PRILOGA C: DIMENZIONIRANJE ČLENKASTEGA SPOJA SEKUNDARNI – PRIMARNI NOSILEC (program CoP2)

Design of joints

1 General

Project name	Diplomska naloga
Project number	/
Comment	Analiza jeklenega poslovnega objekta z upoštevanjem membranskega delovanja stropov med požarom
Client name	/
Client address	/
Company	/
Company address	/
Designer	Žiga Plevel
Calculation in accordance with	CEN EN 1993-1-8

Note: In the following calculations references to the Eurocodes are given. If the relevant part of Eurocode is not specified reference is made to EN 1993-1-8.

1.1 Safety factors

Safety factor	γ_{M0}	=	1
Safety factor	γ_{M1}	=	1
Safety factor	γ_{M2}	=	1.25
Safety factor	γ_{M5}	=	1
Safety factor	γ_{s}	=	1.15
Safety factor	γ_{c}	=	1.5

2 Joint configuration

Name:	Spoj sekundarni nosilec - primarni nosilec
Comment:	
Configuration:	Single sided beam-to-beam joint configuration
Connection type:	Fin plate connection (simple)
Position number:	
Position name:	
Braced structure:	No
Ratio Kb/Kc greater or equal 0.1:	Yes
Global design procedure:	Elastic

2.1 Joint 1

2.1.1 Joint geometry

2.1.1.1 Supporting member profile

Name	IPE 550, S275		
Section height	h	=	550 mm
Section width	b	=	210 mm
Flange thickness	t_f	=	17.2 mm
Web thickness	t_w	=	11.1 mm
Radius	r	=	24 mm
Yield strength of flange	$f_{y,f}$	=	275 N/mm²
Ultimate strength of flange	$f_{u,f}$	=	430 N/mm²
Yield strength of web	$f_{y,w}$	=	275 N/mm²
Ultimate strength of web	$f_{u,w}$	=	430 N/mm²
Web height	d	=	467.6 mm
Profile area	A	=	$1.344 \cdot 10^4$ mm²
Profile shear area	A_{vz}	=	7234 mm²

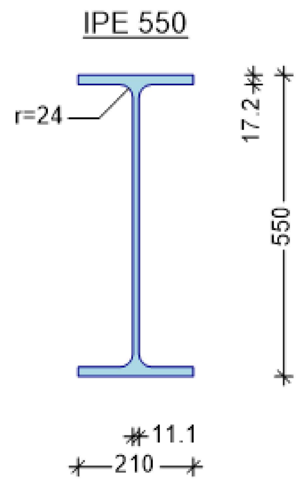

Figure 1: *Supporting member profile*

2.1.1.2 Beam profile

Name	IPE 400, S235		
Section height	h	=	400 mm
Section width	b	=	180 mm

Flange thickness	t_f	=	13.5 mm
Web thickness	t_w	=	8.6 mm
Radius	r	=	21 mm
Yield strength of flange	$f_{y,f}$	=	235 N/mm²
Ultimate strength of flange	$f_{u,f}$	=	360 N/mm²
Yield strength of web	$f_{y,w}$	=	235 N/mm²
Ultimate strength of web	$f_{u,w}$	=	360 N/mm²
Web height	d	=	331 mm
Profile area	A	=	8446 mm²
Profile shear area	A_{vz}	=	4269 mm²

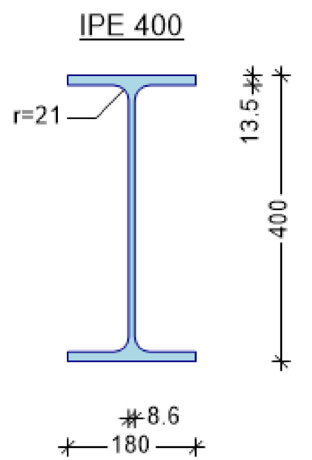

Figure 2: *Beam profile*

2.1.1.3 Notches

Length of notch	L	=	110 mm
Height of upper notch	h_1	=	35 mm
Radius	R	=	5 mm
Type of notches	Notched at upper flange		

2.1.1.4 Fin plate

Section height	h	=	260 mm
Section width	b	=	120 mm
Thickness	t	=	10 mm
Yield strength	f_y	=	235 N/mm²
Ultimate strength	f_u	=	360 N/mm²

2.1.1.5 Bolt pattern

2.1.1.5.1 Bolt properties

Caption	M20		
Diameter	d	=	20 mm
Hole diameter	d_0	=	22 mm
Shank area	A_s	=	245 mm²
Yield strength	f_{yb}	=	640 N/mm²
Ultimate strength	f_{ub}	=	800 N/mm²

2.1.1.5.2 Bolt positions

No. of rows	n_1	=	3
Pitch between bolt rows	p_{11}	=	70 mm
Pitch between bolt rows	p_{12}	=	70 mm
No. of columns	n_2	=	1

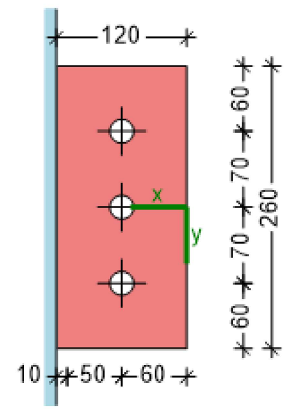

Figure 3: *Fin plate*

2.1.1.6 Welds

Weld type	Fillet weld		
Weld size	a_w	=	6 mm

2.1.2 Loading on joint

Table 1: *Loading*

No.	Name	V [kN]	M [kNm]	N [kN]
1	Construction state (steel joint only)	149.9	0	0

2.1.3 Joint properties

Remark: Member checks according to EN 1993-1-1 are not part of this calculation note.

2.1.3.1 Shear components

2.1.3.1.1 General data

2.1.3.1.1.1 Bolt pattern

No of horizontal bolt rows	n_1	=	3	
No of vertical bolt rows	n_2	=	1	
Longitudinal bolt pitch	p_1	=	70 mm	
Transverse bolt pitch	p_2	=	NaN mm	
Polar moment	I	=	NaN mm²	

2.1.3.1.2 Requirements to ensure sufficient rotation capacity

Fin plate height	h_p	=	260 mm	
Clear depth of supported beam web	d_b	=	331 mm	
Rotation capacity check 1	$h_p \le d_b$			
Available rotation capacity	$\phi_{available}$	=	2.884°	

If the joint is assumed to be a hinge in the global analysis, a sufficient rotation capacity must be ensured. The required rotation capacity can be taken from ECCS publication 126, Annex 1. The available possible rotation must exceed the required one. Moreover the contact plate must not be in place to let the joint work as a hinge.

2.1.3.1.3 Requirements to avoid premature weld failure

Fin plate thickness	t_p	=	10 mm	
Correlation factor	β_w	=	0.8	
Fin plate yield strength	f_{yp}	=	235 N/mm²	
Fin plate ultimate strength	f_{up}	=	360 N/mm²	
Weld size	a	=	6 mm	
Required weld size	a_{req}	=	4.616 mm	$a_{req} = \beta_w/\sqrt{2} \cdot f_{yp}/f_{up} \cdot \gamma_{M2}/\gamma_{M0} \cdot t_p$
Ductility check	$a > a_{req}$			

2.1.3.1.4 Bolts in shear

No of horizontal bolt rows	n_1	=	3	
No of vertical bolt rows	n_2	=	1	
Total number of bolts	n	=	3	
Lever arm	z	=	60 mm	
Shear resistance of bolt	$F_{v,Rd}$	=	120.6 kN	Tbl. 3.4
Factor	α_v	=	0.6	3.6.1 Tbl. 3.4
Bolt area	A	=	314.2 mm²	

Bolt shear area	A_s	=	245 mm²	
Ultimate strength of bolt	f_{ub}	=	800 N/mm²	
Shear resistance	$V_{Rd,1}$	=	222.2 kN	

2.1.3.1.5 Fin plate in bearing

No of horizontal bolt rows	n_1	=	3	
No of vertical bolt rows	n_2	=	1	
Total number of bolts	n	=	3	
Coefficient	α	=	0	
Coefficient	β	=	0.4286	
Bolt diameter	d	=	20 mm	
Fin plate thickness	t_p	=	10 mm	
Ultimate strength of bolt	f_{ub}	=	800 N/mm²	
Fin plate ultimate strength	f_{up}	=	360 N/mm²	
Vertical:				
Factor	α_b	=	0.8106	3.6.1 Tbl. 3.4
Factor	k_1	=	2.5	3.6.1 Tbl. 3.4
Bearing resistance of bolt	$F_{b,Rd,ver}$	=	116.7 kN	Tbl. 3.4
Horizontal:				
Factor	α_b	=	0.9091	3.6.1 Tbl. 3.4
Factor	k_1	=	2.5	3.6.1 Tbl. 3.4
Bearing resistance of bolt	$F_{b,Rd,hor}$	=	130.9 kN	Tbl. 3.4
Bearing resistance	$V_{Rd,2}$	=	230.2 kN	Tbl. 3.4

2.1.3.1.6 Gross section of the fin plate in shear

Shear area	A_v	=	2600 mm²	
Fin plate thickness	t_p	=	10 mm	
Fin plate height	h_p	=	260 mm	
Fin plate yield strength	f_{yp}	=	235 N/mm²	
Shear resistance	$V_{Rd,3}$	=	277.8 kN	

2.1.3.1.7 Net section of the fin plate in shear

Net area in shear	$A_{v,net}$	=	1940 mm²	3.10.2
Resistance	$V_{Rd,4}$	=	322.6 kN	3.10.2

2.1.3.1.8 Shear block of the fin plate

No of horizontal bolt rows	n_1	=	3	
No of vertical bolt rows	n_2	=	1	
Fin plate height	h_p	=	260 mm	
Longitudinal end distance (fin plate)	e_1	=	60 mm	
Fin plate yield strength	f_{yp}	=	235 N/mm²	
Fin plate ultimate strength	f_{up}	=	360 N/mm²	
Net area in tension	$A_{nt,1}$	=	490 mm²	3.10.2
Net area in shear	$A_{nv,1}$	=	1450 mm²	3.10.2
Resistance of shape 1	$V_{Rd,down,1}$	=	267.3 kN	
Resistance	$V_{Rd,5}$	=	267.3 kN	

2.1.3.1.9 Fin plate in bending

Fin plate height	h_p	=	260 mm	
Lever arm	z	=	60 mm	
Shear resistance	$V_{Rd,6}$	=	+∞ kN	

2.1.3.1.10 Buckling of the fin plate

Elastic section modulus	W_{el}	=	$1.127 \cdot 10^5$ mm³	
Fin plate height	h_p	=	260 mm	
Fin plate thickness	t_p	=	10 mm	
Fin plate yield strength	f_{yp}	=	235 N/mm²	
Lever arm	z	=	60 mm	
Horizontal distance from supporting web or flange to first bolt row	z_p =		60 mm	ECCS TC 10 No. 126
Plate slenderness	λ_{LT}	=	28.55	ECCS TC 10 No. 126
Lateral torsional buckling strength of the plate	f_{pLT}	=	235 N/mm²	BS5950-1 Tbl. 17
Shear resistance	$V_{Rd,7}$	=	+∞ kN	

2.1.3.1.11 Beam web in bearing

Bolt diameter	d	=	20 mm	
Beam web thickness	t_{bw}	=	8.6 mm	
Ultimate strength of bolt	f_{ub}	=	800 N/mm²	
Ultimate strength of beam web	f_{ubw}	=	360 N/mm²	
No of horizontal bolt rows	n_1	=	3	
No of vertical bolt rows	n_2	=	1	
Total number of bolts	n	=	3	
Coefficient	α	=	0	
Coefficient	β	=	0.4286	
Vertical:				
Factor	α_b	=	0.8106	3.6.1 Tbl. 3.4
Factor	k_1	=	2.5	3.6.1 Tbl. 3.4
Bearing resistance of supported beam web	$F_{b,Rd,ver}$	=	100.4 kN	Tbl. 3.4
Horizontal:				
Factor	α_b	=	0.7576	3.6.1 Tbl. 3.4
Factor	k_1	=	2.5	3.6.1 Tbl. 3.4
Bearing resistance of supported beam web	$F_{b,Rd,hor}$	=	93.82 kN	Tbl. 3.4
Shear resistance	$V_{Rd,8}$	=	177.1 kN	

2.1.3.1.12 Gross section of the beam web in shear

Shear area of beam	$A_{b,v}$	=	3554 mm²	
Yield strength of beam web	f_{ybw}	=	235 N/mm²	
Shear resistance	$V_{Rd,9}$	=	482.2 kN	

2.1.3.1.13 Net section of the beam web in shear

Net shear area of beam	$A_{b,v,net}$	=	2986 mm²	EN 1993-1-1 6.2.2.2
Ultimate strength of beam web	f_{ubw}	=	360 N/mm²	
Shear area of beam	$A_{b,v}$	=	3554 mm²	EN 1993-1-1 6.2.6 (3)
No of horizontal bolt rows	n_1	=	3	

Hole diameter	d_0	=	22 mm	
Beam web thickness	t_{bw}	=	8.6 mm	
Shear resistance	$V_{Rd,10}$	=	496.5 kN	EN 1993-1-1 6.2.6 (2)

2.1.3.1.14 Shear block failure of the beam web

Beam web thickness	t_{bw}	=	8.6 mm	
Transverse end distance (beam web)	e_{2b}	=	50 mm	
Hole diameter	d_0	=	22 mm	
Net area subjected to tension	A_{nt}	=	335.4 mm²	3.10.2
No of horizontal bolt rows	n_1	=	3	
No of vertical bolt rows	n_2	=	1	
Longitudinal end distance (beam web)	e_{1b}	=	95 mm	
Net area subjected to shear	A_{nv}	=	1548 mm²	3.10.2
Yield strength of beam web	f_{ybw}	=	235 N/mm²	
Ultimate strength of beam web	f_{ubw}	=	360 N/mm²	
Shear resistance	$V_{Rd,11}$	=	258.3 kN	3.10.2 (2) (3.9/3.10)

2.1.3.1.15 Notched beam section in bending and shear

Plastic section modulus of notched section	W_{pl}	=	$2.459 \cdot 10^5$ mm³
Plastic moment resistance of notched section	M_{pl}	=	57.79 kNm
Shear resistance of notched section	V_{Rd}	=	482.2 kN
Lever arm	z	=	116 mm
Maximum shear force at beam end	V_{Rd}	=	245 kN

2.1.3.2 Shear downwards

Shear resistance	V_{Rd}	=	177.1 kN
Failure mode of joint	Beam web in bearing		

Table 2: *Component assembly for shear downwards*

Bolts in shear	$V_{Rd,1}$	222.2 kN
Fin plate in bearing	$V_{Rd,2}$	230.2 kN
Gross section of the fin plate in shear	$V_{Rd,3}$	277.8 kN
Net section of the fin plate in shear	$V_{Rd,4}$	322.6 kN
Shear block of the fin plate	$V_{Rd,5}$	267.3 kN
Fin plate in bending	$V_{Rd,6}$	+∞ kN
Buckling of the fin plate	$V_{Rd,7}$	+∞ kN
Beam web in bearing	$V_{Rd,8}$	177.1 kN
Gross section of the beam web in shear	$V_{Rd,9}$	482.2 kN
Net section of the beam web in shear	$V_{Rd,10}$	496.5 kN
Shear block failure of the beam web	$V_{Rd,11}$	258.3 kN
Notched beam section in bending and shear	$V_{Rd,12}$	245 kN
Total	V_{Rd}	177.1 kN

2.1.3.3 Requirements to ensure plastic redistribution of forces

ECCS TC 10, No. 126, 6.3.4 (1) $V_{Rd} < \mathrm{Min}(V_{Rd,1}, V_{Rd,7})$

ECCS TC 10, No. 126, 6.3.4 (2) $F_{b,hor,Rd} \leq Min(F_{v,Rd}, V_{Rd,7}\ \beta)$

ECCS TC 10, No. 126, 6.3.4 (3) $V_{Rd,1} > Min(V_{Rd,2}, V_{Rd,8})$

2.1.4 Joint checks

2.1.4.1 Moment

Table 3: *Moment check*

LC	M_{Ed}	M_{Rd}	Utilization factor	Design check
1	0 kNm	0 kNm	0	OK

2.1.4.2 Shear

Table 4: *Shear check*

LC	V_{Ed}	V_{Rd}	Utilization factor	Design check
1	149.9 kN	177.1 kN	0.8468	OK

2.1.4.3 M-N interaction

Check if interaction between N and M has to be considered (see 6.2.7.1 (2))

Table 5: *M-N interaction check*

LC	N_{Ed}	5% $N_{pl,Rd,beam}$	
1	0 kN	99.24 kN	Not required

Interaction check M-N is not required.

2.1.4.4 Further checks

2.1.4.4.1 Check of welds

2.1.5 Classification

Not relevant.

3 References

[1] CEN: Eurocode 3: Design of steel structures - Part 1-1: General rules and rules for buildings, EN 1993-1-1:2005 + AC:2009, December 2010

[2] CEN: Eurocode 3: Design of steel structures - Part 1-8: Design of joints, EN 1993-1-8:2005 + AC:2009, December 2010

[3] CEN: Eurocode 4: Design of composite steel and concrete structures - Part 1-1: General rules and rules for buildings, EN 1994-1-1:2004, December 2004

[4] Steel and composite building frames: sway response under conventional loading and developmet of membrane effects in beams further to an exceptional action, Jean-Francois Demonceau, PhD thesis, University of Liege, Belgium, 2008

[5] European recommendations for the design of simple joints in steel structures, ECCS Technical commitee 10 Structural connections, ECCS No. 126, 2009