

# STEEL MOMENT CONNECTIONS ACCORDING TO EUROCODE 3

## Simple design aids for rigid and semi-rigid joints

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on behalf of the RA 351 SPRINT Partners.

### Abstract

In this paper, simplified design procedures for structural joints in building frames are presented. These ones can be used either to obtain the mechanical properties of a given joint or to select a joint so as to comply with expected mechanical properties. They have been prepared so to be in full agreement with the new revised Annex J of Eurocode 3 (Revised Annex J, 1994) in the frame of the european RA 351 SPRINT project involving CRIF (J. JANSS as Coordinator) and the University of Liège (R. MAQUOI, J.P. JASPART) in Belgium, CTICM (B. CHABROLIN, Y. RYAN, A. SOUA) and ENSAIS Strasbourg (A. COLSON) in France, the University of Trento (R. ZANDONINI, O. BURSI) in Italy and LABEIN Bilbao (W. AZPIAZU) in Spain.

## 1. INTRODUCTION

The design of a building frame for economy requires a good knowledge of the response of the constitutive structural joints in terms of flexural stiffness and resistance. In this respect, the freedom for the designer to select the most convenient joint for design, fabrication or erection is quite important. Such a freedom is offered by the new revised Annex J of Eurocode 3 on "Joints in Building Frames".

Through the so-called "component method" [(JASPART and MAQUOI, 1994) and (JASPART et al, 1995)], Annex J allows the designer to cover a large range of usual structural joints. The understanding of the "component method" philosophy and of its application requires anyway some time and efforts from the designer; it has therefore been felt that simplified design guidelines should be prepared so to allow him to profit directly and in an easy way from the advantages linked to the new design concepts on joints.

The opportunity to develop such simplified tools has been given to the above-mentioned SPRINT partners who prepared these two last years a set of design guidelines, a free copy of which has been made available to each of the Workshop participants.

## 2. THE SPRINT DOCUMENT

The SPRINT documents contains the six following chapters:

- Chapter 1 : Simple design model for joint stiffness and resistance calculation
- Chapter 2 : Stiffness and resistance calculation for beam-to-column joints with extended end plate connections
- Chapter 3 : Stiffness and resistance calculation for beam-to-column joints with flush end plate connections
  - a) End plate height smaller than beam depth
  - b) End plate height larger than beam depth
- Chapter 4 : Stiffness and resistance calculations for beam splices with flush end plate connections
  - a) End plate height smaller than beam depth
  - b) End plate height larger than beam depth
- Chapter 5 : Stiffness and resistance calculation for beam-to-column joints with flange cleated connections
- Chapter 6 : Global analysis of frames with semi-rigid joints.

The first part of Chapter 1 gives general indications about the semi-rigid behaviour of the joints, their modelling for frame analysis, their characterization through the component method, the idealization of their characteristic  $M-\phi$  curves and their classification, in terms of stiffness, as pinned, semi-rigid and rigid.

The second part of Chapter 1 gives guidelines on how to use the design tools for joints described in Chapters 2 to 5.

How to perform the global structural analysis of a frame, the constitutive joints of which have been classified as semi-rigid is explained in a simple way in Chapter 6. In this chapter, the designer's attention is turned to elastic methods of global analysis which are of first interest in daily design practice.

### 3. THE DESIGN TOOLS FOR JOINTS

For design purposes, design aids are detailed in chapters 2 to 5. Chapter 2 is partly reproduced, as an example, at the end of the present paper. Each of these chapters is devoted to a specific type of joint. It is composed of two parts:

- a. a calculation procedure, presented in the format of design sheets;
- b. design tables.

The calculation procedure is aimed at assisting the designer who is willing to take account of all the capacities of the semi-rigidity, without having to go through the more complex approach of Annex J of Eurocode 3.

For a specific joint, a first design sheet is devoted to the useful mechanical and geometrical characteristics of the joint under consideration. In the following sheets, 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 whole joint, i.e. its nominal stiffness and its design moment resistance, is summarized at the end of the design sheet. Additional design considerations are given in Chapter 1.

Of course the shear resistance of the joint is of major importance for the design. It is not given in the design sheets for sake of clarity. Relevant information in this respect is however provided in Chapter 1 (as well as information on weld design).

The second part of each of the chapters 2 to 5 consists in design tables, which can be used in a straightforward manner as an alternative to the design sheets. These design tables are established for standard combinations of connected shapes and provide the designer with the values of:

- the initial stiffness  $S_{j,ini}$  and the reduced stiffness  $S_{j,inf}/2$  to be possibly used for elastic design;
- the design moment  $M_{Rd}$  and the shear resistance  $V_{Rd}$  of the joint ;
- the component of the joint which is governing the moment resistance ;
- the reference lengths in case of a braced ( $L_{bb}$ ) or unbraced ( $L_{bu}$ ) structural system.

The knowledge of the "governing component", and of its ductility, allows to determine the level of rotation capacity for the joint while the reference length allows to classify the joint as pinned, semi-rigid or rigid. Reference lengths are boundaries to which the actual beam span (beam to which the considered joint is attached) has to be compared. Too such reference lengths exist for each joint:

- one to distinguish between a rigid and a semi-rigid joint ;
- one to distinguish between a semi-rigid and a pinned joint.

The design tables have been obtained from the expressions given in the design sheets

but by taking some options which generally give conservative results. There are however some extreme situations where the use of the design tables cannot be furthermore recommended. These situations are mostly related to the stress state - shear and direct stresses - which exists in the column web panel and is controlled by factors  $\xi$  and  $\eta$ . Some comments regarding the physical meaning and the values of  $\xi$  and  $\eta$ , recommended for the use of design sheets or adopted implicitly in the design tables, are given in Chapter 1.

In the design tables, the following information is provided to the designer for what concerns the classification:

- a number followed by the label R: the number is the reference length, the label R means that the reference length is the upper boundary between rigid and semi-rigid;
- a label P followed by a number: the number is the reference length, the label P means that the reference length is the lower boundary between pinned and semi-rigid.

In the case of non reasonable values for the reference length, only an ad-hoc indication P, R or S is given (S for semi-rigid).

#### 4. THE DIFFERENT WAYS TO USE THE DESIGN TOOLS

The SPRINT design sheets and tables can be used in isolation or in combination so to assist efficiently the designer in different situations which can result from the design procedure he has decided to follow. Some examples are discussed hereafter.

- The predesign and the design of the frame is based on the assumption that the constitutive joints are rigid or pinned. At the end of the design procedure, the joints have to be designed so to resist the internal forces resulting from the structural analysis and to fulfil the stiffness requirements (pinned or rigid). In such a case, the tables can be used to select an approximate joint.
- To get rigid joints, transverse stiffeners are traditionally welded on the columns, at the level of the beam flanges. In the tables, it is seen that several unstiffened joints (mainly joints with extended end plates) may be considered as rigid for frame analysis. In this respect, the tables allow the designer to profit from a substantial economy on the joint fabrication (no stiffeners) without altering at all the design procedure he is used to apply (rigid design).
- When predesigning a frame, economical benefit from the semi-rigid design may be achieved more easily by selecting, through the use of the design tables, the

most convenient joint for fabrication and erection as well as the corresponding structural properties.

- For joints, components of which are different from these listed in the tables, a combined use of the design sheets and tables can strongly reduce the amount of calculations to be done to characterize the response of the joints.

## 5. CONCLUSIONS

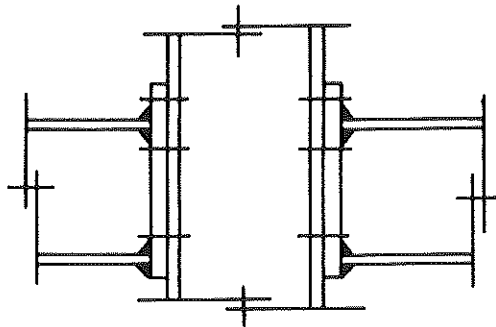
To achieve an economical design of the frames and of the constitutive joints - as it is now possible through the new possibilities offered by Eurocode 3 - the designers require design tools adopted to their search of efficiency and profitability. The RA 351 SPRINT has performed a step in this direction by establishing design tables and design sheets for commonly used types of beam-to column joints and beam splices. These design aids allow the designer to select the well known fully rigid joints or fully pinned joints or to select semi-rigid joints which generally give a significant benefit by simplifying joint details thereby reducing shop and erection costs.

## 6. REFERENCES

1. EUROCODE 3, ENV-1993-1-1, *Revised Annex J*, Design of Steel Structures, European Committee for Standardization, Document CEN/TC250/SC3-N419E, Brussels, June 1994.
2. JASPART, J.P. and MAQUOI, R., *Prediction of the semi-rigid and partial strength properties of structural joints*, Proceedings of the SSRC Technical Annual Session, Lehigh, U.S.A., June 20, 1994, pp. 177-192.
3. JASPART, J.P., STEENHUIS, M. and WEYNAND, K., *The stiffness model of revised Annex J of Eurocode 3*, Proceedings of the Third International Workshop on Connections in Steel Structures, Trento, Italy, May 28-31, 1995.

## CHAPTER 2

### ***STIFFNESS AND RESISTANCE CALCULATION FOR BEAM-TO-COLUMN JOINTS WITH EXTENDED END-PLATE CONNECTIONS***



1. Calculation procedure
2. Design tables

## *1. CALCULATION PROCEDURE*

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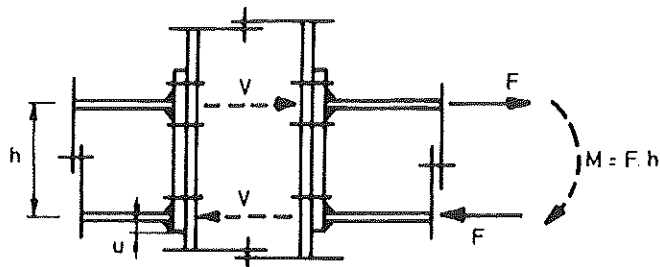
**Mechanical characteristics**

	<u>Yield stresses</u>	<u>Ultimate stresses</u>
Beam web	$f_{ywb}$	-
Beam flange	$f_{yfb}$	-
Column web	$f_{ywc}$	-
Column flange	$f_{yfc}$	$f_{ufc}$
End-plate	$f_{yp}$	$f_{up}$
Bolts	-	$f_{ub}$

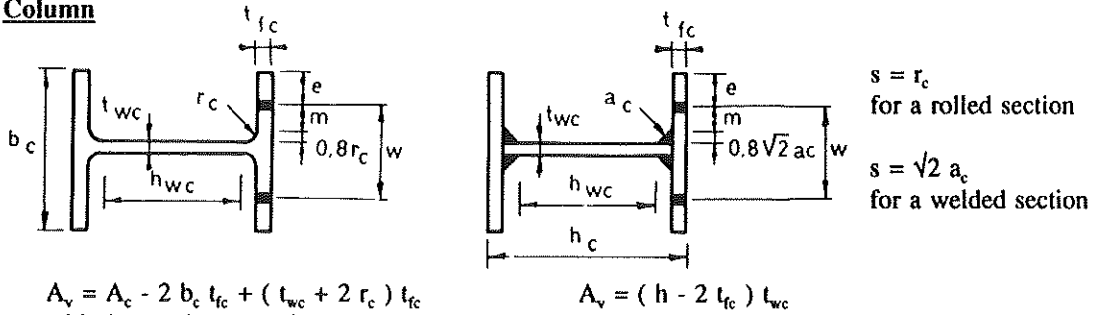
If hot-rolled profiles :  $f_{ywc} = f_{yfc}$  and  $f_{ywb} = f_{yfb}$

**Geometrical characteristics**

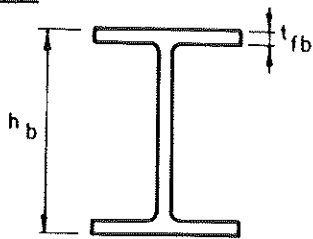
**Joint**



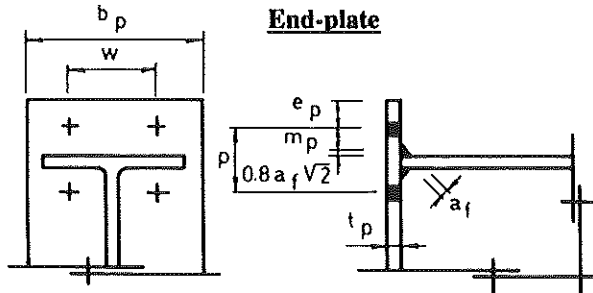
**Column**



**Beam**

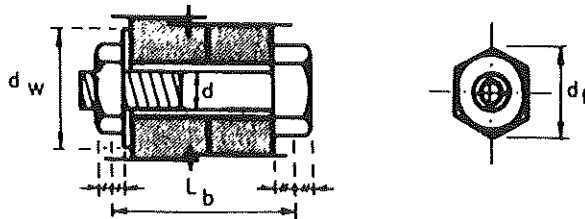


**End-plate**



**Bolts**

$d_w$  : see figure or  $= d_f$  if no washer  
 $A_s$  : resistance area of the bolts





<i>STIFFNESS</i>	<i>RESISTANCE</i>
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<b>Column web panel in shear</b>	$k_1 = \frac{0,385 A_v}{\xi h}$	$F_{Rd,1} = \frac{V_{wc,Rd}}{\xi} \quad \text{with} \quad V_{wc,Rd} = \frac{0,9 A_v f_{ycw}}{\sqrt{3} \gamma_{Mo}}$ <p> <math>\xi = 1</math> for one-sided joint configurations;  <math>0</math> for double sided joint configurations symetrically loaded;  <math>1</math> for double-sided configurations non-symetrically loaded with balanced moments;  <math>2</math> for double-sided joint configurations non-symetrically loaded with unbalanced moments.            For other values, see 1.2.2.1 in chapter 1.         </p>
<b>Column web in compression</b>	$k_2 = \frac{0,7 b_{eff,wc,c} t_{wc}}{h_{wc}}$	$F_{Rd,2} = \eta \rho_c b_{eff,wc,c} t_{wc} f_{ycw} / \gamma_{Mo}$ <p>           with <math>\eta = \min [1,0 ; 1,25 - 0,5 \frac{\sigma_n}{f_{ycw}}]</math> (*)         </p> $\rho_c = \sqrt{\frac{1}{1 + 1,3(\xi b_{eff,wc,c} t_{wc} / A_v)^2}}$ <p> <math>\sigma_n</math> : normal stresses in the column web at the root of the fillet radius         </p> $b_{eff,wc,c} = t_{fb} + a_f \sqrt{2} + t_p + \min(u ; a_f \sqrt{2} + t_p) + 5(t_{fc} + s)$ <p>(*) see 1.2.2.2 in chapter 1.</p>
<b>Beam flange in compression</b>	$k_3 = \infty$	$F_{Rd,3} = M_{c,Rd} / (h_b - t_{fb})$ <p><math>M_{c,Rd}</math> : beam design moment resistance</p>
<b>Bolts in tension</b>	$k_4 = 3,2 \frac{A_s}{L_b}$	$F_{Rd,4} = 4 B_{t,Rd} \quad \text{with} \quad B_{t,Rd} = F_{t,Rd}$ $F_{t,Rd} = \frac{0,9 f_{ub} A_s}{\gamma_{Mb}}$
<b>Column web in tension</b>	$k_5 = \frac{0,7 b_{eff,wc,t} t_{wc}}{h_{wc}}$	$F_{Rd,5} = \rho_t b_{eff,wc,t} t_{wc} f_{ycw} / \gamma_{Mo}$ <p>           with <math>\rho_t = \sqrt{\frac{1}{1 + 1,3(\xi b_{eff,wc,t} t_{wc} / A_v)^2}}</math> </p> $b_{eff,wc,t} = \min [ 4\pi m ; 8m + 2,5e ; p + 4m + 1,25e ]$

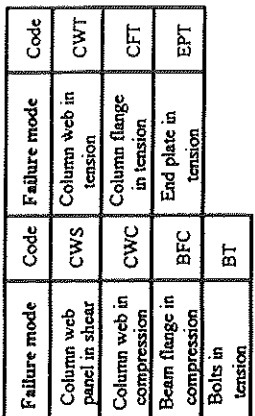
<p>Column flange in bending</p>	$k_6 = \frac{0,85 l_{eff,fc} t_f^3}{m^3}$	$F_{Rd,6} = \min [ F_{fc,Rd,1} ; F_{fc,Rd,2} ]$ $F_{fc,Rd,1} = \frac{(8n - 2e_w) l_{eff,fc} m_{pl,fc}}{2mn - e_w(m+n)}$ $F_{fc,Rd,2} = \frac{2 l_{eff,fc} m_{pl,fc} + 4 B_{t,Rd} n}{m + n}$ $n = \min [ e ; 1,25m ; (b_p - w)/2 ]$ $e_w = d_w / 4$ $m_{pl,fc} = 0,25 t_{fc}^2 f_{fc} / \gamma_{M0}$ $l_{eff,fc} = b_{eff,w,c}$
<p>End-plate in bending</p>	$k_7 = \frac{0,85 l_{eff,p} t_p^3}{m_p^3}$	$F_{Rd,7} = \min [ F_{ep,Rd,1} ; F_{ep,Rd,2} ]$ $F_{ep,Rd,1} = \frac{(8n_p - 2e_w) l_{eff,p} m_{pl,p}}{2m_p n_p - e_w(m_p + n_p)}$ $F_{ep,Rd,2} = \frac{2 l_{eff,p} m_{pl,p} + 4 B_{t,Rd} n_p}{m_p + n_p}$ $n_p = \min [ e_p ; 1,25m_p ]$ $m_{pl,p} = 0,25 t_p^2 f_{yp} / \gamma_{M0}$ $l_{eff,p} = \min [ 4\pi m_p ; 8m_p + 2,5e_p ; w + 4m_p + 1,25e_p ; b_p ]$
<p><b>JOINT</b></p>	<p>Initial stiffness :</p> $S_{joint,init.} = E h^2 / \sum_{i=1}^7 1/k_i$ <p>Nominal stiffness :</p> $S_{joint} = S_{joint,init.} / 2$	$F_{Rd} = \min [ F_{Rd,i} ]$ <p>Plastic design moment resistance :</p> $M_{Rd} = F_{Rd} h$ <p>Elastic moment resistance :</p> $\frac{2}{3} M_{Rd}$

## ***2. DESIGN TABLES***

A thick, black L-shaped graphic element consisting of a horizontal bar extending to the right and a vertical bar extending upwards from the right end of the horizontal bar, positioned to the right of the section header.

Column	Beam	bolts hr88	End-plate: S235 (mm)													Connection detail (mm)				Welds (mm)		Rotational stiffness (kNm/rad)			Resistance			failure mode		Reference length(m)	
			t <sub>p</sub>	b <sub>p</sub>	b <sub>p</sub>	c <sub>p</sub>	p	p <sub>p</sub>	e <sub>p1</sub>	u <sub>1</sub>	u	w <sub>1</sub>	w	u	a <sub>f</sub>	a <sub>w</sub>	t <sub>p</sub>	S <sub>rd</sub>	S <sub>rd/2</sub>	M <sub>Rd</sub>	2/3M <sub>Rd</sub>	V <sub>Rd</sub>	Code	L <sub>bb</sub>	L <sub>bu</sub>						
HEB140	IPE220	M16	15	130	300	35	80	130	55	35	35	70	30	10	3	5	11604	5802	27.2	18.1	157	CWC	4.0-R	S							
	IPE240	M16	15	130	320	35	80	150	55	35	35	70	30	10	4	5	13212	6606	29.7	19.8	157	CWC	4.9-R	S							
	IPE270	M16	15	134	350	35	85	170	60	35	35	70	32	10	4	6	15968	7984	33.7	22.5	157	CWC	6.1-R	S							
	IPE220	M16	15	130	300	35	80	130	55	35	35	70	30	10	3	5	13993	6997	35.7	23.8	157	CWC	3.3-R	S							
	M20	M20	20	160	320	45	100	110	65	45	45	90	35	10	3	5	14344	7172	36.2	24.1	245	CWC	3.2-R	S							
	IPE240	M16	15	130	320	35	80	150	55	35	35	70	30	10	4	5	16008	8004	39.0	26.0	157	CWC	4.1-R	S							
	M20	M20	20	160	340	45	100	130	65	45	45	90	35	10	4	5	16392	8196	39.6	26.4	245	CWC	4.0-R	S							
	IPE270	M16	15	134	350	35	85	170	60	35	35	70	32	10	4	6	19520	9760	44.3	29.5	157	CWC	5.0-R	S							
	M20	M20	20	160	370	45	105	150	70	45	45	90	35	10	4	6	19834	9917	44.9	29.9	245	CWC	4.9-R	S							
	IPE300	M16	15	150	380	35	85	200	60	35	35	70	40	10	4	6	23030	11515	49.4	32.9	157	CWC	6.1-R	S							
	M20	M20	20	160	400	45	105	180	70	45	45	90	35	10	4	6	23189	11594	50.1	33.4	245	CWC	6.1-R	S							
	IPE330	M16	15	160	410	35	85	230	60	35	35	70	45	10	4	6	26543	13271	54.5	36.3	157	CWC	7.4-R	S							
	M20	M20	20	160	430	45	105	210	70	45	45	90	35	10	4	6	26607	13304	55.3	36.8	245	CWC	7.4-R	S							
	IPE220	M16	15	130	300	35	80	130	55	35	35	70	30	10	3	5	14691	7346	39.9	26.6	157	CWC	3.2-R	S							
	M20	M20	20	160	320	45	100	110	65	45	45	90	35	10	3	5	15299	7649	40.5	27.0	245	CWC	3.0-R	S							
	IPE240	M16	15	130	320	35	80	150	55	35	35	70	30	10	4	5	16868	8434	43.7	29.1	157	CWC	3.9-R	S							
	M20	M20	20	160	340	45	100	130	65	45	45	90	35	10	4	5	17538	8769	44.3	29.5	245	CWC	3.7-R	S							
	IPE270	M16	15	134	350	35	85	170	60	35	35	70	32	10	4	6	20691	10345	49.5	33.0	157	CWC	4.7-R	S							
	M20	M20	20	160	370	45	105	150	70	45	45	90	35	10	4	6	21322	10661	50.2	33.5	245	CWC	4.6-R	S							
	IPE300	M16	15	150	380	35	85	200	60	35	35	70	40	10	4	6	24534	12267	55.2	36.8	157	CWC	5.7-R	S							
	M20	M20	20	160	400	45	105	180	70	45	45	90	35	10	4	6	25024	12512	56.0	37.4	245	CWC	5.6-R	S							
	M24	M24	20	180	410	50	115	170	75	50	50	100	40	10	4	6	24667	12334	56.0	37.4	352	CWC	5.7-R	S							

$\zeta = 1$   
 $\gamma_{M0} = 1.10$   
 $\beta = 1$   
 $\gamma_{M6} = 1.25$   
 $\eta = 0.75$



Failure mode	Code	Failure mode	Code
Column web panel in shear	CWS	Column web in tension	CWT
Column web in compression	CWC	Column flange in tension	CFT
Beam flange in compression	BFC	End plate in tension	EPT
Bolts in tension	BT		