.

Abstract: In Eurocode 3 Revised Annex J on « Joints in Building Frames » [1], design rules are provided for the evaluation of the structural properties of beam-to-column joints and beam splices subject to bending moments and shear forces. Amongst these properties, the most important ones are the moment design resistance, the rotational stiffness and the rotation capacity. The application of these rules is limited to cases where the axial force in the beam transferred through the joint does not exceed a limit value which has been arbitrary defined. The objective of the present paper is to reflect recent research works which could allow to extend the scope of Revised Annex J to joints subject to significant axial forces in addition to bending moments and shear forces.

1 INTRODUCTION

Very close contacts exist since some years between the University of Liège, MSM Department, and the ASTRON company with the objective to develop calculation rules for joints between built-up profiles in pitched-roof portal frames. These ones differ from the joints between hot-rolled profiles covered by Eurocode 3 Revised Annex J by the following features:

- the significant slenderness of the plates used for the fabrication of the connected members;
- the significant influence of the axial forces in the joints because of the inclination of the beams.

The higher slenderness of the built-up profiles leads to instability phenomena which may strongly decrease the carrying capacity of the joint. This aspect of the problem is briefly addressed in Chapter 3 while the influence of the axial forces on the structural properties of the joints is discussed in Chapters 4 and 5.

Some different students ([2], [3], [4], [5] and [6]) have already been working in Liège or Diekirch on this topic in the context of their diploma work. Their contribution, as well as the personal contribution of Jaspart are summarised in [7]. A sophisticated computer program called ASCon has also been developed, which takes into account the features of these joints. It is described in Chapter 4. In addition, a certain amount of laboratory tests should be performed in the very near future, in order to improve the knowledge on this type of joints, and ascertain some assumptions. Finally, simple calculation procedures orientated towards practitioners have been developed, allowing to take into account the combined effect of axial and bending forces on the joint resistance.

2 THE ANNEX J OF EUROCODE 3 AND THE CONCEPT OF COMPONENTS

The new rules which are provided by Eurocode 3 Revised Annex J for the verification of joints in steel building construction are based on the concept of "components" in which a joint is systematically considered as an assembly of elementary components. Each of these components has its own behaviour, i.e. its own resistance, stiffness and deformation capacity in tension, in compression or in shear, depending on how the component is loaded in the joint being considered.

In order to evaluate the structural properties of a joint, the three following steps must be successively achieved :

- Identification of the active components in the joints;
- Evaluation of the stiffness and resistance characteristics of these components;
- "Assembly" of the active components with the aim to derive the stiffness and resistance properties of the whole joint.

Revised Annex J of Eurocode 3 provides the user with stiffness and resistance calculation rules for all the components required to cover usual joint configurations (double-sided and single-sided beam-to-column joints, beam splices) and connection types (with endplates, flange cleats and welds). An assembly procedure of these components is also provided. Its scope is however limited to joints mainly subjected to bending moments and shear forces in which the applied axial compression or tension force N_{Sd} in the connected beam(s) does not exceed *10%* of the capacity $N_{b.Rd}$ of the beam cross-section in compression or tension:

$$N_{Sd} / N_{b.Rd} \leq 0.1 \qquad (1)$$

In this range, the influence of the axial force on the bending moment design resistance of the joint is disregarded.

In Chapters 4 and 5, indications are given on how this limitation may be overcome respectively in a numerical way and in a more practical way. More details about these developments are provided in the full-length CD ROM paper.

3 SPECIFIC COMPONENTS FOR SLENDER WELDED PROFILES

In Revised Annex J of Eurocode 3 a library of components is made available to the users. Through the combination of these ones a wide range of connection types may be covered. However some of the rules provided for the evaluation of the stiffness and resistance properties of the components possess a limited scope of validity which, for instance, prevents their application to joints between slender built-up profiles where the significant slenderness of the plates used for the fabrication of the beams (or the columns) leads to premature instability phenomena in the "column web panel in shear" and "beam flange and web in compression" components. For these two components, numerical as well as theoretical studies aimed at extending the scope of application of Revised Annex J have been carried out in Liège and Diekirch and experimental investigations are planned at the end of 1999. The interested readers will find more details about these research works in [8] and [9].

4 NUMERICAL APPLICATION OF THE COMPONENT METHOD TO JOINTS SUBJECT TO BENDING AND AXIAL FORCES

In order to apply the component method to joints simultaneously subject to a bending moment and an axial force, a distribution of the internal forces acting into bolt-rows has to be selected; this distribution on which the assembly procedure is based must at least satisfy the following conditions:

- to be in equilibrium with the loads applied to the joint;
- to be such that the resistance capacity of the components is not exceeded;
- to be such that the deformation capacity of the components is not exceeded.

Preliminary studies ([2], [10]) have shown how difficult it is to determine such a distribution of internal forces through an analytical procedure. Taking advantage of the preliminary studies of Finet [3], Jaspart and Cerfontaine developed a numerical approach aimed at analysing the joint behaviour from the first loading steps up to collapse. As this approach respects also the compatibility of deformations between the constitutive joint components, it represents a sort of "actual" simulation of the joint behaviour.

In this approach the joint is idealised by a mechanical model constituted of extensional springs (Fig. 1), each spring representing a component of the joint and exhibiting a non linear force-displacement behaviour.

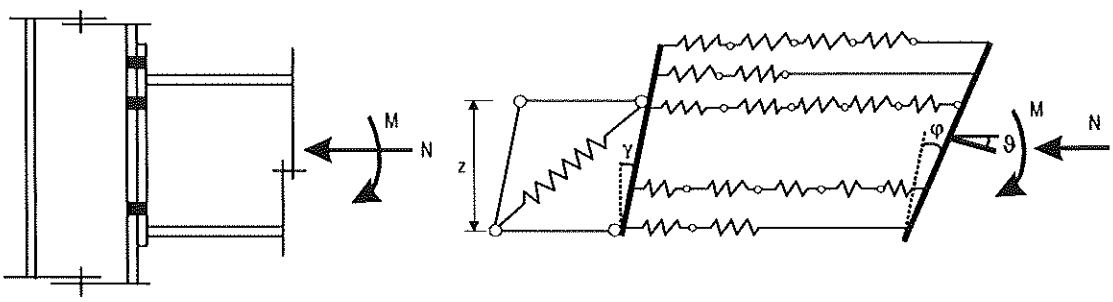

Fig. 1 Joint and its mechanical model

A computer program based on this numerical approach has been written; it is called ASCon. All the component properties are determined by means of the Revised Annex J. The possible interactions between the bolt-rows - which occurs in the case where so-called group effects develop between adjacent bolt-rows - are considered, as well as all the stress interactions between the components. The ASCon computer program allows for plastic redistribution of the internal forces between the successive bolt-rows.

Another main feature of the program is its ability to consider the particularities of the joints used in lightweight steel industrial building construction; for example, the slender components mentioned in Chapter 3, but also specific stiffening and strengthening joint elements not covered by Eurocode 3.

Further developments of the program are planned, such as the extension to non-proportional joint loading and the simulation of the elastic unloading of the components.

5 PRACTICAL CALCULATION PROCEDURE FOR JOINTS SUBJECT TO BENDING AND AXIAL FORCES

The ASCon software appears as a sophisticated research tool involving iterative calculations at each loading step. Its practical interest is therefore rather limited and this explains why its development has been prolonged by the following actions:

- use of the ASCon software as a reference tool in parametric studies in order to point out the influence of the geometry and of the loading ratio N_{Sd}/M_{Sd} on the global response, on the resistance and on the collapse mode of beam-to-column joints and beam splices (N_{Sd} and M_{Sd} being respectively the axial force and the bending moment acting on the joint);
- development of practical rules for joint assembly under N_{Sd} and M_{Sd} forces allowing a hand calculation and validated by means of comparisons with results provided ASCon.

The interested reader will find details about the parametric studies in [5] and [6] while the full-length paper on CD ROM contains background information about the simplified joint assembly procedure. This one is compared to the ASCon software in Fig. 2 for a beam splice with five bolt-rows. The full M_{Sd}-N_{Sd} interaction diagram for design resistance is reported; it is seen to be constituted of a set of straight lines which intersect each other. Each straight line is representative of a specific plastic collapse mode; this means that two different collapse modes develop simultaneously in each intersection point. In the range of low N_{Sd} values, the plastic re-

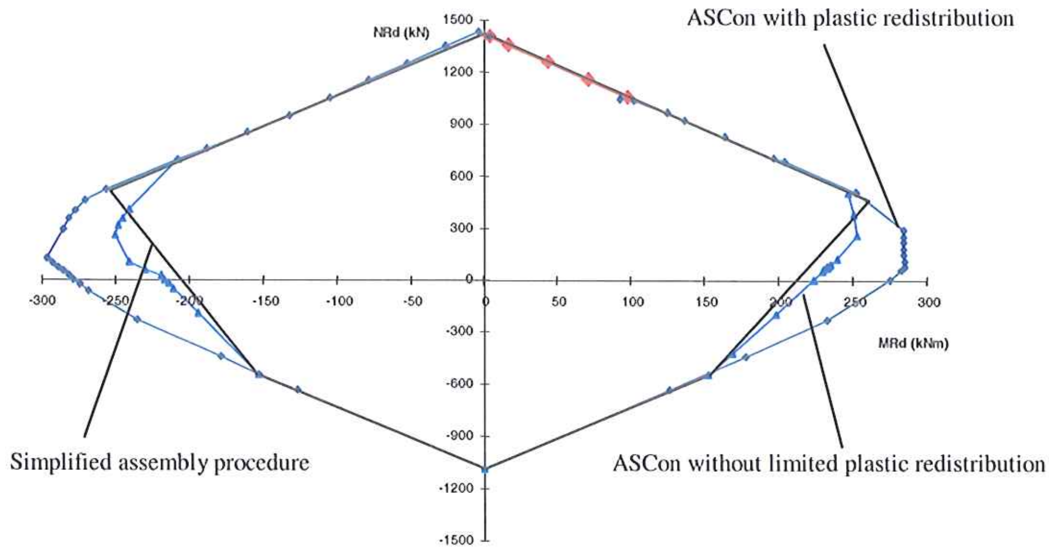

Fig. 2 Example of M_{Sd}/N_{Sd} interaction diagram for joint resistance

distribution of internal forces within the joint is limited in Fig. 2 by the possible lack of deformation capacity of the "beam flange and web in compression" component and a reduced resistance of the joint has to be considered. The originality of the simplified assembly procedure is its ability to detect situations where the plastic redistribution of the internal forces within a joint is limited by the lack of ductility of a component and to evaluate the carrying capacity of the joint accordingly.

As a preliminary conclusion in the present short-length paper, the unsafe character of the "*0,1 criterion*" given by Formula (1) may be pointed out from Fig. 2.

References

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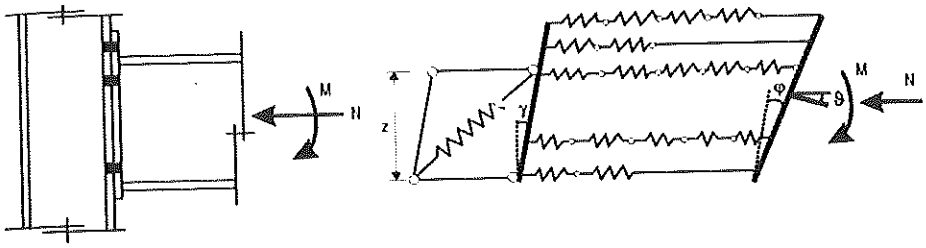

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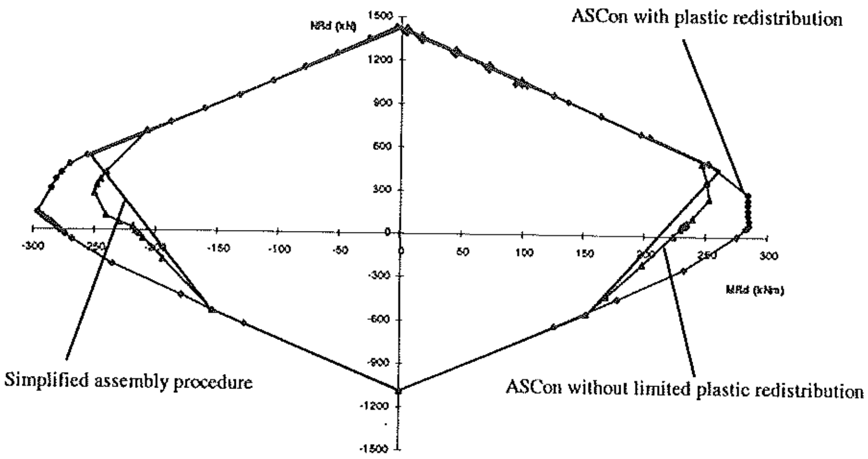

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