

Design example for the application of

**EUROCODE 1 - Part 3: Actions induced by cranes
and machinery**

and

EUROCODE 3 - Part 6: Crane supporting structures

-----2nd DRAFT-----

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Foreword

This report demonstrates the application of Eurocode 1 - Part 3: “Actions induced by cranes and machinery” and the application of Eurocode 3 - Part 6: “Crane supporting structures” for a top mounted crane.

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Part A:

Design example for Eurocode 1 - Part 3: Actions induced by cranes and machinery

1. Data of the crane

1.1 General

The geometric properties which are assumed in the design example are summarized in section 1.2 and the mechanical details of the crane are defined in section 1.3. Further assumptions for the crane are given where they are necessary.

1.2 Geometric properties

The following geometric properties are assumed in the design example for the crane:

Span length of the crane bridge:	15,00 m
Wheel spacing a :	2,50 m
Min. spacing between crab and supports $e_{\min}$:	0,00 m

1.3 Mechanical properties

The following mechanical properties are defined for the crane:

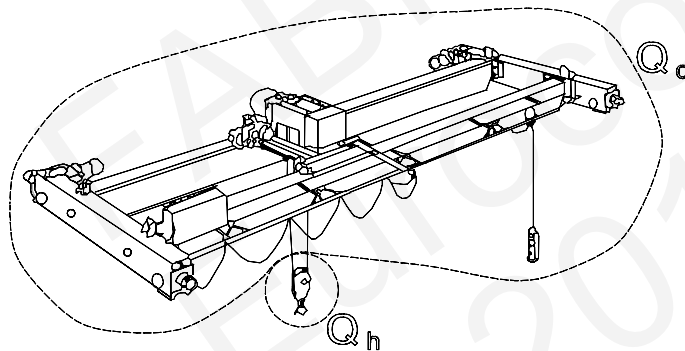


Figure 1.1: Definition of the hoist load and the self-weight of a crane

Self-weight of the crane Q_{c1} :	60,0 kN
Self-weight of the crab Q_{c2} :	10,0 kN
Hoistload $Q_{h,nom}$:	100,0 kN

2. Dynamic magnification factors $\varphi_1 - \varphi_5$

2.1 General

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

2.2 Dynamic magnification factor φ_1

The magnification factor φ_1 takes into account vibrational excitation of the crane structure due to lifting the hoist load off the ground and is to be applied to the self-weight of the crane.

$$\varphi_1 = 1,1 \text{ (upper value of the vibrational pulses)}$$

(EC 1- P 3: Table 2.4)

2.3 Dynamic magnification factor φ_2

The magnification factor φ_2 is only to be applied to the hoistload and takes into account the dynamical effects when the hoistload is transferred from the ground to the crane. The magnification factor depends on the hoisting class of the crane. It is assumed that the crane is classified as HC 3. Recommendations about the classification of cranes are given in Annex B of Eurocode 1 - Part 3.

Assumption:

Hoisting class of the crane: HC 3

$v_h = 6 \text{ m/min}$

$$\varphi_2 = \varphi_{2,\min} + \beta_2 v_h = 1,15 + 0,51 \cdot \frac{6}{60} = 1,20 \quad (\text{EC 1- P 3: Table 2.4})$$

The parameters $\varphi_{2,\min}$ and β_2 were obtained from table 2.5 of EC 1- Part 3.

2.4 Dynamic magnification factor φ_3

The magnification factor φ_3 considers the dynamical effects when a payload is sudden released. These dynamic effects occur at cranes which use magnets as hoist tools. In the design example it is assumed that no part of the payload is able to sudden release.

Assumption:

No sudden release or dropped part of the load.

$$\varphi_3 = 1,00 \quad (\text{EC 1- P 3: Table 2.4})$$

2.5 Dynamic magnification factor φ_4

This magnification factor is to be applied to the self-weight of the crane and to the payload, if the rail track observes not the tolerances specified in ENV 1993 - 6.

Assumption:

The tolerances for rail tracks are observed as specified in ENV 1993 - 6.

$$\varphi_4 = 1,00 \quad (\text{EC 1- P 3: Table 2.4})$$

2.6 Dynamic magnification factor φ_5

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

Assumption:

The drive force change smoothly.

$$\varphi_5 = 1,50 \quad (\text{EC 1- P 3: Table 2.6})$$

3.2 Unloaded crane

The minimum vertical wheel load apply at a crane runway girder when the crane is unloaded.

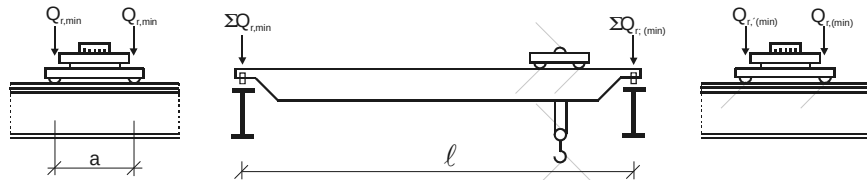


Figure 3.1: Load arrangement of the unloaded crane to obtain the minimum loading on the runway beam

a) Load group 1,2

$$\varphi_I = 1,1: \quad \Rightarrow Q_{C1,k} = 1,1 \cdot 60,0 = 66,0 \text{ kN}$$

$$\Rightarrow Q_{C2,k} = 1,1 \cdot 10,0 = 11,0 \text{ kN}$$

$$\sum Q_{r,(min)} = \frac{1}{2} \cdot 66,0 + 11,0 = 44,0 \text{ kN} \Rightarrow Q_{r,(min)} = 22,0 \text{ kN}$$

$$\sum Q_{r,min} = \frac{1}{2} \cdot 66,0 = 33,0 \text{ kN} \quad \Rightarrow Q_{r,min} = 16,5 \text{ kN}$$

b) Load group 3,4,5,6

$$\varphi_I = 1,0: \quad \Rightarrow Q_{c1,k} = 1,0 \cdot 60,0 = 60,0 \text{ kN}$$

$$\Rightarrow Q_{c2,k} = 1,0 \cdot 10,0 = 10,0 \text{ kN}$$

$$\sum Q_{r,(min)} = \frac{1}{2} \cdot 60,0 + 10,0 = 40,0 \text{ kN} \Rightarrow Q_{r,(min)} = 20,0 \text{ kN}$$

$$\sum Q_{r,min} = \frac{1}{2} \cdot 60,0 = 30,0 \text{ kN} \quad \Rightarrow Q_{r,min} = 15,0 \text{ kN}$$

3.3 Loaded crane

The maximum vertical wheel loads apply at a crane runway girder when the crane is loaded.

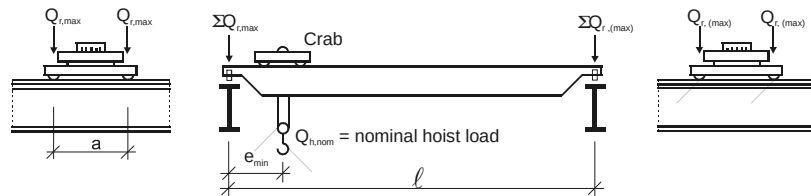


Figure 3.2: Load arrangement of the loaded crane to obtain the maximum loading on the runway beam

a) Load group 1

$$\varphi_I = 1,1: \quad \Rightarrow Q_{c1,k} = 1,1 \cdot 60,0 = 66,0 \text{ kN}$$

$$\Rightarrow Q_{c2,k} = 1,1 \cdot 10,0 = 11,0 \text{ kN}$$

$$\varphi_2 = 1,2: \quad \Rightarrow Q_{h,k} = 1,2 \cdot 100,0 = 120,0 \text{ kN}$$

$$\sum Q_{r,(max)} = \frac{1}{2} \cdot 66,0 = 33,0 \text{ kN} \quad \Rightarrow \quad Q_{r,(max)} = 16,5 \text{ kN}$$

$$\sum Q_{r,max} = \frac{1}{2} \cdot 66,0 + 11,0 + 120,0 = 164,0 \text{ kN} \Rightarrow Q_{r,max} = 82,0 \text{ kN}$$

b) Load group 2

$$\varphi_1 = 1,1: \quad \Rightarrow Q_{c1,k} = 1,1 \cdot 60,0 = 66,0 \text{ kN}$$

$$\Rightarrow Q_{c2,k} = 1,1 \cdot 10,0 = 11,0 \text{ kN}$$

$$\varphi_3 = 1,0: \quad \Rightarrow Q_{h,k} = 1,0 \cdot 100,0 = 100,0 \text{ kN}$$

$$\sum Q_{r,(max)} = \frac{1}{2} \cdot 66,0 = 33,0 \text{ kN} \quad \Rightarrow \quad Q_{r,(max)} = 16,5 \text{ kN}$$

$$\sum Q_{r,max} = \frac{1}{2} \cdot 66,0 + 11,0 + 100,0 = 144,0 \text{ kN} \Rightarrow Q_{r,max} = 72,0 \text{ kN}$$

c) Load group 4,5,6

$$\varphi_4 = 1,0: \quad \Rightarrow Q_{c1,k} = 1,0 \cdot 60,0 = 60,0 \text{ kN}$$

$$\Rightarrow Q_{c2,k} = 1,0 \cdot 10,0 = 10,0 \text{ kN}$$

$$\varphi_4 = 1,0: \quad \Rightarrow Q_{h,k} = 1,0 \cdot 100,0 = 100,0 \text{ kN}$$

$$\sum Q_{r,(max)} = \frac{1}{2} \cdot 60,0 = 30,0 \text{ kN} \quad \Rightarrow \quad Q_{r,(max)} = 15,0 \text{ kN}$$

$$\sum Q_{r,max} = \frac{1}{2} \cdot 60,0 + 10,0 + 100,0 = 140,0 \text{ kN} \Rightarrow Q_{r,max} = 70,0 \text{ kN}$$

4. Determination of the horizontal loads

4.1 General

In this section the following horizontal loads are calculated:

- horizontal loads caused by acceleration and deceleration of the crane bridge, see 4.2;
- horizontal loads caused by skewing of the crane bridge, see 4.3;
- horizontal loads caused by acceleration or braking of the crab, see 4.4;

4.2 Caused by acceleration and deceleration of the crane

4.2.1 Drive force K

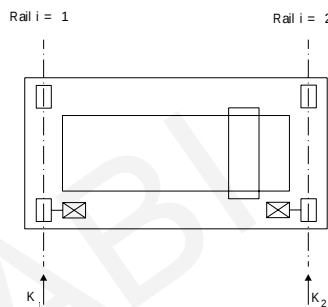


Figure 4.1: Definition of the drive force

Friction factor: $\mu = 0,2$ (EC 1- P 3: 2.7.3(4))

Number of single wheel drivers: $m_w = 2$

$$\sum Q_{r,min}^* = m_w \cdot Q_{r,min} = 2 \cdot 15,0 = 30,0 \text{ kN} \quad (\text{EC 1- P 3: 2.7.3(3)})$$

$$K = \mu \cdot \sum Q_{r,min}^* = 0,2 \cdot 30,0 = 6,0 \text{ kN} \quad (\text{EC 1- P 3: 2.7.3(3)})$$

4.2.2 Longitudinal loads

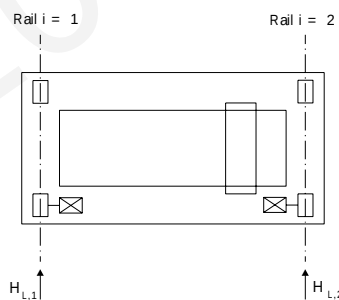


Figure 4.2: Longitudinal horizontal loads $H_{L,i}$

Number of runway beams: $n_R = 2$

$$H_{L,1} = H_{L,2} = \varphi_5 \cdot \frac{K}{n_r} = 1,5 \cdot \frac{6,0}{2} = 4,5 \text{ kN} \quad (\text{EC 1- P 3: 2.7.2(2)})$$

4.2.3 Transverse loads H_T

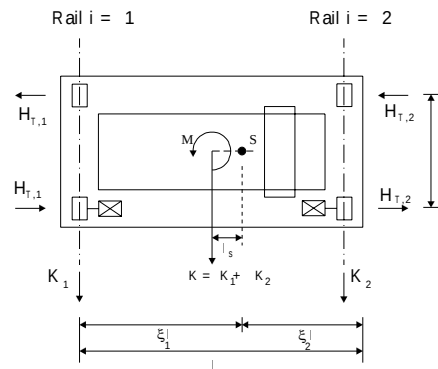


Figure 4.3: Definition of the transverse loads $H_{T,i}$

$$\xi_1 = \frac{\sum Q_{r,\max}}{\sum Q_r} \quad (\text{EC 1- P 3: 2.7.2(3)})$$

$$\sum Q_r = \sum Q_{r,\max} + \sum Q_{r,(\max)} = 140,0 + 30,0 = 170,0 \text{ kN} \quad (\text{EC 1- P 3: 2.7.2(3)})$$

$$\xi_1 = \frac{140,0}{170,0} = 0,82 \quad (\text{EC 1- P 3: 2.7.2(3)})$$

$$\xi_2 = 1 - \xi_1 = 0,18 \quad (\text{EC 1- P 3: 2.7.2(3)})$$

$$l_s = (\xi_1 - 0,5) \cdot l = (0,82 - 0,5) \cdot 15,0 = 4,95 \text{ m} \quad (\text{EC 1- P 3: 2.7.2(3)})$$

$$M = K \cdot l_s = 6,0 \cdot 4,95 = 29,7 \text{ kNm} \quad (\text{EC 1- P 3: 2.7.2(3)})$$

$$H_{T,1} = \varphi_5 \cdot \xi_2 \cdot \frac{M}{a} = 1,5 \cdot 0,18 \cdot \frac{29,7}{2,5} = 3,2 \text{ kN} \quad (\text{EC 1- P 3: 2.7.2(3)})$$

$$H_{T,2} = \varphi_5 \cdot \xi_1 \cdot \frac{M}{a} = 1,5 \cdot 0,82 \cdot \frac{29,7}{2,5} = 14,6 \text{ kN} \quad (\text{EC 1- P 3: 2.7.2(3)})$$

4.3 Caused by skewing of the crane

4.3.1 Skewing angle

$$\alpha_F = \frac{0,75 x}{a} = \frac{10}{2500} = 0,004 \text{ rad} \quad (\text{EC 1- P 3: Table 2.7})$$

$$\alpha_V = \frac{y}{a} = \frac{0,1 \cdot 50}{2500} = 0,002 \text{ rad} \quad (\text{EC 1- P 3: Table 2.7})$$

$$\alpha_0 = \quad \quad \quad = 0,001 \text{ rad} \quad (\text{EC 1- P 3: Table 2.7})$$

$$\alpha = \alpha_F + \alpha_V + \alpha_0 = 0,007 \text{ rad}$$

4.3.2 Non-positive factor

$$f = 0,3(1 - \exp(-250 \alpha)) = 0,3(1 - \exp(-250 \cdot 0,007)) = 0,248 \quad (\text{EC 1- P 3: 2.7.4(2)})$$

4.3.3 Force factors

(a) Distance e_i of the wheel pair i from the guidance means

$e_1 = 0$ as flanged wheels are used

$$e_2 = a = 2,50 \text{ m}$$

(b) Combination of wheel pairs: IFF

$$m = 0$$

(c) Distance h :

$$h = \frac{m\xi_1\xi_2l^2 + \sum e_j^2}{\sum e_j} = \frac{0 + 2,50^2}{2,50} = 2,50 \text{ m} \quad (\text{EC 1- P 3: Table 2.8})$$

$$n = 2$$

$$\lambda_s = 1 - \frac{\sum e_j}{n \cdot h} = 1 - \frac{2,50}{2 \cdot 2,50} = 0,5 \quad (\text{EC 1- P 3: Table 2.9})$$

$$\lambda_{s,1,L} = \lambda_{s,2,L} = 0 \quad (\text{EC 1- P 3: Table 2.9})$$

for wheel pair 1:

$$\lambda_{s,1,1,T} = \frac{\xi_2}{n} \left(1 - \frac{e_1}{h}\right) = \frac{0,18}{2} (1 - 0) = 0,09 \quad (\text{EC 1- P 3: Table 2.9})$$

$$\lambda_{s,2,1,T} = \frac{\xi_1}{n} \left(1 - \frac{e_1}{h}\right) = \frac{0,82}{2} (1 - 0) = 0,41 \quad (\text{EC 1- P 3: Table 2.9})$$

for wheel pair 2:

$$\lambda_{s,1,2,T} = \frac{\xi_2}{n} \left(1 - \frac{e_2}{h}\right) = \frac{0,18}{2} \left(1 - \frac{2,50}{2,50}\right) = 0 \quad (\text{EC 1- P 3: Table 2.9})$$

$$\lambda_{s,2,2,T} = \frac{\xi_1}{n} \left(1 - \frac{e_2}{h}\right) = \frac{0,82}{2} \left(1 - \frac{2,50}{2,50}\right) = 0 \quad (\text{EC 1- P 3: Table 2.9})$$

4.3.4 Longitudinal forces

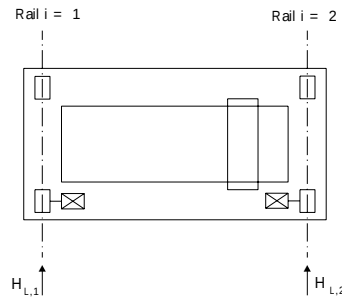


Figure 4.4: Longitudinal horizontal loads $H_{L,i}$

$$H_{S,1,L} = f \cdot \lambda_{S,1,L} \cdot \sum Q_r = 0 \quad (\text{EC 1- P 3: 2.7.4(1)})$$

$$H_{S,2,L} = f \cdot \lambda_{S,2,L} \cdot \sum Q_r = 0 \quad (\text{EC 1- P 3: 2.7.4(1)})$$

4.3.5 Transverse forces

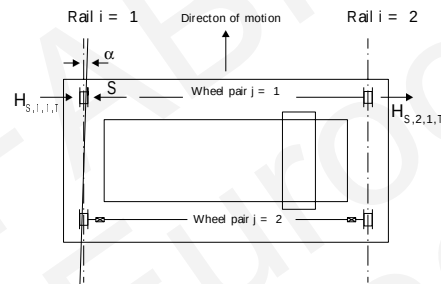


Figure 4.5: Longitudinal horizontal loads $H_{L,i}$

Guide force S :

$$S = f \cdot \lambda_s \cdot \sum Q_r = 0,248 \cdot 0,5 \cdot 170,0 = 21,1 \text{ kN} \quad (\text{EC 1- P 3: 2.7.4(1)})$$

for wheel pair 1:

$$H_{S,1,1,T} = f \cdot \lambda_{S,1,1,T} \cdot \sum Q_r = 0,248 \cdot 0,09 \cdot 170,0 = 3,8 \text{ kN} \quad (\text{EC 1- P 3: 2.7.4(1)})$$

$$H_{S,2,1,T} = f \cdot \lambda_{S,2,1,T} \cdot \sum Q_r = 0,248 \cdot 0,41 \cdot 170,0 = 17,3 \text{ kN} \quad (\text{EC 1- P 3: 2.7.4(1)})$$

$$\Rightarrow H_{S,1,T} = S - H_{S,1,1,T} = 17,3 \text{ kN}$$

$$\Rightarrow H_{S,2,T} = H_{S,2,1,T} = 17,3 \text{ kN}$$

for wheel pair 2:

$$H_{S,1,2,T} = f \cdot \lambda_{S,1,2,T} \cdot \sum Q_r = 0,248 \cdot 0 \cdot 170,0 = 0 \text{ kN} \quad (\text{EC 1- P 3: 2.7.4(1)})$$

$$H_{S,2,2,T} = f \cdot \lambda_{S,2,2,T} \cdot \sum Q_r = 0,248 \cdot 0 \cdot 170,0 = 0 \text{ kN} \quad (\text{EC 1- P 3: 2.7.4(1)})$$

4.4 Caused by acceleration or braking of the crab

$$H_{T,3} = 0,1 \cdot (10,0 + 100,0) = 11,0 \text{ kN}$$

(EC 1- P 3: 2.7.5)

(EC 1- P 3: 2.11.2)

5. Eccentricity of vertical wheel loads

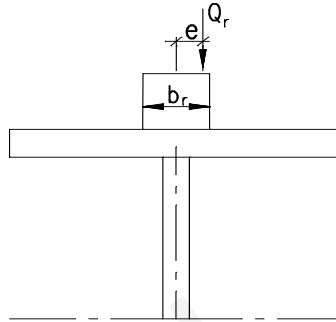


Figure 5.1: Eccentricity of the wheel load

$$e = \frac{1}{4} \cdot b_r = \frac{1}{4} \cdot 55 = 13,75 \text{ mm}$$

(EC 1- P 3: 2.5.3(2))

6. Fatigue loads

$$Q_{e,i} = \varphi_{fat} \cdot \lambda_i \cdot Q_{max,i}$$

(EC 1- P 3: 2.12.1(4))

$$\varphi_{fat,1} = \frac{1 + \varphi_1}{2} = \frac{1 + 1,1}{2} = 1,05$$

(EC 1- P 3: 2.12.1(7))

$$\varphi_{fat,2} = \frac{1 + \varphi_2}{2} = \frac{1 + 1,2}{2} = 1,10$$

(EC 1- P 3: 2.12.1(7))

Assumption: crane is classified in class S₆:

$$\lambda_i = 0,794 \quad \text{for normal stresses}$$

(EC 1- P 3: Table 2.12)

$$\lambda_i = 0,871 \quad \text{for shear stresses}$$

(EC 1- P 3: Table 2.12)

For normal stresses:

$$Q_{e,i} = \varphi_{fat} \cdot \lambda_i \cdot Q_{max,i} = 1,1 \cdot 0,794 \cdot 70,0 = 61,1 \text{ kN}$$

(EC 1- P 3: 2.12.1(4))

For shear stresses:

$$Q_{e,i} = \varphi_{fat} \cdot \lambda_i \cdot Q_{max,i} = 1,1 \cdot 0,871 \cdot 70,0 = 67,1 \text{ kN}$$

(EC 1- P 3: 2.12.1(4))

7. Summary of the crane actions

For the **ultimate limit state** the results are summarised in the following table according to the groups of loads.

Table 7.1: Summary of the vertical and horizontal loads for the crane runway girder

Groups of loads			1	2	3	4	5	6
Magnification factor which are considered for the group of load			$\varphi_1 = 1,10$ $\varphi_2 = 1,20$ $\varphi_5 = 1,50$	$\varphi_1 = 1,10$ $\varphi_3 = 1,00$ $\varphi_5 = 1,50$	$\varphi_1 = 1,00$ $\varphi_5 = 1,50$	$\varphi_4 = 1,00$ $\varphi_5 = 1,50$	$\varphi_4 = 1,00$	$\varphi_4 = 1,00$
Vertical loads	Self-weight of the crane	$Q_{r,(min)}$	22,0 kN	22,0 kN	20,0 kN	20,0 kN	20,0 kN	20,0 kN
		$Q_{r,min}$	16,5 kN	16,5 kN	15,0 kN	15,0 kN	15,0 kN	15,0 kN
	Self-weight of the crane and hoistload	$Q_{r,(max)}$	16,5 kN	16,5 kN	-	15,0 kN	15,0 kN	15,0 kN
		$Q_{r,max}$	82,0 kN	72,0 kN	-	70,0 kN	70,0 kN	70,0 kN
Horizontal loads	Acceleration of the crane	$H_{L,1}$	4,5 kN	4,5 kN	4,5 kN	4,5 kN	-	-
		$H_{L,2}$	4,5 kN	4,5 kN	4,5 kN	4,5 kN	-	-
		$H_{T,1}$	3,2 kN	3,2 kN	3,2 kN	3,2 kN	-	-
		$H_{T,2}$	14,6 kN	14,6 kN	14,6 kN	14,6 kN	-	-
	Skewing of the crane	$H_{S1,L}$	-	-	-	-	0	-
		$H_{S2,L}$	-	-	-	-	0	-
		$H_{S1,T}$	-	-	-	-	17,3 kN	-
		$H_{S2,T}$	-	-	-	-	17,3 kN	-
	Acceleration of the crab	$H_{T,3}$	-	-	-	-	-	11,0 kN

Part B:

Design example for Eurocode 3 - Part 6: Cranes supporting structures

1. Data of the crane runway girder

1.1 System

Single-span girder with fork-support, length: $l = 7,00$ m

1.2 Cross-section properties

1.2.1 General

In the design example it is assumed that the rail is rigid fixed with clamps on the crane runway girder.

The benefit effects of the rigid fixed rail on the design resistance are not taken into account in the design example (see 5.3.3 (2) of EC 3 - Part 6)

Cross-section properties of the crane runway girder (without rail) HE-B 500:

A [cm ²]	I _y [cm ⁴]	I _z [cm ⁴]	W _{el,y} [cm ³]	W _{el,z} [cm ³]
239,0	107200	12620	4290	842

Area of the flange: $A_F = 300 \cdot 28,0 = 84,0$ cm²

Area of the web: $A_W = 444 \cdot 14,5 = 64,4$ cm²

Cross-section properties of the rail A55:

A [cm ²]	I _y [cm ⁴]	I _z [cm ⁴]
40,5	178	337

Material S235

1.2.2 Cross-section classification

The cross-section is classified into class 1.

2. Internal forces and moments of the crane runway girder

2.1 General

For the verification of the crane runway girder the internal forces and moments are calculated with influence lines for the following points:

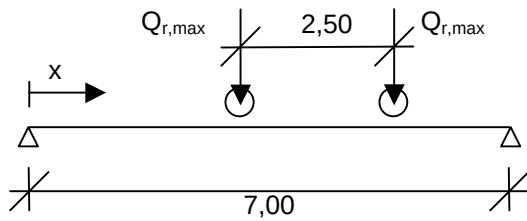
Point 2.875: Maximum bending moment of the crane runway girder (in field)

Support: Maximum shear forces of the crane runway girder (at support)

The design example is carried out for load group 1, see table 7.1.

2.2 Internal forces and moments at point 2.875

Load position for the maximum bending moment:



$$A = \frac{11,5 - 2 \cdot x}{7,0}$$

$$M(x) = A \cdot x = \frac{11,5 \cdot x - 2 \cdot x^2}{7,0}$$

$$M'(x) = \frac{11,5 - 4 \cdot x}{7,0} = 0 \quad \text{for max } M \Rightarrow x = 2,875$$

2.2.1 Selfweight of the crane runway girder

$$g_k = 1,873 + 0,318 = 2,2 \text{ kN}$$

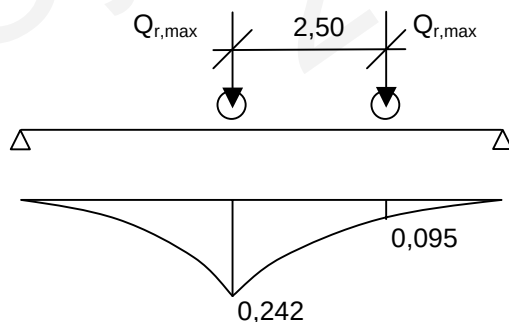
$$A(g_k) = \frac{2,2 \cdot 7,0}{2} = 7,7 \text{ kN}$$

$$M_{y,k} = 7,7 \cdot 2,875 - \frac{2,875^2 \cdot 2,2}{2} = 13,0 \text{ kNm}$$

$$V_{z,k} = 7,7 - 2,875 \cdot 2,2 = 1,4 \text{ kN}$$

2.2.2 Vertical wheel loads of the crane

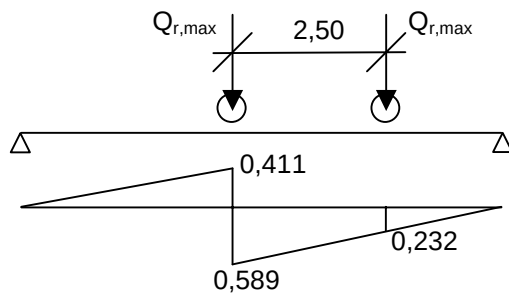
a) Bending moment



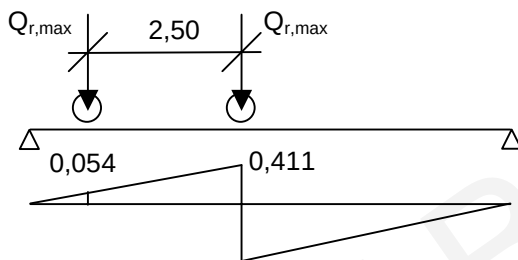
$$\max M_{y,k} = Q_{r,max} \cdot (\eta_1 + \eta_2) \cdot l = 82,0 \cdot (0,242 + 0,095) \cdot 7,0 = 193,7 \text{ kNm}$$

$$\min M_{y,k} = 0 \text{ kNm}$$

b) Shear force



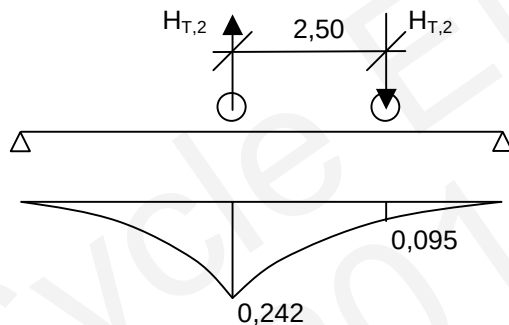
$$\max V_{z,k} = Q_{r,max} \cdot (\eta_1 + \eta_2) = 82,0 \cdot (0,589 + 0,232) = 67,3 \text{ kN}$$



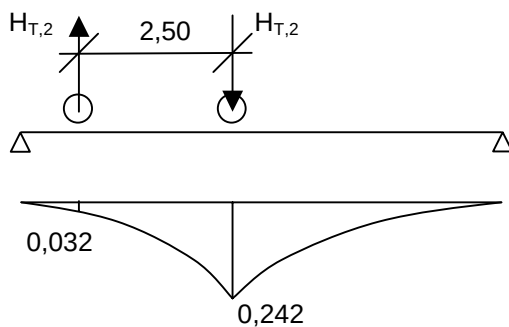
$$\min V_{z,k} = Q_{r,max} \cdot (\eta_1 + \eta_2) = 82,0 \cdot (-0,054 - 0,411) = -38,1 \text{ kN}$$

2.2.3 Acceleration and deceleration

a) Bending moment

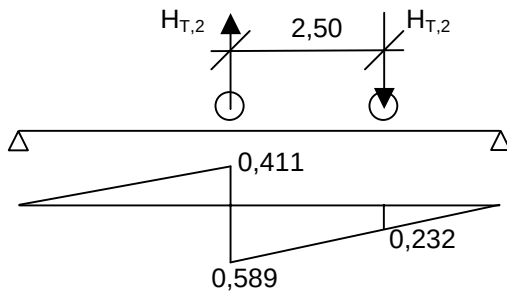


$$\min M_{z,k} = (H_{T,2} \cdot \eta_1 + H_{T,2} \cdot \eta_2) \cdot l = (-14,6 \cdot 0,242 + 14,6 \cdot 0,095) \cdot 7,0 = -15,0 \text{ kNm}$$

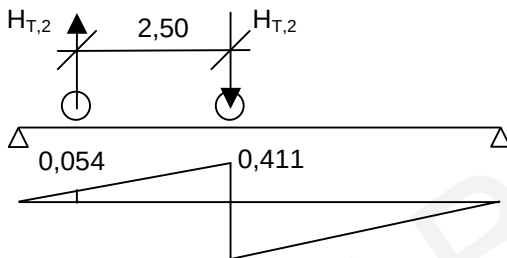


$$\max M_{z,k} = (H_{T,2} \cdot \eta_1 + H_{T,2} \cdot \eta_2) \cdot l = (-14,6 \cdot 0,0316 + 14,6 \cdot 0,242) \cdot 7,0 = 21,5 \text{ kNm}$$

b) Shear force



$$\max V_{y,k} = H_{T,2} \cdot \eta_1 + H_{T,2} \cdot \eta_2 = (-14,6) \cdot (-0,411) + 14,6 \cdot 0,232 = 9,4 \text{ kN}$$



$$\min V_{y,k} = H_{T,2} \cdot \eta_1 + H_{T,2} \cdot \eta_2 = (-14,6) \cdot (-0,054) + 14,6 \cdot (-0,411) = -5,2 \text{ kN}$$

$$N_k = -4,5 \text{ kN}$$

2.2.4 Torsion due to vertical and horizontal loads

Rail A 55: $b_r = 55 \text{ mm}$
 $h_1 = 65 \text{ mm}$

Wheel loads: $Q_{r,\max} = 82,0 \text{ kN}$

$$e_y = 0,25 \cdot b_r = 13,75 \text{ mm}$$

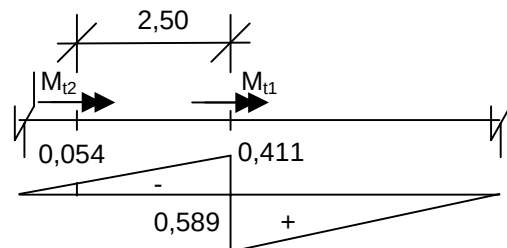
(EC 1-P 3: 2.5.3 (2))

Horizontal loads due to acceleration and deceleration: $H_T = \pm 14,6 \text{ kN}$

$$e_z = 0,5 \cdot h + h_1 = 0,5 \cdot 500 + 65 = 315 \text{ mm}$$

$$M_{t1} = 82,0 \cdot 0,01375 + 14,6 \cdot 0,315 = 5,7 \text{ kNm}$$

$$M_{t2} = 82,0 \cdot 0,01375 - 14,6 \cdot 0,315 = -3,5 \text{ kNm}$$



$$\max M_{t,k} = 5,7 \cdot 0,589 - 3,5 \cdot (-0,054) = 3,5 \text{ kNm}$$

2.3 Internal forces and moments at support

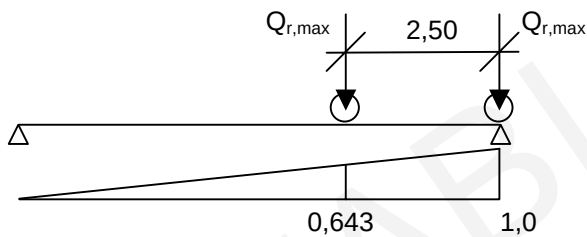
There are no bending moments at the support (Single-span girder)

2.3.1 Selfweight of the crane runway girder

$$V_{z,k} = 7,7 \text{ kN}$$

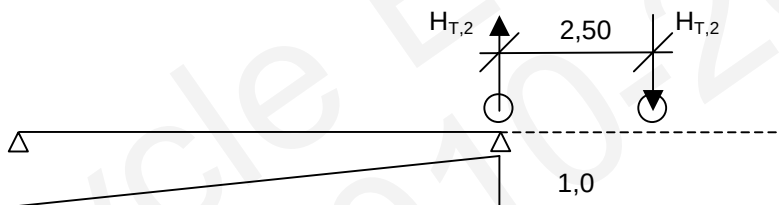
2.3.2 Vertical wheel loads of the crane

$$\max V_{z,k} = Q_{r,\max} \cdot (\eta_1 + \eta_2) = 82,0 \cdot (0,0 + 0,0) = 0 \text{ kN}$$

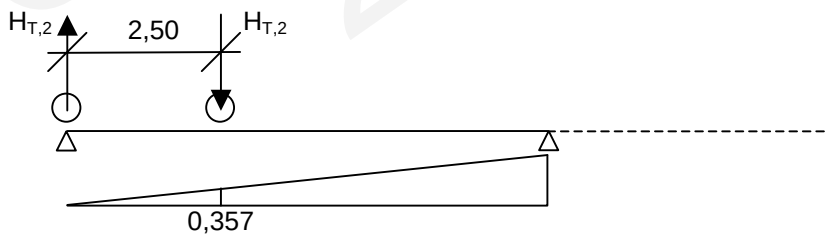


$$\min V_{z,k} = Q_{r,\max} \cdot (\eta_1 + \eta_2) = 82,0 \cdot (-1,0 - 0,6428) = -134,7 \text{ kN}$$

2.3.3 Acceleration and deceleration



$$\max V_{y,k} = H_{T,2} \cdot \eta_1 + H_{T,2} \cdot \eta_2 = (-14,6) \cdot (-1,0) + 14,6 \cdot 0,0 = 14,6 \text{ kN}$$



$$\min V_{y,k} = H_{T,2} \cdot \eta_1 + H_{T,2} \cdot \eta_2 = (-14,6) \cdot 0,0 + 14,6 \cdot (-0,357) = -5,2 \text{ kN}$$

$$N_k = -4,5 \text{ kN}$$

2.3.4 Torsion due to vertical and horizontal loads

Rail A 55: $b_r = 55 \text{ mm}$
 $h_1 = 65 \text{ mm}$

Wheel loads: $Q_{r,\max} = 82,0 \text{ kN}$

$e_y = 0,25 \cdot b_r = 13,75 \text{ mm}$

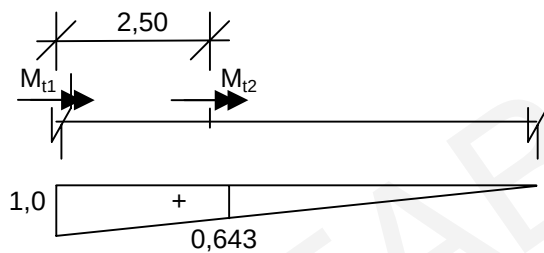
(EC 1- P 3: 2.5.3 (2))

Horizontal loads due to acceleration and deceleration: $H_T = \pm 14,6 \text{ kN}$

$e_z = 0,5 \cdot h + h_1 = 0,5 \cdot 500 + 65 = 315 \text{ mm}$

$M_{t1} = 82,0 \cdot 0,01375 + 14,6 \cdot 0,315 = 5,7 \text{ kNm}$

$M_{t2} = 82,0 \cdot 0,01375 - 14,6 \cdot 0,315 = -3,5 \text{ kNm}$



$\max M_{t,k} = 5,7 \cdot 1,0 - 3,5 \cdot 0,643 = 3,4 \text{ kNm}$

3. Cross-section resistance of the crane runway girder

3.1 Point 2.875

3.1.1 Shear resistance of the web (z-axis)

$d/t_w = 390/14,5 = 26,9 < 60 \Rightarrow$ Verification for shear buckling is not necessary
(EC 3- P 1: 5.1)

$$\max V_{z,Sd} = \gamma_G G_k + \gamma_Q Q_k = 1,35 \cdot 1,4 + 1,35 \cdot 67,3 = 92,75 \text{ kN}$$

$$A_v = 390 \cdot 14,5 = 56,55 \text{ cm}^2$$

$$V_{z,Rd} = A_v \cdot \frac{f_y / \sqrt{3}}{\gamma_M} = 56,55 \cdot \frac{235 / \sqrt{3}}{1,1} = 697,5 \text{ kN} > 92,75 \text{ kN} \quad (\text{EC 3- P 1: 6.2.6})$$

3.1.2 Shear resistance of the top flange (y-axis)

It is assumed that the horizontal loads are resisted by the top flange of the girder.

$$\max V_{y,Sd} = \gamma_Q Q_k = 1,35 \cdot 9,4 = 12,7 \text{ kN}$$

$$A_v = A_{TV} = 300 \cdot 28 = 84,0 \text{ cm}^2$$

$$V_{y,Rd} = A_v \cdot \frac{f_y / \sqrt{3}}{\gamma_M} = 84,0 \cdot \frac{235 / \sqrt{3}}{1,1} = 1036,1 \text{ kN} > 12,7 \text{ kN} \quad (\text{EC 3- P 1: 6.2.6})$$

3.1.3 Shear resistance due to torsion

$$\max M_{t,Sd} = 1,35 \cdot 3,5 = 4,7 \text{ kN}$$

$$\tau_{v,Ed} = \frac{M_{t,Sd} \cdot t}{I_t} = \frac{4,7 \cdot 2,8 \cdot 100}{538} = 2,45 \frac{\text{kN}}{\text{cm}^2} < \frac{f_y / \sqrt{3}}{\gamma_M} = 12,3 \frac{\text{kN}}{\text{cm}^2} \quad (\text{EC 3- P 1: 6.2.6})$$

3.1.4 Interaction between normal and shear forces

$$V_{pl,Rd} = \frac{A_v \cdot (f_y / \sqrt{3})}{\gamma_M} = 697,5 \text{ kN} \quad (\text{EC 3- P 1: 6.2.6 (2)})$$

$$V_{pl,T,Rd} = \sqrt{1 - \frac{\tau_{t,Ed}}{1,25 \cdot (f_y / \sqrt{3}) / \gamma_{M0}}} \cdot V_{pl,Rd} = \sqrt{1 - \frac{2,45}{1,25 \cdot 12,3}} \cdot 697,5 = 639,5 \text{ kN} \quad (\text{EC 3- P 1: 6.2.7})$$

$$V_{Ed} = 92,75 \text{ kN} \leq 319,8 \text{ kN} = 0,5 \cdot V_{pl,T,Rd} \quad (\text{EC 3- P 1: 6.2.8})$$

$\Rightarrow$ no interaction between shear and normal stresses necessary

3.1.5 Bending and axial forces

It is assumed that the horizontal loads are resisted by the top flange.

a) Verification for max $M_{y,Sd}$:

$$N_{Sd} = -1,35 \cdot 4,5 = 6,1 \text{ kN}$$

$$\max M_{y,Sd} = 1,35 \cdot 13,0 + 1,35 \cdot 193,7 = 279,0 \text{ kNm}$$

$$M_{z,Sd} = 1,35 \cdot 15,0 = 20,3 \text{ kNm}$$

$$\begin{aligned} A_{TF} &= 84 \text{ cm}^2 \\ W_{el,y} &= 4290 \text{ cm}^3 \\ W_{el,z} &= 842 \text{ cm}^3 \end{aligned}$$

$$\frac{N_{Sd}}{A_{TF} \cdot f_{y,d}} + \frac{M_{y,Sd}}{W_{el,y} \cdot f_{y,d}} + \frac{M_{z,Sd}}{W_{el,z} \cdot f_{y,d}} \leq 1,0 \quad (\text{EC 3- P 1: 6.2.1})$$

$$\frac{6,1}{84 \cdot 23,5/1,1} + \frac{279,0 \cdot 100}{4290 \cdot 23,5/1,1} + \frac{20,3 \cdot 100}{842 \cdot 23,5/1,1} = 0,42 \leq 1,0$$

b) Verification for max $M_{z,Sd}$:

$$N_{Sd} = -1,35 \cdot 4,5 = 6,1 \text{ kN}$$

$$M_{y,k} = 82,0 \cdot (0,0316 + 0,2420) \cdot 7,0 = 157,0 \text{ kNm}$$

$$M_{y,Sd} = 1,35 \cdot 13,0 + 1,35 \cdot 157,0 = 229,5 \text{ kNm}$$

$$\max M_{z,Sd} = 1,35 \cdot 21,5 = 29,03 \text{ kNm}$$

$$\begin{aligned} A_{TF} &= 84 \text{ cm}^2 \\ W_{el,y} &= 4290 \text{ cm}^3 \\ W_{el,z} &= 842 \text{ cm}^3 \end{aligned}$$

$$\frac{N_{Sd}}{A_{TF} \cdot f_{y,d}} + \frac{M_{y,Sd}}{W_{el,y} \cdot f_{y,d}} + \frac{M_{z,Sd}}{W_{el,z} \cdot f_{y,d}} \leq 1,0 \quad (\text{EC 3- P 1: 6.2.1})$$

$$\frac{6,1}{84 \cdot 23,5/1,1} + \frac{229,5 \cdot 100}{4290 \cdot 23,5/1,1} + \frac{29,03 \cdot 100}{842 \cdot 23,5/1,1} = 0,42 \leq 1,0$$

Note: The cross-section properties of the rail are not taken into account though the rail is rigid fixed.

3.2 Support

3.2.1 Shear resistance of the web (z-axis)

$d/t_w = 390/14,5 = 26,9 < 60 \Rightarrow$ Verification for shear buckling is not necessary
(EC 3- P 1: 5.1)

$$\max V_{z,Sd} = \gamma_G G_k + \gamma_Q Q_k = 1,35 \cdot 7,7 + 1,35 \cdot 134,7 = 192,2 \text{ kN}$$

$$A_v = 390 \cdot 14,5 = 56,55 \text{ cm}^2$$

$$V_{z,Rd} = A_v \cdot \frac{f_y / \sqrt{3}}{\gamma_M} = 56,55 \cdot \frac{235 / \sqrt{3}}{1,1} = 697,5 \text{ kN} > 192,2 \text{ kN} \quad (\text{EC 3- P 1: 6.2.6})$$

3.2.2 Shear resistance of the top flange (y-axis)

It is assumed that the horizontal loads are resisted by the top flange of the girder.

$$\max V_{y,Sd} = \gamma_Q Q_k = 1,35 \cdot 14,6 = 19,7 \text{ kN}$$

$$A_v = A_{TV} = 300 \cdot 28 = 84,0 \text{ cm}^2$$

$$V_{y,Rd} = A_v \cdot \frac{f_y / \sqrt{3}}{\gamma_M} = 84,0 \cdot \frac{235 / \sqrt{3}}{1,1} = 1036,1 \text{ kN} > 19,7 \text{ kN} \quad (\text{EC 3- P 1: 6.2.6})$$

3.2.3 Shear resistance due to torsion (Annex G of Eurocode 3 - Part 1)

$$\max M_{t,Sd} = 1,35 \cdot 3,4 = 4,6 \text{ kN}$$

$$\tau_{v,Ed} = \frac{M_{t,Sd} \cdot t}{I_t} = \frac{4,6 \cdot 2,8 \cdot 100}{538} = 2,39 \frac{\text{kN}}{\text{cm}^2} < \frac{f_y / \sqrt{3}}{\gamma_M} = 12,3 \frac{\text{kN}}{\text{cm}^2} \quad (\text{EC 3- P 1: 6.2.6})$$

3.2.4 Interaction between normal and shear forces

$$V_{pl,Rd} = \frac{A_v \cdot (f_y / \sqrt{3})}{\gamma_M} = 697,5 \text{ kN} \quad (\text{EC 3- P 1: 6.2.6 (2)})$$

$$V_{pl,T,Rd} = \sqrt{1 - \frac{\tau_{t,Ed}}{1,25 \cdot (f_y / \sqrt{3}) / \gamma_{M0}}} \cdot V_{pl,Rd} = \sqrt{1 - \frac{2,39}{1,25 \cdot 12,3}} \cdot 697,5 = 641,0 \text{ kN} \quad (\text{EC 3- P 1: 6.2.7})$$

$$V_{Ed} = 192,2 \text{ kN} \leq 321,0 = 0,5 \cdot V_{pl,T,Rd} \quad (\text{EC 3- P 1: 6.2.8})$$

$\Rightarrow$ no interaction between shear and normal stresses necessary

3.2.5 Axial forces

Note: It is assumed that the horizontal loads are resisted by the top flange. The rail is rigid fixed with clamps on the top flange. Therefore the net section properties of the crane runway girder are considered. The cross-section properties of the rail are not taken into account though the rail is rigid fixed.

$$N_{sd} = -1,35 \cdot 4,5 = -6,1 \text{ kN}$$

$$\Delta A = 2 \cdot 21 \cdot 28 = 11,8 \text{ cm}^2$$

$$A_{TF,net} = A_{TF} - \Delta A = 84,0 - 11,8 = 72,2 \text{ cm}^2$$

$$\frac{N_{sd}}{A_{TF,net} \cdot f_{y,d}} \leq 1,0 \quad (\text{EC 3- P 1: 6.2.4})$$

$$\frac{6,1}{72,2 \cdot 23,5/1,1} = 0,004 \leq 1,0$$

4. Resistance of the web to transverse forces

The resistance of the web to transverse forces is determined according to section 4.4 of the draft of Eurocode 3 - Part 1.5: „Supplementary rules for planar plated structures without transverse loading“.

$$s_s = 2 \cdot h + 50 = 2 \cdot (0,75 \cdot 65) + 50 = 14,75 \text{ cm}$$

$$h_w = 500 - 2 \cdot 28 = 444 \text{ mm}$$

$$k_f = 6,0 + 2,0 \cdot (h_w / a)^2 = 6,0 + 2 \cdot (44,4 / 700)^2 = 6,0 \quad (\text{EC 3- P 5: 6.1 (4)})$$

$$F_{cr} = \frac{0,9 \cdot k_f \cdot E \cdot t_w^3}{h_w} = \frac{0,9 \cdot 6,0 \cdot 21000 \cdot 1,45^3}{44,4} = 7786,4 \text{ kN} \quad (\text{EC 3- P 5: 6.4 (1)})$$

$$m_1 = \frac{f_{yf} \cdot b_f}{f_{yw} \cdot t_w} = \frac{235 \cdot 300}{235 \cdot 14,5} = 20,7 \quad (\text{EC 3- P 5: 6.5 (1)})$$

$$m_2 = 0,02 \cdot \left[\frac{h_w}{t_f} \right]^2 = 0,02 \cdot \left[\frac{444}{28} \right]^2 = 5,0 \quad (\text{EC 3- P 5: 6.5 (1)})$$

$$l_y = s_s + 2 \cdot t_f \cdot \left[1 + \sqrt{m_1 + m_2} \right] = 14,75 + 2 \cdot 1,45 \cdot \left[1 + \sqrt{20,7 + 5,0} \right] = 32,4 \text{ cm} \quad (\text{EC 3- P 5: 6.5 (2)})$$

$$\lambda_F = \sqrt{\frac{l_y \cdot t_w \cdot f_{yw}}{F_{cr}}} = \sqrt{\frac{32,4 \cdot 1,45 \cdot 23,5}{7786,4}} = 0,38 < 0,5 \Rightarrow \kappa_F = 1 \quad (\text{EC 3- P 5: 6.4 (1)})$$

$$\Rightarrow l_{eff} = \kappa_F \cdot l_y = 1,0 \cdot 32,4 = 32,4 \text{ cm} \quad (\text{EC 3- P 5: 6.2})$$

$$F_{Rd} = l_{eff} \cdot t_w \cdot f_{yw} = 32,4 \cdot 1,45 \cdot 23,5 = 1104,0 \text{ kN} \quad (\text{EC 3- P 5: 6.2})$$

$$F_{Sd} = \gamma_Q \cdot Q_{r,max} = 1,35 \cdot 82,0 = 110,7 \text{ kN}$$

$$F_{Sd} < F_{Rd}$$

5. Fatigue

5.1 General

According to 9.1.4 of Eurocode 3 - Part 6 no fatigue assessment is necessary, if the number of load cycles with more than 50 % of the full payload is smaller than 10000 cycles.

In the design example this condition is not fulfilled, so that a fatigue check is necessary.

The fatigue assessment is carried out for the crane runway girder on the basis of nominal stress ranges.

$$\gamma_{Ff} \Delta\sigma_{E2} \leq \frac{\Delta\sigma_c}{\gamma_{Mf}} \quad (\text{EC 3- P 9: 8 (2)})$$

$$\Delta\sigma_{E2} = \lambda \cdot \Phi_{fat} \cdot \Delta\sigma_p \quad (\text{EC 3- P 6: 9.4.1 (4)})$$

$$\gamma_{Ff} = 1,0 \quad (\text{EC 3- P 6: 9.3 (1)})$$

$$\gamma_{Mf} = 1,15 \quad (\text{EC 3- P 9: Table 3.1})$$

Provided that the crane is classified into loading class S6 the following values are obtained from Eurocode 1 – Part 3:

$$\lambda = 0,794 \quad \text{for normal stresses} \quad (\text{EC 1- P 3: Table 2.12})$$

$$\lambda = 0,871 \quad \text{for shear stresses} \quad (\text{EC 1- P 3: Table 2.12})$$

$$\Phi_{fat} = 1,1 \quad (\text{EC 1- P 3: 2.12.1 (7)})$$

In the design example the stresses $\Delta\sigma_{E2}$ are direct calculated with the following fatigue loads:

for normal stresses:

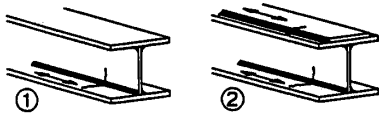
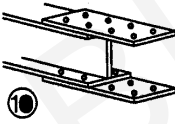
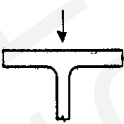
$$Q_{e,i} = \lambda \cdot \Phi_{fat} \cdot Q_{max,i} = 0,794 \cdot 1,1 \cdot 70,0 = 61,1 \text{ kN} \quad (\text{EC 1- P 3: 2.12.1 (4)})$$

for shear stresses:

$$Q_{e,i} = \lambda \cdot \Phi_{fat} \cdot Q_{max,i} = 0,871 \cdot 1,1 \cdot 70,0 = 67,1 \text{ kN} \quad (\text{EC 1- P 3: 2.12.1 (4)})$$

5.2 Detail categories

The runway beam is checked for the following detail categories which were obtained from Eurocode 3 - Part 9 (Tab. 8.1, 8.2, 8.10).

Detail category	Constructional detail	Amendments
125		Verification of normal stresses in the runway beam.
80		Verification of normal stresses in the runway beam.
80		Verification of shear stresses in the web.
160		Verification of vertical stresses in the web due to wheel loads. (Eurocode 3 - Part 6)

5.3 Point 2.785

5.3.1 Verification of the cross-section

a) Selfweight

$$M_y = 13,0 \text{ kNm}$$

b) Wheel loads

$$\max M_y = Q_{e,i} \cdot (\eta_1 + \eta_2) \cdot l = 61,1 \cdot (0,242 + 0,0952) \cdot 7,0 = 144,2 \text{ kNm}$$

$$\min M_y = 0,0 \text{ kNm}$$

Normal stresses at the top flange

Detail category 80 (due to the net section properties by clamps)

$$\max \sigma_x = \frac{144,2 + 13,0}{4290,0} = 3,7 \frac{\text{kN}}{\text{cm}^2}$$

$$\min \sigma_x = \frac{0,0 + 13,0}{4290,0} = 0,3 \frac{\text{kN}}{\text{cm}^2}$$

$$\Delta \sigma_{E2} = 3,7 - 0,3 = 3,4 \frac{\text{kN}}{\text{cm}^2}$$

$$\Delta \sigma_c = \frac{8,0}{1,15} = 7,0 \frac{\text{kN}}{\text{cm}^2}$$

$$\Delta \sigma_{E2} < \Delta \sigma_c$$

Normal stresses at the lower flange

Detail category 125

$$\max \sigma_x = \frac{144,2 + 13,0}{4290,0} = 3,7 \frac{\text{kN}}{\text{cm}^2}$$

$$\min \sigma_x = \frac{0,0 + 13,0}{4290,0} = 0,3 \frac{\text{kN}}{\text{cm}^2}$$

$$\Delta \sigma_{E2} = 3,7 - 0,3 = 3,4 \frac{\text{kN}}{\text{cm}^2}$$

$$\Delta \sigma_c = \frac{12,5}{1,15} = 10,9 \frac{\text{kN}}{\text{cm}^2}$$

$$\Delta \sigma_{E2} < \Delta \sigma_c$$

5.3.2 Verification of the web

5.3.2.1 Shear stresses

a) Selfweight

$$V_z = 1,4 \text{ kN}$$

$$\tau_{xz} \approx 0 \frac{\text{kN}}{\text{cm}^2}$$

b) Wheel loads

$$\max V_z = Q_{e,i} \cdot (\eta_1 + \eta_2) = 67,1 \cdot (0,589 + 0,232) = 55,1 \text{ kN}$$

$$\min V_z = Q_{e,i} \cdot (\eta_1 + \eta_2) = 67,1 \cdot (-0,054 - 0,411) = -31,2 \text{ kN}$$

$$\max \tau_{xz} = \frac{55,1}{44,4 \cdot 1,45} = 0,9 \frac{\text{kN}}{\text{cm}^2}$$

$$\min \tau_{xz} = \frac{-31,2}{44,4 \cdot 1,45} = -0,5 \frac{\text{kN}}{\text{cm}^2}$$

c) Local shear stresses in the web due to wheel loads

$$d_r = 0,75 \cdot h_r + t_f + r = 0,75 \cdot 65 + 28 + 27 = 104 \text{ mm} \quad (\text{EC 3- P 6: 7.5.2 (1)})$$

$$b_{\text{eff}} = b_{\text{fr}} + d_r = 150 + 104 = 254 \text{ mm} < b = 300 \text{ mm} \quad (\text{EC 3- P 6: 7.5.2 (2)})$$

$$I_{f,\text{eff}} = \frac{t_f^3 \cdot b_{\text{eff}}}{12} = \frac{2,8^3 \cdot 25,4}{12} = 46,5 \text{ cm}^4 \quad (\text{EC 3- P 6: 7.5.2 (2)})$$

$$I_r = 136 \text{ cm}^4 \quad (25 \% \text{ wear, see "Petersen Stahlbau", page 1360}) \quad (\text{EC 3- P 6: 6.2.1 (13)})$$

$$I_{\text{rf}} = I_r + I_{f,\text{eff}} = 136 + 46,5 = 182,5 \text{ cm}^4 \quad (\text{EC 3- P 6: 7.5.2 (2)})$$

$$l_{\text{eff}} = 3,25 \cdot [I_{\text{rf}} / t_w]^{\frac{1}{3}} = 3,25 \cdot [182,5 / 1,45]^{\frac{1}{3}} = 16,3 \text{ cm} \quad (\text{EC 3- P 6: 7.5.2 (2)})$$

$$\sigma_{\perp} = \frac{F_z}{l_{\text{eff}} \cdot t_w} = \frac{67,1}{16,3 \cdot 1,45} = 2,8 \frac{\text{kN}}{\text{cm}^2} \quad (\text{EC 3- P 6: 7.5.2 (1)})$$

$$\tau_{\parallel} = 0,2 \cdot \sigma_{\perp} = 0,2 \cdot 2,8 = 0,6 \frac{\text{kN}}{\text{cm}^2}$$

$$\max \tau_{\parallel} = 0,9 + 0,6 = 1,5 \frac{\text{kN}}{\text{cm}^2}$$

$$\min \tau_{\parallel} = -0,5 - 0,6 = -1,1 \frac{\text{kN}}{\text{cm}^2}$$

$$\Delta \tau_{E2} = 1,5 + 1,1 = 2,6 \frac{\text{kN}}{\text{cm}^2}$$

$$\Delta \tau_c = \frac{8,0}{1,25} = 6,4 \frac{\text{kN}}{\text{cm}^2}$$

$$\Delta \tau_{E2} < \Delta \tau_c$$

5.3.2.2 Direct stresses

a) Local stresses in the web due to wheel loads

$$l_{\text{eff}} = 16,3 \text{ cm} \quad (\text{EC 3- P 6: 7.5.2 (2)})$$

$$\sigma_{\perp} = \frac{F_z}{l_{\text{eff}} \cdot t_w} = \frac{61,1}{16,3 \cdot 1,45} = 2,6 \frac{\text{kN}}{\text{cm}^2} \quad (\text{EC 3- P 6: 7.5.2 (1)})$$

b) Local stresses in the web due to bending

$$T_{\text{Sd}} = F_{z,d} \cdot e_y = 61,1 \cdot 0,01375 = 0,84 \text{ kNm} \quad (\text{EC 3- P 6: 9.4.2.2 (1)})$$

$$a = 700,0 \text{ cm}$$

$$d_w = 50,0 - 2 \cdot 2,8 = 44,4 \text{ cm}$$

$$t_w = 1,45 \text{ cm}$$

$$I_t \approx \frac{1}{3} \cdot 30,0 \cdot 2,8^3 = 220 \text{ cm}^4$$

$$\eta = \left[\frac{0,75 a t_w^3}{I_t} \cdot \frac{\sinh^2(\pi d_w / a)}{\sinh(2 \pi d_w / a) - 2 \pi d_w / a} \right]^{0,5} \quad (\text{EC 3- P 6: 9.4.2.2 (1)})$$

$$= \left[\frac{0,75 \cdot 700 \cdot 1,45^3}{220} \cdot \frac{\sinh^2(\pi \cdot 44,4 / 700)}{\sinh(2 \cdot \pi \cdot 44,4 / 700) - 2 \cdot \pi \cdot 44,4 / 700} \right]^{0,5} = 5,247$$

$$\begin{aligned} \sigma_{T,Ed} &= \frac{6 T_{\text{Sd}}}{a t_w^2} \cdot \eta \cdot \tanh(\eta) \\ &= \frac{6 \cdot 0,84 \cdot 100}{700 \cdot 1,45^2} \cdot 5,247 \cdot \tanh(5,247) = 1,8 \frac{\text{kN}}{\text{cm}^2} \end{aligned} \quad (\text{EC 3- P 6: 9.4.2.2 (1)})$$

$$\max \sigma_{T,Sd} = 1,8 + 1,8 = 3,6 \frac{\text{kN}}{\text{cm}^2}$$

$$\min \sigma_{T,Sd} = 1,8 - 1,8 = 0 \frac{\text{kN}}{\text{cm}^2}$$

$$\Rightarrow \max \Delta \sigma_E = 3,6 \frac{\text{kN}}{\text{cm}^2}$$

$$\Delta \sigma_c = \frac{16,0}{1,25} = 12,8 \frac{\text{kN}}{\text{cm}^2}$$

$$\Delta \sigma_E < \Delta \sigma_c$$

5.3.2.3 Interaction between direct and shear stresses in the web

$$\left[\frac{\gamma_{Ff} \cdot \Delta\sigma_{E2}}{\frac{\Delta\sigma_c}{\gamma_{Mf}}} \right]^3 + \left[\frac{\gamma_{Ff} \cdot \Delta\tau_{E2}}{\frac{\Delta\tau_c}{\gamma_{Mf}}} \right]^5 \leq 1,0 \quad (\text{EC 3- P 9: 8 (3)})$$

$$\left[\frac{1,0 \cdot 3,6}{\frac{16,0}{1,25}} \right]^3 + \left[\frac{1,0 \cdot 2,6}{\frac{8,0}{1,25}} \right]^5 = 0,033 \leq 1,0$$

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5.4 Support

5.4.1 Verification of the web

5.4.1.1 Shear stresses

a) Selfweight

$$V_z = -7,7 \text{ kN}$$

$$\tau_{xz} = \frac{-7,7}{44,4 \cdot 1,45} = -0,1 \frac{\text{kN}}{\text{cm}^2}$$

b) Wheel loads

$$\max V_z = Q_{e,i} \cdot (\eta_1 + \eta_2) = 67,1 \cdot 0,0 = 0,0 \text{ kN}$$

$$\min V_z = Q_{e,i} \cdot (\eta_1 + \eta_2) = 67,1 \cdot (-1,0 - 0,6428) = -110,2 \text{ kN}$$

$$\max \tau_{xz} = \frac{0,0}{44,4 \cdot 1,45} = 0,0 \frac{\text{kN}}{\text{cm}^2}$$

$$\min \tau_{xz} = \frac{-110,2}{44,4 \cdot 1,45} = -1,7 \frac{\text{kN}}{\text{cm}^2}$$

c) Local shear stresses in the web due to wheel loads

$$l_{\text{eff}} = 3,25 \cdot \left[I_{\text{rf}} / t_w \right]^{\frac{1}{3}} = 3,25 \cdot \left[182,5 / 1,45 \right]^{\frac{1}{3}} = 16,3 \text{ cm} \quad (\text{EC 3- P 6: 7.5.2 (2)})$$

$$\sigma_{\perp} = \frac{F_z}{l_{\text{eff}} \cdot t_w} = \frac{67,1}{16,3 \cdot 1,45} = 2,8 \frac{\text{kN}}{\text{cm}^2} \quad (\text{EC 3- P 6: 7.5.2 (1)})$$

$$\tau_{xz} = 0,2 \cdot \sigma_{\perp} = 0,2 \cdot 2,8 = 0,6 \frac{\text{kN}}{\text{cm}^2}$$

$$\max \tau_{xz} = 0,0 + 0,6 = 0,6 \frac{\text{kN}}{\text{cm}^2}$$

$$\min \tau_{xz} = -1,7 - 0,6 = -2,3 \frac{\text{kN}}{\text{cm}^2}$$

$$\Delta \tau_{E2} = 0,6 + 2,3 = 2,9 \frac{\text{kN}}{\text{cm}^2}$$

$$\Delta \tau_c = \frac{8,0}{1,25} = 6,4 \frac{\text{kN}}{\text{cm}^2}$$

$$\Delta \tau_{E2} < \Delta \tau_c$$

5.4.1.2 Direct stresses**a) Local stresses in the web due to wheel loads**

$$l_{\text{eff}} = 16,3 \text{ cm} \quad (\text{EC 3- P 6: 7.5.2 (2)})$$

$$\sigma_{\perp} = 2,6 \frac{\text{kN}}{\text{cm}^2}, \text{ see 6.3.2.2 (a)} \quad (\text{EC 3- P 6: 7.5.2 (1)})$$

b) Local stresses in the web due to bending

$$\sigma_{\text{T,Ed}} = 1,8 \frac{\text{kN}}{\text{cm}^2}, \text{ see 6.3.2.2 (b)} \quad (\text{EC 3- P 6: 9.4.2.2 (1)})$$

$$\sigma_{\text{T,Ed}} = 1,8 \frac{\text{kN}}{\text{cm}^2}$$

$$\max \sigma_{\text{T,Sd}} = 1,8 + 1,8 = 3,6 \frac{\text{kN}}{\text{cm}^2}$$

$$\min \sigma_{\text{T,Sd}} = 1,8 - 1,8 = 0 \frac{\text{kN}}{\text{cm}^2}$$

$$\Rightarrow \max \Delta \sigma_{\text{E}} = 3,6 \frac{\text{kN}}{\text{cm}^2}$$

$$\Delta \sigma_{\text{c}} = \frac{16,0}{1,25} = 12,8 \frac{\text{kN}}{\text{cm}^2}$$

$$\Delta \sigma_{\text{E}} < \Delta \sigma_{\text{c}}$$

5.4.1.3 Interaction between direct and shear stresses in the web

$$\left[\frac{\gamma_{\text{Ff}} \cdot \Delta \sigma_{\text{E2}}}{\frac{\Delta \sigma_{\text{c}}}{\gamma_{\text{Mf}}}} \right]^3 + \left[\frac{\gamma_{\text{Ff}} \cdot \Delta \tau_{\text{E2}}}{\frac{\Delta \tau_{\text{c}}}{\gamma_{\text{Mf}}}} \right]^5 \leq 1,0 \quad (\text{EC 3- P 9: 8 (3)})$$

$$\left[\frac{1,0 \cdot 3,6}{\frac{16,0}{1,25}} \right]^3 + \left[\frac{1,0 \cdot 2,9}{\frac{8,0}{1,25}} \right]^5 = 0,041 \leq 1,0$$