VTT Technical Research Centre of Finland P.O. Box 1000, FI-02044 VTT Tel. +358 20 722 111 Fax +358 20 722 7001	Job No.	VALCOSS	Sheet	1 of 9	Rev	A
	Job Title	RFCS Stainless Steel Valorisation Project				
	Subject	Design Example 13 – Stainless steel lattice girder made of hollow sections				
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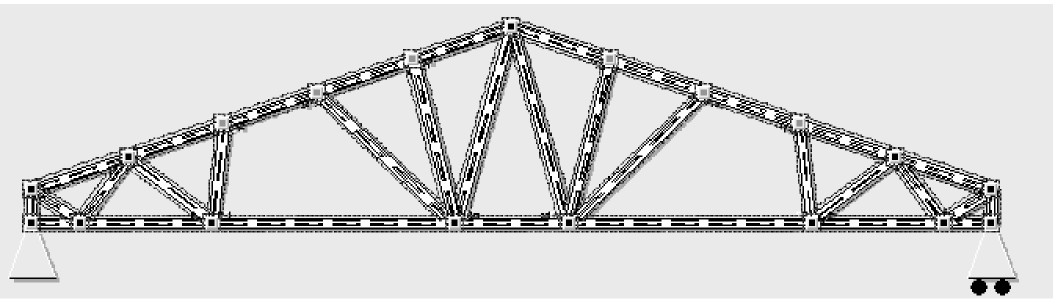
DESIGN EXAMPLE 13 - HOLLOW SECTION LATTICE GIRDER

The lattice girder supports roof glazing and is made of square and rectangular hollow sections of grade 1.4301 stainless steel; a comparison is made between material in two strength levels - the annealed condition (f_y=220 N/mm^2) and in the cold worked condition (strength level CP460, f_y = 460 N/mm^2). Calculations are performed at the ultimate limit state and then at the fire limit state for a fire duration of 30 minutes. For the CP460 material the reduction factors for the mechanical properties at elevated temperatures are conservatively taken as those for grade 1.4318 C850 (Table 7.1).

The structural analysis was carried out using the FE-program WINRAMI marketed by Finnish Constructional Steelwork Association (FCSA) (www.terasrakenneyhdistys.fi). The WINRAMI design environment includes square, rectangular and circular hollow sections for stainless steel structural analysis. WINRAMI solves the member forces, deflections and member resistances for room temperature and structural fire design and also joint resistance at room temperature (it also checks all the geometrical restraints of truss girder joints). In the example, the chord members are modelled as continuous beams and the diagonal members as hinge jointed. According to EN 1993-1-1, the buckling lengths for the chord and diagonal members could be taken as 0,9 times and 0,75 times the distance between nodal points respectively, but in this example conservatively the distance between nodal points has been used as the buckling length. The member forces were calculated by using WINRAMI with profile sizes based on the annealed strength condition. These member forces were used for both the annealed and CP460 girders.

This example focuses on checking 3 members: mainly axial tension loaded lower chord (member 0), axial compression loaded diagonal (member 31) and combination of axial compression and bending loaded upper chord member (member 5). The weight of the girders is also compared.

The welded joints should be designed according to the Section 6.3, which is not included in this example.



Annealed : lower chord 100x60x4, upper chord 80x80x5, corner vertical 60x60x5 diagonals from left to middle: 50x50x3, 50x50x3, 40x40x3, 40x40x3, 40x40x3,40x40x3, 40x40x3.
CP460 : lower chord 60x40x4, upper chord 70x70x4, corner vertical 60x60x5, all diagonals 40x40x3.

Span length 15m, height in the middle 3,13 m, height at the corner 0,5 m.
Weight of girders: Annealed: 407 kg, CP460 307 kg. The weight is not fully optimized.

Actions

Assuming the girder carries equally distributed snow load, glazing and its support structures and weight of girder :

Permanent actions (G): Load of glazing and supports 1 kN/m^2

Dead load of girder (WINRAMI calculates the weight)

Variable actions (Q): Snow load 2 kN/m^2

Load case 1 to be considered (ultimate limit state): $\sum_j \gamma_{G,j} G_{k,j} + \gamma_{Q,1} Q_{k,1}$ — Eq. 2.3

Load case 2 to be considered (fire situation): $\sum_j \gamma_{GA,j} G_{k,j} + \gamma_{\psi 1,1} Q_{k,1}$

Ultimate limit state (room temperature design) — Fire design — EN 1990, EN 1991-1-2

$\gamma_{G,j}$ = 1,35 (unfavourable effects) — $\gamma_{GA,j}$ =1,0

$\gamma_{Q,1}$ = 1,5 — $\gamma_{\psi 1,1}$ = 0,2

(Recommended partial safety factors for actions shall be used in this example)

Factored actions for ultimate limit state:

Permanent action: Load on nodal points: 1,35 x 4,1 kN

Self weight of girder (is included by WINRAMI)

Variable action Load from snow: 1,5 x 8,1 kN

Forces at critical member are:

Forces are determined by the model using profiles in the annealed strength condition

Lower chord member , member 0

Annealed: 100x60x4 mm, CP460: 60x40x4 mm

$N_{t,Ed}$ =142,2 kN, $N_{t,fi,Ed}$ = 46,9 kN

$M_{max,Ed}$ = 0,672 kNm, $M_{max,fire,Ed}$ =0,245 kNm

Upper chord member, member 5

Annealed: 80x80x5 mm, CP460: 70x70x4 mm

$N_{c,Ed}$ = -149,1 kN, $N_{c,fire,Ed}$ = -49,2 kN

$M_{max,Ed}$ = 2,149 kNm, $M_{max,fire,Ed}$ = 0,731 kNm

Diagonal member, member 31

Annealed: 50x50x3mm, CP460: 40x40x3 mm

$N_{c,Ed}$ = -65,9 kN, $N_{c,fire,Ed}$ = -21,7 kN

Material properties

Use material grade 1.4301

Annealed: $f_y = 220$ N/mm^2 $f_u = 550$ N/mm^2 E = 200 000 N/mm^2 — Table 3.1

CP460: $f_y = 460$ N/mm^2 $f_u = 650$ N/mm^2 E = 200 000 N/mm^2 — Section 3.2.4

Partial safety factors — Table 2.1

The following partial safety factors are used throughout the design example:

$\gamma_{M0} = 1,1$, $\gamma_{M1} = 1,1$, $\gamma_{M,fi} = 1,0$

Cross section properties

Annealed

Member 0:	A= 1175 mm^2			$W_{pl,y}$= 37,93·1000 mm^3
Member 5:	A=1436 mm^2	I_y=131,44·10^4 mm^4	i_y=30,3 mm	$W_{pl,y}$ =39,74 ·10^3 mm^3
Member 31:	A=541 mm^2	I_y=19,47·10^4 mm^4	i_y = 19 mm	$W_{pl,y}$ = 9,39·10^3 mm^3

CP460

Member 0:	A= 695 mm			$W_{pl,y}$= 13,16·1000 mm^3
Member 5:	A=1015 mm^2	I_y=72,12·10^4 mm^4	i_y=26,7 mm	$W_{pl,y}$ = 24,76·10^3 mm^3

Classification of the cross-section of member 5 and member 31

Annealed : ε=1,01 CP460 : ε =0,698 — Table 4.2

Assume conservatively that $c = h - 2t$

Annealed 80x80x5 : c = 80 – 10 = 70 mm CP460 70x70x4 : c = 70 – 8 = 62 mm

Annealed 50x50x3 : c = 50 – 6 = 44 mm CP460 40x40x3 : c = 40 – 6 = 34 mm

Flange/web subject to compression: — Table 4.2

Annealed 80x80x5 : c/t = 14 CP460 70x70x4 : c/t = 15,5

Annealed 50x50x3 : c/t = 14,6 CP460 40x40x3 : c/t = 11,3

For Class 1, $\frac{c}{t} \leq 25{,}7\varepsilon$, therefore both profiles are classified as Class 1

Member 31: A=421 mm^2 I_y=9,32·10^4 mm^4 i_y = 14,9 mm $W_{pl,y}$ = 5,72·10^3 mm^3

LOWER CHORD MEMBER, DESIGN IN ROOM AND FIRE TEMPERATURE — (Member 0)

A) Room temperature design

Tension resistance of cross section — Section 4.7.2

$N_{pl,Rd} = A_g f_y / \gamma_{M0}$ — Eq. 4.22

Annealed : $N_{pl,Rd}$ = 1175 mm^2×220 N/mm^2 / 1,1 = 235 kN > 142,2 kN OK.

CP460 : $N_{pl,Rd}$ = 695 mm^2×460 N/mm^2 / 1,1 = 290 kN > 142,2 kN OK.

Moment resistance of cross-section — Sec. 4.7.4

$M_{c,Rd} = W_{pl} f_y / \gamma_{M0}$ — Eq. 4.27

Annealed : $M_{c,Rd} = \dfrac{37{,}93 \times 10^3 \times 220}{1{,}1 \times 10^6} = 7{,}58$ kNm > 0,672 kNm OK.

CP460 : $M_{c,Rd} = \dfrac{13{,}16 \cdot 10^3 \cdot 460}{1{,}1 \cdot 10^6} = 5{,}50$ kNm > 0,672 kNm OK.

Axial tension and bending moment interaction

$\dfrac{N_{Ed}}{N_{Rd}} + \dfrac{M_{y,Ed}}{M_{y,Rd}} \le 1$ — Eq. 5.39

Annealed : $\dfrac{142{,}2\,\text{kN}}{235\,\text{kN}} + \dfrac{0{,}672\,\text{kNm}}{7{,}58\,\text{kNm}} = 0{,}69 \le 1$ OK.

CP460 : $\dfrac{142{,}2\,\text{kN}}{290\,\text{kN}} + \dfrac{0{,}672\,\text{kNm}}{5{,}50\,\text{kNm}} = 0{,}61 \le 1$ OK.

B) Fire temperature design

$\varepsilon_{res} = 0{,}2$ — Section 7.4.7

Steel temperature after 30 min fire Θ = 823 °C

$f_{2,\theta} = f_{0,2proof,\theta} + g_{2,\theta}\,(f_{u,\theta} - f_{0,2proof,\theta})$ — Eq. 7.1

Annealed :

$k_{0,2\ proof,\theta} = 0{,}27\text{-}23/100 \times (0{,}27\text{-}0{,}14) = 0{,}240$ — Section 7.2

$f_{0,2proof,\theta} = 0{,}240 \times 220\ \text{N/mm}^2 = 52{,}8\ \text{N/mm}^2$ — Table 7.1

$g_{2,\theta} = (0{,}35\ \text{-}23/100 \times (0{,}35 - 0{,}38) = 0{,}357$

$f_{u,\theta} = (\,0{,}27\text{-}\ 23/100 \times (0{,}27\text{-}0{,}15)) \times 550\ \text{N/mm}^2 = 133{,}3\ \text{N/mm}^2$

$f_{2,\theta} = 52{,}8\ \text{N/mm}^2 + 0{,}357 \times (133{,}3 - 52{,}8)\ \text{N/mm}^2 = 81{,}5\ \text{N/mm}^2$ — Eq. 7.1

$k_{2,\theta} = 81{,}5/220 = 0{,}37$

CP460 :

$k_{0,2proof,\theta} = 0{,}23\text{-}23/100 \times (0{,}23\text{-}0{,}11) = 0{,}202$ — Section 7.2

$f_{0,2proof,\theta} = 0{,}202 \times 460\ \text{N/mm}^2 = 93{,}1\ \text{N/mm}^2$ — Table 7.1

$g_{2,\theta} = 0{,}25$

$f_{u,\theta} = (\,0{,}24\ \text{-}\ 23/100 \times (0{,}24\text{-}0{,}10)) \times 650\ \text{N/mm}^2 = 135{,}1\ \text{N/mm}^2$

$f_{2,\theta} = 93{,}1\ \text{N/mm}^2 + 0{,}25 \times (135{,}1 - 93{,}1)\ \text{N/mm}^2 = 103{,}6\ \text{N/mm}^2$ — Eq. 7.1

$k_{2,\theta} = 103{,}6\ /460 = 0{,}225$

Tension resistance of cross section

$N_{fi,\theta,Rd} = k_{2,\theta} N_{Rd}\,[\gamma_{M0} / \gamma_{M,fi}]$ — Eq. 7.6

Annealed : $N_{fi,\theta,Rd}$ = 0,370×235 kN×1,1/1,0 = 95,6 kN > 46,9 kN OK.

CP460 : $N_{fi,\theta,Rd}$ = 0,225×290 kN×1,1/1,0 = 59,3 kN > 46,9 kN OK.

Moment resistance of cross-section

$M_{fi,\theta,Rd} = k_{2,\theta} M_{Rd} [\gamma_{M0} / \gamma_{M,fi}]$ — Eq. 7.13

Annealed : $M_{fi,\theta,Rd}$ = 0,370 ×7,58 kNm ×1,1/1,0= 3,08 kNm > 0,245 kNm OK.

CP460 : $M_{fi,\theta,Rd}$ = 0,225 × 5,50 kNm ×1,1/1,0= 1,36 kNm > 0,245 kNm OK.

Axial tension and bending moment interaction

$$\frac{N_{Ed}}{N_{Rd}} + \frac{M_{y,Ed}}{M_{y,Rd}} \leq 1$$ Eq. 5.39

Annealed : $\frac{46{,}9\,\text{kN}}{95{,}6\,\text{kN}} + \frac{0{,}245\,\text{kNm}}{3{,}08\,\text{kNm}} = 0{,}57 \leq 1$ OK.

CP460 : $\frac{46{,}9\,\text{kN}}{59{,}3\,\text{kN}} + \frac{0{,}245\,\text{kNm}}{1{,}36\,\text{kNm}} = 0{,}97 \leq 1$ OK.

DIAGONAL MEMBER DESIGN IN ROOM AND FIRE TEMPERATURE (Member 31)

Buckling length = 1253 mm

A) Room temperature design

$N_{b,Rd} = \chi A f_y / \gamma_{M1}$ — Eq. 5.2a

Annealed :

$$\bar{\lambda} = \frac{L_{cr}}{i}\frac{1}{\pi}\sqrt{(f_y / E)} = \frac{1253}{19}\frac{1}{\pi}\sqrt{(220/200000)} = 0{,}696$$ Eq. 5.5a

$$\varphi = 0{,}5(1+\alpha(\bar{\lambda}-\bar{\lambda}_0)+\bar{\lambda}^2) = 0{,}5(1+0{,}49(0{,}696-0{,}4)+0{,}696^2) = 0{,}815$$ Eq. 5.4

$$\chi = \frac{1}{\varphi+\sqrt{(\varphi^2-\bar{\lambda}^2)}} = \frac{1}{0{,}815+\sqrt{(0{,}815^2-0{,}696^2)}} = 0{,}807$$ Eq. 5.3

$N_{b,Rd}$ = 0,807×541 mm²×220 N/mm²/1,1 = 87,3 kN > 65,9 kN OK.

CP460 :

$$\bar{\lambda} = \frac{L_{cr}}{i}\frac{1}{\pi}\sqrt{(f_y / E)} = \frac{1253}{14{,}9}\frac{1}{\pi}\sqrt{(460/200000)} = 1{,}283$$ Eq. 5.5a

$$\varphi = 0{,}5(1+\alpha(\bar{\lambda}-\bar{\lambda}_0)+\bar{\lambda}^2) = 0{,}5(1+0{,}49(1{,}283-0{,}4)+1{,}283^2) = 1{,}540$$ Eq. 5.4

$$\chi = \frac{1}{\varphi+\sqrt{(\varphi^2-\bar{\lambda}^2)}} = \frac{1}{1{,}540+\sqrt{(1{,}540^2-1{,}283^2)}} = 0{,}418$$ Eq. 5.3

$N_{b,Rd}$ = 0,418×421 mm²×460 N/mm²/1,1 = 73,6 kN > 65,9 kN OK.

B) Fire temperature design

$\varepsilon_{res} = 0{,}2$ — Section 7.4.7

Steel temperature after 30 min fire Θ= 832 °C

Annealed :

$k_{0{,}2proof,\theta} = 0{,}27\text{-}32/100\times(0{,}27\text{-}0{,}14) = 0{,}228$ — Section 7.2

$k_{E,\theta} = 0{,}63\text{-}32/100\times(0{,}63\text{-}0{,}45) = 0{,}572$ — Table 7.1

CP460 :

$k_{0{,}2proof,\theta} = 0{,}23\text{-}32/100\times(0{,}23\text{-}0{,}11) = 0{,}191$ — Section 7.2

$k_{E,\theta} = 0{,}52\text{-}32/100\times(0{,}52\text{-}0{,}35) = 0{,}465$ — Table 7.1

$$N_{b,fi,t,Rd} = \chi_{fi} A k_{0{,}2proof,\theta} f_y / \gamma_{M,fi}$$ — Eq. 7.8

Annealed :

$$\bar{\lambda}_\theta = \bar{\lambda}\sqrt{(k_{0{,}2proof,\theta}/k_{E,\theta})} = 0{,}696\sqrt{(0{,}228/0{,}572)} = 0{,}439$$ — Eq. 7.12

$$\varphi_\theta = 0{,}5(1+\alpha(\bar{\lambda}_\theta - \bar{\lambda}_0) + \bar{\lambda}_\theta^2) = 0{,}5(1+0{,}49(0{,}439\text{-}0{,}4)+0{,}439^2) = 0{,}606$$ — Eq. 7.11

$$\chi_{fi} = \frac{1}{\varphi_\theta + \sqrt{(\varphi_\theta^2 - \bar{\lambda}_\theta^2)}} = \frac{1}{0{,}606+\sqrt{(0{,}606^2-0{,}439^2)}} = 0{,}977$$ — Eq. 7.10

$N_{b,fi,t,Rd} = 0{,}977\times541\ mm^2\times0{,}228\times220\ N/mm^2/1{,}0 = 26{,}5\ kN > 21{,}7\ kN$ OK.

CP460 :

$$\bar{\lambda}_\theta = \bar{\lambda}\sqrt{(k_{0{,}2proof,\theta}/k_{E,\theta})} = 1{,}283\sqrt{(0{,}191/0{,}465)} = 0{,}822$$ — Eq. 7.12

$$\varphi_\theta = 0{,}5(1+\alpha(\bar{\lambda}_\theta - \bar{\lambda}_0) + \bar{\lambda}_\theta^2) = 0{,}5(1+0{,}49(0{,}822\text{-}0{,}4)+0{,}822^2) = 0{,}941$$ — Eq. 7.11

$$\chi_{fi} = \frac{1}{\varphi_\theta + \sqrt{(\varphi_\theta^2 - \bar{\lambda}_\theta^2)}} = \frac{1}{0{,}941+\sqrt{(0{,}941^2-0{,}822^2)}} = 0{,}714$$ — Eq. 7.10

$N_{b,fi,t,Rd} = 0{,}714\times421\ mm^2\times0{,}191\times460\ N/mm^2/1{,}0 = 26{,}4\ kN > 21{,}7\ kN$ OK.

UPPER CHORD MEMBER DESIGN IN ROOM AND FIRE TEMPERATURE — (Member 5)

Buckling length = 1536 mm

A) Room temperature design

$$\frac{N_{Ed}}{(N_{b,Rd})_{min}} + k_y\left(\frac{M_{y,Ed}+N_{Ed}e_{Ny}}{\beta_{W,y}W_{pl,y}f_y/\gamma_{M1}}\right) \le 1{,}0$$ — Eq. 5.40

Annealed *:*

$\beta_{W,y} = 1{,}0$ class 1 cross section — Sec. 5.5.2

$k_y = 1{,}0+2(\lambda_y - 0{,}5)N_{Ed}/N_{b,Rd,y}$, but $1{,}2 \le k_y \le 1{,}2+2N_{Ed}/N_{b,Rd,y}$

$$\bar{\lambda} = \frac{L_{cr}}{i}\frac{1}{\pi}\sqrt{(f_y/E)} = \frac{1536}{30{,}3}\frac{1}{\pi}\sqrt{(220/200000)} = 0{,}535$$ — Eq. 5.5a

$\varphi = 0{,}5(1+\alpha(\bar{\lambda}-\bar{\lambda}_0)+\bar{\lambda}^2)$ = 0,5(1+0,49(0,535-0,4)+0,535^2) = 0,676 — Eq. 5.4

$$\chi = \frac{1}{\varphi+\sqrt{(\varphi^2-\bar{\lambda}^2)}} = \frac{1}{0{,}676+\sqrt{(0{,}676^2-0{,}535^2)}} = 0{,}917$$ — Eq. 5.3

$N_{b,Rd,y}$ = 0,917×1436 mm^2×220 N/mm^2/1,1 = 263,3 kN > 149,1 kN — Eq. 5.2a

k_y = 1,0+2(0,535-0,5) ×149,1/263,3 = 1,039 because calculated value is less than 1,2, the value of k_y = 1,2.

$$\frac{149{,}1}{263{,}3}+1{,}2\left(\frac{2{,}149\times1000^2}{1{,}0\times39{,}74\times10^3\times220/1{,}1}\right) = 0{,}890 \quad < 1{,}0 \text{ OK.}$$ — Eq. 5.40

CP460

$\beta_{W,y}$ = 1,0 class 1 cross section — Sec. 5.5.2

$$\bar{\lambda} = \frac{L_{cr}}{i}\frac{1}{\pi}\sqrt{(f_y/E)} = \frac{1536}{26{,}7}\frac{1}{\pi}\sqrt{(460/200000)} = 0{,}878$$ — Eq. 5.5a

$\varphi = 0{,}5(1+\alpha(\bar{\lambda}-\bar{\lambda}_0)+\bar{\lambda}^2)$ = 0,5(1+0,49(0,878-0,4)+0,878^2) = 1,002 — Eq. 5.4

$$\chi = \frac{1}{\varphi+\sqrt{(\varphi^2-\bar{\lambda}^2)}} = \frac{1}{1{,}002+\sqrt{(1{,}002^2-0{,}878^2)}} = 0{,}673$$ — Eq. 5.3

$N_{b,Rd,y}$ = 0,673×1015 mm^2 ×460 N/mm^2/1,1 =285,6 kN > 149,1 kN — Eq. 5.2a

k_y = 1,0+2(0,878-0,5)149,1/285,6 = 1,394, but 1,2 ≤ k_y ≤ 1,2 + 2(149,1/285,6) = 2,244, thus k_y = 1,394

$$\frac{149{,}1}{285{,}6}+1{,}394\left(\frac{2{,}149\times1000^2}{1{,}0\times24{,}76\times10^3\times460/1{,}1}\right) = 0{,}81 \quad < 1{,}0 \text{ OK.}$$ — Eq. 5.40

B) Fire temperature design

ε_{res} = 0,2 — Section 7.4.7
Steel temperature 80x80x5 mm Θ= 810 °C
Steel temperature 70x70x4 mm Θ= 823 °C

Annealed :

$k_{0,2proof,\theta}$ = 0,27-10/100× (0,27-0,14) = 0,257 — Section 7.2
$f_{0,2proof,\theta}$ = 0,257×220 N/mm^2 = 56,5 N/mm^2 — Table 7.1
$g_{2,\theta}$ = (0,35 -10/100× (0,35 – 0,38) = 0,353
$f_{u,\theta}$ = (0,27- 10/100× (0,27-0,15)) ×550 N/mm^2 = 141,9 N/mm^2
$f_{2,\theta}$ = 56,5N/mm^2 + 0,353× (141,9 – 56,5) N/mm^2 = 86,6 N/mm^2 — Eq. 7.1
$k_{2,\theta}$ = 86,6 /220 = 0,394
$k_{E,\theta}$ = 0,63 – 10/100× (0,63-0,45) = 0,612

CP460 :

$k_{0,2proof,\theta}$ = 0,23-23/100× (0,23-0,11) = 0,202 — Section 7.2, Table 7.2

$f_{0,2proof,\theta}$ = 0,202×460 N/mm² = 93,1 N/mm²

$g_{2,\theta}$ = 0,25

$f_{u,\theta}$ = (0,24- 23/100× (0,24-0,10)) ×650 N/mm² = 135,1N/mm²

$f_{2,\theta}$ = 93,1 N/mm² + 0,25× (135,1 – 93,1) N/mm² = 103,6 N/mm² — Eq. 7.1

$k_{2,\theta}$ = 103,6 /460 = 0,225

$k_{E,\theta}$ = 0,52 – 23/100·(0,52-0,35) = 0,481

$$\frac{N_{fi,Ed}}{\chi_{\min,fi} A_g k_{0,2proof,\theta} \frac{f_y}{\gamma_{M,fi}}} + \frac{k_y M_{y,fi,Ed}}{M_{y,fi,\theta,Rd}} \le 1,0$$ Eq. 7.24

Annealed :

$\bar{\lambda}_\theta = \bar{\lambda}\sqrt{(k_{0,2proof,\theta}/k_{E,\theta})} = 0,535\sqrt{(0,257/0,612)} = 0,347$ — Eq. 7.12

$\varphi_\theta = 0,5(1+\alpha(\bar{\lambda}_\theta - \bar{\lambda}_0) + \bar{\lambda}_\theta^2)$ = 0,5(1+0,49(0,347-0,4)+0,347²) = 0,547 — Eq. 7.11

$$\chi_{fi} = \frac{1}{\varphi_\theta + \sqrt{(\varphi_\theta^2 - \bar{\lambda}_\theta^2)}} = \frac{1}{0,547 + \sqrt{(0,547^2 - 0,347^2)}} = 1,03 = 1,0$$ Eq. 7.10

$$k_y = 1 - \frac{\mu_y N_{fi,Ed}}{\chi_{y,fi} A_g k_{0,2proof,\theta} f_y / \gamma_{M,fi}} \le 3$$ Eq. 7.28

$$\mu_y = (1,2\beta_{M,y} - 3)\bar{\lambda}_{y,\theta} + 0,44\beta_{M,y} - 0,29 \le 0,8$$ Eq. 7.29

$\chi_{\min,fi} A_g k_{0,2proof,\theta} f_y / \gamma_{M,fi}$ =1,0×1436 mm²×0,257×220 N/mm²/1,0= 81,2 kN > 49,2 kN OK. — Eq. 7.8

$M_{y,fi,\theta,Rd} = k_{2,\theta}[\gamma_{M0}/\gamma_{M,fi}]M_{Rd}$ = 0,394 ×1,1/1,0×39,74×10³×220/1000² = 3,79 kNm >0,731 kNm OK. — Eq. 7.13

ψ = -0,487 kNm/0,731 kNm = -0,666 — Table 7.3

$\beta_{M,y}$ = 1,8-0,7×ψ = 2,466

μ_y = (1,2×2,466-3)0,347 + 0,44×2,466 – 0,29 = 0,78, — Eq. 7.29

because calculated value is less than 0,8, the value of μ_y = 0,8

k_y = 1- 0,80×49,2 kN/81,2 kN = 0,515 — Eq. 7.28

$$\frac{49,2}{81,2} + 0,515 \times \frac{0,731}{3,79} = 0,70 < 1,0 \quad \text{OK.}$$ Eq. 7.24

CP460 :

$\bar{\lambda}_\theta = \bar{\lambda}\sqrt{(k_{0,2proof,\theta}/k_{E,\theta})} = 0,878\sqrt{(0,202/0,481)} = 0,569$ — Eq. 7.12

$\varphi_\theta = 0,5(1+\alpha(\bar{\lambda}_\theta - \bar{\lambda}_0) + \bar{\lambda}_\theta^2)$ = 0,5(1+0,49(0,569-0,4)+0,569²) = 0,703 — Eq. 7.11

$$\chi_{fi} = \frac{1}{\varphi_\theta + \sqrt{(\varphi_\theta^2 - \bar{\lambda}_\theta^2)}} = \frac{1}{0,703 + \sqrt{(0,703^2 - 0,569^2)}} = 0,896$$ Eq. 7.10

$\chi_{\min,fi} A_g k_{0,2proof,\theta} f_y / \gamma_{M,fi}$ =0,896×1015 mm²×0,202×460 N/mm²/1,0=84,5 kN >49,2 kN OK. — Eq. 7.8

$M_{y,fi,\theta,Rd} = k_{2,\theta}[\gamma_{M0}/\gamma_{M,fi}]M_{Rd} = 0,225 \times 1,1/1,0 \times 24,76 \times 10^3 \times 460/1000^2 = 2,81$ kNm >0,731 kNm OK. — Eq. 7.13

ψ = -0,487 kNm/0,731 kNm = -0,666 — Table 7.3

$\beta_{M,y}$ = 1,8-0,7×ψ = 2,466

μ_y = (1,2×2,466-3)0,569 + 0,44×2,466 – 0,29 = 0,771, — Eq. 7.29

because calculated value is less than 0,8, the value of μ_y = 0,8

k_y = 1- 0,80 × 49,2 kN/84,5 kN = 0,534 — Eq. 7.28

$$\frac{49,2}{84,5} + 0,534 \times \frac{0,731}{2,81} = 0,72 < 1,0 \quad \text{OK.}$$ — Eq. 7.24