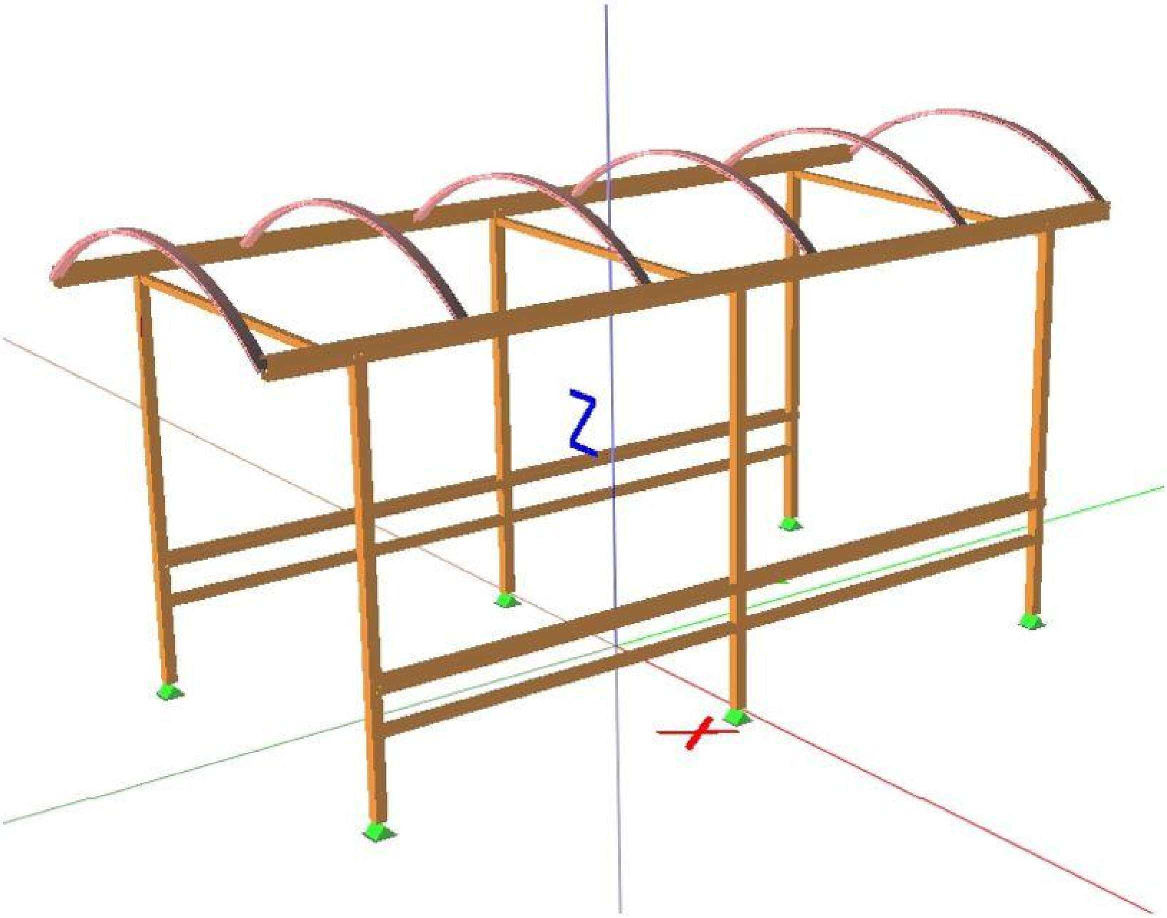
STRUCTURELE ANALYSE VAN DE STAALCONSTRUCTIE VOOR TROLLEY SHELTER VAN HET TYPE "F3 ST" VOLGENS EN 1993 EN AANVERWANTE NORMEN

Lodz, juli 2014



Het onderwerp van de studie is de berekening van de staalconstructie van F3 ST type parkbox, inclusief de staalconstructie, mechanische verbindingen en funderingen. De berekeningen werden uitgevoerd in overeenstemming met de Europese ontwerpnormen, rekening houdend met de EXC2-klassestructuur volgens PN EN 1090 1+A2 en PN-EN 1090-2+A1-normen .

INHOUD VAN HET ONDERZOEK:

1. Belastingen.

1.1. Polen.

Algemene acties - sneeuwbelastingen en windacties :

Windzone 1 A≤650m n.p.m. ($V_{b,0}$=26,62m/s, q_p=0,77kN/m2) terreincategorie:II,
Windzone 2 ($V_{b,0}$=26,0m/s, q_p=0,74kN/m^2) terreincategorie:II,
Windzone 3 A≤720m n.p.m. ($V_{b,0}$=27,54m/s, q_p=0,77kN/m^2) terreincategorie:II,
Zone 1 A≤430m n.p.m. (sk -1.61kN/m^2),
Zone 2 (s_k =0,90kN/m^2),
Zone 3 A≤365m n.p.m. (s_k =1,59kN/m^2), Zone4 (s_k =1,60kN/m^2).

A - hoogte boven het zie niveau s_k - karakteristieke

grondsneeuwbelasting op de plaats

$V_{b,0}$ - fundamentele waarde van de basiswindsnelheid

Permanente belastingen

L.p.	Impact beschrijving	Type-impact	Gewaardeerde tank. kN/m^2		rep. waarde kN/m^2	F	Waarde berekenend kN/m^2
1.	Cellulair polycarbonaat 6mm, 2 muren vast	Permanente Invloed	0.02	--	0.02	1.35	0.03
2.	Gehard glas 6 mm [25.000kN/m3·0,006m]	permanente invloed	0.15	--	0.15	1.35	0.20

De muur van de wind

L.p.	Impact beschrijving	Type-impact	Waardeteken . kN/m^2		rep. waarde kN/m^2	F	Waarde berekenend kN/m^2
1.	Windbelasting op het D-veld van de bovengevel van het gebouw in 0,91 rechthoekige plattegrond volgens PN-EN 1991-1-4/7.2.2 (strefa 3, A=720 m n.p.m. -> vb,0 = 27,54m/s, teren II, co=1, ze=h=2,5 m > cr=0,79, gebouwafmetingen h=2,5 m, d=2,1 m, b=5,0 m -> qp=0,77 kPa, cscd=1.000, cpe=0,80) [0,615kN/m2]	variabele	0,61	1,00	0,61		1,50
2.	Windbelasting op de E-field van de benedengevel van het gebouw in -0,59 rechthoekige plattegrond volgens PN-EN 1991-1-4/7.2.2 (strefa 3, A=720 m n.p.m. -> vb,0 = 27,54m/s, teren II, co=1, ze=h=2,5 m -> cr=0,79, gebouwafmetingen h=2,5 m, d=2,1 m, b=5,0 m -> qp=0,77 kPa, cscd=1.000, cpe=-0,51) [-0,391kN/m2]	variabele	-0,39	1,00	-0,39		1,50

De schuilplaats van de wind

L.p.	Impact beschrijving	dLJĐĞ ŝŵĐĂĐł	Waardeteken . kN/m²	⍰	rep. waarde kN/m²	⍰F	sĂůƶĞ ĐĂůĐƶůĂƚĞ Y kN/m²
1.	Windbelasting op veld A van de boogdakhelling volgens PN-EN 1991-1-4/7.2.8 (strefa 3, A=720 m n.p.m. -> vb,0 = 27,54m/s, teren II, co=1, ze=h=2,5 m -> cr=0,79, dakafmetingen h=2,5 m, d=2,1 m, b=5,0 m, pijl f=0,5 m -> qp=0,77 kPa, cscd=1.000, cpe=-0,66) [-0,658kN/m2]	Variabele	-0.66	1.00	-0.66	1.50	-0.99
2.	Windbelasting op veld B van de boogdakhelling volgens PN-EN 1991-1-4/7.2.8 (strefa 3, A=720 m n.p.m. -> vb,0 = 27,54m/s, teren II, co=1, ze=h=2,5 m -> cr=0,79, dakafmetingen h=2,5 m, d=2,1 m, b=5,0 m, pijl f=0,5 m -> qp=0,77 kPa, cscd=1.000, cpe=-0,72) [-0,721kN/m2]	Variabele	-0.72	1.00	-0.72	1.50	-1.08
3.	Windbelasting op veld C van de boogdakhelling volgens PN-EN 1991-1-4/7.2.8 (strefa 3, A=720 m n.p.m. -> vb,0 = 27,54m/s, teren II, co=1, ze=h=2,5 m -> cr=0,79, dakafmetingen h=2,5 m, d=2,1 m, b=5,0 m, pijl f=0,5 m -> qp=0,77 kPa, cscd=1.000, cpe=-0,31) [-0,307kN/m2]	Variabele	-0.31	1.00	-0.31	1.50	-0.46

De interne druk van de wind

L.p.	Impact beschrijving	dLJĐĞ ŝŵĐĂĐł	Waardeteken . kN/m²	⍰	rep. waarde kN/m²	⍰F	sĂůƶĞ ĐĂůĐƶůĂƚĞ Y kN/m²
1.	Windbelasting in slee volgensPN-EN 1991-1-4 (qp=0,77 kPa, cscd=1.000, cpi=-0,3) [-0,231kN/m2]	Variabele	-0.23	1.00	-0.23	1.50	-0.35
2.	Windbelasting interne druk, druk acc. naar PN-EN 1991-1-4 (qp=0,77 kPa, cscd=1.000, cpi=0,2) [0,154kN/m2]	Variabele	0.15	1.00	0.15	1.50	0.23

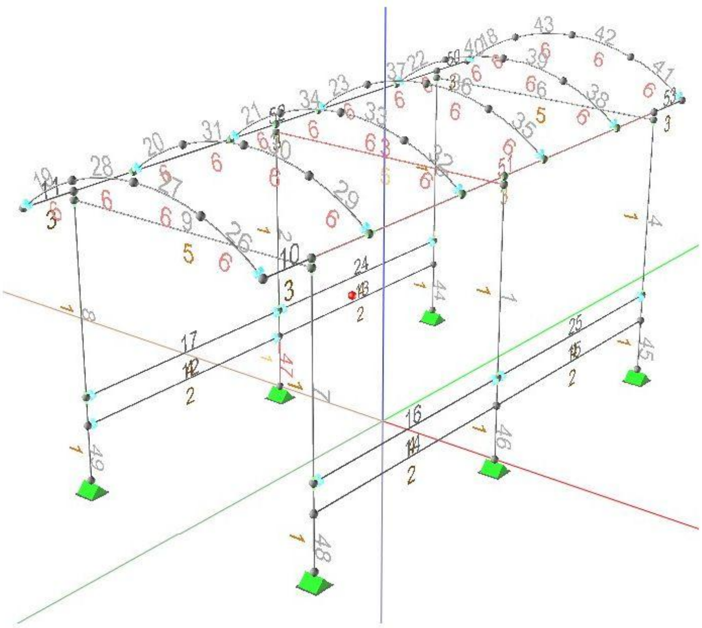
Sneeuw

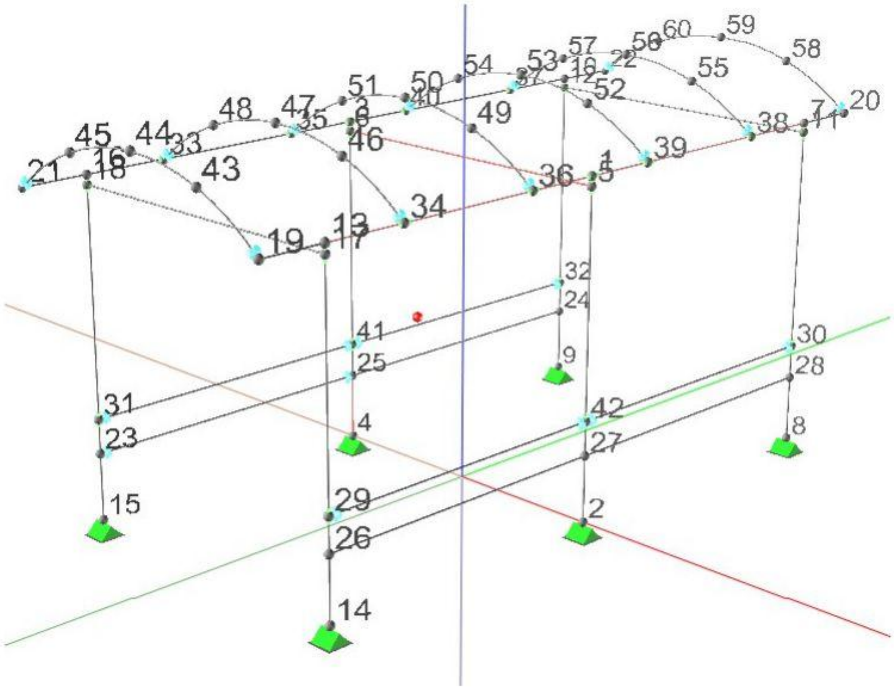
L.p.	Impact beschrijving	dǇƉĞ ŝŵĐĂĐł	Waardeteken . kN/m²	?	rep. waarde kN/m²	?F	sĂůƵĞ ĐĂůĐƵůĂłĞ Y kN/m²
1.	Sneeuwbelasting op cilindrische dakhelling - geval (i) acc. Naar PN-EN 1991-1-3 p.5.3.5 (zone 4 -> sk = 1.6 kN/m2, case . A, dakverhoging h=0,5 m, overspanning b=2,1 m ->0,8, Ce=0,8, Ct=1,0) [1.024kN/m2]	variabele	1,02	1,00	1,02	1,50	1,53
2.	Minimale sneeuwbelasting op de cilindrische dakhelling - geval (ii) acc. naar PN-EN 1991-1-3 p.5.3.5 (zone 4 -> sk = 1.6 kN/m2, case. A, dakverhoging h=0,5 m, overspanning b=2,1 m ->1,0, Ce=0,8, Ct=1,0) [1.280kN/m2]	variabele	1,28	1,00	1,28	1,50	1,92
3.	Maximale sneeuwbelasting op de cilindrische dakhelling - case (ii) wg PN-EN 1991-1-3 p.5.3.5 (zone4 -> sk = 1,6 kN/m2, case. A, dakverhoging h=0,5 m, overspanning b=2,1 m - >2,0, Ce=0,8, Ct=1,0) [2.560kN/m2]	variabele	2,56	1,00	2,56	1,50	3,84

2. Materiële aannames.

Nee, dat is niet waar.	Type:	Naam:	En:	G:	▌:	? T:	?:	Ro:
			[GPa]	[GPa]	[-]	[1/K]	[kg/m³]	[MPa]
1	Aluminium	aluminium PA4/6082	70	27	0,3	0	2710	270
2	Staal1993	S 235	210	81	0,3	0	7850	235

3. Bouwelementen van de goedgekeurde stalen schuilplaats , regeling.

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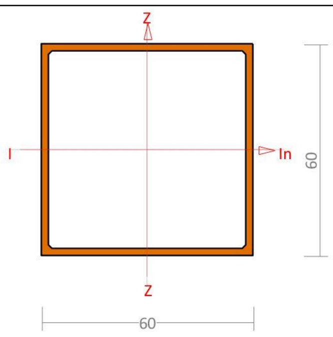
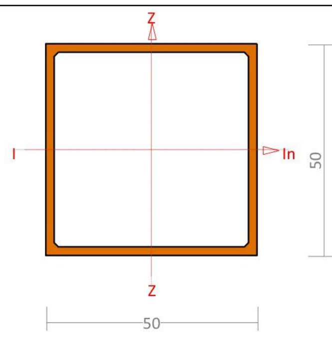
Profielen:

1 - H 60x60x2



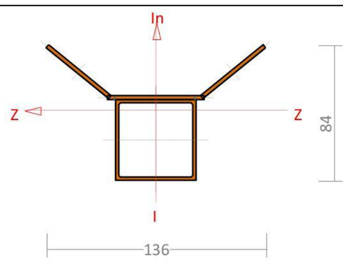
Materiaal:	S 235
A [cm^2]	4.66
Jij [cm^4]	26.20
Jz [cm^4]	26.20
Dyz [cm^4]	0.00
⍰[U]	0.00
Ja [cm^4]	26.20
Dat [cm^4]	26.20
Jt [cm^4]	39.94
J- [cm^4]	0.06
iy [cm]	2.37
van [cm]	2.37
is [cm]	3.35
m [kg/m]	3.66

2 - H 50x50x2



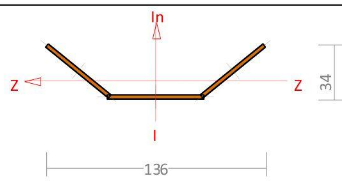
Materiaal:	S 235
A [cm^2]	3.86
Jij [cm^4]	14.87
Jz [cm^4]	14.87
Dyz [cm^4]	0.00
⍰[U]	0.00
Ja [cm^4]	14.87
Vanaf [cm^4]	14.87
Jt [cm^4]	22.74
J- [cm^4]	0.03
iy [cm]	1.96
van [cm]	1.96
is [cm]	2.78
m [kg/m]	3.03

3 – interne balk



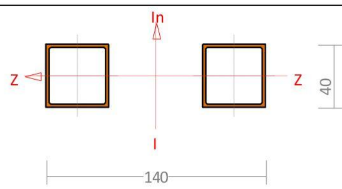
Materiaal:	S 235
A [cm^2]	7.86
Jij [cm^4]	45.31
Jz [cm^4]	80.12
Dyz [cm^4]	0.00
⍰[U]	90.00
Ja [cm^4]	80.12
Vanaf [cm^4]	45.31
Jt [cm^4]	22.20
J- [cm^4]	0.00
iy [cm]	3.19
van [cm]	2.40
is [cm]	3.99
m [kg/m]	6.17

4 – externe balk



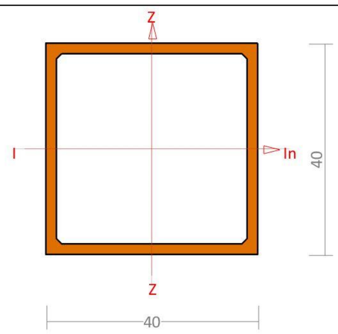
Materiaal:	S 235
A [cm^2]	4.00
Jij [cm^4]	4.50
Jz [cm^4]	65.25
Dyz [cm^4]	0.00
⍰[U]	90.00
Ja [cm^4]	65.25
Dat [cm^4]	4.50
Jt [cm^4]	0.08
J- [cm^4]	0.00
iy [cm]	4.04
van [cm]	1.06
is [cm]	4.18

5 - 2x H 40x40x2



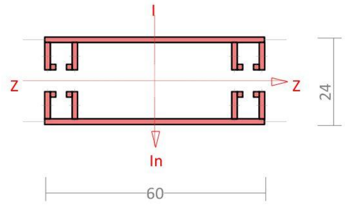
Materiaal:	S 235
A [cm^2]	6.12
Jij [cm^4]	14.80
Jz [cm^4]	167.80
Dyz [cm^4]	0.00
⍰[U]	90.00
Ja [cm^4]	167.80
Vanaf [cm^4]	14.80
Jt [cm^4]	21.95
J- [cm^4]	0.00
iy [cm]	5.24
van [cm]	1.55
is [cm]	5.46

6 - H 40x40x2



Materiaal:	S 235
A [cm^2]	3.06
Jij [cm^4]	7.40
Jz [cm^4]	7.40
Dyz [cm^4]	0.00
⍰[U]	0.00
Ja [cm^4]	7.40
Vanaf [cm^4]	7.40
Jt [cm^4]	11.36
J- [cm^4]	0.02
iy [cm]	1.55
van [cm]	1.55
is [cm]	2.20

m [kg/m]	3.14	m [kg/m]	4.80	m [kg/m]	2.40
7 - U 60x15x2x2					



Materiaal:	aluminium PA4/6082	Materiaal:		Materiaal:	
A [cm^2]	2.88	A [cm^2]		A [cm^2]	
Jij [cm^4]	2.75	Jij [cm^4]		Jij [cm^4]	
Jz [cm^4]	12.58	Jz [cm^4]		Jz [cm^4]	
Dyz [cm^4]	0.00	Dyz [cm^4]		Dyz [cm^4]	
⍰[U]	-90.00	⍰[U]		⍰[U]	
Ja [cm^4]	12.58	Ja [cm^4]		Ja [cm^4]	
Dat [cm^4]	2.75	Vanaf [cm^4]		Vanaf [cm^4]	
Jt [cm^4]	0.02	Jt [cm^4]		Jt [cm^4]	
J- [cm^4]	0.00	J- [cm^4]		J- [cm^4]	
iy [cm]	2.09	iy [cm]		iy [cm]	
van [cm]	0.98	van [cm]		van [cm]	
is [cm]	2.31	is [cm]		is [cm]	
m [kg/m]	0.78	m [kg/m]		m [kg/m]	

Leden:

Nee, dat is niet waar.	Gewrichten: A:	B:	Conections	Gevoeligheid	Eccenrics Imperfekcje	Oriënteren. [u]	L[m]:	F [m]:	Profiel:
Artikel 1									
1	1	27	SP: stijf			0.0	1.730		1 H 60x60x2
2	3	25	SP: stijf			0.0	1.730		1 H 60x60x2
4	7	28	SP: stijf			0.0	1.730		1 H 60x60x2
5	10	24	SP: divers			0.0	1.730		1 H 60x60x2
7	13	26	SP: stijf			0.0	1.730		1 H 60x60x2
8	16	23	SP: stijf			0.0	1.730		1 H 60x60x2
44	24	9	SP: divers			0.0	0.430		1 H 60x60x2
45	28	8	SP: stijf			0.0	0.430		1 H 60x60x2
46	27	2	SP: stijf			0.0	0.430		1 H 60x60x2
47	25	4	SP: stijf			0.0	0.430		1 H 60x60x2
48	26	14	SP: stijf			0.0	0.430		1 H 60x60x2
49	23	15	SP: stijf			0.0	0.430		1 H 60x60x2

Artikel 2									
3	6	5	SP: stijf			0.0	2.060		6 H 40x40x2
6	12	11	SP: stijf			0.0	2.060		6 H 40x40x2

9	18	17	SP: stijf			0.0	2.060		6 H 40x40x2
18	22	60	A:yz			0.0	0.561	0.025	7 U 60x15x2x2
			SP: stijf						
19	21	45	A:yz			0.0	0.561	0.025	7 U 60x15x2x2
			SP: stijf						
20	33	48	A:yz			0.0	0.561	0.025	7 U 60x15x2x2
			SP: stijf						
21	35	51	A:yz			0.0	0.561	0.025	7 U 60x15x2x2
			SP: stijf						
22	37	57	A:yz			0.0	0.561	0.025	7 U 60x15x2x2
			SP: stijf						
23	40	54	A:yz			0.0	0.561	0.025	7 U 60x15x2x2
			SP: stijf						
26	43	19	B:yz			0.0	0.561	0.025	7 U 60x15x2x2
			SP: stijf						
27	44	43	SP: stijf			0.0	0.561	0.025	7 U 60x15x2x2
28	45	44	SP: stijf			0.0	0.561	0.025	7 U 60x15x2x2
29	46	34	B:yz			0.0	0.561	0.025	7 U 60x15x2x2
			SP: stijf						
30	47	46	SP: stijf			0.0	0.561	0.025	7 U 60x15x2x2
31	48	47	SP: stijf			0.0	0.561	0.025	7 U 60x15x2x2
32	49	36	B:yz			0.0	0.561	0.025	7 U 60x15x2x2
			SP: stijf						
33	50	49	SP: stijf			0.0	0.561	0.025	7 U 60x15x2x2
34	51	50	SP: stijf			0.0	0.561	0.025	7 U 60x15x2x2
35	52	39	B:yz			0.0	0.561	0.025	7 U 60x15x2x2
			SP: stijf						
36	53	52	SP: stijf			0.0	0.561	0.025	7 U 60x15x2x2
37	54	53	SP: stijf			0.0	0.561	0.025	7 U 60x15x2x2
38	55	38	B:yz			0.0	0.561	0.025	7 U 60x15x2x2
			SP: stijf						
39	56	55	SP: stijf			0.0	0.561	0.025	7 U 60x15x2x2
40	57	56	SP: stijf			0.0	0.561	0.025	7 U 60x15x2x2
41	58	20	B:yz			0.0	0.561	0.025	7 U 60x15x2x2
			SP: stijf						
42	59	58	SP: stijf			0.0	0.561	0.025	7 U 60x15x2x2
43	60	59	SP: stijf			0.0	0.561	0.025	7 U 60x15x2x2

Artikel 3									
10	19	13	SP: stijf			0.0	0.440		4 buitenste bout
11	21	16	SP: stijf			0.0	0.440		4 buitenste bout
50	10	22	SP: stijf			0.0	0.440		4 buitenste bout
51	13	7	SP: stijf			0.0	4.120		3 binnenbout
52	16	10	SP: stijf			0.0	4.120		3 binnenbout
53	7	20	SP: stijf			0.0	0.440		4 buitenste bout
Artikel 4									
12	23	25	SP: stijf			0.0	2.060		2 H 50x50x2
13	25	24	SP: stijf			1.9	2.060		2 H 50x50x2
14	26	27	SP: stijf			0.0	2.060		2 H 50x50x2

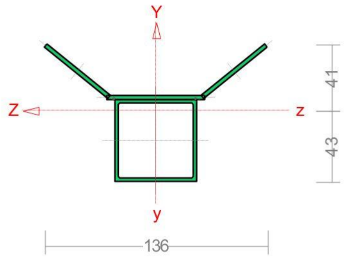
15	27	28	SP: stijf			0.0	2.060		2 H 50x50x2
16	29	42	A:yz B:yz			0.0	2.060		5 2x H 40x40x2
17	31	41	A:yz B:yz			-1.9	2.060		5 2x H 40x40x2
24	41	32	A:yz B:yz			-1.9	2.060		5 2x H 40x40x2
25	42	30	A:yz B:yz			0.0	2.060		5 2x H 40x40x2

4. Dimensioning of structural elements according to PN-EN 1993

Results acc. to EN 1993 (Stal1993_3d v. 1.85 license 33492, CadSIS)

4.1. Upper beam of the shed – member no. 51.

Profile: 3 – internal bar



Profile dimensions:
h=84,1 s=136,4.
Profile geometrical characteristics:
Iyg=80,1 Izg=45,3 A=7,86 iy=3,2 iz=2,4.
Material: **S 235**. Yield strength $\mathbf{f_y=235}$ MPa
and ultimate tensile stregth $\mathbf{f_u = 360}$ for **g=2,0**.

Member reducing buckling length:

Span Yc 5 (2,560;3,560)

Joint tractabilities determined by mechanic principles :

$\kappa_a = 0{,}396$ $\kappa_b = 0{,}426$ $\kappa_V = 0{,}068$ $\Rightarrow$ $\mu = 0{,}734$ for $l_o = 1{,}000$

$l_w = 0{,}734 \times 1{,}000 = 0{,}734$ m

Span Zc 4 (2,560;3,560)

Joint tractabilities determined by mechanic principles :

$\kappa_a = 0{,}803$ $\kappa_b = 0{,}904$ $\kappa_V = 0{,}652$ $\Rightarrow$ $\mu = 2{,}384$ for $l_o = 1{,}000$

$l_w = 2{,}384 \times 1{,}000 = 2{,}384$ m

Span ω 5 (2,560;3,560)

Reducing buckling length:

Y: $\kappa_a = 0{,}803$ $\kappa_b = 0{,}904$ $\kappa_V = 0{,}068$ $\Rightarrow$ $\mu = 2{,}384$ dla $l_o = 1{,}000$

$l_w = 2{,}384 \times 1{,}000 = 2{,}384$ m

Z: $\kappa_a = 0{,}396$ $\kappa_b = 0{,}426$ $\kappa_V = 0{,}652$ $\Rightarrow$ $\mu = 0{,}734$ dla $l_o = 1{,}000$

$l_w = 0{,}734 \times 1{,}000 = 0{,}734$ m

Critical forces:

$$N_{cr,y} = \frac{\pi^2 EI_y}{l_{wy}^2} = \frac{3{,}1416^2 \times 210 \times 80{,}1}{2{,}384^2} \times 10^{-2} = 292{,}2 \text{ kN}$$

$$N_{cr,z} = \frac{\pi^2 EI_z}{l_{wz}^2} = \frac{3{,}1416^2 \times 210 \times 45{,}3}{0{,}734^2} \times 10^{-2} = 1743{,}03 \text{ kN}$$

Warping:

Span no.: 4 (2,060;2,560)

The coordinate of loading applied point $a_o = 0{,}00$ cm. Difference between coordinates of shearing and forcing applied point $a_s = 0{,}00$ cm. Following parameters values of warping are accepted: $A_1 = 0{,}000$, $A_2 = 3{,}400$, $B = 4{,}100$.

$$A_o = A_1\, b_y + A_2\, a_s = 0{,}000 \times 0{,}00 + 3{,}400 \times 0{,}00 = 0{,}000$$

$$M_{cr} = \pm A_o\, N_{cr,z} + \sqrt{(A_o\, N_{cr,z})^2 + B^2\, i_s^2\, N_{cr,z} N_{cr,T}} =$$

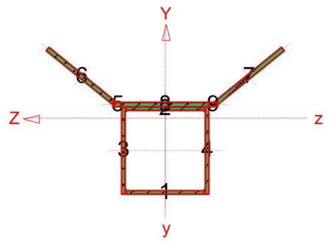
$$0{,}000 \times 866{,}56 + \sqrt{(0{,}000 \times 866{,}56)^2 + 4{,}100^2 \times 0{,}040^2 \times 866{,}56 \times \mathrm{INF}} = 0 \text{ kNm}$$

Load capacity.

xa = 4,120; xb = 0,000; Span no.: 6, 5, 6. Loads: OW+St+1,5·(W2+W4)

Following partial factors are accepted γ_M:

$\gamma_{M0} = 1$; $\gamma_{M1} = 1$; $\gamma_{M2} = 1{,}1$.



Profile class:

$$\varepsilon = \sqrt{235/f_y} = \sqrt{235/235} = 1{,}000$$

No.:	c [mm]	t [mm]	α	ψ	k_σ	$(c/t)_1$	$(c/t)_2$	$(c/t)_3$	c/t	Class
1	44,0	2,0	0,500	0,000	-	72,000	83,000	INF	22,000	1
2	44,0	2,0	0,500	-0,392	-	72,000	82,909	77,709	22,000	1
3	50,0	2,0	0,000	0,000	-	INF	INF	INF	25,000	
4	50,0	2,0	1,000	-1,574	-	33,000	38,000	200,252	25,000	1
5	5,0	2,5	1,000	0,000	0	9,000	10,000	INF	2,000	1
6	50,0	2,5	1,000	-3,264	-	33,000	38,000	477,642	20,000	1
7	50,0	2,5	1,000	0,309	-	33,000	38,000	54,415	20,000	1
8	50,0	2,5	1,000	-0,289	-	33,000	38,000	73,086	20,000	1
9	5,0	2,5	1,000	0,886	0,439	9,000	10,000	13,912	2,000	1

Profile fulfils the conditions of class section **1**.

Tensile strength capacity:

xa = 3,560; xb = 0,560; Span no.: 5, 4, 5. Loads: OW+St+1,5·(W1+W4)

Axial force: $N_{Ed} = 0{,}17$ kN

Profile surface area: $A = 7{,}86\ cm^2$

Weakening by holes: $A_o = 0{,}00\ cm^2$

Profile **net** surface area: $A_{net} = 7{,}86\ cm^2$

Profile tensile strength capacity:

- design plastic resistance

$$N_{pl,Rd} = \frac{A f_y}{\gamma_{M0}} = \frac{7{,}86 \times 235}{1} \times 10^{-1} = 184{,}71 \text{ kN} \qquad (6.6)$$

- design ultimate resistance

$$N_{u,Rd} = \frac{0{,}9\, A_{net}\, f_u}{\gamma_{M2}} = \frac{0{,}9 \times 7{,}86 \times 360}{1{,}1} \times 10^{-1} = 231{,}51 \text{ kN} \qquad (6.7)$$

Member has plastic deformation capacity ($N_{pl,Rd} < N_{u,Rd}$).

Tensile strength capacity:

$$N_{t,Rd} = N_{pl,Rd} = 184{,}71 \text{ kN}$$

Load capacity condition (6.5):

$$\frac{N_{Ed}}{N_{t,Rd}} = \frac{0{,}17}{184{,}71} = \mathbf{0{,}001 < 1} \qquad (6.5)$$

Compression strength capacity:

xa = 3,560; xb = 0,560; Span no.: 5, 4, 5. Loads: 1,35·(OW+St)+1,5·S3

Class section **1**.

Axial force: $N_{Ed} = -0{,}17$ kN

Profile surface area: $A = 7{,}86\ cm^2$

Profile effective surface area: $A_{eff} = 7{,}86\ cm^2$

Center of gravity shift: $e_{Ny} = 0{,}00$; $e_{Nz} = 0{,}00$ cm.

$$N_{c,Rd} = \frac{A f_y}{\gamma_{M0}} = \frac{7{,}86 \times 235}{1} \times 10^{-1} = 184{,}71 \text{ kN} \qquad (6.10)$$

Load capacity condition:

$$\frac{N_{Ed}}{N_{c,Rd}} = \frac{0{,}17}{184{,}71} = \mathbf{0{,}001 < 1} \qquad (6.9)$$

Stability of compressed element:

Buckling for axis Y (curve "d")	Buckling for axis Z (curve "d")	Buckling torsional (curve "d")
$\bar{\lambda} = \sqrt{\frac{A_{eff}\, f_y}{N_{cr,y}}} = \sqrt{\frac{7{,}86\times235}{292{,}2\times10}}$ = 0,795 $\Phi = 0{,}5\left[1+\alpha(\bar{\lambda}-0{,}2)+\bar{\lambda}^2\right] =$ 0,5×[1+0,76×(0,795-0,2)+0,795^2] = 1,042 $\chi = \frac{1}{\Phi+\sqrt{\Phi^2-\bar{\lambda}^2}} = \frac{1}{1{,}042+\sqrt{1{,}042^2-0{,}795^2}}$ = 0,583	$\bar{\lambda} = \sqrt{\frac{A_{eff}\, f_y}{N_{cr,z}}} = \sqrt{\frac{7{,}86\times235}{1743{,}03\times10}}$ = 0,326 $\Phi = 0{,}5\left[1+\alpha(\bar{\lambda}-0{,}2)+\bar{\lambda}^2\right] =$ 0,5×[1+0,76×(0,326-0,2)+0,326^2] = 0,601 $\chi = \frac{1}{\Phi+\sqrt{\Phi^2-\bar{\lambda}^2}} = \frac{1}{0{,}601+\sqrt{0{,}601^2-0{,}326^2}}$ = 0,905	$\bar{\lambda} = \sqrt{\frac{A_{eff}\, f_y}{N_{cr,T}}} = \sqrt{\frac{7{,}86\times235}{INF\times10}}$ = 0,000 $\Phi = 0{,}5\left[1+\alpha(\bar{\lambda}-0{,}2)+\bar{\lambda}^2\right] =$ 0,5×[1+0,76×(0,000-0,2)+0,000^2] = 0,424 $\chi = \frac{1}{\Phi+\sqrt{\Phi^2-\bar{\lambda}^2}} = \frac{1}{0{,}424+\sqrt{0{,}424^2-0{,}000^2}}$ = 1,179
It is accepted χ = 0,583 ≤ 1	it is accepted χ = 0,905 ≤ 1	it is accepted χ = 1,000 ≤ 1

Lowest coefficient value is accepted χ = 0,583

$$N_{b,Rd} = \frac{\chi A\, f_y}{\gamma_{M1}} = \frac{0{,}583\times7{,}86\times235}{1}\times10^{-1} = 107{,}64 \text{ kN} \qquad (6.47)$$

Stability condition:

$$\frac{N_{Ed}}{N_{b,Rd}} = \frac{0{,}17}{107{,}64} = \mathbf{0{,}002 < 1} \qquad (6.46)$$

Tortion (capacity of profile):

xa = 4,120; xb = 0,000; Span no.: 6, 5, 6. Loads: OW+St+1,5·(W2+W4)

Stresses from torsion:

$$W_t = \frac{J_t}{t_{max}} = \qquad = 0{,}00 \text{ cm}^3$$

$WyrWt$

$$T_{Rd} = \frac{W_t\, f_y}{\sqrt{3}\,\gamma_{M0}} = \frac{0{,}00\times235}{1{,}732\times1}\times10^{-3} = 0{,}00 \text{ kNm}$$

$$\frac{T_{Ed}}{T_{Rd}} = \frac{0{,}02}{0{,}00} = \qquad (6.23)$$

Shearing (capacity of profile):

xa = 2,060; xb = 2,060; Span no.: 4, 3, 4. Loads: 1,35·(OW+St)+1,5·S3

- along axis Z

$$V_{pl,Rd} = \frac{A_v(f_y/\sqrt{3})}{\gamma_{M0}} = \frac{6{,}78\times235/1{,}732}{1}\times10^{-1} = 92{,}03 \text{ kN}$$

load capacity condition:

$$\frac{V_{Ed}}{V_{c,Rd}} = \frac{2{,}39}{92{,}03} = \mathbf{0{,}026 < 1}$$

- along axis Y

$$V_{pl,Rd} = \frac{A_v(f_y/\sqrt{3})}{\gamma_{M0}} = \frac{3{,}78\times235/1{,}732}{1}\times10^{-1} = 51{,}3 \text{ kN}$$

load capacity condition:

$$\frac{V_{Ed}}{V_{c,Rd}} = \frac{2{,}38}{51{,}30} = \mathbf{0{,}046 < 1}$$

For material with field strength 235 MPa, η = 1,2 is accepted.

Acc. to p. 5.1(2) EN 1993-1-5 shear buckling condition doesn't have to be checked:

h_w / t_w = 50,0/2,0 = **25,000 < 59,700** = 72×1,000/1,200 = 72 ε / η

Bending (capacity of profile):

xa = 2,060; xb = 2,060; Span no.: 4, 3, 4. Loads: 1,35·(OW+St)+1,5·S3

Class section **1**.

Bending capacity for axis Y:

$$M_{c,Rd} = M_{pl,Rd} = \frac{W_{pl}\, f_y}{\gamma_{M0}} = \frac{21{,}21\times235}{1}\times10^{-3} = 4{,}98 \text{ kNm}$$

Bending capacity for axis Z:

$$M_{c,Rd} = M_{pl,Rd} = \frac{W_{pl}\, f_y}{\gamma_{M0}} = \frac{14{,}19 \times 235}{1} \times 10^{-3} = 3{,}33 \text{ kNm}$$

Reduced bending capacity:

$n = N_{Ed} / N_{pl,Rd} = 0{,}17 / 184{,}71 = 0{,}001$; it is accepted $n = 0{,}001 \le 1$;

For any kind of section it is accepted:

$$M_{N,y,Rd} = M_{pl,y,Rd}\,(1 - n) = 4{,}98 \times (1 - 0{,}001) = 4{,}98 \text{ kNm}$$
$$M_{N,z,Rd} = M_{pl,z,Rd}\,(1 - n) = 3{,}33 \times (1 - 0{,}001) = 3{,}33 \text{ kNm}$$

Condition for load capacity:

$$\left[\frac{M_{y,Ed}}{M_{N,y,Rd}}\right]^{\alpha} + \left[\frac{M_{z,Ed}}{M_{N,z,Rd}}\right]^{\beta} = \left[\frac{0{,}98}{4{,}98}\right]^{1} + \left[\frac{0{,}94}{3{,}33}\right]^{1} = \mathbf{0{,}479 < 1} \qquad (6.41)$$

Load capacity estimate (not a critical condition):

$$\frac{N_{Ed}}{N_{Rd}} + \frac{M_{y,Ed}}{M_{y,Rd}} + \frac{M_{z,Ed}}{M_{z,Rd}} = \frac{0{,}17}{184{,}71} + \frac{0{,}98}{4{,}98} + \frac{0{,}94}{3{,}33} = \mathbf{0{,}479 < 1} \qquad (6.2)$$

Bending with compression (stability) (capacity of member):

Span no.: 4, 3, 4. Loads: 1,35·(OW+St)+1,5·S3

Interaction factors acc. to method 2:

$C_{my} = 0{,}9$ – sway buckling mode.

$C_{mz} = 0{,}9$ - sway buckling mode.

$$k_{yy} = C_{my}\left(1 + (\bar{\lambda}_y - 0{,}2)\frac{N_{Ed}}{\chi_y N_{Rk} / \gamma_{M1}}\right) = 0{,}900 \times \left(1 + (0{,}785 - 0{,}2) \times \frac{0{,}17}{0{,}589 \times 184{,}71/1}\right) = 0{,}901$$

it is accepted $k_{yy} = \mathbf{0{,}901} \le 0{,}901 = 0{,}900 \times \left(1 + 0{,}8 \times \frac{0{,}17}{0{,}589 \times 184{,}71/1}\right) = C_{my}\left(1 + 0{,}8\frac{N_{Ed}}{\chi_y N_{Rk} / \gamma_{M1}}\right)$

$$k_{zz} = C_{mz}\left(1 + (2\bar{\lambda}_z - 0{,}6)\frac{N_{Ed}}{\chi_z N_{Rk} / \gamma_{M1}}\right) = 0{,}900 \times \left(1 + (2 \times 0{,}462 - 0{,}6) \times \frac{0{,}17}{0{,}806 \times 184{,}71/1}\right) = 0{,}900$$

it is accepted $k_{zz} = \mathbf{0{,}900} \le 0{,}901 = 0{,}900 \times \left(1 + 1{,}4 \times \frac{0{,}17}{0{,}806 \times 184{,}71/1}\right) = C_{mz}\left(1 + 1{,}4\frac{N_{Ed}}{\chi_z N_{Rk} / \gamma_{M1}}\right)$

$$k_{yz} = 0{,}6\, k_{zz} = 0{,}6 \times 0{,}900 = 0{,}540$$
$$k_{zy} = 0{,}6\, k_{yy} = 0{,}6 \times 0{,}901 = 0{,}540$$

Load capacity conditions :

$$\frac{N_{Ed}}{\chi_y N_{Rk} / \gamma_{M1}} + k_{yy}\frac{M_{y,Ed} + \Delta M_{y,Ed}}{\chi_{LT} M_{y,Rk} / \gamma_{M1}} + k_{yz}\frac{M_{z,Ed} + \Delta M_{z,Ed}}{M_{z,Rk} / \gamma_{M1}} = \frac{0{,}17}{0{,}589 \times 184{,}71/1} + 0{,}901 \times \frac{0{,}98+0}{1{,}000 \times 4{,}98/1} +$$
$$0{,}540 \times \frac{0{,}94+0}{3{,}33/1} = \mathbf{0{,}331 < 1} \qquad (6.61)$$

$$\frac{N_{Ed}}{\chi_z N_{Rk} / \gamma_{M1}} + k_{zy}\frac{M_{y,Ed} + \Delta M_{y,Ed}}{\chi_{LT} M_{y,Rk} / \gamma_{M1}} + k_{zz}\frac{M_{z,Ed} + \Delta M_{z,Ed}}{M_{z,Rk} / \gamma_{M1}} = \frac{0{,}17}{0{,}806 \times 184{,}71/1} + 0{,}540 \times \frac{0{,}98+0}{1{,}000 \times 4{,}98/1} +$$
$$0{,}900 \times \frac{0{,}94+0}{3{,}33/1} = \mathbf{0{,}361 < 1} \qquad (6.62)$$

Vervormingen:

Span no.: 3, 3, 3. Belastingen: OW+St+S3 Karakteristieke combinatie

Vervorming in as Z berekend op basis van lidakkoord is gelijk: een_{max} = 0,1 mm a_{gr} = l / 250 = 500 / 250 = 2,0 mm a_{max} = **0,1 < 2,0** = a_{gr}

Vervorming in as Y berekend op basis van lidakkoord is equal: een_{max} = 0,5 mm a_{gr} = l / 250 = 1000 / 250 = 4,0 mm a_{max} = **0,5 < 4,0** = a_{gr}

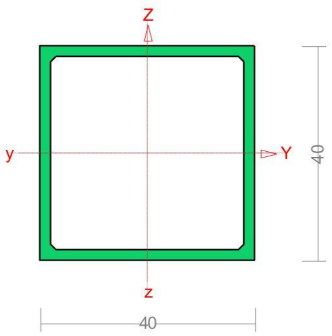
De grootste resulterende vervorming is gelijk aan:

a - 0,489 mm; L/a - 500,0 / 0,489 - 1022,1

4.2. Bracing beam- member no. 3.

Profiles: 6 - H 40x40x2

Profile dimensions:



h=40,0 s=40,0 g=2,0 t=2,0 vy=1,0 vz=1,0 r=2,9.

Profile geometrical characteristics:

Iyg=7,4 Izg=7,4 A=3,06 iy=1,6 iz=1,6 Iw=0,0 It=11,4 is=2,2.

Material: **S 235**. Yield strength **f_y=235** MPa and ultimate tensile stregth **f_u = 360** for **g=2,0**.

Member reducing buckling length:

Span Yc

Joint tractabilities determined by mechanic principles :

$\kappa_a = 0{,}199$ $\kappa_b = 0{,}199$ unmovable joints $\Rightarrow$ $\mu = 0{,}552$ for $l_o = 2{,}060$

$l_w = 0{,}552 \times 2{,}060 = 1{,}137$ m

Span Zc

Joint tractabilities determined by mechanic principles :

$\kappa_a = 0{,}121$ $\kappa_b = 0{,}121$ $\kappa_V = 0{,}020$ $\Rightarrow$ $\mu = 0{,}524$ for $l_o = 2{,}060$

$l_w = 0{,}524 \times 2{,}060 = 1{,}079$ m

Span ω

For torsional buckling a buckling length coefficient is accepted $\mu_\omega = 1{,}000$. Spacing of the security bracing against the turning $l_{o\omega} = 2{,}060$ m. Reduced buckling length $l_\omega = 2{,}060$ m.

Critical forces:

$$N_{cr,y} = \frac{\pi^2 EI_y}{l_{wy}^2} = \frac{3{,}1416^2 \times 210 \times 7{,}4}{1{,}137^2} \times 10^{-2} = 118{,}6 \text{ kN}$$

$$N_{cr,z} = \frac{\pi^2 EI_z}{l_{wz}^2} = \frac{3{,}1416^2 \times 210 \times 7{,}4}{1{,}079^2} \times 10^{-2} = 131{,}61 \text{ kN}$$

$$N_{cr,T} = \frac{1}{i_s^2}\left(\frac{\pi^2 EI_\varpi}{l_\varpi^2} + GI_T\right) = \frac{1}{2{,}20^2} \times \left(\frac{3{,}1416^2 \times 210 \times 0{,}0152}{2{,}060^2} \times 10^{-2} + 81 \times 11{,}4 \times 10^2\right) = 19034{,}89 \text{ kN}$$

Warping:

The coordinate of loading applied point $a_o = 0{,}00$ cm. Difference between coordinates of shearing and forcing applied point $a_s = 0{,}00$ cm. Following parameters values of warping are accepted: $A_1 = 0{,}000$, $A_2 = 0{,}000$, B = 0,000.

$A_o = A_1 b_y + A_2 a_s = 0{,}000 \times 0{,}00 + 0{,}000 \times 0{,}00 = 0{,}000$

$$M_{cr} = \pm A_o N_{cr,z} + \sqrt{(A_o N_{cr,z})^2 + B^2 i_s^2 N_{cr,z} N_{cr,T}} =$$

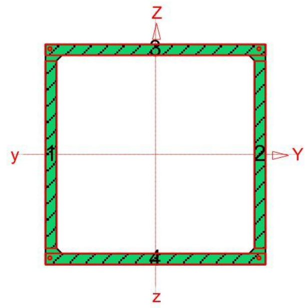
$$0{,}000 \times 131{,}61 + \sqrt{(0{,}000 \times 131{,}61)^2 + 0{,}000^2 \times 0{,}022^2 \times 131{,}61 \times 19034{,}89} = 0 \text{ kNm}$$

Load capacity.

xa = 2,060; xb = 0,000; Span no.: 1, 1, 1. Loads: OW+St+1,5·(W2+W4)

Following partial factors are accepted γ_M:

$\gamma_{M0} = 1$; $\gamma_{M1} = 1$; $\gamma_{M2} = 1{,}1$.



Profile class:

$$\varepsilon = \sqrt{235/f_y} = \sqrt{235/235} = 1{,}000$$

No.:	c [mm]	t [mm]	α	ψ	k_σ	$(c/t)_1$	$(c/t)_2$	$(c/t)_3$	c/t	Class
1	34,0	2,0	1,000	-0,606	-	33,000	38,000	89,347	17,000	1
2	34,0	2,0	0,544	-0,957	-	65,201	75,080	118,588	17,000	1
3	40,0	2,0	0,538	0,000	-	66,138	76,159	INF	20,000	1
4	40,0	2,0	1,000	0,828	-	33,000	38,000	44,525	20,000	1

Profile fulfils the conditions of class section **1**.

Tensile strength capacity:

xa = 2,060; xb = 0,000; Span no.: 1, 1, 1. Loads: 1,35·(OW+St)+1,5·S3

Axial force: N_{Ed} = 4,96 kN

Profile surface area: A = 3,06 cm^2

Weakening by holes: A_o= 0,00 cm^2

Profile **net** surface area: A_{net}= 3,06 cm^2

Profile tensile strength capacity:

- design plastic resistance

$$N_{pl,Rd} = \frac{A\,f_y}{\gamma_{M0}} = \frac{3{,}06\times 235}{1}\times 10^{-1} = 71{,}91\text{ kN} \qquad (6.6)$$

- design ultimate resistance

$$N_{u,Rd} = \frac{0{,}9\,A_{net}\,f_u}{\gamma_{M2}} = \frac{0{,}9\times 3{,}06\times 360}{1{,}1}\times 10^{-1} = 90{,}13\text{ kN} \qquad (6.7)$$

Member has plastic deformation capacity ($N_{pl,Rd}<N_{u,Rd}$).

Tensile strength capacity:

$$N_{t,Rd} = N_{pl,Rd} = 71{,}91\text{ kN}$$

Load capacity condition (6.5):

$$\frac{N_{Ed}}{N_{t,Rd}} = \frac{4{,}96}{71{,}91} = \mathbf{0{,}069 < 1} \qquad (6.5)$$

Compression strength capacity:

xa = 2,060; xb = 0,000; Span no.: 1, 1, 1. Loads: OW+St+1,5·(W1+W4)

Class section **1**.

Axial force: N_{Ed} = -3,33 kN

Profile surface area: A = 3,06 cm^2

Profile effective surface area: A_{eff} = 3,06 cm^2

Center of gravity shift: e_{Ny} = 0,00; e_{Nz} = 0,00 cm.

$$N_{c,Rd} = \frac{A\,f_y}{\gamma_{M0}} = \frac{3{,}06\times 235}{1}\times 10^{-1} = 71{,}91\text{ kN} \qquad (6.10)$$

Load capacity condition:

$$\frac{N_{Ed}}{N_{c,Rd}} = \frac{3{,}33}{71{,}91} = \mathbf{0{,}046 < 1} \qquad (6.9)$$

Stability of compressed element:

Buckling for axis Y (curve "c")	Buckling for axis Z (curve "c")	Buckling torsional (curve "c")
$\bar{\lambda} = \sqrt{\frac{A_{eff}\,f_y}{N_{cr,y}}} = \sqrt{\frac{3{,}06\times235}{118{,}6\times10}}$ = 0,779 $\Phi = 0{,}5\left[1+\alpha(\bar{\lambda}-0{,}2)+\bar{\lambda}^2\right] =$ 0,5×[1+0,49×(0,779-0,2)+0,779²] = 0,945 $\chi = \frac{1}{\Phi+\sqrt{\Phi^2-\bar{\lambda}^2}} = \frac{1}{0{,}945+\sqrt{0{,}945^2-0{,}779^2}} =$ 0,676	$\bar{\lambda} = \sqrt{\frac{A_{eff}\,f_y}{N_{cr,z}}} = \sqrt{\frac{3{,}06\times235}{131{,}61\times10}}$ = 0,739 $\Phi = 0{,}5\left[1+\alpha(\bar{\lambda}-0{,}2)+\bar{\lambda}^2\right] =$ 0,5×[1+0,49×(0,739-0,2)+0,739²] = 0,905 $\chi = \frac{1}{\Phi+\sqrt{\Phi^2-\bar{\lambda}^2}} = \frac{1}{0{,}905+\sqrt{0{,}905^2-0{,}739^2}} =$ 0,700	$\bar{\lambda} = \sqrt{\frac{A_{eff}\,f_y}{N_{cr,T}}} = \sqrt{\frac{3{,}06\times235}{19034{,}89\times10}}$ = 0,0615 $\Phi = 0{,}5\left[1+\alpha(\bar{\lambda}-0{,}2)+\bar{\lambda}^2\right] =$ 0,5×[1+0,49×(0,0615-0,2)+0,061²] = 0,468 $\chi = \frac{1}{\Phi+\sqrt{\Phi^2-\bar{\lambda}^2}} = \frac{1}{0{,}468+\sqrt{0{,}468^2-0{,}0615^2}} =$ 1,073
It is accepted χ = 0,676 ≤ 1	it is accepted χ = 0,700 ≤ 1	it is accepted χ = 1,000 ≤ 1

Lowest coefficient value is accepted χ = 0,676

$$N_{b,Rd} = \frac{\chi A f_y}{\gamma_{M1}} = \frac{0{,}676\times3{,}06\times235}{1}\times10^{-1} = 48{,}58\ \text{kN} \qquad (6.47)$$

Stability condition:

$$\frac{N_{Ed}}{N_{b,Rd}} = \frac{3{,}33}{48{,}58} = \mathbf{0{,}069 < 1} \qquad (6.46)$$

Shearing (capacity of profile):

xa = 2,060; xb = 0,000; Span no.: 1, 1, 1. Loads: 1,35·(OW+St)+1,5·(S2+W1+W4)

- along axis Z

$$V_{pl,Rd} = \frac{A_v(f_y/\sqrt{3})}{\gamma_{M0}} = \frac{1{,}44\times235/1{,}732}{1}\times10^{-1} = 19{,}54\ \text{kN}$$

load capacity condition:

$$\frac{V_{Ed}}{V_{c,Rd}} = \frac{0{,}54}{19{,}54} = \mathbf{0{,}028 < 1}$$

- along axis Y

$$V_{pl,Rd} = \frac{A_v(f_y/\sqrt{3})}{\gamma_{M0}} = \frac{1{,}73\times235/1{,}732}{1}\times10^{-1} = 23{,}45\ \text{kN}$$

load capacity condition:

$$\frac{V_{Ed}}{V_{c,Rd}} = \frac{0{,}00}{23{,}45} = \mathbf{0{,}000 < 1}$$

For material with field strength 235 MPa, η = 1,2 is accepted.
Acc. to p. 5.1(2) EN 1993-1-5 shear buckling condition doesn't have to be checked:
h_w / t_w = 40,0/2,0 = **20,000 < 59,705** = 72×1,000/1,200 = 72 ε / η

Bending (capacity of profile):

xa = 2,060; xb = 0,000; Span no.: 1, 1, 1. Loads: 1,35·(OW+St)+1,5·(S3+W1+W3)
Class section **1**.

Bending capacity for axis Y:

$$M_{c,Rd} = M_{pl,Rd} = \frac{W_{pl} f_y}{\gamma_{M0}} = \frac{4{,}37\times235}{1}\times10^{-3} = 1{,}03\ \text{kNm}$$

Bending capacity for axis Z:

$$M_{c,Rd} = M_{pl,Rd} = \frac{W_{pl} f_y}{\gamma_{M0}} = \frac{4{,}37\times235}{1}\times10^{-3} = 1{,}03\ \text{kNm}$$

Reduced bending capacity:

$n = N_{Ed} / N_{pl,Rd}$ = 1,90 / 71,91 = 0,026; it is accepted n =0,026 ≤ 1;

For rectangular tubes and bisymetrical box-profiles:

$a_w = (A- 2\,b\,t_f)/A$ = (3,06-2×4,00×0,20)/3,06 = 0,477; assumed a_w = 0,477 ≤ 0,5
$a_f = (A- 2\,h\,t_w)/A$ = (3,06-2×4,00×0,20)/3,06 = 0,477; assumed a_f = 0,477 ≤ 0,5
$M_{N,y,Rd} = M_{pl,y,Rd}\,(1 – n)/(1 – 0{,}5a_w)$ = 1,03×(1-0,026)/(1-0,5×0,477) = 1,31 (6.39)
but $M_{N,y,Rd} \le M_{pl,y,Rd}$, przyjęto $M_{N,y,Rd}$ = 1,03 kNm
$M_{N,z,Rd} = M_{pl,z,Rd}\,(1 – n)/(1 – 0{,}5a_f)$ = 1,03×(1-0,026)/(1-0,5×0,477) = 1,31; (6.40)
but $M_{N,z,Rd} \le M_{pl,z,Rd}$, przyjęto $M_{N,z,Rd}$ = 1,03 kNm
Linear condition for load capacity:

$$\left\{\left[\frac{M_{y,Ed}}{M_{N,y,Rd}}\right]^{\alpha}+\left[\frac{M_{z,Ed}}{M_{N,z,Rd}}\right]^{\beta}\right\}^{1/\gamma}=\left\{\left[\frac{0,57}{1,03}\right]^{1,66}+\left[\frac{0}{1,03}\right]^{1,66}\right\}^{1/1,66} = 0,376^{1/1,66} = \mathbf{0,555 < 1} \qquad (6.41)$$

Load capacity estimate (not a critical condition):

$$\frac{N_{Ed}}{N_{Rd}}+\frac{M_{y,Ed}}{M_{y,Rd}}+\frac{M_{z,Ed}}{M_{z,Rd}}=\frac{1,9}{71,91}+\frac{0,57}{1,03}+\frac{0}{1,03} = \mathbf{0,582 < 1} \qquad (6.2)$$

Bending with compression (stability) (capacity of member):

Span no.: 1, 1, 1. Loads: OW+St+1,5·(W1+W4)

Interaction factors acc. to method 1:

$C_{my,0} = 0,79 + 0,21\ \psi_y + 0,36\ (\psi_y - 0,33)\ N_{Ed} / N_{cr,y} = 0,79+0,21\times-0,926+0,36\times(-0,926-0,33)\times 3,33/118,60 = 0,583$

$C_{mz,0} = 1 + 0,03\ N_{Ed} / N_{cr,z} = 1+0,03\times 3,33/131,61 = 1,001$

$C_1 = k_c^{-2} = 0,611^{-2} = 2,675$

$$\bar{\lambda}_0=\sqrt{\frac{W_y f_y}{M_{cr}}}=\sqrt{\frac{4,37\times235}{34,81}\times10^{-3}} = 0,172 < 0,325 = 0,2\times\sqrt{2,675}\times\sqrt[4]{1-\frac{3,33}{131,61}}\times\sqrt[4]{1-\frac{3,33}{19034,89}} =$$

$$0,2\sqrt{C_1}\sqrt[4]{\left(1-\frac{N_{Ed}}{N_{cr,z}}\right)\left(1-\frac{N_{Ed}}{N_{cr,TF}}\right)}$$

$C_{my} = C_{my,0} = 0,583$

$C_{mz} = C_{mz,0} = 1,001$

$C_{mLT} = 1,0$

$w_y = W_{pl,y} / W_{el,y} = 4,37 / 3,70 = 1,181$ it is accepted $w_y = \mathbf{1,181} \leq 1,5$

$w_z = W_{pl,z} / W_{el,z} = 4,37 / 3,70 = 1,182$ it is accepted $w_z = \mathbf{1,182} \leq 1,5$

$n_{pl} = N_{Ed} / (N_{Rk}/\gamma_{M0}) = 3,33 / (71,91/1) = 0,0463$

$$b_{LT}=0,5a_{LT}\bar{\lambda}_0^2\frac{M_{y,Ed}}{\chi_{LT}M_{pl,y,Rd}}\frac{M_{z,Ed}}{M_{pl,z,Rd}}=0,5\times-0,536\times0,172^2\times\frac{0,53\times0,00}{1,000\times1,03\times1,03} = 0,000$$

$$C_{yy}=1+(w_y-1)\left[\left(2-\frac{1,6}{w_y}C_{my}^2\bar{\lambda}_{max}-\frac{1,6}{w_y}C_{my}^2\bar{\lambda}_{max}^2\right)n_{pl}-b_{LT}\right] = 1+(1,181-1)\times\left[\left(2-\frac{1,6}{1,181}\times0,583^2\times0,779\right.\right.$$

$$\left.\left.-\frac{1,6}{1,181}\times0,583^2\times0,779^2\right)\times0,0463-0,000\right] = 1,011$$

it is accepted $C_{yy} = \mathbf{1,011} \geq 0,847 = 3,70 / 4,37 = W_{el,y} / W_{pl,y}$

$$c_{LT}=10a_{LT}\frac{\bar{\lambda}_0^2}{5+\bar{\lambda}_z^4}\frac{M_{y,Ed}}{C_{my}\chi_{LT}M_{pl,y,Rd}} = 10\times-0,536\times\frac{0,172^2\times0,53}{(5+0,739^4)\times0,583\times1,000\times1,03} = -0,026$$

$$C_{yz}=1+(w_z-1)\left[\left(2-14\frac{C_{mz}^2\bar{\lambda}_{max}^2}{w_z^5}\right)n_{pl}-c_{LT}\right] = 1+(1,182-1)\times\left[\left(2-14\times\frac{1,001^2\times0,779^2}{1,182^5}\right)\times0,0463--0,026\right] =$$

0,991

it is accepted $C_{yz} = \mathbf{0,991} \geq 0,508 = 0,6\times\sqrt{\frac{1,182}{1,181}\times\frac{3,70}{4,371}} = 0,6\sqrt{\frac{w_z}{w_y}\frac{W_{el,z}}{W_{pl,z}}}$

$$d_{LT}=2a_{LT}\frac{\bar{\lambda}_0}{0,1+\bar{\lambda}_z^4}\frac{M_{y,Ed}}{C_{my}\chi_{LT}M_{pl,y,Rd}}\frac{M_{z,Ed}}{C_{mz}M_{pl,z,Rd}}=$$

$$2\times-0,536\times\frac{0,172^2\times0,53\times0,00}{(0,1+0,739^4)\times0,583\times1,000\times1,03\times1,001\times1,03} = 0,000$$

$$C_{zy} = 1 + (w_y - 1)\left[\left(2 - 14\frac{C_{my}^2\bar{\lambda}_{max}^2}{w_y^5}\right)n_{pl} - d_{LT}\right] = 1+(1{,}181-1)\times\left[\left(2 - 14\times\frac{0{,}583^2\times0{,}779^2}{1{,}181^5}\right)\times0{,}0463-0{,}000\right] =$$

1,006

it is accepted C_{zy} = **1,006** $\geq 0{,}508 = 0{,}6\times\sqrt{\frac{1{,}181}{1{,}182}\times\frac{3{,}70}{4{,}367}} = 0{,}6\sqrt{\frac{w_y}{w_z}\frac{W_{el,y}}{W_{pl,y}}}$

$$e_{LT} = 1{,}7\,a_{LT}\frac{\bar{\lambda}_0}{0{,}1+\bar{\lambda}_z^4}\frac{M_{y,Ed}}{C_{my}\chi_{LT}M_{pl,y,Rd}} = 1{,}7\times-0{,}536\times\frac{0{,}172\times0{,}53}{(0{,}1+0{,}739^4)\times0{,}583\times1{,}000\times1{,}03} = -0{,}348$$

$$C_{zz} = 1 + (w_z - 1)\left[2 - \frac{1{,}6}{w_z}C_{mz}^2\bar{\lambda}_{max} - \frac{1{,}6}{w_y}C_{mz}^2\bar{\lambda}_{max}^2 - e_{LT}\right]n_{pl} = 1+(1{,}182-1)\times\left[2 - \frac{1{,}6}{1{,}182}\times1{,}001^2\times0{,}779\right.$$

$$\left. - \frac{1{,}6}{1{,}181}\times1{,}001^2\times0{,}779^2 - -0{,}348\right]\times0{,}0463 = 1{,}004$$

it is accepted C_{zz} = **1,004** $\geq$ 0,846 = 3,70 / 4,37 = $W_{el,z} / W_{pl,z}$

$$\mu_y = \frac{1 - N_{Ed}/N_{cr,y}}{1 - \chi_y N_{Ed}/N_{cr,y}} = \frac{1 - 3{,}33/118{,}60}{1 - 0{,}676\times3{,}33/118{,}60} = 0{,}991$$

$$\mu_z = \frac{1 - N_{Ed}/N_{cr,z}}{1 - \chi_z N_{Ed}/N_{cr,z}} = \frac{1 - 3{,}33/131{,}61}{1 - 0{,}700\times3{,}33/131{,}61} = 0{,}992$$

$$k_{yy} = C_{my}C_{mLT}\frac{\mu_y}{1 - N_{Ed}/N_{Ncr,y}}\frac{1}{C_{yy}} = 0{,}583\times1{,}000\times\frac{0{,}991}{1-3{,}33/118{,}6}\times\frac{1}{1{,}011} = 0{,}588$$

$$k_{yz} = C_{mz}\frac{\mu_y}{1 - N_{Ed}/N_{Ncr,z}}\frac{0{,}6}{C_{yz}}\sqrt{\frac{w_z}{w_y}} = 1{,}001\times\frac{0{,}991}{1-3{,}33/131{,}61}\times\frac{0{,}6}{0{,}991}\times\sqrt{\frac{1{,}182}{1{,}181}} = 0{,}616$$

$$k_{zy} = C_{my}C_{mLT}\frac{\mu_z}{1 - N_{Ed}/N_{Ncr,y}}\frac{0{,}6}{C_{zy}}\sqrt{\frac{w_y}{w_z}} = 0{,}583\times1{,}000\times\frac{0{,}992}{1-3{,}33/118{,}6}\times\frac{0{,}6}{1{,}006}\times\sqrt{\frac{1{,}181}{1{,}182}} = 0{,}355$$

$$k_{zz} = C_{mz}\frac{\mu_z}{1 - N_{Ed}/N_{Ncr,z}}\frac{1}{C_{zz}} = 1{,}001\times\frac{0{,}992}{1-3{,}33/131{,}61}\times\frac{1}{1{,}004} = 1{,}015$$

Load capacity conditions :

$$\frac{N_{Ed}}{\chi_y N_{Rk}/\gamma_{M1}} + k_{yy}\frac{M_{y,Ed}+\Delta M_{y,Ed}}{\chi_{LT}M_{y,Rk}/\gamma_{M1}} + k_{yz}\frac{M_{z,Ed}+\Delta M_{z,Ed}}{M_{z,Rk}/\gamma_{M1}} = \frac{3{,}33}{0{,}676\times71{,}91/1} + 0{,}588\times\frac{0{,}53+0}{1{,}000\times1{,}03/1} +$$

$$0{,}616\times\frac{0+0}{1{,}03/1} = \mathbf{0{,}372 < 1} \quad (6.61)$$

$$\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}} + k_{zy}\frac{M_{y,Ed}+\Delta M_{y,Ed}}{\chi_{LT}M_{y,Rk}/\gamma_{M1}} + k_{zz}\frac{M_{z,Ed}+\Delta M_{z,Ed}}{M_{z,Rk}/\gamma_{M1}} = \frac{3{,}33}{0{,}700\times71{,}91/1} + 0{,}355\times\frac{0{,}53+0}{1{,}000\times1{,}03/1} +$$

$$1{,}015\times\frac{0+0}{1{,}03/1} = \mathbf{0{,}249 < 1} \quad (6.62)$$

Deformations:

Span no.: 1, 1, 1. Loads: OW+St+S2+W1+W3 Characteristic combination

Deformation in axis Z calculated from member chord is equal:

a_{max} = 2,2 mm

a_{gr} = l / 250 = 2060 / 250 = 8,2 mm

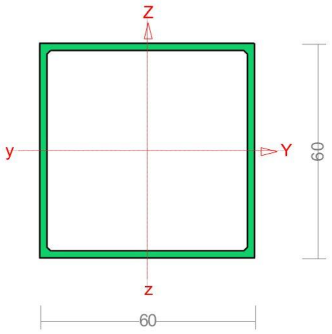
a_{max} = **2,2 < 8,2** = a_{gr}

Largest resultant deformation is equal:

a = 2,155 mm;   L / a = 2060,0 / 2,155 = 956,0

4.3. The lower part of the column - member no. 47.

Task: wiata_F3_STANDART EN.rm3
Profile: 1 - H 60x60x2



Profile dimensions:
h=60,0 s=60,0 g=2,0 t=2,0 vy=1,0 vz=1,0 r=2,9.
Profile geometrical characteristics:
Iyg=26,2 Izg=26,2 A=4,66 iy=2,4 iz=2,4 Iw=0,1 It=39,9 is=3,4.
Material: **S 235**. Yield strength **f_y=235** MPa
and ultimate tensile stregth **f_u = 360** for **g=2,0**.

Member reducing buckling length:

Span Yc

Joint tractabilities determined by mechanic principles :

κ_a = 0,844 κ_b = 0,000 κ_V = 0,897 ⇒ μ = 1,603 for l_o = 0,430

l_w = 1,603×0,430 = 0,689 m

Span Zc

Joint tractabilities determined by mechanic principles :

κ_a = 0,532 κ_b = 1,000 κ_V = 0,292 ⇒ μ = 1,620 for l_o = 0,430

l_w = 1,620×0,430 = 0,697 m

Span ω

For torsional buckling a buckling length coefficient is accepted μ_ω = 1,000. Spacing of the security bracing against the turning $l_{o\omega}$ = 0,430 m. Reduced buckling length l_ω = 0,430 m.

Critical forces:

$$N_{cr,y} = \frac{\pi^2 EI_y}{l_{wy}^2} = \frac{3,1416^2 \times 210 \times 26,2}{0,689^2} \times 10^{-2} = 1142,88 \text{ kN}$$

$$N_{cr,z} = \frac{\pi^2 EI_z}{l_{wz}^2} = \frac{3,1416^2 \times 210 \times 26,2}{0,697^2} \times 10^{-2} = 1119,02 \text{ kN}$$

$$N_{cr,T} = \frac{1}{i_s^2}\left(\frac{\pi^2 EI_\varpi}{l_\varpi^2} + GI_T\right) = \frac{1}{3,35^2} \times \left(\frac{3,1416^2 \times 210 \times 0,0567}{0,430^2} \times 10^{-2} + 81 \times 39,9 \times 10^2\right) = 28770,73 \text{ kN}$$

Warping:

The coordinate of loading applied point a_o = 0,00 cm. Difference between coordinates of shearing and forcing applied point a_s = 0,00 cm. Following parameters values of warping are accepted: A_1 = 0,000, A_2 = 0,000, B = 0,000.

$A_o = A_1\, b_y + A_2\, a_s$ = 0,000 ×0,00 + 0,000 ×0,00 = 0,000

$$M_{cr} = \pm A_o N_{cr,z} + \sqrt{(A_o N_{cr,z})^2 + B^2 i_s^2 N_{cr,z} N_{cr,T}} =$$

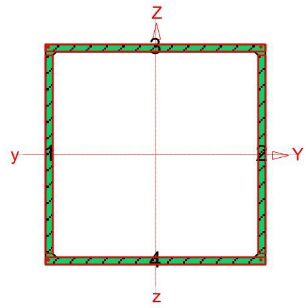
$$0,000 \times 1119,02 + \sqrt{(0,000 \times 1119,02)^2 + 0,000^2 \times 0,034^2 \times 1119,02 \times 28770,73} = 0 \text{ kNm}$$

Load capacity.

xa = 0,430; xb = 0,000; Span no.: 1, 1, 1. Loads: OW+St+1,5·(S3+W2+W4)

Following partial factors are accepted γ_M:

γ_{M0} = 1; γ_{M1} = 1; γ_{M2} = 1,1.



Profile class:

$$\varepsilon = \sqrt{235/f_y} = \sqrt{235/235} = 1{,}000$$

No.:	c [mm]	t [mm]	α	ψ	k_σ	$(c/t)_1$	$(c/t)_2$	$(c/t)_3$	c/t	Class
1	54,0	2,0	0,509	-0,964	-	70,458	81,133	119,377	27,000	1
2	54,0	2,0	0,509	-0,964	-	70,458	81,133	119,377	27,000	1
3	60,0	2,0	1,000	1,000	-	33,000	38,000	42,000	30,000	1
4	60,0	2,0	1,000	0,000	-	33,000	38,000	INF	30,000	1

Profile fulfils the conditions of class section **1**.

Tensile strength capacity:

xa = 0,027; xb = 0,403; Span no.: 1, 1, 1. Loads: OW+St+1,5·(W1+W4)

Axial force: N_{Ed} = 2,34 kN

Profile surface area: A = 4,66 cm^2

Weakening by holes: A_o= 0,00 cm^2

Profile **net** surface area: A_{net}= 4,66 cm^2

Profile tensile strength capacity:

- design plastic resistance

$$N_{pl,Rd} = \frac{A\, f_y}{\gamma_{M0}} = \frac{4{,}66 \times 235}{1} \times 10^{-1} = 109{,}51 \text{ kN} \qquad (6.6)$$

- design ultimate resistance

$$N_{u,Rd} = \frac{0{,}9\, A_{net}\, f_u}{\gamma_{M2}} = \frac{0{,}9 \times 4{,}66 \times 360}{1{,}1} \times 10^{-1} = 137{,}26 \text{ kN} \qquad (6.7)$$

Member has plastic deformation capacity ($N_{pl,Rd}$<$N_{u,Rd}$).

Tensile strength capacity:

$$N_{t,Rd} = N_{pl,Rd} = 109{,}51 \text{ kN}$$

Load capacity condition (6.5):

$$\frac{N_{Ed}}{N_{t,Rd}} = \frac{2{,}34}{109{,}51} = \mathbf{0{,}021 < 1} \qquad (6.5)$$

Compression strength capacity:

xa = 0,430; xb = 0,000; Span no.: 1, 1, 1. Loads: 1,35·(OW+St)+1,5·S2

Class section **1**.

Axial force: N_{Ed} = -5,83 kN

Profile surface area: A = 4,66 cm^2

Profile effective surface area: A_{eff} = 4,66 cm^2

Center of gravity shift: e_{Ny} = 0,00; e_{Nz} = 0,00 cm.

$$N_{c,Rd} = \frac{A\, f_y}{\gamma_{M0}} = \frac{4{,}66 \times 235}{1} \times 10^{-1} = 109{,}51 \text{ kN} \qquad (6.10)$$

Load capacity condition:

$$\frac{N_{Ed}}{N_{c,Rd}} = \frac{5{,}83}{109{,}51} = \mathbf{0{,}053 < 1} \qquad (6.9)$$

Stability of compressed element:

Buckling for axis Y (curve "c")	Buckling for axis Z (curve "c")	Buckling torsional (curve "c")
$\bar{\lambda} = \sqrt{\frac{A_{eff}\, f_y}{N_{cr,y}}} = \sqrt{\frac{4{,}66 \times 235}{1142{,}88 \times 10}} = 0{,}310$	$\bar{\lambda} = \sqrt{\frac{A_{eff}\, f_y}{N_{cr,z}}} = \sqrt{\frac{4{,}66 \times 235}{1119{,}02 \times 10}} = 0{,}313$	$\bar{\lambda} = \sqrt{\frac{A_{eff}\, f_y}{N_{cr,T}}} = \sqrt{\frac{4{,}66 \times 235}{28770{,}73 \times 10}} = 0{,}0617$

$\Phi = 0{,}5\left[1+\alpha(\bar\lambda-0{,}2)+\bar\lambda^2\right] =$ 0,5×[1+0,49×(0,310-0,2)+0,310^2] = 0,575 $\chi = \frac{1}{\Phi+\sqrt{\Phi^2-\bar\lambda^2}} = \frac{1}{0{,}575+\sqrt{0{,}575^2-0{,}310^2}}$ = 0,944	$\Phi = 0{,}5\left[1+\alpha(\bar\lambda-0{,}2)+\bar\lambda^2\right] =$ 0,5×[1+0,49×(0,313-0,2)+0,313^2] = 0,577 $\chi = \frac{1}{\Phi+\sqrt{\Phi^2-\bar\lambda^2}} = \frac{1}{0{,}577+\sqrt{0{,}577^2-0{,}313^2}}$ = 0,943	$\Phi = 0{,}5\left[1+\alpha(\bar\lambda-0{,}2)+\bar\lambda^2\right] =$ 0,5×[1+0,49×(0,0617-0,2)+0,062^2] = 0,468 $\chi = \frac{1}{\Phi+\sqrt{\Phi^2-\bar\lambda^2}} = \frac{1}{0{,}468+\sqrt{0{,}468^2-0{,}0617^2}}$ = 1,073
It is accepted χ = 0,944 ≤ 1	it is accepted χ = 0,943 ≤ 1	it is accepted χ = 1,000 ≤ 1

Lowest coefficient value is accepted χ = 0,943

$$N_{b,Rd} = \frac{\chi A f_y}{\gamma_{M1}} = \frac{0{,}943\times4{,}66\times235}{1}\times10^{-1} = 103{,}22\ \text{kN} \qquad (6.47)$$

Stability condition:

$$\frac{N_{Ed}}{N_{b,Rd}} = \frac{5{,}83}{103{,}22} = \mathbf{0{,}056 < 1} \qquad (6.46)$$

Tortion (capacity of profile):

xa = 0,430; xb = 0,000; Span no.: 1, 1, 1. Loads: OW+St+1,5·(S3+W2+W4)

Stresses from torsion:

$$W_t = J_t\left(\frac{t}{Fs}\right)_{min} = \quad \text{\$WyrWt\$} \quad = 13{,}45\ \text{cm}^3$$

$$T_{Rd} = \frac{W_t f_y}{\sqrt{3}\gamma_{M0}} = \frac{13{,}45\times235}{1{,}732\times1}\times10^{-3} = 1{,}82\ \text{kNm}$$

$$\frac{T_{Ed}}{T_{Rd}} = \frac{0{,}06}{1{,}82} = \mathbf{0{,}033 < 1} \quad (6.23)$$

Shearing (capacity of profile):

xa = 0,430; xb = 0,000; Span no.: 1, 1, 1. Loads: 1,35·(OW+St)+1,5·(S3+W1+W3)

- along axis Z

$$V_{pl,Rd} = \frac{A_v(f_y/\sqrt{3})}{\gamma_{M0}} = \frac{2{,}24\times235/1{,}732}{1}\times10^{-1} = 30{,}39\ \text{kN}$$

with torsion:

$$V_{pl,T,Rd} = \left[1-\frac{\tau_{t,Ed}}{(f_y/\sqrt{3})/\gamma_{M0}}\right]V_{pl,Rd} = 1 - \frac{0{,}0}{(235/1{,}732)/1}\times30{,}39 = 30{,}39\ \text{kN}$$

load capacity condition:

$$\frac{V_{Ed}}{V_{c,Rd}} = \frac{3{,}30}{30{,}39} = \mathbf{0{,}109 < 1}$$

- along axis Y

$$V_{pl,Rd} = \frac{A_v(f_y/\sqrt{3})}{\gamma_{M0}} = \frac{2{,}69\times235/1{,}732}{1}\times10^{-1} = 36{,}47\ \text{kN}$$

with torsion:

$$V_{pl,T,Rd} = \left[1-\frac{\tau_{t,Ed}}{(f_y/\sqrt{3})/\gamma_{M0}}\right]V_{pl,Rd} = 1 - \frac{0{,}0}{(235/1{,}732)/1}\times36{,}47 = 36{,}47\ \text{kN}$$

load capacity condition:

$$\frac{V_{Ed}}{V_{c,Rd}} = \frac{0{,}00}{36{,}47} = \mathbf{0{,}000 < 1}$$

For material with field strength 235 MPa, η = 1,2 is accepted.

Acc. to p. 5.1(2) EN 1993-1-5 shear buckling condition doesn't have to be checked:

h_w / t_w = 60,0/2,0 = **30,000 < 60,131** = 72×1,000/1,200 = 72 ε / η

Bending (capacity of profile):

xa = 0,430; xb = 0,000; Span no.: 1, 1, 1. Loads: 1,35·(OW+St)+1,5·(S2+W1+W3)

Class section **1**.

Bending capacity for axis Y:

$$M_{c,Rd} = M_{pl,Rd} = \frac{W_{pl}\, f_y}{\gamma_{M0}} = \frac{10{,}15\times 235}{1}\times 10^{-3} = 2{,}38 \text{ kNm}$$

Bending capacity for axis Z:

$$M_{c,Rd} = M_{pl,Rd} = \frac{W_{pl}\, f_y}{\gamma_{M0}} = \frac{10{,}15\times 235}{1}\times 10^{-3} = 2{,}39 \text{ kNm}$$

Reduced bending capacity:

$n = N_{Ed} / N_{pl,Rd} = 3{,}83 / 109{,}51 = 0{,}035;$ it is accepted $n = 0{,}035 \leq 1;$

For rectangular tubes and bisymetrical box-profiles:

$a_w = (A - 2\, b\, t_f)/A = (4{,}66-2\times 6{,}00\times 0{,}20)/4{,}66 = 0{,}485;$ przyjęto $a_w = 0{,}485 \leq 0{,}5$

$a_f = (A - 2\, h\, t_w)/A = (4{,}66-2\times 6{,}00\times 0{,}20)/4{,}66 = 0{,}485;$ przyjęto $a_f = 0{,}485 \leq 0{,}5$

$M_{N,y,Rd} = M_{pl,y,Rd}\,(1 - n)/(1 - 0{,}5a_w) = 2{,}38\times(1-0{,}035)/(1-0{,}5\times 0{,}485) = 3{,}04$ (6.39)

but $M_{N,y,Rd} \leq M_{pl,y,Rd}$, przyjęto $M_{N,y,Rd} = 2{,}38$ kNm

$M_{N,z,Rd} = M_{pl,z,Rd}\,(1 - n)/(1 - 0{,}5a_f) = 2{,}39\times(1-0{,}035)/(1-0{,}5\times 0{,}485) = 3{,}04;$ (6.40)

but $M_{N,z,Rd} \leq M_{pl,z,Rd}$, przyjęto $M_{N,z,Rd} = 2{,}39$ kNm

Linear condition for load capacity:

$$\left\{\left[\frac{M_{y,Ed}}{M_{N,y,Rd}}\right]^{\alpha} + \left[\frac{M_{z,Ed}}{M_{N,z,Rd}}\right]^{\beta}\right\}^{1/\gamma} = \left\{\left[\frac{2{,}31}{2{,}38}\right]^{1{,}66} + \left[\frac{0}{2{,}39}\right]^{1{,}66}\right\}^{1/1{,}66} = 0{,}949^{1/1{,}66} = \mathbf{0{,}969 < 1} \quad (6.41)$$

Load capacity estimate (not a critical condition):

$$\frac{N_{Ed}}{N_{Rd}} + \frac{M_{y,Ed}}{M_{y,Rd}} + \frac{M_{z,Ed}}{M_{z,Rd}} = \frac{3{,}83}{109{,}51} + \frac{2{,}31}{2{,}38} + \frac{0}{2{,}39} = \mathbf{1{,}004 > 1} \quad (6.2)$$

Bending with compression (stability) (capacity of member):

Span no.: 1, 1, 1. Loads: 1,35·(OW+St)+1,5·(S2+W1+W3)

Interaction factors acc. to method 1:

$$C_{my,0} = 0{,}79 + 0{,}21\,\psi_y + 0{,}36\,(\psi_y - 0{,}33)\,N_{Ed} / N_{cr,y} = 0{,}79+0{,}21\times 0{,}384+0{,}36\times(0{,}384-0{,}33)\times 3{,}83/1142{,}88 = 0{,}871$$

$$C_{mz,0} = 1 + 0{,}03\,N_{Ed} / N_{cr,z} = 1+0{,}03\times 3{,}83/1119{,}02 = 1{,}000$$

$$C_1 = k_c^{-2} = 0{,}831^{-2} = 1{,}448$$

$$\bar{\lambda}_0 = \sqrt{\frac{W_y f_y}{M_{cr}}} = \sqrt{\frac{10{,}15\times 235}{190{,}26}\times 10^{-3}} = 0{,}112 < 0{,}240 = 0{,}2\times\sqrt{1{,}448}\times\sqrt[4]{1 - \frac{3{,}83}{1119{,}02}}\times\sqrt[4]{1 - \frac{3{,}83}{28770{,}73}} =$$

$$0{,}2\sqrt{C_1}\sqrt[4]{\left(1-\frac{N_{Ed}}{N_{cr,z}}\right)\left(1-\frac{N_{Ed}}{N_{cr,TF}}\right)}$$

$$C_{my} = C_{my,0} = 0{,}871$$

$$C_{mz} = C_{mz,0} = 1{,}000$$

$$C_{mLT} = 1{,}0$$

$w_y = W_{pl,y} / W_{el,y} = 10{,}15 / 8{,}73 = 1{,}162$ it is accepted $w_y = \mathbf{1{,}162} \leq 1{,}5$

$w_z = W_{pl,z} / W_{el,z} = 10{,}15 / 8{,}73 = 1{,}162$ it is accepted $w_z = \mathbf{1{,}162} \leq 1{,}5$

$n_{pl} = N_{Ed} / (N_{Rk}/\gamma_{M0}) = 3{,}83 / (109{,}51/1) = 0{,}0350$

$$b_{LT} = 0{,}5\,a_{LT}\,\bar{\lambda}_0^2\,\frac{M_{y,Ed}}{\chi_{LT} M_{pl,y,Rd}}\,\frac{M_{z,Ed}}{M_{pl,z,Rd}} = 0{,}5\times -0{,}524\times 0{,}112^2\times\frac{2{,}31\times 0{,}00}{1{,}000\times 2{,}38\times 2{,}39} = 0{,}000$$

$$C_{yy} = 1 + (w_y - 1)\left[\left(2 - \frac{1{,}6}{w_y} C_{my}^2 \bar{\lambda}_{max} - \frac{1{,}6}{w_y} C_{my}^2 \bar{\lambda}_{max}^2\right) n_{pl} - b_{LT}\right] = 1+(1{,}162-1)\times\left[\left(2 - \frac{1{,}6}{1{,}162}\times 0{,}871^2\times 0{,}313\right.\right.$$

$$\left.\left. - \frac{1{,}6}{1{,}162}\times 0{,}871^2\times 0{,}313^2\right)\times 0{,}0350 - 0{,}000\right] = 1{,}009$$

it is accepted $C_{yy} = \mathbf{1{,}009} \geq 0{,}861 = 8{,}73 / 10{,}15 = W_{el,y} / W_{pl,y}$

$$c_{LT} = 10\,a_{LT}\,\frac{\bar{\lambda}_0^2}{5+\bar{\lambda}_z^4}\,\frac{M_{y,Ed}}{C_{my}\chi_{LT} M_{pl,y,Rd}} = 10\times -0{,}524\times\frac{0{,}112^2\times 2{,}31}{(5+0{,}313^4)\times 0{,}871\times 1{,}000\times 2{,}38} = -0{,}015$$

$$C_{yz} = 1 + (w_z - 1)\left[\left(2 - 14\frac{C_{mz}^2 \bar{\lambda}_{max}^2}{w_z^5}\right)n_{pl} - c_{LT}\right] = 1+(1{,}162-1)\times\left[\left(2 - 14\times\frac{1{,}000^{\ 2}\times 0{,}313^{\ 2}}{1{,}162^{\ 5}}\right)\times 0{,}0350\text{--}0{,}015\right] =$$

1,010

it is accepted C_{yz} = **1,010** $\geq 0{,}516 = 0{,}6\times\sqrt{\frac{1{,}162}{1{,}162}\times\frac{8{,}73}{10{,}151}} = 0{,}6\sqrt{\frac{w_z}{w_y}\frac{W_{el,z}}{W_{pl,z}}}$

$$d_{LT} = 2\,a_{LT}\frac{\bar{\lambda}_0}{0{,}1+\bar{\lambda}_z^4}\frac{M_{y,Ed}}{C_{my}\chi_{LT}M_{pl,y,Rd}}\frac{M_{z,Ed}}{C_{mz}M_{pl,z,Rd}} =$$

$$2\times\text{-}0{,}524\times\frac{0{,}112^{\ 2}\times 2{,}31\times 0{,}00}{(0{,}1+0{,}313^{\ 4})\times 0{,}871\times 1{,}000\times 2{,}38\times 1{,}000\times 2{,}39} = 0{,}000$$

$$C_{zy} = 1 + (w_y - 1)\left[\left(2 - 14\frac{C_{my}^2 \bar{\lambda}_{max}^2}{w_y^5}\right)n_{pl} - d_{LT}\right] = 1+(1{,}162-1)\times\left[\left(2 - 14\times\frac{0{,}871^{\ 2}\times 0{,}313^{\ 2}}{1{,}162^{\ 5}}\right)\times 0{,}0350\text{-}0{,}000\right] =$$

1,009

it is accepted C_{zy} = **1,009** $\geq 0{,}516 = 0{,}6\times\sqrt{\frac{1{,}162}{1{,}162}\times\frac{8{,}73}{10{,}147}} = 0{,}6\sqrt{\frac{w_y}{w_z}\frac{W_{el,y}}{W_{pl,y}}}$

$$e_{LT} = 1{,}7\,a_{LT}\frac{\bar{\lambda}_0}{0{,}1+\bar{\lambda}_z^4}\frac{M_{y,Ed}}{C_{my}\chi_{LT}M_{pl,y,Rd}} = 1{,}7\times\text{-}0{,}524\times\frac{0{,}112\times 2{,}31}{(0{,}1+0{,}313^{\ 4})\times 0{,}871\times 1{,}000\times 2{,}38} = \text{-}1{,}013$$

$$C_{zz} = 1 + (w_z - 1)\left[2 - \frac{1{,}6}{w_z}C_{mz}^2\bar{\lambda}_{max} - \frac{1{,}6}{w_y}C_{mz}^2\bar{\lambda}_{max}^2 - e_{LT}\right]n_{pl} = 1+(1{,}162-1)\times\left[2 - \frac{1{,}6}{1{,}162}\times 1{,}000^{\ 2}\times 0{,}313\right.$$

$$\left.-\frac{1{,}6}{1{,}162}\times 1{,}000^{\ 2}\times 0{,}313^{\ 2}\ \text{-}\text{-}1{,}013\right]\times 0{,}0350 = 1{,}014$$

it is accepted C_{zz} = **1,014** $\geq 0{,}860 = 8{,}73 / 10{,}15 = W_{el,z} / W_{pl,z}$

$$\mu_y = \frac{1 - N_{Ed}/N_{cr,y}}{1 - \chi_y N_{Ed}/N_{cr,y}} = \frac{1 - 3{,}83/1142{,}88}{1 - 0{,}944\times 3{,}83/1142{,}88} = 1{,}000$$

$$\mu_z = \frac{1 - N_{Ed}/N_{cr,z}}{1 - \chi_z N_{Ed}/N_{cr,z}} = \frac{1 - 3{,}83/1119{,}02}{1 - 0{,}943\times 3{,}83/1119{,}02} = 1{,}000$$

$$k_{yy} = C_{my}C_{mLT}\frac{\mu_y}{1 - N_{Ed}/N_{Ncr,y}}\frac{1}{C_{yy}} = 0{,}871\times 1{,}000\times\frac{1{,}000}{1\text{-}3{,}83/1142{,}88}\times\frac{1}{1{,}009} = 0{,}866$$

$$k_{yz} = C_{mz}\frac{\mu_y}{1 - N_{Ed}/N_{Ncr,z}}\frac{0{,}6}{C_{yz}}\sqrt{\frac{w_z}{w_y}} = 1{,}000\times\frac{1{,}000}{1\text{-}3{,}83/1119{,}02}\times\frac{0{,}6}{1{,}010}\times\sqrt{\frac{1{,}162}{1{,}162}} = 0{,}596$$

$$k_{zy} = C_{my}C_{mLT}\frac{\mu_z}{1 - N_{Ed}/N_{Ncr,y}}\frac{0{,}6}{C_{zy}}\sqrt{\frac{w_y}{w_z}} = 0{,}871\times 1{,}000\times\frac{1{,}000}{1\text{-}3{,}83/1142{,}88}\times\frac{0{,}6}{1{,}009}\times\sqrt{\frac{1{,}162}{1{,}162}} = 0{,}520$$

$$k_{zz} = C_{mz}\frac{\mu_z}{1 - N_{Ed}/N_{Ncr,z}}\frac{1}{C_{zz}} = 1{,}000\times\frac{1{,}000}{1\text{-}3{,}83/1119{,}02}\times\frac{1}{1{,}014} = 0{,}990$$

Load capacity conditions :

$$\frac{N_{Ed}}{\chi_y N_{Rk}/\gamma_{M1}} + k_{yy}\frac{M_{y,Ed}+\Delta M_{y,Ed}}{\chi_{LT}M_{y,Rk}/\gamma_{M1}} + k_{yz}\frac{M_{z,Ed}+\Delta M_{z,Ed}}{M_{z,Rk}/\gamma_{M1}} = \frac{3{,}83}{0{,}944\times 109{,}51/1} + 0{,}866\times\frac{2{,}31+0}{1{,}000\times 2{,}38/1} +$$

$$0{,}596\times\frac{0+0}{2{,}39/1} = \mathbf{0{,}876 < 1}\ \ (6.61)$$

$$\frac{N_{Ed}}{\chi_z N_{Rk}/\gamma_{M1}} + k_{zy}\frac{M_{y,Ed}+\Delta M_{y,Ed}}{\chi_{LT} M_{y,Rk}/\gamma_{M1}} + k_{zz}\frac{M_{z,Ed}+\Delta M_{z,Ed}}{M_{z,Rk}/\gamma_{M1}} = \frac{3{,}83}{0{,}943\times 109{,}51/1} + 0{,}520\times\frac{2{,}31+0}{1{,}000\times 2{,}38/1} +$$

$$0{,}990\times\frac{0+0}{2{,}39/1} = \mathbf{0{,}540 < 1} \qquad (6.62)$$

Deformations:

Span no.: 1, 1, 1. Loads: OW+St+S2+W1+W3 Characteristic combination

Deformation in axis Z calculated from member chord is equal:

a_{max} = 0,4 mm

a_{gr} = l / 250 = 430 / 250 = 1,7 mm

a_{max} = **0,4 < 1,7** = a_{gr}

Largest resultant deformation is equal:

a = 0,448 mm; L / a = 430,0 / 0,448 = 959,9

4.4. Resultaten acc. naar EN 1993

Memb. no.:	Memb. group:	Profile:	Critical condition:	Capacity:		Load comb.:
47	Pozycja nr 1	1 - H 60x60x2	Bending	0.965		CW+St+S2+W1+W3
46	Pozycja nr 1	1 - H 60x60x2	Bending	0.835		CW+St·γ_f2+W1+W4
44	Pozycja nr 1	1 - H 60x60x2	Bending	0.688		CW+St+S3+W1+W3
49	Pozycja nr 1	1 - H 60x60x2	Bending	0.688		CW+St+S3+W1+W3
45	Pozycja nr 1	1 - H 60x60x2	Bending	0.629		CW+St·γ_f2+W1+W4
48	Pozycja nr 1	1 - H 60x60x2	Bending	0.629		CW+St·γ_f2+W1+W4
10	Pozycja nr 3	4 – external bar	Bending	0.593		CW+St+S3
11	Pozycja nr 3	4 - external bar	Bending	0.593		CW+St·γ_f2+S2
50	Pozycja nr 3	4 - external bar	Bending	0.593		CW+St·γ_f2+S2
53	Pozycja nr 3	4 - external bar	Bending	0.593		CW+St+S3
3	Pozycja nr 2	6 - H 40x40x2	Bending	0.555		CW+St+S3+W1+W3
6	Pozycja nr 2	6 - H 40x40x2	Bending	0.539		CW+St·γ_f2+S3+W1+W3
9	Pozycja nr 2	6 - H 40x40x2	Bending	0.539		CW+St·γ_f2+S3+W1+W3
51	Pozycja nr 3	3 – internal bar	Bending	0.481		CW+St+S3
52	Pozycja nr 3	3 - internal bar	Bending	0.481		CW+St+S2
1	Pozycja nr 1	1 - H 60x60x2	Bending	0.394		CW+St·γ_f2+W1+W4
2	Pozycja nr 1	1 - H 60x60x2	Bending	0.390		CW+St+S3+W1+W3
5	Pozycja nr 1	1 - H 60x60x2	Bending with compression (stability)	0.358		CW+St+S2+W1+W3
8	Pozycja nr 1	1 - H 60x60x2	Bending with compression (stability)	0.358		CW+St+S2+W1+W3
7	Pozycja nr 1	1 - H 60x60x2	Bending	0.352		CW+St+W1+W4
4	Pozycja nr 1	1 - H 60x60x2	Bending	0.352		CW+St+W1+W4
13	Pozycja nr 4	2 - H 50x50x2	Bending	0.227		CW+St·γ_f2+W1+W3
12	Pozycja nr 4	2 - H 50x50x2	Bending	0.224		CW+St+S2+W1+W3
15	Pozycja nr 4	2 - H 50x50x2	Bending with compression (stability)	0.181		CW+St·γ_f2+W2+W4
14	Pozycja nr 4	2 - H 50x50x2	Bending with compression (stability)	0.165		CW+St·γ_f2+W2+W4
16	Pozycja nr 4	5 - 2x H 40x40x2	Deformations	0.044		CW+St+S3+W2+W4
17	Pozycja nr 4	5 - 2x H 40x40x2	Deformations	0.044		CW+St+W1+W4
24	Pozycja nr 4	5 - 2x H 40x40x2	Deformations	0.044		CW+St+S2+W1+W3
25	Pozycja nr 4	5 - 2x H 40x40x2	Deformations	0.044		CW+St+S3+W1+W4

CW – dead load;
St – steady load;
S1 – snow load, roof type: cylindrical, case:I
S2 - snow load, roof type: cylindrical, case:II-a;
S3 – snow load, roof type: cylindrical, case:II-b;
W1 – wind load, wind direction: 0^0;
W2 - wind load, wind direction : 45^0;
W3 - wind load, negative internal pressure;
W4 - obciążenie positive internal pressure,

5. Dimensionering van de verbinding tussen de bracing transom en de frame post.

5.1. Filetlas die de bracingtransom verbindt met het uiteinde plat- Node No. 6.

Checking the load-bearing condition of the fillet weld. PN-EN 1993		
node load		
V_{Ed}=	0,58	kN
M_{Ed}=	0,57	kNm
N_{Ed}=	-4,98	kN
steel grade:	235	
f_y=	235	N/mm^2
f_u=	360	N/mm^2
Correction factor for steel grade 235:		
β_w	0,8	
Partial safety factor γ_{M0}	1,0	
Partial safety factor γ_{M2}	1,25	
profile 40x40x2		
h=	40	mm
b=	40	mm
g=	2	mm
t=	2	mm
r=	1,5	mm
A=	304	mm^2
weld		
a=	2	mm
J_y=	74400	mm^4

Maximum stresses in the horizontal part p.1				
	σ_1=	170	N/mm^2	
	$\tau_{równl}$=	0	N/mm^2	
Verification of the resistance of the weld				
Condition 1				
240	N/mm^2	<	360	N/mm^2
Condition 2				
120	N/mm^2	<	230	N/mm^2
Maximum stresses in the vertical p.2				
	σ_2=	154	N/mm^2	
σ_{prost}=	τ_{prost}=	109	N/mm^2	
	$\tau_{równl}$=	36	N/mm^2	
Verification of the resistance of the weld				
Condition 1				
227	N/mm^2	<	360	N/mm^2
Condition 2				
109	N/mm^2	<	230	N/mm^2
The weld resistance conditions are fulfilled				

Andere lassen worden **verondersteld 2 mm dikke structurele filetlassen te zijn.**

5.2. Vastgeschroefde verbinding tussen de bracing transom sheeting en de frame post - Node No. 6.

Verificatie van de boutweerstandstoestand PN-EN 1993		
knooppuntbelasting		
V_{Ed}=	0,58	Kn
M_{Ed}=	0,57	kNm

	N_{Ed}=	-4,98	Kn
gedeeltelijke veiligheidsfactor γ_{M0}		1,0	
gedeeltelijke veiligheidsfactor γ_{M2}		1,25	
verbindingscategorie		D	
boutklasse		8,8	
Diameter	M	8	
boutdoorsnedegebied		36,6	mm^2
staalkarakteristieken van de bevestigingsmiddelen:			
	f_{yb}=	640	N/mm^2
	f_{ub}=	800	N/mm^2
kenmerken van staal van verbonden elementen:			
	$f_{\&}$	235	N/mm^2
	f_u=	360	N/mm^2
spanningsweerstand van de bout			
	k_2=	0,9	
	$F_{t,Rd}$=	21,1	Kn
dode koersweerstand van de bout			
plaatdikte	t=	2	Mm
	$B_{p,Rd}$=	8,7	Kn
plaatdikte	t=	4	Mm
	$B_{p,Rd}$=	17,4	Kn
Resulterende bedrijfskracht 1 bevestiging:			
boutafstand	r=	90	Mm
	$F_{t,Ed}$=	8,8	Kn
"VERSTERKING VAN DE KOLOMWANDEN BIJ DE AANSLUITING OP DE SPANT (TWEE OPLOSSINGEN): - DUBBELE WAND: 2x2mm OF - LASSEN VAN EEN MEMBRAANPLAAT".			
"MINIMALE DIKTE VAN DE EINDPLAAT IN DE SPIEGEL: - 5 mm"			
CORRECTE AANSLUITING			

6. Funderingsdimensie.

6.1. Externe fundering.

Externe funderingsafmetingen
funderingsbelasting

N_{max}=	3,56	Kn
N_{min}	-1,52	Kn
V_{max}=	1,84	Kn

Maat I						**Maat II**					
Basisdimensie						Basisdimensie					
a=	0,30	M				a=	0,50	M			
b=	0,30	M				b=	0,50	M			
Spanningen onder de voet						Spanningen onder de voet					
p_{max}=	39,6	Kpa				p_{max}=	14,2	Kpa			
Hoogte						Hoogte					
H	0,80	M				H	0,30	M			
Gewicht						Gewicht					
g=	1,58	Kn	>	1,52	Kn	g=	1,7	Kn	>	1,52	Kn

Maat III						**Maat IV**					
Basisdimensie						Basisdimensie					
a=	0,70	M				D	0,35	M			
b=	0,70	M									
Spanningen onder de voet						Spanningen onder de voet					
p_{max}=	7,27	Kpa				p_{max}=	37,0	Kpa			
Hoogte						Hoogte					
H	0,15	M				H	0,75	M			
Gewicht						Gewicht					
g=	1,62	kN	>	1,52	kN	g=	1,59	kN	>	1,52	kN

LET OP: De stichting is aangenomen als:

- maat I, II - kubieke betonnen fundering
- maat III - betonplaat 15 cm dik
- maat IV - fundering gemaakt met een Ø35cm boormachine

6.2. Interne basis.

Interne funderingsdimensies		
funderingsbelasting		
N_{max}=	5,86	Kn

N_{min}	-2,10	Kn
V_{max}=	3,30	Kn

Maat I						Maat II					
Basisdimensie						Basisdimensie					
a=	0,30	M				a=	0,50	M			
b=	0,30	M				b=	0,50	M			
Spanningen onder de voet						Spanningen onder de voet					
p_{max}=	65,1	Kpa				p_{max}=	23,4	Kpa			
Hoogte						Hoogte					
H	1,15	M				H	0,45	M			
Gewicht						Gewicht					
g=	2,28	Kn	>	2,1	Kn	g=	2,48	Kn	>	2,1	Kn

Maat III						Maat IV					
Basisdimensie						Basisdimensie					
a=	0,85	M				D	0,35	M			
b=	0,85	M									
Spanningen onder de voet						Spanningen onder de voet					
p_{max}=	8,1	Kpa				p_{max}=	60,9	Kpa			
Hoogte						Hoogte					
H	0,15	M				H	1,05	M			
Gewicht						Gewicht					
g=	2,38	Kn	>	2,1	Kn	g=	2,22	Kn	>	2,1	Kn

LET OP: De stichting is aangenomen als:

- maat I, II - kubieke betonnen fundering
- maat III - betonplaat 15 cm dik
- maat IV - fundering gemaakt met een Ø35cm boormachine

7. Eisen voor de kwaliteit van de staalconstructie .

Het uitvoeringscontrolesysteem volgens EN 1090 2 wordt gebruikt.

Gedetailleerde eisen kunnen worden opgenomen in het productdossier, dat buiten het toepassingsgebied van deze studie valt. In de following worden alleen de basisvereisten met betrekking tot de kwaliteit van het vakmanschap gepresenteerd.

7.1. Bouwmaterialen .

De in het project gebruikte producten moeten voldoen aan de technische leveringsvoorwaarden vermeld in PN EN 10025 1, PN EN 10025 2, PN EN 10025 3, PN EN 10210, PN EN 10219.

Alle stalen onderdelen moeten zijn gemaakt van ongelegeerd constructiestaal S235 in gewalste toestand (zonder speciale eisen met betrekking tot walsomstandigheden of warmtebehandeling). Genormaliseerd of thermomechanisch gewalst staal mag worden gebruikt.

De parkbox wordt blootgesteld aan de elementen, zodat wordt aangenomen dat de bedrijfstemperatuur negatief is (buitenfaciliteit).

Verbeterde kunststofeigenschappen loodrecht op het productoppervlak en geschiktheid voor koude vormen zijn niet vereist. Afhankelijk van de design specificatie, kan het nodig zijn om gegalvaniseerd staal te gebruiken.

Lasmaterialen moeten voldoen aan de eisen van PN EN 13479 en de relevante vaknormen (overeenkomstig tabel 5 van PN EN 1090 2).

7.2. Inspectiematerialen .

De eigenschappen van geleverde structurele producten worden opgenomen in de in EN 1092 2 vereiste inspectiedocumenten (tabel 1).

7.3. Prestatieklasse.

Gebruikscategorie: SC1 volgens EN 1990 2

Productiecategorie : PC1 volgens EN 1990 2

Categorie van gevolg: CC1 volgens DIN EN 1990

Uitvoeringsklasse EXC2 is vastgesteld in overeenstemming met de richtlijnenvan de klant .

De onderdelen moeten voldoen aan de prestatieklasse EXC2-eisen van Table A3 van EN 1990 2.

7.4. Vastgeschroefde verbindingen.

De voorschriften voor mechanische aansluitingen overeenkomstig EN 1090 2 moeten worden toegepast.

7.5. Gelaste verbindingen.

Volgens de vereiste uitvoeringsklasse EXC2 worden de standaardkwaliteitseisen voor lassen volgens EN ISO 3834 toegepast .

Lasacceptatieniveau: niveau C volgens EN ISO 5817.

7.6. Productietoleranties .

Defabricagetolerantie van de assemblage moet in overeenstemming zijn met de basistoleranties overeenkomstig EN 1090 2.

Auteurs van de studie:

[redacted]

Mevrouw Ind. [redacted]

knop. Nr. 180/99/ON

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