Metal Structures II

Lecture III

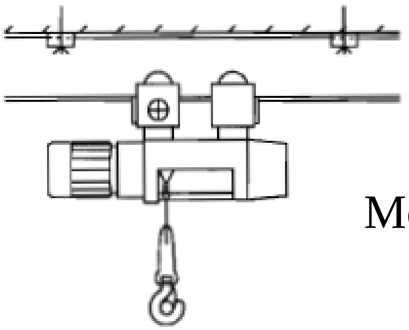
Crane supporting structures

Beams

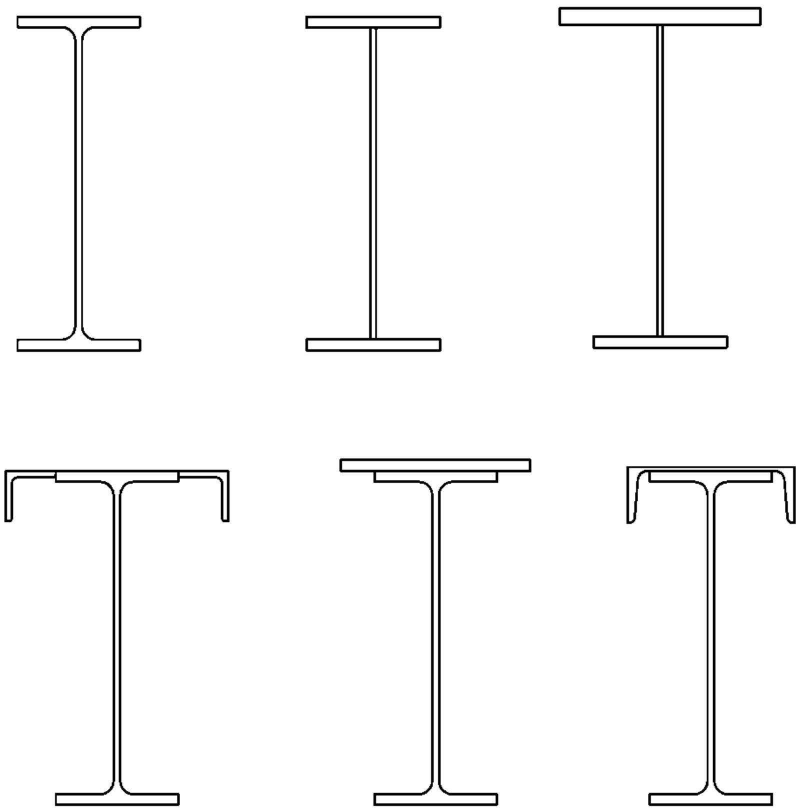
Contents

Recommended cross-sections of run-beams

Photo: EN 1991-3 fig.1.2



Monorail hoist block

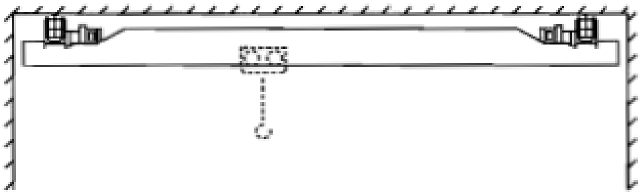


I-beam, hot-rolled or welded,

I-beam with reinforced top flange

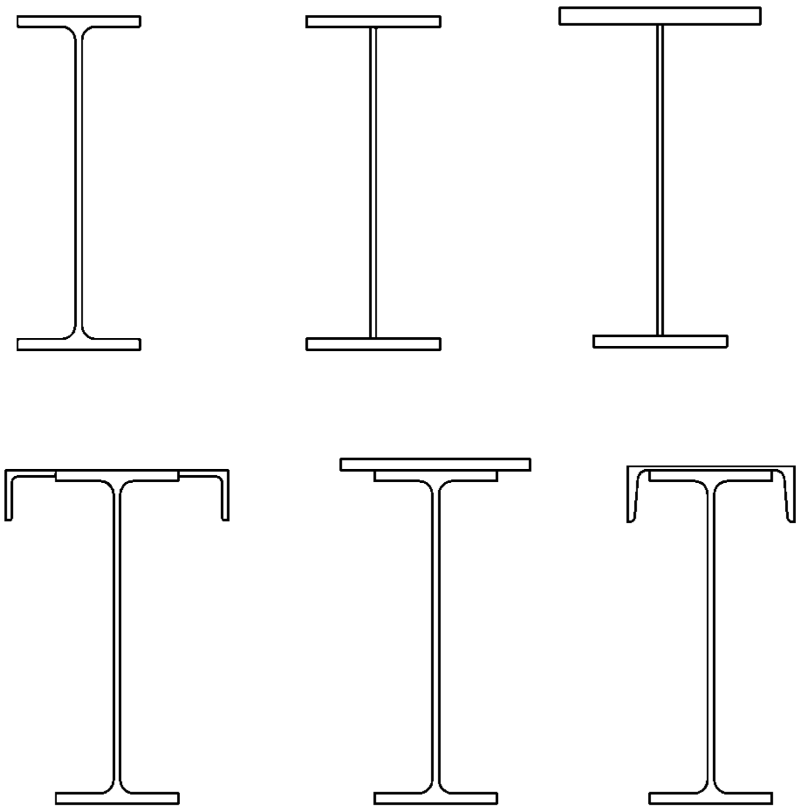
Photo: Author

Photo: EN 1991-3 fig.1.3



Overhead underslung crane

Photo: Author



I-beam, hot-rolled or welded,

I-beam with reinforced top flange

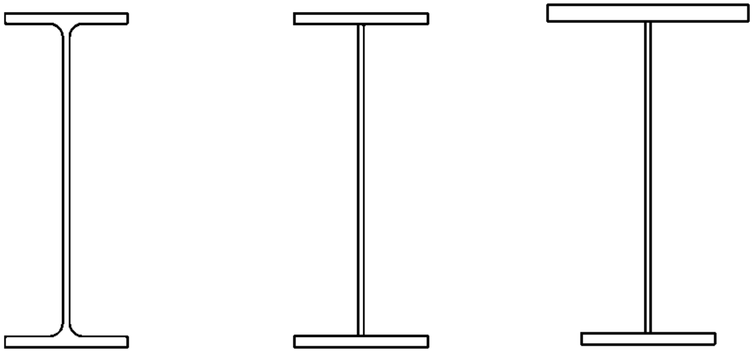


Photo: Author

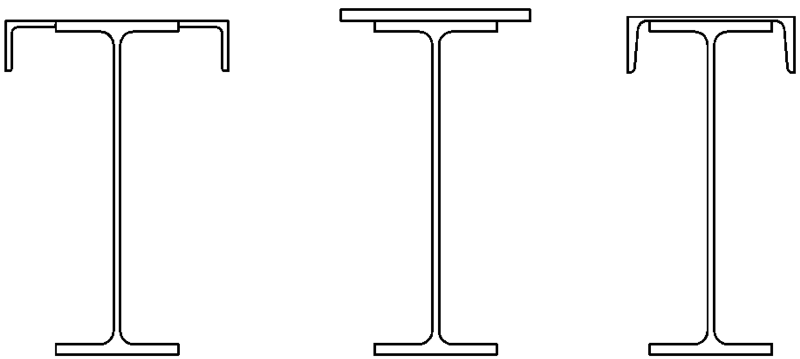
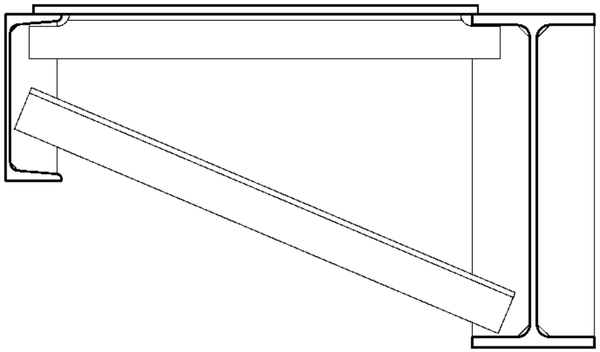


Photo: EN 1991-3 fig.1.4

Overhead top-mounted crane



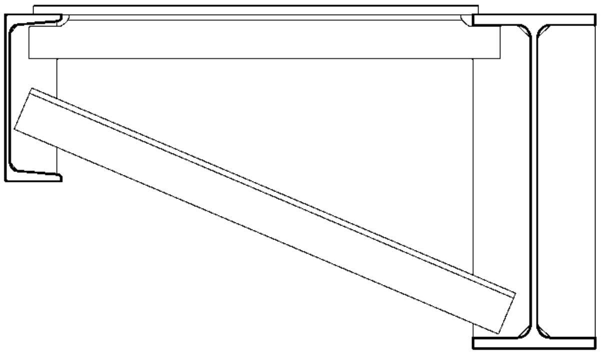


Photo: Author

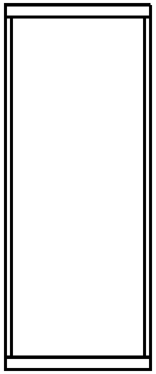
I-beam, hot-rolled or welded,

I-beam with reinforced top flange,

I-beam with surge girder,

Photo: EN 1991-3 fig.1.4

Overhead top-mounted crane,
extremely heavy crane or hoist load



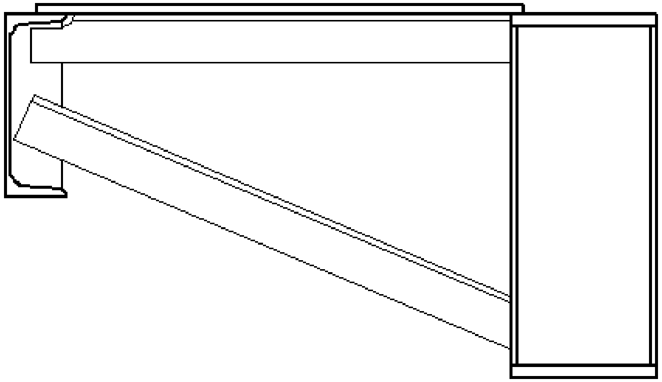


Photo: Author

Hollow section,

Hollow section with surge girder,

Initial assumptions about dimensions

HEB, HEA, IKS

$$h \approx \sqrt{[\,2\,M_{V,\,max} / (f_y\,t_0)]}$$

$$t_0 = 10\ \text{mm}$$

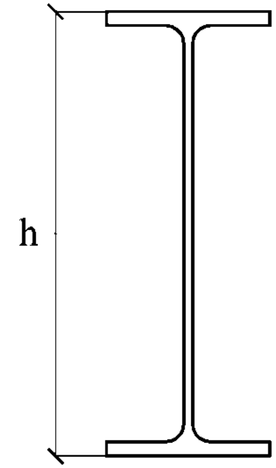


Photo: Author

$M_{V,\,max}$ – max bending moment in vertical plane according to #2 / 86

Welded I-beam

$$h \approx \sqrt{[\,2\,M_{V,\,max} / (f_y\,t_0)]}$$

$$t_0 = 10\text{ mm}$$

$$t_w\,[\text{mm}] \approx 7\,[\text{mm}] + 3\,h\,[\text{m}]$$

$$t_f \approx 1{,}5\,t_w \div 2{,}0\,t_w$$

$$b_f \approx 0{,}2\,h \div 0{,}3\,h$$

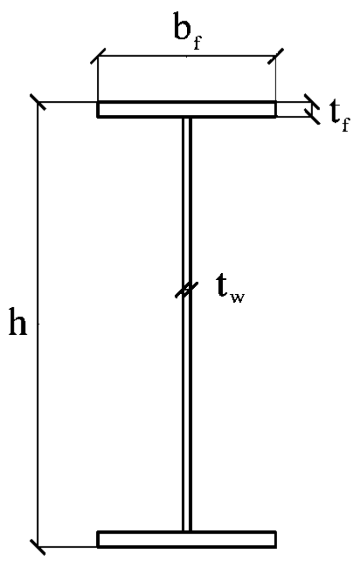


Photo: Author

Welded I-beam

$t_f \approx 1{,}5\ t_w \div 2{,}0\ t_{f,\ bottom}$

$b_{f,\ top} \approx 0{,}3\ h \div 0{,}4\ h$

Rest dimensions the same as for previous case

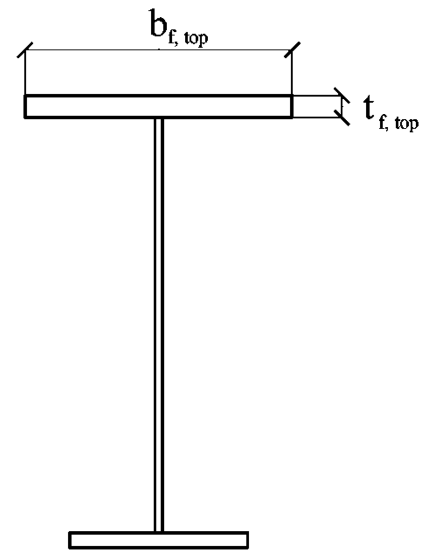


Photo: Author

HEB, HEA, IKS

A (top flange) ≈ 2 A (bottom flange)

Rest dimensions the same as for previous case

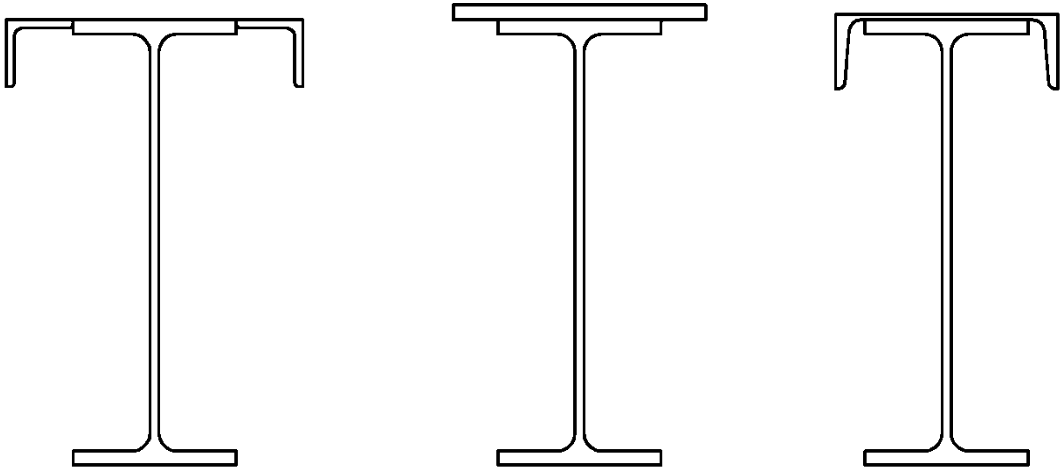
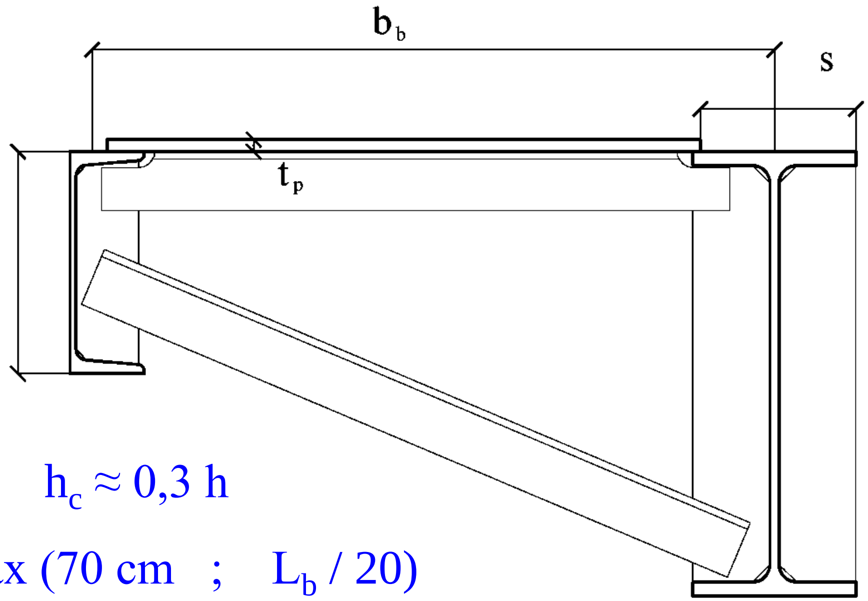


Photo: Author

HEB, HEA, IKS, welded I-beam

plate surge girder

Photo: Author



$h_c \approx 0{,}3\ h$

$b_b \approx \max\ (70\ \mathrm{cm}\ \ ;\ \ L_b / 20)$

s = enough space for rail and connection with beam

$t_p \approx 0{,}5\ (t_f + t_w)$

$b_b / t_p \rightarrow$ no IVth class of cross-section

Rest dimensions the same as for I-beam

Photo: despaw.pl

HEB, HEA, IKS, welded I-beam

lattice surge girder

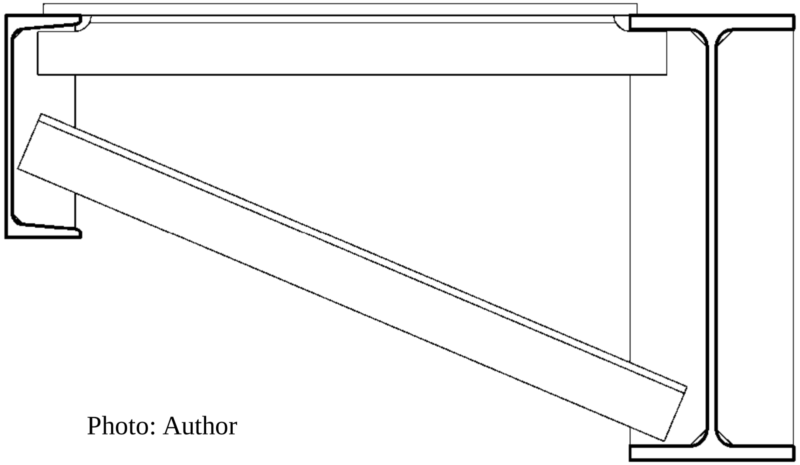


Photo: Author

Photo: zinkpower.com.pl

Dimensions the same as for I-beam

Welded hollow section

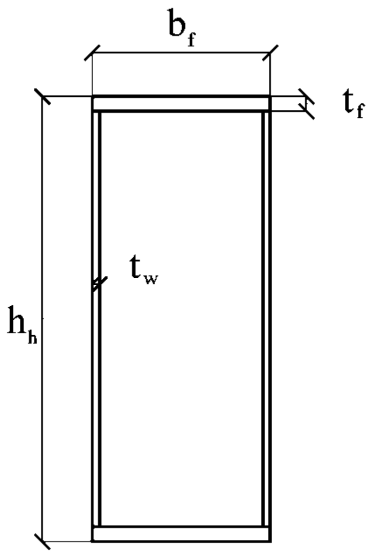
$$h \approx \sqrt{[\,1{,}5\, M_{V,\,max} / (f_y\, t_0)]}$$

$$t_0 = 10 \text{ mm}$$

$$t_w\, [mm] \approx 7\, [mm] + 3\, h\, [m]$$

$$t_f \approx 1{,}5\, t_w \div 2{,}0\, t_w$$

$$b_f \approx 0{,}2\, h \div 0{,}3\, h$$



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Welded hollow section with surge girder

The same dimension as for welded hollow section and plate surge girder

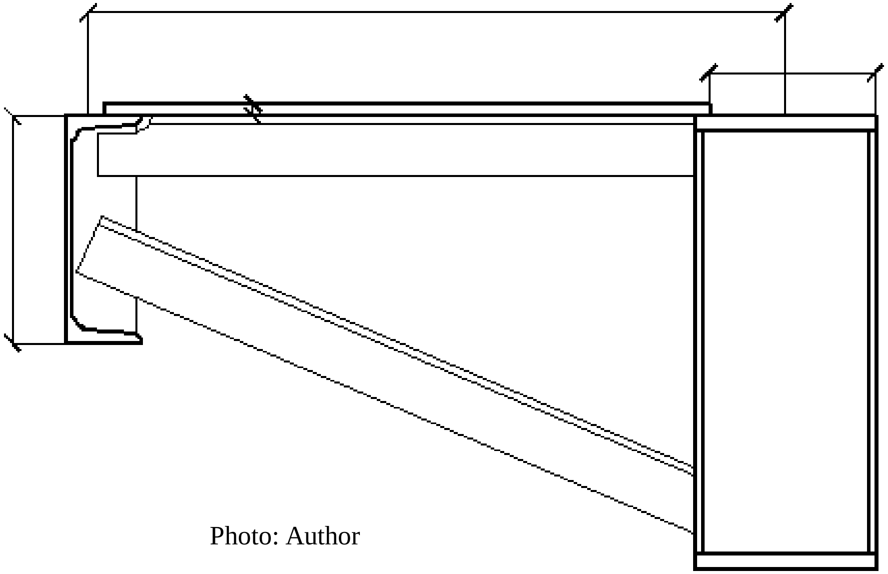


Photo: Author

Low temperatures can act on crane supporting structure

EN 1993-1-10

Table 2.1: Maximum permissible values of element thickness t in mm

Steel grade	Sub-grade	KV		Reference temperature T_{Ed} [°C]																				
		at T [°C]	J_{min}	10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50	10	0	-10	-20	-30	-40	-50
				$\sigma_{Ed} = 0{,}75\ f_y(t)$							$\sigma_{Ed} = 0{,}50\ f_y(t)$							$\sigma_{Ed} = 0{,}25\ f_y(t)$						
S235	JR	20	27	60	50	40	35	30	25	20	90	75	65	55	45	40	35	135	115	100	85	75	65	60
	J0	0	27	90	75	60	50	40	35	30	125	105	90	75	65	55	45	175	155	135	115	100	85	75
	J2	-20	27	125	105	90	75	60	50	40	170	145	125	105	90	75	65	200	200	175	155	135	115	100
S275	JR	20	27	55	45	35	30	25	20	15	80	70	55	50	40	35	30	125	110	95	80	70	60	55
	J0	0	27	75	65	55	45	35	30	25	115	95	80	70	55	50	40	165	145	125	110	95	80	70
	J2	-20	27	110	95	75	65	55	45	35	155	130	115	95	80	70	55	200	190	165	145	125	110	95
	M,N	-20	40	135	110	95	75	65	55	45	180	155	130	115	95	80	70	200	200	190	165	145	125	110
	ML,NL	-50	27	185	160	135	110	95	75	65	200	200	180	155	130	115	95	230	200	200	200	190	165	145
S355	JR	20	27	40	35	25	20	15	15	10	65	55	45	40	30	25	25	110	95	80	70	60	55	45
	J0	0	27	60	50	40	35	25	20	15	95	80	65	55	45	40	30	150	130	110	95	80	70	60
	J2	-20	27	90	75	60	50	40	35	25	135	110	95	80	65	55	45	200	175	150	130	110	95	80
	K2,M,N	-20	40	110	90	75	60	50	40	35	155	135	110	95	80	65	55	200	200	175	150	130	110	95
	ML,NL	-50	27	155	130	110	90	75	60	50	200	180	155	135	110	95	80	210	200	200	200	175	150	130
S420	M,N	-20	40	95	80	65	55	45	35	30	140	120	100	85	70	60	50	200	185	160	140	120	100	85
	ML,NL	-50	27	135	115	95	80	65	55	45	190	165	140	120	100	85	70	200	200	200	185	160	140	120
S460	Q	-20	30	70	60	50	40	30	25	20	110	95	75	65	55	45	35	175	155	130	115	95	80	70
	M,N	-20	40	90	70	60	50	40	30	25	130	110	95	75	65	55	45	200	175	155	130	115	95	80
	QL	-40	30	105	90	70	60	50	40	30	155	130	110	95	75	65	55	200	200	175	155	130	115	95
	ML,NL	-50	27	125	105	90	70	60	50	40	180	155	130	110	95	75	65	200	200	200	175	155	130	115
	QL1	-60	30	150	125	105	90	70	60	50	200	180	155	130	110	95	75	215	200	200	200	175	155	130
S690	Q	0	40	40	30	25	20	15	10	10	65	55	45	35	30	20	20	120	100	85	75	60	50	45
	Q	-20	30	50	40	30	25	20	15	10	80	65	55	45	35	30	20	140	120	100	85	75	60	50
	QL	-20	40	60	50	40	30	25	20	15	95	80	65	55	45	35	30	165	140	120	100	85	75	60
	QL	-40	30	75	60	50	40	30	25	20	115	95	80	65	55	45	35	190	165	140	120	100	85	75
	QL1	-40	40	90	75	60	50	40	30	25	135	115	95	80	65	55	45	200	190	165	140	120	100	85
	QL1	-60	30	110	90	75	60	50	40	30	160	135	115	95	80	65	55	200	200	190	165	140	120	100

Connection between rail and beam and cooperation rail-beam

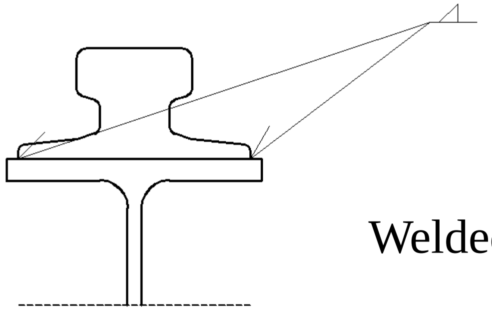
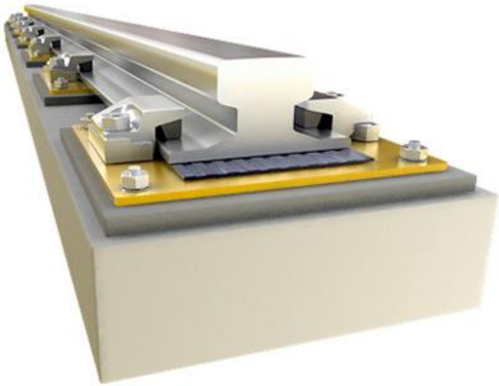


Photo: Author

Welded connection

Photo: dzwigar.info.pl

Bolted connection without elastomeric bearing pad

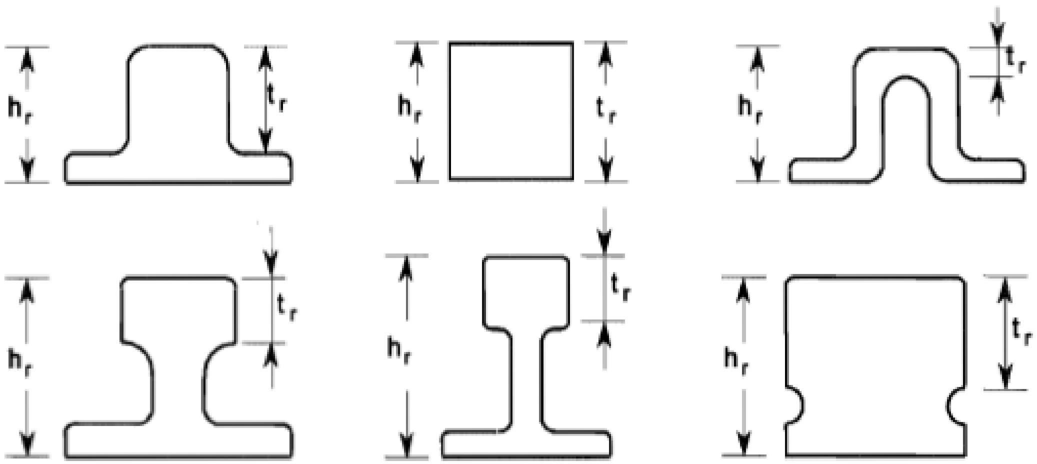


Bolted connection with elastomeric bearing pad

Photo: rialex.com.pl

Part of rail cross-section can be added to beam cross-section

Connection between rail and beam	Technical solution	Cross-section	Rail after reduction - static and stability	Rail after reduction - fatigue
Rigidly	◆ welded connection ◆ bolted connection without elastomeric bearing pad	Beam + reducted part of rail	h_r - 0,250 t_r	h_r - 0,125 t_r
Non-rigidly	◆ other types	Beam only	0	



EN 1993-6 5.6.2

Resistance - ways of calculations

There is only small pieces of information in EN 1993-6 about way of calculations. We must use special type of static calculations, according to:

EN 1993-6 5.4 .1 (2) – elastic analysisi (not plastic) is recommended (#t / 20);

EN 1993-6 5.6.2 (4) – way of calculation according to reduced stresses method (#t / 39-59);

EN 1993-6 6.3 – alternative method of checking stability (#t / 68-70);

EN 1993-6 7.5 – checking conditions for elastic limit state (#t / 87-88);

EN 1993-6 app.A – alternative method of checking stability (#t / 71-72);

These calculations base, first of all, on EN 1993-1-1 6.2

Classes of the cross-section

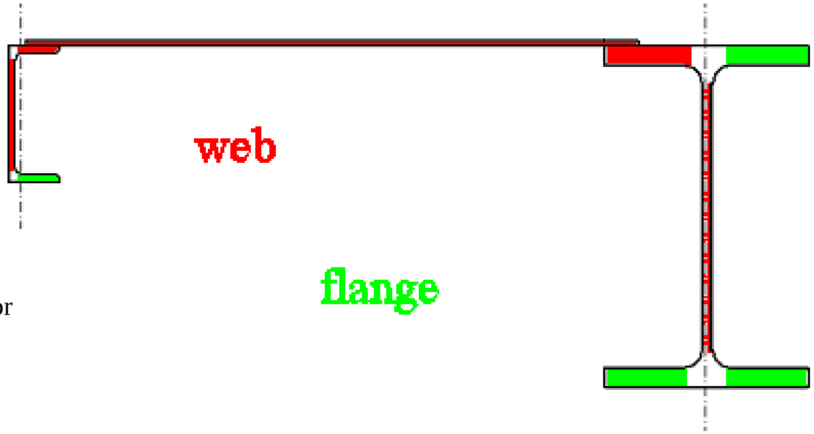


Photo: Author

Two methods of calculations can be used: Reduced Stresses Method (RSM) or Effective Cross-Sections Method (ECSM).

Class of cross-section	Calculations - end of resistance		Way of calculations for crane supporting structures
	"Normal" structure (for example: Ist step of study)	Crane supporting structures	
Ist	Plastic + redistribution of bending moments	Elastic	RSM
IInd	Plastic		
IIIrd	Elastic		
IVth	Local buckling	Local buckling	RSM, ECSM

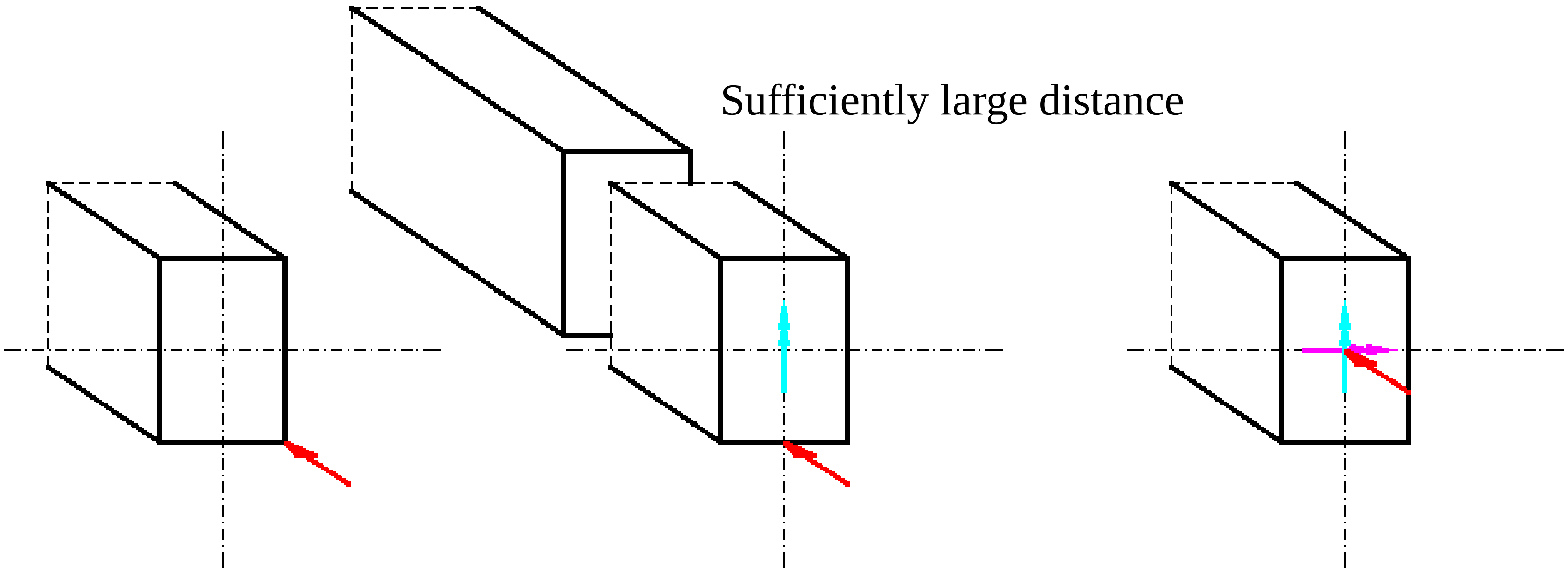
EN 1993-6   5.4.1 (2)

IVth class of crosss-ection is not recommended for crane supportong strucrures.

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.

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

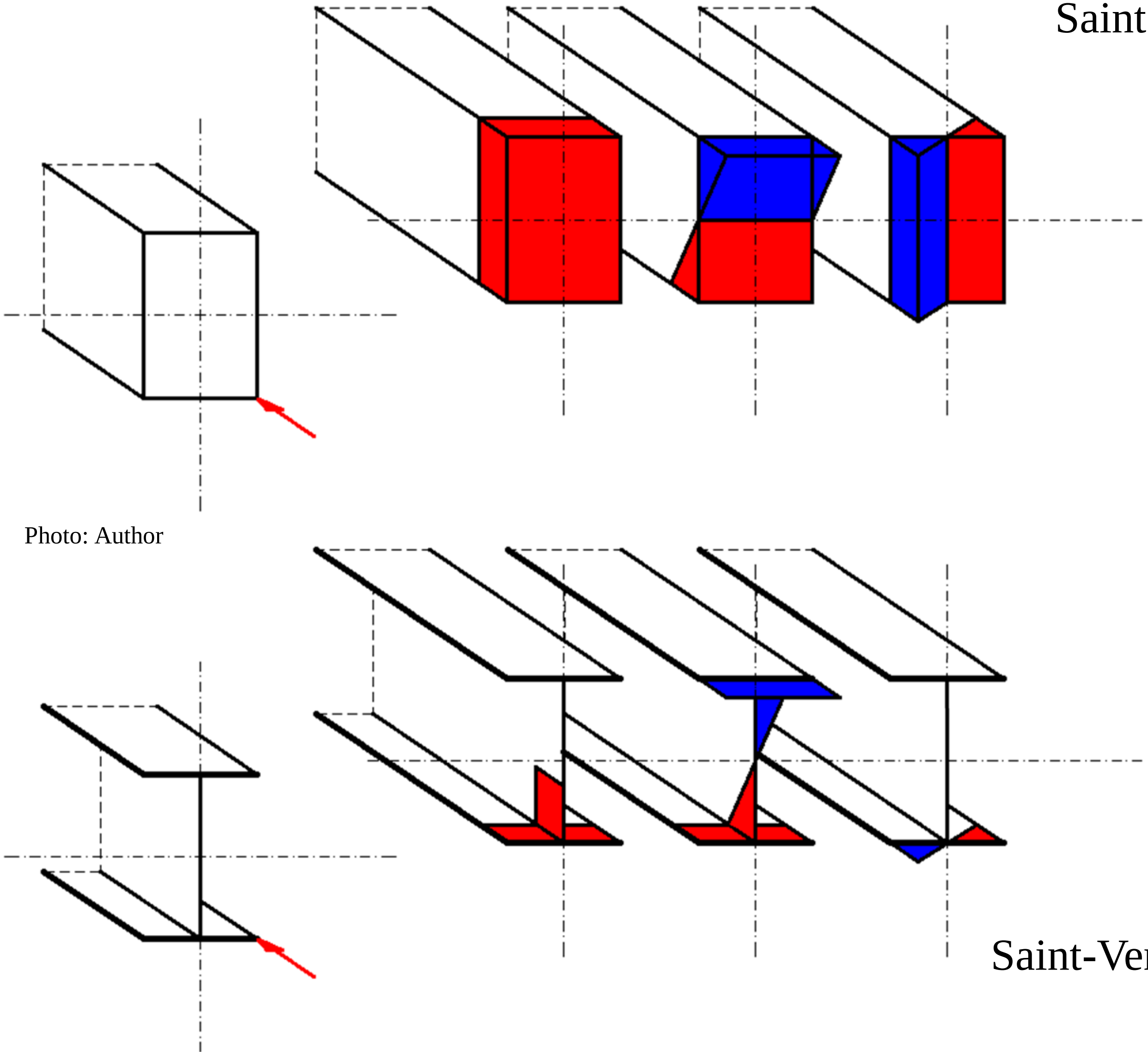
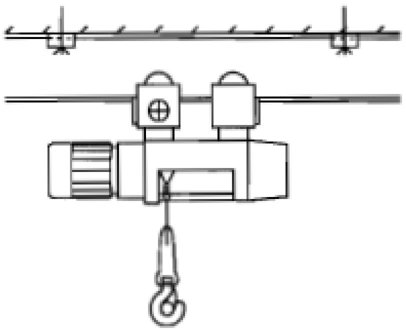


Photo: Author

Saint-Venant Principle is not true

Type of run-beam's cross-section	Class of run-beam's cross-section	Type of crane		
		Monorail hoist block	Overhead underslung crane	Overhead top-mounted crane
I-beam	I^{st} - III^{rd}	RSM		
	IV^{th}	ECSM, RSM		
I-beam with plate surge girder	I^{st} - III^{rd}	Cross-section not applicable for these types of trane		RSM
	IV^{th}			ECSM, RSM
Hollow section, hollow section with surge girder, I-beam with lattice surge girder	I^{st} - III^{rd}			Procedures and formulas in Eurocodes are not dedicated to such types of run-beam
	IV^{th}			

Photo: EN 1991-3 fig.1.2



Monorail hoist block

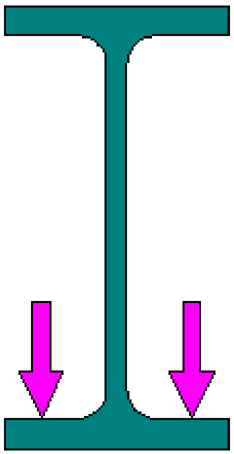


Photo: Author

Loads applied to bottom flange:

- Vertical forces $V_{z,\,Ed}$;
- Horizontal longitudinal forces N_{Ed} ;

There is no transverse loads; there is no torsional moment

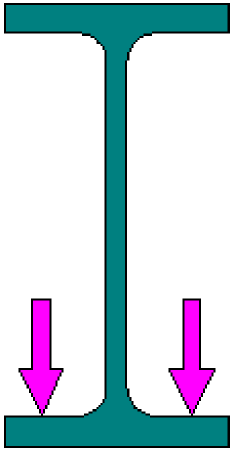
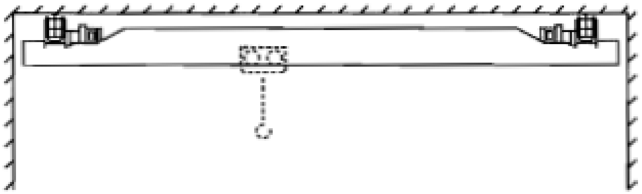


Photo: Author

Photo: EN 1991-3 fig.1.3



Overhead underslung crane

Loads applied to bottom flange:

- Vertical forces $V_{z,\ Ed}$;
- Horizontal longitudinal forces N_{Ed} ;
- Horizontal transversal forces $V_{y,\ Ed}$;

Photo: EN 1991-3 fig.1.4

Overhead top-mounted crane

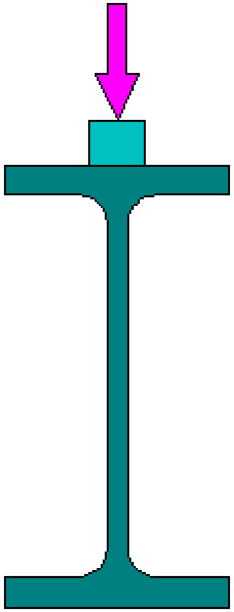


Photo: Author

Loads applied to top flange:

- Vertical forces $V_{z,\,Ed}$;
- Horizontal longitudinal forces N_{Ed};
- Horizontal transversal forces $V_{y,\,Ed}$;
- Additional vertical forces from worker's activity $V_{y1,\,Ed}$;

Additionally, we must analize effects of worker's activity.

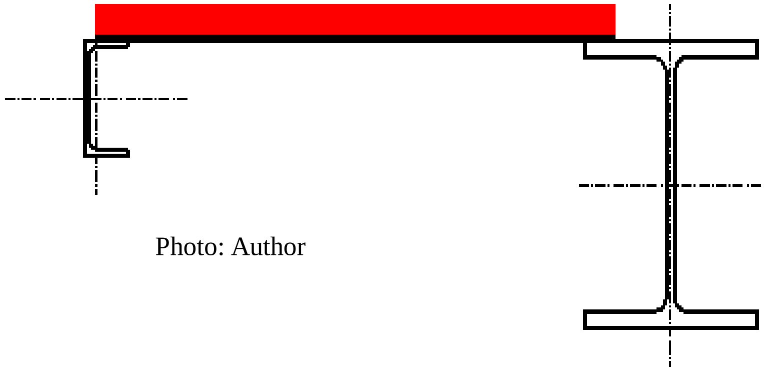


Photo: Author

Photo: rapmet.pl

This load is applied to walkways:
on plate surge girder (walkway = steel plate) or
on lattice surge girder (walkway = steel frame
lattice walkways).

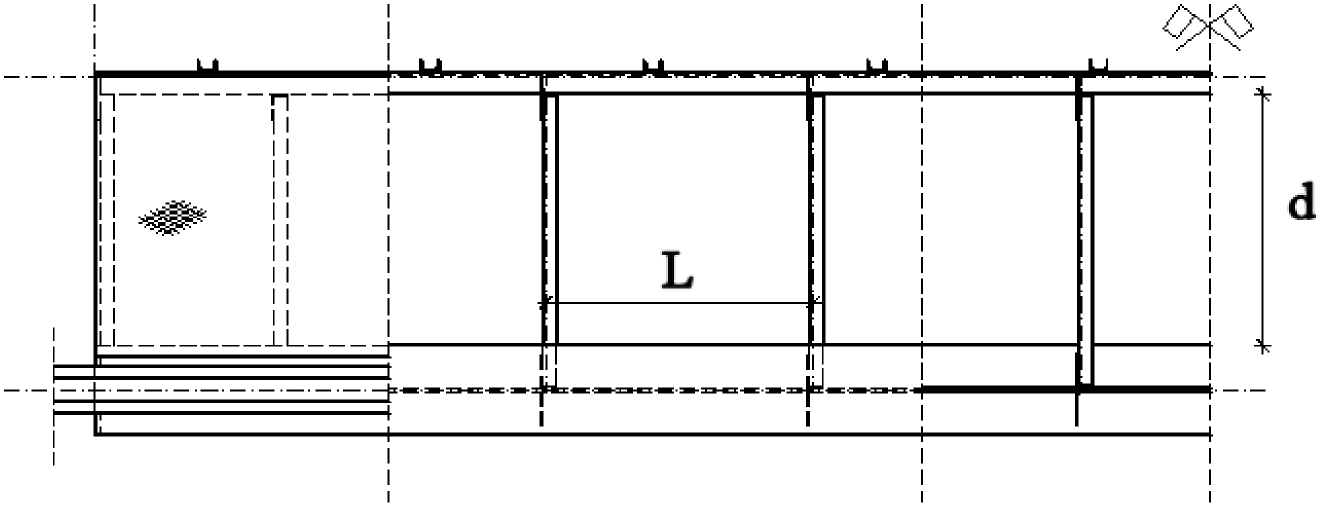
Steel plate or steel frame lattice walkways must be supported by additional horizontal bars (plate) or bracings (lattice). Fields between bars/bracings, I-beam and C-section should be similar to the square:

$$L \approx d$$

max

$$L \approx 2\,d$$

Below bars/bracings exist additonal diagonal cross-bracings.



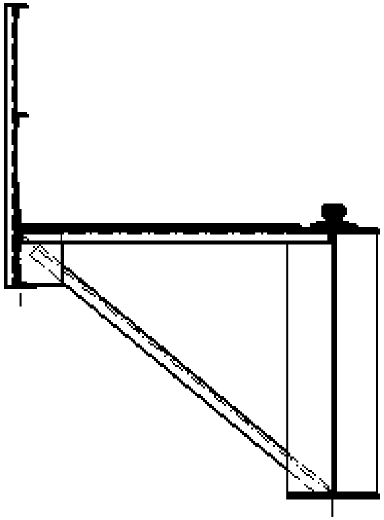


Photo: Author

Photo: Author

Main I-beams are supported by columns.

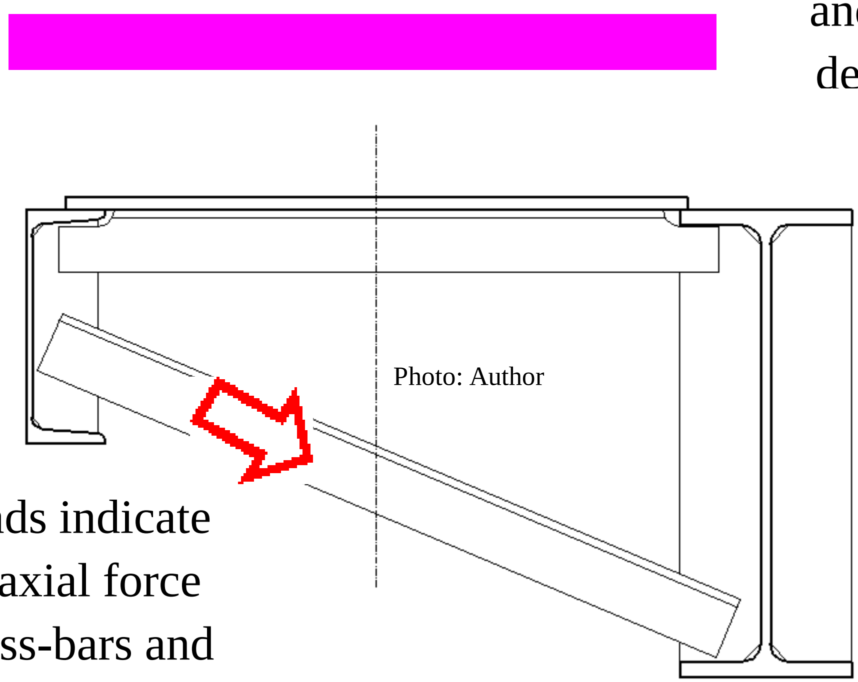
Photo: Author

C-sections are supported by diagonal cross-bars
and columns.

Worker's activity +
+ surge girder's dead-weight:
q

Half of worker's activity and part of surge girder's dead-weight act directly on I-beam.
V (q / 2)
M (q / 2)

Half of worker's activity and rest of surge girder's dead-weight act directly on C-section.
V (q / 2)
M (q / 2)



These two loads indicate compressive axial force in vertical cross-bars and go to I-beam.

Finally, these two groups of loads act on I-beam:

V = V (q / 2) + V (q / 2) = V (q)

M = M (q / 2) + M (q / 2) = M (q)

Cross-bars between I-beam and C-section, compressive axial force:

Flexural buckling u-u

Flexural buckling v-v

Torsional buckling

Fexural-torsional buckling

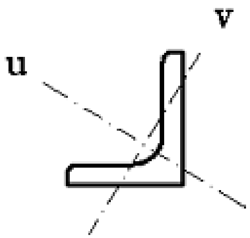


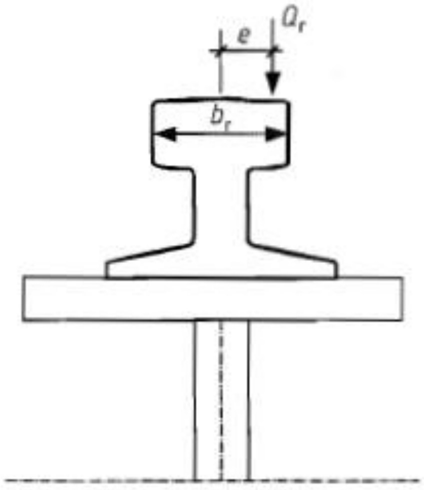
Photo: Author

Horizontal bars for plate surge girder - the same cross-section as cross-bars.

There are horizontal forces from overhead underslung crane and from overhead top-mounted crane. These forces indicate torsional moment in run-beam. There are two methods of recalculation for this type of crss-sectional force → #t / 34-38

Value of torsional moment depends on geometry of cross-section. For overhead top-mounted crane we must additionally take into consideration eccentricity for vertical force applied to rail.

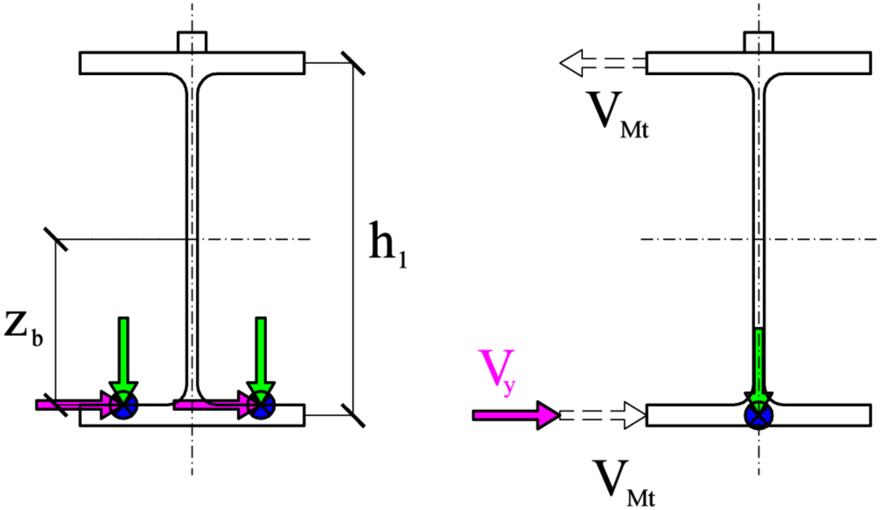
Photo: EN 1991-3 fig. 2.2



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

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

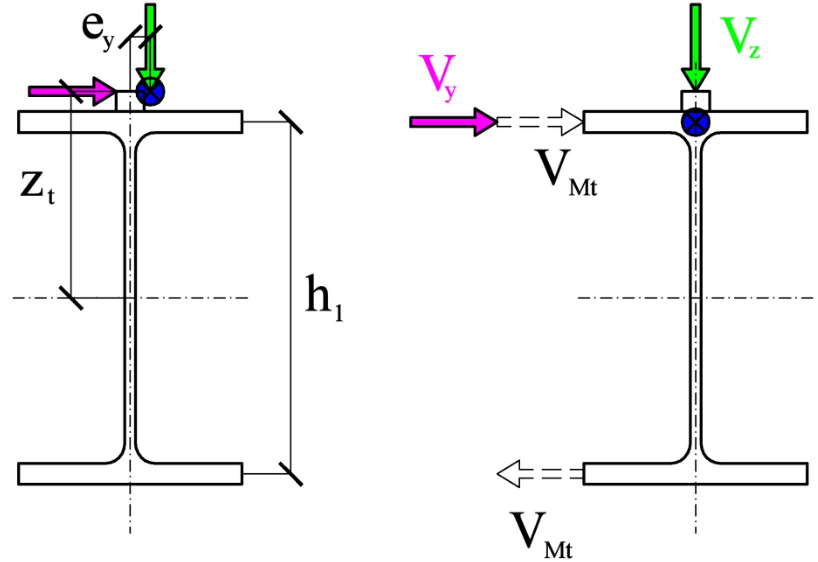
Overhead underslug crane



$$T = V_y z_b$$

$$V_T = (V_y z_b) / h_1$$

Overhead top-mounted crane

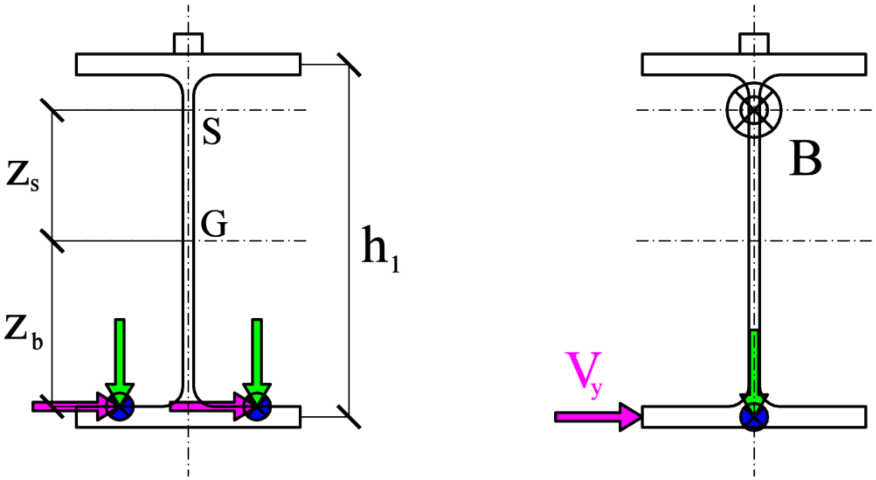


$$T = V_y z_t + V_z e_y$$

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

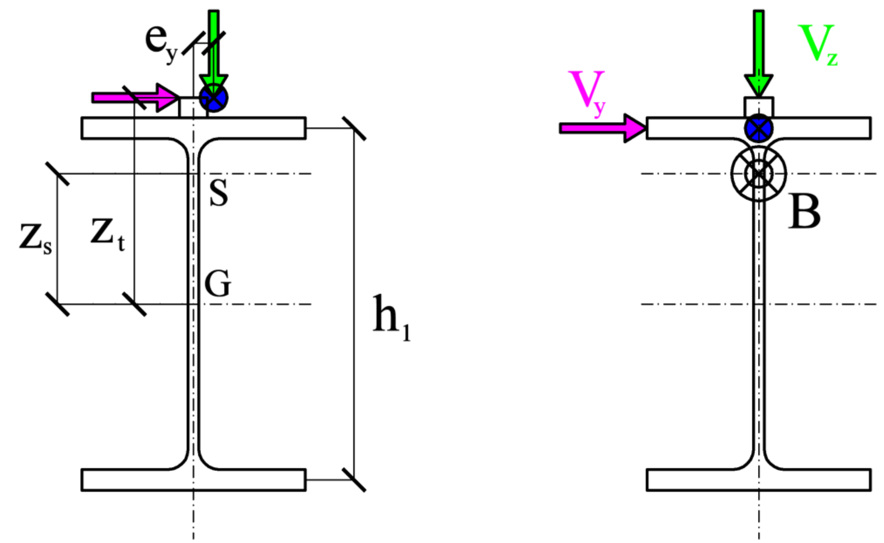
Photo: Author

Second method of recalculations (according to Old Polish Standard and experience) - torsional moment as a bimoment in centre of shear:



Overhead underslug crane

Overhead top-mounted crane



$T = V_y (z_b + z_b)$

$B = B(T)$

Photo: Author

$T = V_y (z_t - z_s) + V_z e_y$

$B = B(T)$

According to theory of thin-walled structures:

$k = \sqrt{[(G J_T) / (E J_w)]} \approx 0{,}62 \sqrt{(J_T / J_w)}$

J_T - torsion constant

J_w - warping constant

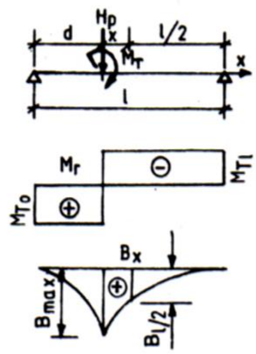
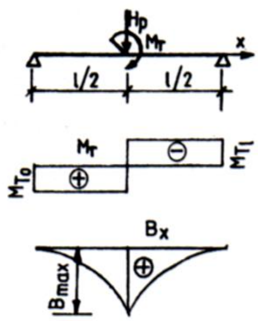
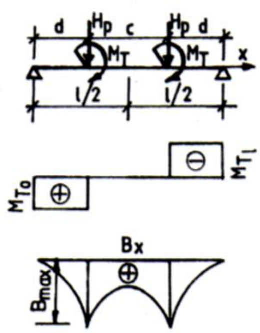
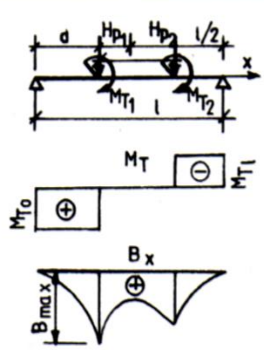
$B = -E J_w \Theta''$

$T = -E J_w \Theta''' + G J_T \Theta'$

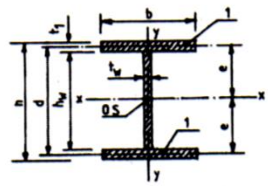
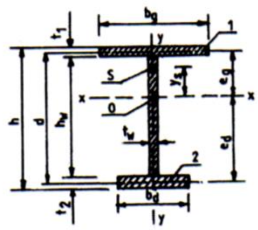
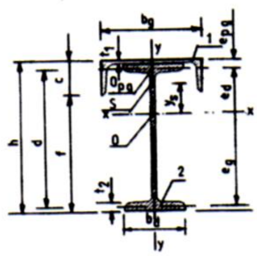
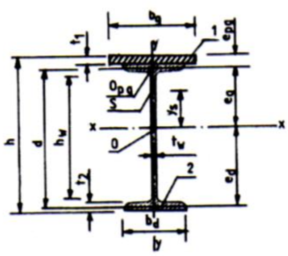
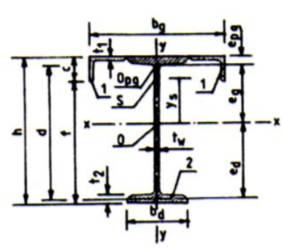
$\Theta = A \,\mathrm{sh}\,(kx) + B \,\mathrm{ch}\,(kx) + Cx + D + \Theta_s(x)$

There is relation between T and B by Θ.

Tablica 3.1

Lp		współrz.	Moment
			koło jednej suwnicy usytuowane w odległości x od środka belki
1		0	$M_{Tx} = M_{T0} = M \frac{l-d}{l}$
		l	$M_{Tx} = M_{Tl} = M_T \cdot \frac{d}{l}$
		d	$B_x = B_{max} = \frac{M_T\, sh\,(kd)\, sh\,[k\,(l-d)]}{k\, sh\,(kl)}$
		$l/2$	$B_x = B_{l/2} = M_T \frac{sh\,(kd)}{2\,k\, ch\,(½\, kl)}$
		$0 \le x \le d$	$B_x = M_T \frac{sh\,)kd)}{ksh\,(kl)} \cdot sh\, kx$
			koło suwnicy w środku rozpiętości belki
2		0	$M_{Tx} = M_{T0} = ½\, M_T$
		l	$M_{Tx} = M_{Tl} = ½\, M_T$
		$l/2$	$B_x = B_{max} = \frac{M_T}{2k}\, th\,(½\, kl)$
		$0 \le x \le ½$	$B_x = M_T \frac{sh\,(2 - ½\, l)}{2k\, ch\,(½\, kl)}$
			koła dwu suwnic o jednakowych naciskach usytuowane w jednakowych odległościach od środka belki
3		0	$M_{Tx} = M_{T0} = M_T$
		l	$M_{Tx} = M_{Tl} = M_T$
		d	$B_x = B_{max} = \frac{M_T\, ch\, k(½ - d)\, sh\,(kd)}{k\, ch\,(^{k l}/_2)}$
		$0 \le x \le d$	$B_x = \frac{M_T\, ch\, k\,(½ - d)\, sh\,(kx)}{ch\,(^{kl}/_2)}$
			koła dwu suwnic o różnych naciskach usytuowane najniekorzystniej
4		0	$M_{Tx} = M_{T0} = M_{T1} \frac{l-d}{l} + M_{T2} \frac{l-d-c}{l}$
		l	$M_{Tx} = M_{Tl} = M_{T1} \frac{d}{l} + M_{T2} \frac{d+c}{l}$
		d	$B_x = B_{max} = M_{T1} \frac{shk(l-d)}{ksh\,(l-d)}\, shkd + \frac{M_{T2}\, shkd}{ksh(kl)}\, shk\,(l-d)$
		$0 \le x \le d$	$B_x = \frac{M_{T1}\, sh\,[k\,(l-d)]\, sh(kx)}{ksh(kl)} + \frac{M_{T2}\, sh(kx)}{ksh(kl)}\, sh[k(l-x)]$

J. Żmuda, "Projektowanie torów jezdnych suwnic i elektrowciągów", TiT Opole 1997

lp.	Schemat obciążenia	
1		$y_s = 0$ $I_\omega = (I_y \cdot d^2)/4$ $\omega_g = \omega_d = \frac{b \cdot d}{4}$ $I_T = \frac{1}{3}(2b \cdot t^3 = h_w t_w^3)$ $r_x = 0$
2		$y_s = e_g - \frac{I_{y2}}{I_y} d$ $I_\omega = \frac{I_{y1} \cdot I_{y2} \cdot d^2}{I_y}$ $\omega_g = b_g (e_g - y_s)/2, \quad \omega_d = d_d (e_d + y_s)/2$ $I_T = \frac{1}{3}(b_g \cdot t_1^3 + h_w \cdot t_w^3 + b_d \cdot t_2^3)$ $r_x = 1/I_x \{y_s \cdot I_y + b_g t_1 e_g^3 - b_d t_2 e_d^3 + 0{,}25\, t_w (e_g^4 - e_d^4)\}$
3		$y_s = e_g - \frac{I_{y2} \cdot d}{2 I_y}$ $I_\omega = \frac{2 I_{y1} \cdot I_{y2} \cdot d^2}{4 I_y}$ $\omega_g = b_g \cdot c/2, \quad \omega_d = b_d \cdot f/2$ $I_T = I_{T1} + I_{T2}$ $r_x = 1/I_x (y_s \cdot I_y + (b_{g1} \cdot t_1 + b_2 \cdot t_2) e_g^3 +$ $+ b_2 t_2 \cdot e_d^3 + 0{,}25\, t_w (e_g^4 - e_d^4))$
4		$y_s = e_g - I_{y2} \cdot d/2 I_y$ $I_\omega = \frac{(4 I_{y1} + I_{y2}) \cdot I_{y2} \cdot d^2}{8 I_y}$ $\omega_g = b_g \cdot c/2, \quad \omega_d = b_d \cdot f/2$ $I_T = I_{T1} + I_{T2}$ $r_x = 1/I_x \{y_s \cdot I_y + [(b_g - b_d) \cdot t_1 + b_2 \cdot t_2] \cdot e_g^3 +$ $+ b_2 t_2 \cdot e_d^3 + 0{,}25\, t_w (e_g^4 - e_d^4)\}$
5		$y_s = e_g - \frac{I_{y2}}{2 I_y} \cdot d$ $I_\omega = (2 I_{y1} + I_{y2}) I_{y2}/4 I_y$ $\omega_g = b_g (e_g - y_s)/2, \quad \omega_d = b_d (e_d + y_s)/2$ $I_T = I_{T1} + I_{T2}$ $r_x = 1/I_x (y_s \cdot I_y + (b_g \cdot t_1 + b_d \cdot t_2) \cdot e_g^3 -$ $- b_d \cdot t_2 e_d^3 + 0{,}25\, t_w (e_g^4 - e_d^4)$

Reduced stresses method (RSM)

I[st], II[nd], III[rd] and IV[th] class of cross-section, EN 1993-1-1 (6.1):

$$[\sigma_{x,\,Ed} / (f_y / \gamma_{M0})]^2 + [\sigma_{z,\,Ed} / (f_y / \gamma_{M0})]^2 - [\sigma_{x,\,Ed} / (f_y / \gamma_{M0})][\sigma_{z,\,Ed} / (f_y / \gamma_{M0})] +$$
$$+ 3\,[\tau_{Ed} / (f_y / \gamma_{M0})]^2 \le 1{,}0$$

Additionally for IV[th] class of cross-section, EN 1993-1-1 (6.44):

$$N_{Ed} / (A_{eff}\, f_y / \gamma_{M0}) + (M_{y,\,Ed} + N_{Ed}\, e_{Ny}) / (W_{y,\,eff}\, f_y / \gamma_{M0}) +$$
$$+ (M_{z,\,Ed} + N_{Ed}\, e_{Nz}) / (W_{z,\,eff}\, f_y / \gamma_{M0}) \le 1{,}0$$

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

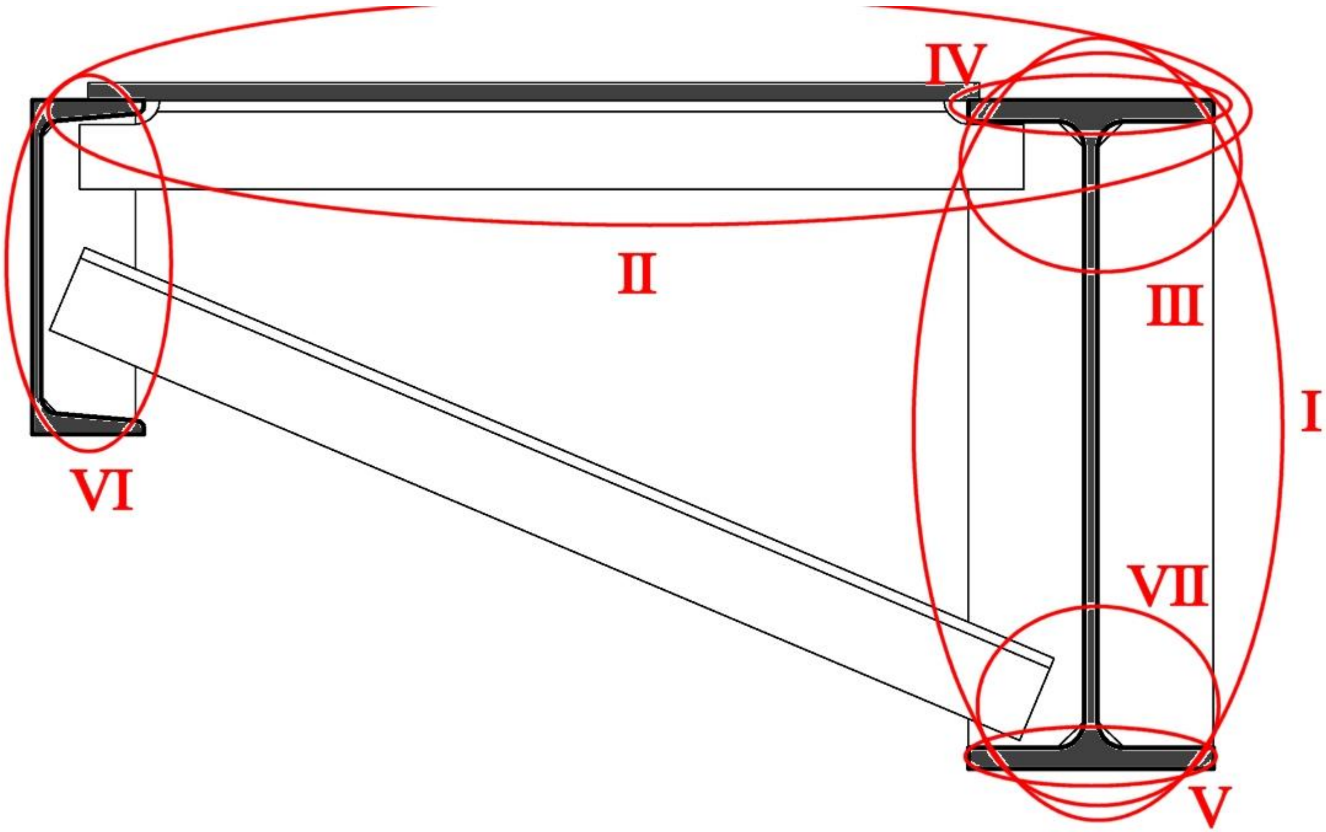
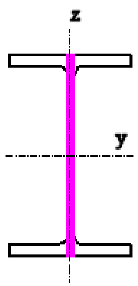
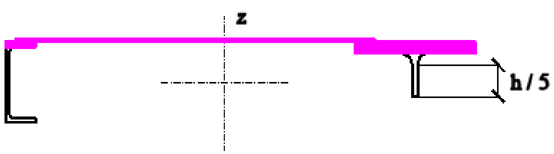
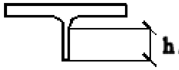
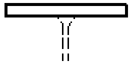
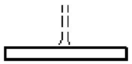
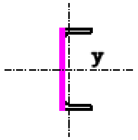
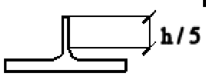


Photo: Author

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:

Vertical forces from crane V_z

Horizontal forces V_y

Couple of forces from torsional moment V_T

Bimoment B

Axial forces N

Vertical bending moment $M_y = M_y (V_z)$

Horizontal bending moment $M_z = M_z (V_y)$

Vertical forces from worker's activity $V_{w, z}$

Vertical forces from worker's activity $V_{w, z} / 2$

Vertical bending moment from worker's activity $M_{w, y} = M_{w, y} (V_{w, z})$

Vertical bending moment from worker's activity $M_{w, y} = M_{w, y} (V_{w, z} / 2)$

The most important points of cross-section:

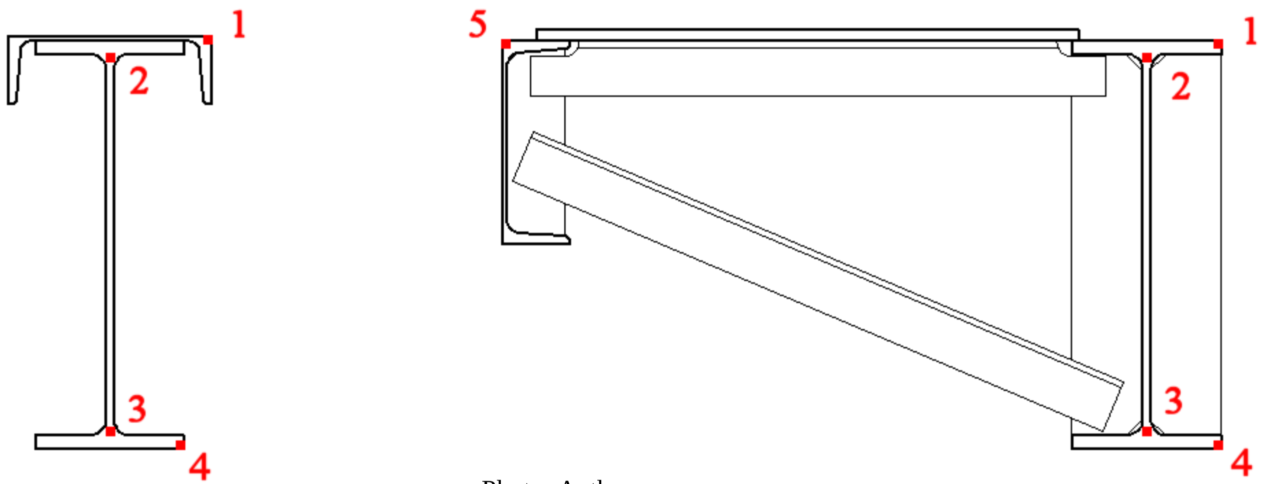


Photo: Author

Point #1:

Type of crane	Cross-sectional force	Part of cross-section (→ #t / 41)	Stress
Monorail hoist block	$M_y = M_y (V_z)$	$W_y^{I,1}$	$\sigma_x (M_y) = M_y / W_y^{I,1}$
Overhead underslung crane	V_T (torsional moment as a coulpe of force)	A^{IV}	$\tau_y (V_T) = V_T / A^{IV}$
	B (torsional moment as a bimoment)	$J^I_w \quad \omega^I_{max}$	$\sigma_x (B) = B\, \omega^I_{max} / J^I_w$
	$M_y = M_y (V_z)$	$W_y^{I,1}$	$\sigma_x (M_y) = M_y / W_y^{I,1}$
	$M_z = M_z (V_y)$	$W_z^{I,1}$	$\sigma_x (M_z) = M_z / W_z^{I,1}$

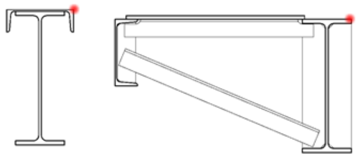


Photo: Author

Point #1:

Type of crane	Cross-sectional force	Part of cross-section ($\rightarrow$ #t / 41)	Stress
Overhead top-mounted crane without surge girder	V_y	A^{IV}	$\tau_y (V_y) = V_y / A^{IV}$
	V_T (torsional moment as a coulpe of force)	A^{IV}	$\tau_y (V_T) = V_T / A^{IV}$
	B (torsional moment as a bimoment)	J^{I}_{w} ω^{I}_{max}	$\sigma_x (B) = B\, \omega^{I}_{max} / J^{I}_{w}$
	N	A^{III}	$\sigma_x (N) = N / A^{III}$
	$M_y = M_y (V_z)$	$W_y^{I,1}$	$\sigma_x (M_y) = M_y / W_y^{I,1}$
	$M_z = M_z (V_y)$	$W_z^{I,1}$	$\sigma_x (M_y) = M_z / W_z^{I,1}$

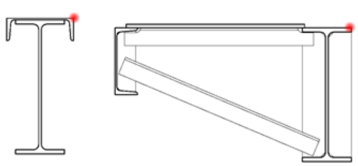


Photo: Author

Point #1:

Type of crane	Cross-sectional force	Part of cross-section ($\rightarrow$ #t / 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}	$\sigma_x (N) = N / A^{III}$
	$M_y = M_y (V_z)$	$W_y^{I,1}$	$\sigma_x (M_y) = M_y / W_y^{I,1}$
	$M_z = M_z (V_y)$	$W_z^{II,1}$	$\sigma_x (M_y) = M_z / W_z^{II,1}$
	$M_{w,\,y} = M_{w,\,y} \; (V_{w,\,z})$	$W_y^{I,1}$	$\sigma_x (M_{w,\,y}) = M_{w,\,y} / W_y^{I,1}$

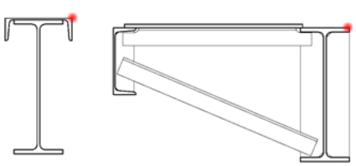


Photo: Author

Point #2:

Type of crane	Cross-sectional force	Part of cross-section ($\rightarrow$ #t / 41)	Stress
Monorail hoist block	V_z	A^I	$\tau_z (V_z) = V_z / A^I$
	$M_y = M_y (V_z)$	$W_y^{I,2}$	$\sigma_x (M_y) = M_y / W_y^{I,2}$
Overhead underslung crane	V_z	A^I	$\tau_z (V_z) = V_z / A^I$
	V_T (torsional moment as a coulpe of force)	A^{IV}	$\tau_y (V_T) = V_T / A^{IV}$
	B (torsional moment as a bimoment)	J^I_w $\omega^{I,\,2} = 0$	$\sigma_x (B) = 0$
	$M_y = M_y (V_z)$	$W_y^{I,2}$	$\sigma_x (M_y) = M_y / W_y^{I,2}$
	$M_z = M_z (V_y)$	$W_z^{I,2}$	$\sigma_x (M_z) = M_z / W_z^{I,2}$

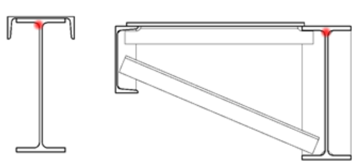


Photo: Author

Point #2:

Type of crane	Cross-sectional force	Part of cross-section (→ #t / 41)	Stress
Overhead top-mounted crane without surge girder	V_z	A^{I}	$\tau_z (V_z) = V_z / A^{I}$
	V_y	A^{IV}	$\tau_y (V_y) = V_y / A^{IV}$
	V_T (torsional moment as a coulpe of force)	A^{IV}	$\tau_y (V_T) = V_T / A^{IV}$
	B (torsional moment as a bimoment)	J^{I}_{w} $\omega^{I, 2} = 0$	$\sigma_x (B) = 0$
	N	A^{III}	$\sigma_x (N) = N / A^{III}$
	$M_y = M_y (V_z)$	$W_y^{I,2}$	$\sigma_x (M_y) = M_y / W_y^{I,2}$
	$M_z = M_z (V_y)$	$W_z^{I,2}$	$\sigma_x (M_y) = M_z / W_z^{I,2}$

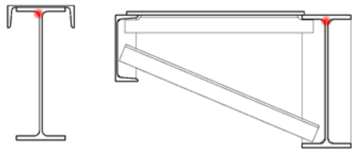


Photo: Author

Point #2:

Type of crane	Cross-sectional force	Part of cross-section ($\rightarrow$ #t / 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}	$\tau (V_{w, z}) = V_{w, z} / A^{I}$
	$M_{w, y} = M_{w, y} (V_{w, z})$	$W_y^{I,2}$	$\sigma_x (M_{w, y}) = M_{w, y} / W_y^{I,2}$

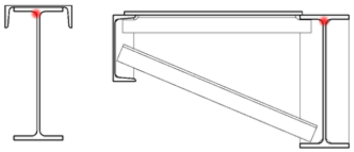
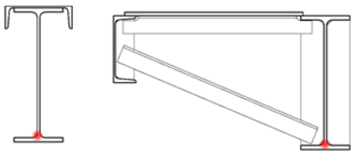


Photo: Author

Point #3:

Type of crane	Cross-sectional force	Part of cross-section (→ #t / 41)	Stress
Monorail hoist block	V_z	A^I	$\tau_z (V_z) = V_z / A^I$
	N	A^{VII}	$\sigma_x (N) = N / A^{VII}$
	$M_y = M_y (V_z)$	$W_y^{I.3}$	$\sigma_x (M_y) = M_y / W_y^{I,3}$
Overhead underslung crane	V_y	A^V	$\tau_y (V_y) = V_y / A^V$
	V_z	A^I	$\tau_z (V_z) = V_z / A^I$
	V_T (torsional moment as a coulpe of force)	A^V	$\tau_y (V_T) = V_T / A^V$
	B (torsional moment as a bimoment)	J^I_w $\omega^{I,\,3} = 0$	$\sigma_x (B) = 0$
Photo: Author	N	A^{VII}	$\sigma_x (N) = N / A^{VII}$
	$M_y = M_y (V_z)$	$W_y^{I,3}$	$\sigma_x (M_y) = M_y / W_y^{I,3}$
	$M_z = M_z (V_y)$	$W_z^{I,3}$	$\sigma_x (M_z) = M_z / W_z^{I,3}$

Point #3:

Type of crane	Cross-sectional force	Part of cross-section (→ #t / 41)	Stress
Overhead top-mounted crane without 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	$\tau_y (V_T) = V_T / A^V$
	B (torsional moment as a bimoment)	J^I_w $\omega^{I, 3} = 0$	$\sigma_x (B) = 0$
	$M_y = M_y (V_z)$	$W_y^{I,3}$	$\sigma_x (M_y) = M_y / W_y^{I,3}$
	$M_z = M_z (V_y)$	$W_z^{I,3}$	$\sigma_x (M_z) = M_z / W_z^{I,3}$

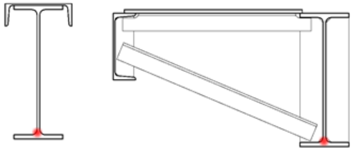


Photo: Author

Point #3:

Type of crane	Cross-sectional force	Part of cross-section (→ #t / 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	$\tau (V_{w,\,z}) = V_{w,\,z} / A^I$
	$M_{w,\,y} = M_{w,\,y} \; (V_{w,\,z})$	$W_y^{I,3}$	$\sigma_x (M_{w,\,y}) = M_{w,\,y} / W_y^{I,3}$

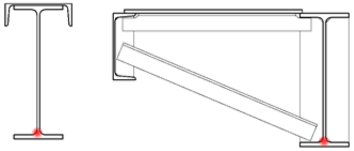
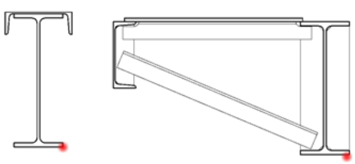


Photo: Author

Point #4:

Type of crane	Cross-sectional force	Part of cross-section (→ #t / 41)	Stress
Monorail hoist block	N	A^{VII}	$\sigma_x (N) = N / A^{VII}$
	$M_y = M_y (V_z)$	$W_y^{I,4}$	$\sigma_x (M_y) = M_y / W_y^{I,4}$
Overhead underslung crane	V_y	A^V	$\tau_y (V_y) = V_y / A^V$
	V_T (torsional moment as a coulpe of force)	A^V	$\tau_y (V_T)= V_T / A^V$
	B (torsional moment as a bimoment)	J^I_w ω^I_{max}	$\sigma_x (B) = B\, \omega^I_{max} / J^I_w$
 Photo: Author	N	A^{VII}	$\sigma_x (N) = N / A^{VII}$
	$M_y = M_y (V_z)$	$W_y^{I,4}$	$\sigma_x (M_y) = M_y / W_y^{I,4}$
	$M_z = M_z (V_y)$	$W_z^{I,4}$	$\sigma_x (M_z) = M_z / W_z^{I,4}$

Point #4:

Type of crane	Cross-sectional force	Part of cross-section (→ #t / 41)	Stress
Overhead top-mounted crane without surge girder	V_T (torsional moment as a coulpe of force)	A^V	$\tau_y (V_T) = V_T / A^V$
	B (torsional moment as a bimoment)	J^I_w ω^I_{max}	$\sigma_x (B) = B \omega^I_{max} / J^I_w$
	$M_y = M_y (V_z)$	$W_y^{I,4}$	$\sigma_x (M_y) = M_y / W_y^{I,4}$
	$M_z = M_z (V_y)$	$W_z^{I,4}$	$\sigma_x (M_z) = M_z / W_z^{I,4}$

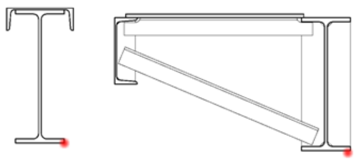


Photo: Author

Point #4:

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

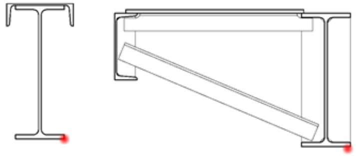


Photo: Author

Point #5:

Type of crane	Cross-sectional force	Part of cross-section (→ #t / 41)	Stress
Monorail hoist block	Point #5 not exists		
Overhead underslung crane			
Overhead top-mounted crane without surge girder			

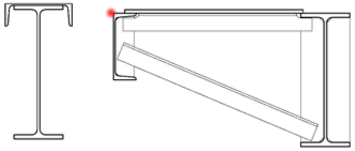


Photo: Author

Point #5:

Type of crane	Cross-sectional force	Part of cross-section (→ #t / 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}	$\tau (V_{w, z}) = V_{w, z} / 2A^{VI}$
	$M_{w, y} = M_{w, y} (V_{w, z} / 2)$	$W_y^{VI,5}$	$\sigma_x (M_y) = M_{w, y} / W_y^{VI,5}$

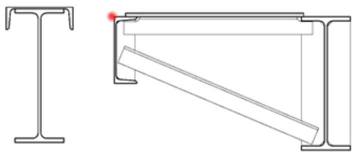


Photo: Author

For each point i, there must be calculated total value of stress. For example, i = 1:

$\sigma_{x,Ed,\,1} = \sigma_{x,\,1}(N) + \sigma_{x,\,i}(M_y) + \sigma_{x,\,i}(M_z) + \sigma_{x,\,i}(B) + \sigma_{x,\,i}(B) + \Sigma\,\sigma_{x,\,i}$ (local effects)

$\sigma_{y,Ed,\,1} = \Sigma\,\sigma_{y,\,1}$ (local effects)

$\sigma_{z,Ed,\,1} = \Sigma\,\sigma_{z,\,1}$ (local effects)

$\tau_{y,\,1} = \tau_{y\,,\,1}(V_y) + \tau_{y\,,\,1}(V_T) + \tau_{y\,,\,1}$ (local effects)

$\tau_{z,\,1} = \tau_{z\,,\,1}(V_z) + \tau_{z\,,\,1}$ (local effects)

$[\tau_{Ed,\,i}]^2 = [\tau_{y,\,i}]^2 + [\tau_{z,\,i}]^2$

Local effects → #t / 73-86

Checking of resistance → #t / 87-88

IVth class of cross-section: distinction on sub-parts of cross-section (→ #t / 41); effective geometry for I-beam sub-part, according to the same rules as on Ist step of study:

Compressed part

A_{eff} , $W_{y,\ top\ ,\ eff}$, $W_{y,\ bottom,\ eff}$, $W_{z,\ eff}$ for calculation of stresses

Tensed part

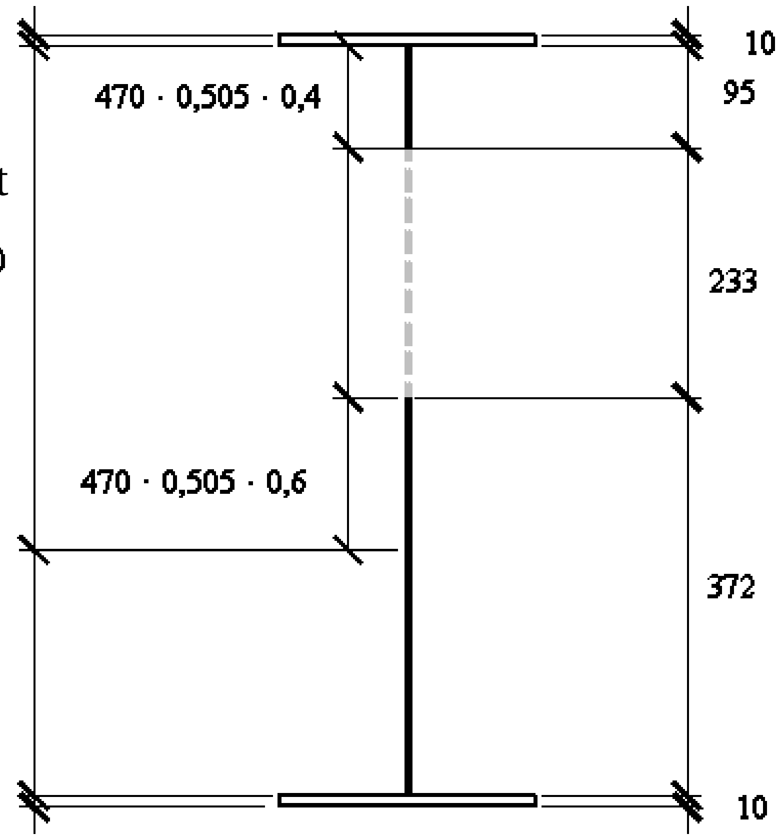


Photo: Autor

Effective Cross-Sections Method (ECSM)

The same rules as on Ist step of study for IVth class of cross-section:

$$\eta_1 = N_{Ed} / (f_y A_{eff} / \gamma_{M0}) + (M_{y,\,Ed} + N_{Ed}\, e_{y,N}) / (f_y W_{y,\,eff} / \gamma_{M0}) +$$
$$+ (M_{y,\,Ed} + N_{Ed}\, e_{z,N}) / (f_y W_{z,\,eff} / \gamma_{M0}) \leq 1{,}0$$

EN 1993-1-5 (4.15)

$$\eta_2 = F_s / (f_{yw} L_{eff} t_w / \gamma_{M0}) \leq 1{,}0$$

EN 1993-1-5 (6.14)

$$\eta_3 = V_{Ed} / V_{b,\,Rd} \leq 1{,}0$$

EN 1993-1-5 (5.10)

…

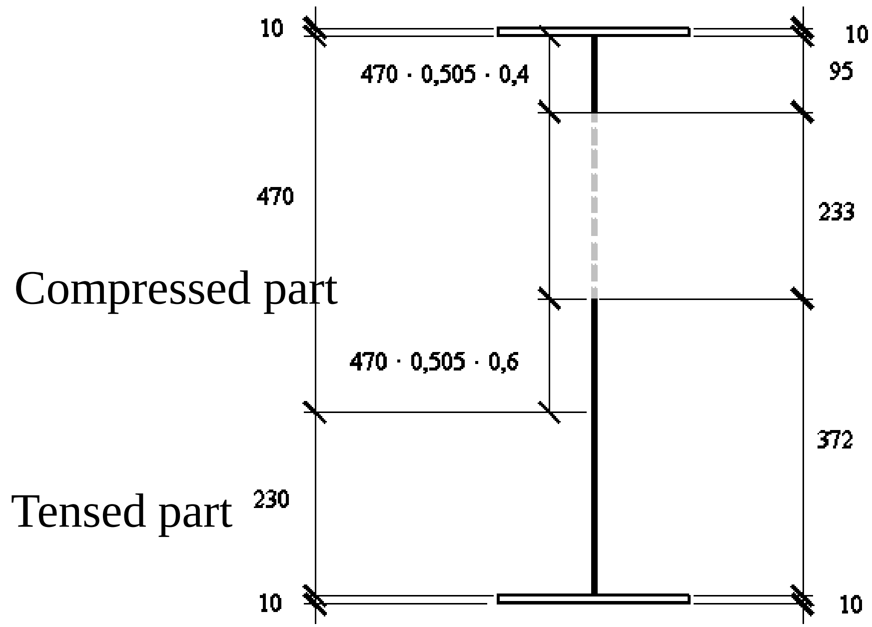


Photo: Autor

Other run-beams

Truss run-beams - global name concerns four possibilities:

- I-beam and lattice surge girder;
- truss vertical girder and no surge girder;
- truss vertical girder and plate surge girder;
- truss vertical girder and lattice surge girder;

Second calse: box run-beams

Truss vertical girdera are rarely used, because of problems with fatigue calculations. There are rather temporary structures.

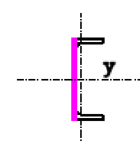
Photo: everychina.com

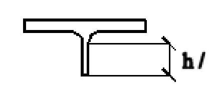
Lattice girder – the same problem in horizontal direction.

Photo: konar.eu

This horizontal truss have unequal chords:

Photo: Author





Left chord

Right chord

Photo: zinkpower.com.pl

Photo: rapmet.pl

In case of lattice surge girder, walkways are made as steel frame lattice walkways.

I-run-beam: bending moment, calculated as for bar member.

Box run-beam: bi-directional bending as for shell member.

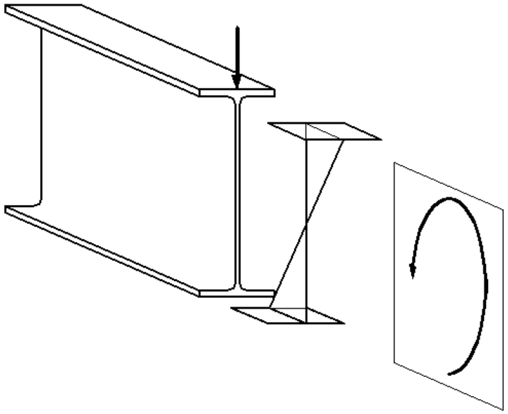
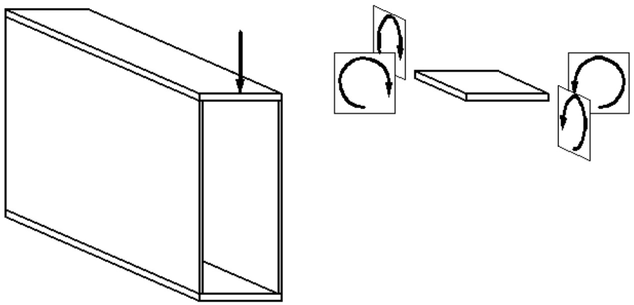


Photo: Author



Box run-beams are dedicated for extremelly heavy cranes and, because of this, are rather rare used. This type of structre should be calculated by FEM.

Photo: skandius.pl

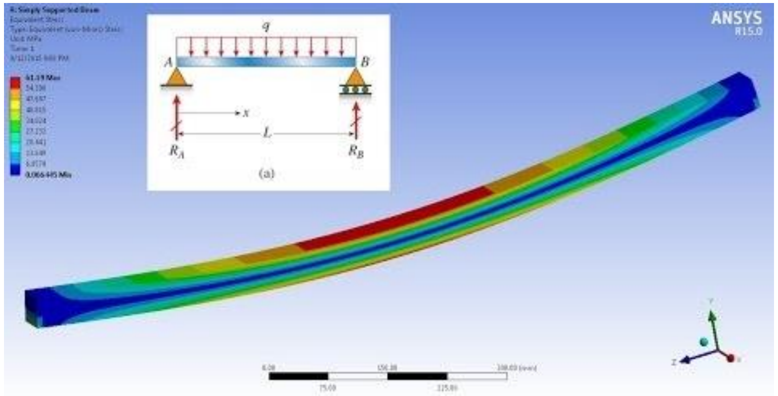


Photo: article.wn.com

Instability

According to Eurocodes, there are three ways of calculation:

EN 1993-1-1 6.3 → #t / 67

or

EN 1993-6 6.3 → #t / 68 - 70

or

EN 1993-6 app.A → #t / 71 - 72

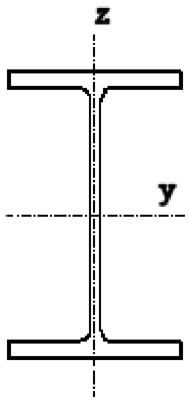
First way

EN 1993-1-1 6.3

For run-beams for monorail hoist block, overhead underslung crane or overhead top-mounted crane without surge girder

„Classical” calculations of instability for compressed and bending I-beam (flexural, torsional, flexural-torsional, lateral).

Photo: Author



Second way

EN 1993-6 6.3

Buckling is calculated as flexural buckling of compressed flange about axis z under equivalent force N_{equ}

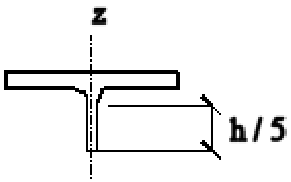
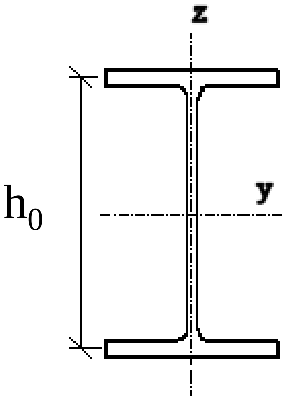


Photo: Author

Photo: Author



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

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

Equivalent force N_{equ} is calculated based on bending moment, axial stresses and distance between centref of gravity of flanges h_0

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

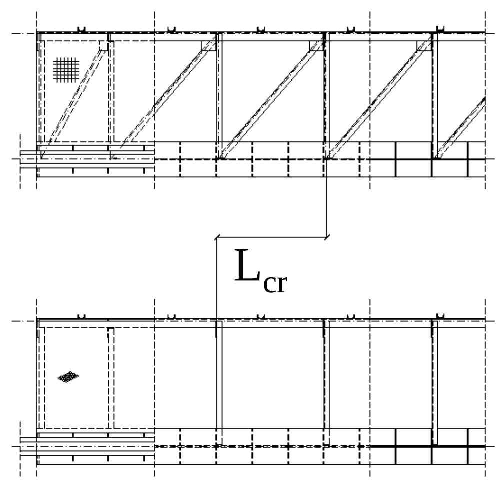
	$\sigma (N)$	$\sigma (M_y)$	$\sigma (M_z)$	$\sigma (B)$
Monorail hoist block	0	$M_y / W_y^{I,1}$	0	0
Overhead underslung crane	0	$M_y / W_y^{I,1}$	$M_z / W_z^{I,1}$	$B\ \omega_{max} / J_w$
Overhead top-mounted crane without surge girder	N / A^{III}	$M_y / W_y^{I,1}$	$M_z / W_z^{I,1}$	$B\ \omega_{max}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

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

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	
Overhead top-mounted crane, no surge girder	
Overhead top-mounted crane, plate or lattice surge girder	Distance between transversal stiffeners of surge girder

Photo: Author



$$\chi_T = \chi_T(\lambda_T, c)$$

$$N_{T,Rd} = \chi_T A_T f_y$$

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

Third way

EN 1993-6 A.2

For I-III class of cross-section.

$$m_y / \chi_{LT} + C_{mz}\, m_z + k_w\, k_{zw}\, k_\alpha\, t_{Tw} \leq 1$$

$$m_y = M_{y,\,Ed}\, \gamma_{M1} / M_{y,\,Rk}$$

$$m_z = M_{z,\,Ed}\, \gamma_{M1} / M_{z,\,Rk}$$

$$t_{Tw} = T_{w,\,Ed}\, \gamma_{M1} / T_{w,\,Rk}$$

$$k_w = 0{,}7 - 0{,}2\, t_{Tw}$$

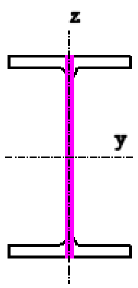
$$k_{zw} = 1 - m_z$$

$$k_\alpha = 1 / (1 - M_{y,\,Ed} / M_{y,\,cr})$$

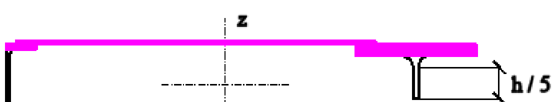
$$C_{mz} \rightarrow \text{EN 1993-1-1 tab B.3}$$

$M_{y,\,Rk}$ $M_{z,\,Rk}$ $T_{w,\,Rk}$ for cross-sections according to #t / 41

Photo: Author



$M_{y,\,Rk}$ $T_{w,\,Rk}$



$M_{z,\,Rk}$

Third way

EN 1993-6 A.2

For IV[th] class of cross-section:

EN 1993-1-5 (10.5)

$$(\Sigma \sigma_x \gamma_{M1} / \rho_x f_y)^2 + (\Sigma \sigma_z \gamma_{M1} / \rho_z f_y)^2 - (\Sigma \sigma_x \gamma_{M1} / \rho_x f_y)(\Sigma \sigma_z \gamma_{M1} / \rho_z f_y)^2 +$$

$$+ 3 [(\Sigma \tau_y \gamma_{M1} / \chi_w f_y)^2 + (\tau_z \gamma_{M1} / \chi_w f_y)^2] \leq 1,0$$

ρ_x ρ_z → EN 1993-1-5 tab 4.1, tab 4.2

χ_w → EN 1993-1-5 tab 5.1

Local effects

Local stress in web σ_z → #t / 75-78

Local stress in web τ_{xz} → #t / 79-80

Local bending in web → #t / 81

Local bending in flange → #t / 82-83 (RSM), 84-86 (ECSM)

Vibration of the bottom flange → #t / 89

Web breathing → #t / 90

Local bending of surge girder → #t / 91

According to two methods of calculations (RSM / ECSM), there are two methods of analysis of local effects:

<table>
<tr><th>Phenomenon</th><th>According to RSM</th><th>According to ECSM</th></tr>
<tr><td>Local stress in web σ_z</td><td rowspan="4">Stresses, added to global stresses in RSM method</td><td>Resistance for local transverse load according to EN 1993-1-5</td></tr>
<tr><td>Local stress in web τ_{xz}</td><td>Resistance for shear force according to EN 1993-1-5; value of shear force applied to structure is increased to 120%</td></tr>
<tr><td>Local bending in web</td><td>Can be neglected
(EN 1993-6 6.5.(2))</td></tr>
<tr><td>Local bending in flange</td><td>Resistance of flange for local force – separated rules</td></tr>
<tr><td>Vibration of the bottom flange</td><td colspan="2" rowspan="3">Separated rules, the same for both methods</td></tr>
<tr><td>Web breathing</td></tr>
<tr><td>Local bending of surge girder</td></tr>
</table>

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

RSM method:

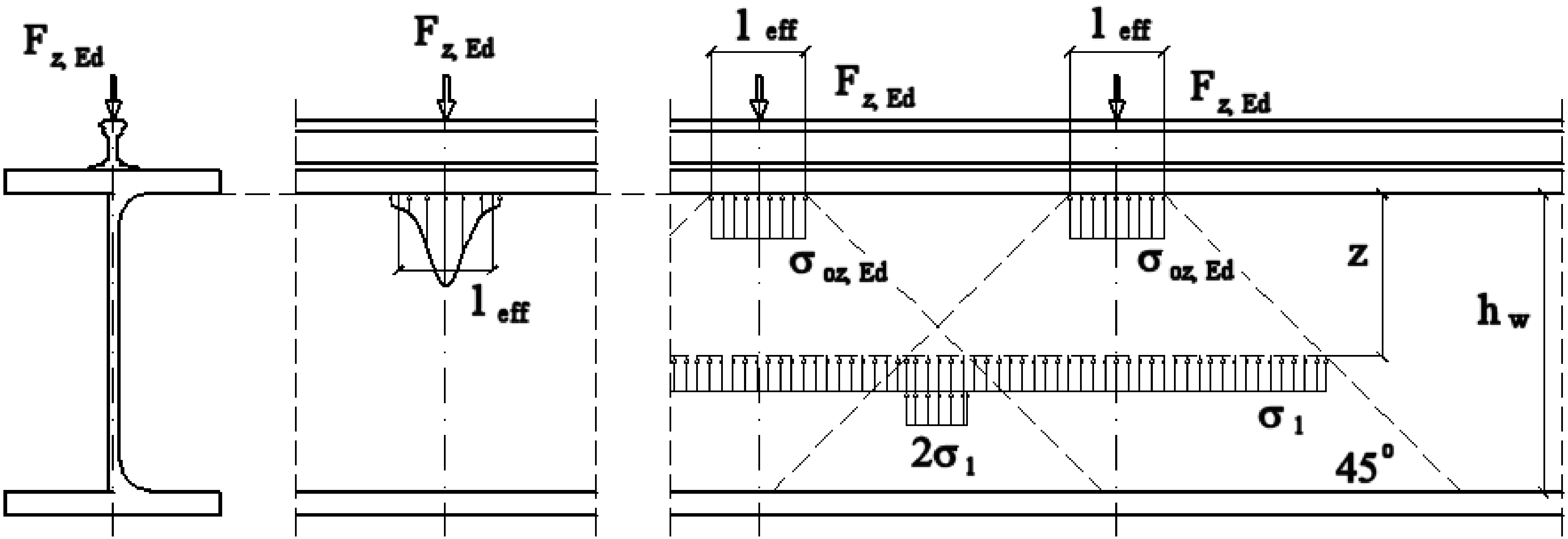


Photo: Author

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

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

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

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

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

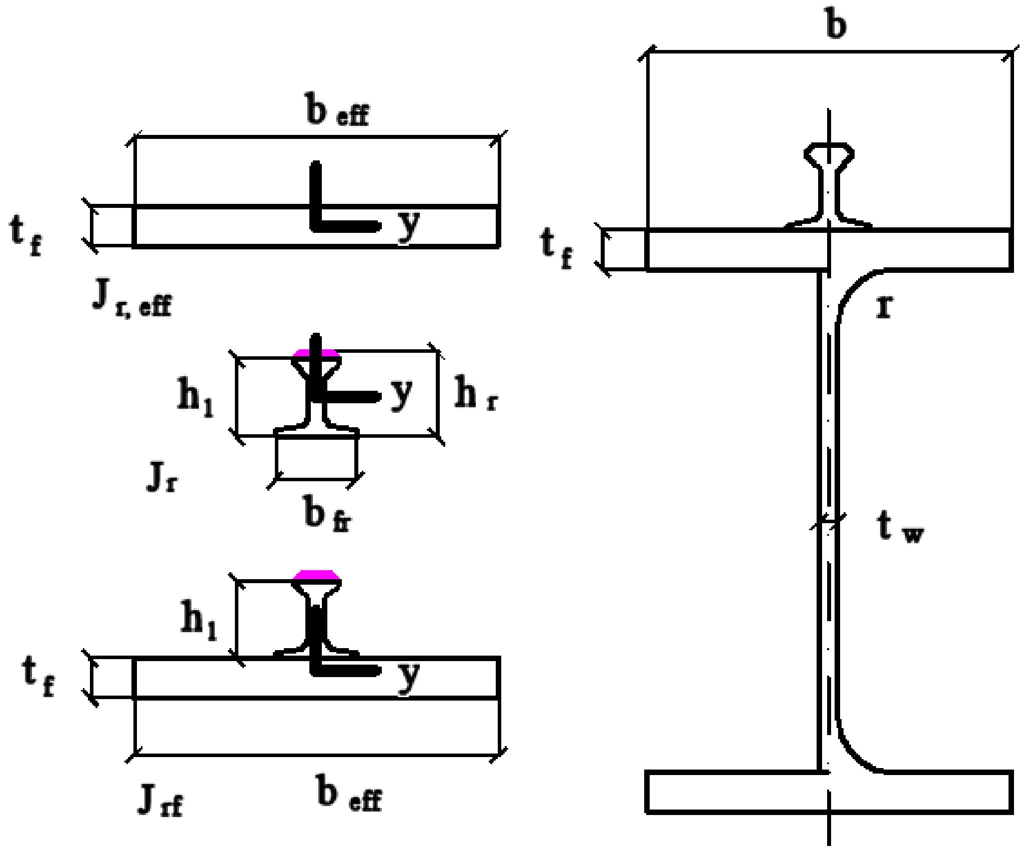


Photo: Author

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 → #t / 17

EN 1993-3 tab. 5.1

The same type of analysis is needed for non-end post support:

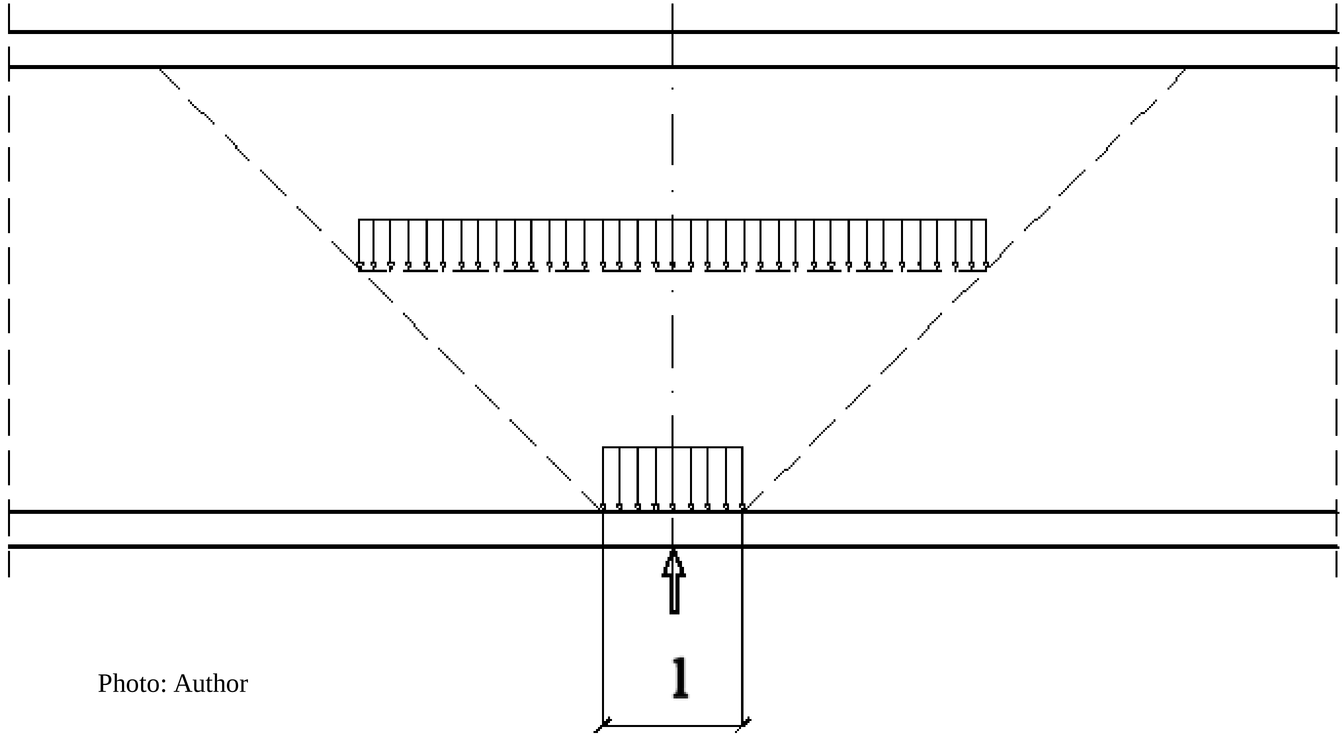


Photo: Author

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

RSM method:

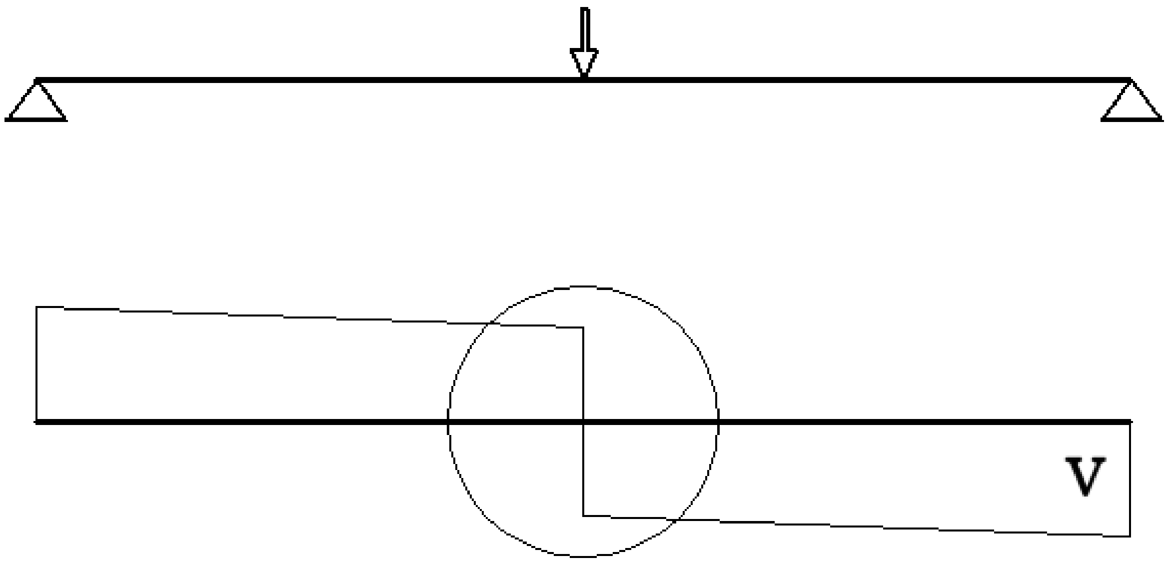


Photo: Author

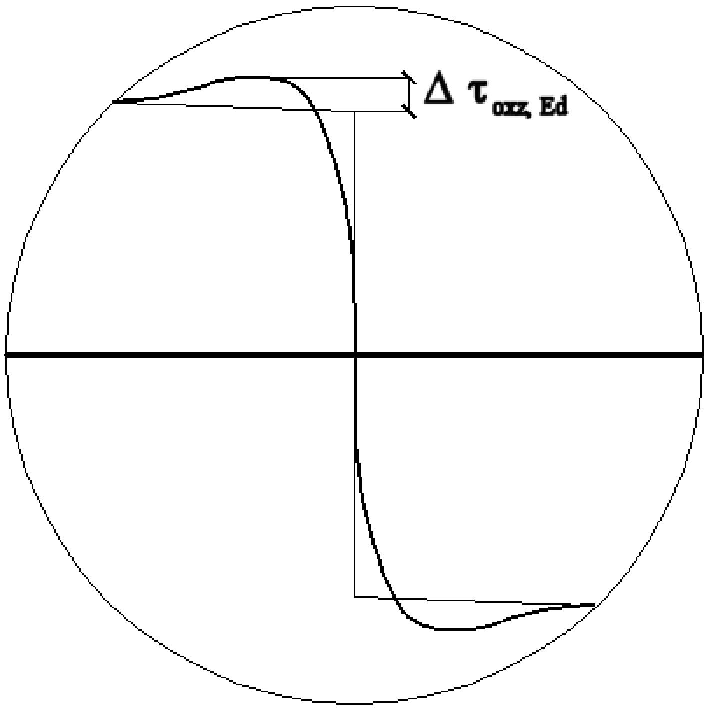


Photo: Author

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

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

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

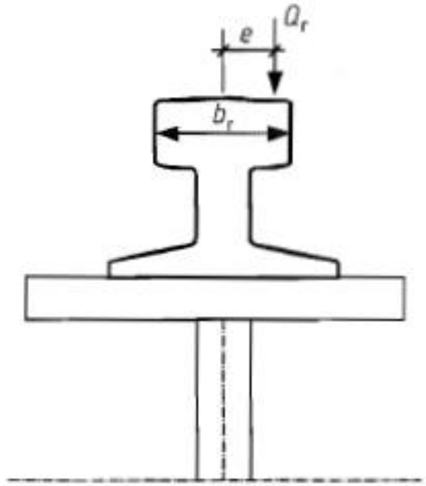
$$\sigma_{oz,\,Ed} \rightarrow \#t / 75$$

Local bending in web

RSM method:

EN 1993-6 5.7.3

Photo: EN 1991-3 fig. 2.2



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

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

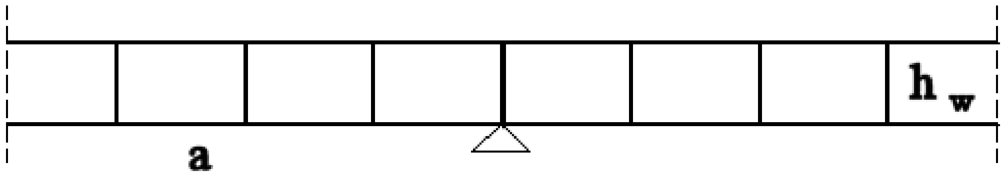


Photo: Author

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

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

Local bending in flange

EN 1993-6 5.8

RSM method:

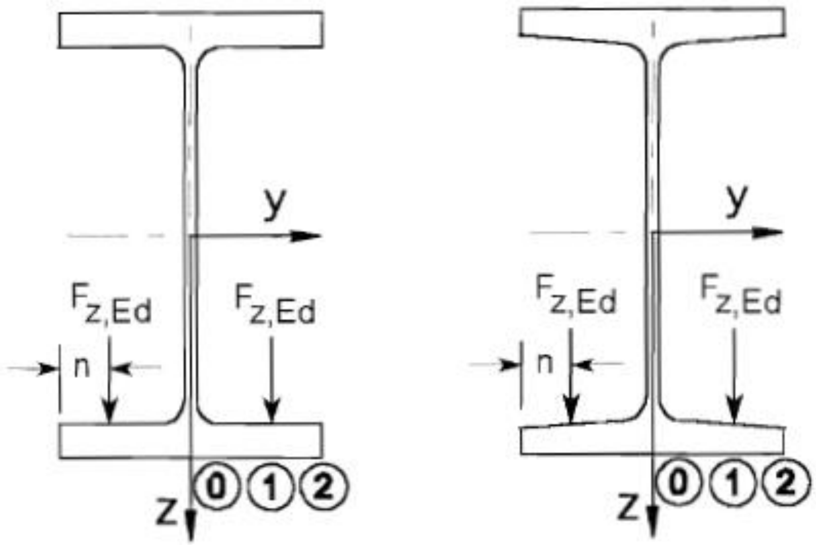
$$\sigma_{ox,\,Ed} = c_x\, F_{z,\,Ed} \,/\, (t_1)^2$$

$$\sigma_{oy,\,Ed} = c_y\, F_{z,\,Ed} \,/\, (t_1)^2$$

$$c_x\,,\, c_y = c(\mu) \rightarrow \#t \,/\, 83$$

$$\mu = 2\,n \,/\, (b - t_w)$$

t_1 - thickness of flange under $F_{z,\,Ed}$



parallel flange beam　　taper flange beam

EN 1993-6 tab. 5.2

Stress	Parallel flange beams	Taper flange beams
Longitudinal bending stress $\sigma_{0x,Ed}$	$c_{x0} = 0{,}050 - 0{,}580\ \mu + 0{,}148\ e^{3{,}015\mu}$	$c_{x0} = -0{,}981 - 1{,}479\ \mu + 1{,}120\ e^{1{,}322\mu}$
	$c_{x1} = 2{,}230 - 1{,}490\ \mu + 1{,}390\ e^{-18{,}330\mu}$	$c_{x1} = 1{,}810 - 1{,}150\ \mu + 1{,}060\ e^{-7{,}700\mu}$
	$c_{x2} = 0{,}730 - 1{,}580\ \mu + 2{,}910\ e^{-6{,}000\mu}$	$c_{x2} = 1{,}990 - 2{,}810\ \mu + 0{,}840\ e^{-4{,}690\mu}$
Transverse bending stress $\sigma_{0y,Ed}$	$c_{y0} = -2{,}110 + 1{,}977\ \mu + 0{,}007\ e^{6{,}530\mu}$	$c_{y0} = -1{,}096 + 1{,}095\ \mu + 0{,}192\ e^{-6{,}000\mu}$
	$c_{y1} = 10{,}108 - 7{,}408\ \mu - 10{,}108\ e^{-1{,}364\mu}$	$c_{y1} = 3{,}965 - 4{,}835\ \mu - 3{,}965\ e^{-2{,}675\mu}$
	$c_{y2} = 0{,}000$	$c_{y2} = 0{,}000$
Sign convention: c_{xi} and c_{yi} are positive for tensile stresses at the bottom face of the flange		

Resistance of flange; EN 1993-6 6.7

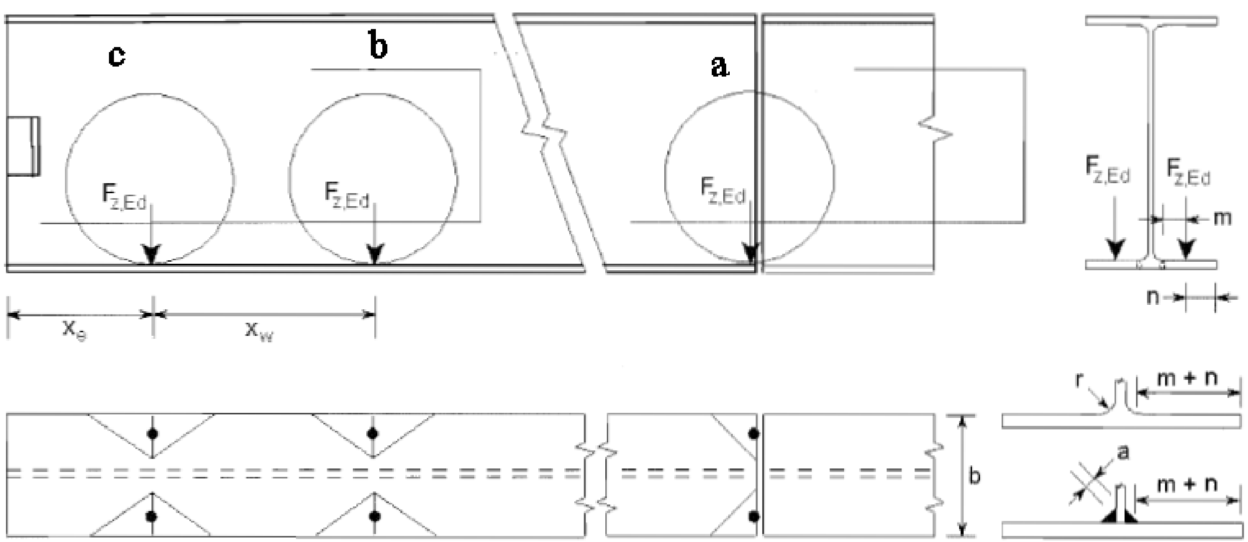
ECSM method:

$$F_{t,\,Ed} / F_{t,\,Rd} \leq 1{,}0$$

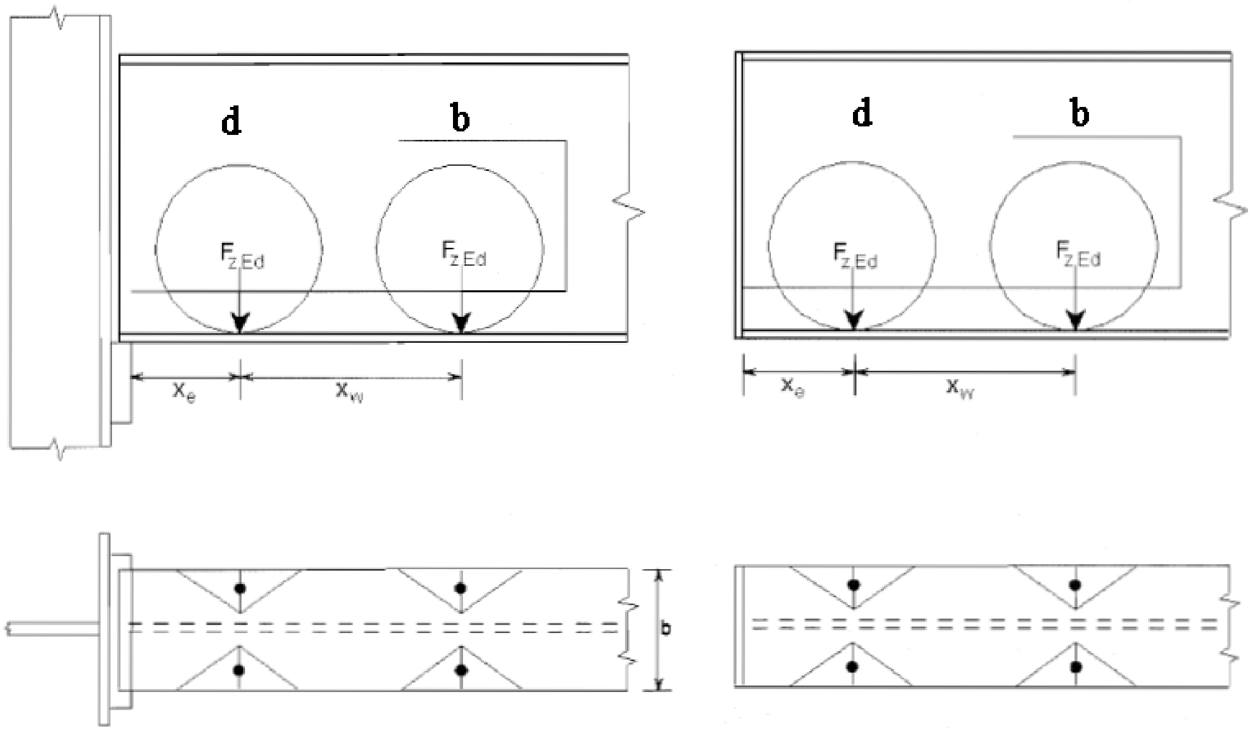
$$F_{t,\,Rd} = l_{eff}\, t_f^2\, f_y\, [\, 1 - (\sigma_{f,\,Ed}\, \gamma_{M0} / f_y)^2\,] / (4\, m\, \gamma_{M0}\,)$$

$$\sigma_{f,\,Ed} = \sigma_{f,\,Ed}\, (M_y) \text{ under } F_{z,\,Ed}$$

$$l_{eff} \rightarrow \#t / 86$$



EN 1993-6 fig 6.2



EN 1993-6 fig 6.2

Position of wheel		**l_{eff}**
a		$2\,(m + n)$
b	$x_w \geq 4\,(m + n)\,\sqrt{2}$	$4\,(m + n)\,\sqrt{2}$
	$x_w < 4\,(m + n)\,\sqrt{2}$	$x_w\,(m + n)\,\sqrt{2}$
c $x_e \leq 2\,(m + n)\,\sqrt{2}$	$x_w \geq 2\,(m + n)\,\sqrt{2} + x_e$	$\min\{\,2\,(m + n)\,[\,(x_e/m)\,\sqrt{[1 + (x_e/m)^2]}\,]\;;\;\sqrt{2}\,(m + n) + x_e\,\}$
	$x_w < 2\,(m + n)\,\sqrt{2} + x_e$	$\min\{\,2\,(m + n)\,[\,(x_e/m)\,\sqrt{[1 + (x_e/m)^2]}\,]\;;\;\sqrt{2}\,(m + n) + (x_e + x_w)\,/\,2\,\}$
d $x_e \leq 2\,(m + n)\,\sqrt{2}$	$x_w \geq 2\,(m + n)\,\sqrt{2} + x_e + 2\,(m + n)^2 / x_e$	$2\,(m + n)\,\sqrt{2} + x_e + 2\,(m + n)^2 / x_e$
	$x_w < 2\,(m + n)\,\sqrt{2} + x_e + 2\,(m + n)^2 / x_e$	$2\,(m + n)\,\sqrt{2} + (x_e + x_w)\,/\,2 + (m + n)^2 / x_e$

x_w - distance between axis of wheel

EN 1993-6 tab. 6.2

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

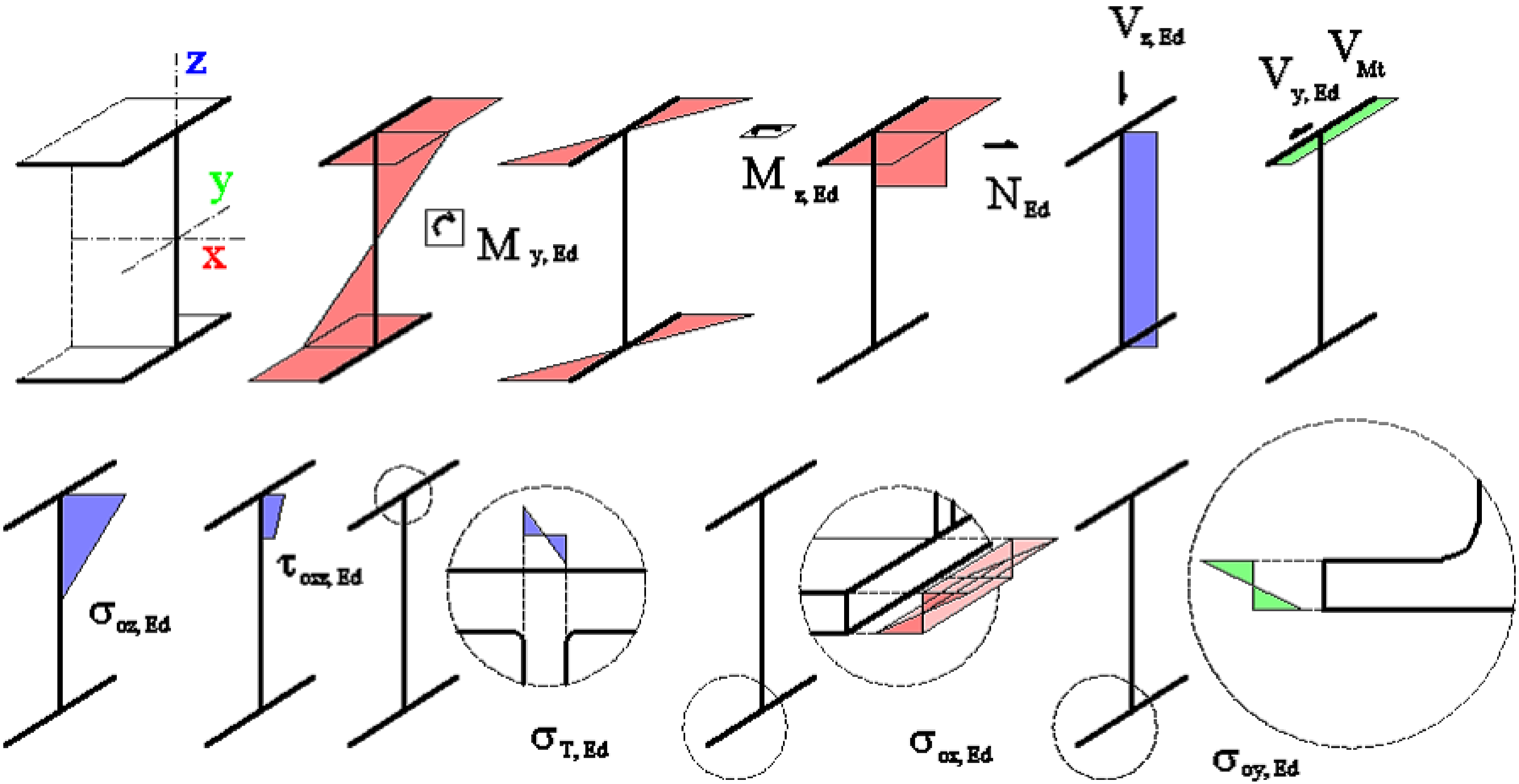


Photo: Author

EN 1993-1-1 6.2.9.2

EN 1993-6 7.5

$$(\Sigma \sigma_x \gamma_{M1} / f_y)^2 + (\Sigma \sigma_z \gamma_{M1} / f_y)^2 - (\Sigma \sigma_x \gamma_{M1} / f_y)(\Sigma \sigma_z \gamma_{M1} / f_y)^2 +$$

$$+ 3 [(\Sigma \tau_y \gamma_{M1} / f_y)^2 + (\tau_z \gamma_{M1} / f_y)^2] \leq 1{,}0$$

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

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

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

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

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

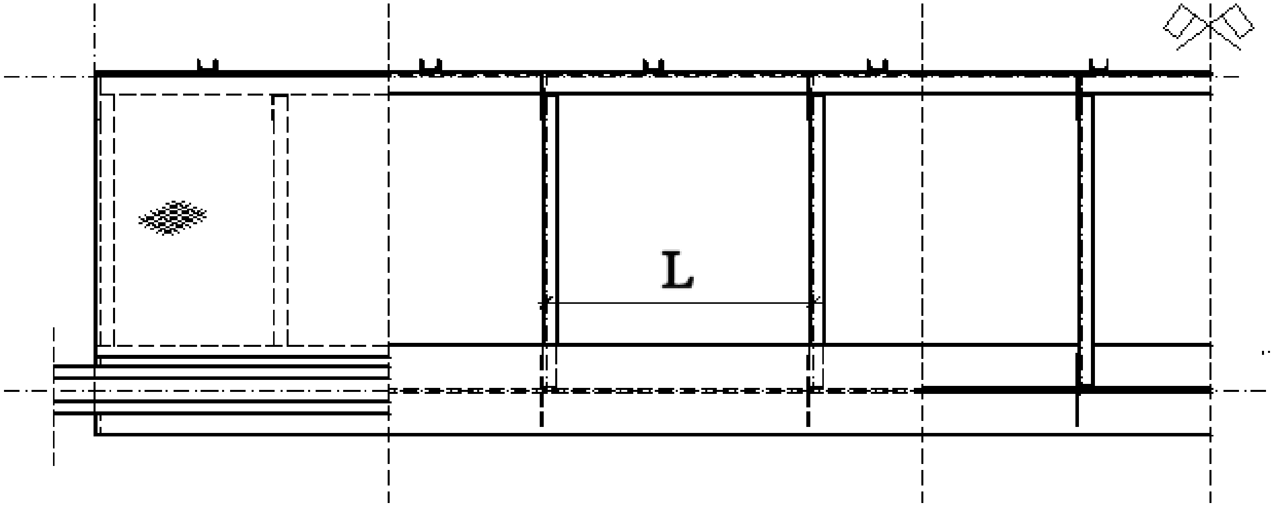
$$\sqrt{} [\sigma_{x, Ed, ser}^2 + 3 (\tau_{y, Ed, ser}^2 + \tau_{z, Ed, ser}^2)] \leq f_y / \gamma_{Mser}$$

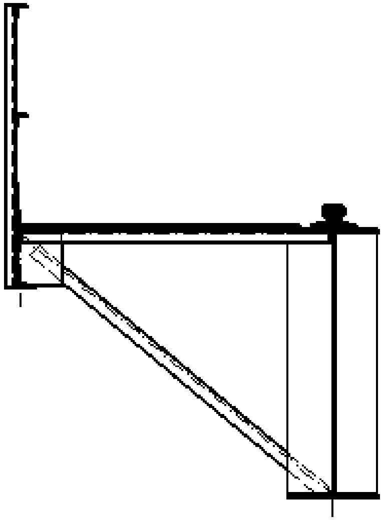
$$\sqrt{} [\sigma_{x, Ed, ser}^2 + \sigma_{y, Ed, ser}^2 - \sigma_{x, Ed, ser} \sigma_{y, Ed, ser} + 3 (\tau_{y, Ed, ser}^2 + \tau_{z, Ed, ser}^2)] \leq f_y / \gamma_{Mser}$$

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

Vibration of the botom flange

Photo: Author





There is no vibration of the botom flange, if:

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

<u>Web breathing</u>

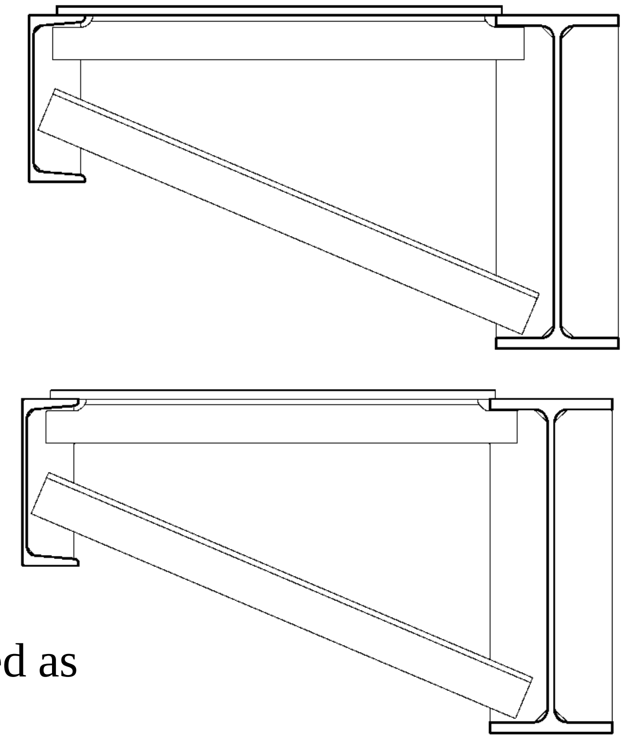
$$\sqrt{\left\{ \left[\boldsymbol{\sigma}_{\mathbf{x,\,Ed,\,ser}} / (k_\sigma\, \sigma_E) \right]^2 + \left[1{,}1\, \boldsymbol{\tau}_{\mathbf{z,\,Ed,\,ser}} / (k_\tau\, \sigma_E) \right]^2 \right\}} \le 1{,}1$$

$$\sigma_E = 190 \text{ GPa} \cdot (b / t_w)^2$$

$$k_\sigma,\ k_\tau \rightarrow \text{EN 1993-1-5} \quad 4.4,\ \ \text{A.3}$$

Local bending of surge girder

Photo: Author



Elements, which support walkways, should be analised as one-span bending beam.

In case of lattice surge girder there is interaction between axial force (hotizontal truss) and bending moment.

Transverse stiffeners

Photo: steelbuildingstructure.com

Photo: Author

Photo: steelbuildingstructure.com

Horizontal and vertical stifeners are calculated according to the same rules as were presented on Ist step of study.

Bumpers

Bumpers - massive elements at the ends of run-beam. They must stop runaway crane in accidental situation. Cantilever, on which act horizontal buffer force H_B and bending moment $h_B \cdot H_B$

$$H_B \rightarrow \#2 / 58$$

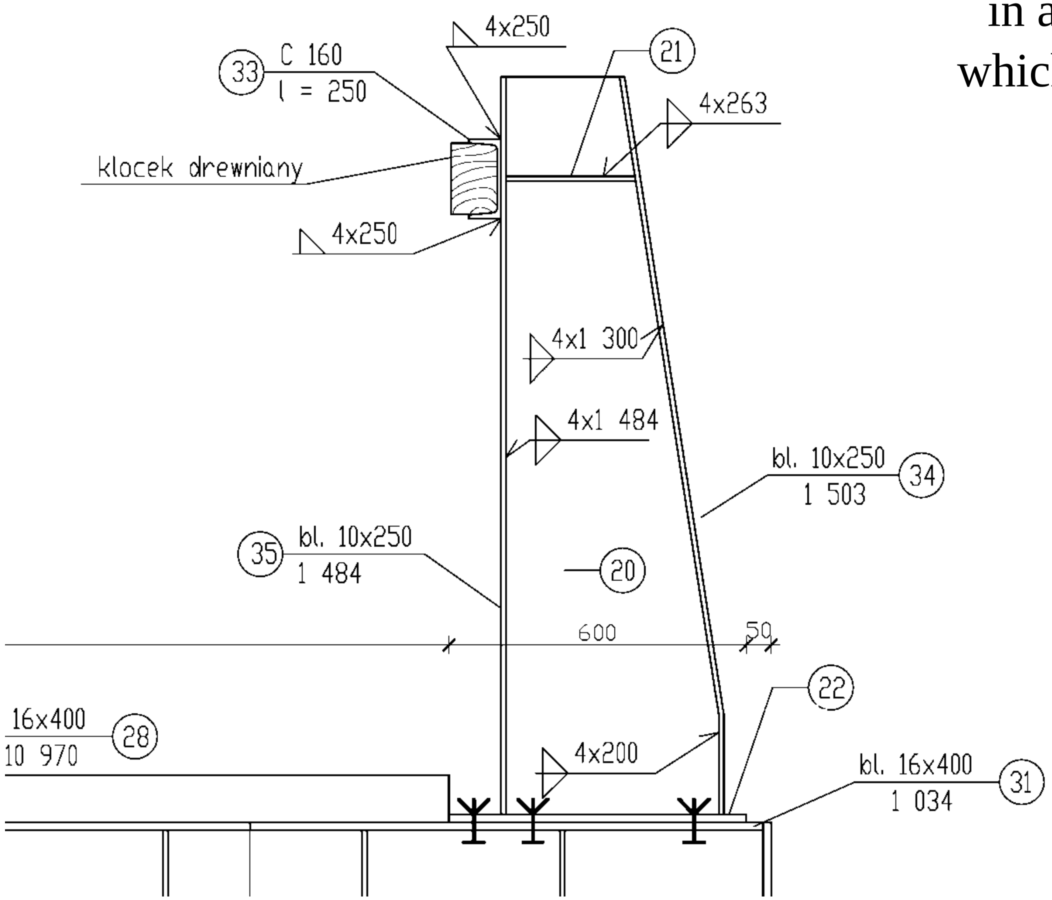


Photo: Author

Photo: mussellcrane.com

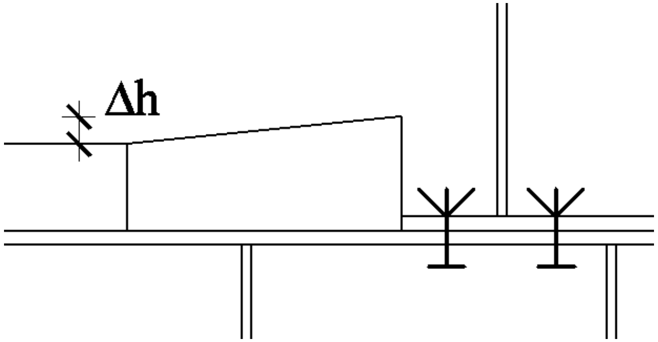


Photo: Author

Sometimes there are special end part of rail - wedge shape. This element transforms kinetic energy of crane to potential energy and reduces velocity

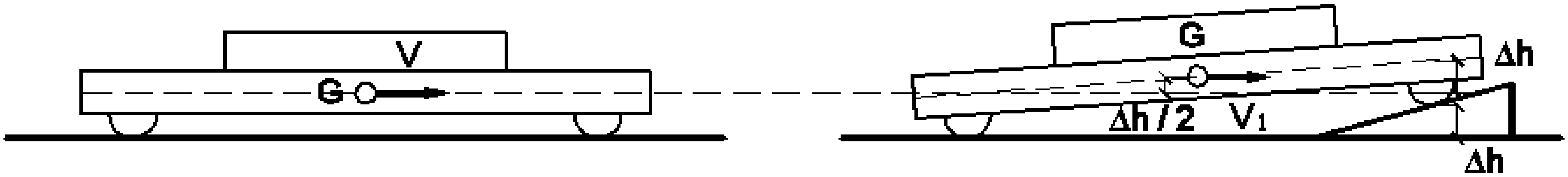


Photo: Author

$$m V^2 / 2 = m V_1^2 / 2 + m g (\Delta h / 2)$$

$$V^2 = V_1^2 + g \Delta h$$

$$V_1 = \sqrt{(V^2 - g \Delta h)}$$

V_1 [m / s] (V_1 / V)		V [m / s]			
		0,50	1,00	1,50	2,00
Δh [mm]	10	0,39 (0,78)	0,95 (0,95)	1,47 (0,98)	1,98 (0,99)
	20	0,23 (0,46)	0,90 (0,90)	1,43 (0,95)	1,95 (0,98)
	30	0,00 (0,00)	0,84 (0,84)	1,40 (0,93)	1,93 (0,97)

Examination issues

Reduced stresses method (RSM), way of calculations

Sub-parts of cross-section for RSM

Instability of run-beam, way of calculations

Types of local effects

Plate surge girder - tężnik poziomy pełnościenny
Lattice surge girder -tężnik poziomy kratowy
Steel frame lattice walkway - krata pomostowa
Local instability, local buckling - niestateczność lokalna
Shear lag in flange - efekt szerokiego pasa
Hogging - strefa przęsłowa
Sagging - strefa podporowa
Plate buckling effect - niestateczność ścianek
Stability - stateczność
Buckling - wyboczenie / utrata stateczności
Flexural buckling - wyboczenie giętne
Flexural-torsional buckling - wyboczenie gietno-skrętne
Torsional buckling - wyboczenie skrętne
Lateral buckling - zwichrzenie
Local buckling - niestateczność lokalna
Shear centre - środek ścinania
Torsion constant - moment bezwładności przy skręcaniu
Warping constant - wycinkowy moment bezwładności
Stiffener - żebro
Foot of the rail - stopka szyny
Taper flange beam - dwuteownik o półce zbieżnej (IPN)
End stop - odbojnica
Non-reinforced simple joint - swobodny koniec, dylatacja

Thank you for attention

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