STEEL BUILDINGS IN EUROPE

Multi-Storey Steel Buildings Part 8: Description of member resistance calculator

Multi-Storey Steel Buildings Part 1: Description of member resistance calculator

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: Description of member resistance calculator
- Part 9: Description of simple connection resistance calculator
- Part 10: Guidance to developers of software for the design of 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.

Part 8: Description of member resistance calculator

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SUMMARY

This document describes the member resistance calculator, created in Excel, for members in axial compression, in bending, in combined axial compression and bending and in tension, used in steel buildings. It explains the scope of the workbook and lists the National Annexes and languages that are supported in the workbook. A description is given of each of the worksheets and the input information on each sheet. A screenshot of typical output is presented.

1 INTRODUCTION

This document provides an introduction to the Excel workbook that calculates the design resistance of steel members (beams and columns) in accordance with EN 1993-1-1, as part of the design guide *Multi-storey steel buildings*. The workbook offers the alternative of different languages, and selection of National Annex values.

The operation of the spreadsheet is described in the following Section 2. Screenshots of the various sheets in the workbook are given in Section 3.

1.1 Visual Basic

The spreadsheet depends on extensive visual basic code. Some users may have security settings set to disable such code.

The security level can be changed by selecting: "Tools", "Options". Select the "Security" tab and select "Macro security". The setting must be at least "Medium". Usually, Excel must be closed and re-started for the changes in security levels to become effective.

1.2 Scope

The spreadsheet calculates resistances of steel members subject to the following types of forces and moments:

- Axial compression
- Bending
- Combined axial compression and bending
- Tension
- Shear
- Point load (Web bearing and buckling)

Each worksheet provides a cross-sectional view of the selected section as well as the main geometric data. In the case of tension and web bearing and buckling resistance, it also provides a graphic illustration drawn to scale showing what the detail looks like.

Member resistances and drawn details are immediately updated as input data is modified by the user.

1.2.1 National Annex

The workbook includes National Annex values for γ_{M0} , γ_{M1} and γ_{M2} . for the following countries:

- Belgium
- France
- Germany
- Italy

- Netherlands
- Poland
- Spain
- United Kingdom

The user has the option to overwrite the in-built National Annex values, allowing flexibility should the values be modified by the national standards body. If this option is selected, then the calculation procedure reverts to the recommended options for all engineering methods, such as design strength of steel, buckling curves or imperfection factors, rather than those in the National Annex.

1.2.2 Language

The language for input and output may be set by the user. The following languages are supported:

- French
- German
- Italian
- Polish
- Spanish
- English

1.3 Design rules

The design resistances of members are evaluated in accordance with EN 1993-1-1 and EN 1993-1-5 and the selected National Annexes.

2 OPERATION OF THE WORKBOOK

2.1 Introduction worksheet

The "introduction" sheet merely records the scope of the spreadsheet. On the initial loading of the spreadsheet, this is the only tab visible. Choosing to "continue" reveals the remaining tabs.

2.2 Localisation Worksheet

The "localisation" worksheet allows the user to select the language and the National Annex (which determines the Nationally Determined Parameters (NDPs) that are to be used in calculations).

Checking the "overwrite" option allows the user to enter partial factor values of their choice. The engineering functionality which is set by the National Annex is taken from the recommended options in the Eurocodes.

Deselecting the "overwrite" option leaves the National Annex selection as a blank – the user must select National Annex from the drop down menu.

Default settings of Language and National Annex may be saved. The values are written to a simple text file, stored in the same folder as the workbook. Subsequent saving will merely overwrite this file.

Loading defaults will import whatever settings of language and National Annex that had previously been saved.

User Information

User name, project name and job number may be entered. Any data entered will appear on the printed output.

2.3 Functionalities on the member resistance worksheets

Each of the worksheets for axial compression, bending, combined axial compression and bending, tension, shear and point load have three buttons – "Print", "Create new comparison file" and "Add to comparison file".

2.3.1 Print

A new sheet will open, where the user information (see section 2.2) and the details of the calculated resistance will appear. The print window will open up, where the user can select a printer and print.

2.3.2 Add to comparison file

By clicking on this button, a compare worksheet will open up where the main details of the resistance calculated are registered (see Section 2.9).

2.3.3 Create new comparison file

This option deletes any existing calculations in the comparison file and adds the most recent values. Therefore when this option is selected, a single calculation will appear in this file.

2.4 Bending Worksheet

The following data may be selected:

Section type

Section data is included for the following section types (profiles):

- IPE
- HD
- HE
- HL
- UPE

Section

All the standard sections within each section type are available for selection from the drop-down menu.

Beam grade

The steel grade for the beams may be selected from the following:

- S235
- S275
- S355
- S460

C₁ factor

The C_1 factor related to the bending moment diagram may be selected from the following:

- 1,13
- 1,21
- 1,23
- 1,35
- 1,49
- 1,68
- Linear

A diagram shows which bending moment diagram corresponds to a given C_1 factor. If the option "linear" is selected then two additional input boxes appear where the user must input:

- The maximum bending moment
- The minimum bending moment

Buckling length

The calculated resistance that is displayed is the design value of the lateral torsional buckling (LTB) resistance in kNm.

The figure shows a cross-section of the selected section, to scale, and the main geometric properties.

2.5 N-M (combined axial force and bending moment) Worksheet

The following data may be selected:

Section type

Section data is included for the following section types (profiles):

- IPE
- HD
- HE
- HL

Section

All the standard sections within each section type are available for selection from the drop-down menu.

Beam grade

The steel grade for the beams may be selected from the following:

- **S235**
- S275
- **S**355
- S460

The internal moments and forces

- Maximum bending moment about the major axis, $M_{y,Ed,max}$
- Minimum bending moment about the major axis, $M_{y,Ed,min}$
- Maximum bending moment about the minor axis, $M_{z,Ed,max}$
- Minimum bending moment about the minor axis, $M_{z,Ed,min}$
- Axial force, $N_{\rm Ed}$

Buckling lengths

- Major axis buckling length, *L*_y
- Minor axis buckling length, L_z
- Torsional buckling length, $L_{\rm T}$
- Lateral torsional buckling length, L_{LTB}

Choice of Annex A or Annex B

The result that is displayed is the unity factor from the interaction equations 6.61 and 6.62 from EN 1993-1-1 and according to the chosen National Annex.

2.6 Tension Worksheet

The following data may be selected:

Section type

Section data is included for the following section types (profiles):

- IPE
- HE
- UPE
- Equal Angles
- Unequal Angles (long leg attached)
- Unequal Angles (short leg attached)

Section

All the standard sections within each section type are available for selection from the drop-down menu.

Beam grade

The steel grade for the beams may be selected from the following:

- S235
- S275
- S355
- S460

Number of bolts

When designing an angle, the number of bolts may be selected from the following :

- No bolt (weld)
- 1 bolt
- 2 bolts
- 3 bolts

Bolt size

The bolt size may be selected from the following:

- M12
- M14
- M16
- M18
- M20
- M22
- M22
- M24
- M27

The output is the tension resistance, calculated as the resistance of the gross section at yield for I sections or the minimum resistance of the gross section at yield and the net section at ultimate for angles, all given in kN.

The top figure shows a cross-section of the selected section, to scale and the main geometric properties.

The bottom figure shows the bolted detail, only when angle sections are selected.

2.7 Compression Worksheet

The following data may be selected:

Section type

Section data is included for the following section types (profiles):

- IPE
- HD
- HE
- HL
- UPE
- Equal Angles
- Unequal Angles

Section

All the standard sections within each section type are available for selection from the drop-down menu.

Beam grade

The steel grade for the beams may be selected from the following:

- S235
- S275
- S355
- S460

Buckling lengths

- Major axis buckling length, *L*_y
- Minor axis buckling length, *L*_z
- Torsional buckling length, $L_{\rm T}$

The calculated resistances are the design values of compression resistance, for flexural buckling resistance about the major axis and the minor axis ($N_{b,y,Rd}$ and $N_{b,z,Rd}$) as well as the torsional buckling resistance ($N_{b,T,Rd}$), all given in kN for the relevant buckling lengths. In addition, the worksheet displays the minimum of these values.

The figure shows a cross-section of the selected section, to scale and the main geometric properties.

2.8 Web resistance (bearing and buckling) Worksheet

The following data may be selected:

Section type

Section data is included for the following section types (profiles):

- IPE
- HD
- HE
- HL
- UPE

Section

All the standard sections within each section type are available for selection from the drop-down menu.

Beam grade

The steel grade for the beams may be selected from the following:

- S235
- S275
- S355
- S460

Position of the transverse load

- *d*: distance from the end of the load to the member end.
- *s*_s: stiff bearing length.

The output is the web bearing and buckling resistance, calculated as per EN 1993-1-5, given in kN.

The top figure shows a cross-section of the selected section, to scale and the main geometric properties.

The bottom figure shows the detail of the transverse load with respect to the end of the member.

2.9 Compare worksheet

The compare worksheet will display in a single line the main details of the resistance calculated. This sheet also shows any previously added calculations for any members, so it serves as a summary of all calculations.

Additional calculations can be added to this worksheet by selecting the "Add to comparison file" button on any other member resistance worksheets (see section 2.3.2).

Note that the compare worksheet is hidden if no details have been added to comparison file.

2.9.1 Print comparison file

This button formats the comparison file and opens up the print window, where the user can select a printer and print.

3 SCREENSHOTS

Microsoft Excel - PrelimExcel/017		- 0
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This Excel workbook calculates the resistance of steel members in accordance with EN 1993-1-1.		
Design resistances are compression, tension, bending, N-M and web resistance.		
The workbook offers the alternative of different languages and selection of National Anney values from the "Localisation" sheet		
National Annex values may be overwritten and default values may be stored		
A number of design resistances may be calculated and stored in summary form. The summary and individual individual factors may be profited.		
The summary and mandual design vertications may be printed.		
Continue		
A second se	1.1	12

Figure 3.1 Introduction worksheet

Language right I Load defaults National Annex Via 1 Sofely Factors Via 1 Outer MA values Outer MA values Outer Via	St yew Insert Format Icols Data Window Help Adobe FOF	Type a question for hep
Language English National Annex x yin = 1 Yin = 1 Yin = 1 Yin = 1 Yin = 1 Overwrite User Edurne Nunez Project Stadium Arch ob Number 12345	7997 48 * 98 • 4 4 • • · 8 x · 111 184	150% • 😥
National Annex Ux Yang = 1 Observation Yang = 1.1 Observation Project Stadium Arch ob Number (12345)	Language	
National Annex Save as default Yno = 1 Outer VA values Yno = 1.1 Overwrite User Edume Nunez Project Stadium Arch ob Projekt Stadium Arch ob Number 112345 Overwrite		Load defaults
Ywa = 1 Ywa = 1.1 Overwrite	National Annex	Save as default
Yur = 1 Overwrite User[Edurne Nunez Project Stadium Arch ob Number [12345	γ _{MD} = 1 Γ Safety Factors	
Vice = 1.1 Obviorine User Edurne Nunez Project Stadium Arch ob Number 12345	y _{M1} = 1 Ouse NA values	
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Figure 3.2 Localisation worksheet

$M_{B,Rd} = 1532 \text{ kNm}$	h = 834.9 mm b = 291.7 mm tf = 18.8 mm tw = 14 mm 176 kg/m	Print Create new comparison file Add to comparison file
-------------------------------	--	--

Figure 3.3 Bending worksheet

Section type		
HE V	O Annex A	Print
Section HE 1000 x 393	Arrax B	Create new comparison file
Steel grade		Add to comparison file
L _y = 10 m		
<i>L</i> _z = 10 m	1500 85 0	
L _T = 5m	Eq. 6.61: $\frac{1000}{12408} + 0.606 \frac{100}{2564} + 0.597 \frac{100}{553} = 0.13$	< 1.0
L _{LT} =15 m		
$M_{y,Ed,max} = \frac{0}{M_{y,Ed,max}} kNm$ $M_{y,Ed,min} = \frac{65}{kNm}$	1500 65 0	
$M_{z,Ed,max} = 0$ $M_{z,Ed,max} = 0$ kNm	Eq. 6.62: $+ 0.865 - + 0.996 = 0.49$	< 1.0
N _{Ed} = 1500 kN		

Figure 3.4 N-M worksheet

LNEQA (long leg attached)		Print
L 150 x 75 x 11 V		Create new comparison file
Bolt(s) 5275	h = 150 mm	Add to comparison file
Number of bolts	b = 75 mm t = 11 mm	
Bolt size	19 kg/m	
M22		
e, = 10 mm		
p ₁ = 100 mm		
N _{1,04} = kN		

Figure 3.5 Tension worksheet

Section type FE \checkmark Section $FE + 600$ \checkmark Steel grade 5275 \checkmark $L_{\gamma} = 0$ m $L_{\gamma} = 3352$ kN $N_{b,\gamma,Rd} = 3352$ kN $N_{b,\gamma,Rd} = 3352$ kN	h = 597 mm b = 220 mm t = 17.5 mm 108 kg/m	
N _{k,Rd} = 3352 kN		

Figure 3.6 Compression worksheet

Section type		1
U/8		Print
Section 1016x305x272	h = 990.1 mm	Create new comparison file
Steel grade	b = 300 mm tf = 31 mm	Add to comparison file
c =200]mm	tw = 16.5 mm	
s, = 50 mm		
F _{Rd} = 237 kN		
$V_{c,Rd}$ = 627 kN		
Check availability		

Figure 3.7 Web resistance worksheet

E E	Edt Ym	w Insert Format Icols	Data Wox	dow Help Adobe PDF												Type a qui	estion for her	• • • •
13	999	97 25 1 2 2 4	5. 1 10.	(r-18 x - 21 2	1 150%													
	A	В	С	D	E	F	G	н	ા	J		ĸ	L	- X -	М	N	6 _	0
1	-	1																
2																		
3																		
4																		
5																		
6																		
7		IPE A 600	S235	c = 200 mm	ss = 50 mm			FRd = 23	6 kN Vc	Rd = 62	6 kN	(1:	1; 1.1) NA:	UK CH	neck ava	ilability	
8		IPE A 600	S275	Lyy = 0 m	Lzz = 0 m	LT = 0.001 m		NRd,min =	3351 kN	(1:	1; 1.1)	NA: L	JK					
9		L 150 x 75 x 11	S275	e1 = mm	p1 = mm	2 M22 Bolt(s)		FRd = 0 k	dN (1;1;	1.1) NA	UK	heck a	vailab	oility				
10		HE 1000 x 393	S275	= 10m; Lt = 5	im; LLTB = 1	5m		6.61: 0.14	4; 6.62; 0.	.49; Safe	ty Fact	ors: (1	; 1; 1.	.1) NA	UK			
11		838x292x176	S235	$L_LTB = 0.00$	l m			Mb,Rd =	1532 kNm	(1;	1; 1.1)	NA; L	JK					
2																		
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	H Introdu	ction / Localisation / Bendir	Q/NM/TH	nsion / Compression / V	Web Resistance Con	npare/									1.	1		1 2

Figure 3.8 Compare worksheet

Part 8: Description of member resistance calculator

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
 - Supplementary calculations to demonstrate the influence of the French National Annex
- 2. Combined axial force and bending moment (N-M interaction)
- 3. Tension resistance
- 4. Compression resistance
- 5. Web resistance

Note that supplementary calculations are included to show that the influence of the French National Annex has been incorporated into the calculation routines.

S 2 Steel Alliance	Worked Example 1: Bending moment resistance			1	of 3
Calculation about		Made by	CZT	Date	02/2010
Calculation sheet		Checked by	ENM	Date	02/2010
1. Bending This example presents	moment resistance the method used in the member resis	tance calcula	ator for	Refere EN 19 unless	ences are to 193-1-1 otherwise
of EN 1993-1-1.	g moment resistance, adopting the rec	commended	values	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 (Sheet	5.2 : 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 (Sheet	5.2 (2)
The limit for Class 1 is	$\varepsilon: 9\varepsilon = 9 \times 0.81 = 7.3$				
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		
1.2. Lateral-to	rsional buckling resistance	e, M _{b,Rd}			
< 3800	>				
$\psi = \frac{0}{444} = 0$	$\rightarrow C_1 = 1,77$			Apper Single Steel I Part 4	ndix C of Storey Building,

Title	Worked Example: Bending moment resistance	2 of 3
$M_{\rm cr} = C_1 \frac{\pi^2}{2}$	$\frac{2^2 EI_z}{L^2} \sqrt{\frac{I_w}{I_z} + \frac{L^2 GI_t}{\pi^2 EI_z}}$	
$= 1,77 \times \frac{124}{214}$ $\times \sqrt{\frac{124}{214}}$	$\frac{\pi^{2} \times 210000 \times 2142 \times 10^{4}}{3800^{2}}$ $\frac{9 \times 10^{9}}{2 \times 10^{4}} + \frac{3800^{2} \times 81000 \times 89, 3 \times 10^{4}}{\pi^{2} \times 210000 \times 2142 \times 10^{4}}$	Appendix C of Single-Storey Steel Building, Part 4
$M_{\rm cr} = 1556 \times \frac{1}{\lambda_{\rm LT}} = \sqrt{\frac{W_{\rm y} J}{M_{\rm cr}}}$	$\frac{10^6 \text{ Nmm}}{\frac{7}{y}} = \sqrt{\frac{2194 \times 10^3 \times 355}{100000000000000000000000000000000000$	§6.3.2.2
$\int M_{c}$ For hot rolled $\phi_{LT} = 0.5 [1 +$	$\alpha_{LT} \left(\overline{\lambda}_{LT} - \overline{\lambda}_{LT,0} \right) + \beta \overline{\lambda}_{LT}^{2} $ sections	§6.3.2.3
$\overline{\lambda}_{\text{LT},0} = 0,4$ $\frac{h}{b} = 2,5$	and $\beta = 0.75$	Table 6.3 Table 6.5
$\rightarrow \text{Curve } \mathbf{c} \text{ for} \\ \rightarrow \alpha_{\text{LT}} = 0,49$	r hot rolled I sections	
$\varphi_{LT} = 0,5[1 + \chi_{LT}] = \frac{1}{\varphi_{LT} + \chi_{LT}}$	$\frac{1}{\sqrt{\phi_{LT}^{2} - \beta \overline{\lambda}_{LT}^{2}}}$	§6.3.2.3
$\chi_{\rm LT} = \frac{1}{0,763}$	$\frac{1}{\sqrt{0,763^2 - 0,75 \times 0,708^2}} = 0,822$	
$\frac{1}{\overline{\lambda}_{LT}^2} = \frac{1}{0,708}$	$\frac{1}{3^2} = 1,99$ = 0.822	
f = 1 - 0.5 (1 - 0.5)	$(-k_c) [1-2,0 (\overline{\lambda}_{LT}-0,8)^2]$	
$k_{\rm c} = \frac{1}{1,33+0,3}$	$\frac{1}{13\psi} = \frac{1}{1,33+0,33\times0} = 0,75$	
f = 1 - 0,5 (1 - 1)	$(-0,75) [1-2,0 (0,708-0,8)^2] = 0,877$	
$\chi_{\rm LT\ mod} = \frac{\chi_{\rm LT}}{f}$	$=\frac{0,822}{0,877}=0,937$	
$M_{\rm b,Rd} = \frac{\chi_{\rm LT} W}{\gamma}$	$\frac{V_{\text{pl,y}} f_{\text{y}}}{M1} = \frac{0.937 \times 2194 \times 10^3 \times 355}{1.0} \times 10^{-6} = 730 \text{ kNm}$	

 $\beta = 1,0$

The French National Annex requires alternative values for $\overline{\lambda}_{LT,0}$, α_{LT} and β .	
The revised calculations are demonstrated below.	

$$\overline{\lambda}_{\text{LT},0} = 0,2 + 0,1\frac{b}{h} = 0,2 + 0,1\frac{1}{2,5} = 0,24$$

French NA

French NA French NA

$$\alpha_{\rm LT} = 0.4 - 0.2 \frac{b}{h} \overline{\lambda}_{\rm LT}^2 = 0.4 - 0.2 \times \frac{1}{2.5} \times 0.708^2 = 0.36$$

$$\phi_{\text{LT}} = 0.5 \left[1 + 0.36 (0.708 - 0.24) + 0.708^2 \right] = 0.835$$
$$\chi_{\text{LT}} = \frac{1}{0.835 + \sqrt{0.835^2 - 0.708^2}} = 0.783$$
$$\chi_{\text{LT mod}} = \frac{\chi_{\text{LT}}}{f} = \frac{0.783}{0.877} = 0.892$$

$$M_{\rm b,Rd} = \frac{0.892 \times 2194 \times 10^3 \times 355}{1.0} \times 10^{-6} = 695 \text{ kNm}$$

Sidel	Worked Example 2: Combined axial force and bending moment (N-M Interaction)			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)
$d_{\rm N} = \frac{N_{\rm Ed}}{t_{\rm w} f_{\rm y}} = \frac{127000}{9,4 \times 35}$				
$\alpha = \frac{d_{\rm w} + d_{\rm N}}{2d_{\rm w}} = \frac{378}{2\times3}$				
The limit between Cla				
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 ε = 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. Bud	ckling 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)
$\frac{\frac{N_{\rm Ed}}{\chi_{\rm y}N_{\rm Rk}}}{\gamma_{\rm M1}} + k_{\rm yy}$	$\frac{M_{y,\text{Ed}} + \Delta M_{y,\text{Ed}}}{\chi_{\text{LT}} \frac{M_{y,\text{Rk}}}{\gamma_{\text{Ml}}}} + k_{yz} \frac{M_{z,\text{Ed}} + \Delta M_{z,\text{Ed}}}{\frac{M_{z,\text{Rk}}}{\gamma_{\text{Ml}}}} \le 1,0$	
$\frac{N_{\rm Ed}}{\frac{\chi_{\rm z}N_{\rm Rk}}{\gamma_{\rm M1}}} + k_{\rm zy}$	$\frac{M_{y,Ed} + \Delta M_{y,Ed}}{\chi_{LT} \frac{M_{y,Rk}}{\gamma_{M1}}} + k_{zz} \frac{M_{z,Ed} + \Delta M_{z,Ed}}{\frac{M_{z,Rk}}{\gamma_{M1}}} \le 1,0$	
These express	ions can be simplified as follows:	
• $\Delta M_{y,Ed} =$	0 and $\Delta M_{z,Ed} = 0$ for Class 1, Class 2 and Class 3 sections.	
• $M_{z,Ed} = 0$ Therefore exp	ressions (6.61) and (6.62) can be written as:	
$\frac{N_{\rm Ed}}{N_{\rm b,y,Rd}} + k_{\rm yy} \frac{M}{M}$		
1.3. Equ	uation 6.61 (EN 1993-1-1)	
1.3.1. Flex		
$\frac{h}{b} = \frac{450}{190} = 2$		
$t_{\rm f} = 14,6 \ {\rm mm}$		
buckling abou	t y-y axis:	Table 6.1
\rightarrow Curve a for	hot rolled I sections	Table 6.2
$\rightarrow \alpha_{\rm y} = 0,21$		
$\lambda_1 = \pi \sqrt{\frac{E}{f_y}}$	$=\pi\sqrt{\frac{210000}{355}}=76,4$	§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
$\phi_y = 0,5[1+$		
$\chi_{y} = \frac{1}{\phi_{y} + \sqrt{1-\phi_{y}}}$	$\frac{1}{\overline{\phi_y}^2 - \overline{\lambda}_y^2} = \frac{1}{0.50 + \sqrt{0.50^2 - 0.12^2}} = 1.0$	

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_{b,Rd} 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 ψ . **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_{b,z,Rd} $\frac{h}{h} = \frac{450}{190} = 2,37$ $t_{\rm f} = 14,6 \, {\rm mm}$ 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
$\chi_z = \frac{1}{\phi_z + \sqrt{1-\phi_z}}$	$\frac{1}{\phi_z^2 - \overline{\lambda}_z^2} = \frac{1}{0,704 + \sqrt{0,704^2 - 0,540^2}} = 0,865$	
$N_{\mathrm{b,z,Rd}} = \frac{\chi_z}{\gamma}$	$\frac{Af_y}{M_{M1}} = \frac{0.865 \times 9880 \times 355}{1.0} \times 10^{-3} = 3034 \text{ kN}$	
$N_{\rm Ed} = 127$	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	1 of 1				
		Made by	CZT	Date	02/2010
Calculation sheet		Checked by	ENM	Date	02/2010
1. Tension This example presents for calculating the tens EN 1993-1-8.	Resistance the method used in the memb sion resistance, adopting the re	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					
Total number of bolts					
Diameter of the holes					
Partial safety factors					
$\gamma_{M0} = 1,0$					
$\gamma_{M2} = 1,25$ (for shear resistance of bolts)					
1.2. Angle in t	ension				
$N_{\rm Rd} = \frac{\beta_3 A_{\rm net} f_{\rm u}}{\gamma_{\rm M2}}$				§3.10	.3
$2,5 d_0 = 2,5 \times 22 = 5$	55 mm				
$5 d_0 = 5 \times 22 = 11$	0 mm				
$2.5 d_0 < p_1 < 5 d_0$					2.0
β_3 can be determined	1 able	3.8			
Therefore $\beta_3 = 0.59$					
$A_{\text{net}} = A - t_{\text{ac}} d_0 = 227$	$0 - 12 \times 22 = 2006 \text{ mm}^2$				
$N_{\rm Rd} = \frac{0.59 \times 2006 \times 30}{1.25}$	$\frac{60}{2} \times 10^{-3} = 341 \text{ kN}$				

SSS	Steel Alliance Worked Example 4: Compression Resistance					
Amarice		Made by	CZT	Date 02/2010		
Calculation sheet		Checked by	ENM	Date 02/2010		
1. Compres This example presents for calculating the flex subject to pure compre EN 1993-1-1. Section: IPE 500	the method used in the member resist tural and the torsional buckling resistance ession, adopting the recommended values	tance calcul ance of mem lues of	ator ibers	References are to EN 1993-1-1 unless otherwise stated		
Steel grade: S235						
$L_{\rm y} = 3.8 {\rm m}$						
$L_z = 3.8 \text{ m}$						
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> _{b,y,Rd}	ouckling resistance about t	he major	axis,			
$L_{\rm y} = 3,8 {\rm m}$						
$\frac{h}{b} = \frac{500}{200} = 2,5$						
$t_{\rm f} = 16 \ {\rm mm}$						
Buckling about y-y ax	is:					

Title	Worked Example: Compression Resistance	2 of 3
\rightarrow Curve a for	Table 6.2	
$\rightarrow \alpha_{\rm y} = 0.21$		Table 6.1
$\lambda_1 = \pi \sqrt{\frac{E}{f_y}} =$	$= \pi \sqrt{\frac{210000}{235}} = 93,9$	§6.3.1.3
$\overline{\lambda}_{y} = \frac{L_{cr}}{i_{z}} \frac{1}{\lambda_{1}}$	$=\frac{3800}{204}\times\frac{1}{93,9}=0,198$	
$\phi_{\rm y}=0,5\Big[1+\alpha$	$z_{y}\left(\overline{\lambda}_{y}-0,2\right)+\overline{\lambda}_{y}^{2}$	§6.3.1.2
$\phi_{\rm y}=0,5\Big[1+0$	$,21(0,198-0,2)+0,198^{2}] = 0,519$	
$\chi_{\rm y} = \frac{1}{\phi_{\rm y} + \sqrt{\phi_{\rm y}}}$	$\frac{1}{\left(0.519 + \sqrt{0.519^2 - 0.198^2}\right)} = 1.0$	
$N_{\rm b,y,Rd} = \frac{\chi_{\rm y} A_{\rm y}}{\gamma_{\rm M1}}$	$\frac{f_y}{1,0} = \frac{1.0 \times 11600 \times 235}{1,0} \times 10^{-3} = 2726 \text{ kN}$	
1.3. Flei axis		
$L_z = 3,8 \text{ m}$		
$\frac{h}{b} = \frac{500}{200} = 2,3$		
$t_{\rm f} = 16 \ {\rm mm}$		
Buckling abou	at z-z axis:	
\rightarrow Curve b fo	Table 6.1	
$\rightarrow \alpha_z = 0,21$		
$\lambda_{\rm l} = \pi \sqrt{\frac{E}{f_{\rm y}}} =$	$= \pi \sqrt{\frac{210000}{235}} = 93,9$	§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	
$\phi_z = 0.5 [1 + 0.5]$		
$\chi_{z} = \frac{1}{\phi_{z} + \sqrt{\phi_{z}}^{2}}$		
$N_{\rm b,z,Rd} = \frac{\chi_z A_j}{\gamma_{\rm M1}}$		

1.4. Torsional buckling *N*_{b,T,Rd}

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

$$N_{\rm eTT} = \frac{1}{i_0^{-5}} \left(\frac{\pi^2 EI_w}{L_{\rm T}^2} + GI_{\rm T} \right)$$

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

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

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

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

$$a_z = 0.34$$

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

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

$$N_{\rm b,T,Rd} = \frac{\chi_{\rm T} 4f_y}{\gamma_{\rm M1}} = \frac{0.791 \times 11600 \times 235}{1.0} \times 10^{-3} = 2156 \text{ kN}$$

S	Sicel Alliance Worked Example 5: Web Resistance					1 of 2		
Calcul	ation shoot					Made by	CZT	Date 02/2010
Calcul	alion Sheel					Checked by	ENM	Date 02/2010
1.	Web Res	sista	nce					
This ex for calc recomm	ample presents ulating the web nended values of	the me b resista of the E	thod use nce and N 1993-	d in the the shea 1-5 and 1	member res r resistance EN 1993-1-	sistance calcu , adopting the -1.	lator e	
Section	: IPE 500							
Steel gr	ade: S355							
С	= 10 mm							
S _s	= 100 mm							
1.1.	Shear res	sistan	се					
In the a area, w	bsence of torsic hich is given by	on, the s y:	shear pla	stic resis	stance depe	nds on the sh	ear	
$A_{ m v}$	$= A - 2 b t_{\rm f} +$	$(t_{\rm w} + 2$	$r) t_{\rm f}$					EN 1993-1-1
$A_{\rm v}$	= 11600 - 2 >	× 200 ×	16 + (10),2 + 2 ×	21) × 16 =	6035 mm ²		§ 6.2.6 (3)
$V_{\rm pl,Rd}$	$= \frac{A_{\rm v}f_{\rm y}}{\sqrt{3}\gamma_{\rm M0}} =$	$\frac{6035\times}{\sqrt{2}}$	$\frac{355 \times 10}{\overline{3} \times 1,0}$	$\frac{-3}{-1} = 122$	37 kN			EN 1993-1-1 § 6.2.6 (2)
$V_{\rm pl,Rd}$	= 1237 kN							
1.2.	Desian re	esista	nce to	local	bucklind			
с	= 10 mm							
S _S	= 100 mm							
m_1	$=\frac{b_{\rm f}}{t_{\rm w}}=\frac{200}{10,2}=$	=19,6						
<i>m</i> ₂	$=0.02\left(\frac{h_{\rm w}}{t_{\rm f}}\right)^2$	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> ₂	$=0,02\left(\frac{468}{16}\right)$	$\Big)^2 = 17,$	11					
$k_{ m F}$	$= 2 + 6 \left(\frac{s_{\rm s}}{h_{\rm w}}\right)$	$\left(\frac{-c}{c}\right)^2$	but $k_{\rm F} \leq$	6				
$k_{ m F}$	$=2+6\left(\frac{100}{46}\right)$	$\frac{+10}{68}$						

Title		Worked Example: Web Resistance and Shear Resistance	2 of 2
$k_{ m F}$	= 3,4	1 < 6	
le	$=\frac{k_{\rm F}}{2}$	$\frac{E t_{w}^{2}}{f_{y} h_{w}} \qquad \text{but} \le s_{s} + c$	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	the $\ell_e =$	110	
ℓ_{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)
ℓ_{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	
ℓ_{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)
ℓ_{y}	= mi	n $(\ell_{y1}; \ell_{y2}; \ell_{y3}) = \min(325; 248; 207) = 207 \text{ mm}$	1()
F _{cr}	= 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 appropr	ore the ed bas then iate ex	initial assumption was correct and the web resistance can be sed on this value of λ_F . Should the calculated value of λ_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)