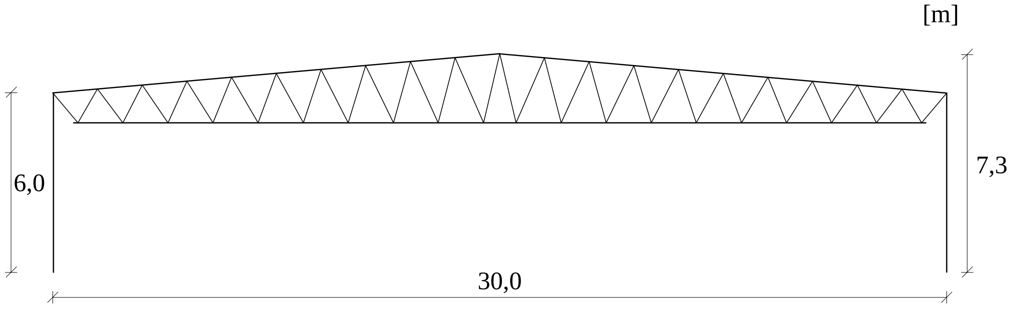
# Example: Single span truss and post frame for a low pitch roof using battened section chords

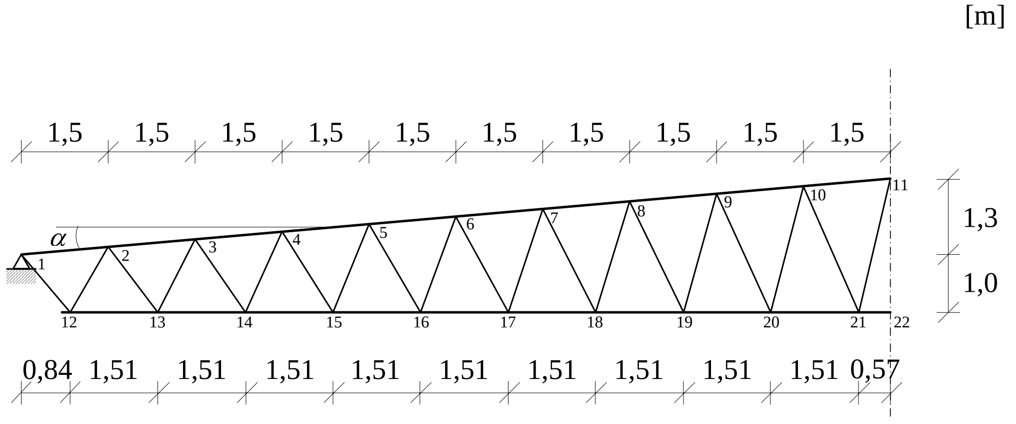
***This example deals with the design of a low pitch roof truss. The truss is part of the roof structure in a 72 m long single storey building and spans 30 m. The spacing of the trusses is 7,2 m and the roofing is an insulated steel sheeting on purlins.***

The building where the truss is situated is based on that shown in worked example SX016. In the Figure below, one frame from the building is shown.

SX016




The truss is symmetric about its centre. In the figure below a more detailed geometry of the truss is shown. The inclination of the upper chord of the truss is $\alpha = 5°$. The roof is providing lateral restraint for the top chord, either by a wind bracing or by diaphragm action of corrugated sheeting in structural class I or II according to EN 1993-1-3.



Partial safety factors

EN 1990

- $\gamma_G$ = 1,35 or 1,0 (permanent loads)
- $\gamma_Q$ = 1,5 (imposed loads)

EN 1993-1-1

- $\gamma_{M0}$ = 1,0
- $\gamma_{M1}$ = 1,0
- $\gamma_{M2}$ = 1,25

## Loads

Permanent loads

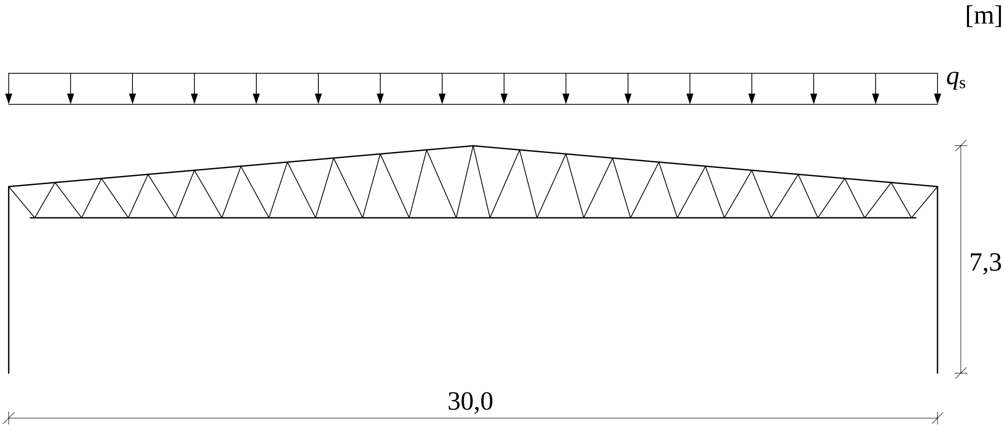
| | |
|---|---|
| Roof and insulation | 0,35 kN/m$^2$ |
| Purlins | 0,05 kN/m$^2$ |
| Truss self weight | 0,12 kN/m$^2$ |

$$g = (0,35 + 0,05 + 0,12) \cdot 7,2 = 3,74 \text{ kN/m}$$

Snow load

The imposed load from snow, $q_s$, is shown in the figure below. In SX016 a detailed description of how to calculate this snow load can be found.

$q_s$ = 4,45 kN/m



Wind load

The wind load, when wind on the side is considered is shown below. The details of how to determine this load can be found in SX016.

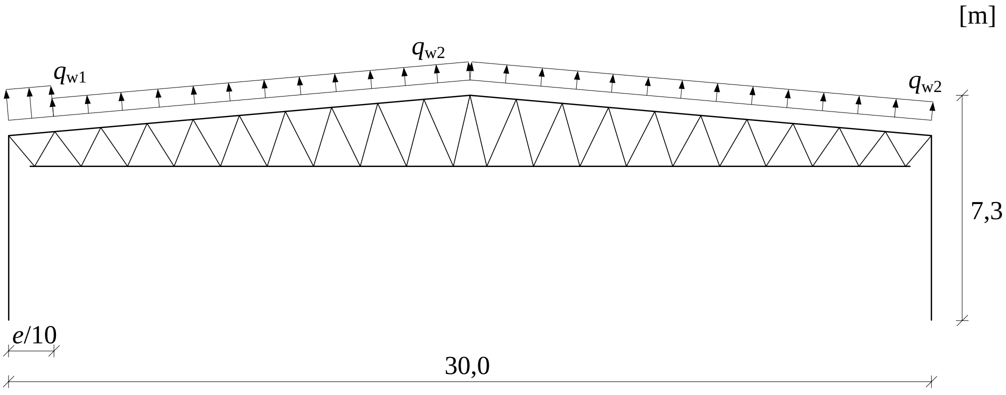
See SX016

$q_{w1} = -9,18$ kN/m

$q_{w2} = -5,25$ kN/m

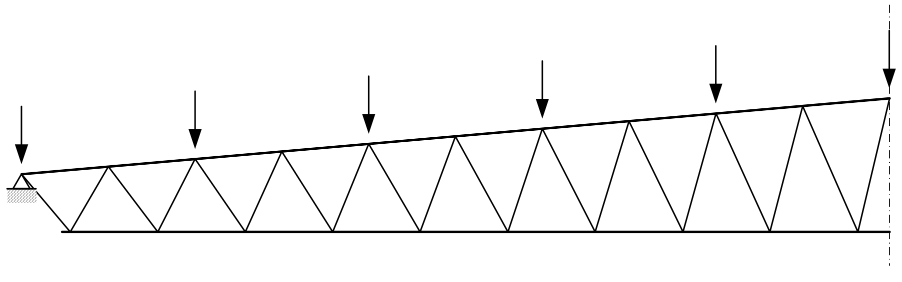
$e = \min(b;\ 2h) = \min(72,0;\ 14,6) = 14,6$ m

In this context $q_{w1}$ is negligible.




**Member forces**

The roof is attached to purlins fixed at every second joint of the truss, implying that all loads will be applied at the truss joints, as shown in the figure below.



The member forces are calculated under the assumption of pinned joints. This simplification is allowed when the compression chord is in cross section class 1. The calculations are performed by means of a computer, meaning that only the member forces will be shown here.

Two different load cases were considered;

- Dead Load (*DL*) + Snow Load (*SL*) and
- Dead Load (*DL*) + Wind Load (*WL*).

*DL* + *SL*

$$\gamma_{\mathrm{G}} \cdot g + \gamma_{\mathrm{Q}} \cdot q_s = 1{,}35 \cdot g + 1{,}5 \cdot q_s$$

*DL* + *WL*

$$\gamma_{\mathrm{G}} \cdot g + \gamma_{\mathrm{Q}} \cdot q_w = 1{,}0 \cdot g + 1{,}5 \cdot q_w$$

All member forces under these design loads are shown in the table below. Forces are in kN and negative sign means compression.

| Member | DL+SL | DL+WL | Member | DL+SL | DL+WL |
|---|---|---|---|---|---|
| *1-2* | -139 | 52 | *1-12* | 214, | -77 |
| *2-3* | -344 | 126 | *12-2* | -189 | 68 |
| *3-4* | -487 | 179 | *2-13* | 183 | -66 |
| *4-5* | -588 | 213 | *13-3* | -164 | 59 |
| *5-6* | -653 | 238 | *3-14* | 119 | -41 |
| *6-7* | -695 | 252 | *14-4* | -108 | 37 |
| *7-8* | -715 | 260 | *4-15* | 106 | -36 |
| *8-9* | -721 | 262 | *15-5* | -96 | 33 |
| *9-10* | -711 | 260 | *5-16* | 56 | -19 |
| *10-11* | -693 | 253 | *16-6* | -52 | 17 |
| *12-13* | 233 | -84 | *6-17* | 51 | -17 |
| *13-14* | 418 | -151 | *17-7* | -47 | 16 |
| *14-15* | 530 | -189 | *7-18* | 9,0 | -2,3 |
| *15-16* | 622 | -221 | *18-8* | -8,4 | 2,1 |
| *16-17* | 668 | -237 | *8-19* | 8,3 | -2,1 |
| *17-18* | 708 | -250 | *19-9* | -7,8 | 2,0 |
| *18-19* | 714 | -252 | *9-20* | -29 | 11 |
| *19-20* | 720 | -253 | *20-10* | 28 | -11 |
| *20-21* | 701 | -246 | *10-21* | -28 | 11 |
| *21-22* | 684 | -239 | *21-11* | 26 | -10 |

## Member design

Channel sections will be used for all members. The upper and lower chords each consist of two profiles and are designed as uniform built-up members when out of plane deformations are considered.

Buckling resistance of member in compression

EN 1993-1-1 §6.3.1

$$N_{\mathrm{b,Rd}} = \frac{\chi \cdot A \cdot f_{\mathrm{y}}}{\gamma_{\mathrm{M1}}}$$

The reduction factor, $\chi$, is calculated as

$$\chi = \frac{1}{\Phi + \sqrt{\Phi^2 - \bar{\lambda}^2}} \leq 1,0$$

where

$$\Phi = 0,5\left[1 + \alpha\left(\bar{\lambda} - 0,2\right) + \bar{\lambda}^2\right]$$

and

$$\bar{\lambda} = \sqrt{\frac{A \cdot f_{\mathrm{y}}}{N_{\mathrm{cr}}}}$$

$\alpha$ is an imperfection factor corresponding to the appropriate buckling curve.

The buckling length, $L_{\mathrm{cr}}$, should be taken as the system length for in plane buckling of the chords and for out of plane buckling of the web members. For in plane buckling, a buckling length of 90% of the system length should be used for the web members. The buckling length for out of plane buckling of the upper chord should be taken as the distance between the purlins in this case.

EN 1993-1-1 Annex BB

Resistance of uniform built-up members in compression

EN 1993-1-1 §6.4

Out of plane buckling for a built-up member

$$N_{cr} = \frac{\pi^2 \cdot EI_{eff}}{L_{cr}^2}$$

where $I_{eff}$ for a battened strut should be calculated as

$$I_{eff} = 0,5 \cdot h_0^2 \cdot A_{ch} + 2 \cdot \mu \cdot I_{ch}$$

Eq. (6.74)

in which

$A_{ch}$ is the area of one chord

$I_{ch}$ is the second moment of area of one chord

$\mu$ is determined according to Table 6.8 in EN 1993-1-1 and

Table 6.8

$h_0$ is the distance between the centroids of the chords.

Except for this it is designed for buckling as described above.

Check of the chords in a built-up section

EN 1993-1-1 §6.4

For a member with two identical chords the design force $N_{ch,Ed}$ should be determined as

$$N_{ch,Ed} = 0,5 \cdot N_{Ed} + \frac{M_{Ed} \cdot h_0 \cdot A_{ch}}{2 \cdot I_{eff}}$$

Eq. (6.69)

where

$$M_{Ed} = \frac{N_{Ed} \cdot e_0 + M_{Ed}^{I}}{1 - \frac{N_{Ed}}{N_{cr}} - \frac{N_{Ed}}{S_v}}$$

in which

$$S_v = \frac{2 \cdot \pi^2 \cdot EI_{ch}}{a^2} \qquad \text{(stiff battens)}$$

Eq. (6.73)

$$e_0 = \frac{L}{500}$$

$M_{Ed}^{I}$ is the design value of the maximum moment in the middle of the chord

$a$ is the distance between battens

$L$ is the distance between lateral supports or the buckling length, $L_{cr}$

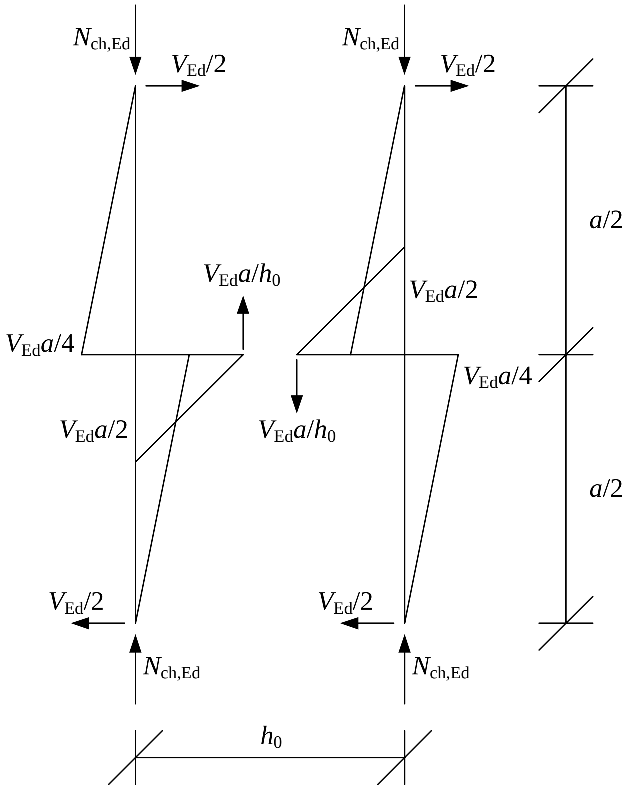
The shear force that the battened strut should be designed for is

$$V_{Ed} = \frac{\pi \cdot M_{Ed}}{L}$$

Eq. (6.70)

This shear force causes a moment in the chords distributed according to the figure below.

EN 1993-1-1 Figure 6.11




The individual chords should be checked for axial force, bending moment and shear force according to the figure above.

Resistance of members in tension

EN 1993-1-1 §6.2.3

The tension resistance is determined as

$$N_{\mathrm{b,Rd}} = \frac{A \cdot f_{\mathrm{y}}}{\gamma_{\mathrm{M0}}}$$

Upper chord

The member in the upper chord that carries the highest force is member *8-9*.

Compression force: $N_{Ed}$ = -721 kN (under dead load and snow load)

Tension force: $N_{Ed}$ = 262 kN (under dead load and wind load)

Only this member will be checked since if this member has enough resistance then the other members in the upper chord will as well.

Two UPE 160 S355 are used as upper chord. Battens of the same section as the web members are used.

$f_y = 355 \cdot 10^6$ Pa

$E = 210 \cdot 10^9$ Pa

$A = A_{ch} = 2{,}17 \cdot 10^{-3}$ m$^2$ (one profile) — From trade literature

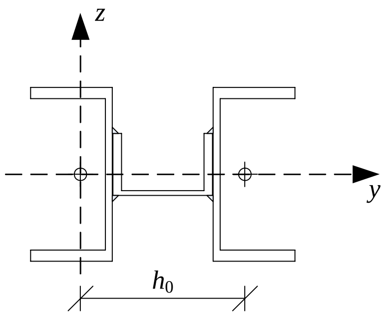
$I_y = 9{,}11 \cdot 10^{-6}$ m$^4$ (one profile)

$I_z = I_{ch} = 1{,}07 \cdot 10^{-6}$ m$^4$ (one profile)

$W_{pl} = 40{,}7 \cdot 10^{-6}$ m$^3$ (one profile)

$h_0$ = 0,1254 m (UPE 80 in between)

$\alpha$ = 0,49 (buckling curve c) — EN 1993-1-1 §6.3.1.2



In-plane buckling

$$L_{\mathrm{cr}} = L / \cos(5°) = 1,5 / \cos(5°) = 1,51 \text{ m}$$

$$N_{\mathrm{cr}} = \frac{\pi^2 \cdot EI_{\mathrm{y}}}{L_{\mathrm{cr}}^2} = \frac{\pi^2 \cdot 210 \cdot 10^9 \cdot 2 \cdot 9,11 \cdot 10^{-6}}{1,51^2}$$

$N_{\mathrm{cr}}$ = 16 562 000 N = 16 562 kN

$$\bar{\lambda} = \sqrt{\frac{2 \cdot 2,17 \cdot 10^{-3} \cdot 355 \cdot 10^6}{16562 \cdot 10^3}} = 0,305$$

$$\Phi = 0,5\left[1 + 0,49\left(0,305 - 0,2\right) + 0,305^2\right] = 0,572$$

$$\chi = \frac{1}{0,572 + \sqrt{0,572^2 - 0,305^2}} = 0,947$$

$$N_{\mathrm{b,Rd}} = \frac{0,947 \cdot 2 \cdot 2,17 \cdot 10^{-3} \cdot 355 \cdot 10^6}{1,0}$$

$N_{\mathrm{cr}}$ = 1 459 000 N = 1459 kN > 721 kN = $N_{\mathrm{Ed}}$

Design of battened strut

The upper chord is designed with battens with length 200 mm at a distance of $a$ ~ 1,0 m, meaning that at every purlin position a batten is attached and two in between those positions.

Purlins that work as lateral support are attached at every second joint, i.e. the out of plane buckling length is between two joints.

$$L_{\mathrm{cr}} = L / \cos(5°) = 3,0 / \cos(5°) = 3,01 \text{ m}$$

$$I_1 = 0,5 \cdot h_0^2 \cdot A_{\mathrm{ch}} + 2 \cdot I_{\mathrm{ch}} = 0,5 \cdot 0,1254^2 \cdot 2,17 \cdot 10^{-3} + 2 \cdot 1,07 \cdot 10^{-6}$$

$$I_1 = 19,2 \cdot 10^{-6} \text{m}^4$$

$$i_0 = \sqrt{\frac{I_1}{2 \cdot A_{\mathrm{ch}}}} = \sqrt{\frac{19,2 \cdot 10^{-6}}{2 \cdot 2,17 \cdot 10^{-3}}} = 0,067 \text{ m}$$

$$\lambda = \frac{L_{\mathrm{cr}}}{i_0} = \frac{3,01}{0,067} = 44,9 \rightarrow \mu = 1,0$$

$$I_{eff} = I_1 = 19,2 \cdot 10^{-6} \text{mm}^4$$

$$N_{\mathrm{cr}} = \frac{\pi^2 \cdot 210 \cdot 10^9 \cdot 19,2 \cdot 10^{-6}}{3,01^2} = 4\ 392\ 000 \text{ N} = 4392 \text{ kN}$$

$$S_{\mathrm{v}} = \frac{2 \cdot \pi^2 \cdot EI_{\mathrm{ch}}}{a^2} = \frac{2 \cdot \pi^2 \cdot 210 \cdot 10^9 \cdot 1,07 \cdot 10^{-6}}{1,0^2} = 4\ 435\ 00 \text{ N} = 4435 \text{ kN}$$

$$M_{\mathrm{Ed}} = \frac{N_{\mathrm{Ed}} \cdot e_0 + M_{\mathrm{Ed}}^{\mathrm{I}}}{1 - \frac{N_{\mathrm{Ed}}}{N_{\mathrm{cr}}} - \frac{N_{\mathrm{Ed}}}{S_{\mathrm{v}}}} = \frac{721 \cdot \frac{3,01}{500} + 0}{1 - \frac{721}{4392} - \frac{721}{4435}} = 6,6 \text{ kNm}$$

$$N_{\mathrm{ch,Ed}} = 0,5 \cdot N_{\mathrm{Ed}} + \frac{M_{\mathrm{Ed}} \cdot h_0 \cdot A_{\mathrm{ch}}}{2 \cdot I_{\mathrm{eff}}} = 0,5 \cdot 721 + \frac{6,4 \cdot 0,1254 \cdot 2,17 \cdot 10^{-3}}{2 \cdot 19,2 \cdot 10^{-6}}$$

$N_{\mathrm{ch,Ed}}$ = 405,9 kN

The shear force that the battened strut should be designed for is

$$V_{\mathrm{Ed}} = \frac{\pi \cdot M_{\mathrm{Ed}}}{L} = \frac{\pi \cdot 6,6}{3,01} = 6,9 \text{ kN}$$

and the moment from this shear force at the position of the battens is

EN 1993-1-1 §6.4.3

Figure 6.11

$$M_{\mathrm{ch,Ed}} = \frac{V_{\mathrm{Ed}} \cdot a}{4} = \frac{6,9 \cdot 1,0}{4} = 1,7 \text{ kNm}$$

Buckling resistance of one chord in lateral direction

$$L_{\mathrm{cr}} = a = 1,0 \text{ m}$$

$$N_{\mathrm{cr}} = \frac{\pi^2 \cdot EI_{\mathrm{ch}}}{L_{\mathrm{cr}}^2} = \frac{\pi^2 \cdot 210 \cdot 10^9 \cdot 1,07 \cdot 10^{-6}}{1,0^2} = 2\,218\,000 \text{ N} = 2218 \text{ kN}$$

$$\bar{\lambda} = \sqrt{\frac{2,17 \cdot 10^{-3} \cdot 355 \cdot 10^6}{2218 \cdot 10^3}} = 0,589$$

$$\Phi = 0,5\left[1 + 0,49\left(0,589 - 0,2\right) + 0,589^2\right] = 0,769$$

$$\chi = \frac{1}{0,769 + \sqrt{0,769^2 - 0,589^2}} = 0,792$$

$$N_{\mathrm{b,Rd}} = \frac{0,792 \cdot 2,17 \cdot 10^{-3} \cdot 355 \cdot 10^6}{1,0}$$

$N_{\mathrm{b,Rd}}$ = 610 000 N = 610 kN > 405,9 kN = $N_{\mathrm{ch,Ed}}$

Both axial force and shear force occur simultaneously. If the design shear force, $V_{\mathrm{Ed}}$, does not exceed 50% of the plastic shear resistance no reduction of the resistance to axial force is needed. EN 1993-1-1 §6.2.10 (2)

$$V_{\mathrm{pl,Rd}} = \frac{A_{\mathrm{v}} \cdot f_{\mathrm{y}} / \sqrt{3}}{\gamma_{\mathrm{M0}}}$$

where

$A_{\mathrm{v}}$ is the shear area, in this case the flange area of the U-section

$$A_{\mathrm{v}} = 2 \cdot h_{\mathrm{f}} \cdot t_{\mathrm{f}} = 2 \cdot (70 - 5,5 - 12) \cdot 9,5 \cdot 10^{-6} = 9,975 \cdot 10^{-4} \text{ m}^2$$

$$V_{\mathrm{pl,Rd}} = \frac{2 \cdot 9,975 \cdot 10^{-4} \cdot 355 \cdot 10^{6} / \sqrt{3}}{1,0}$$

$V_{\mathrm{pl,Rd}}$= 408 900 N = 409 kN > 6,7 kN = $V_{\mathrm{Ed}}$

$0,5 \cdot V_{\mathrm{pl,Rd}} = 0,5 \cdot 409 = 204,5$ kN > 6,7 kN = $V_{\mathrm{Ed}}$

No reduction of the buckling resistance of the chord needs to be made.

At the batten position, the combination of moment and axial force needs to be checked. Equation (6.62) in EN 1993-1-1 can for this case be reduced to EN 1993-1-1 §6.3.3 (4)

$$\frac{N_{\mathrm{ch,Ed}}}{N_{\mathrm{b,Rd}}} + k_{\mathrm{zz}} \frac{M_{\mathrm{ch,Ed}}}{M_{\mathrm{z,Rd}}} \leq 1,0$$

§6.2.5

$$M_{\mathrm{z,Rd}} = M_{\mathrm{pl,Rd}} = \frac{W_{\mathrm{pl}} \cdot f_{\mathrm{y}}}{\gamma_{\mathrm{M0}}} = \frac{40,7 \cdot 10^{-6} \cdot 355 \cdot 10^{6}}{1,0}$$

$M_{\mathrm{z,Rd}}$ = 14 450 N = 14,4 kNm

Annex B

$$k_{\mathrm{zz}} = C_{\mathrm{mz}} \left( 1 + \left( 2 \cdot \bar{\lambda}_{\mathrm{z}} - 0,6 \right) \frac{N_{\mathrm{ch,Ed}}}{N_{\mathrm{b,Rd}}} \right) \leq C_{\mathrm{mz}} \left( 1 + 1,4 \frac{N_{\mathrm{ch,Ed}}}{N_{\mathrm{b,Rd}}} \right)$$

$C_{\mathrm{mz}}$ = 0,9 (sway buckling)

$$k_{\mathrm{zz}} = 0,9 \left( 1 + \left( 2 \cdot 0,589 - 0,6 \right) \frac{405,9}{610} \right) = 1,25$$

$$\frac{405,9}{610} + 1,25 \cdot \frac{1,7}{14,4} = 0,81 < 1,0$$

The battens are made of 200 mm long UPE 80

$t_w$ = 4 mm. From trade literature

$$W_{pl} = \frac{t_w \cdot l^2}{4} = \frac{0,004 \cdot 0,200^2}{4} = 40 \cdot 10^{-6}\ \mathrm{m}^3$$

EN 1993-1-1 Figure 6.11

$$V_{b,Ed} = \frac{V_{Ed} \cdot a}{h_0} = \frac{6,7 \cdot 1,0}{0,1254} = 53,4 \text{ kN}$$

$$A_v = l \cdot t_w = 0,20 \cdot 0,004 = 8 \cdot 10^{-4}\ \mathrm{m}^2$$

$$V_{pl,Rd} = \frac{8 \cdot 10^{-4} \cdot 355 \cdot 10^6 / \sqrt{3}}{1,0} = 164\,000 \text{ N} = 164 \text{ kN} > 53,4 \text{ kN} = V_{b,Ed}$$

$$M_{Ed} = \frac{V_{Ed} \cdot a}{2} = \frac{6,7 \cdot 1,0}{2} = 3,35 \text{ kNm}$$

$$M_{pl,Rd} = \frac{W_{pl} \cdot f_y}{\gamma_{M0}} = \frac{40 \cdot 10^{-6} \cdot 355 \cdot 10^6}{1,0}$$

$M_{pl,Rd}$ = 14 200 Nm = 14,2 kNm > 3,35 kNm = $M_{Ed}$

Tension resistance of the upper chord

$$N_{b,Rd} = \frac{A \cdot f_y}{\gamma_{M0}} = \frac{2 \cdot 2,17 \cdot 10^{-3} \cdot 355 \cdot 10^6}{1,0} = 1541 \text{ kN} > 262 \text{ kN} = N_{Ed}$$

Web members

The most utilized web members are

Compression force: *12-2* $N_{Ed}$ = -189 kN (under dead load and snow load)

Tension force: *1-12* $N_{Ed}$ = 214 kN (under dead load and snow load)

The web members are attached with their weak direction in the plane of the truss and their strong direction out of plane.

UPE 80 is used for the web members.

$A = 1{,}01 \cdot 10^{-3}\ \mathrm{m}^2$

$I_y = 1{,}07 \cdot 10^{-6}\ \mathrm{m}^4$

$I_z = 25 \cdot 10^{-8}\ \mathrm{m}^4$

$\alpha = 0{,}49$ (buckling curve c)

$L = 1{,}31$ m

From trade Literature

EN 1993-1-1 §6.3.1.2

In-plane buckling

$$L_{cr} = 0{,}9 \cdot L = 0{,}9 \cdot 1{,}31 = 1{,}18 \text{ m}$$

$$N_{cr} = \frac{\pi^2 \cdot EI}{L_{cr}^2} = \frac{\pi^2 \cdot 210 \cdot 10^9 \cdot 25 \cdot 10^{-8}}{1{,}18^2} = 372\,100 \text{ N} = 372{,}1 \text{ kN}$$

$$\bar{\lambda} = \sqrt{\frac{1{,}01 \cdot 10^{-3} \cdot 355 \cdot 10^6}{372{,}1 \cdot 10^3}} = 0{,}982$$

$$\Phi = 0{,}5\left[1 + 0{,}49\left(0{,}982 - 0{,}2\right) + 0{,}982^2\right] = 1{,}17$$

$$\chi = \frac{1}{1{,}17 + \sqrt{1{,}17^2 - 0{,}982^2}} = 0{,}554$$

$$N_{b,Rd} = \frac{0{,}554 \cdot 1{,}01 \cdot 10^{-3} \cdot 355 \cdot 10^6}{1{,}0}$$

$N_{b,Rd} = 198\,600$ N = 199 kN > 189 kN = $N_{Ed}$

Out of plane buckling

$L_{cr} = L = 1{,}31$ m

$$N_{cr} = \frac{\pi^2 \cdot EI}{L_{cr}^2} = \frac{\pi^2 \cdot 210 \cdot 10^9 \cdot 1{,}07 \cdot 10^{-6}}{1{,}31^2} = 1\ 292\ 000 \text{ N} = 1292 \text{ kN}$$

$$\bar{\lambda} = \sqrt{\frac{1{,}01 \cdot 10^{-3} \cdot 355 \cdot 10^6}{1292 \cdot 10^3}} = 0{,}527$$

$$\Phi = 0{,}5\left[1 + 0{,}49\left(0{,}527 - 0{,}2\right) + 0{,}527^2\right] = 0{,}719$$

$$\chi = \frac{1}{0{,}719 + \sqrt{0{,}719^2 - 0{,}527^2}} = 0{,}828$$

$$N_{b,Rd} = \frac{0{,}828 \cdot 1{,}01 \cdot 10^{-3} \cdot 355 \cdot 10^6}{1{,}0}$$

$N_{b,Rd} = 297\ 000 = 297$ kN > 189 kN = $N_{Ed}$

Tension resistance of the web members

$$N_{b,Rd} = \frac{1010 \cdot 355}{1{,}0} = 358\ 600 \text{ N} = 359 \text{ kN} > 214 \text{ kN} = N_{Ed}$$

Web members of UPE 80 are enough.

Lower chord

The most utilized member in the lower chord is the member *19-20*.

Compression force: $N_{Ed}$ = -253 kN (under dead load and wind load)

Tension force: $N_{Ed}$ = 720 kN (under dead load and snow load)

Two UPE 140 are used for the lower chord.

From trade literature

$A_{ch} = 1{,}84 \cdot 10^{-3}$ m$^2$ (one profile)

$I_y = 5{,}99 \cdot 10^{-6}$ m$^4$ (one profile)

$I_z = I_{ch} = 79 \cdot 10^{-8}$ m$^4$ (one profile)

$h_0 = 0{,}1234$ m

EN 1993-1-1 §6.3.1.2

$\alpha = 0{,}49$ (buckling curve c)

In-plane buckling

$L_{cr} = L = 1,51$ m

$$N_{cr} = \frac{\pi^2 \cdot EI}{L_{cr}^2} = \frac{\pi^2 \cdot 210 \cdot 10^9 \cdot 2 \cdot 5,99 \cdot 10^{-6}}{1,51^2} = 10\ 890\ 000 \text{ N} = 10890 \text{ kN}$$

$$\bar{\lambda} = \sqrt{\frac{2 \cdot 1,84 \cdot 10^{-3} \cdot 355 \cdot 10^6}{10889 \cdot 10^3}} = 0,346$$

$$\Phi = 0,5\left[1 + 0,49(0,346 - 0,2) + 0,346^2\right] = 0,596$$

$$\chi = \frac{1}{0,596 + \sqrt{0,596^2 - 0,346^2}} = 0,925$$

$$N_{b,Rd} = \frac{0,925 \cdot 2 \cdot 1,84 \cdot 10^{-3} \cdot 355 \cdot 10^6}{1,0}$$

$N_{b,Rd} = 1\ 208\ 000$ N $= 1208$ kN $> 253$ kN $= N_{Ed}$

Out of plane buckling (lateral buckling) of the battened lower chord

In this case the lower chord does not have any lateral supports and should be designed with a continuous elastic lateral restraint. This lateral restraint depends on the stiffness of the purlins $k_p$, the screws between purlins $k_c$ and upper chord and the web members $k_w$. SN027

A Z250x2,0 section is used as purlins

$I_z = 7,33 \cdot 10^{-6}$ m$^4$

$h = 1,9$ m (height of truss in the most utilized section)

$l_p = 7,2$ m (distance between trusses)

Stiffness, $k_p$, for the purlins

Assume a force of 1 N per unit length, yielding a moment of

$$M = 3 \cdot h$$

with purlins at every 3 m.

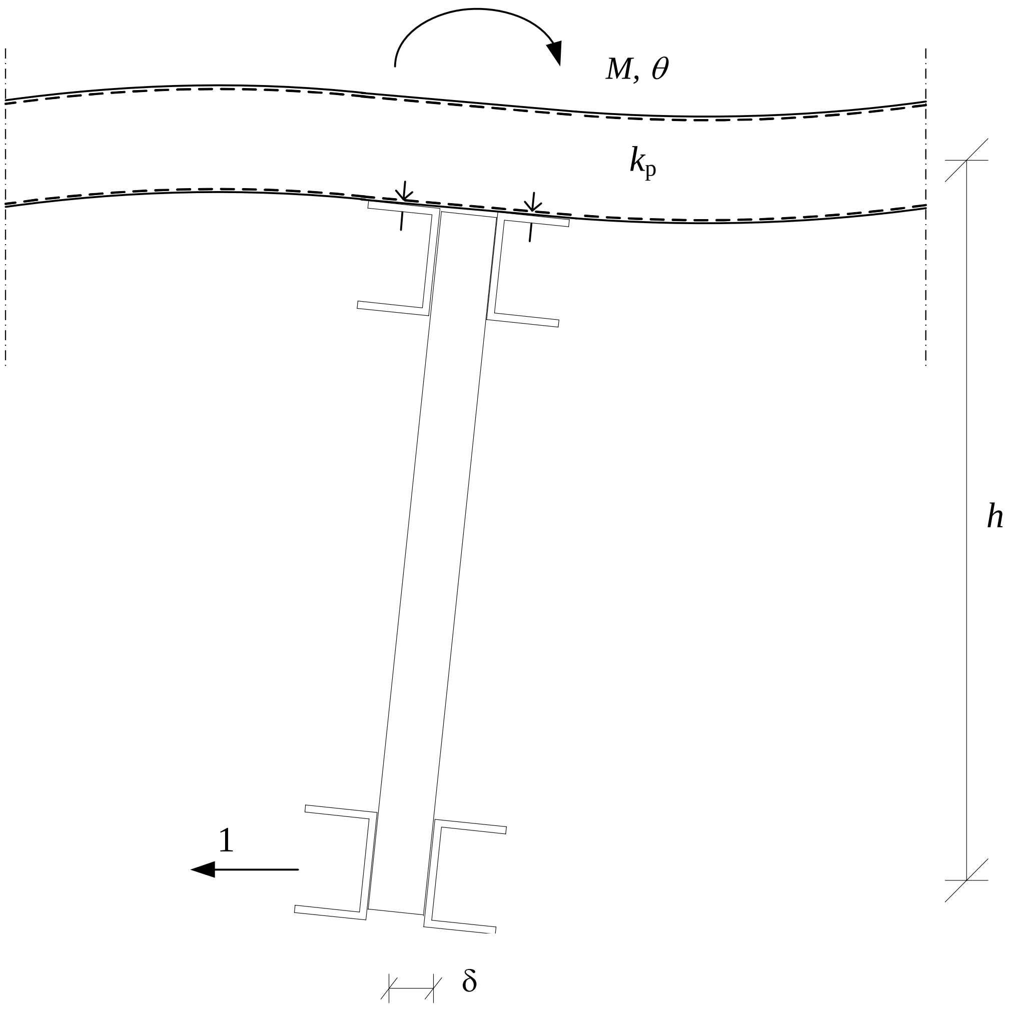
The corresponding angel of rotation, $\theta$, from this moment is

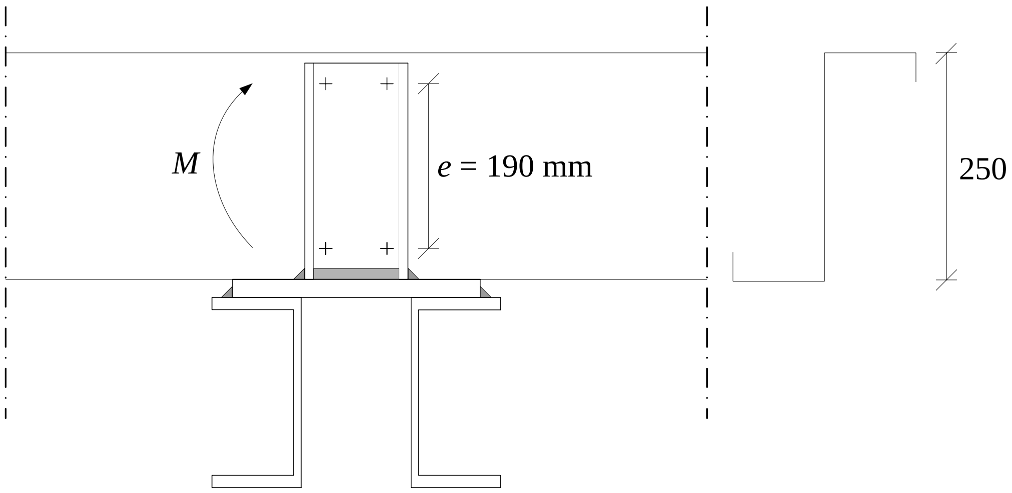
$$\theta = \frac{M \cdot l_{\mathrm{p}}}{2 \cdot EI_{\mathrm{p}}} = \frac{3 \cdot h \cdot l_{\mathrm{p}}}{2 \cdot EI_{\mathrm{p}}}$$

The displacement of the lower chord due to this unit force is

$$\delta = h \cdot \theta = h \cdot \frac{3 \cdot h \cdot l_{\mathrm{p}}}{2 \cdot EI_{\mathrm{p}}} = 1{,}9 \cdot \frac{3 \cdot 1{,}9 \cdot 7{,}2}{2 \cdot 210 \cdot 10^{9} \cdot 7{,}33 \cdot 10^{-6}} = 2{,}53 \cdot 10^{-5}\ \mathrm{m}$$

$$k_{\mathrm{p}} = \frac{1}{\delta} = \frac{1}{2{,}53 \cdot 10^{-5}} = 39\,500\ \mathrm{N/m^2} = 39{,}5\ \mathrm{kN/m^2}$$






Stiffness of the connection between the purlins and the upper chord

Four self tapping screws with diameter, $d$ = 6,3 mm, are used for the connection.

Screw force

$$F_s = \frac{3 \cdot h}{2 \cdot e} = \frac{3 \cdot 1,9}{2 \cdot 0,19} = 15 \text{ N}$$

Design thickness of purlin

$$t = (2,0 - 0,05) \cdot 0,98 = 1,91 \text{ mm}$$

The shear deformation, $v$, in the connection can be calculated according to the following equation from the Swedish handbook for cold-formed sections and sheeting. (Force in N, $d$ and $t$ in mm)

$$v = \frac{F_s}{d\sqrt{t} \cdot 10^3} = \frac{15}{6,3\sqrt{1,91} \cdot 10^3} = 1,72 \cdot 10^{-3} \text{ mm}$$

$$\theta = \frac{v}{e/2} = \frac{1,72 \cdot 10^{-3}}{190/2} = 1,81 \cdot 10^{-5}$$

$$\delta = h \cdot \theta = 1,9 \cdot 1,81 \cdot 10^{-5} = 3,44 \cdot 10^{-5} \text{ m}$$

$$k_c = \frac{1}{3,44 \cdot 10^{-5}} = 29\,070 \text{ N/m}^2 = 29,1 \text{ kN/m}^2$$

Stiffness, $k_w$, of the web members

SN027

Only the web members that are connected to the joints with purlins are used in the calculations of the stiffness, i.e. two web members are used.

$$I_w = 1,07 \cdot 10^{-6}\,\mathrm{m}^4$$

$l_1$ = 3,0 m (distance between purlins)

$l_w$ = 2,2 m (length of web member)

$$k_w = 2 \cdot \frac{3 \cdot EI_w}{l_1 \cdot l_w^3} = 2 \cdot \frac{3 \cdot 210 \cdot 10^9 \cdot 1,07 \cdot 10^{-6}}{3,0 \cdot 2,2^3}$$

$k_w$ = 42 200 N/m$^2$ = 42,2 kN/m$^2$

The total stiffness

$$k_s = \frac{1}{\frac{1}{k_p} + \frac{1}{k_c} + \frac{1}{k_w}} = \frac{1}{\frac{1}{39,5} + \frac{1}{29,1} + \frac{1}{42,2}} = 12,0\ \mathrm{kN/m^2}$$

Effective second moment of area for the lower chord

EN 1993-1-1 §6.4

$$I_1 = 0,5 \cdot h_0^2 \cdot A_{ch} + 2 \cdot I_{ch} = 0,5 \cdot 0,1234^2 \cdot 1,84 \cdot 10^{-3} + 2 \cdot 79 \cdot 10^{-8}$$

$$I_1 = 15,59 \cdot 10^{-6}\,\mathrm{m}^4$$

Table 6.8

$$i_0 = \sqrt{\frac{I_1}{2 \cdot A_{ch}}} = \sqrt{\frac{15,59 \cdot 10^{-6}}{2 \cdot 1,84 \cdot 10^{-3}}} = 0,065\ \mathrm{m}$$

The wave length, $l_0$, is calculated according to

SN027

$$l_c = \pi \sqrt[4]{\frac{EI_1}{k_s}} = \pi \sqrt[4]{\frac{210 \cdot 10^9 \cdot 15,59 \cdot 10^{-6}}{12 \cdot 10^3}} = 12,8\ \mathrm{m}$$

$$\lambda = \frac{l_c}{i_0} = \frac{12,8}{0,065} = 187 \rightarrow \mu = 0$$

$$I_{eff} = 0,5 \cdot 0,1234^2 \cdot 1,84 \cdot 10^{-3} = 14,0 \cdot 10^{-6}\,\mathrm{m}^4$$

The effective second moment of area will give a new value of the wave length, $l_c$

$$l_c = \pi \sqrt[4]{\frac{210 \cdot 10^9 \cdot 14,0 \cdot 10^{-6}}{12 \cdot 10^3}} = 12,4\ \mathrm{m}$$

Battens are placed at a spacing of $a \approx 1{,}0$ m.

$$S_{\mathrm{v}} = \frac{2 \cdot \pi^2 \cdot EI_{\mathrm{ch}}}{a^2} = \frac{2 \cdot \pi^2 \cdot 210 \cdot 10^9 \cdot 79 \cdot 10^{-8}}{1{,}0^2} = 3\,275\,000 \text{ N} = 3275 \text{ kN}$$

$$N_{\mathrm{cr}} = \sqrt{k_{\mathrm{s}} \cdot EI_{\mathrm{eff}}} \left[ 2 - \frac{\sqrt{k_{\mathrm{s}} \cdot EI_{\mathrm{eff}}}}{S_{\mathrm{v}}} \right] \text{ if } S_{\mathrm{v}} / \sqrt{k_{\mathrm{s}} \cdot EI_{\mathrm{eff}}} > 1$$ SN027

$$\sqrt{k_{\mathrm{s}} \cdot EI_{\mathrm{eff}}} = \sqrt{12 \cdot 10^3 \cdot 210 \cdot 10^9 \cdot 14{,}0 \cdot 10^{-6}} = 187\,800 \text{ N} = 187{,}8 \text{ kN}$$

$$S_{\mathrm{v}} / \sqrt{k_{\mathrm{s}} \cdot EI_{\mathrm{eff}}} = 17{,}4 > 1$$

$$N_{cr} = 187{,}8 \left( 2 - \frac{1}{17{,}4} \right) = 365 \text{ kN}$$

$$\bar{\lambda} = \sqrt{\frac{2 \cdot 1{,}84 \cdot 10^{-3} \cdot 355 \cdot 10^6}{365 \cdot 10^3}} = 1{,}89$$

$$\Phi = 0{,}5 \left[ 1 + 0{,}49 (1{,}89 - 0{,}2) + 1{,}89^2 \right] = 2{,}70$$

$$\chi = \frac{1}{2{,}70 + \sqrt{2{,}70^2 - 1{,}89^2}} = 0{,}216$$

$$N_{\mathrm{b,Rd}} = \frac{0{,}216 \cdot 2 \cdot 1{,}84 \cdot 10^{-3} \cdot 355 \cdot 10^6}{1{,}0}$$

$N_{\mathrm{b,Rd}} = 282\,000$ N = 282 kN > 253 kN = $N_{\mathrm{Ed}}$

Check of battened strut in the lower chord for compression and bending

$S_{\mathrm{v}} = 3275$ kN

$$M_{\mathrm{Ed}} = \frac{N_{\mathrm{Ed}} \cdot e_0 + M_{\mathrm{Ed}}^{\mathrm{I}}}{1 - \frac{N_{\mathrm{Ed}}}{N_{\mathrm{cr}}}} = \frac{253 \cdot \frac{12{,}4}{500} + 0}{1 - \frac{253}{365}} = 20{,}4 \text{ kNm}$$ SN027

$$N_{\mathrm{ch,Ed}} = 0{,}5 \cdot N_{\mathrm{Ed}} + \frac{M_{\mathrm{Ed}} \cdot h_0 \cdot A_{\mathrm{ch}}}{2 \cdot I_{\mathrm{eff}}} = 0{,}5 \cdot 253 + \frac{20{,}4 \cdot 0{,}1234 \cdot 1{,}84 \cdot 10^{-3}}{2 \cdot 14{,}0 \cdot 10^{-6}}$$

$N_{\mathrm{ch,Ed}} = 292$ kN

The shear force that the battened strut should be designed for is

$$V_{\mathrm{Ed}} = \frac{\pi \cdot M_{\mathrm{Ed}}}{l_{\mathrm{c}}} = \frac{\pi \cdot 20,4}{12,4} = 5,2 \text{ kN}$$

and the moment from this shear force at the position of the battens is

$$M_{\mathrm{ch,Ed}} = \frac{V_{\mathrm{Ed}} \cdot a}{4} = \frac{5,2 \cdot 1,0}{4} = 1,3 \text{ kNm}$$

Buckling resistance of one chord in lateral direction

$$L_{\mathrm{cr}} = a = 1,0 \text{ m}$$

$$N_{\mathrm{cr}} = \frac{\pi^2 \cdot EI_{\mathrm{ch}}}{L_{\mathrm{cr}}^2} = \frac{\pi^2 \cdot 210 \cdot 10^9 \cdot 79 \cdot 10^{-8}}{1,0^2} = 1\,637\,000 \text{ N} = 1637 \text{ kN}$$

$$\bar{\lambda} = \sqrt{\frac{1,84 \cdot 10^{-3} \cdot 355 \cdot 10^6}{1637 \cdot 10^3}} = 0,632$$

$$\Phi = 0,5\left[1 + 0,49\left(0,632 - 0,2\right) + 0,632^2\right] = 0,806$$

$$\chi = \frac{1}{0,806 + \sqrt{0,806^2 - 0,632^2}} = 0,766$$

$$N_{\mathrm{b,Rd}} = \frac{0,766 \cdot 1,84 \cdot 10^{-3} \cdot 355 \cdot 10^6}{1,0}$$

$N_{\mathrm{b,Rd}} = 500\,000 \text{ N} = 500 \text{ kN} > 293 \text{ kN} = N_{\mathrm{ch,Ed}}$

From the upper chord it could be concluded that the shear force in the chord is not important for this case.

At the batten position, the combination of moment and axial force needs to be checked.

$$\frac{N_{\mathrm{ch,Ed}}}{N_{\mathrm{b,Rd}}} + k_{\mathrm{zz}} \frac{M_{\mathrm{ch,Ed}}}{M_{\mathrm{z,Rd}}} \leq 1,0$$

$$M_{\mathrm{z,Rd}} = M_{\mathrm{pl,Rd}} = \frac{W_{\mathrm{pl}} \cdot f_{\mathrm{y}}}{\gamma_{\mathrm{M0}}} = \frac{32,6 \cdot 10^{-6} \cdot 355 \cdot 10^6}{1,0} = 11\,600 \text{ N} = 11,6 \text{ kNm}$$

$$k_{\mathrm{zz}} = C_{\mathrm{mz}} \left(1 + \left(2 \cdot \bar{\lambda}_{\mathrm{z}} - 0,6\right) \frac{N_{\mathrm{ch,Ed}}}{N_{\mathrm{b,Rd}}}\right) \leq C_{\mathrm{mz}} \left(1 + 1,4 \frac{N_{\mathrm{ch,Ed}}}{N_{\mathrm{b,Rd}}}\right)$$

$C_{\mathrm{mz}} = 0,9$ (sway buckling)

$$k_{\mathrm{zz}} = 0,9\left(1 + (2 \cdot 0,632 - 0,6)\frac{293}{500}\right) = 1,25$$

$$\frac{293}{500} + 1,25 \cdot \frac{1,3}{11,6} = 0,73 < 1,0$$

Tension

$$N_{\mathrm{b,Rd}} = \frac{2 \cdot 1,84 \cdot 10^{-3} \cdot 355 \cdot 10^{6}}{1,0}$$

$N_{\mathrm{b,Rd}} = 1\ 306\ 000$ N = 1306 kN > 720 kN = $N_{\mathrm{Ed}}$ OK

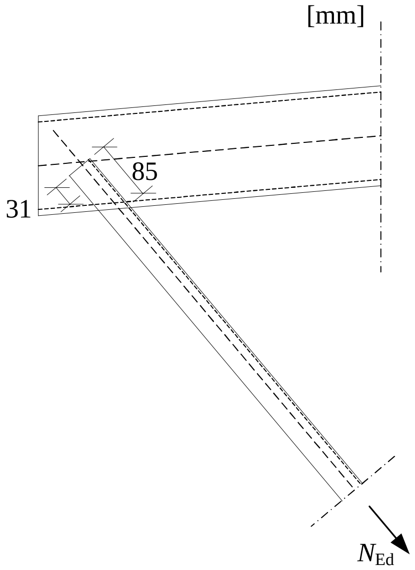
The battens are of the same type as for the upper chord and they can carry the forces without any problems.

Two battened UPE 140 as lower chord is sufficient.

Joints

The web members are welded to the upper and lower chords. Only one joint will be designed here but the procedure is the same for all joints.

Joint 1



The force in the web member is

$N_{Ed} = 214$ kN

This force needs to be transferred through the weld into the upper chord.

The weld will be a fillet weld with

$a = 4$ mm

$f_u = 510\ 10^6$ Pa

The resistance of the weld is determined according to — EN 1993-1-8 §4.5.3.3

$$F_{w,Rd} = f_{vw.d} \cdot a$$

where

$$f_{vw.d} = \frac{f_u / \sqrt{3}}{\beta_w \cdot \gamma_{M2}}$$

$\beta_w$ is a correlation factor, $\beta_w = 0,9$ — Table 4.1

$\gamma_{M2} = 1,25$

$$F_{w,Rd} = \frac{510 \cdot 10^6 / \sqrt{3}}{0,9 \cdot 1,25} \cdot 0,004 = 1\ 047\ 000 \text{ N} = 1047 \text{ kN/m}$$

Design criterion

$$F_{w,Rd} \cdot l \geq N_{Ed}$$

where

$l$ is the required length of the weld

$$l \geq \frac{214}{1047} = 204 \text{ mm}$$

With the design according to the figure above the weld length on one side of the web member is

$l = 85 + 31 = 116$ mm

As the upper chord consists of two sections, the web member will be welded to both yielding a symmetric joint. The total length of the weld is

$l = 2 \cdot 116 = 232$ mm

which is sufficient.

The truss has two UPE 160 as upper chord, UPE 80 as the web members and two UPE 140 as lower chord.

# Quality Record

| | | | |
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| **Reference(s)** | | | |
| **ORIGINAL DOCUMENT** | | | |
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