## **STEEL BUILDINGS IN EUROPE**

Multi-Storey Steel Buildings Part 8: Design software – Section Capacity

# Multi-Storey Steel Buildings Part 1: Design software – Section Capacity

#### FOREWORD

This publication is part eight of the design guide, *Multi-Storey Steel Buildings*.

The 10 parts in the Multi-Storey Steel Buildings guide are:

- Part 1: Architect's guide
- Part 2: Concept design
- Part 3: Actions
- Part 4: Detailed design
- Part 5: Joint design
- Part 6: Fire Engineering
- Part 7: Model construction specification
- Part 8: Design software section capacity
- Part 9: Design software simple connections
- Part 10: Software specification for composite beams.

*Multi-Storey Steel Buildings* is one of two design guides. The second design guide is *Single-Storey Steel Buildings*.

The two design guides have been produced in the framework of the European project "Facilitating the market development for sections in industrial halls and low rise buildings (SECHALO) RFS2-CT-2008-0030".

The design guides have been prepared under the direction of Arcelor Mittal, Peiner Träger and Corus. The technical content has been prepared by CTICM and SCI, collaborating as the Steel Alliance.

Section type US Section 899x292x176 Steel grade SSS C1 Factor Urver M <sub>Edmax</sub> = L <sub>17</sub> = M <sub>b,R4</sub> =	EIIIIIIIIIIIIIIIIIIII 120 kNm 120 kNm C1 = 1 0.001 m 1532 kNm	h = 834.9 mm b = 291.7 mm tf = 18.8 mm tv = 14 mm 176 kg/m	Print Create new comparison file Add to comparison file
[			

Figure 3.3 Bending worksheet

HE ▼	Choice of annex	Print
Section HE 1000 x 393	Annex B	Create new comparison file
Steel grade		Add to comparison file
L <sub>y</sub> = [ 10]		
L = 10	1500 65 0	
	Eq. 0.01;	5 5 1.0
$M_{y,Ed,max} = 0$ $M_{y,Ed,min} = 65$ $M_{z,Ed,max} = 0$	$\lim_{\text{fm}} \text{Eq. 6.62:}  \frac{1500}{200} + 0.865 \frac{65}{200} + 0.996 \frac{0}{200} = 0.49$	9 < 1.0
$M_{x,Ed,min} = 0$ $N_{Ed} = 1500$	lm 3184 2564 553 I	

Figure 3.4 N-M worksheet

Section type		
LNEQA (long leg attached)		Print
Section L 150 x 75 x 11		Create new comparison file
Bolt(s) \$275	h = 150 mm b = 75 mm	Add to comparison file
Number of bolts	t = 11 mm	
Bolt size	19 kg/m	
M22		
σ <sub>1</sub> = 10 mm		
$p_1 = 100$ mm		
N <sub>she</sub> = kN		

Figure 3.5 Tension worksheet

Section type $\mathbb{PE}$ Section $\mathbb{PE} \land 600$ Steel grade S275 $L_{\gamma} = 0$ m $L_{z} = 0$ m $L_{\gamma} = 0$ m $L_{\gamma} = 0$ m $L_{\gamma} = 0$ m $L_{\gamma} = 0$ M $N_{h,\gamma Rd} = 3352 \text{ kN}$	h = 597 mm b = 220 mm t = 17.5 mm 108 kg/m
N <sub>b,274</sub> = 3352 kN N <sub>b,774</sub> = 3352 kN N <sub>b,26</sub> = 3352 kN	

Figure 3.6 Compression worksheet

Section type		_
Section 1016:005:272 ▼ Steel grade 5225 ▼ c =200 mm c =50 mm	h = 990.1 mm b = 300 mm tf = 31 mm tw = 16.5 mm 272 kg/m	Print Create new comparison file Add to comparison file
$V_{c,Rd}$ = 627 kN Check availability		7

Figure 3.7 Web resistance worksheet

E E	Edt Yew	v Insert Format Icols	Data Work	tow Help Adope FOF	1 10 - 45 11016													Type a qui	stion for he	ф. •••
1	A	B	C	D	E	F	G	н		1	J		К	1	L	1	м	N		0
2																				
3																				
5																				
3																				
1		IPE A 600	S235	c = 200 mm	ss = 50 mm			FRd =	236 kl	V Vc,	Rd = 63	26 kN	(1	: 1;	1.1)	NA: UH	( Che	eck ava	ilability	
1		IPE A 600	S275	Lyy = 0 m	Lzz = 0 m	LT = 0.001 m		NRd,mir	1 = 33	351 kN	(1	: 1; 1.1	) NA:	UK						
9		L 150 x 75 x 11	S275	e1 = mm	p1 = mm	2 M22 Bolt(s)		FRd =	0 kN	(1; 1;	1.1) N	A: UK	Check	avai	labilit	ý				
0		HE 1000 x 393	S275	= 10m; Lt = 5	m; LLTB = 1	5m		6.61: 0	.14; 6	3.62: 0.	49; Saf	ety Fa	ctors: (	1; 1;	1.1)	NA: U	ж			
1		838X292X176	5235	L_LIB = 0.00	i m			MD,Rd	= 153	2 KNM	0	1, 1.1	) NA;	UK						
3																				
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Figure 3.8 Compare worksheet

Part 8: Design Software – Section Capacity

#### **APPENDIX A Worked Examples**

The worked examples show the design procedure used by the member resistance calculator for members in multi-storey building according to the Eurocodes.

The worked examples cover different type of designs:

- 1. Bending moment resistance
- 2. Combined axial force and bending moment (N-M interaction)
- 3. Tension resistance
- 4. Compression resistance
- 5. Web resistance

S 2 Steel Alliance	Worked Example 1: Bending moment resistance			1 of 2
Calculation about		Made by	CZT	Date 02/2010
Calculation sheet		Checked by	ENM	Date 02/2010
<b>1. Bending</b> This example presents calculating the bending	the method used in the member resist moment resistance, adopting the rec	tance calcula	ator for values	References are to EN 1993-1-1 unless otherwise stated
of EN 1993-1-1.	,,,,,,			Stated
Section: IPE 500				
Steel grade: S355				
L = 3,8  m				
1.1. Cross-see	ction classification			
1.1.1. The web				
$\frac{c}{t_{\rm w}} = \frac{426}{10,2} = 41.8$				Table 5.2 (Sheet 1)
The limit for Class 1 is	$s: 72\varepsilon = 72 \times 0.81 = 58.3$			
Then : $\frac{c}{t_{\rm w}} = 41.8 < 58$	3,3			
$\rightarrow$ The web is class 1.				
1.1.2. The flange				
$\frac{c}{t_{\rm f}} = \frac{73,9}{16} = 4,6$				Table 5.2 (Sheet 2)
The limit for Class 1 is	$s: 9\varepsilon = 9 \times 0.81 = 7.3$			
Then : $\frac{c}{t_{\rm f}} = 4,6 < 8,3$				
$\rightarrow$ The flange is Class	1			
Therefore the section i on the plastic resistance	s Class 1. The verification of the men e of the cross-section.	nber will be	based	
<b>1.2.</b> Lateral-to	rsional buckling resistance	e, M <sub>b,Rd</sub>		
$\psi = \frac{0}{444} = 0$	$\rightarrow C_1 = 1,77$			Appendix C of Single-Storey Steel Building, Part 4

Title	Worked Example: Bending moment resistance	2 of 2
$M_{\rm cr} = C_1 \frac{\pi^2}{2}$	$\frac{EI_z}{L^2} \sqrt{\frac{I_w}{I_z} + \frac{L^2 GI_t}{\pi^2 EI_z}}$	
$= 1,77 \times \frac{124}{214}$	$\frac{\pi^{2} \times 210000 \times 2142 \times 10^{4}}{3800^{2}}$ $\frac{9 \times 10^{9}}{2 \times 10^{4}} + \frac{3800^{2} \times 81000 \times 89, 3 \times 10^{4}}{\pi^{2} \times 210000 \times 2142 \times 10^{4}}$	Appendix C of Single-Storey Steel Building, Part 4
$M_{\rm cr} = 1556 \times$	10 <sup>6</sup> Nmm	
$\overline{\lambda}_{\rm LT} = \sqrt{\frac{W_{\rm y} f}{M_{\rm c}}}$	$\int_{0}^{\frac{1}{y}} = \sqrt{\frac{2194 \times 10^{3} \times 355}{1556 \times 10^{6}}} = 0,708$	§6.3.2.2
For hot rolled	sections	§6.3.2.3
$\phi_{\rm LT} = 0,5 \Big[1 +$	$\alpha_{\rm LT} \left( \overline{\lambda}_{\rm LT} - \overline{\lambda}_{\rm LT,0} \right) + \beta \overline{\lambda}_{\rm LT}^{2} \right]$	
$\overline{\lambda}_{LT,0} = 0,4$	and $\beta = 0,75$	
$\frac{h}{b} = 2,5$		Table 6.3 Table 6.5
$\rightarrow$ Curve <b>c</b> for	r hot rolled I sections	
$\rightarrow \alpha_{\rm LT} = 0,49$		
$\phi_{\rm LT} = 0,5[1+$	$0,49(0,708-0,4)+0,75\times0,708^{2} = 0,763$	
$\chi_{\rm LT} = \frac{1}{\phi_{\rm LT} + \sqrt{1 + 1}}$	$\frac{1}{\phi_{\rm LT}^2 - \beta \overline{\lambda}_{\rm LT}^2}$	§6.3.2.3
$\chi_{\rm LT} = \frac{1}{0,763}$	$\frac{1}{-\sqrt{0,763^2 - 0,75 \times 0,708^2}} = 0,822$	
$\frac{1}{\overline{\lambda}_{LT}^2} = \frac{1}{0,708}$	$\frac{1}{3^2} = 1,99$	
Therefore $\chi_{LT}$	= 0,822	
f = 1 - 0,5 (1 - 1)	$(k_{\rm c}) [1-2,0 (\overline{\lambda}_{\rm LT}-0,8)^2]$	
$k_{\rm c} = \frac{1}{1,33+0,3}$	$\frac{1}{3\psi} = \frac{1}{1,33+0,33\times0} = 0,75$	
f = 1 - 0,5 (1 - 0)	$(-0,75) [1-2,0 (0,708-0,8)^2] = 0,877$	
$\chi_{\rm LT \ mod} = \frac{\chi_{\rm LT}}{f}$	$=\frac{0,822}{0,877}=0,937$	
$M_{\rm b,Rd} = \frac{\chi_{\rm LT} M}{\gamma}$	$\frac{f_{\text{pl},y}f_{y}}{M_{1}} = \frac{0.937 \times 2194 \times 10^{3} \times 355}{1.0} \times 10^{-6} = 730 \text{ kNm}$	

S C Steel	Worked Example 2: Combined bending moment (N-M Interact	axial force ion)	e and	1 of 5
		Made by	CZT	Date 02/2010
Calculation sneet		Checked by	ENM	Date 02/2010
1. Combine	ed axial force and bendi	ng mon	nent	<i>References are to EN 1993-1-1</i>
for calculating the out- resistance, adopting th	-of-plane buckling resistance and in-p e recommended values of EN 1993-1	lane bucklir -1.	ator 1g	unless otherwise stated
Section: IPE 450				
Steel grade: S355				
$N_{\rm Ed} = 127 \ \rm kN$				
$M_{\rm y,Ed} = 356 \text{ kNm}$ (ben	ding moment constant along the bean	n)		
$M_{\rm z,Ed} = 0  \rm kNm$				
$L_{\rm y} = L_{\rm z} = L_{\rm LT} = L_{\rm cr} = 1$	,7 m			
1.1. Cross-see	ction classification			
1.1.1. The web				
$\frac{c}{t_{\rm w}} = \frac{378,8}{9,4} = 40,3$				Table 5.2 (Sheet 1)
$d_{\rm N} = \frac{N_{\rm Ed}}{t_{\rm w} f_{\rm y}} = \frac{127000}{9,4 \times 35}$	$\frac{0}{55} = 38$			
$\alpha = \frac{d_{\mathrm{w}} + d_{\mathrm{N}}}{2d_{\mathrm{w}}} = \frac{378,3}{2\times3}$	$\frac{8+38}{578,8} = 0.55 > 0.50$			
The limit between Cla	ss 1 and Class 2 is : $\frac{396\varepsilon}{13\alpha - 1} = \frac{396\times}{13\times 0}$	$\frac{(0,81)}{(55-1)} = 52$	,1	
Then : $\frac{c}{t_{\rm w}} = 40.3 < 52$	2,1			
$\rightarrow$ The web is class 1.				
1.1.2. The flange				
$\frac{c}{t_{\rm f}} = \frac{69,3}{14,6} = 4,7$				Table 5.2 (Sheet 2)
The limit between Cla	ss 1 and Class 2 is : 9 $\varepsilon$ = 9 × 0,81 = 7	7,3		
Then : $\frac{c}{t_{\rm f}} = 4,7 < 7,3$				
$\rightarrow$ The flange is Class	1			
Therefore, the section on the plastic resistance	is Class 1. The verification of the me e of the cross-section.	mber will be	e based	

Title	Worked Example: Axial compression and bending interaction (N-M Interaction)	2 of 5
1.2. Buc	kling verification	
The buckling of moment are ca	checks due to the interaction of axial compression and bending arried out using expressions 6.61 and 6.62 from EN 1993-1-1.	Expressions (6.61) and (6.62)
$\frac{\frac{N_{\rm Ed}}{\chi_{\rm y}N_{\rm Rk}}}{\gamma_{\rm M1}} + k_{\rm yy}$	$\frac{M_{y,\text{Ed}} + \Delta M_{y,\text{Ed}}}{\chi_{\text{LT}} \frac{M_{y,\text{Rk}}}{\gamma_{\text{M1}}}} + k_{yz} \frac{M_{z,\text{Ed}} + \Delta M_{z,\text{Ed}}}{\frac{M_{z,\text{Rk}}}{\gamma_{\text{M1}}}} \le 1,0$	
$\frac{N_{\rm Ed}}{\frac{\chi_{\rm z}N_{\rm Rk}}{\gamma_{\rm M1}}} + k_{\rm zy}$	$\frac{M_{y,Ed} + \Delta M_{y,Ed}}{\chi_{LT} \frac{M_{y,Rk}}{\gamma_{M1}}} + k_{zz} \frac{M_{z,Ed} + \Delta M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}} \le 1,0$	
These express	ions can be simplified as follows:	
$\Delta M_{\rm y,Ed} = 0$ and	ad $\Delta M_{z,Ed} = 0$ for Class 1, Class 2 and Class 3 sections.	
$M_{\rm z,Ed} = 0$		
Therefore exp	ressions (6.61) and (6.62) can be written as:	
$\frac{N_{\rm Ed}}{N_{\rm b,y,Rd}} + k_{\rm yy} \frac{M}{M}$	$\frac{M_{y,Ed}}{M_{b,Rd}} \le 1,0 \text{ and } \frac{N_{Ed}}{N_{b,z,Rd}} + k_{zy} \frac{M_{y,Ed}}{M_{b,Rd}} \le 1,0$	
1.3. Equ	uation 6.61 (EN 1993-1-1)	
1.3.1. Flex	ural buckling resistance about the major axis, <i>N</i> <sub>b,y,Rd</sub>	
$\frac{h}{b} = \frac{450}{190} = 2$	37	
$t_{\rm f} = 14,6 \ {\rm mm}$		
buckling abou	t y-y axis:	Table 6.1
$\rightarrow$ Curve <b>a</b> for	hot rolled I sections	Table 0.2
$\rightarrow \alpha_{\rm y} = 0,21$		
$\lambda_1 = \pi \sqrt{\frac{E}{f_y}}$	$=\pi\sqrt{\frac{210000}{355}}=76,4$	§6.3.1.3
$\overline{\lambda}_{y} = \frac{L_{cr}}{i_{y}} \frac{1}{\lambda_{1}}$	$=\frac{1700}{185}\times\frac{1}{76,4}=0,12$	
$\phi_{y} = 0,5[1 +$	$\alpha_{y}\left(\overline{\lambda}_{y}-0,2\right)+\overline{\lambda}_{y}^{2}$	§6.3.1.2
$\phi_y = 0,5[1 +$	$0,21(0,12-0,2)+0,12^2$ ] = 0,50	
$\chi_{\rm y} = \frac{1}{\phi_{\rm y} + \sqrt{1-\phi_{\rm y}}}$	$\frac{1}{\phi_{y}^{2} - \overline{\lambda}_{y}^{2}} = \frac{1}{0.50 + \sqrt{0.50^{2} - 0.12^{2}}} = 1.0$	

Worked Example: Axial compression and bending interaction (N-M Title 3 of 5 Interaction)  $N_{\rm b,y,Rd} = \frac{\chi_y A f_y}{\gamma_{\rm M1}} = \frac{1.0 \times 9880 \times 355}{1.0} \times 10^{-3} = 3507 \text{ kN}$  $N_{\rm Ed}$ = 127 kN < 3507 kNOK 1.3.2. Lateral-torsional buckling resistance for bending, M<sub>b,Rd</sub> In order to determine the critical moment of the rafter, the  $C_1$  factor takes account of the shape of the bending moment diagram. In this case the bending moment diagram is constant along the segment in Appendix C of consideration, so  $\psi = 1,0$ . Therefore: Single-Storey  $\rightarrow C_1 = 1,0$ Steel Building, Part 4  $M_{\rm cr} = C_1 \frac{\pi^2 E I_z}{L^2} \sqrt{\frac{I_{\rm w}}{I_z} + \frac{L^2 G I_{\rm t}}{\pi^2 E I}}$ Appendix C of Single-Storey Steel Building,  $= 1.0 \times \frac{\pi^2 \times 210000 \times 1676 \times 10^4}{1700^2}$ Part 4  $\times \sqrt{\frac{791 \times 10^9}{1676 \times 10^4} + \frac{1700^2 \times 81000 \times 66,9 \times 10^4}{\pi^2 \times 210000 \times 1676 \times 10^4}}$  $M_{\rm cr} = 2733 \times 10^6 \,\rm Nmm$ §6.3.2.2  $\bar{\lambda}_{LT} = \sqrt{\frac{W_{pl,y}f_y}{M}} = \sqrt{\frac{1702 \times 10^3 \times 355}{2722 \times 10^6}} = 0,470$  $\phi_{\rm LT} = 0.5 \left[ 1 + \alpha_{\rm LT} \left( \overline{\lambda}_{\rm LT} - \overline{\lambda}_{\rm LT,0} \right) + \beta \overline{\lambda}_{\rm LT}^2 \right]$ §6.3.2.3  $\overline{\lambda}_{LT,0} = 0,4$  and  $\beta = 0,75$  $\frac{h}{1} = 2,37$  $\rightarrow$  Curve **c** for hot rolled I sections Table 6.3  $\rightarrow \alpha_{\rm LT} = 0.49$ Table 6.5  $\phi_{\text{LT}} = 0.5 [1+0.49(0.470-0.4)+0.75\times0.470^2] = 0.60$ §6.3.2.3  $\chi_{\rm LT} = \frac{1}{\phi_{\rm LT} + \sqrt{\phi_{\rm LT}^2 - \beta \,\overline{\lambda}_{\rm LT}^2}}$  $\chi_{\rm LT} = \frac{1}{0.60 + \sqrt{0.60^2 - 0.75 \times 0.470^2}} = 0.961$  $\frac{1}{\overline{a}_{1}^{2}} = \frac{1}{0.470^{2}} = 4,53$ Therefore  $\chi_{LT} = 0.961$ 

Worked Example: Axial compression and bending interaction (N-M Title 4 of 5 Interaction)  $M_{\rm b,Rd} = \frac{\chi_{\rm LT} W_{\rm pl,y} f_{\rm y}}{\gamma_{\rm M1}} = \frac{0.961 \times 1702 \times 10^3 \times 355}{1.0} \times 10^{-6} = 581 \text{ kNm}$  $M_{\rm Ed} = 356 \ \rm kNm < 581 \ \rm kNm$ OK 1.3.3. Interaction of axial force and bending moment The interaction factor,  $k_{yy}$ , is calculated as follows:  $k_{yy} = \min \left| C_{my} \left( 1 + \left( \overline{\lambda}_y - 0, 2 \right) \frac{N_{Ed}}{N_{by Rd}} \right); C_{my} \left( 1 + 0, 8 \frac{N_{Ed}}{N_{by Rd}} \right) \right|$ Annex B Table The expression for  $C_{\rm my}$  depends on the values of  $\alpha_{\rm h}$  and  $\psi$ . **B.3**  $\psi = 1,0.$ Therefore  $C_{my}$  is calculated as:  $C_{\rm mv} = 0.6 + 0.4 \ \psi = 0.4 + 0.4 \times 1.0 = 1.0$ Annex B  $k_{yy} = \min \left| 1,0 \left( 1 + (0,12 - 0,2) \frac{127}{3507} \right); 1 \left( 1,0 + 0,8 \frac{127}{3507} \right) \right|$ Table B.2  $= \min [0,997; 1,029] = 0,997$  $\frac{N_{\rm Ed}}{N_{\rm burned}} + k_{\rm yy} \frac{M_{\rm y, Ed}}{M_{\rm burned}} = \frac{127}{3507} + 0.997 \frac{356}{581} = 0.647 < 1.0$ OK The member satisfies the in-plane buckling check. 1.4. Expression 6.62 (EN 1993-1-1) 1.4.1. Flexural buckling resistance about minor axis bending, N<sub>b,z,Rd</sub>  $\frac{h}{h} = \frac{450}{190} = 2,37$  $t_{\rm f} = 14,6 \, {\rm mm}$ buckling about z-z axis Table 6.1 Table 6.2  $\rightarrow$  Curve **b** for hot rolled I sections  $\rightarrow \alpha_z = 0.34$ §6.3.1.3  $\lambda_1 = \pi \sqrt{\frac{E}{f}} = \pi \sqrt{\frac{210000}{355}} = 76,4$  $\overline{\lambda}_{z} = \frac{L_{cr}}{i_{z}} \frac{1}{\lambda_{1}} = \frac{1700}{41.2} \times \frac{1}{76.4} = 0,540$  $\phi_z = 0.5 \left[ 1 + \alpha_z \left( \overline{\lambda}_z - 0.2 \right) + \overline{\lambda}_z^2 \right]$ §6.3.1.2  $\phi_z = 0.5 [1+0.34(0.540-0.2)+0.540^2] = 0.704$ 

Title	Worked Example: Axial compression and bending interaction (N-M Interaction)	5 of 5
$\chi_z = \frac{1}{\phi_z + \sqrt{1-\phi_z}}$	$\frac{1}{\phi_z^2 - \overline{\lambda}_z^2} = \frac{1}{0,704 + \sqrt{0,704^2 - 0,540^2}} = 0,865$	
$N_{\mathrm{b,z,Rd}} = \frac{\chi_z}{\gamma}$	$\frac{Af_y}{f_{M1}} = \frac{0.865 \times 9880 \times 355}{1.0} \times 10^{-3} = 3034 \text{ kN}$	
$N_{\rm Ed} = 127$	7  kN < 3034  kN OK	
1.4.2. Inte	raction of axial force and bending moment	§6.3.3(4)
The interactio	n factor, $k_{zy}$ is calculated as follows:	
For $\overline{\lambda}_z \ge 0,4$	:	
$k_{zy} = \max\left[\left(\right.$	$1 - \frac{0,1\bar{\lambda}_{z}}{(C_{mLT} - 0,25)} \frac{N_{Ed}}{N_{b,z,Rd}} \bigg];  \left(1 - \frac{0,1}{(C_{mLT} - 0,25)} \frac{N_{Ed}}{N_{b,z,Rd}}\right) \bigg]$	
The bending r	noment is linear and constant. Therefore $C_{mLT}$ is 1,0.	Annex B Table
$k_{zy} = \max\left[\left(\right.$	$1 - \frac{0,1 \times 0,540}{(1 - 0,25)} \frac{127}{3034} \bigg;  \left(1 - \frac{0,1}{(1 - 0,25)} \frac{127}{3034}\right) \bigg]$	Annex B Table B.2
$= \max(0,$	997, 0,994) = 0,997	
$\frac{N_{\rm Ed}}{N_{\rm b,z,Rd}} + k_{\rm zy}$	$\frac{M_{\rm y,Ed}}{M_{\rm b,Rd}} = \frac{127}{3034} + 0,997\frac{356}{581} = 0,653 < 1,0 \text{ OK}$	

S 2 Steel Alliance	Steel Alliance					
		Made by	CZT	Date	02/2010	
Calculation sheet		Checked by	ENM	Date	02/2010	
<b>1. Tension</b> This example presents for calculating the tens EN 1993-1-8.	<b>Resistance</b> the method used in the member sion resistance, adopting the res	er resistance calcul commended value	ator s of the	Refer EN 19 unles stated	ences are to 993-1-8 s otherwise l	
$\begin{array}{c c} & & & \\ & & & & \\ & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\$						
Section: L 120 $\times$ 80 $\times$	12					
Steel grade: S235						
Area: $A = 2270 \text{ mm}^2$						
Bolts: M20, grade 8.8						
Spacing between bolts	$p_1 = 70 \text{ mm}$					
Total number of bolts	<i>n</i> = 3					
Diameter of the holes	$d_0 = 22 \text{ mm}$					
Partial safety factors	S					
$\gamma_{M0} = 1,0$						
$\gamma_{M2} = 1,25$ (for sh	ear resistance of bolts)					
1.2. Angle in t	tension					
$N_{\rm Rd} = \frac{\beta_3 A_{\rm net} f_{\rm u}}{\gamma_{\rm M2}}$				§3.10	.3	
$2,5 d_0 = 2,5 \times 22 = 5$	55 mm					
$5 d_0 = 5 \times 22 = 11$	0 mm					
$2,5 d_0 < p_1 < 5 d_0$				T 11	2.0	
$\beta_3$ can be determined	by linear interpolation:			Table	3.8	
Therefore $\beta_3 = 0.59$						
$A_{\text{net}} = A - t_{\text{ac}} d_0 = 227$	$0 - 12 \times 22 = 2006 \text{ mm}^2$					
$N_{\rm Rd} = \frac{0.59 \times 2006 \times 30}{1.25}$	$\frac{60}{2} \times 10^{-3} = 341 \text{ kN}$					

SSasteel	Worked Example 4: Compression Resistance			1 of 3
Amarice		Made by	CZT	Date 02/2010
Calculation sheet		Checked by	ENM	Date 02/2010
<b>1. Compres</b> This example presents for calculating the flex subject to pure compre EN 1993-1-1. Section: IPE 500 Steel grade: \$235	References are to EN 1993-1-1 unless otherwise stated			
$L_{\alpha} = 3.8 \text{ m}$				
$L_{z} = 3.8 \text{ m}$				
<i>L</i> <sub>Z</sub> 5,6 m				
1.1. Cross-see	ction classification			
1.1.1. The web				
$\frac{c}{t_{\rm w}} = \frac{426}{10,2} = 41,8$				Table 5.2 (Sheet 1)
The limit between Clas	ss 3 and Class 4 is : $42\varepsilon = 42 \times 1, 0 = 42$	42		
Then : $\frac{c}{t_{\rm w}} = 41,8 < 42$	2			
$\rightarrow$ The web is class 3.				
1.1.2. The flange				
$\frac{c}{t_{\rm f}} = \frac{73,9}{16} = 4,6$ The limit between Class	ss 1 and Class 2 is : $9\varepsilon = 9 \times 1, 0 = 9$			Table 5.2 (Sheet 2)
Then : $\frac{c}{t_{\rm f}} = 4,6 < 9$				
$\rightarrow$ The flange is Class	1.			
Therefore the section i	s Class 3.			
1.2. Flexural k <i>N</i> <sub>b,y,Rd</sub>	ouckling resistance about t	he major	axis,	
$L_{\rm y} = 3.8 {\rm m}$				
$\frac{h}{b} = \frac{500}{200} = 2,5$				
$t_{\rm f} = 16 \text{ mm}$				
Buckling about y-y ax				

Title	Worked Example: Compression Resistance	2 of 3
$\rightarrow$ Curve <b>a</b> for	Table 6.2	
$\rightarrow \alpha_{\rm v} = 0.21$		Table 6.1
$\lambda_1 = \pi \sqrt{\frac{E}{f_y}} =$	§6.3.1.3	
$\overline{\lambda}_{y} = \frac{L_{cr}}{i_{z}} \frac{1}{\lambda_{1}}$		
$\phi_{\rm y}=0,5\Big[1+\alpha$	§6.3.1.2	
$\phi_{\rm y}=0,5\Big[1+0$		
$\chi_{\rm y} = \frac{1}{\phi_{\rm y} + \sqrt{\phi_{\rm y}}}$		
$N_{\rm b,y,Rd} = \frac{\chi_{\rm y} A_{\rm y}}{\gamma_{\rm M1}}$		
1.3. Flex axis		
$L_{\rm z} = 3.8 {\rm m}$		
$\frac{h}{b} = \frac{500}{200} = 2,5$		
$t_{\rm f} = 16 \ {\rm mm}$		
Buckling abou		
$\rightarrow$ Curve <b>b</b> fo	Table 6.1	
$\rightarrow \alpha_z = 0,21$		14010 0.2
$\lambda_{\rm l} = \pi \sqrt{\frac{E}{f_{\rm y}}} =$	$=\pi\sqrt{\frac{210000}{235}}=93,9$	§6.3.1.3
$\overline{\lambda}_{y} = \frac{L_{cr}}{i_{z}} \frac{1}{\lambda_{1}} =$		
$\phi_{\rm z} = 0.5 \left[1 + \alpha_{\rm z}\right]$	86312	
$\phi_z = 0.5[1+0.2]$		
$\chi_{z} = \frac{1}{\phi_{z} + \sqrt{\phi_{z}}^{2}}$		
$N_{\rm b,z,Rd} = \frac{\chi_z A_j}{\gamma_{\rm M1}}$		

### **1.4.** Torsional buckling *N*<sub>b,T,Rd</sub>

$$L_{\rm T} = 3.8 \text{ m}$$

$$N_{\rm eTT} = \frac{1}{i_0^{-z}} \left( \frac{\pi^2 E I_w}{L_{\rm T}^2} + G I_{\rm T} \right)$$

$$i_0^2 = i_y^2 + i_z^2 = 204^2 + 43.1^2 = 43474$$

$$N_{\rm eTT} = \frac{1}{43474} \left( \frac{\pi^2 \times 210000 \times 1249 \times 10^9}{3800^2} + 81000 \times 89.3 \times 10^4 \right) \times 10^{-3} = 5787 \text{ kN}$$

$$\overline{\lambda}_{\rm T} = \sqrt{\frac{A f_y}{N_{\rm eTT}}} = \sqrt{\frac{11600 \times 235}{5787 \times 10^3}} = 0.686$$

$$\phi_{\rm T} = 0.5 \left[ 1 + \alpha_{\rm T} \left( \lambda_{\rm T} - 0.2 \right) + \overline{\lambda}_{\rm T}^2 \right]$$
The buckling curve for torsional buckling is the same as for minor axis buckling, therefore choose buckling curve b
$$a_z = 0.34$$

$$\phi_{\rm T} = 0.5 \left( 1 + 0.34 \left( 0.686 - 0.2 \right) + 0.686^2 \right] = 0.818$$

$$\chi_{\rm T} = \frac{1}{\phi + \sqrt{\phi^2 - \lambda_{\rm T}^2}} = \frac{1}{0.818 + \sqrt{0.818^2 - 0.686^2}} = 0.791$$

$$N_{\rm b, T, Rd} = \frac{\chi_{\rm T} A f_y}{\gamma_{\rm MI}} = \frac{0.791 \times 11600 \times 235}{1.0} \times 10^{-3} = 2156 \text{ kN}$$

Si	Worked Example 5: Web Resistance				1 of 2			
Calcul	ation sheet					Made by	CZT	Date 02/2010
Calcul						Checked by	ENM	Date 02/2010
1.	Web Res	sista	nce					
This ex for calc recomn	ample presents ulating the web nended values of	s the me b resista of the E	thod used ince and N 1993-1	d in the the shea 1-5 and	member re r resistanc EN 1993-1	sistance calcu e, adopting the -1.	llator e	
Section	: IPE 500							
Steel gr	ade: S355							
С	= 10 mm							
S <sub>s</sub>	= 100 mm							
1.1.	Shear res	sistan	се					
In the a area, w	bsence of torsic hich is given by	on, the y:	shear pla	stic resi	stance dep	ends on the sh	lear	
$A_{\rm v}$	$= A - 2 b t_{\rm f} +$	$(t_{\rm w} + 2$	$r$ ) $t_{\rm f}$					EN 1993-1-1
$A_{\rm v}$	= 11600 - 2 >	× 200 ×	16 + (10	,2 + 2 ×	21) × 16 =	$= 6035 \text{ mm}^2$		§ 6.2.6 (3)
$V_{\rm pl,Rd}$	$= \frac{A_{\rm v}f_{\rm y}}{\sqrt{3}\gamma_{\rm M0}} =$	$\frac{6035\times}{}$	$\frac{355 \times 10}{\overline{3} \times 1,0}$	<sup>-3</sup> = 12	37 kN			EN 1993-1-1 § 6.2.6 (2)
$V_{\rm pl,Rd}$	= 1237 kN							
1.2.	Desian re	esista	nce to	local	bucklin	a		
с	= 10 mm					5		
S <sub>S</sub>	= 100 mm							
$m_1$	$=\frac{b_{\rm f}}{t_{\rm w}}=\frac{200}{10,2}=$	=19,6						
<i>m</i> <sub>2</sub>	$=0.02 \left(\frac{h_{\rm w}}{t_{\rm f}}\right)^2$	if $\overline{\lambda}_{\mathrm{F}}$	> 0,5					
$m_2$	= 0	if $\overline{\lambda}_{\mathrm{F}}$	< 0,5					
First as	sume that $\overline{\lambda}_{\rm F}$ >	> 0,5						
<i>m</i> <sub>2</sub>	$=0,02\left(\frac{468}{16}\right)$	$\Big)^2 = 17,$	11					
$k_{ m F}$	$= 2 + 6 \left(\frac{s_{\rm s} + h_{\rm w}}{h_{\rm w}}\right)$	$\left(\frac{-c}{c}\right)^2$	but $k_{\rm F} \leq 0$	6				
$k_{ m F}$	$=2+6\left(\frac{100}{40}\right)$	$\left(\frac{+10}{68}\right)$						

Title		Worked Example: Web Resistance and Shear Resistance	2 of 2		
$k_{ m F}$	= 3,4	1 < 6			
ℓ <sub>e</sub>	$=\frac{k_{\rm F}}{2}$	$\frac{E t_{w}^{2}}{f_{y} h_{w}} \qquad \text{but} \le s_{s} + c$	EN 1993-1-5 Eq (6.13)		
le	$=\frac{3}{2}$	$\frac{41 \times 210000 \times 10.2^2}{2 \times 355 \times 468} = 224 \le 100 + 10 = 110$			
therefor					
$\ell_{y1}$	$= s_s -$	+ 2 $t_{\rm f} \left(1 + \sqrt{m_1 + m_2}\right) = 100 + 2 \times 16 \left(1 + \sqrt{19, 6 + 17, 11}\right) = 325 \text{ mm}$	EN 1993-1-5 Eq (6.10)		
$\ell_{y2}$	$=\ell_{\rm e}$	$+ t_{\rm f} \sqrt{\frac{m_1}{2} + \left(\frac{\ell_{\rm e}}{t_{\rm f}}\right)^2 + m_2} = 110 + 16\sqrt{\frac{19.6}{2} + \left(\frac{110}{16}\right)^2 + 17.11}$	EN 1993-1-5 Eq (6.11)		
	= 243	3 mm			
$\ell_{y3}$	$= \ell_{e}$	$t_{\rm f} \sqrt{m_1 + m_2} = 110 + 16\sqrt{19,6 + 17,22} = 207 {\rm mm}$	EN 1993-1-5 Ea (6.12)		
$\ell_{\mathrm{y}}$	= mi	n $(\ell_{y1}; \ell_{y2}; \ell_{y3}) = \min(325; 248; 207) = 207 \text{ mm}$	1()		
F <sub>cr</sub>	= 0,9	$k_{\rm F} E \frac{t_{\rm w}^{3}}{h_{\rm w}} = 0.9 \times 3.41 \times 210000 \times \frac{10.2^{3}}{468} = 1461406 \text{ N}$			
$\overline{\lambda}_{\mathrm{F}}$	$=\sqrt{\frac{1}{2}}$	$\frac{\ell_{\rm y} t_{\rm w} f_{\rm y}}{F_{\rm cr}} = \sqrt{\frac{207 \times 10.2 \times 355}{1461406}} = 0.72$			
$\overline{\lambda}_{\mathrm{F}}$	= 0,	72 > 0,5			
Therefo calculat than 0,5 appropri	ore the ed bas then tiate ex	initial assumption was correct and the web resistance can be sed on this value of $\lambda_F$ . Should the calculated value of $\lambda_F$ be less the calculation would need to be carried out again, using the appression for $M_2$			
$\chi_{ m F}$	$=\frac{0,t}{\overline{\lambda}_{\rm F}}$	$\frac{5}{2} = \frac{0.5}{0.72} = 0.69$			
χf	= 0,6	9			
$L_{\rm eff}$	$=\chi_{\rm F}$	y y			
$L_{\rm eff}$	= 0,6	$9 \times 207 = 143 \text{ mm}$			
$F_{\rm Rd}$	$=\frac{f_{y}}{f_{y}}$	$\frac{L_{\rm eff} t_{\rm w}}{\gamma_{\rm M1}} = \frac{355 \times 143 \times 10.2}{1.0} = 518 \text{ kN}$	EN 1993-1-5 § 6.2 (1)		