Design of Steel Connections according ENV 1993-1

Jean-Pierre JASPART
Research Associate FNRS
Doctor Engineer
University of Liège
Liège
BELGIUM

Jean-Pierre JASPART, born 1962 got his Civil Engineering Degree in 1985 and his Ph.D Degree in 1991. He is the author of more than 60 papers on connection and frame design, one of the members of the Drafting Group of EC3, Annex J and Chairman of the COST C1 Working Group on "Steel and Composite Connections"

Summary

In this paper, the component method on which the new revised Annex J of Eurocode 3 dealing with "Joints in Building Frames" [1] is based is first described. Simplified design tools allowing the designer to take full profit of the new design concepts proposed by Annex J are then presented. As an example, the simplified design procedure for beam splices with flush end plates is given.

1. Introduction

In the last decades, many research works have been devoted to the improvement of the design and analysis procedures for structural frames and for their constitutive beam and column elements. More and more refined design procedures have been developed and progressively introduced in the national and international (Eurocodes) design codes. Comparatively less works have been devoted to connections which are still traditionnally considered, in most of the national design codes, as pinned or rigid.

Since a bit more than ten years however, the situation has changed. It is now well recognized that the design of actual pinned or rigid connections is often leading to high fabrication and erection costs. It is well known that a strong reduction of these costs may result from the use of so-called semi-rigid connections but it has also to be said that, till now, the knowledge on how to design semi-rigid connections and on how to design structural frames including semi-rigid connections is mainly in the hands of the scientists who deeply investigated these problems in the last decade.

In this context, the drafters of Eurocode 3 have been faced to the following situation : "do we open or not the door to semi-rigid design in Eurocode 3 ?". The reply was "yes!". As a matter of fact, it has been thought that Eurocode 3 had not to prevent designers from designing economically.

It has however to be recognized that the present situation is quite unusual in the sense that new design rules and procedures which have almost never been used in practical applications are now codified, at the European level, in the recently revised Annex J of Eurocode 3 [1].

The task of the scientists is now to disseminate the new design techniques by organizing workshops, seminars and conferences, by preparing design handbooks and simplified design guidelines and by teaching the new concepts in the universities. This task is now in progress in some countries.

2. Design of connections according Annex J

The component method, as expressed in EC3 Annex J, allows to evaluate by means of a unified procedure, the stiffness and resistance properties of various bolted and welded steel connections Its extension to composite connections is now in progress in the frame of the joint activities of the COST C1 Working Group on "Steel and Composite" and ECCS TC11 on "Composite Structures". This work should lead in a very near future to the publication of an EC4 Annex J on "Joints in Composite Building Frames".

2.1. The Component Method

A joint is generally considered as a whole and is studied accordingly; the originality of the component method is to consider any joint as a set of "individual basic components". In the particular case of figure 1 (joint with extended end plate connection subject to bending), the relevant components are the following :

- compression zone :
  - column web in compression;
  - beam flange in compression;
- tension zone :
  - column web in tension;
  - column flange in bending;
  - bolts in tension;
  - endplate in bending;
  - beam web in tension;
- shear zone :
  - column web panel in shear.

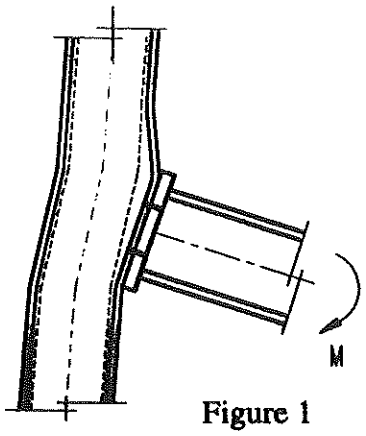


Figure 1

Each of these basic components possesses its own level of strength and stiffness in tension, compression or shear. The coexistence of several components within the same joint element - for instance, the column web which is simultaneously subjected to compression (or tension) and shear - can obviously lead to stress interactions that are likely to decrease the strength and the stiffness of each individual basic component; this interaction affects the shape of the deformability curve of the related components but does not call the principles of the component method in question again.

The application of the component method requires the following steps :

a) listing of the "activated" components for the studied joint;

b) evaluation of the stiffness and/or strength characteristics of each individual basic component (specific characteristics - initial stiffness, design strength, ... - or whole deformability curve);

c) "assembling" of the components in view of the evaluation of the stiffness and/or strength characteristics of the whole joint (specific characteristics - initial stiffness, design resistance, ... - or whole deformability curve). The "assembling" is based on an assumed distribution of the internal forces within the joint.

The application of the component method requires a sufficient knowledge of the behaviour of the basic components. Twelve are given in EC3 Annex J. The combination of these components allows to cover a wide range of joint configurations, what should largely be sufficient to satisfy the needs of practitioners as far as beam-to-column joints and beam splices in bending are concerned.

The framework of the component method is sufficiently general to allow the use of various techniques of component characterization and joint "assembling".

In particular, the stiffness and strength characteristics of the components may result from experimentations in laboratory, numerical simulations by means of finite element programs or analytical models based on theory, as in Annex J.

22. Design aids

The possible interactions between some of the components as well as the redistribution of the internal forces in the joint for increasing applied moments make the use of Annex J rather complicated for design practice. In fact, this annex is not of real practical use and has more to be considered as a reference document, on the basis of which computer programs or simplified application procedures may be derived.

Such practical tools have been recently developed in the frame of two European projects, SPRINT [2] and ECSC [3].

In the SPRINT project, simplified design procedures have been established for five usual types of beam-to-column joints and beam splices. They are aimed at assisting the designer who is willing to take account of the benefits which can result from a semi-rigid design, without having to go through the more complex approach of EC3 Annex J.

For a specific joint, the calculation procedure gives the expressions of both stiffness and resistance for all the components of the joint. How to derive the global properties of the joint - rotational stiffness and design moment resistance - is summarized at the end of the design sheet.

Such a design sheet is given at the end of the paper (case of a beam splice with flush end plates).

Besides these sheets, design tables for standardized joints have been produced. They can be used in a straightforward manner, as an alternative to the design sheets. These tables are established for standard combinations of connected shapes and provide the designer with the values of :

- the rotational stiffness;
- the design moment and shear resistances of the joint;
- the component of the joint which is governing the moment resistance and therefore an indication on the rotation capacity of the joint;
- the reference length which allows the joint to be classified as rigid, pinned or semi-rigid.

The design tables can be used either to obtain the mechanical properties of a given joint or to select a joint so as to comply with specific expected mechanical properties.

In case of complex or less usual joint geometry, reference has to be made to Annex J. To avoid any complexity, a software program has been developed in the frame of the above-mentioned ECSC project [3]. It is called DESIMAN. It allows to calculate any type of joint in any joint configuration according to the rules given in Annex J. This PC-mounted program provides a very user friendly way to enter the data (through specific databases for profiles, bolts, ...) by using all the possibilities of the Microsoft Windows environment. The simplified SPRINT design rules are also included in the program. The Institute of Steel Construction of RWTH Aachen in Germany is developing the graphical pre- and post-processors, while the CRIF Research Centre and the Department MSM of the University of Liège in Belgium are responsible for the calculation module.

3. Conclusions

Eurocode 3 Annex J, and in particular the component method, allows nowadays to cover a wide range of different joints. Its use for daily practice is however not recommended. In this paper, it is shown that this may be overcome through the use of available simplified design tools as design sheets, design tables and a PC-mounted software

4. References

[1] New Revised Annex J of Eurocode 3 "Joints in Building Frames", Doc. CEN/TC250/SC3-N419E, Brussels, June 1994.

[2] SPRINT Contract RA351.
"Steel moment connections according to Eurocode 3. Simple design aids for rigid and semi-rigid joints", 1992-1996, CRIF(B), University of Liège (B), CTICM (F), University of Trento (I), LABEIN Bilbao (SP).

[3] ECSC Research Contracts 7210-SA/212 and 320.
"Elaboration of a design handbook in view of the application of the semi-rigid concept for connections to the structural analysis", 01.07.93 to 30.06.96, University of Liège (B), CTICM (F), CRIF (B), RWTH Aachen (D) and TNO Delft (NL).

5. Example of simplified design procedure

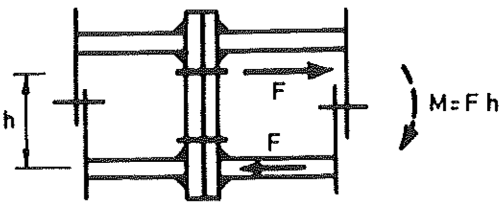
Mechanical characteristics

	Yield stresses	Ultimate stresses
Beam webs	f_{ywb}	-
Beam flanges	f_{yfb}	-
End-plates	f_{yp}	f_{up}
Bolts	-	f_{ub}

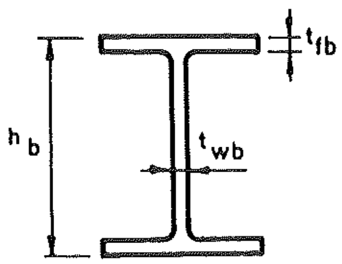
If hot-rolled profiles : $f_{ywb} = f_{yfb}$

Geometrical characteristics

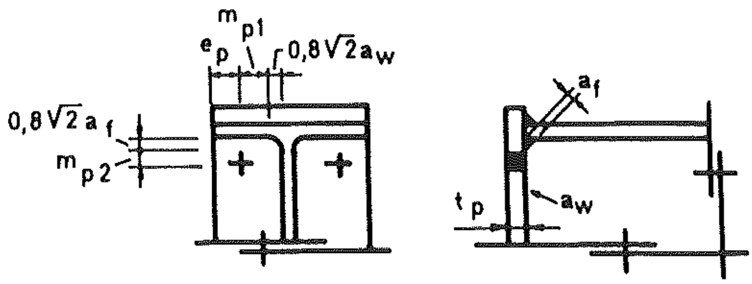
Joint



Beams



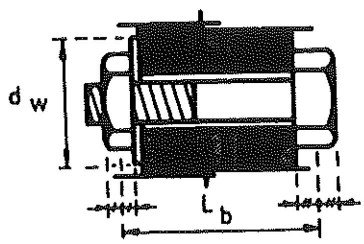
End-plates

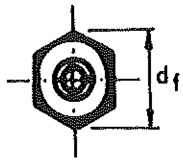


Bolts

d_w : see figure or = d_f if no washer

A_s : resistance area of the bolt





	STIFFNESS	*RESISTANCE*
Beam flanges in compression	$k_3 = \infty$	$F_{Rd,3} = M_{c.Rd} / (h_b - t_{fb})$ $M_{c.Rd}$: beam design moment resistance
Bolts in tension	$k_4 = 1{,}6 \dfrac{A_s}{L_b}$	$F_{Rd,4} = 2\ B_{t.Rd}$ with $B_{t.Rd} = F_{t.Rd}$ $F_{t.Rd} = \dfrac{0{,}9\ f_{ub}\ A_s}{\gamma_{Mb}}$
End-plates in bending	$k_7 = \dfrac{0{,}85\ l_{eff,t}\ t_p^3}{2\ m_{p1}^3}$	$F_{Rd,7} = \min [\ F_{ep.Rd,1}\ ;\ F_{ep.Rd,2}\ ]$ $F_{ep.Rd,1} = \dfrac{(8n_p - 2e_w)\ l_{eff,t}\ m_{pl,p}}{2m_{p1}\ n_p - e_w(m_{p1} + n_p)}$ $F_{ep.Rd,2} = \dfrac{2\ l_{eff,t}\ m_{pl,p} + 2\ B_{t.Rd}\ n_p}{m_{p1} + n_p}$ $n_p = \min [\ e_p\ ;\ 1{,}25m_{p1}\ ]$ $m_{pl,p} = 0{,}25\ t_p^2\ f_{yp} / \gamma_{M0}$ $e_w = d_w / 4$
	$l_{eff,t} = \min [\ 2\pi m_{p1}\ ;\ \alpha m_{p1}\ ]$ where α is defined in EC3 Annex J	
Beam web in tension	$k_8 = \infty$	$F_{Rd,8} = b_{eff.wb,t}\ t_{wb}\ f_{ywb} / \gamma_{M0}$
	$b_{eff.wb,t} = l_{eff,t}$	
JOINT	Initial stiffness : $S_{j,ini} = E\ h^2 / \sum_{i=3,4,7,8} 1/k_i$ Nominal stiffness : $S_j = S_{j,ini} / 3$	$F_{Rd} = \min [\ F_{Rd,i}\ ]$ Plastic design moment resistance : $M_{Rd} = F_{Rd}\ h$ Elastic moment resistance : $\frac{2}{3} M_{Rd}$