DESIGN AIDS FOR THE DESIGN OF STEEL MOMENT CONNECTIONS

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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 [1] 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" [2,3], 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-ϕ 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 $S_{j,ini}/2$ 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 β, k_{wc} and k_{fc}.
Some comments regarding the physical meaning and the values of β, k_{wc} and k_{fc}, recommended for the use of design sheets or adopted implicitely 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 effeciently 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 traditionnally 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 selct semi-rigid joints which generally give a significant benefit by simplifying joint details thereby reducing shop and erection costs.

6. REFERENCES

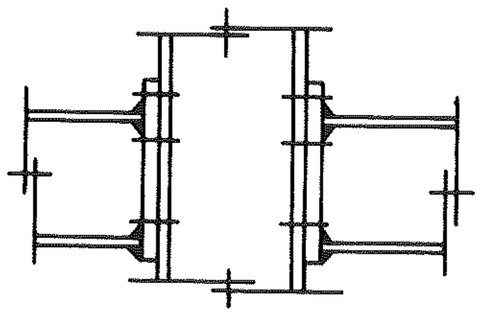
1. EUROCODE 3, ENV-1993-1-1, *Revised Annex J*, Design of Steel Structures, European Committee for Standardization, Document CEN/TC250/SC3-N419E, Brussels, June 1994.

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

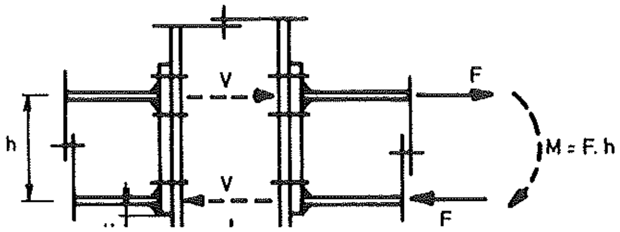
Mechanical characteristics

	Yield stresses	Ultimate stresses
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}

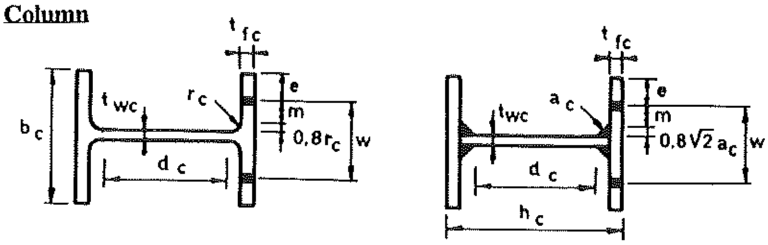
If hot-rolled profiles : $f_{ywc} = f_{yfc}$ and $f_{ywb} = f_{yfb}$

Geometrical characteristics

Joint



Column



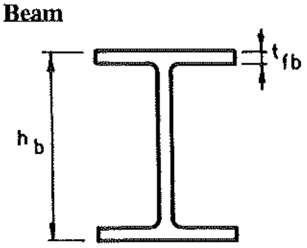
$s = r_c$
for a rolled section

$s = \sqrt{2}\, a_c$
for a welded section

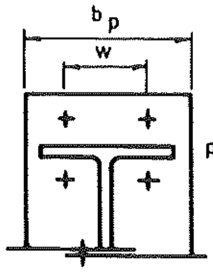
$A_{vc} = A_c - 2\, b_c\, t_{fc} + (\, t_{wc} + 2\, r_c\,)\, t_{fc}$
with A_c = column section area

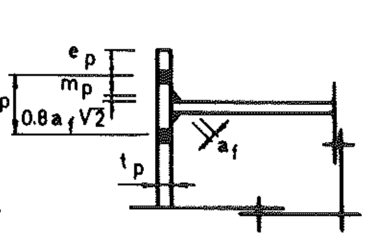
$A_{vc} = (\, h_c - 2\, t_{fc}\,)\, t_{wc}$

Beam



End-plate

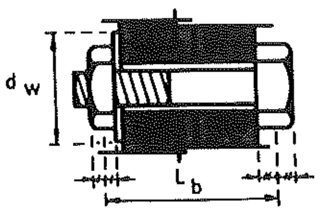


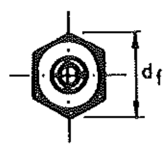


Bolts

d_w : see figure or = d_f if no washer

A_s : resistance area of the bolts

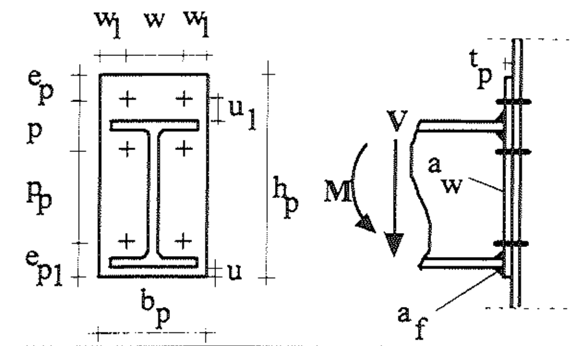




	STIFFNESS	*RESISTANCE*
Column web panel in shear	$k_1 = \frac{0{,}385\ A_{vc}}{\beta\ h}$	$F_{Rd,1} = \frac{V_{wc,Rd}}{\beta}$ *with* $V_{wc,Rd} = \frac{0{,}9\ A_{vc}\ f_{ycw}}{\sqrt{3}\ \gamma_{Mo}}$
	β = 1 for one-sided joint configurations; 0 for double sided joint configurations symetrically loaded; 1 for double-sided configurations non-symetrically loaded with balanced moments; 2 for double-sided joint configurations non-symetrically loaded with unbalanced moments. For other values, see 1.2.2.1 in chapter 1.	
Column web in compression	$k_2 = \frac{0{,}7\ b_{eff,wc,c}\ t_{wc}}{d_c}$	$F_{Rd,2} = k_{wc}\ \rho_c\ b_{eff,wc,c}\ t_{wc}\ f_{ywc}\ /\gamma_{Mo}$ *if* $\bar{\lambda}_{wc} \leq 0{,}67$ $F_{Rd,2} = k_{wc}\ \rho_c\ b_{eff,wc,c}\ t_{wc}\ f_{ywc} [\frac{1}{\bar{\lambda}_{wc}}(1 - \frac{0{,}22}{\bar{\lambda}_{wc}})]/\gamma_{Mo}$ *if* $\bar{\lambda}_{wc} > 0{,}67$ *with* $\bar{\lambda}_{wc} = 0{,}93 \sqrt{\frac{b_{eff,wc,c}\ d_c\ f_{ywc}}{E\ t_{wc}^2}}$ $k_{wc} = \min\ [1{,}0\ ;\ 1{,}25 - 0{,}5 \frac{\sigma_{n,wc}}{f_{ywc}}]$ (*) $\rho_c = 1$ *if* $\beta = 0$ $= \rho_{c1}$ *if* $\beta = 1$ $= \rho_{c2}$ *if* $\beta = 2$ *where* $\rho_{c1} = \frac{1}{\sqrt{1 + 1{,}3\ (b_{eff,wc,c}\ t_{wc}\ /\ A_{vc})^2}}$ $\rho_{c2} = \frac{1}{\sqrt{1 + 5{,}2\ (b_{eff,wc,c}\ t_{wc}\ /\ A_{vc})^2}}$ $\sigma_{n,wc}$: normal stresses in the column web at the root of the fillet radius or of the weld
	$b_{eff,wc,c} = t_{fb} + a_f\sqrt{2} + t_p + \min(u\ ;\ a_f\sqrt{2} + t_p) + 5(t_{fc} + s)$ (*) see 1.2.2.2 in chapter 1.	
Beam flange in compression	$k_3 = \infty$	$F_{Rd,3} = M_{c,Rd}\ /\ (h_b - t_{fb})$ $M_{c,Rd}$: beam design moment resistance

End-plate in bending	$k_7 = \frac{0,85\ l_{eff,p,t}\ t_p^3}{m_p^3}$	$F_{Rd,7} = \min\ [\ F_{ep.Rd,1}\ ;\ F_{ep.Rd,2}\ ]$ $F_{ep.Rd,1} = \frac{(8n_p - 2e_w)\ l_{eff,p,t}\ m_{pl,p}}{2m_p n_p - e_w(m_p + n_p)}$ $F_{ep.Rd,2} = \frac{2\ l_{eff,p,t}\ m_{pl,p} + 4\ B_{t,Rd}\ n_p}{m_p + n_p}$ $n_p = \min\ [\ e_p\ ;\ 1,25m_p\ ]$ $m_{pl,p} = 0,25\ t_p^2\ f_{yp}\ /\ \gamma_{Mo}$
	$l_{eff,p,t} = \min\ [\ 4\pi m_p\ ;\ 8m_p + 2,5e_p\ ;\ w + 4m_p + 1,25e_p\ ;\ b_p\ ]$	
JOINT	**Initial stiffness :** $S_{j,ini} = E\ h^2\ /\ \sum_{i=1}^{7} 1/k_i$ **Nominal stiffness :** $S_j = S_{j,ini}\ /\ 2$	$F_{Rd} = \min\ [\ F_{Rd,i}\ ]$ **Plastic design moment resistance :** $M_{Rd} = F_{Rd}\ h$ **Elastic moment resistance :** $\frac{2}{3}\ M_{Rd}$

2. DESIGN TABLES



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		

$\beta = 1$

$k_{wc} =$

$k_{fc} = 1$

$\gamma_{M0} = 1.10$

$\gamma_{Mb} = 1.25$

Column	Beam	Bolts hr88	End-plate: S235 (mm)			Connection detail (mm)							Welds (mm)		Rotational stiffness (kNm/rad)		Resistance: Moment (kNm)		Resistance: Shear (kN)	failure mode	Reference length(m)	
S235			t_p	b_p	h_p	e_p	p	p_p	e_{p1}	u_1	w	w_1	u	a_w	a_f	$S_{j,ini}$	$S_{j,ini}/2$	M_{Rd}	$2/3M_{Rd}$	V_{Rd}	Code	L_{bb}	L_{bu}
HEB140	IPE220	M16	15	140	305	35	90	120	60	40	90	25	10	3	5	10618	5309	30.6	20.4	157	CWS	4.4-R	S
	IPE240	M16	15	140	325	35	90	140	60	40	90	25	10	4	5	12136	6068	33.4	22.3	157	CWS	5.4-R	S
	IPE270	M16	15	140	355	35	95	160	65	40	90	25	10	4	6	14740	7370	37.7	25.1	157	CWS	6.6-R	S
HEB160	IPE220	M16	15	140	305	35	90	120	60	40	90	25	10	3	5	12928	6464	41.2	27.4	157	CWS	3.6-R	S
	IPE240	M16	15	140	325	35	90	140	60	40	90	25	10	4	5	14835	7418	45.0	30.0	157	CWS	4.4-R	S
	IPE270	M16	15	154	355	35	95	160	65	40	90	32	10	4	6	18351	9175	50.7	33.8	157	CWS	5.3-R	S
		M20	20	154	365	45	95	160	65	40	90	32	10	4	6	20161	10081	50.7	33.8	245	CWS	4.8-R	S
	IPE300	M16	15	160	385	35	95	190	65	40	90	35	10	4	6	21630	10815	56.5	37.7	157	CWS	6.5-R	S
		M20	20	160	395	45	95	190	65	40	90	35	10	4	6	23591	11796	56.5	37.7	245	CWS	6.0-R	S
	IPE330	M16	15	160	415	35	95	220	65	40	90	35	10	4	6	24908	12454	62.2	41.5	157	CWS	7.9-R	S
		M20	20	160	425	45	95	220	65	40	90	35	10	4	6	27044	13522	62.2	41.5	245	CWS	7.3-R	S
HEB180	IPE220	M16	15	140	305	35	90	120	60	40	90	25	10	3	5	13692	6846	47.4	31.6	157	CWS	3.4-R	S
	IPE240	M16	15	140	325	35	90	140	60	40	90	25	10	4	5	15761	7881	51.7	34.5	157	CWS	4.1-R	S
	IPE270	M16	15	154	355	35	95	160	65	40	90	32	10	4	6	19609	9804	58.4	38.9	157	CWS	5.0-R	S
		M20	20	154	365	45	95	160	65	40	90	32	10	4	6	21718	10859	58.4	38.9	245	CWS	4.5-R	S
	IPE300	M16	15	170	385	35	95	190	65	40	90	40	10	4	6	23353	11677	65.0	43.3	157	CWS	6.0-R	S
		M20	20	170	395	45	95	190	65	40	90	40	10	4	6	25586	12793	65.0	43.3	245	CWS	5.5-R	S
	IPE330	M16	15	180	415	35	95	220	65	40	90	45	10	4	6	27122	13561	71.6	47.7	157	CWS	7.3-R	S
		M20	20	180	425	45	95	220	65	40	90	45	10	4	6	29497	14748	71.6	47.7	245	CWS	6.7-R	S
		M24	20	180	440	50	115	200	75	50	110	35	10	4	6	27626	13813	71.6	47.7	352	CWS	7.2-R	S
	IPE360	M16	15	180	455	35	95	250	75	40	90	45	20	5	7	31322	15661	78.0	52.0	157	CWS	8.7-R	S