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Parameters of crane

Description	Value	Unit
Nominal weights of crane and hoistload		
Weight of crane bridge	74.1	kN
Weight of crab	12.7	kN
Hoist load	100.0	kN
Crane Geometry		
Span of crane bridge	20	m
Minimum distance between hoist and rail	1.65	m
Rail type	2	
Width of top of rail	0.06	m
Height of rail	0.06	m
Travel and hoist Speeds		
Steady hoisting speed	10	m/min
Longitudinal travel speed	36	m/min
Lateral crab travel speed	24	m/min
Hoist Type and Characteristics		
Crane tType (EN 1991-3 Annex B-Table B.1)	6	
Spectrum type (EN 1991-3 Table 2.11)	S3	
Hoist class	HC3	
Type of the load lifting mechanism	Hook	
Hoistload free to swing	True	
Wheels and Wheel Drives		
Number of wheels	4	
Wheel spacing	3.15	mm
Type of wheel drive	Single	
Number of single wheel drives	2	
Behavior of drives	Changes Smoothly	
Combination of wheel pairs	Independent Fixed-Fixed	
Clearance between rail and wheel flange	0.025	m

CRANE GIRDER PARAMETERS

Wheel loads on top flange	True
Use of transverse stiffener	False
Distance between transverse stiffeners	0
Crane flange connection case	Crane rail rigidly fixed to the flange
Distance between lateral restrains for vibration	6

-1991-1, EN-1993-1, EN-1993-6

Crane runway beam design results:

Description	Formula	Value	Requirement	Ratio
For FrameID : 0				
EN1993 Part 1-1				
Resistance of cross section	6.2	0.44		0.44
Buckling Resistance of member	6.61, 6.62	0.74		0.74
EN1993 Part 6				
Check against web breathing	7.4	35.00	≤ 120	0.29
Vertical deflection	Tables 7.1 and 7.2	0.0030		0.30
Horizontal deflection	Tables 7.1 and 7.2	0.0000	≤ L/600	0.00
Check against bottom flange vibration	7.6	74.2307	≤ 250	0.30
Check of the connection between top flange and web against fatigue	9.4.2	0.0047		0.00
Check against reversible behaviour	7.5	True		
EN1993 Part 1-5				
Interaction ratio between transverse force	7.2	0.36	≤ 1.0	0.36

-1991-1, EN-1993-1, EN-1993-6

LOAD ANALYSIS [EN 1991-3]

Crane Loads: The dynamic effects of a crane structure are taken into account by magnification factors which are defined in Eurocode 1 - Part 3.

Dynamic Factors:

ϕ_1 – *vibrational excitation of the crane structure due to lifting of the hoist load of the ground*

$$\phi_{1,min} = 0.9$$

$$\phi_{1,max} = 1.1$$

ϕ_2 – *dynamic effects of transferring the hoist load from the ground to the crane*

$$\phi_2 = \phi_{2,min} + \beta_2 v_h = 1.150 + 0.510 \times \frac{10.000}{60} = 1.235$$

The crane is HC3therefore $\phi_{2,min} = 1.150$ *and* $\beta_2 = 0.510$

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ϕ_4 – *dynamic effect induced when travelling on rail track or runways*

$$\phi_4 = 1.000$$

[Eurocode 1 - Part 3 Table 2.4]

ϕ_5 – *This magnification factor takes into account the dynamic effects caused by drive forces and depends on the characteristic of the drive forces.*

$$\phi_5 = 1.500$$

The drive force change smoothly:

[Eurocode 1 - Part 3 Table 2.6]

ϕ_6 – *dynamic effects of test load.*

$\phi_{6,dyn}$ – *when test load moved by drives in the way the crane is used*

$$\phi_{6,dyn} = 0.5 \times (1 + \phi_2) = 0.5 \times (1 + 1.235) = 1.118$$

$\phi_{6,stat}$ – *when a test load is not moved by drives.*

$$\phi_{6,stat} = 1.000$$

ϕ_7 – *elastic effect of impact on buffers.*

$$\phi_7 = 1.25 + 0.7 \times (\xi - 0.5) = 1.25 + 0.7 \times (0.752 - 0.5) = 1.530$$

Vertical Loads:

$$LC_1 = \phi_1(Self\,Weight) + \phi_2(Hoist\,Load)$$

Maximum wheel load:

$$Q_{r,max} = \frac{1}{2} \times \left[\phi_1 \times \frac{Q_{br}}{2} + \frac{l - e_{min}}{l} \times (\phi_1 \times Q_{cr} + \phi_2 \times Q_h)\right]$$

$$= \frac{1}{2} \times \left[1.1 \times \frac{74.134}{2} + \frac{20.000 - 1.650}{20.000} \times (1.1 \times 12.660 + 1.235 \times 100.000)\right]$$

$$= 83.431\,kN$$

Minimum wheel load:

$$Q_{r,min} = \frac{1}{2} \times \left[\phi_1 \times \frac{Q_{br}}{2} + \frac{e_{min}}{l} \times (\phi_1 \times Q_{cr} + \phi_2 \times Q_h)\right]$$

$$= \frac{1}{2} \times \left[1.1 \times \frac{74.134}{2} + \frac{1.650}{20.000} \times (1.1 \times 12.660 + 1.235 \times 100.000)\right]$$

$$= 26.056\,kN$$

$$LC_{3,7} = Self\,Weight + \eta\,(Hoist\,Load)$$

Maximum wheel load:

$$Q_{r,max} = \frac{1}{2} \cdot \left[\frac{Q_{br}}{2} + \frac{l - e_{min}}{l} \cdot Q_{cr}\right]$$

$$= \frac{1}{2} \cdot \left[\frac{74.134}{2} + \frac{20.000 - 1.650}{20.000} \cdot 12.660\right]$$

$$= 24.341\,kN$$

Minimum wheel load:

$$Q_{r,min} = \frac{1}{2} \cdot \left[\frac{Q_{br}}{2} + \frac{e_{min}}{l} \cdot Q_{cr}\right]$$

$$= \frac{1}{2} \cdot \left[\frac{74.134}{2} + \frac{1.650}{20.000} \cdot 12.660\right]$$

$$= 19.056\,kN$$

$LC_{4,5,6} = \phi_4(Self\ Weight) + \phi_4(Hoist\ Load)$

Maximum wheel load:

$$Q_{r,max} = \frac{\phi_4}{2} \times \left[\frac{Q_{br}}{2} + \frac{l - e_{min}}{l} \times (Q_{cr} + Q_h) \right]$$

$$= \frac{1.000}{2} \times \left[\frac{74.134}{2} + \frac{20.000 - 1.650}{20.000} \times (12.660 + 100.000) \right]$$

$$= 70.216\,kN$$

Minimum wheel load:

$$Q_{r,min} = \frac{\phi_4}{2} \times \left[\frac{Q_{br}}{2} + \frac{e_{min}}{l} \times (Q_{cr} + Q_h) \right]$$

$$= \frac{1.000}{2} \times \left[\frac{74.134}{2} + \frac{1.650}{20.000} \times (12.660 + 100.000) \right]$$

$$= 23.181\,kN$$

$LC_{4,5,6} = (Self\ Weight) + (Hoist\ Load)$

Maximum wheel load:

$$Q_{r,max} = \frac{1}{2} \times \left[\frac{Q_{br}}{2} + \frac{l - e_{min}}{l} \times (Q_{cr} + Q_h) \right]$$

$$= \frac{1}{2} \times \left[\frac{74.134}{2} + \frac{20.000 - 1.650}{20.000} \times (12.660 + 100.000) \right]$$

$$= 70.216\,kN$$

Minimum wheel load:

$$Q_{r,min} = \frac{1}{2} \times \left[\frac{Q_{br}}{2} + \frac{e_{min}}{l} \times (Q_{cr} + Q_h) \right]$$

$$= \frac{1}{2} \times \left[\frac{74.134}{2} + \frac{1.650}{20.000} \times (12.660 + 100.000) \right]$$

$$= 23.181\,kN$$

Horizontal Loads:

[*Eurocode 1 - Part 3 (2.7.3)*]

Longitudinal and transverse loads caused by acceleration and braking of crane.

...Horizontal longitudinal force:

$$H_L = \phi_5 \times K \times \frac{1}{n_r}$$

where:

n_r − *is the number of rails*

Drive Force K:

$$K = \mu \times \sum Q_{r,min}$$

$$= \mu \times m_w \times Q_{rmin}$$

$$= 0.200 \times 2 \times 19.056 = 7.622$$

where:

μ − *friction factor*

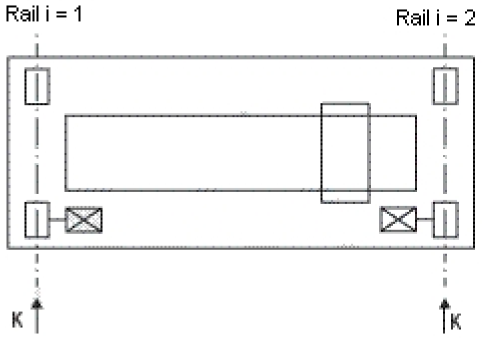

Figure : Defination of the drive force

Therefore:

$$H_L = 1.500 \times 7.622 \times \frac{1}{2} = 5.717$$

Horizontal Transverse Forces:

$$H_{T,1} = \phi_5 \times \xi_2 \times \frac{M}{a}$$

$$H_{T,2} = \phi_5 \times \xi_1 \times \frac{M}{a}$$

Position of center of mass of crane:

$$\xi_1 = \frac{\sum Q_{r,max}}{\sum Q_r} = \frac{2 \times 70.216}{74.134 + 12.660 + 100.000} = 0.752$$

$$\xi_2 = 1 - \xi_1 = 1 - 0.752 = 0.248$$

Moment caused by drive forces not acting at the center of mass

$$M = K \times l_s = K \times (\xi_1 - 0.5) \times l$$

$$= 7.622 \times (0.752 - 0.5) \times 20.000 = 38.387 kN\,m$$

Therefore: :

$$H_{T,1} = 1.500 \times 0.248 \times \frac{38.387}{3.150} = 4.537$$

$$H_{T,2} = 1.500 \times 0.752 \times \frac{38.387}{3.150} = 13.742$$

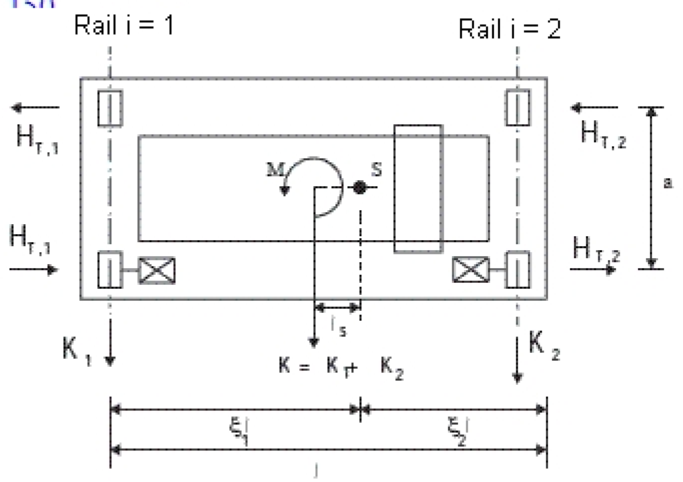

Figure : Definiation of the transverse loads $H_{T,i}$

Horizontal Loads:

Horizontal loads and the guide force caused by skewing

Guide force

$$S = f \times \lambda_{sj} \times \sum Q_r$$

Horizontal longitudinal forces:

$$H_{s,i,j,L} = f \times \lambda_{s,i,j,L} \times \sum Qr$$

Horizontal Transverse Forces:

$$H_{s,i,j,T} = f \times \lambda_{s,i,j,T} \times \sum Qr$$

Where :

$i -$ *is the rail number*

$j -$ *is the wheel pair number*

$L -$ *stands for longitudinal forces*

Non positive factor:

$$f=0.3\left(1-e^{-250\alpha}\right)\leq 0.3$$

Skewing angle :

$$\alpha_F=\frac{0.75x}{a}\ (x=Clearance)$$

$$=\frac{0.75\times 0.025}{3.150}=0.006$$

$$\alpha_v=\frac{y}{a}\ (y=wear\ of\ rail\ and\ guide\ means\geq 0.10b)$$

$$=\frac{0.006}{3.150}=0.0019$$

$$\alpha_0=0.001$$

$$\alpha=\alpha_F+\alpha_v+\alpha_0\leq 0.015\rightarrow\alpha=0.009$$

$$f=0.3\left(1-e^{-250 \cdot 0.009}\right)=0.267$$

Combination of wheel pairs : :Independent Fixed-Fixed

Distance to instantaneous slide pole: :

$$h=\frac{\sum e_j^2}{}=\frac{3.150^2}{}=3.150m$$

Force Factor:

$$\lambda_{sj}=1-\frac{\sum e_j}{nh}=\frac{3.15}{2\times 3.15}=0.5$$

$$\lambda_{s,1,j,L}=0$$

Guide force :

$$S=f\times\lambda_{sj}\times\sum Q_r$$

$$S=0.267\times 0.500\times(74.134+12.660+100.000)$$

$$S=24.959\ kN$$

Horizontal Transverse Force :

$$H_{s,1,1,T}=f\times\lambda_{s,i,j,T}\times\sum Qr$$

$$=0.267\times 0.000\times(74.134+12.660+100.000)kN$$

$$H_{s,1,1,T}=6.195$$

MEHMET KAPAR
MKA YAZILIM VE MUHENDISLIK HIZM TIC LTD STI

-1991-1

Summary of the vertical and horizontal load for the runway girder

Group of Loads			1	2	3	4	5	6
Magnification factor which are considered for the group of load			φ1= 1.10	φ1 = 1.10	φ1= 1.10	φ1= 1.00	φ4= 1.00	φ4= 1.00
			φ2= 1.24	φ3 = 1.00	φ4= 1.50	φ5= 1.50		
			φ5= 1.50	φ5 = 1.50				
Vertical Loads	Self Weight of the crane	Qr(min)	26.06	25.09	19.06	23.18		23.18
		Qr min	20.96	20.96	19.06	19.06	19.06	19.06
	Self-Weight of the crane and hoist load	Qr(max)	26.78	26.78		24.34	24.34	24.34
		Qr max	83.43	72.65		70.22	70.22	70.22
Horizontal Loads	Accelaration of the crane	HL1	5.72		5.72	5.72	-	-
		HL2	11.43	11.43	11.43	11.43		
		HT1		4.54	4.54	4.54		
		HT2	4.54	13.74	13.74	13.74		
Horizontal Loads	Skewing of the crane	HS1L	-	-	-	-	0.00	23.18
		HS2L					0.00	
		HS1T					6.19	
		HS2T					17.59	
	Accelaration of Crab	HT3	-	-	-	-	-	11.27

-1991-1, EN-1993-1, EN-1993-6

Design Summary   EN1993- 1,EN1993- 4

Frame ID	Maxiumum Forced Load Combination	Horizontal deflection Ratio	Buckling Check Ratio	Section Check Ratio	Max Ratio
0		0.302	0.737	0.442	0.737

RESISTANCE OF CROSS SECTION [EN 1993-1-1 (6.2)]

Design Summary

Check	Reference	Ratio
Section Capacity	6.2	0.33

CROSS-SECTION CHECK [EN1993.1.1(6.2)]

Loading

Axial Force $N_{Ed} = 0.0$ kN

Shear Force of Major Axis $V_{Ed,y} = 89$ kN

Shear Force of Minor Axis $V_{Ed,z} = 0.0$ kN

Moment Force of Major Axis $M_{y,Ed} = -90.3$ kN m

Moment Force of Minor Axis $M_{z,Ed} = 0.0$ kN m

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Cross-Section Properties

Section : HEA280 (Hot Rolled)

h : 270 mm

b : 280 mm

t_w : 8 mm

t_f : 13 mm

r : 24 mm

A : 94.8 cm^2

I_{yy} : 13339.86 cm^4

i_y : 11.9 cm

I_{zz} : 4759.06 cm^4

i_z : 7.09 cm

$W_{el,y}$: 339.93 cm^3

$W_{el,z}$: 339.93 cm^3

$W_{pl,y}$: 1083.32 cm^3

$W_{pl,z}$: 515.4 cm^3

$W_{eff,y}$: 962.94 cm^3

$W_{eff,z}$: 339.73 cm^3

Steel Grade : S275

Material Properties

Modulus of Elasticity, $E = 2.100E+8$ kN/m^2

Shear Modulus, $G = 8.077E+7$ kN/m^2

Yield Strength, $f_y = 275000$ kN/m^2

-1991-1, EN-1993-1, EN-1993-6

– *Compression Resistance* [EN 1993- 6.2.4]

$$N_{c,Rd}=\frac{A \times f_y}{\gamma_{M0}}=\frac{0.009475\times275000}{1.1}=2368.84\,kN$$

$$\frac{N_{Ed}}{N_{c,Rd}}=\frac{|0.0|}{|2368.84|}=0.0\leq1\rightarrow Satisfactory$$

– *Shear Resistance About Major Axis* [EN 1993−6.2.6]

$$V_{pl,y,Rd}=\frac{A_{vz}\times(f_y/\sqrt{3})}{\gamma_{M0}}=\frac{0.01\times(275000/\sqrt{3})}{1.1}=421.95\,kN$$

$$\tau_{t,Ed}=\frac{T_{Ed}}{I_t}\times max\{t_w,t_f\}=\frac{0.0}{6.21E\text{-}07}max\{0.008,0.013\}=0.0\,kN/m^2$$

$$\tau_{t,Ed}=0\rightarrow V_{pl,y,T,Rd}=V_{pl,y,Rd}$$

$$\frac{V_{Ed,y}}{V_{pl,y,T,Rd}}=\frac{|89|}{|421.95|}=0.211\leq1\rightarrow Satisfactory$$

– *Shear Resistance About Minor Axis* [EN 1993−6.2.6]

$$V_{Ed,z}=0\rightarrow Satisfactory$$

– *Bending Resistance About Major Axis* [EN 1993−6.2.5]

$$V_{Ed,y}\leq0.5V_{pl,T,Rd}\rightarrow 89\leq0.5\times421.95\,(210.98\,kN)$$

$\rightarrow$ *No moment reduction needed* (6.2.8)

$$M_{c,y,Rd}=M_{pl,y,Rd}=\frac{W_{pl,y}\times f_y}{\gamma_{M0}}=\frac{0.00108\times275000}{1.1}=270.83\,kN\,m$$

– *Bending Resistance About Minor Axis* [EN 1993−6.2.5]

$V_{Ed,z}=0\rightarrow$ *No moment reduction needed* (6.2.8)

$$M_{c,z,Rd}=M_{pl,z,Rd}=\frac{W_{pl,z}\times f_y}{\gamma_{M0}}=\frac{0.000515\times275000}{1.1}=128.85\,kN\,m$$

– *Section Check Ratio* [EN 1993−6.2.9]

$$N_{Ed}=0\ \rightarrow$$

$$\frac{M_{y,Ed}+\Delta M_{y,Ed}}{M_{y,Rd}}+\frac{M_{z,Ed}+\Delta M_{z,Ed}}{M_{z,Rd}}\leq1$$

$$\frac{|-90.3+0.0|}{270.83}+\frac{|0.0+0.0|}{128.85}=0.333\leq1\rightarrow Satisfactory$$

BUCKLING RESISTANCE OF MEMBER [1993-1-1 (6.3)]

~ *BUCKLING RESISTANCE OF MEMBER* [EN 1993.1− 1(6.3)]

The buckling resistance of the member is sufficient if the following conditions are fullfilled.

(No compression force, $N_{Ed}=0, M_z=0, \Delta M_z=0$)

$M_{y,Ed}=90.3\ kN\ m$

$$k_{yy}\frac{M_{y,Ed}+\Delta M_{y,Ed}}{\chi_{LT}\frac{M_{y,Rk}}{\gamma_{M1}}}\leq 1\ (6.61)$$

$$k_{zy}\frac{M_{y,Ed}+\Delta M_{y,Ed}}{\chi_{LT}\frac{M_{y,Rk}}{\gamma_{M1}}}\leq 1\ (6.62)$$

Design Summary

Check	Reference	Ratio
Lateral Torsional Buckling For Crane Girder	6.3.1.4	0.74
Compression and biaxial bending	6.61	0.56
Compression and biaxial bending	6.62	0.28

Loading

Axial Force $N_{Ed}=0.0\ kN$

Bending Moment of Major Axis $M_{y,Ed}=90.3\ kN\ m$

Bending Moment of Minor Axis $M_{z,Ed}=0.0\ kN\ m$

Combination Name

Cross-Section Properties

Section : HEA280 (Hot Rolled)

h : 270 mm

b : 280 mm

t_w : 8 mm

t_f : 13 mm

r : 24 mm

A : 94.8 cm^2

I_{yy} : 13339.86 cm^4

i_y : 11.9 cm

I_{zz} : 4759.06 cm^4

i_z : 7.09 cm

$W_{el,y}$: 339.93 cm^3

$W_{el,z}$: 339.93 cm^3

$W_{pl,y}$: 1083.32 cm^3

$W_{pl,z}$: 515.4 cm^3

$W_{eff,y}$: 962.94 cm^3

$W_{eff,z}$: 339.73 cm^3

Steel Grade : S275

Material Properties

Modulus of Elasticity , $E = 2.100E+8\ kN/m^2$

Shear Modulus, $G = 8.077E+7\ kN/m^2$

Yield Strength , $f_y = 275000\ kN/m^2$

– Buckling curves definiation: [EN 1993.1.1(Table6.2)]

h/b : 0.96

Imperfection factor or strong axis buckling : $\alpha_y = 0.34$

Imperfection factor or strong axis buckling : $\alpha_z = 0.49$

– Reduction factor for Major axis [EN 1993.1.1(6.3.1.2)]

$$N_{cr,y} = \frac{\pi^2 \times E \times I_{yy}}{L_{cr,y}^2} = \frac{\pi^2 \times 2.100E+8 \times 0.000133}{6^2} = 7680.11\ kN$$

$$N_{Ed} = 0 \rightarrow \frac{N_{Ed}}{N_{cr,y}} \leq 0.04\ thus;\ \chi_y = 1.000\ \ [EN\ 1993.1.1(6.3.1.2(4))]$$

– Reduction factor for Minor axis [EN 1993.1.1(6.3.1.2)]

$$N \quad = \frac{\pi^2 \times E \times I_{zz}}{N_{Ed}} = \frac{\pi^2 \times 2.100E+8 \times 4.76E-05}{} = 2739.92\ kN$$

$$N_{Ed} = 0 \rightarrow \frac{N_{Ed}}{N_{cr,z}} \leq 0.04\ thus;\ \chi_z = 1.000\ \ [EN\ 1993.1.1(6.3.1.2(4))]$$

-1991-1, EN-1993-1, EN-1993-6

– Auxilary Terms [EN 1993.1.1(Annex A)]

$N_{Ed}=0 \rightarrow \mu_y, \mu_z=1$

$$w_y=\frac{W_{pl,y}}{W_{el,y}} \leq 1.5=min\left\{\frac{0.00108}{0.00034}=3.19, 1.5\right\}=1.1$$

$$w_z=\frac{W_{pl,z}}{W_{el,z}} \leq 1.5=min\left\{\frac{0.000515}{0.00034}=1.52, 1.5\right\}=1.5$$

– Equivalent uniform momemt factor for major axis ($C_{m,y,0}$)

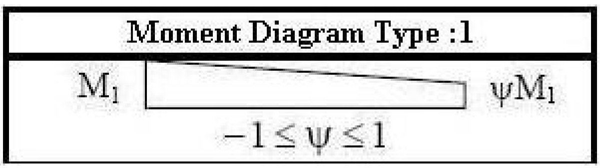
[EN 1993.1.1(Table A.2)]

Moment Diagram Type : Type 1

$$C_{m,y,0}=0.79+0.21\psi_y+0.36(\psi_y-0.33)\frac{N_{Ed}}{N_{cr,y}}$$

$N_{Ed}=0 \rightarrow$

$$C_{m,y,0}=0.79+0.21\times 0.967=0.993$$



– Equivalent uniform momemt factor for minor axis ($C_{m,z,0}$)

[EN 1993.1.1(Table A.2)]

Moment Diagram Type : Type 1

$$C_{m,z,0}=0.79+0.21\psi_z+0.36(\psi_z-0.33)\frac{N_{Ed}}{N_{cr,z}}$$

$N_{Ed}=0 \rightarrow$

$$C_{m,z,0}=0.79+0.21\times 0.967=1$$

– Resistance to lateral torsional buckling

Section Class of Major Axis : 1

$C_1=1.29 \quad C_2=0 \quad C_3=1$

$z_j=0 \rightarrow$

$$s_{q,0}=\sqrt{\frac{I_w}{I_{zz}}+\frac{L^2}{\pi^2}\times\frac{G\times I_t}{E\times I_{zz}}}=\sqrt{\frac{7.86E\text{-}07}{4.76E\text{-}05}+\frac{6000^2}{\pi^2}\times\frac{8.077E{+}7\times 6.21E\text{-}07}{2.100E{+}8\times 4.76E\text{-}05}}=0.282$$

$$M_{cr,0}=C_1\times\frac{\pi^2\times E\times I_{zz}}{L^2}\times s_{q,0}=1.29\times\frac{\pi^2\times 2.100E{+}8\times 4.76E\text{-}05}{6000^2}\times 0.282=248.93\ kN\,m$$

$$\bar{\lambda}_0=\sqrt{\frac{W_{ply}\times f_y}{M_{cr,0}}}=\sqrt{\frac{0.00108\times 275000}{248.93}}=0.763$$

-1991-1, EN-1993-1, EN-1993-6

The elastic torsional buckling force $(N_{cr,T})$:

$$i_s^2 = i_y^2 + i_z^2 + a^2 = 0.119^2 + 0.0709^2 + 0.0^2 = 0.0191\ kN^2$$

where

a is the distance between the centroid of the member and the centroid of the restraining members

L_t *is the distance between the torsional restraints*

$$N_{cr,T} = \frac{1}{i_s^2}\left(\frac{\pi^2 \times E \times I_w}{L_t^2} + G \times I_t\right)$$

$$= \frac{1}{0.0191}\left(\frac{\pi^2 \times 2.100E{+}8 \times 7.86E{-}07}{6000^2} + 8.077E{+}7 \times 6.21E{-}07\right) = 4994.35\ kN$$

$$N_{cr,TF} = min(N_{cr,T}; N_{cr,y}; N_{cr,z}) = 4994.35\ kN\ (Doubly\ Symmetrical\ Section)$$

$$N_{Ed} = 0 \rightarrow \lambda_{0,lim} = 0.2\sqrt{C_1} = 0.227$$

– *Reduction factor for Lateral Buckling* χ_{LT} [EN 1993.1.1(6.3.2.2)]

$C_1 = 1.29 \quad C_2 = 1.56 \quad C_3 = 0.753$

Section = *HEA280 (Hot Rolled)*

Section Class = 1

$h/b = 0.964$

$$\alpha_{LT} = 1 - \frac{I_t}{I_{yy}} \geq 0 = Max\left(1 - \frac{6.21E{-}07}{0.000133}, 0\right) \rightarrow \alpha_{LT} = 0.995$$

$$s_q = \sqrt{\frac{I_w}{I_{zz}} + \frac{L^2}{\pi^2} \times \frac{G \times I_t}{E \times I_{zz}} + (C_2 \times z_g - C_3 \times z_j)^2}$$

$$s_q = \sqrt{\frac{7.86E{-}07}{4.76E{-}05} + \frac{6^2}{\pi^2} \times \frac{8.077E{+}7 \times 6.21E{-}07}{2.100E{+}8 \times 4.76E{-}05} + (1.56 \times 0.135 - 0.753 \times 0.0)^2} = 0.282$$

$$M_{cr} = C_1 \times \frac{\pi^2 \times E \times I_{zz}}{L^2}(s_q(C_2 \times z_g - C_3 \times z_j))$$

$$M_{cr} = 1.29 \times \frac{\pi^2 \times 2.100E{+}8 \times 4.76E{-}05}{6^2} \times (0.282 \times (1.56 \times 0.135 - 0.753 \times 0.0))$$

$$M_{cr} = 248.93\ kN\ m$$

$$\bar{\lambda}_{LT} = \sqrt{\frac{W_{ply} \times f_y}{M_{cr}}} = \sqrt{\frac{0.00108 \times 275000}{248.93}} = 1.09$$

$$\Phi_{LT} = 0.5\left[1 + \alpha_{LT}\left(\bar{\lambda}_{LT} - 0.2\right) + \bar{\lambda}_{LT}^2\right] = 0.5[1 + 0.995 \times (1.09 - 0.2) + 1.09^2] = 1.19$$

$$\chi_{LT} = \frac{1}{\Phi_{LT} + \sqrt{\Phi_{LT}^2 - \bar{\lambda}_{LT}^2}} \leq 1 = min\left(\frac{1}{1.19 + \sqrt{1.19^2 - 1.09^2}}, 1\right) = 0.6$$

$\lambda_0 > \lambda_{0,lim} \rightarrow$

$$C_{my} = C_{my,0} + (1 - C_{my,0})\frac{\sqrt{\varepsilon_y} a_{LT}}{1+\sqrt{\varepsilon_y} a_{LT}} = 0.993 + (1 - 0.993)\frac{\sqrt{8658.97} \times 0.995}{1+\sqrt{8658.97} \times 0.995} = 1$$

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

$$C_{mLT} = C_{my}{}^2 \frac{a_{LT}}{\sqrt{\left(1 - \frac{N_{Ed}}{N_{cr,z}}\right)\left(1 - \frac{N_{Ed}}{N_{cr,T}}\right)}} \geq 1$$

$$C_{mLT} = max\left(1^2 \frac{0.995}{\sqrt{\left(1 - \frac{0.0}{2739.92}\right)\left(1 - \frac{0.0}{4994.35}\right)}}, 1\right) = 1$$

-1991-1, EN-1993-1, EN-1993-6

–Cij Factors [EN 1993.1.1(Table A.1)]

$Section\ class = 1$

$N_{Rk} = A \times f_y = 0.00948 \times 275000 = 2605.72\ kN$

$n_{pl} = \frac{N_{Ed}}{N_{Rk}/\gamma_{M1}}, N_{Ed} = 0 \rightarrow n_{pl} = 0.0$

$a_{LT} = max\left(1 - \frac{I_T}{I_{yy}}, 0\right) = max\left(1 - \frac{6.21E\text{-}07}{0.000133}, 0\right) = 0.995$

$M_{y,Ed} = 0\ \ veya\ \ M_{z,Ed} = 0\ \ \rightarrow\ b_{LT} = 0$

$C_{yy} = 1 + \left(w_y - 1\right) \times \left[\left(2 - \frac{1.6}{w_y} \times C_{my}^2 \times \bar{\lambda}_{max} - \frac{1.6}{w_y} \times C_{my}^2 \times \bar{\lambda}_{max}^2\right) n_{pl} - b_{LT}\right] \geq \frac{W_{el,y}}{W_{pl,y}}$

$\frac{W_{el,y}}{W_{pl,y}} = \frac{0.00033993}{0.0010833} = 0.31$

$n_{pl} = 0.0, b_{LT} = 0.0 \rightarrow$

$C_{yy} = 1 \geq 0.31 \rightarrow\ C_{yy} = 1$

$M_{y,Ed} = 0\ \ or\ \ M_{z,Ed} = 0\ \ \rightarrow d_{LT} = 0$

$C_{zy} = 1 + \left(w_y - 1\right)\left[\left(2 - 14\frac{C_{my}^2 \times \bar{\lambda}_{max}^2}{w_y^5}\right) \times n_{pl} - d_{LT}\right] \geq 0.6 \times \sqrt{\frac{w_y}{w_z}} \times \frac{W_{el,y}}{W_{pl,y}}$

$0.6 \times \sqrt{\frac{w_y}{w_z}} \times \frac{W_{el,y}}{W_{pl,y}} = 0.6 \times \sqrt{\frac{1.1}{1.5}} \times \frac{0.00033993}{0.0010833} = 0.16$

$n_{pl} = 0, d_{LT} = 0 \rightarrow$

$C_{zy} = 1 \geq 0.16$

$C_{zy} = 1$

– *Interaction Factors* (k_{ij}) (*Table A*.1)

Section Class = 1

$$k_{yy} = C_{my} \times C_{mLT} \times \frac{\mu_y}{1 - \frac{N_{Ed}}{N_{cr,y}}} \times \frac{1}{C_{yy}}$$

$$= 1 \times 1 \frac{1}{1 - \frac{0.0}{7680.11}} \times \frac{1}{1} = 1$$

$$k_{zy} = C_{my} \times C_{mLT} \times \frac{\mu_z}{1 - \frac{N_{Ed}}{N_{cr,y}}} \times \frac{1}{C_{zy}} \times 0.6\sqrt{\frac{w_y}{w_z}}$$

$$= 1 \times 1 \times \frac{1}{1 - \frac{0.0}{7680.11}} \times \frac{1}{1} \times 0.6\sqrt{\frac{1.1}{1.5}} = 0.513$$

– *Capacity Ratios for buckling* [*EN* 1993.1.1(6.3.3)]

$(M_{z,Ed} = 0,\ \Delta M_z = 0,\ N_{Ed} = 0)$

$$k_{yy} \frac{|M_{y,Ed}| + |\Delta M_{y,Ed}|}{\chi_{LT} \frac{M_{y,Rk}}{\gamma_{M1}}} \leq 1 \quad (6.61)$$

$$1 \times \frac{|90.3| + |0.0|}{0.6 \times \frac{297.91}{1.1}} = 0.556 \leq 1 \rightarrow \textit{Satisfactory}$$

$$k_{zy} \frac{|M_{y,Ed}| + |\Delta M_{y,Ed}|}{\chi_{LT} \frac{M_{y,Rk}}{\gamma_{M1}}} \leq 1 \quad (6.62)$$

$$0.513 \times \frac{|90.3| + |0.0|}{0.6 \times \frac{297.91}{1.1}} = 0.285 \leq 1 \rightarrow \textit{Satisfactory}$$

So the buckling resistance of the member is Satisfactory.

-1991-1, EN-1993-1, EN-1993-6

WEB LOADS CHECK [EN 1993-1-5 (7.2)]

For Lc :

FrameID	Loc	Leff	Ss	n1	n2	$\text{Ratio} = \dfrac{n_2 + 0.8 \cdot n_1}{1.4}$
0	0.00	0.127	0.101	0.442	0.148	0.359
	1.20	0.127	0.101	0.078	0.148	0.359
	1.50	0.127	0.101	0.090	0.148	0.359
	3.00	0.127	0.101	0.142	0.148	0.359
	4.35	0.127	0.101	0.182	0.148	0.359
	4.50	0.127	0.101	0.127	0.148	0.359
	6.00	0.127	0.101	0.428	0.148	0.359

SLS DEFLECTIONS CHECKS [EN 1993-6 (Table 7.1 and 7.2)]

$-SLS\ deflections\ checks\ [EN\ 1993-6\ (Table\ 7.1\ and\ 7.2)]$

$L = 6000\ m$

$\delta_{y,max} = 0.000\ m$

$\delta_{y,max} \leq \frac{L}{600} = 10 \rightarrow Satisfactory$

$\delta_{z,max} = 0.003\ m$

$\delta_{z,max} \leq min\left(\frac{L}{600}, 25mm\right) = 10 \rightarrow Satisfactory$

$\rightarrow Deflection\ checks\ are\ Satisfactory$

EN 1993-6 (Table 7.4)

WEB BREATHING [EN 1993-6 (Table 7.4)]

$-\,Web\,Breathing\quad [EN\ 1993-6(7.4)]$

$b/t_w = 0.28/0.008 \leq 120 \rightarrow Sonuc$

1993-6 (7.5)

For Lc :

			Leff	SxEdser	SzEdser	TEdser
0	0.00	83.43	0.15	89798.67	81968.01	29929.87
	1.20	83.43	0.15	15925.04	81968.01	29630.35
	1.50	83.43	0.15	18237.45	81968.01	2567.98
	3.00	83.43	0.15	28802.59	81968.01	2193.58
	4.35	83.43	0.15	36890.64	81968.01	1856.61
	4.50	83.43	0.15	25730.05	81968.01	25168.31
	6.00	83.43	0.15	86789.66	81968.01	25542.72

		Checks				
		1	2	3	4	
0	0.00	True	True	True	True	True
	1.20	True	True	True	True	True
	1.50	True	True	True	True	True
	3.00	True	True	True	True	True
	4.35	True	True	True	True	True
	4.50	True	True	True	True	True
	6.00	True	True	True	True	True

REVERSIBLE BEHAVIOUR [EN 1993-6 (7.5)]

$$-Reversible\,Behaviour\quad [EN\;1993-6\,(7.5)]$$

$$\sigma_{x,Ed,ser}=\frac{N}{A}+\frac{M_3}{W_{ely}}+\frac{M_2}{W_{elz}}$$

$$\sigma_{z,Ed,ser}=\frac{F_{z,Ed}}{l_{eff}\cdot t_w}\qquad (5.1a)$$

$$\tau_{Ed,ser}=\frac{V_2}{A_{vz}}$$

$Limited\,Stress\,Checks:$

$$\sigma_{x,Ed,ser}\leq f_y/\gamma_{M,ser}\qquad (7.2a)$$

$$\tau_{Ed,ser}\leq f_y/(\sqrt{3}\cdot\gamma_{M,ser})\qquad (7.2b)$$

$$\sqrt{(\sigma_{x,Ed,ser})^2+3(\tau_{Ed,ser})^2}\leq f_y/\gamma_{M,ser}\qquad (7.2c)$$

$$\sqrt{(\sigma_{x,Ed,ser})^2+(\sigma_{z,Ed,ser})^2-(\sigma_{x,Ed,ser})\cdot(\sigma_{z,Ed,ser})+3(\tau_{Ed,ser})^2}\leq f_y/\gamma_{M,ser}\qquad (7.2e)$$

VIBRATION OF THE BOTTOM FLANGE [EN 1993-6:2006]

$-Vibration\ of\ the\ bottom\ flange\quad [EN\ 1993-6:2006]$

$$I_{zz}=\frac{t_f \cdot b^3}{12}=\frac{0.013 \cdot 0.28^3}{12}=2.38E\text{-}05\ m^4$$

$$i_z=\sqrt{\frac{I_{zz}}{t_f \cdot b}}=\sqrt{\frac{2.38E\text{-}05}{0.013 \cdot 0.28}}=0.081\ m$$

$$L/i_z=6/0.081=74.231 \leq 250 \rightarrow Satisfactory$$

CHECK AGAINST FATIGUE [EN 1993-6, 1991-3]

Width of the foot of the rail, according to figure 5.2, *EN* 1993 − 6

$b_f = b_r = 0.060\,m$

Second moment of area, about rail horizontal centridal axis, allowing for wear by reducting t_r *by* 12.5% *according to* 5.6.2(2)*EN* 1993 − 6 $(t_r = 0.875\,t_r)$

Distance between lower section edge and its center of gravity

$z_{cg} = t_r/2 = 0.060/2 = 0.026\,m$

$I_{r,0.12.5} = b_r \times t_r^3/12 = 0.060 \times 0.060^3/12 = IR\,m^4$

Effective loaded lenght calculation according to Table 5.1 *EN* 1993 − 6

$b_{eff} = min\{b_f \times h_r + t_f, b\} = min(0.060 + tfKesit, 0.280) = 0.133\,m$

$I_{f,eff} = b_{eff} \times t_f^3/12 = 0.133 \times 0.013^3/12 = 2.435\text{E-}8\,m^4$

Distance between lower edge and center of gravity of the combined section comprising the rail and a flange with an effective lenght of b_{eff}, *according to Figure* 5.3, *EN* 1993 − 6

$z = t_f/2 \times t_f \times b_{eff} + (t_f + z_{cg})A_{rail}/(t_f \times b_{eff} + A_{rail})$

$= 0.013/2 \times 0.133 + (0.013 + 0.026) \times 0.000/(0.013 \times 0.133 + 0.000)$

$= 0.007\,m$

$I_{rf} = I_{f,eff} + b_{eff} \times t_f \times (z - t_f/2)^2 + I_{r,0.125} + A_{0.125} \times (z - t_f - z_{cg})^2$

$= 2.435\text{E-}8 + 0.133 \times 0.013 \times (0.007 - 0.013/2)^2 + 7.235\text{E-}7$

$+ 0.000 \times (0.007 - 0.013 - 0.026)^2$

$= 7.479\text{E-}7\,m^4$

Crane rail rigidly fixed to the flange (*Case* 1):

$l_{eff} = 3.25 \times \left(\frac{I_{rf}}{t_w}\right)^{\frac{1}{3}} = 3.25 \times \left(\frac{7.479\text{E-}7}{0.008}\right)^{\frac{1}{3}} = 0.148\,m$

$\phi_{fat} = (1 + \phi_2)/2 = (1 + 1.235)/2 = 1.118$

$Q_{e-\sigma} = Q_{maxi} \times \phi_{fat} \times \lambda_\sigma = 83.431 \times 1.118 \times 0.198 = 18.460$

$Q_{e-\tau} = Q_{maxi} \times \phi_{fat} \times \lambda_\tau = 83.431 \times 1.118 \times 0.378 = 35.242$

EN 1993-6, 1991-3

$\sigma_{oz,Ed} = F_{z,Ed}/(t_w \times l_{eff}) = 18.460/(0.008 \times 0.148)) = 15644.277 kN/m^2$

$$\eta = \sqrt{0.75 \times a \times t_w^3 \Big/ I_t \times Sinh^2\left(\frac{\pi \times (h-2c)}{a}\right) \Big/ \left(Sinh\left(\frac{2\pi \times (h-2c)}{a}\right) - \frac{2\pi(h-2c)}{a}\right)}$$

$where a = Distance between transverse stiffners$

$$\eta = \sqrt{0.75 \times 6.000 \times 0.008^3 \Big/ 6.21E\text{-}7 \times Sinh^2\left(\frac{\pi \times 0.176}{6.000}\right) \Big/ \left(Sinh\left(\frac{2\pi \times 0.176}{6.000}\right) - \frac{2\pi \times 0.176}{6.000}\right)}$$

$= 4.672$

$$\sigma_{T,Ed} = \frac{6F_{z,Ed} \times e_y}{a \times t_w^2} \times \eta \times tanh(\eta) = \frac{6 \times 18.460 \times 0.004}{6.000 \times 0.008^2} = 5497.426 kN \Big/ m^2$$

Damage equivalent direct shear range:

$\Delta\sigma_{E2} = \sigma_{oz,Ed} + \sigma_{T,Ed} = 15644.277 + 5497.426 = 21141.703 kN/m^2$

$\Delta\sigma_c = Detail\ Category = 160000 kN$ EN 1993−6 *Table* 8.10

$T = Q_{e-\tau} \times (1 + d_{wheels}/L) = 35.242 \times (1 + 0.000/6.000) = 35.242 kN$

Shear force due to bending

$$T_1 = T \times t_f \times b \times \left(\frac{h}{2 \times t_w \times \iota_{yy}}\right) = 35.242 \times 0.013 \times 0.280 \times \left(\frac{0.270}{2 \times 0.008 \times 0.00013}\right) = 16227.837$$

Additional shear stresses due to wheel concentrated load

$T_2 = 0.2 \times \sigma_{oz,Ed} = 0.2 \times 15644.277 = 3128.855$

Damage equivalent shear stress range:

$\Delta\tau_{E2} = T_1 + 2T_2 = 16227.837 + 2 \times 3128.855 = 22485.548$

$\Delta\tau_c = Detail\ Category = 160000 kN$ EN 1993−6 *Table* 8.10

$D_i = Ratio\ between\ top\ flange\ and\ web$ EN 1993−6 (F:9.4)

$$D_i = \left[\frac{\gamma_{Ff} \times \Delta\sigma_{E2}}{\Delta\sigma_c/\gamma_{Mf}}\right]^3 + \left[\frac{\gamma_{Ff} \times \Delta\tau_{E2}}{\Delta\tau_c/\gamma_{Mf}}\right]^5 = \left[\frac{1.000 \times 21141.703}{160000/1.250}\right]^3 + \left[\frac{1.000 \times 22485.548}{160000/1.250}\right]^5$$

$D_i = 0.00467 \leq\leq 1.00$ *Satisfactory*