Metal Structures II

Design project II

Crane supporting structures

Example of calculation part II

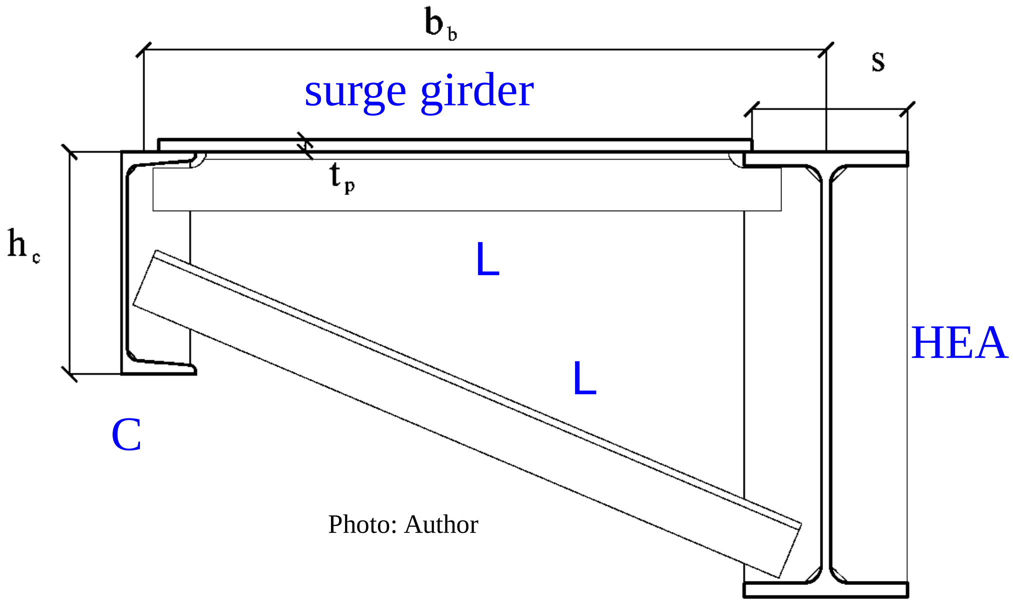

Photo: Author

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S 355

$h \approx \sqrt{[\,2\,M_{V,\,max} / (f_y\,t_0)]} = 0{,}658$ m →

HEA 650

$h_c \approx 0{,}3\,h$ → C 200

$t_f = 26$ mm, $t_w = 13{,}5$ mm

$b_b \approx \max\,(70$ cm ; $L_b / 20) = 80$ cm

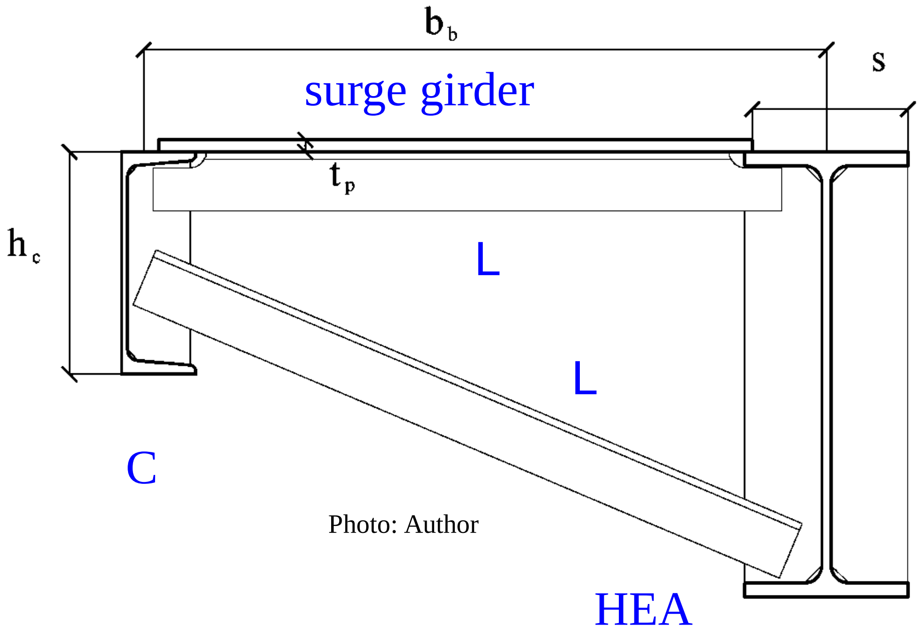
$t_p \approx 0{,}5\,(t_f + t_w) = 20$ mm; the thickest riffled plate was adopted: 10 mm

Surge girder:

$\varepsilon = \sqrt{(235 / f_y)} = 0{,}814$

Limit III / IV class of cross-section for bending: $72\,\varepsilon = 58{,}6$

$b_b / t_p = 800 / 10 = 80$ → is in range of IV section class.



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s → width of DS 100 rail foot is 200 mm. Requirements for bolts securing crane rails are:

space width = width of the rail foot + approx. 150 mm ≈ 350 mm

Flange width HEA 650 = 300 mm. We will need an additional overlay for the 400 mm wide top chord with thickness non less than "old" chord (26 mm). It will be adopted plate 30 mm.

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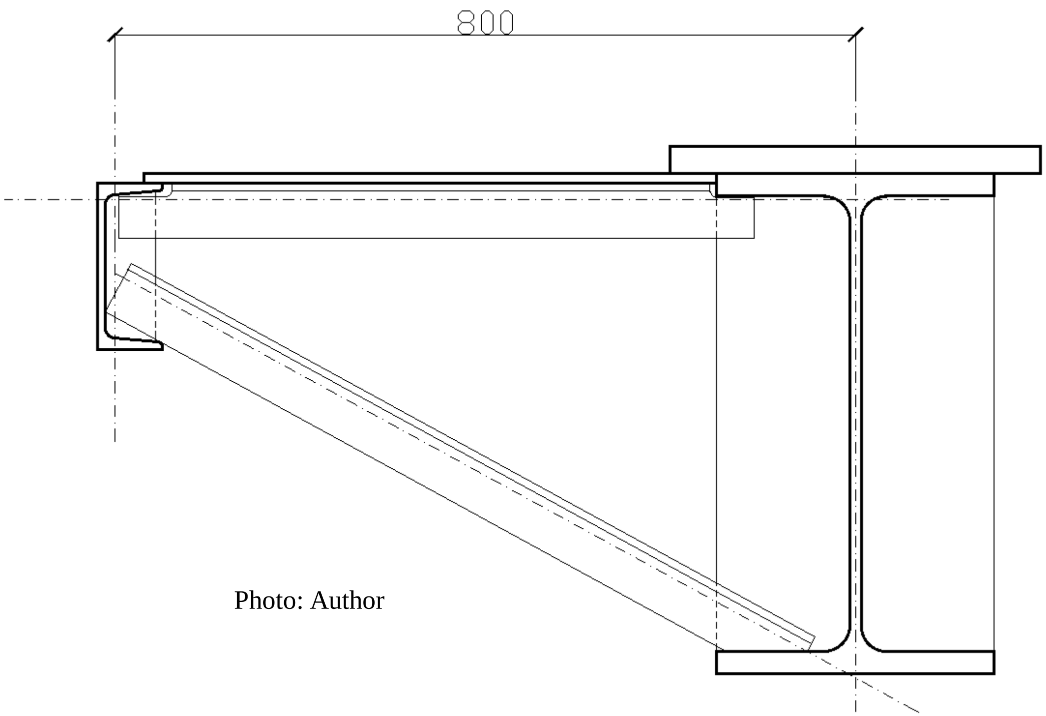
Surge girder is also working platform. Working platform must be supported with additional beams between the main beam and the auxiliary C-section. These additional elements will be L-sections 60x60x8.



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Surge girder is supported transversally by L-sections. Recommended distance between transversal elements is:

$$L \approx d$$

In analised case, because of problem with class of crosss-ection for surge girder, additional diagonal L-sections are recommended. Such complex made horizontal truss, cooperated with plate surge girder. Thank to this, surge girder in Ivth class of cross-section could be adopted witout additional problems.

$$L = 1000 \text{ mm} \quad ; \quad d = 800 \text{ mm}$$

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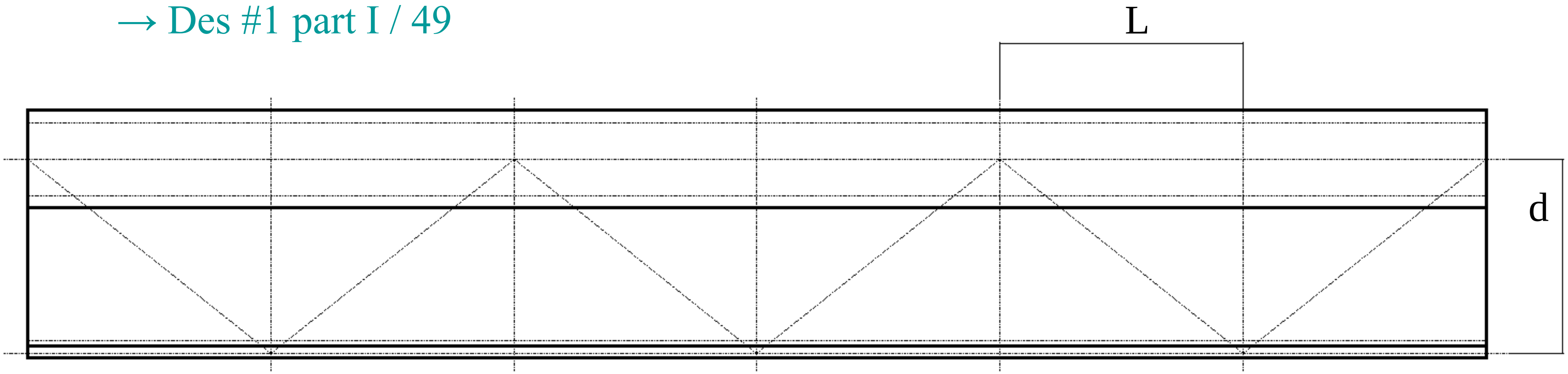
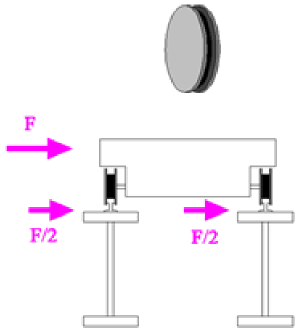


Photo: Author

Additional information for calculations, the same for everybody:

- One crane only
- Assembly crane, HC1, S0
- Steady hoisting speed $v_h = 0{,}08$ m / s
- Hook $\rightarrow \varphi_3 = 0{,}0$
- $\varphi_4 = 1{,}0$
- $\varphi_5 = 1{,}5$
- $\eta = 0$
- Single wheel drive, $m_w = 2$
- Friction coefficent $\mu = 0{,}2$
- Wheel flanges, $a_{ext} = R$
- Fixing of wheel IFF
- Longitudinal velocity of crane $v = 0{,}7$ m / s
- Spring constant of the buffer $S_B = 65$ kN / m
- $\xi_b = 0{,}5$
- Rail supported on an elastomeric bearing pad



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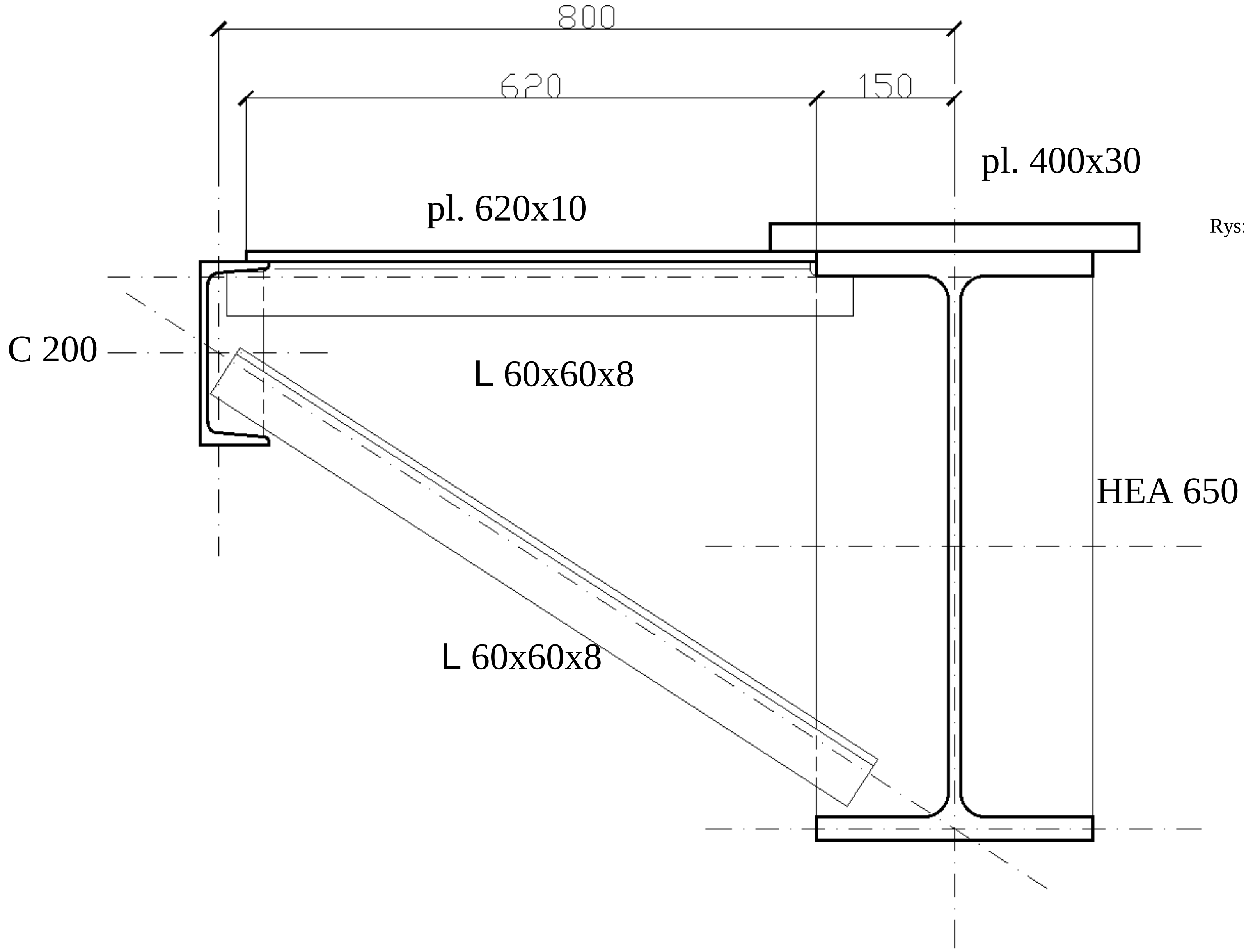
Rail is separated from beam by an elastomeric bearing pad - no cooperation between rail and beam; rail cross-section is not included in beam cross-section.


800
620
150
pl. 400x30
pl. 620x10
C 200
L 60x60x8
HEA 650
L 60x60x8

Rys: Autor

Limit State STR (strength + stability)

Fundamental condition is, as usual:

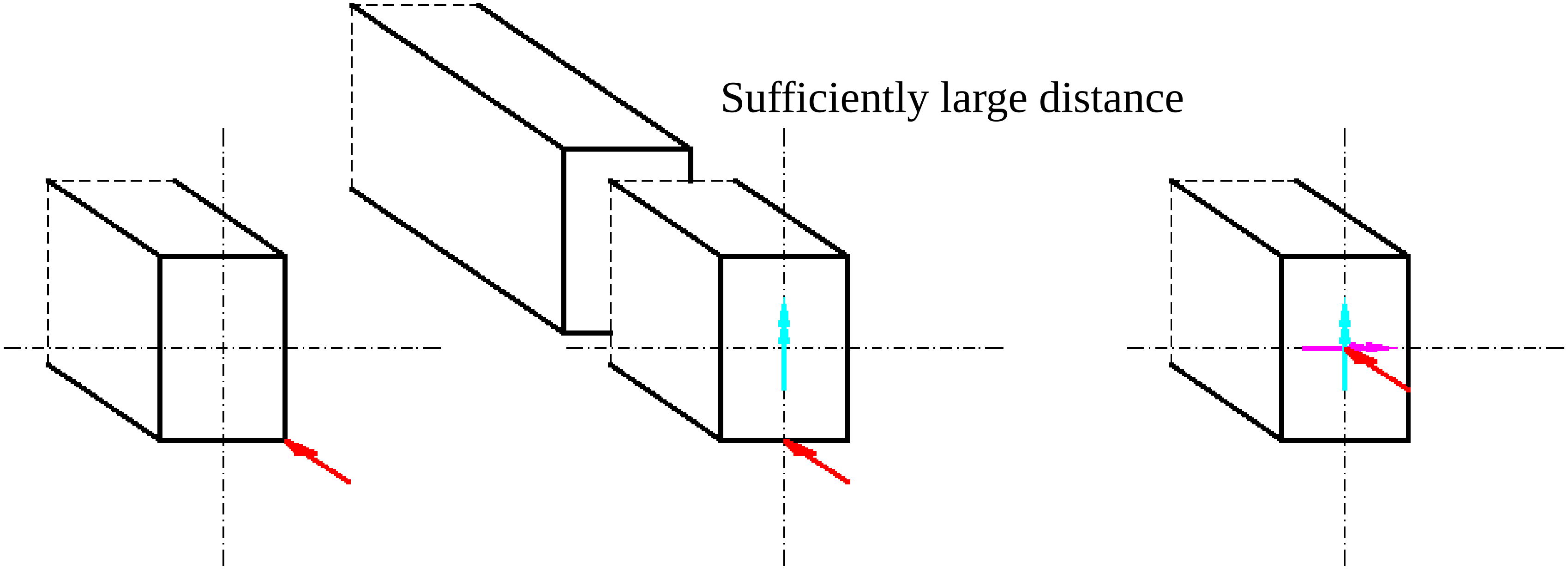
$$E / R \leq 1{,}0$$

In contrast to „normal” bar structures, analised on I grade of study, here E is equivalent stress Huber-Miises-Hencky, and R is yield strength f_y. This approach - by stresses, not by cross-sectional forces - is dictated by fact that for crane beams Saint-Venant Principle is not correct.

Saint-Venant Principle:

The difference between the effects of two different but statically equivalent loads becomes very small at sufficiently large distances from load.

The same effect (stresses, cross-sectional forces, deformations)



Various statically equivalent loads

Photo: Author

- Run-beams for cranes are specific type of cross-section - very big loads are applied into few (< 10) points of structure.
- Cross-section of this struture is wide and high, rather thin-walled.
- Proportion between length of run-beam and its max cross-sectional diameter (total width, total height) is usually smaller than 10.

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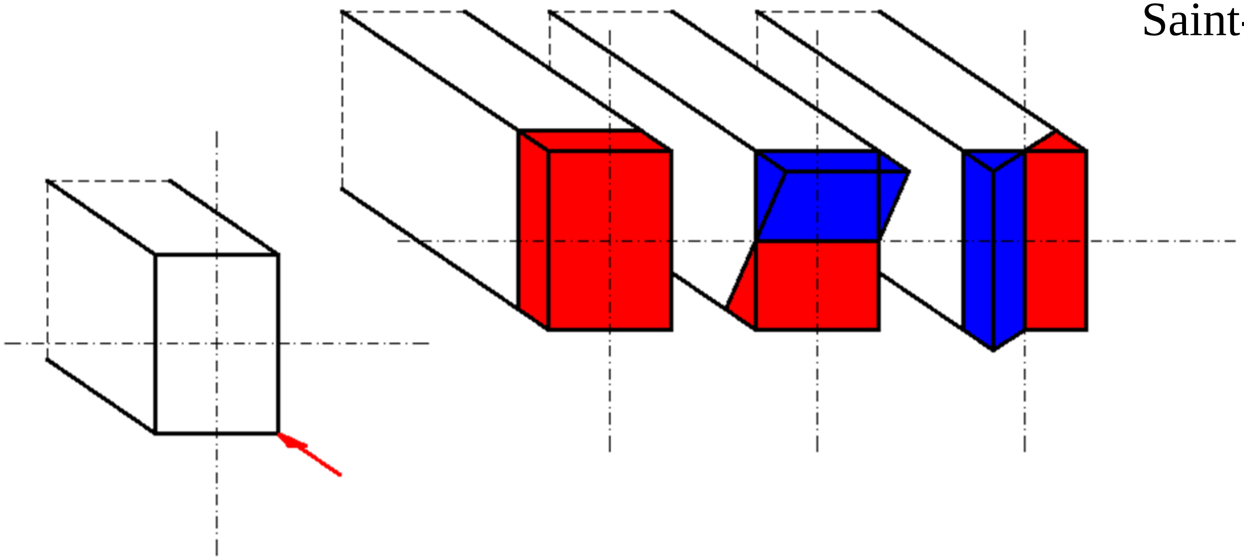
Case	Calculations
"Normal" structure (for example: Ist step of study)	Saint-Venant Principle is true; loads can be calculated as statically equivalent applied to the centre of gravity
Run-beam: I-beam, I-beam with surge girder, hollow section, hollow section with surge girder	Saint-Venant Principle is not true; Statically equivalent loads produce various cross-sectional forces; points of application of loads are very important

Saint-Venant Principle is true



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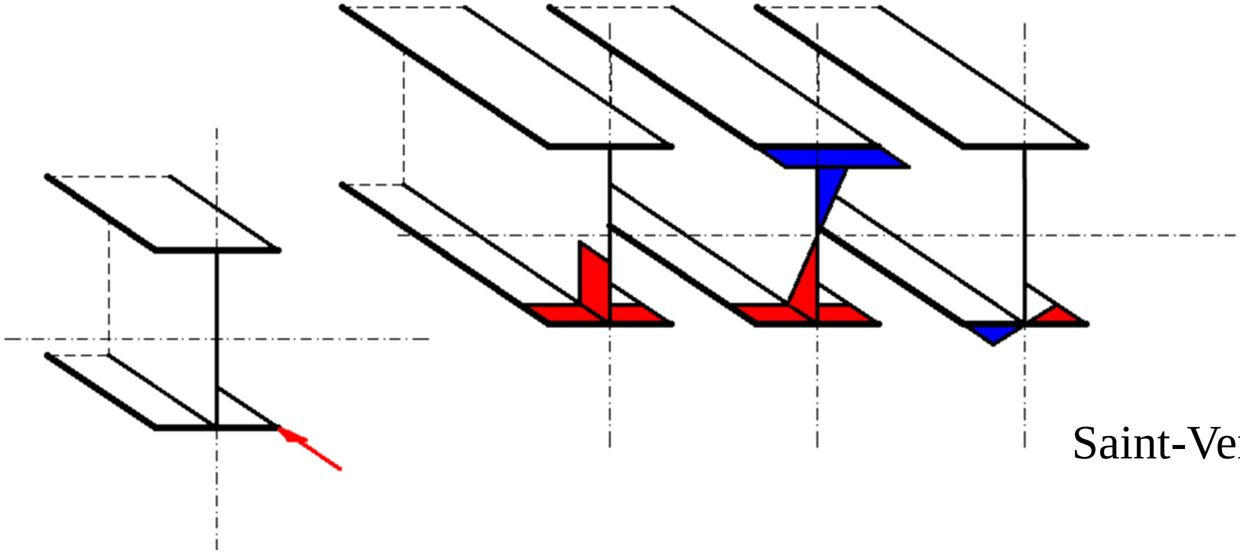
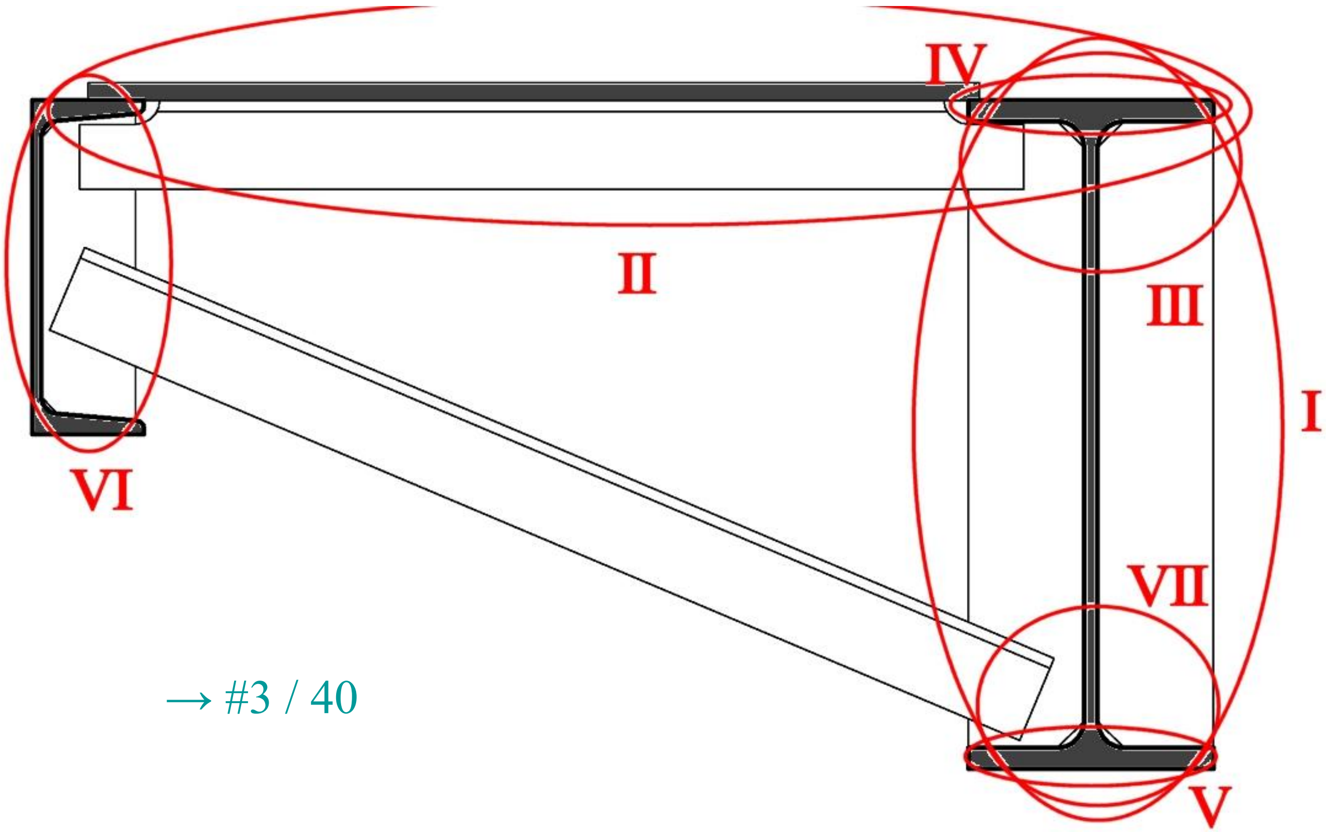


Saint-Venant Principle is not true

<table>
<tr><th rowspan="2">Type of run-beam's cross-section</th><th rowspan="2">Class of run-beam's cross-section</th><th colspan="3">Type of crane</th></tr>
<tr><th>Monorail hoist block</th><th>Overhead underslung crane</th><th>Overhead top-mounted crane</th></tr>
<tr><td rowspan="2">I-beam</td><td>Ist - IIIrd</td><td colspan="3">RSM</td></tr>
<tr><td>IVth</td><td colspan="3">ECSM, RSM</td></tr>
<tr><td rowspan="2">I-beam with plate surge girder</td><td>Ist - IIIrd</td><td colspan="2" rowspan="4">Cross-section not applicable for these types of trane

→ #3 / 24</td><td>RSM</td></tr>
<tr><td>IVth</td><td>ECSM, RSM</td></tr>
<tr><td rowspan="2">Hollow section,
hollow section with surge girder,
I-beam with lattice surge girder</td><td>Ist - IIIrd</td><td rowspan="2">Procedures and formulas in Eurocodes are not dedicated to such types of run-beam</td></tr>
<tr><td>IVth</td></tr>
</table>

Reduced stresses method - we divide cross-section into few sub-parts; for each sub-parts we applied other part of cross-sectional forces.



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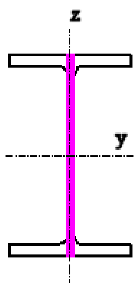
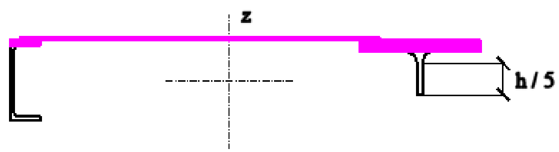
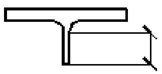
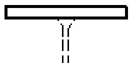
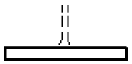
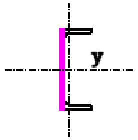
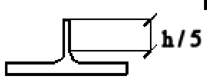
We must calculate geometrical characteristics for few sub-part of cross-section.
Sometimes geometry for area is not the same as geometry for sectional modulus.

Photo: Author	Sub-parts:					
I	II	III	IV	V	VI	VII
						
W_y^I W_z^I J^I_w ω^I_{max} A^I	W_z^{II} A^{II}	A^{III}	A^{IV}	A^V	W_y^{VI} A^{VI}	A^{VII}

If run-beam is in IV[th] class of cross-section, for I[st] sub-part we must take into consideration effective cross-section.

According to EN 1993-6 5.6.2 (4), we must analyse different types of cross-sectional forces acts on diferent sub-part of cross-section. Because of this, we must calculate stresses in few the most important points of cross-section.

Cross-sectional forces:

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Vertical forces from crane Vz

Horizontal forces Vy

    Couple of forces from torsional moment VT

    Bimoment B

Axial forces N

Vertical bending moment My = My (Vz)

Horizontal bending moment Mz = Mz (Vy)

Vertical forces from worker's activity Vw, z

Vertical forces from worker's activity Vw, z / 2

Vertical bending moment from worker's activity Mw, y = Mw, y (Vw, z)

Vertical bending moment from worker's activity Mw, y = Mw, y (Vw, z / 2)

The most important points of cross-section:

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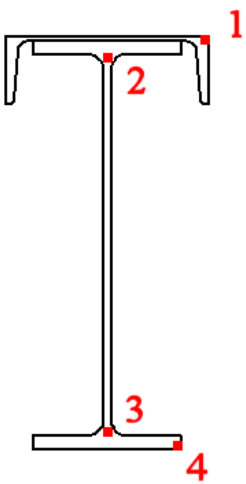

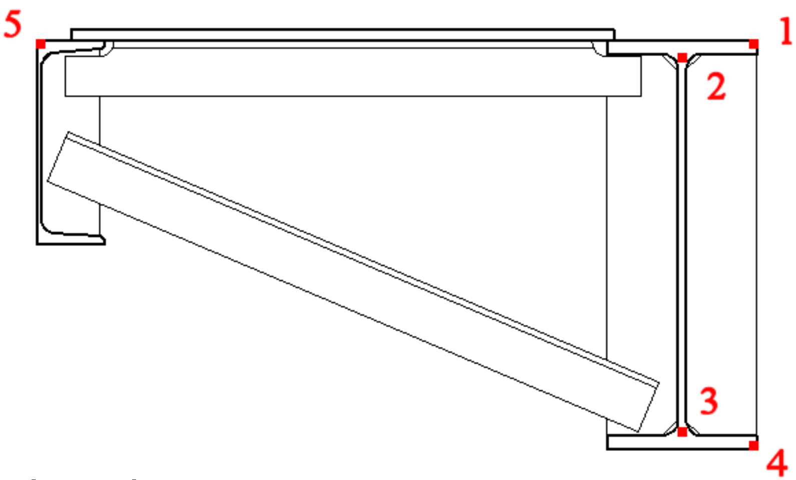

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First method of recalculations (according to EN 1993-6 5.6.2 (4)) - torsional moment as a couple of forces in flanges:

Overhead underslug crane

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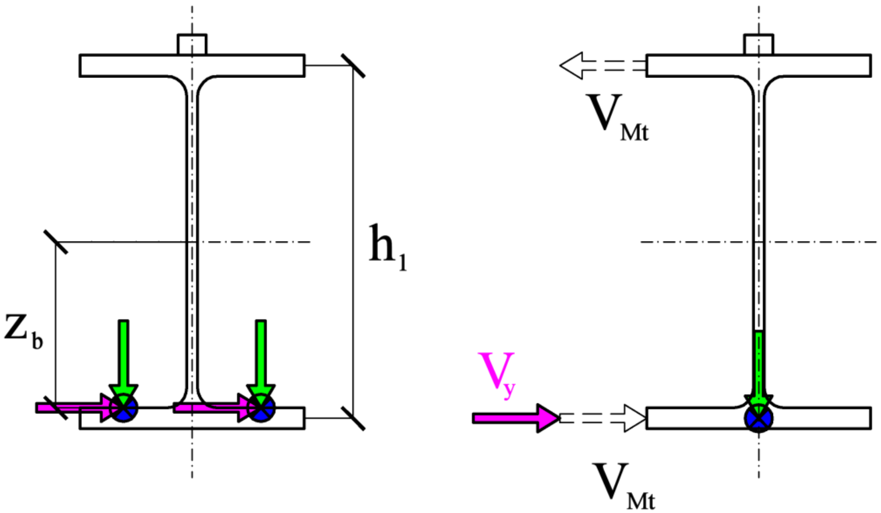
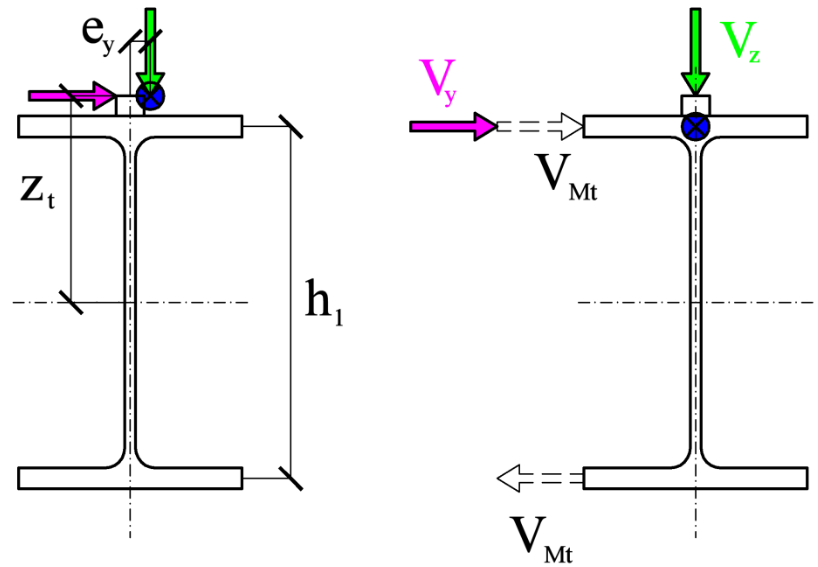


Overhead top-mounted crane



$T = V_y z_b$

$V_T = (V_y z_b) / h_1$

Photo: Author

$T = V_y z_t + V_z e_y$

$V_T = (V_y z_t + V_z e_y) / h_1$

Point #1:

Type of crane	Cross-sectional force	Part of cross-section (→ #3 / 41)	Stress
Overhead top-mounted crane with plate surge girder	V_y	A^{II}	$\tau_y (V_y) = V_y / A^{II}$
	V_T (torsional moment as a coulpe of force)	A^{IV}	$\tau_y (V_T) = V_T / A^{IV}$
	N	A^{III}	$\sigma_x (N) = N / A^{III}$
	$M_y = M_y (V_z)$	$W_y^{I,1}$	$\sigma_x (M_y) = M_y / W_y^{I,1}$
	$M_z = M_z (V_y)$	$W_z^{II,1}$	$\sigma_x (M_y) = M_z / W_z^{II,1}$
	$M_{w, y} = M_{w, y} \ (V_{w, z})$	$W_y^{I,1}$	$\sigma_x (M_{w, y}) = M_{w, y} / W_y^{I,1}$

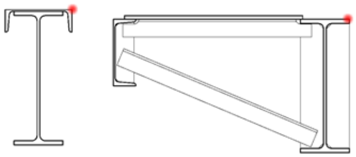


Photo: Author

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Point #2:

Type of crane	Cross-sectional force	Part of cross-section (→ #3 / 41)	Stress
Overhead top-mounted crane with plate surge girder	V_z	A^I	$\tau_z (V_z) = V_z / A^I$
	V_y	A^{II}	$\tau_y (V_y) = V_y / A^{II}$
	V_T (torsional moment as a coulpe of force)	A^{IV}	$\tau_y (V_T) = V_T / A^{IV}$
	N	A^{III}	$\sigma_x (N) = N / A^{III}$
	$M_y = M_y (V_z)$	$W_y^{I,2}$	$\sigma_x (M_y) = M_y / W_y^{I,2}$
	$M_z = M_z (V_y)$	$W_z^{II,2}$	$\sigma_x (M_y) = M_z / W_z^{II,2}$
	$V_{w, z}$	A^I	$\tau (V_{w, z}) = V_{w, z} / A^I$
	$M_{w, y} = M_{w, y} (V_{w, z})$	$W_y^{I,2}$	$\sigma_x (M_{w, y}) = M_{w, y} / W_y^{I,2}$

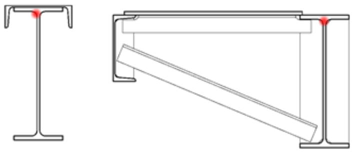

Photo: Author

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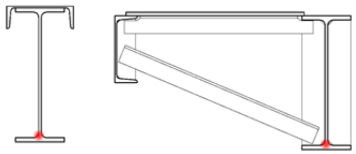
Point #3:

Type of crane	Cross-sectional force	Part of cross-section (→ #3 / 41)	Stress
Overhead top-mounted crane with plate surge girder	V_z	A^I	$\tau_z\ (V_z) = V_z / A^I$
	V_T (torsional moment as a coulpe of force)	A^V	$\tau_y\ (V_T) = V_T / A^V$
	$M_y = M_y\ (V_z)$	$W_y^{I,3}$	$\sigma_x\ (M_y) = M_y / W_y^{I,3}$
	$V_{w,\,z}$	A^I	$\tau\ (V_{w,\,z}) = V_{w,\,z} / A^I$
	$M_{w,\,y} = M_{w,\,y}\ (V_{w,\,z})$	$W_y^{I,3}$	$\sigma_x\ (M_{w,\,y}) = M_{w,\,y} / W_y^{I,3}$



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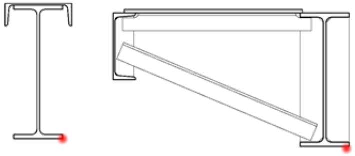
Point #4:

Type of crane	Cross-sectional force	Part of cross-section (→ #3 / 41)	Stress
Overhead top-mounted crane with plate surge girder	V_T (torsional moment as a coulpe of force)	A^V	$\tau_y (V_T) = V_T / A^V$
	$M_y = M_y (V_z)$	$W_y^{I,4}$	$\sigma_x (M_y) = M_y / W_y^{I,4}$
	$M_{w, y} = M_{w, y} (V_{w, z})$	$W_y^{I,4}$	$\sigma_x (M_y) = M_{w, y} / W_y^{I,4}$



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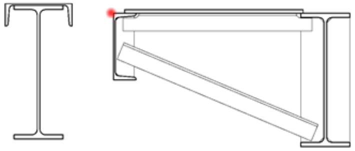
Point #5:

Type of crane	Cross-sectional force	Part of cross-section (→ #3 / 41)	Stress
Overhead top-mounted crane with plate surge girder	V_y	A^{II}	$\tau_y (V_y) = V_y / A^{II}$
	$M_z = M_z (V_y)$	$W_z^{II,5}$	$\sigma_x (M_z) = M_z / W_z^{II,5}$
	$V_{w, z} / 2$	A^{VI}	$\tau (V_{w, z}) = V_{w, z} / 2A^{VI}$
	$M_{w, y} = M_{w, y} (V_{w, z} / 2)$	$W_y^{VI,5}$	$\sigma_x (M_y) = M_{w, y} / W_y^{VI,5}$



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Part I:

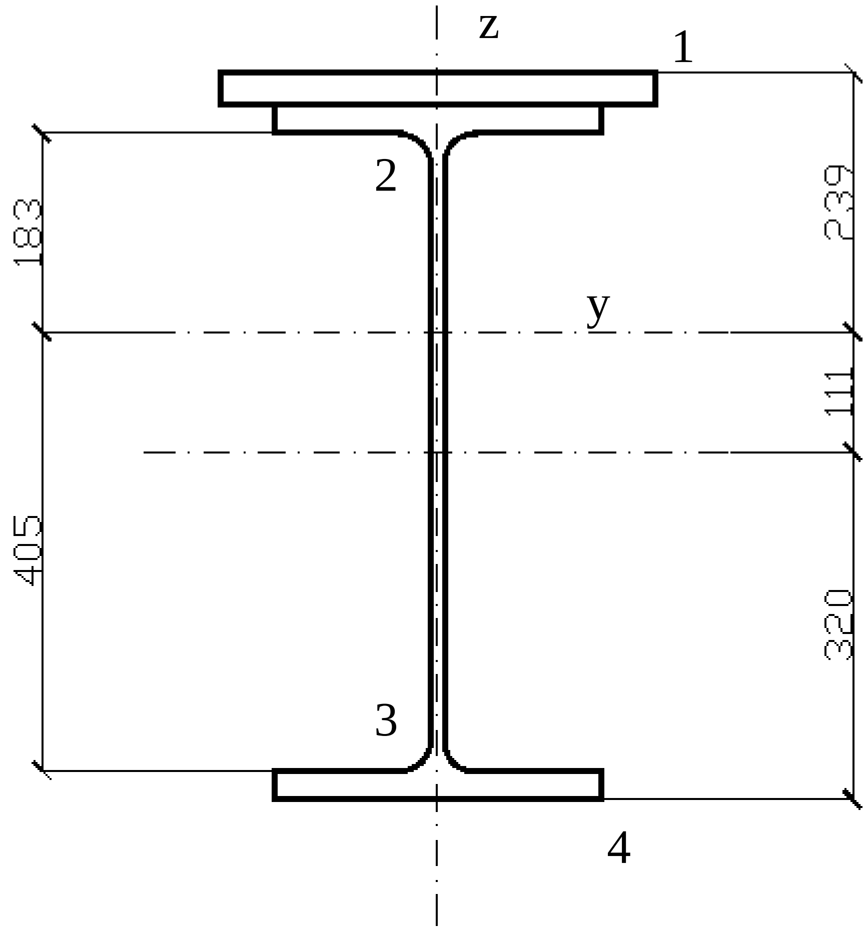
$W_y^{I,1} = 11\,095\ cm^3$

$W_y^{I,2} = 14\,491\ cm^3$

$W_y^{I,3} = 6\,548\ cm^3$

$W_y^{I,4} = 6\,153\ cm^3$

$A_v^{I} = 90\ cm^2$

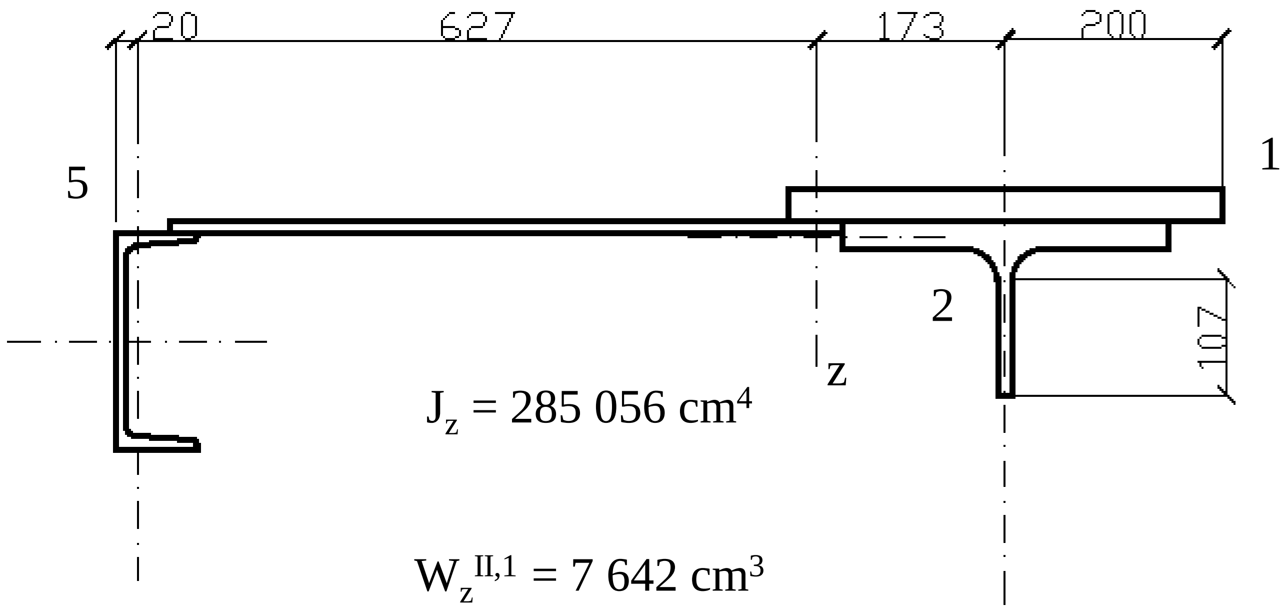


$J_y = 273\,513\ cm^4$

Part II:

Centre of gravity and J_z according to AutoCAD, functions REGION and MASSPROP

Rys: Autor



$J_z = 285\ 056\ cm^4$

$W_z^{II,1} = 7\ 642\ cm^3$

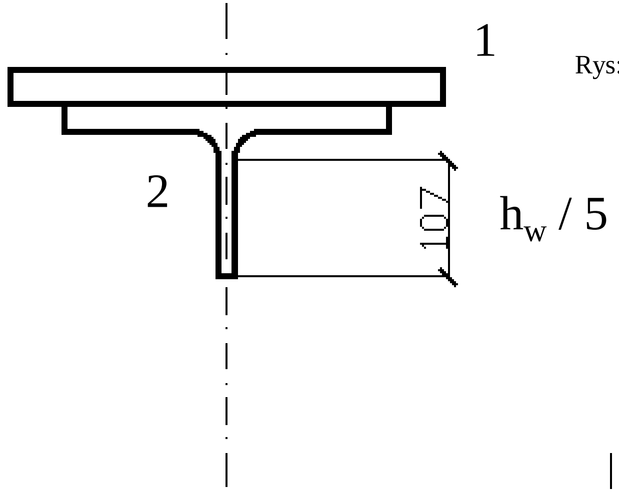
$W_z^{II,2} = 16\ 477\ cm^3$

$W_z^{II,5} = 4\ 406\ cm^3$

$A_v^{II} = 268{,}63\ cm^2$

Part III

$A^{III} = 217{,}58\ cm^2$



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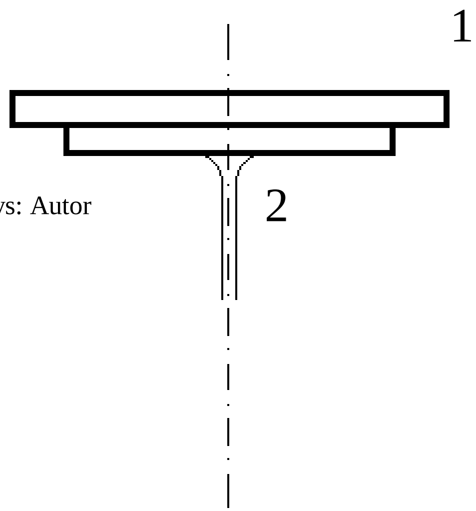
Part IV

$A^{IV} = 198{,}00\ cm^2$



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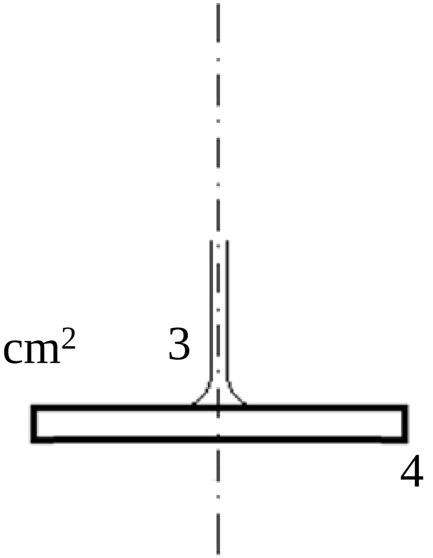
Part V

$A^{V} = 78{,}00\ cm^2$



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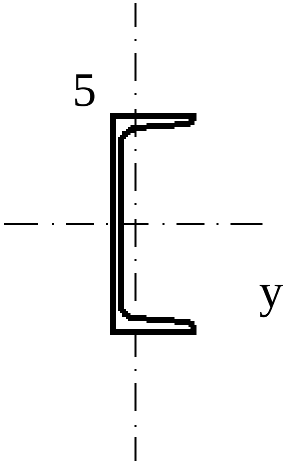
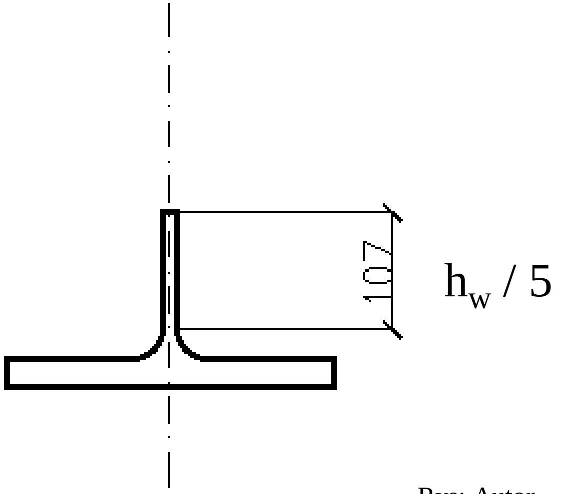
Part VI

Important only for very accurate calculation of effects from workers



Part VII

Important only for loads applied directly to bottom flange: from monorail hoist block and overhead underslung crane



Rys: Autor

Max M, under force

Force	Combination			
	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
M_V [kNm]	533,846	533,846	726,419	726,419
M_H [kNm]	239,042	254,171	192,609	207,734
M_T [kNm]	35,686	37,254	31,178	32,745
V_V [kN]	187,396	187,396	251,587	251,587
V_H [kN]	79,681	85,798	64,203	70,319
N [kN]	14,092	0,000	39,447	25,355

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Max V, under force

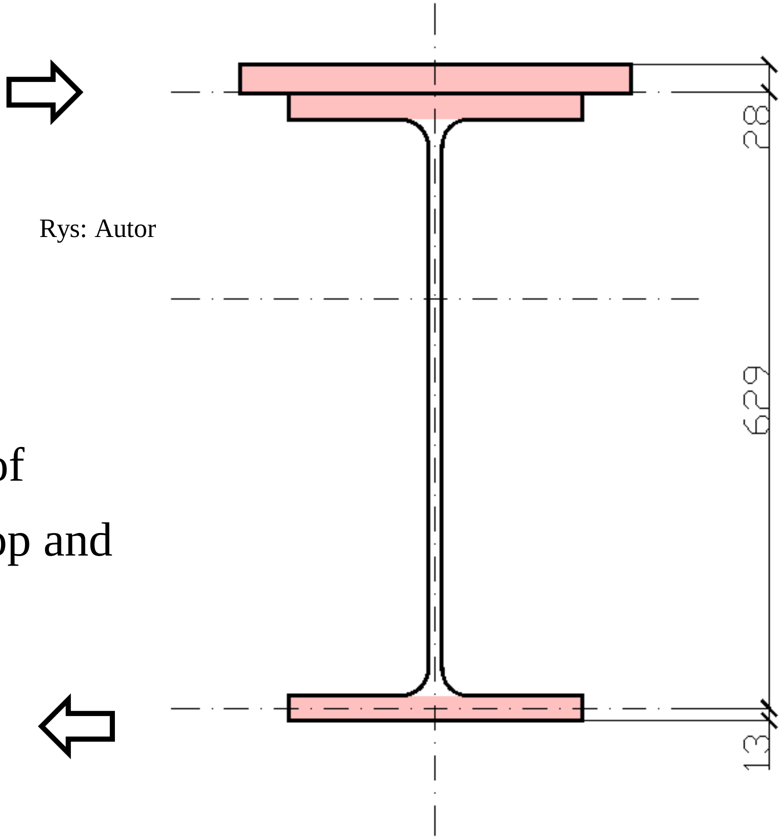
Force	Combination			
	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
M_V [kNm]	272,726	272,726	375,175	375,175
M_H [kNm]	127,170	133,936	102,468	109,232
M_T [kNm]	60,033	62,736	52,503	55,142
V_V [kN]	302,651	302,651	410,748	410,748
V_H [kN]	134,023	143,014	108,118	116,947
N [kN]	11,865	0,000	54,564	55,142

→ Des #1 part I / 70

Max V, over support

Force	Combination			
	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
M_V [kNm]	0,000	0,000	0,000	0,000
M_H [kNm]	0,000	0,000	0,000	0,000
M_T [kNm]	72,704	76,335	13,473	17,102
V_V [kN]	409,143	409,143	557,810	557,810
V_H [kN]	159,361	170,701	0,000	11,337
N [kN]	32,637	0,000	91,360	58,723

→ Des #1 part I / 71



Rys: Autor

Torsional moment M_T is recalculated to coulpe of horizontal forces, applied in centres of gravity top and bottom horizontal part.

$$V_{T\text{-}H} = M_T / r$$

$$r = 629 \text{ mm}$$

Final version of cross-sectiona forces:

Max M, under force

Force	Combination			
	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
M_V [kNm]	533,846	533,846	726,419	726,419
M_H [kNm]	239,042	254,171	192,609	207,734
$V_{T\text{-}H}$ [kN]	56,734	59,227	49,566	52,059
V_V [kN]	187,396	187,396	251,587	251,587
V_H [kN]	79,681	85,798	64,203	70,319
N [kN]	14,092	0,000	39,447	25,355

Final version of cross-sectiona forces:

Max V, under force

Force	Combination			
	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
M_V [kNm]	272,726	272,726	375,175	375,175
M_H [kNm]	127,170	133,936	102,468	109,232
$V_{T\text{-}H}$ [kN]	95,442	99,739	83,471	87,666
V_V [kN]	302,651	302,651	410,748	410,748
V_H [kN]	134,023	143,014	108,118	116,947
N [kN]	11,865	0,000	54,564	55,142

Final version of cross-sectiona forces:

Max V, over support

Force	Combination			
	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
M_V [kNm]	0,000	0,000	0,000	0,000
M_H [kNm]	0,000	0,000	0,000	0,000
V_{T-H} [kN]	115,587	121,359	21,420	22,420
V_V [kN]	409,143	409,143	557,810	557,810
V_H [kN]	159,361	170,701	0,000	11,337
N [kN]	32,637	0,000	91,360	58,723

Point #1 [MPa]: Max M, under force $\sigma_{HMH} = \sqrt{[\sigma^2 + 3(\tau_1{}^2)]}$

Stress	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
$\tau_y\ (V_H) = V_H / A^{II}$	2,966	3,194	2,390	2,618
$\tau_y\ (V_{T\text{-}H}) = V_{T\text{-}H} / A^{IV}$	2,865	2,991	2,503	2,629
$\sigma_x\ (N) = N / A^{III}$	0,648	0,000	1,813	1,165
$\sigma_x\ (M_V) = M_V / W_y^{I,1}$	48,116	48,116	65,473	65,473
$\sigma_x\ (M_H) = M_H / W_z^{II,1}$	31,280	33,260	25,204	27,183
$\sigma_x\ (1) =$	80,044	81,376	92,490	93,821
$\tau_y\ (1) =$	5,832	6,185	4,893	5,247
$\sigma_{HMH}\ (1) =$	80,678	82,078	92,877	94,260
$\sigma_{HMH}\ (1) / f_y =$	0,227	0,231	0,262	0,266

Point #1 [MPa]: Max V, under force

Stress	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
σ_{HMH} (1) =	45,091	45,772	51,739	52,877
σ_{HMH} (1) / f_y =	0,127	0,129	0,146	0,149

Max V, over support

Stress	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
σ_{HMH} (1) =	20,441	21,622	4,598	3,812
σ_{HMH} (1) / f_y =	0,058	0,061	0,013	0,011

Point #2 [MPa]: Max M, under force

Stress	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
$\tau_z (V_V) = V_V / A^I$	20,822	20,822	27,954	27,954
$\tau_y (V_H) = V_H / A^{II}$	2,966	3,194	2,390	2,618
$\tau_y (V_{T-H}) = V_{T-H} / A^{IV}$	2,865	2,991	2,503	2,629
$\sigma_x (N) = N / A^{III}$	0,648	0,000	1,814	1,166
$\sigma_x (M_V) = M_V / W_y^{I,2}$	36,840	36,840	50,129	50,129
$\sigma_x (M_H) = M_H / W_z^{II,2}$	14,508	15,426	11,690	12,608
$\sigma_x (2) =$	51,995	52,266	63,632	63,902
$\tau_y (2) =$	5,832	6,185	4,893	5,247
$\tau_z (2) =$	20,822	20,822	27,954	27,954

Point #2 [MPa]:

Max V, under force

Stress	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
σ_x (2) =	27,084	26,949	34,618	35,055
τ_y (2) =	9,809	10,361	8,240	8,781
τ_z (2) =	33,628	33,628	45,639	45,639

Max V, over support

Stress	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
σ_x (2) =	1,501	0,000	4,200	2,700
τ_y (2) =	11,770	12,484	1,082	1,554
τ_z (2) =	45,460	45,460	61,979	61,979

In point 2, at interface between web and upper flange, for run-beam of top-mounted crane, in addition to global effects, 3 local phenomena should be considered::

- lateral compression of web under crane wheel
- shear concentration under crane wheel
- local bending in web

In Reduced Stresses Method, local stresses should be added to corresponding global stresses.

Local stress in the web σ_z → under crane wheel EN 1993-3 5.7.1

RSM method:

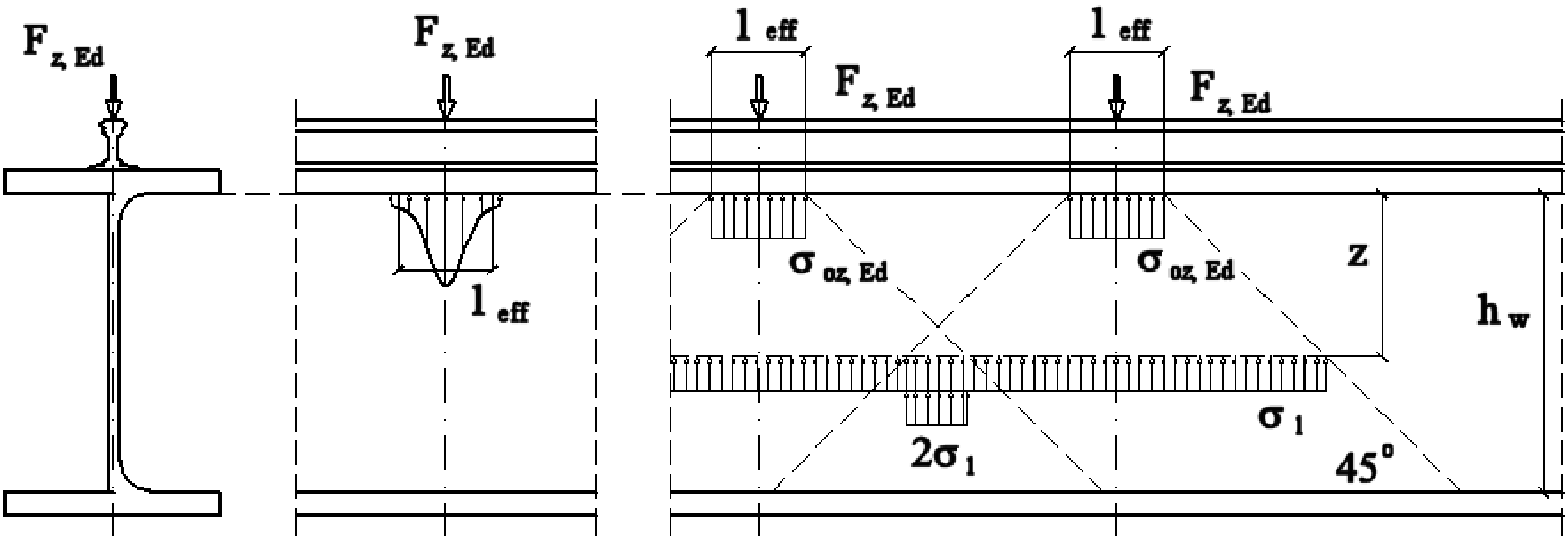


Photo: Author

$$\sigma_{oz,\,Ed} = F_{z,\,Ed} / (l_{eff}\, t_w)$$

$$\sigma_1 = \sigma_{oz,\,Ed}\,(1 - 2\, z / h_w)$$

$$z_{max} = h_w / 2$$

→ #3 / 75

$$z > z_{max} \rightarrow \sigma_{oz,\,Ed} = 0$$

Connection rail - flange	l_{eff}
1. Crane rail rigidly fixed to the flange (welded or bolted C)	$3{,}25 \sqrt[3]{(J_{rf} / t_w)}$
2. Crane rail not rigidly fixed to flange (no first, no third)	$3{,}25 \sqrt[3]{[(J_r + J_{r,eff}) / t_w]}$
3. Crane rail mounted on a suitable resilient elastomeric bearing pad at least 6mm thick	$4{,}25 \sqrt[3]{[(J_r + J_{r,eff}) / t_w]}$

EN 1993-3 tab. 5.1

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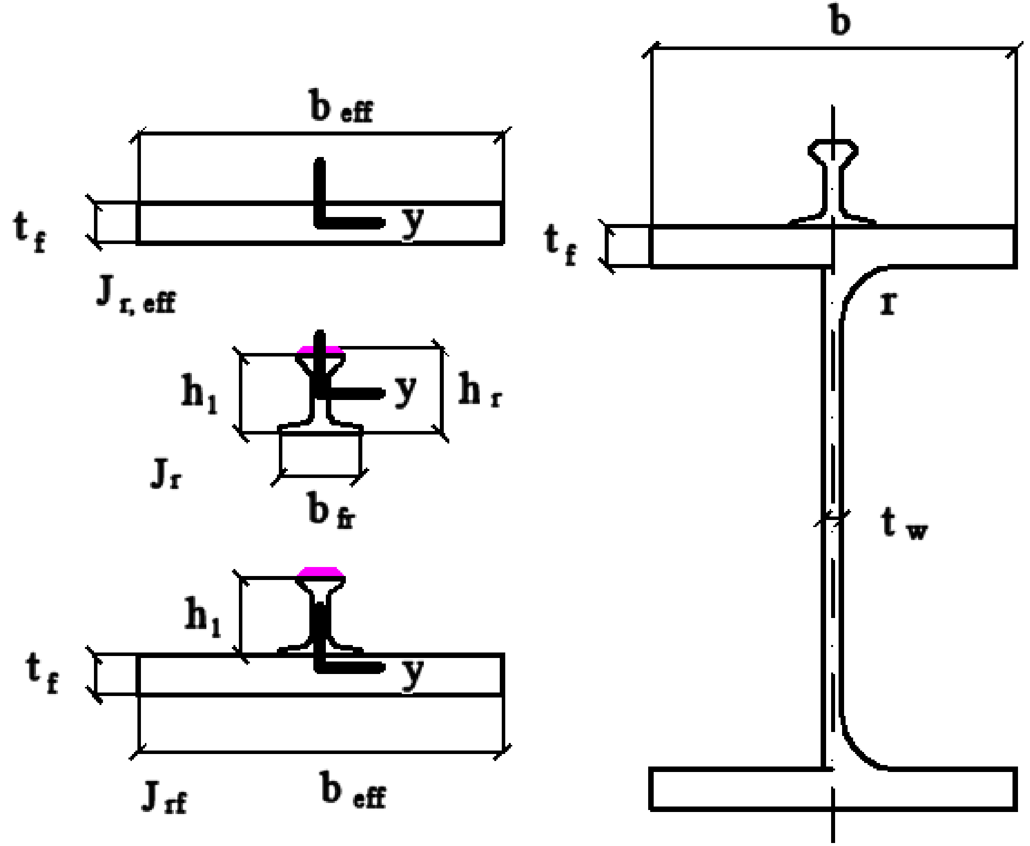


Photo: Author

J_{rf} , J_r , $J_{r,eff}$ - about axis y

$b_{eff} = \min (b \; ; \; b_{fr} + h_r + t_f)$

$h_1 = h_r$ after reduction → #3 / 17

→ #3 / 77

EN 1993-3 tab. 5.1

Additional information for calculations, the same for everybody:

- One crane only
- Assembly crane, HC1, S0
- Steady hoisting speed $v_h = 0{,}08$ m / s
- Hook → $\varphi_3 = 0{,}0$
- $\varphi_4 = 1{,}0$
- $\varphi_5 = 1{,}5$
- $\eta = 0$
- Single wheel drive, $m_w = 2$
- Friction coefficent $\mu = 0{,}2$
- Wheel flanges, $a_{ext} = R$
- Fixing of wheel IFF
- Longitudinal velocity of crane $v = 0{,}7$ m / s
- Spring constant of the buffer $S_B = 65$ kN / m
- $\xi_b = 0{,}5$
- Rail supported on an elastomeric bearing pad

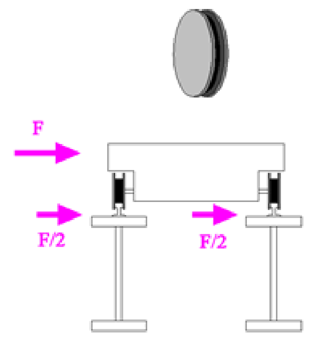


Photo: Author

Connection rail - flange	l_{eff}
3. Crane rail mounted on a suitable resilient elastomeric bearing pad at least 6mm thick	$4{,}25 \sqrt[3]{[(J_r + J_{r,eff}) / t_w]}$

Chamber of Bridge, Metal and Timber Structures
Cracow University of Technology

J_{rf} (top I-beam's flange + plate 400x30 mm) = 378,3 cm^4

J_r (rail DS 100 without 25% of the top of the head) ≈ 653,4 cm^4 (AutoCAD, REGION, MASSPROP)

l_{eff} = 0,399 m

External action: max vertical force under one wheel

For combination #5: $Q_c + Q_h$ = 337,500 kN

For combination #8: ,1, $Q_c + Q_T$ = 465,485 kN

$\sigma_z = Q_{r,\ max} / (l_{eff}\ t_w)$

σ_z (c#5) = 62,657 MPa

σ_z (c#8) = 86,417 MPa

Local stress in the web τ_{xz} → under crane wheel   EN 1993-3 5.7.2

RSM method:

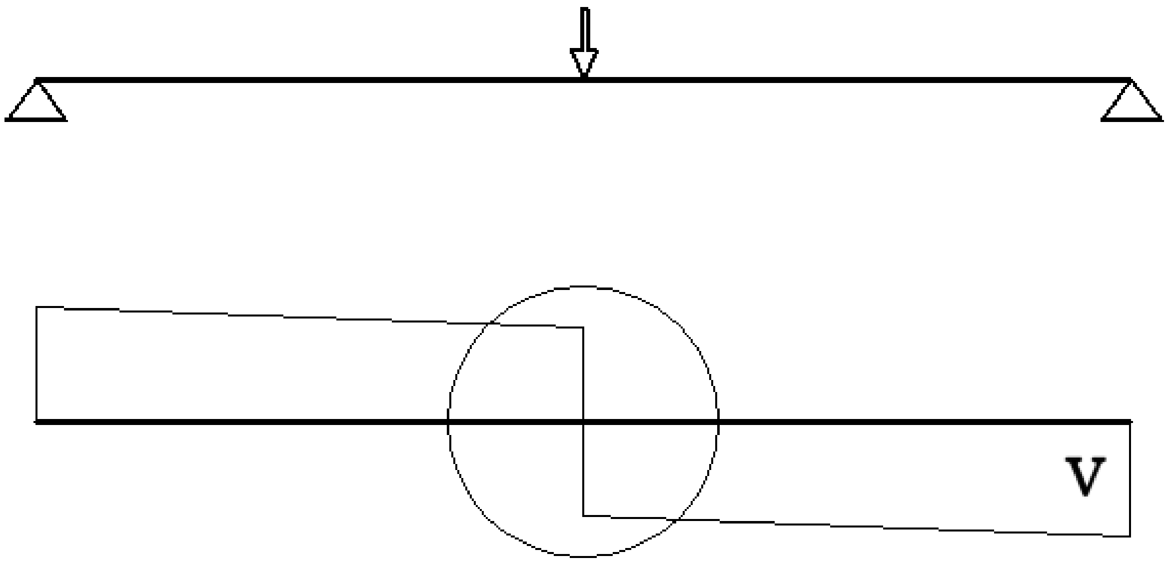


Photo: Author

→ #3 / 79

→ #3 / 80

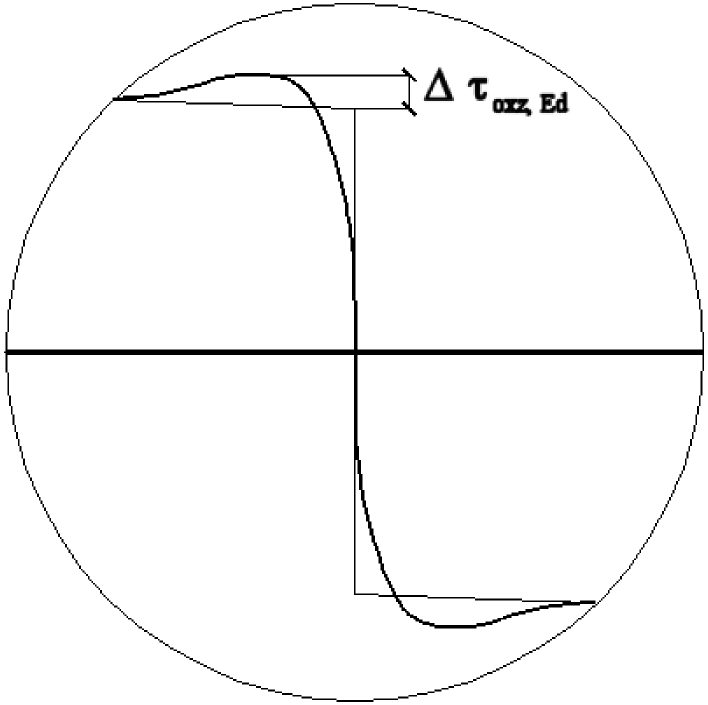


Photo: Author

$$\Delta\tau_{oxz,\,Ed} = 0{,}2\ \sigma_{oz,\,Ed}$$

$$\Delta\tau_1 = \Delta\tau_{oxz,\,Ed}\ (1 - 2\ z\ /\ h_w)$$

$$z_{max} = h_w\ /\ 5$$

$\sigma_{oz,\,Ed}$ → #3 / 75

Point #2 [MPa]:

Max M, under force

Stress	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
σ_z (2) =	62,657	62,657	86,417	86,417
τ_z (2) +0,2 σ_z (2) =	33,353	33,353	45,237	45,237

Point #2 [MPa]:

Max V, under force

Stress	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
σ_z (2) =	62,657	62,657	86,417	86,417
τ_z (2) +0,2 σ_z (2) =	46,159	46,159	62,922	62,922

Max V, over support

Stress	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
σ_z (2) =	62,657	62,657	86,417	86,417
τ_z (2) +0,2 σ_z (2) =	57,991	57,991	82,262	82,262

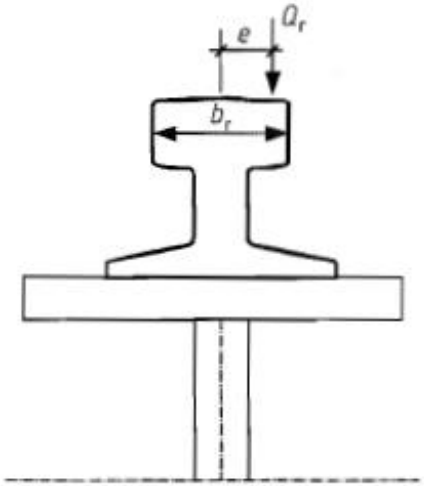
→ #3 / 81

Local bending in web

RSM method:

EN 1993-6 5.7.3

Photo: EN 1991-3 fig. 2.2



$$e = \max(0{,}25\, b_r \;\; ; \;\; 0{,}5\, t_w)$$

$$T_{Ed} = F_{z,\,Ed}\, e$$

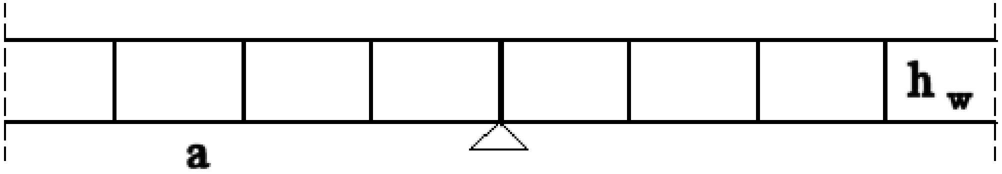


Photo: Author

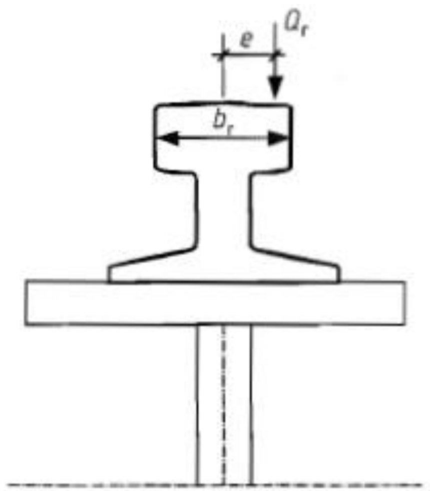
$$\eta = \sqrt{\{\, 0{,}75\, a\, t_w^3 \sinh^2(\pi\, h_w / a) / [J_t (\sinh(2\,\pi\, h_w / a) - 2\,\pi\, h_w / a)]\,\}}$$

$$\sigma_{T,\,Ed} = 6\, T_{Ed}\, \eta\, \mathrm{tgh}(\eta) / a\, t_w^2$$

External action: max vertical force under one wheel

For combination #5: $Q_c + Q_h = 337{,}500$ kN ; T_{Ed} (c#5) = 8,438 kNm

For combination #8: ,1, $Q_c + Q_T = 465{,}485$ kN ; T_{Ed} (c#8) = 11,637 kNm kNm



Rys: EN 1991-3 fig. 2.2

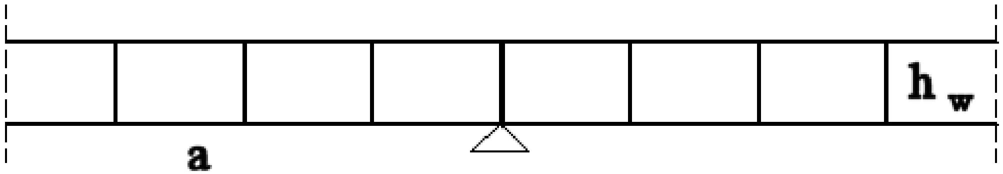
$a = 1{,}000$ m

$h_w = 0{,}534$ m

$t_w = 0{,}0135$ m

J_t (HEA 650) = 448,3 cm^4

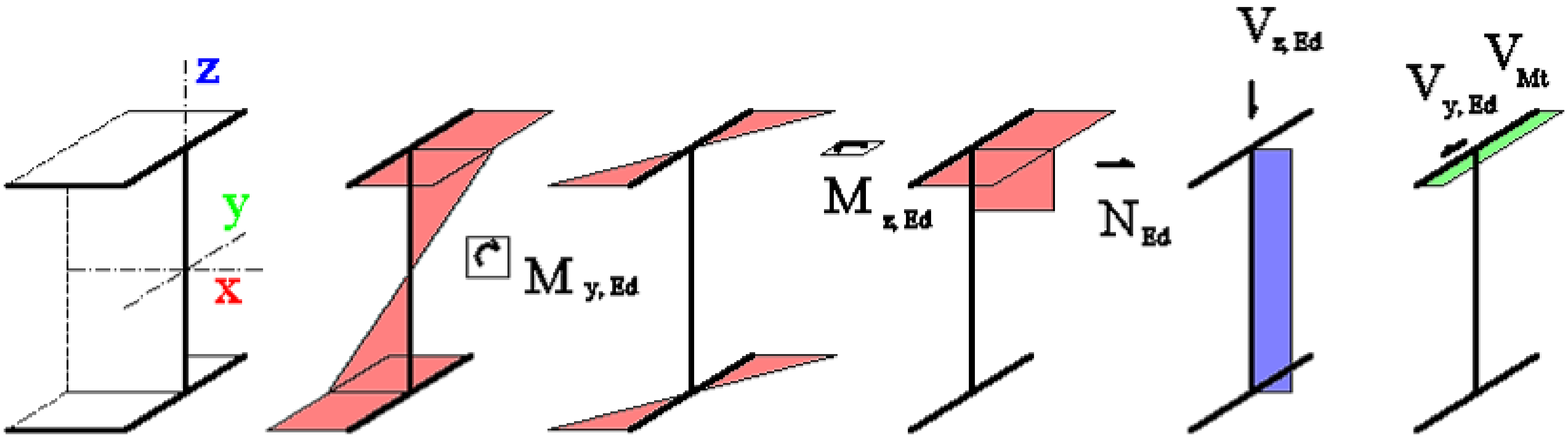
$\eta = 0{,}578$

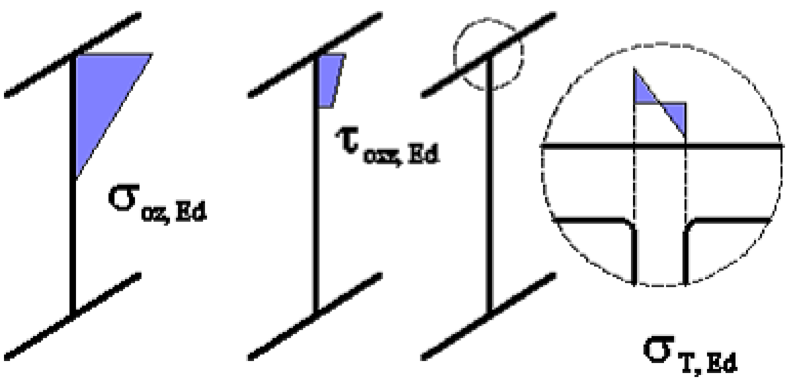


Rys: Autor

Stress [MPa]	c#5	c#8
$\sigma_{T, Ed}$	83,736	115,482

RSM method: each types of stresses must be taken into consideration





Stresses from transverse compression and transverse bending of web under crane wheel create an additional system of axial stresses σ_z parallel to the vertical axis z. Stresses resulting from concentration under crane wheel refer to increase of shear stress τ_z

Photo: Author

Point #2 [MPa]:

Max M, under force

Stress	Page
σ_x (2) =	#t / 36
σ_z (2) =	#t / 46 + #t / 49
τ_y (2) =	#t / 36
τ_z (2) =	#t / 36 + #t / 46

Point #2 [MPa]:

Max M, under force

$$\sigma_{HMH} = \sqrt{[\sigma_{11}^2 + \sigma_{22}^2 + \sigma_{33}^2 - \sigma_{11}\sigma_{22} - \sigma_{11}\sigma_{33} - \sigma_{22}\sigma_{33} + 3(\tau_{12}^2 + \tau_{23}^2 + \tau_{13}^2)]}$$

Stress	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
σ_x (2) =	51,995	52,266	63,632	63,902
σ_z (2) =	146,393	148,393	201,899	201,899
τ_y (2) =	5,832	6,185	4,893	5,247
τ_z (2) =	54,175	54,175	73,191	73,191
σ_{HMH} (2) =	159,466	160,984	219,334	219,313
σ_{HMH} (2) / f_y =	0,449	0,453	0,618	0,618

Point #2 [MPa]: Max V, under force

$$\sigma_{HMH} = \sqrt{[\sigma_{11}^2 + \sigma_{22}^2 + \sigma_{33}^2 - \sigma_{11}\sigma_{22} - \sigma_{11}\sigma_{33} - \sigma_{22}\sigma_{33} + 3(\tau_{12}^2 + \tau_{23}^2 + \tau_{13}^2)]}$$

Stress	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
σ_x (2) =	27,084	26,949	34,618	35,055
σ_z (2) =	146,393	146,393	201,899	201,899
τ_y (2) =	9,809	10,361	8,24	8,781
τ_z (2) =	79,787	79,787	108,561	108,561
σ_{HMH} (2) =	193,871	193,990	265,579	265,523
σ_{HMH} (2) / f_y =	0,546	0,546	0,748	0,748

Point #2 [MPa]:

Max V, over support

$$\sigma_{HMH} = \sqrt{[\sigma_{11}^2 + \sigma_{22}^2 + \sigma_{33}^2 - \sigma_{11}\sigma_{22} - \sigma_{11}\sigma_{33} - \sigma_{22}\sigma_{33} + 3(\tau_{12}^2 + \tau_{23}^2 + \tau_{13}^2)]}$$

Stress	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
σ_x (2) =	1,501	0,000	4,2	2,7
σ_z (2) =	146,393	146,393	201,899	201,899
τ_y (2) =	11,77	12,484	1,082	1,554
τ_z (2) =	103,451	103,451	144,241	144,241
σ_{HMH} (2) =	231,809	232,389	319,926	320,389
σ_{HMH} (2) / f_y =	0,653	0,655	0,901	0,903

Poin #3 [MPa]:

Max M, under force

$$\sigma_{HMH} = \sqrt{[\sigma^2 + 3(\tau_1{}^2 + \tau_2{}^2)]}$$

Stress	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
$\tau_z (V_V) = V_V / A^I$	20,822	20,822	27,954	27,954
$\tau_y (V_{T\text{-}H}) = V_{T\text{-}H} / A^V$	7,274	7,593	6,355	6,674
$\sigma_x (M_V) = M_V / W_y{}^{I,3}$	81,528	81,528	110,938	110,938
$\sigma_{HMH} (3) =$	90,034	90,113	121,542	121,594
$\sigma_{HMH} (3) / f_y =$	0,254	0,254	0,342	0,343

Poin #3 [MPa]:

$$\sigma_{HMH} = \sqrt{[\sigma^2 + 3(\tau_1{}^2 + \tau_2{}^2)]}$$

Max V, under force

Stress	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
σ_{HMH} (3) =	74,675	74,952	99,373	99,551
σ_{HMH} (3) / f_y =	0,210	0,211	0,280	0,280

Max V, over support

Stress	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
σ_{HMH} (3) =	82,817	83,224	107,456	107,466
σ_{HMH} (3) / f_y =	0,233	0,234	0,303	0,303

Point #4 [MPa]:

Max M, under force

$$\sigma_{HMH} = \sqrt{[\sigma^2 + 3(\tau_1{}^2)]}$$

Stress	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
$\tau_y\ (V_{T\text{-}H}) = V_{T\text{-}H} / A^V$	7,274	7,593	6,355	6,674
$\sigma_x\ (M_V) = M_V / W_y^{I,4}$	86,762	86,762	118,059	118,059
$\sigma_{HMH}\ (4) =$	87,672	87,753	118,571	118,624
$\sigma_{HMH}\ (4) / f_y =$	0,247	0,247	0,334	0,334

Poin #4 [MPa]:

$$\sigma_{HMH} = \sqrt{[\sigma^2 + 3(\tau_1{}^2)]}$$

Max V, under force

Stress	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
σ_{HMH} (3) =	49,130	49,549	63,729	64,006
σ_{HMH} (3) / f_y =	0,138	0,140	0,180	0,180

Max V, over support

Stress	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
σ_{HMH} (3) =	25,667	26,949	4,756	4,979
σ_{HMH} (3) / f_y =	0,072	0,076	0,013	0,014

Point #5 [MPa]:

Max M, under force

$$\sigma_{HMH} = \sqrt{[\sigma^2 + 3(\tau_1{}^2)]}$$

Stress	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
$\tau_y (V_H) = V_H / A^{II}$	2,966	3,194	2,390	2,618
$\sigma_x (M_H) = M_H / W_z^{II,5}$	54,254	57,687	43,715	47,148
$\sigma_{HMH} (5) =$	54,496	57,952	43,911	47,365
$\sigma_{HMH} (5) / f_y =$	0,154	0,163	0,124	0,133

Poin #5 [MPa]:

$$\sigma_{HMH} = \sqrt{[\sigma^2 + 3(\tau_1{}^2)]}$$

Max V, under force

Stress	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
σ_{HMH} (3) =	30,129	31,766	24,279	25,913
σ_{HMH} (3) / f_y =	0,085	0,089	0,068	0,073

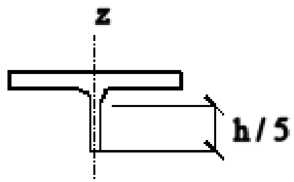
Max V, over support

Stress	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
σ_{HMH} (3) =	10,275	11,006	0,000	0,731
σ_{HMH} (3) / f_y =	0,029	0,031	0,000	0,002

Lateral buckling

EN 1993-6 6.3

Lateral buckling of beam is calcultated as flexural buckling of flange about vertical axis under equivalent compressive axial force N_{equ}

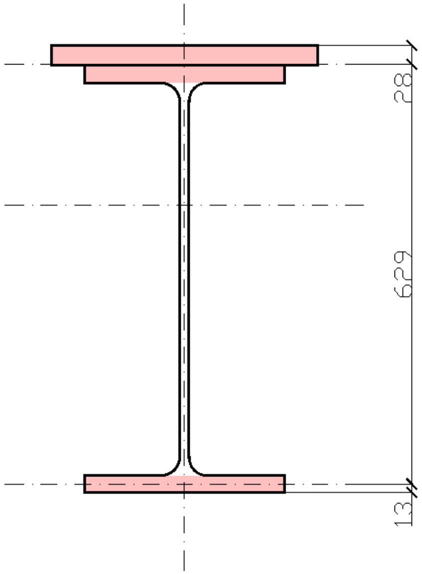


Rys: Autor

$i_z = \sqrt{(J_{T,z} / A_T)}$

$\lambda_T = (L_{cr} / i_z) [1 / (93,9\varepsilon)]$

Rys: Autor



$h_0 = 629$ mm

Equivalent force N_{equ} is caluclated based on both bending moments, global axial force and distanve between centres of gravity of flanges h_0

$$\sigma_{equ} = |\sigma(N)| + |\sigma(M_z)| + |\sigma(B)|$$

	$\sigma(N)$	$\sigma(M_y)$	$\sigma(M_z)$	$\sigma(B)$
Monorail hoist block	0	$M_y / W_y^{I,1}$	0	0
Overhead underslung crane	0	$M_y / W_y^{I,1}$	$M_z / W_z^{I,1}$	$B\, \omega_{max} / J_w$
Overhead top-mounted crane without surge girder	N / A^{III}	$M_y / W_y^{I,1}$	$M_z / W_z^{I,1}$	$B\, \omega_{max} / J_w$
Overhead top-mounted crane with plate surge girder	N / A^{III}	$M_y / W_y^{I,1}$	$M_z / W_z^{II,1}$	$B\, \omega_{max} / J_w$

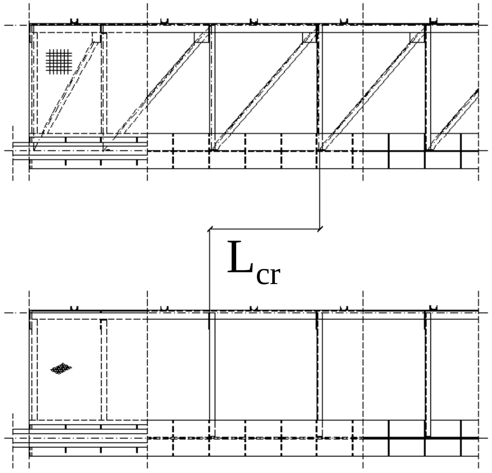
$$N_{equ} = A^{III} \sigma_{equ} + M_y / h_0$$

→ #3 / 69

Buckling length L_{cr} depends on type of crane and type of structure:

Crane, structure	L_{cr}
Monorail hoist block	Total length of run-beam
Overhead underslung crane	Total length of run-beam
Overhead top-mounted crane, no surge girder	Total length of run-beam
Overhead top-mounted crane, plate or lattice surge girder	Distance between transversal stiffeners of surge girder

Photo: Author



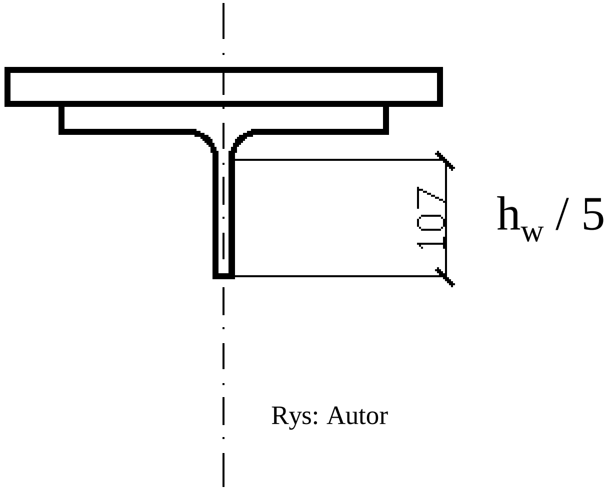
$$\chi_{T} = \chi_{T}(\lambda_{T}, c)$$

$$N_{T,Rd} = \chi_{T} A_{T} fy$$

$$N_{equ} / N_{T,Rd} \leq 1{,}0$$

→ #3 / 70

Top part of beam + plate:



Rys: Autor

$J_{\perp, z} = 21\ 857\ cm^4$

$A_{\perp} = 217{,}58\ cm^2$

$i_z = \sqrt{(J_{\perp, z} / A_{\perp})} = 10{,}023\ cm$

$\lambda_{\perp} = (L_{cr} / i_z)\ [1 / (93{,}9\varepsilon)] = 0{,}131$

$\chi_{\perp} = \chi_{\perp} (\lambda_{\perp}, c) = |||\ \lambda_{\perp} < 0{,}2\ ||| = 1{,}0$ olny resistance under equivalent force

$N_{\perp, Rd} = A_{\perp}\ f_y = 7\ 724{,}090\ kN$

Max M, under force (point #1)

Force	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
N_{equ}	1 543,405	1 572,387	1 742,715	1 771,686
$N_{equ} / N_{T,Rd}$	0,200	0,204	0,226	0,229

Max V, under force (point #1)

Force	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
N_{equ}	807,525	814,924	942,769	962,606
$N_{equ} / N_{T,Rd}$	0,105	0,106	0,122	0,125

Max V, over support (point #1)

Force	5, wind longitudinal	5, wind transversal	8, wind longitudinal	8, wind transversal
N_{equ}	32,637	0,000	91,360	58,723
$N_{equ} / N_{T,Rd}$	0,004	0,000	0,012	0,008

Limit state FAT

Fatigue resistance is related to level of imperfections introduced into analyzed element during its cutting and welding.

EN 1991-3 (2.16)

Stresses are calculated for cpecific value of live load:

$$\Delta\sigma_E = \sigma_E \text{ (dead weight of structure + } Q_e) - \sigma_E \text{ (dead weight of structure)} = \sigma_E (Q_e)$$

$$\Delta\tau_E = \tau_E \text{ (dead weight of structure + } Q_e) - \tau_E \text{ (dead weight of structure)} = \tau_E (Q_e)$$

$Q_e \rightarrow$ lecture #2 / 69 - 78

→ #4 / 9

EN 1993-1-9 (8.1), (8.2), (8.3)

$$\Delta\sigma_E / (1{,}5\, f_y) \leq 1{,}0$$

$$\Delta\tau_E / (1{,}5\, f_y / \sqrt{3}) \leq 1{,}0$$

$$\gamma_{Ff}\, \Delta\sigma_E / (\Delta\sigma_R\, \gamma_{Mf}) \leq 1{,}0$$

$$\gamma_{Ff}\, \Delta\tau_{E,} / (\Delta\tau_R\, \gamma_{Mf}) \leq 1{,}0$$

$$[\gamma_{Ff}\, \Delta\sigma_E / (\Delta\sigma_R\, \gamma_{Mf})]^3 + [\gamma_{Ff}\, \Delta\tau_E / (\Delta\tau_R\, \gamma_{Mf})]^5 \leq 1{,}0$$

→ #4 / 4

One span run-beam – high consequence of destruction

Safe life method is taken into consideration

$$\gamma_{Mf} = 1{,}35$$

$$\gamma_{Ff} = 1{,}0$$

5 million load cycles have been assumed during operation of the structure

Fatigue

Lec #2 / 66 - 78

Additional information for calculations, the same for everybody:

- One crane only
- Assembly crane, HC1, S0
- Steady hoisting speed $v_h = 0{,}08$ m / s
- Hook $\rightarrow \varphi_3 = 0{,}0$
- $\varphi_4 = 1{,}0$
- $\varphi_5 = 1{,}5$
- $\eta = 0$
- Single wheel drive, $m_w = 2$
- Friction coefficent $\mu = 0{,}2$
- Wheel flanges, $a_{ext} = R$
- Fixing of wheel IFF
- Longitudinal velocity of crane v = 0,7 m / s
- Spring constant of the buffer $S_B = 65$ kN / m
- $\xi_b = 0{,}5$
- Rail supported on an elastomeric bearing pad

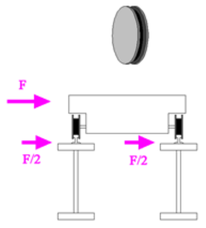


Photo: Author

Chamber of Bridge, Metal and Timber Structures
Cracow University of Technology

Simplified approach can be adopted

$$S0 \rightarrow \lambda_{i,\sigma} = 0{,}198 \qquad \lambda_{i,\tau} = 0{,}379$$

$$\varphi_{fat,1} = (1 + \varphi_1) / 2 = 1{,}05$$

$$\varphi_{fat,2} = (1 + \varphi_2) / 2 = 1{,}032$$

$$\varphi_{fat} = \max(\varphi_{fat,1} \; ; \; \varphi_{fat,2}) = 1{,}05$$

$$Q_{r,\,max,\,i} = 337{,}500 \text{ kN}$$

$$Q_{e,\sigma} = Q_{max,i}\,\varphi_{fat}\,\lambda_{i,\sigma} = 70{,}166 \text{ kN}$$

$$Q_{e,\tau} = Q_{max,i}\,\varphi_{fat}\,\lambda_{i,\tau} = 134{,}308 \text{ kN}$$

In span:

$$M_{V,\,fat,\,max} = M_{V,\,fat}(Q_{e,\sigma}) = 105{,}249 \text{ kNm}$$

$$V_{V,\,fat,\,max} = V_{V,\,fat}(Q_{e,\tau}) = 67{,}154 \text{ kN}$$

Over support:

$$M_{V,\,fat,\,max} = M_{V,\,fat}(Q_{e,\sigma}) = 0{,}000 \text{ kNm}$$

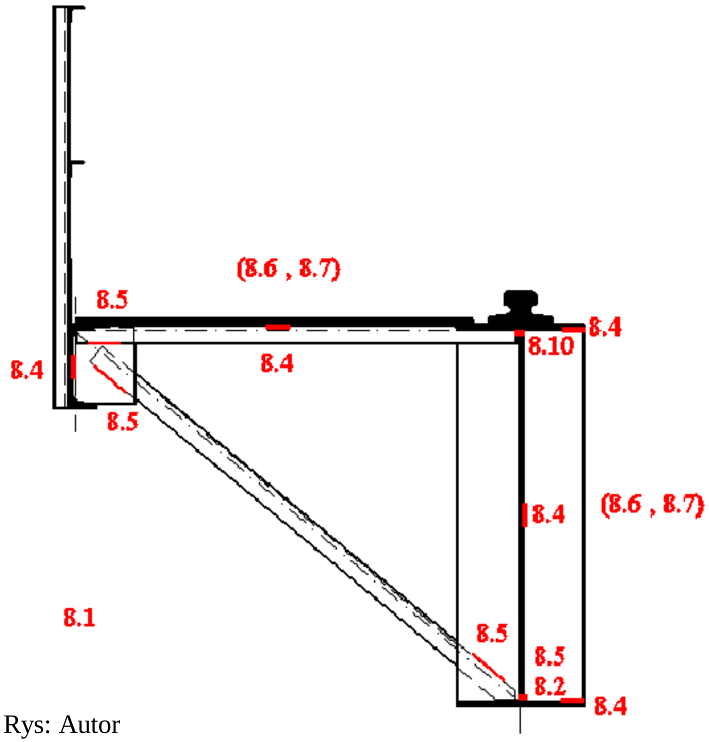
$$V_{V,\,fat,\,max} = V_{V,\,fat}(Q_{e,\tau}) = 155{,}529 \text{ kN}$$

→ Des #1 part I / 72

Stress $\Delta\sigma_E$ comes from bending moment $M_{V, fat, max}$

Stress $\Delta\tau_E$ comes from shear force $V_{V, fat, max}$

Stress values result from point, where fatigue resistance should be checked.



Rys: Autor

Numbers of tables in EN 1993-1-9, important for various points in structure (tab. 8.1 – effects of cutting members):

Calculation could be made for chatacteristic points 1, 2, 3, 4. Analised imperfections come from:

Point	Axial stress	Shear stress
1	• Cutting of member (8.1 / 2) • Longitudinal weld flange-plate (8.5 / 6)	• Cutting of member (8.1 / 6) • Longitudinal weld flange-plate (8.5 / 6)
2	• Cutting of member (8.1 / 2) • Wertical weld web-stiffener (8.4 / 7) • Contact web-flange (8.10 / 1)	• Cutting of member (8.1 / 6) • Wertical weld web-stiffener (8.4 / 7) • Contact web-flange (8.10 / 1)
3	• Cutting of member (8.1 / 2) • Wertical weld web-stiffener (8.4 / 7)	• Cutting of member (8.1 / 6) • Wertical weld web-stiffener (8.4 / 7)
4	• Cutting of member (8.1 / 2)	• Cutting of member (8.1 / 6)

Values of resistances:

Point	Axial stress	Shear stress
1	• 160 MPa • 45 MPa	• 100 MPa • Important for axial only
2	• 160 MPa (concerns σ_x) • Important for shear only • 160 MPa (concerns σ_z)	• 100 MPa • 80 MPa • Important for axial only
3	• 160 MPa • Important for shear only	• 100 MPa • 80 MPa
4	• 160 MPa	• 100 MPa

Minimal values:

Point	Axial stress	Shear stress
1	45 MPa	100 MPa
2	160 Mpa (concerns σ_x) 160 MPa (concerns σ_z)	80 MPa
3	160 MPa	80 MPa
4	160 MPa	100 MPa

Fatigue resistance $\Delta\sigma_C$ is defined for 2 milions of cycles. It must be recalculated to $\Delta\sigma_R$ for N = 5 milions..

$$\Delta\sigma_R = \Delta\sigma_C \sqrt[3]{(2\,000\,000 / N)}$$

$$\Delta\tau_R = \Delta\tau_C \sqrt[5]{(2\,000\,000 / N)}$$

Point	$\Delta\sigma_R$	$\Delta\tau_R$
1	33,156 MPa	83,256 MPa
2	117,889 MPa (concerns σ_x) 117,889 MPa (concerns σ_z)	66,604 MPa
3	117,889 MPa	66,604 MPa
4	117,889 MPa	83,256 MPa

Stresses for FAT:

$\Delta\sigma_{E,\,x} = M_{V,\,fat,\,max} / W_y^{I,\,point}$

$\Delta\sigma_{E,\,z}$ = local vertical stress ($Q_{e,\,\sigma}$), #t / 39 + local bending of web ($Q_{e,\,\sigma}$), #t / 48

$\Delta\tau_E = V_{V,\,fat,\,max} / A^I$ + local concentration ($Q_{e,\,\tau}$), #t / 44

In span:

Point	$\Delta\sigma_E$	$\Delta\tau_E$
1	9,517 MPa	0,000 MPa
2	7,263 MPa (concerns σ_x) 30,432 MPa (concerns σ_z)	10,067 MPa
3	16,073 MPa	7,462 MPa
4	17,105 MPa	0,000 MPa

Over support:

Point	$\Delta\sigma_E$	$\Delta\tau_E$
1	0,000 MPa	0,000 MPa
2	0,000 MPa (concerns σ_x) 30,432 MPa (concerns σ_z)	19,886 MPa
3	0,000 MPa	17,281 MPa
4	0,000 MPa	0,000 MPa

$$\Delta\sigma_E / (1{,}5\ f_y) \leq 1{,}0$$

In span:

$$\Delta\tau_E / (1{,}5\ f_y / \sqrt{3}) \leq 1{,}0$$

Point	$\Delta\sigma_E$	$\Delta\tau_E$
1	0,018	0,000
2	0,013 (concerns σ_x) 0,057 (concerns σ_z)	0,033
3	0,030	0,024
4	0,032	0,000

Over support:

Point	$\Delta\sigma_E$	$\Delta\tau_E$
1	0,000	0,000
2	0,000 (concerns σ_x) 0,057 (concerns σ_z)	0,065
3	0,000	0,056
4	0,000	0,000

$$\gamma_{Ff}\,\Delta\sigma_E \,/\, (\Delta\sigma_R\,\gamma_{Mf}) \le 1{,}0$$

In span:

$$\gamma_{Ff}\,\Delta\tau_{E,} / (\Delta\tau_R\,\gamma_{Mf}) \le 1{,}0$$

Point	$\Delta\sigma_E$	$\Delta\tau_E$
1	0,213	0,000
2	0,046 (concerns σ_x) 0,191 (concerns σ_z)	0,112
3	0,101	0,083
4	0,107	0,000

Over support:

Point	$\Delta\sigma_E$	$\Delta\tau_E$
1	0,000	0,000
2	0,000 (concerns σ_x) 0,191 (concerns σ_z)	0,221
3	0,000	0,201
4	0,000	0,000

$$[\gamma_{Ff}\, \Delta\sigma_E / (\Delta\sigma_R\, \gamma_{Mf})]^3 + [\gamma_{Ff}\, \Delta\tau_E / (\Delta\tau_R\, \gamma_{Mf})]^5 \leq 1{,}0$$

In span:

Point	
1	0,010
2	< 0,001 (concerns σ_x) 0,007 (concerns σ_z)
3	0,001
4	0,001

Over support:

Point	
1	0,000
2	< 0,001 (concerns σ_x) 0,007 (concerns σ_z)
3	< 0,001
4	0,000

Serviceability limit states

In case of crane beams, it is necessary to check not only deflections, but also certain conditions regarding the cross-sectional geometry and stress:

- vibration of bottom flange
- web breathing
- stresses in SLS

Vibration of the botom flange

There is no vibration of the botom flange, if:

$$L / i_{z,\, bot\text{-}f} \leq 250$$

i_z (radius of gyration for bottom flange) = 8,66 cm

L (distance between vertical stiffeners) = 1,000 m

$$L / i_z = 1{,}0 / 0{,}0866 = 11{,}547 \leq 250$$

OK

Web breathing

$$\sqrt{\{ [\boldsymbol{\sigma}_{\mathbf{x, Ed, ser}} / (k_\sigma \sigma_E)]^2 + [1{,}1\ \boldsymbol{\tau}_{\mathbf{z, Ed, ser}} / (k_\tau \sigma_E)]^2\}} \leq 1{,}1$$

k_σ, k_τ → EN 1993-1-5 4.4 A3

$\sigma_E = 190\ \text{GPa} / (b / t_w)^2 = |b = h_w| = 121{,}434\ \text{MPa}$

k_σ = (for proportion of stress σ_x between point #3 {#t / 55} or #2 {#t / 36}) = value between 7,810 and 48,743

$k_\tau = 7{,}476$

Because of enormous huge value of reference level of stresses $k_x\ \sigma_E$ (thousands of MPa), condition can be considered as satisfied without further calculations.

$$\sigma_{x, Ed, ser} \leq f_y / \gamma_{Mser}$$

$$\sigma_{y, Ed, ser} \leq f_y / \gamma_{Mser}$$

$$\sigma_{z, Ed, ser} \leq f_y / \gamma_{Mser}$$

$$\tau_{y, Ed, ser} \leq f_y / (\sqrt{3}\, \gamma_{Mser})$$

$$\tau_{z, Ed, ser} \leq f_y / (\sqrt{3}\, \gamma_{Mser})$$

$$\sqrt{[\sigma_{x, Ed, ser}^2 + 3 (\tau_{y, Ed, ser}^2 + \tau_{z, Ed, ser}^2)]} \leq f_y / \gamma_{Mser}$$

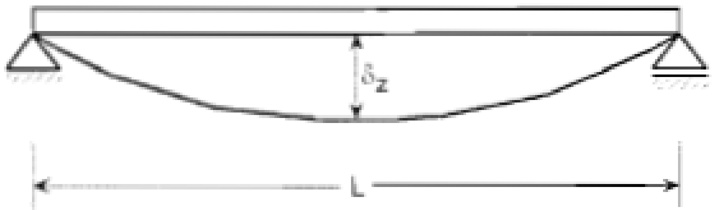
$$\sqrt{[\sigma_{x, Ed, ser}^2 + \sigma_{y, Ed, ser}^2 - \sigma_{x, Ed, ser}\, \sigma_{y, Ed, ser} + 3 (\tau_{y, Ed, ser}^2 + \tau_{z, Ed, ser}^2)]} \leq f_y / \gamma_{Mser}$$

$$\sqrt{[\sigma_{x, Ed, ser}^2 + \sigma_{z, Ed, ser}^2 - \sigma_{x, Ed, ser}\, \sigma_{z, Ed, ser} + 3 (\tau_{y, Ed, ser}^2 + \tau_{z, Ed, ser}^2)]} \leq f_y / \gamma_{Mser}$$

Recommended value of γ_{Mser} is 1,0.

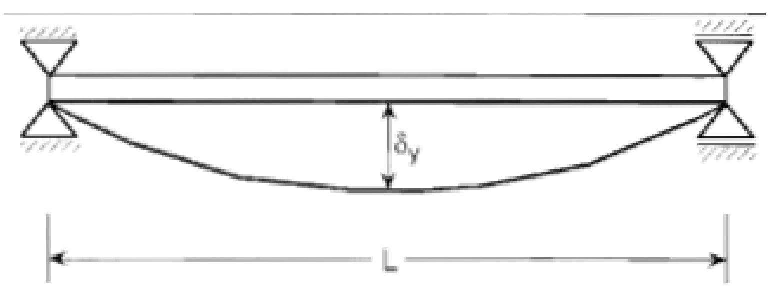
Complex of above formulas were checked for design values of stresses. Index „ser" means, that above values are calculated for characteristic values of loads. Characteristic values are smaller than design about 1,45 times. Bigger stresses in ULS satisified formulas, this means smaller stresses satisfied the same.

Vertical: EN 1993-6 tab. 7.1



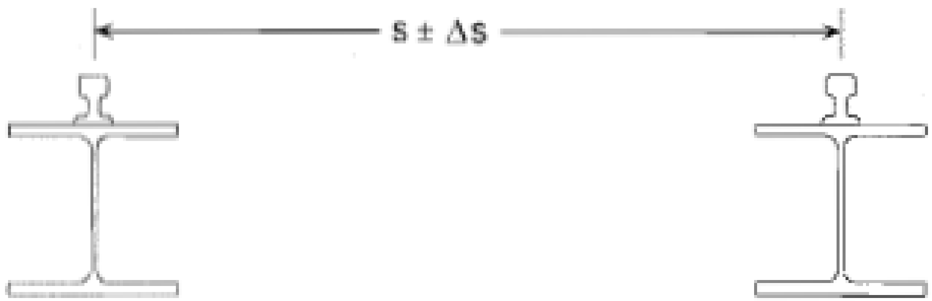
$\delta_z \leq \min(L / 600 \quad ; \quad 25 \text{ mm}) = 10 \text{ mm}$

Horizontal:



EN 1993-6 tab. 7.1

$\delta_y \leq L / 600 = 10 \text{ mm}$



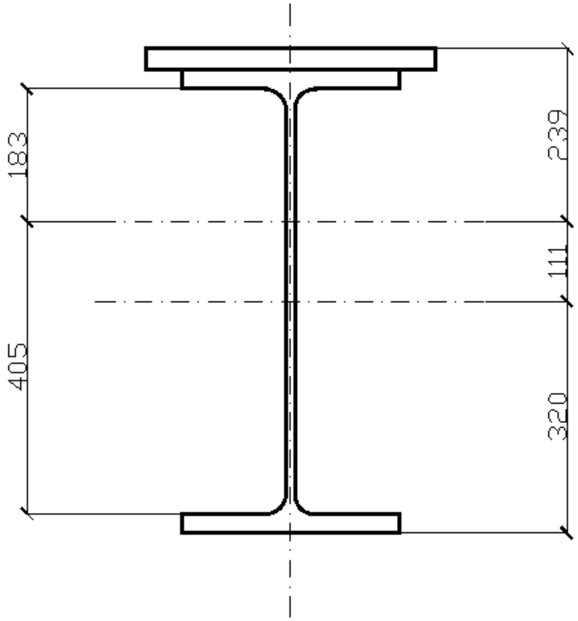
EN 1993-6 tab. 7.1

$$\Delta_s = \delta_{left} + \delta_{right} \leq 10 \text{ mm}$$

EN 1993-6 tab. 7.1

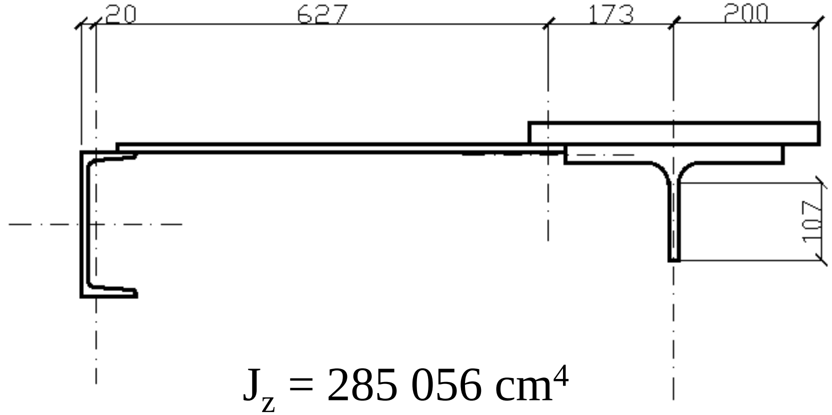
$$h_c \leq s / 600 = 53 \text{ mm}$$

Cross-section important for vertical deformations



$J_y = 273\ 513\ cm^4$

Rys: Autor



$J_z = 285\ 056\ cm^4$

Cross-section important for horizontal deformations

Various positions of crab and various positions of crane must be analised for vertical actions.

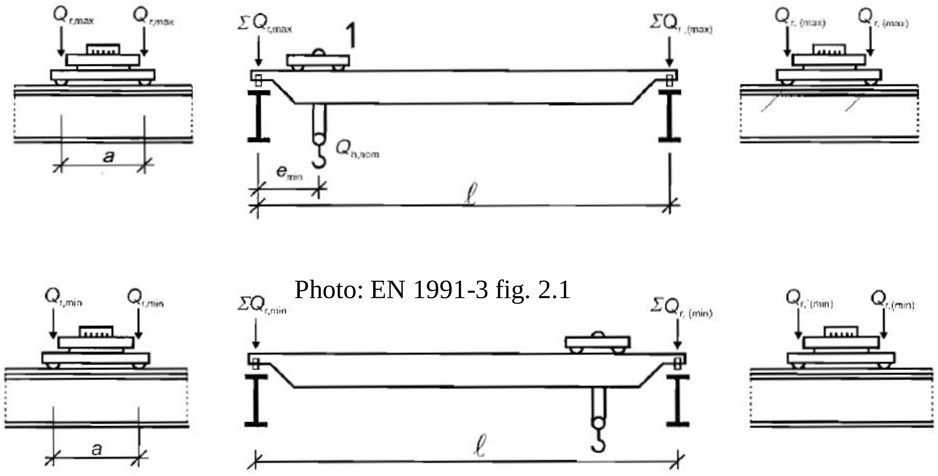
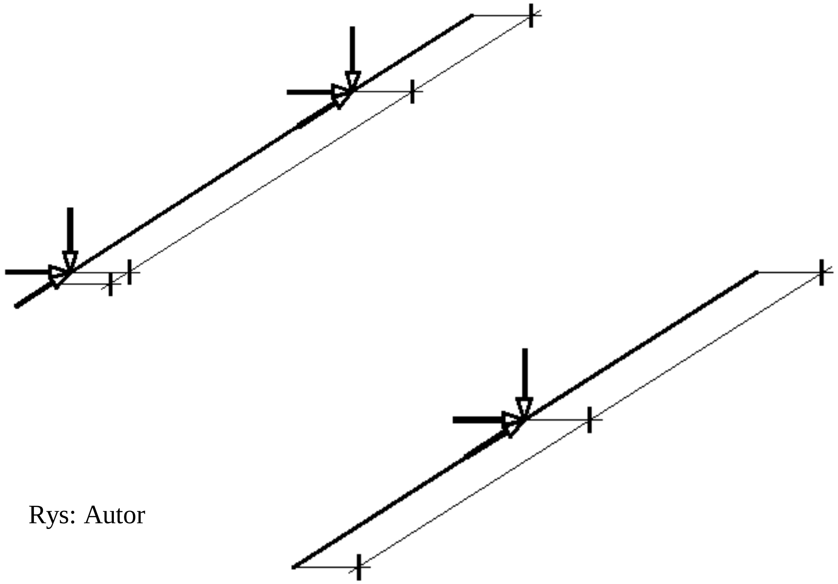


Photo: EN 1991-3 fig. 2.1



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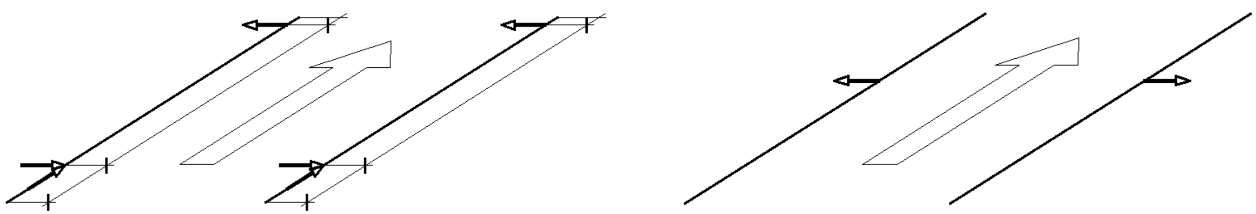
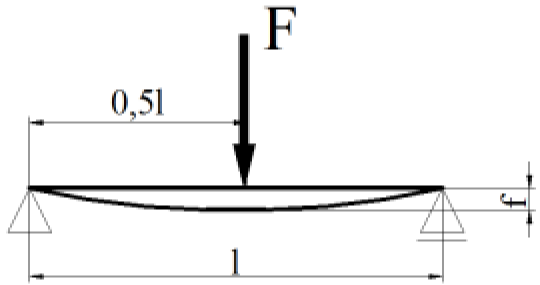
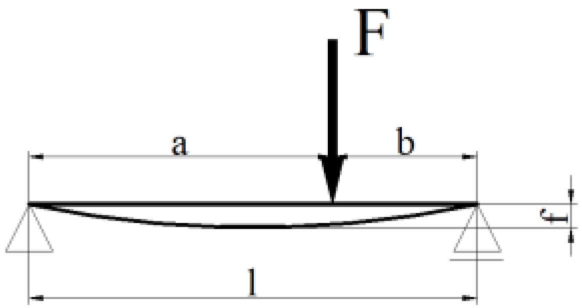
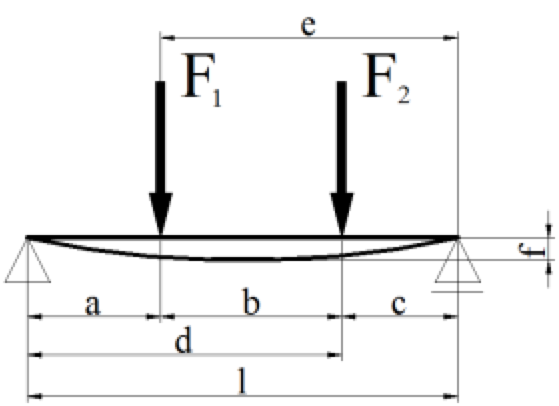
For horizontal the same.



Rys: agh.edu.pl

	$$f = \frac{F \cdot l^3}{48EJ}$$
	$$f = \frac{F \cdot a^2 \cdot b^2}{3EJ \cdot l}$$
	$$f = \frac{F_1 \cdot a^2 \cdot e^2 + F_2 \cdot c^2 \cdot d^2}{3EJ \cdot l}$$

Deformations:

Max vertical deflection: 0,8 mm < 10 mm   OK

Max difference: 0,7 mm < 57 mm   OK

Max horizontal deformation: 0,8 mm < 10 mm   OK

Max difference: = 1,6 mm   <10 mm   OK

Thank you for attention

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