Univerza
v Ljubljani
Fakulteta
za gradbeništvo
in geodezijo

Katedra za metalne konstrukcije

JEKLENE STAVBE IN MOSTOVI

NOSILCI ŽERJAVNIH PROG

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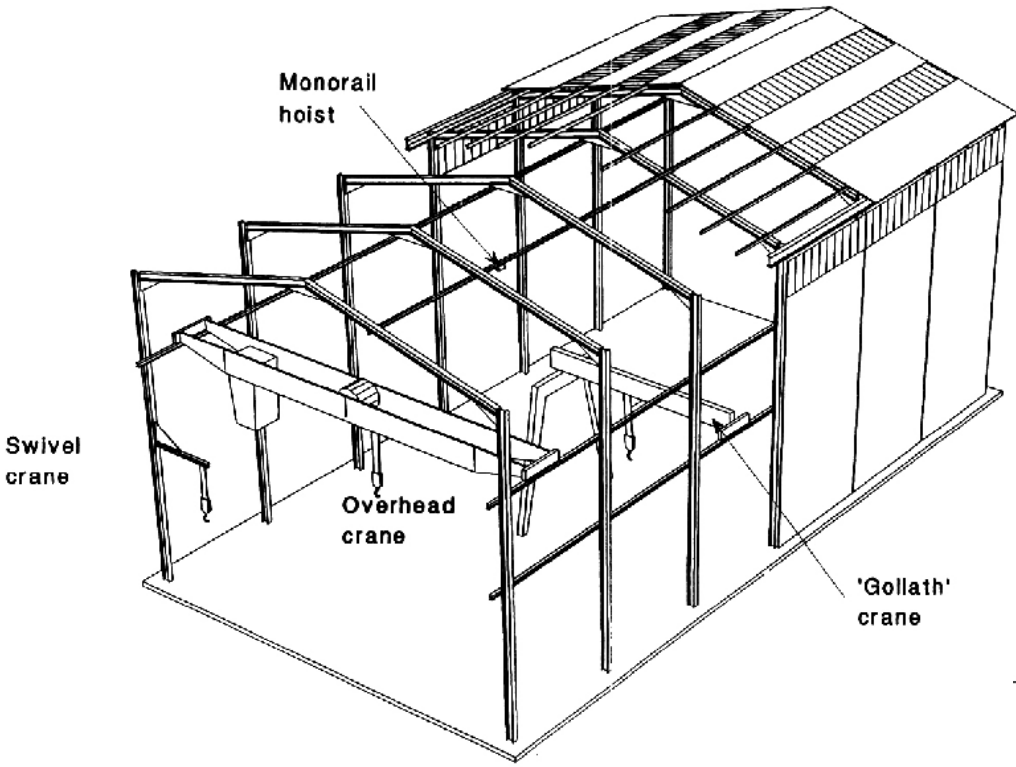
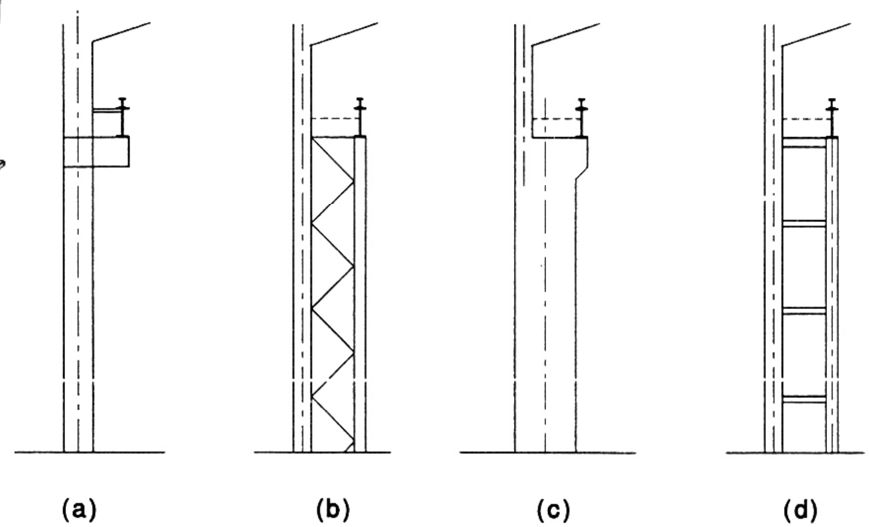
Uvod

Nosilec žerjavne proge je zasnovana kot nosilec, po katerem potuje mostni transportni žerjav.



Primer žerjava v jekleni okvirni konstrukciji



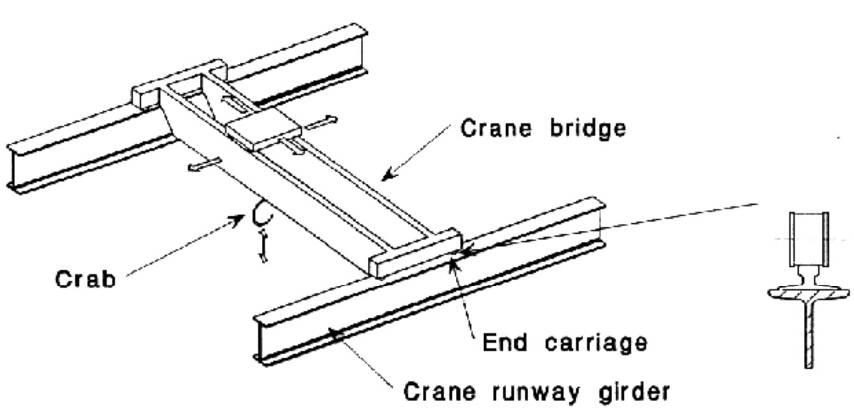
Primeri žerjavnih stebrov

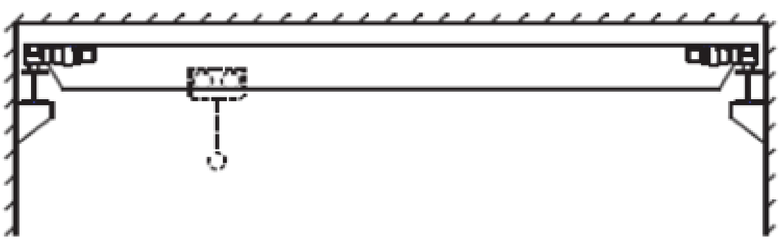
SIST EN 1991-3 (Vplivi)

SIST EN 1993-6 (Projektiranje)

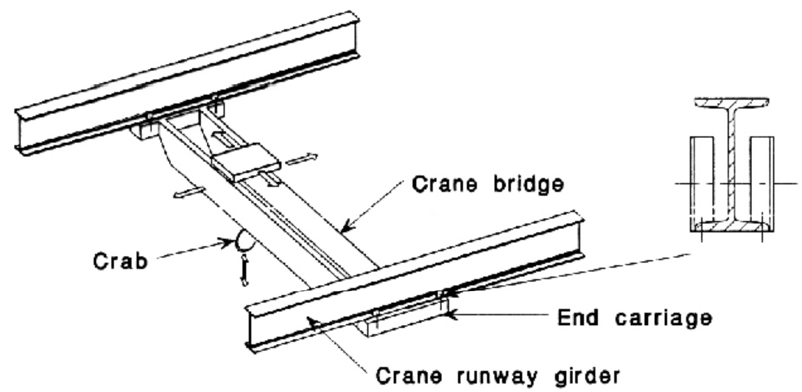
Uvod

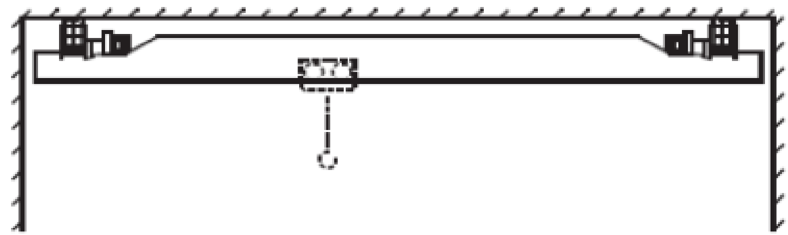
- Dve različni vrsti žerjavov





Žerjavi, ki potujejo po vrhu nosilca žerjavne proge





Žerjavi, ki potujejo po spodnji pasnici nosilca žerjavne proge

Uvod

- Razvrstitev žerjavov v razrede po SIST EN 1991-3

Item	Type of crane	Hoisting class	*S-classes*
1	Hand-operated cranes	HC 1	S0, S1
2	Assembly cranes	HC1, HC2	S0, S1
3	Powerhouse cranes	HC1	S1, S2
4	Storage cranes - with intermittend operation	HC2	S4
5	Storage cranes, spreader bar cranes, scrap yard cranes -with continuous operation	HC3, HC4	S6 ,S7
6	Workshop cranes	HC2, HC3	S3,S4
7	Overhead travelling cranes, ram cranes - with grab or magnet operation	HC3, HC4	S6, S7
8	Casting cranes	HC2, HC3	S6, S7
9	Soaking pit cranes	HC3, HC4	S7, S8
10	Stripper cranes, charging cranes	HC4	S8, S9
11	Forging cranes	HC4	S6, S7
12	Transporter bridges, semi-portal cranes, portal cranes with trolley or slewing crane - with hook operation	HC2	S4, S5
13	Transporter bridges, semi-portal cranes, portal cranes with trolley or slewing crane – with grab or magnet operation	HC3, HC4	S6, S7
14	Travelling belt bridge with fixed or sliding belt(s)	HC1	S3, S4

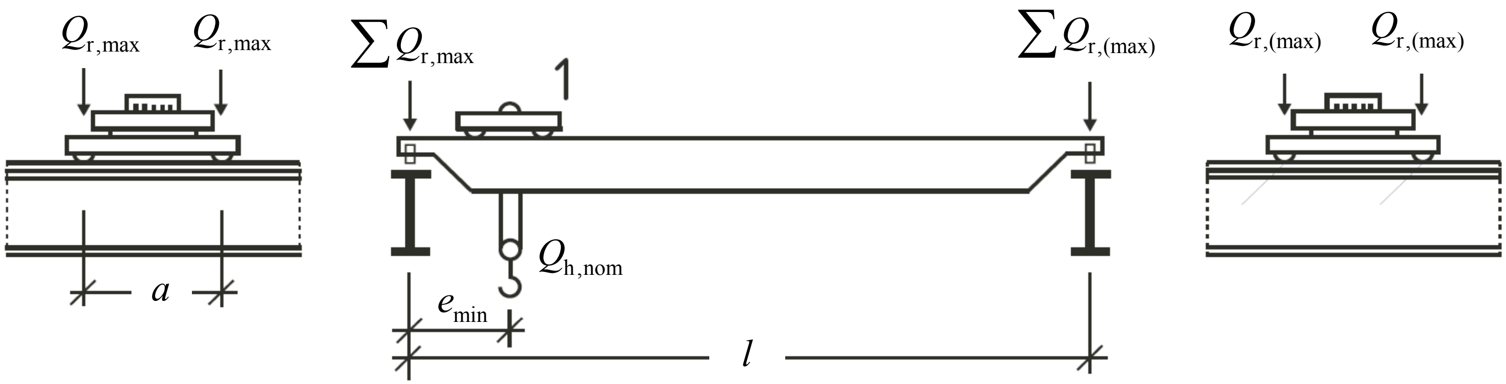
Uvod

…nadaljevanje tabele "Razvrstitev žerjavov v razrede po SIST EN 1991-3"

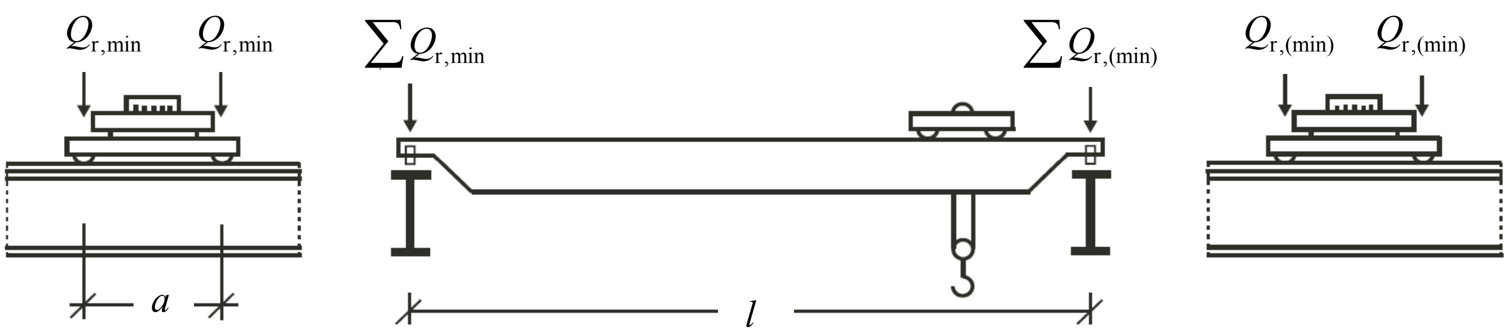
15	Dockyard cranes, slipway cranes, fitting-out cranes - with hook operation	HC2	S3, S4
16	Wharf cranes, slewing, floating cranes, level luffing slewing - with hook operation	HC2	S4, S5
17	Wharf cranes, slewing, floating cranes, level luffing slewing - with grab or magnet operation	HC3, HC4	S6, S7
18	Heavy duty floating cranes, gantry cranes	HC1	S1, S2
19	Shipboard cargo cranes - with hook operation	HC2	S3, S4
20	Shipboard cargo cranes - with grab or magnet operation	HC3, HC4	S4, S5
21	Tower slewing cranes for the construction industry	HC1	S2, S3
22	Erection cranes, derrick cranes - with hook operation	HC1, HC2	S1, S2
23	Rail mounted slewing cranes - with hook operation	HC2	S3, S4
24	Rail mounted slewing cranes - with grab or magnet operation	HC3, HC4	S4, S5
25	Railway cranes authorised on trains	HC2	S4
26	Truck cranes, mobile cranes - with hook operation	HC2	S3, S4
27	Truck cranes, mobile cranes - with grab or magnet operation	HC3, HC4	S4, S5
28	Heavy duty truck cranes, heavy duty mobile cranes	HC1	S1, S2

Obtežbe

❑Vertikalna obtežba koles žerjava



Postavitev obtežbe za določitev maksimalnih vertikalnih vplivov



Postavitev obtežbe za določitev minimalnih vertikalnih vplivov

Obtežbe

- Obtežne kombinacije

		Symbol	Section	Groups of loads									
				Ultimate Limit State							Test load	Acci-dental	
				1	2	3	4	5	6	7	8	9	10
1	Self-weight of crane	Q_c	2.6	φ_1	φ_1	1	φ_4	φ_4	φ_4	1	φ_1	1	1
2	Hoist load	Q_h	2.6	φ_2	φ_3	-	φ_4	φ_4	φ_4	$\eta^{1)}$	-	1	1
3	Acceleration of crane bridge	H_L, H_T	2.7	φ_5	φ_5	φ_5	φ_5	-	-	-	φ_5	-	-
4	Skewing of crane bridge	H_S	2.7	-	-	-	-	1	-	-	-	-	-
5	Acceleration or braking of crab or hoist block	H_{T3}	2.7	-	-	-	-	-	1	-	-	-	-
6	In-service wind	F_W^*	Annex A	1	1	1	1	1	-	-	1	-	-
7	Test load	Q_T	2.10	-	-	-	-	-	-	-	φ_6	-	-
8	Buffer force	H_B	2.11	-	-	-	-	-	-	-	-	φ_7	-
9	Tilting force	H_{TA}	2.11	-	-	-	-	-	-	-	-	-	1

NOTE: For out of service wind, see Annex A.

[1] η is the proportion of the hoist load that remains when the payload is removed, but is not included in the self-weight of the crane.

Dinamični faktorji

Z dinamičnimi faktorji zajamemo dinamične vplive žerjava, ki jih povzroča na nosilec žerjavne proge s svojim premikanjem po tirnici.

Dinamični faktorji	**Vpliv, ki ga zajema**	**Kje se upošteva**
φ_1	Vpliv vibracij žerjava med dvigovanjem bremena s tal	Lastna teža žerjava
φ_2 ali φ_3	Dinamični učinki, ki se pojavijo zaradi prenosa bremena od tal do žerjava Dinamični učinki, ki so posledica nenadnega spusta bremena	Teža bremena
φ_4	Dinamični učinki , ki so posledica premikanja žerjava po tirnicah	Lastna teža žerjava in teža bremena
φ_5	Dinamičen učinek zaradi sil ki se pojavijo med vožnjo žerjava po žerjavni progi	Vozne sile
φ_6	Dinamičen učinek testne obremenitve med vožnjo žerjava	Testna obremenitev
φ_7	Dinamičen učinek zaradi trka v odbojnik	Obtežba odbojnika

Dinamični faktorji

Vrednosti faktorjev φ_i

	Values of dynamic factors
φ_1	$0{,}9 < \varphi_1 < 1{,}1$ The two values 1,1 and 0,9 reflect the upper and lower values of the vibrational pulses.
φ_2	$\varphi_2 = \varphi_{2,\min} + \beta_2 v_h$ v_h - steady hoisting speed in m/s $\varphi_{2,\min}$ and β_2 see Table 2.5
φ_3	$\varphi_3 = 1 - \frac{\Delta m}{m}(1 + \beta_3)$ where Δm released or dropped part of the hoisting mass m total hoisting mass $\beta_3 = 0{,}5$ for cranes equipped with grabs or similar slow-release devices β_3 = 1,0 For cranes equipped with magnets or similar rapid-release devices
φ_4	φ_4 = 1,0 provided that the tolerances for rail tracks as specified in EN 1993-6 are observed.
NOTE: If the tolerances for rail tracks as specified in EN 1993-6 are not observed, the dynamic factor φ_4 can be determined with the model provided by EN 13001-2.	

Dinamični faktorji

Vrednosti faktorjev φ_i

Values of the dynamic factor φ_5	**Specific use**
$\varphi_5 = 1,0$	for centrifugal forces
$1,0 \le \varphi_5 \le 1,5$	for systems where forces change smoothly
$1,5 \le \varphi_5 \le 2,0$	for cases where sudden changes can occur
$\varphi_5 = 3,0$	for drives with considerable backlash

Values of the dynamic factor φ_6	**Specific use**
$\varphi_6 = 0.5(1.0 + \varphi_2)$	Dynamic test load
$\varphi_6 = 1.0$	Static test load

Values of dynamic factor φ_7	**Buffer characteristic**
$\varphi_7 = 1,25$	$0,0 \le \xi_b \le 0,5$
$\varphi_7 = 1,25 + 0,7\,(\xi_b - 0,5)$	$0,5 \le \xi_b \le 1$
NOTE: ξ_b may be approximately determined from Figure 2.9	

Obtežbe

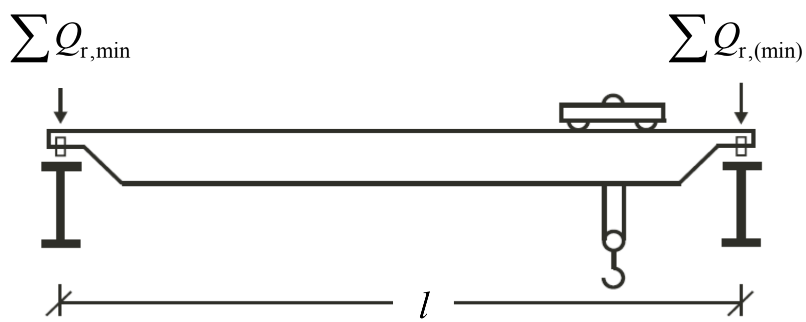
- Lastna teža žerjava (Q_C)

$$\sum Q_{r,(min)} = Q_T \cdot \frac{(l - e_{min})}{l} + 0.5 \cdot Q_C$$

$$\sum Q_{r,min} = Q_T + Q_C - \sum Q_{r,(min)}$$

Q_C …lastna teža mostu žerjava

Q_T …lastna teža vozička

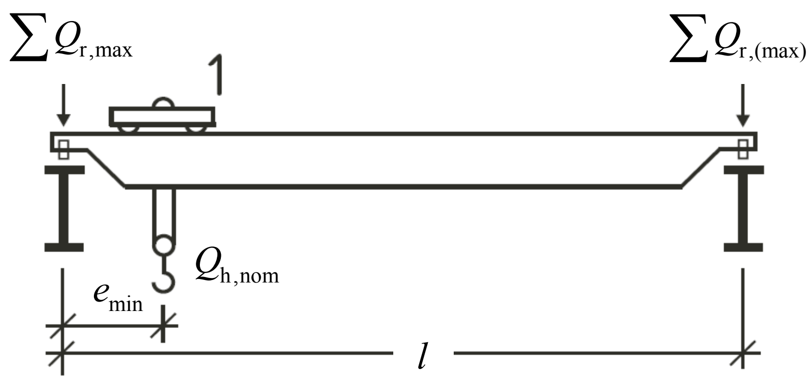


- Teža tovora (Q_H)

$$\sum Q_{r,max} = Q_H \cdot \frac{(l - e_{min})}{l}$$

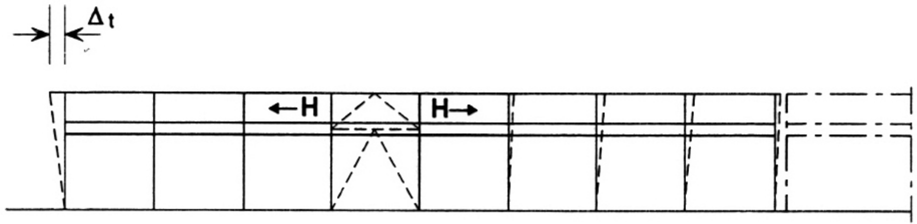
$$\sum Q_{r,(max)} = Q_H - \sum Q_{r,max}$$

Q_H …nosilnost žerjava



Obtežbe

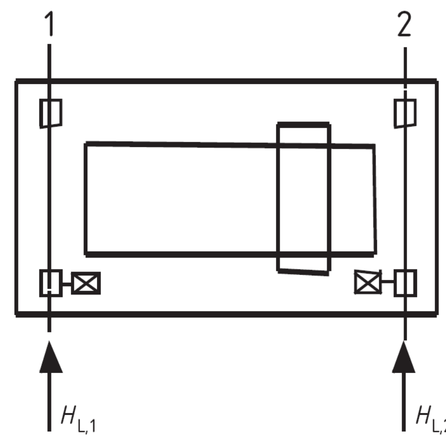
❑Horizontalna obtežba koles žerjava



•Pospeševanje in zaviranje mostu žerjava (H_L, H_T)

- Vzdolžne sile (posledice trenja med kolesom in tirnico)

$$H_{L,i} = \varphi_5 \, K \frac{1}{n_r}$$



n_r …število nosilcev, ki podpirajo žerjav

φ_5 …dinamični faktor

i … zaporedna številka nosilca (i = 1,2)

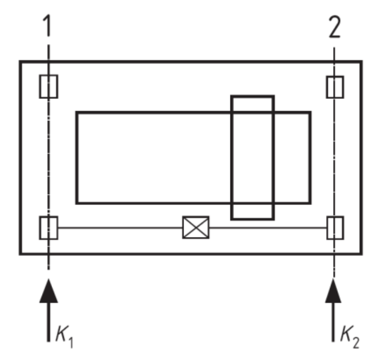
K … vozna sila

VOZNA SILA

$$K = K_1 + K_2 = \mu \sum Q^*_{r,\,min}$$

μ … koeficient trenja (μ = 0.2 za jeklo-jeklo, μ = 0.5 za jeklo-guma)

$$\sum Q^*_{r,\,min} = Q_{r,\,min} + Q_{r,\,(min)}$$ … centralni pogon



Obtežbe

- Prečni sili (posledica ekscentričnosti lege tovora)

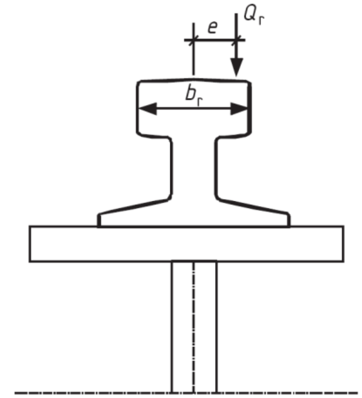
$$M = K \cdot l_S$$

$$M_1 = \xi_2 M$$

$$M_2 = \xi_1 M$$

$$H_{T,1} = \varphi_5 \, \xi_2 \, \frac{M}{a}$$

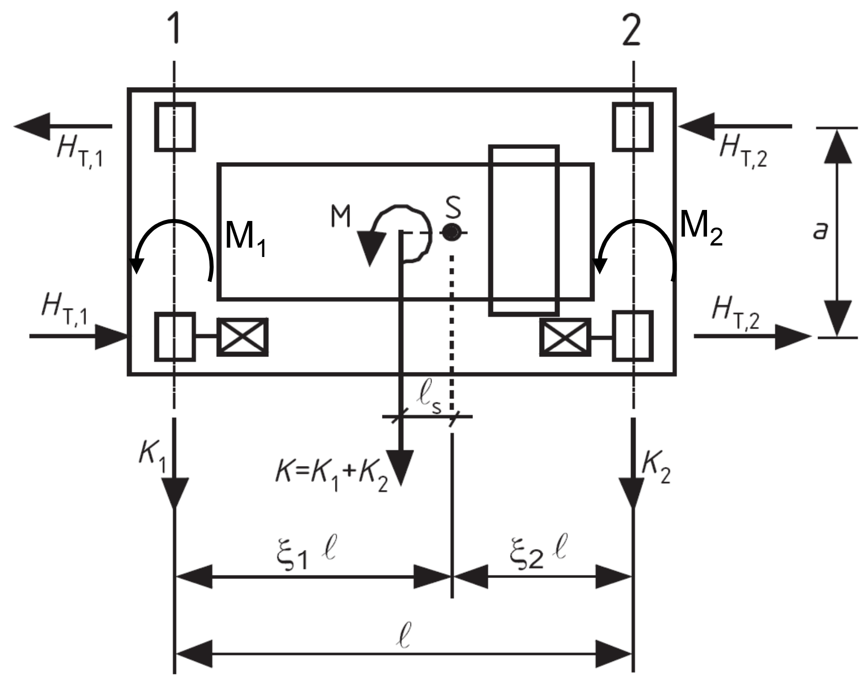
$$H_{T,2} = \varphi_5 \, \xi_1 \, \frac{M}{a}$$



kjer sta

$$\xi_1 = \frac{\sum Q_{r,max}}{\sum Q_{r,max} + \sum Q_{r,(max)}}$$

$$\xi_2 = 1 - \xi_1$$

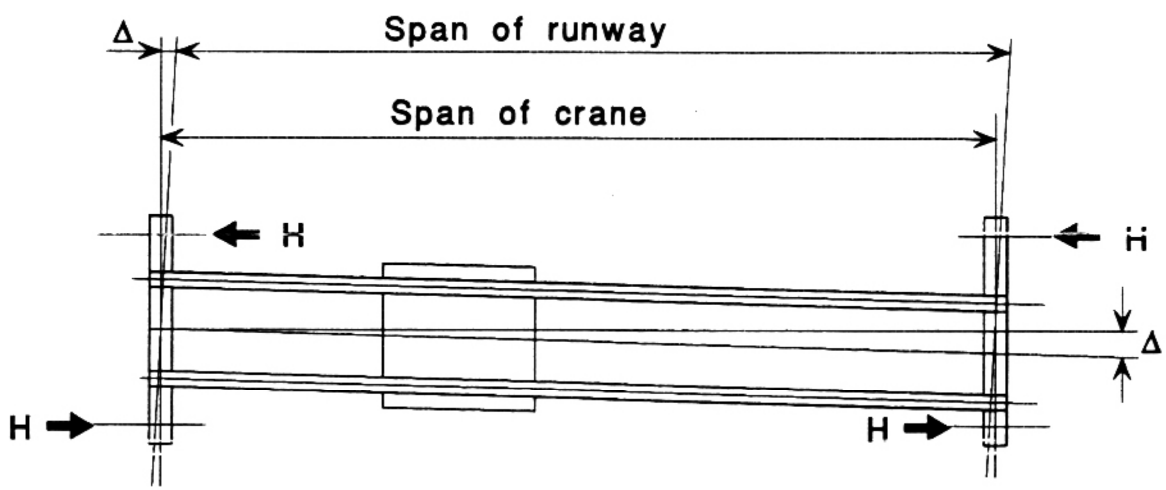


Obtežbe

•Sile zaradi odklona med vodili in tirnico (H_S)

Kadar je mostni žerjav nesimetrično obremenjen in se premika vzdolž proge, se v njegovem težišču pojavi moment, ki ga nosilec žerjavne proge prevzame z dvojico sil.

Velikost teh sil je odvisna od velikosti špranje med vodilom in tirnico, obrabe tirnice, tolerance pri izdelavi ter razdalje *a* med kolesi.



Obtežbe

- Pospeševanje in ustavljanje vozička ($H_{T,3}$)

Predpostavimo, da sila pospeševanja oziroma zaviranja vozička, ki vozi po mostu žerjava ne presega 10% mase vozička in bremena.

$$H_{\mathrm{T},3} = 0.1\left(Q_{\mathrm{T}} + Q_{H}\right)$$

Obtežbe

- Obtežba vetra
- Testna obtežba
  - Dinamična testna obremenitev

    Dinamična testna obremenitev poteka tako, da se testno obtežbo vozi po poti, katero bo žerjav opravljal v svoji življenjski dobi. Testna obtežba znaša vsaj 110% nominalne teže bremena $Q_{h,nom}$.

  - Statična testna obremenitev

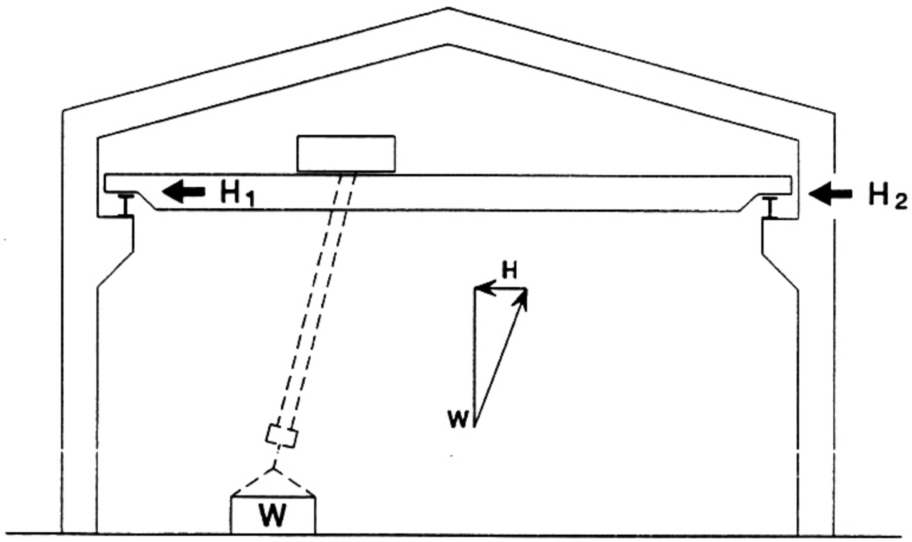
    Statična testna obremenitev poteka tako, da se na žerjav v mirovanju postopoma dodaja testno obtežbo. Testna obtežba mora na koncu znašati vsaj 125% nominalne teže bremena $Q_{h,nom}$.

- Obtežba odbojnika (nezgodna obtežba)

  Obtežba, ki nastane v primeru, ko se žerjav zaleti v odbojnik na koncu nosilca žerjavne proge.

Obtežbe

- Obtežba zaradi nihanja bremena (nezgodna obtežba)



Obtežni faktorji

- Priporočene vrednosti delnih varnostnih faktorjev γ za stalno, začasno in nezgodno stanje

Action	Symbol	Situation	
		P/T	A
Permanent crane actions			
- unfavourable	$\gamma_{G\,sup}$	1,35	1,00
- favourable	$\gamma_{G\,inf}$	1,00	1,00
Variable crane actions			
- unfavourable	$\gamma_{Q\,sup}$	1,35	1,00
- favourable	$\gamma_{Q\,inf}$		
crane present		1,00	1,00
crane not present		0,00	0,00
Other variable actions	γ_{Q}		
- unfavourable		1,50	1,00
- favourable		0,00	0,00
Accidental actions	γ_{A}		1,00

P - Persistent situation T - Transient situation A - Accidental situation

Obtežni faktorji

- ψ – faktorji za obtežbo žerjava
  - Priporočene vrednosti

$$\psi_0 = 1.0$$

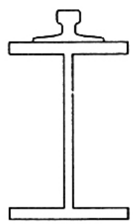
$$\psi_1 = 0.9$$

$$\psi_2 = \frac{Q_{r,min}}{Q_{r,min} + Q_{r,max}}$$

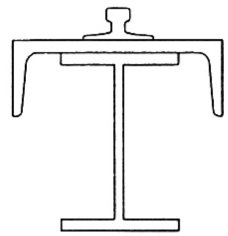
…razmerje med stalnim in skupnim vplivom žerjava.

Prečni prerezi

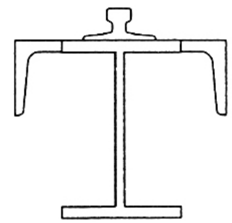
❑Tipični primeri prečnih prerezov



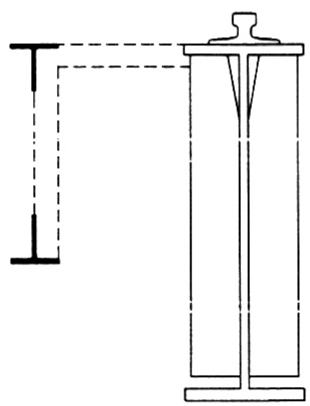
(a) Valjani nosilec



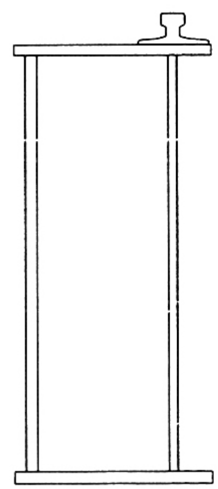
(b) Sestavljen nosilec



(c) Sestavljen nosilec



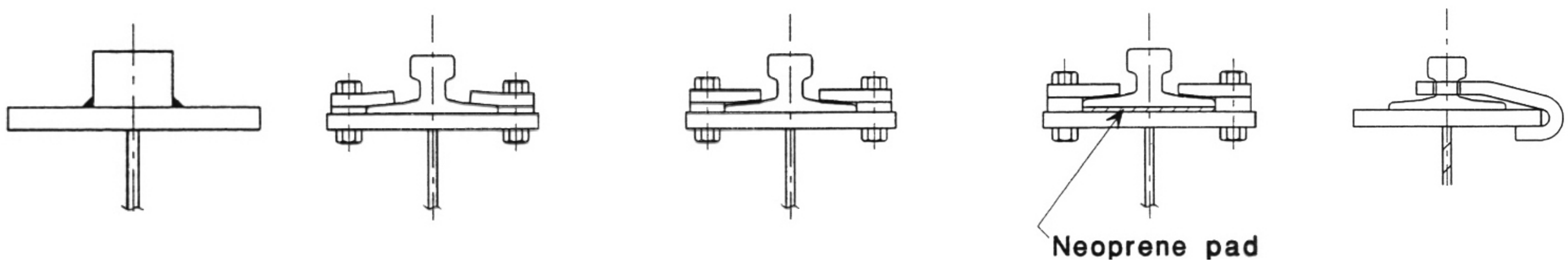
(d) Ojačani nosilec



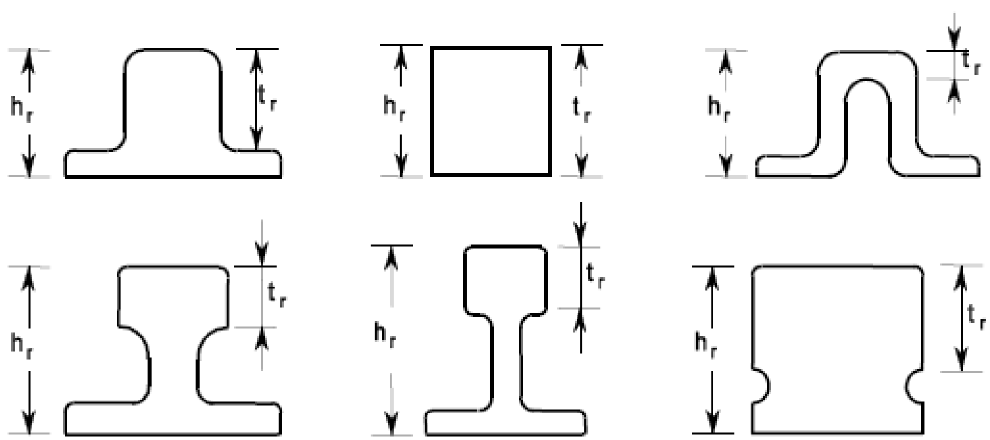
(e) Škatlasti nosilec

Tirnice

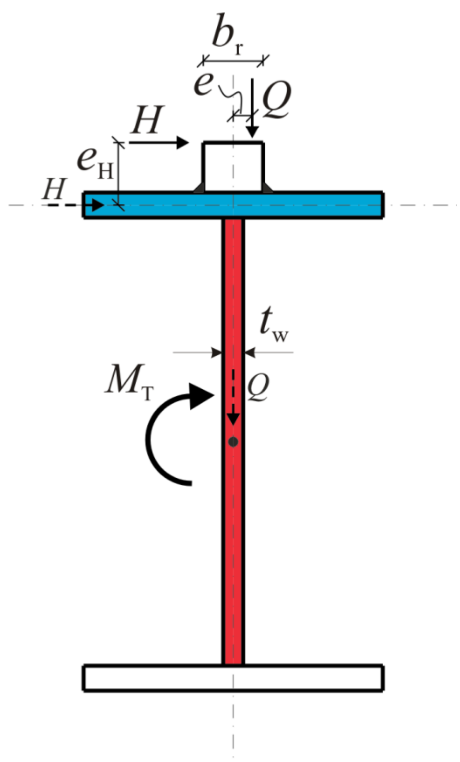
- ❑Ločimo med varjenimi (fiksno pritrjene) in elastično pritrjenimi tirnicami



- ❑Varjene lahko upoštevamo tudi v računu pri nosilnosti nosilca žerjavne proge, pri čemer pa moramo t_r zmanjšati za 25% zaradi obrabe tirnice

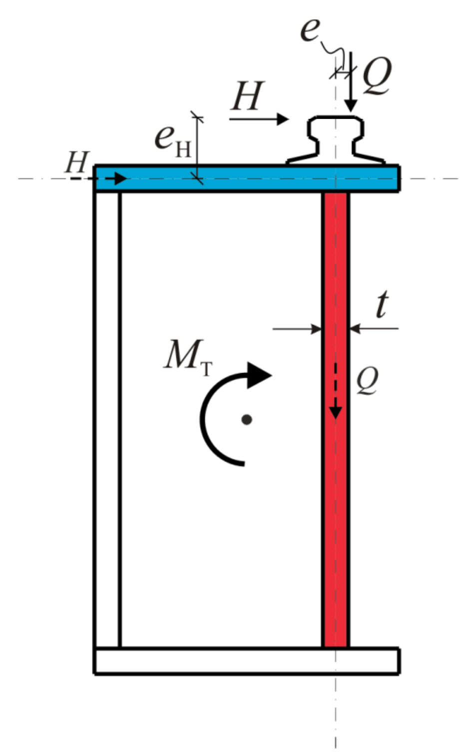


Račun napetosti (globalno)



$$e = 0.25\, b_r$$

$$M_T = H \cdot e_H + Q \cdot e$$



Notranje statične količine, ki jih dobimo v nosilcu zaradi žerjava:

$$M_y, M_z(zg.pas), N(pospeševanje, zaviranje), M_T, Q_H, Q_Q$$

Račun napetosti (lokalno)

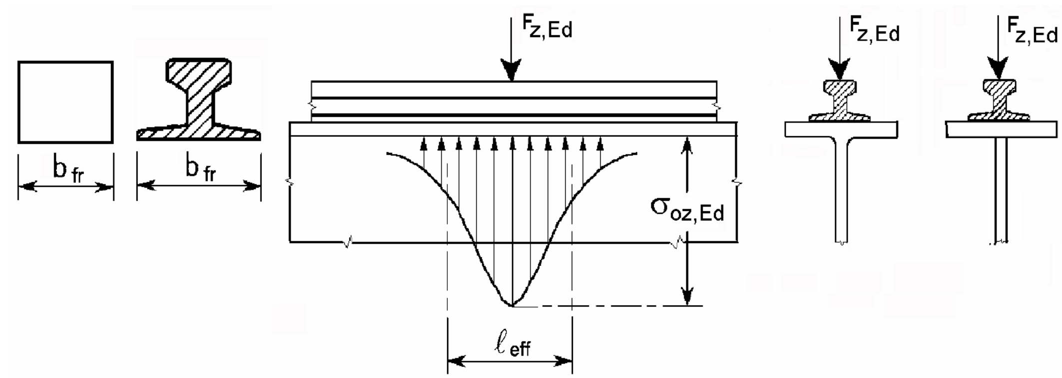
❑Normalne napetosti

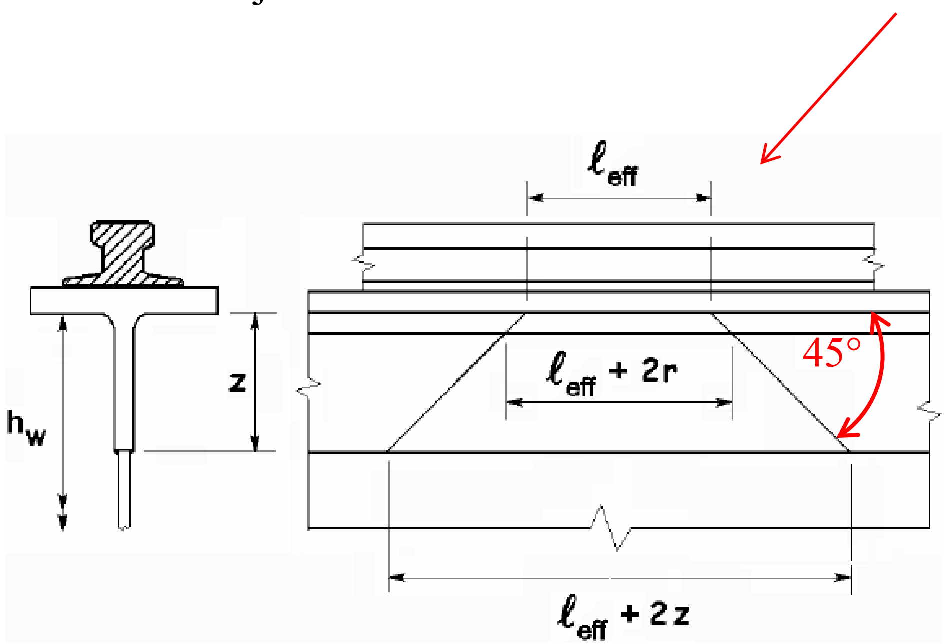
$$\sigma_{\text{lok}} = \sigma_{0z,\text{Ed}} = \frac{F_{z,\text{Ed}}}{l_{\text{eff}}\, t_{\text{w}}}$$

$F_{z,\text{Ed}}$ … obtežba koles

l_{eff} … efektivna širina

t_{w} … debelina stojine





Račun napetosti (lokalno)

-račun efektivnih širin l_{eff}

Case	Description	Effective loaded length ℓ_{eff}
(a)	Crane rail rigidly fixed to the flange	$\ell_{eff} = 3{,}25\,[I_{rf} / t_w]^{1/3}$
(b)	Crane rail not rigidly fixed to flange	$\ell_{eff} = 3{,}25\,[(I_r + I_{f,eff}) / t_w]^{1/3}$
(c)	Crane rail mounted on a suitable resilient elastomeric bearing pad at least 6mm thick.	$\ell_{eff} = 4{,}25\,[(I_r + I_{f,eff}) / t_w]^{1/3}$

$I_{f,eff}$ is the second moment of area, about its horizontal centroidal axis, of a flange with an effective width of b_{eff}

I_r is the second moment of area, about its horizontal centroidal axis, of the rail

I_{rf} is the second moment of area, about its horizontal centroidal axis, of the combined cross-section comprising the rail and a flange with an effective width of b_{eff}

t_w is the web thickness.

$b_{eff} = b_{fr} + h_r + t_f$ but $b_{eff} \leq b$

where: b is the overall width of the top flange;

b_{fr} is the width of the foot of the rail, see figure 5.2;

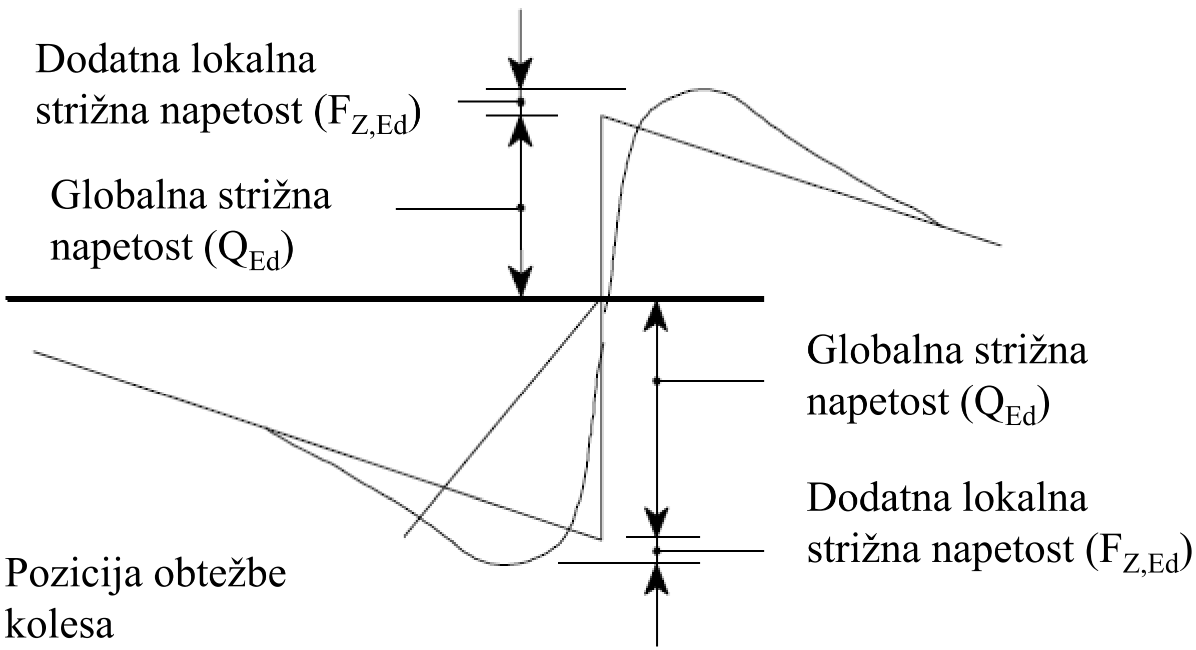
h_r is the height of the rail, see figure 5.1;

t_f is the flange thickness.

Račun napetosti (lokalno)

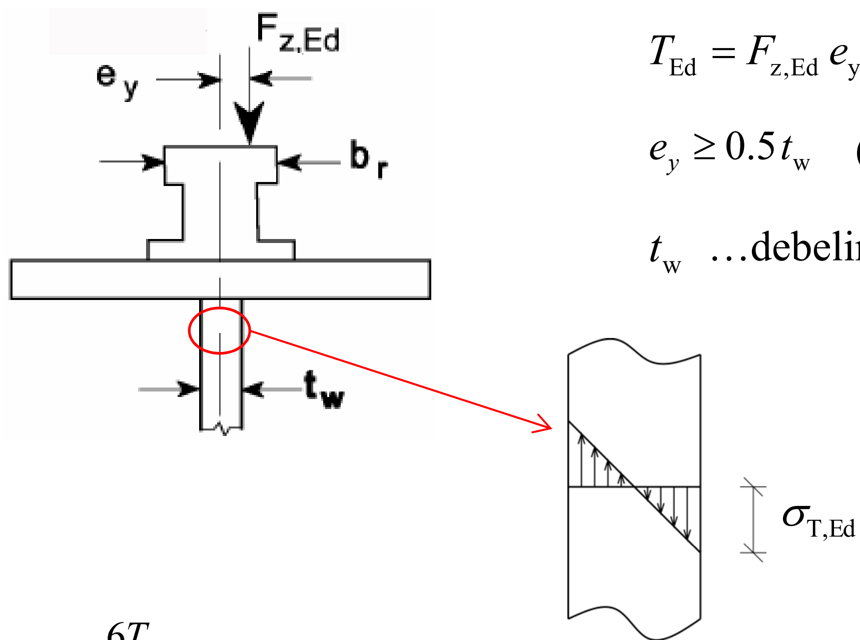
- Strižne napetosti

$$\tau_{\text{lok}} = \tau_{\text{0xz,Ed}} \approx 0.2\,\sigma_{\text{0z,Ed}}$$



Račun napetosti (lokalno)

❑Upogibne napetosti



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

$e_y \geq 0.5\, t_w$ (priporočena vrednost $e_y = 0.25\, b_r$)

t_w …debelina stojine

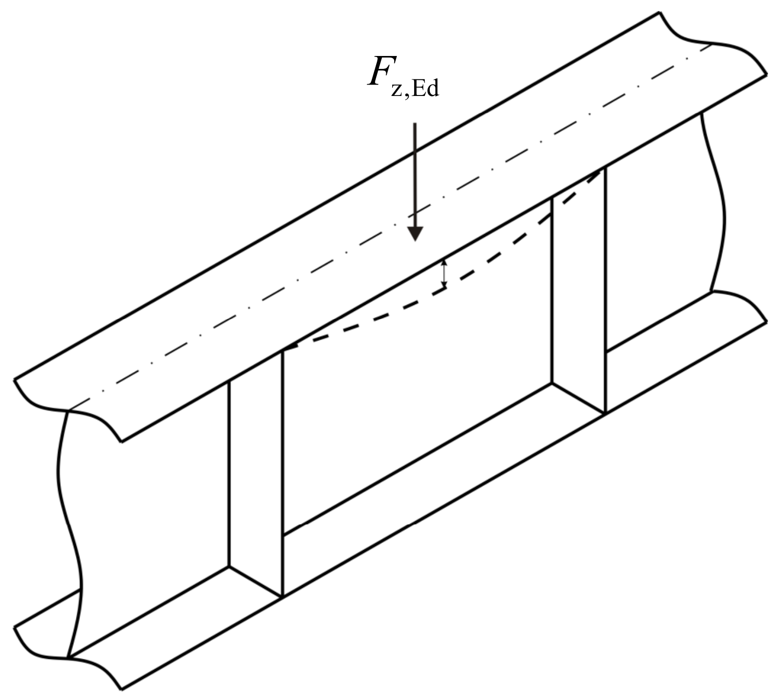
$$\sigma_{T,Ed} = \frac{6T_{Ed}}{a\, t_w^{\,2}} \eta \tan h(\eta),$$

$$\eta = \left[\frac{0.75\, a\, t_w^{\,3}}{I_t} \times \frac{\sin h^2(\pi h_w / a)}{\sin h(2\pi h_w / a) - 2\pi h_w / a} \right]^{0.5}$$

a…razdalja med prečnimi ojačitvami

h_w…višina stojine

I_t…torzijski vztrajnostni moment pasnice



Račun napetosti (palični nosilci)

- Sekundarni momenti v paličnih nosilcih (utrujanje)

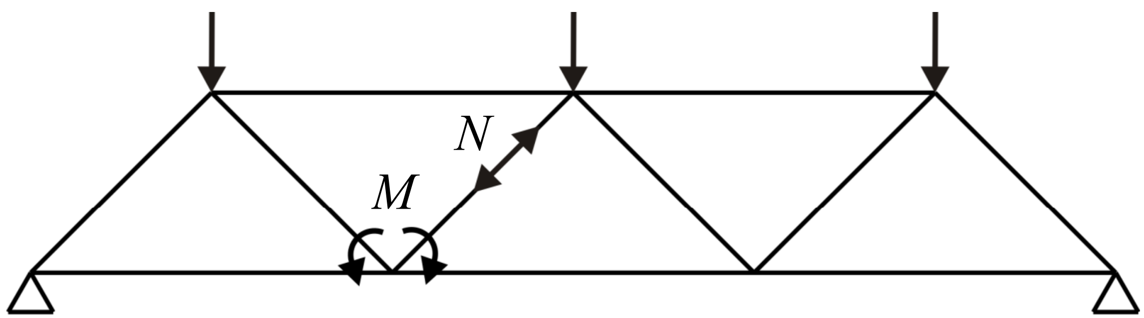
  -votli profili

k_1 faktorji za okrogle votle profile:

Type of joint		Chords	Verticals	Diagonals
Gap joints	K type	1,5	1,0	1,3
	N type / KT type	1,5	1,8	1,4
Overlap joints	K type	1,5	1,0	1,2
	N type / KT type	1,5	1,65	1,25

k_1 faktorji za pravokotne votle profile:

Type of joint		Chords	Verticals	Diagonals
Gap joints	K type	1,5	1,0	1,5
	N type / KT type	1,5	2,2	1,6
Overlap joints	K type	1,5	1,0	1,3
	N type / KT type	1,5	2,0	1,4



$$\sigma = \sigma_N + \sigma_M = k \cdot \sigma_N$$

Račun napetosti (palični nosilci)

-odprti profili

(a) Lattice girders loaded only at nodes			
Range of L/y values	$L/y \leq 20$	$20 < L/y < 50$	$L/y \geq 50$
Chord members End and internal members	1,57	$\frac{1,1}{0,5 + 0,01 L/y}$	1,1
Secondary members, see Note	1,35	1,35	1,35

(b) Lattice girders with chord members loaded between nodes		
Range of L/y values	$L/y < 15$	$L/y \geq 15$
Loaded chord members	$\frac{0,4}{0,25 + 0,01 L/y}$	1,0
Unloaded chord members Secondary members, see Note	1,35	1,35
End members	2,50	2,50
Internal members	1,65	1,65

Key:

L is the length of the member between nodes;

y is the perpendicular distance, in the plane of triangulation, from the centroidal axis of the member to its relevant edge, measured, as follows:

- compression chord: in the direction from which the loads are applied;
- tension chord: in the direction in which the loads are applied;
- other members: the larger distance.

NOTE: Secondary members comprise members provided to reduce the buckling lengths of other members or to transmit applied loads to nodes. In an analysis assuming hinged joints, the forces in secondary members are not affected by loads applied at other nodes, but in practice they are affected due to joint rigidity and the continuity of chord members at joints.

Račun napetosti (polnostenski nosilci)

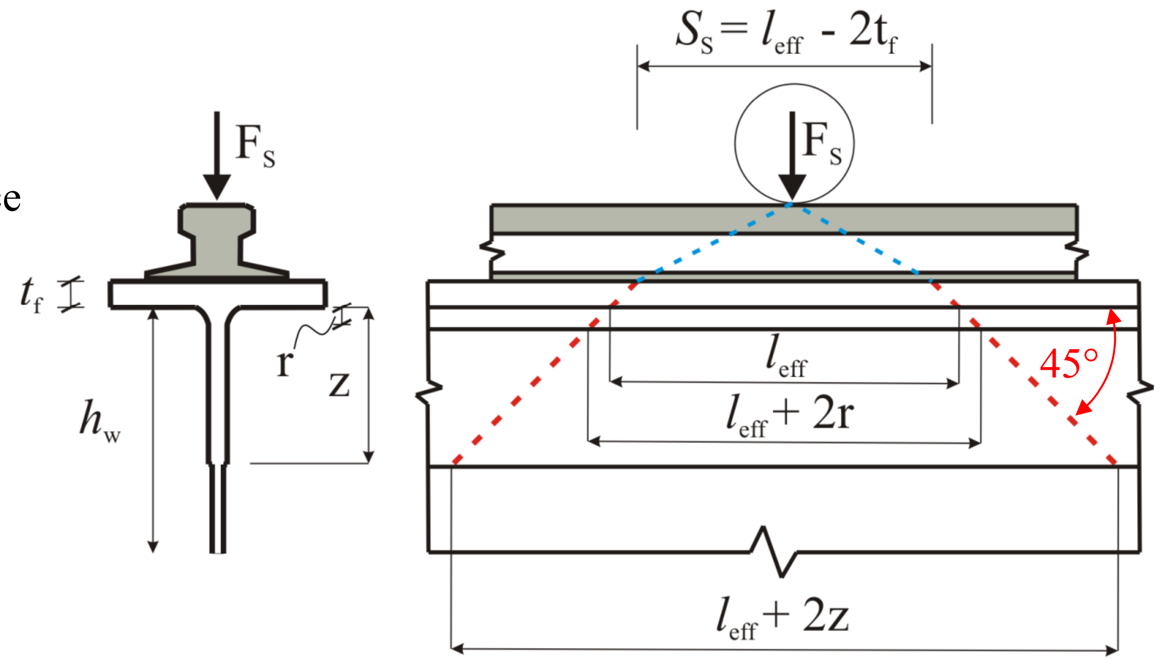
❑Polnostenski profili – 4. razred kompaktnosti

Račun napetosti poteka po postopku kot ga priporoča SIST EN 1993-1-5, pri čemer za širino naleganja koncentrirane obtežbe S_S upoštevamo:

$$S_S = l_{eff} - 2t_f$$

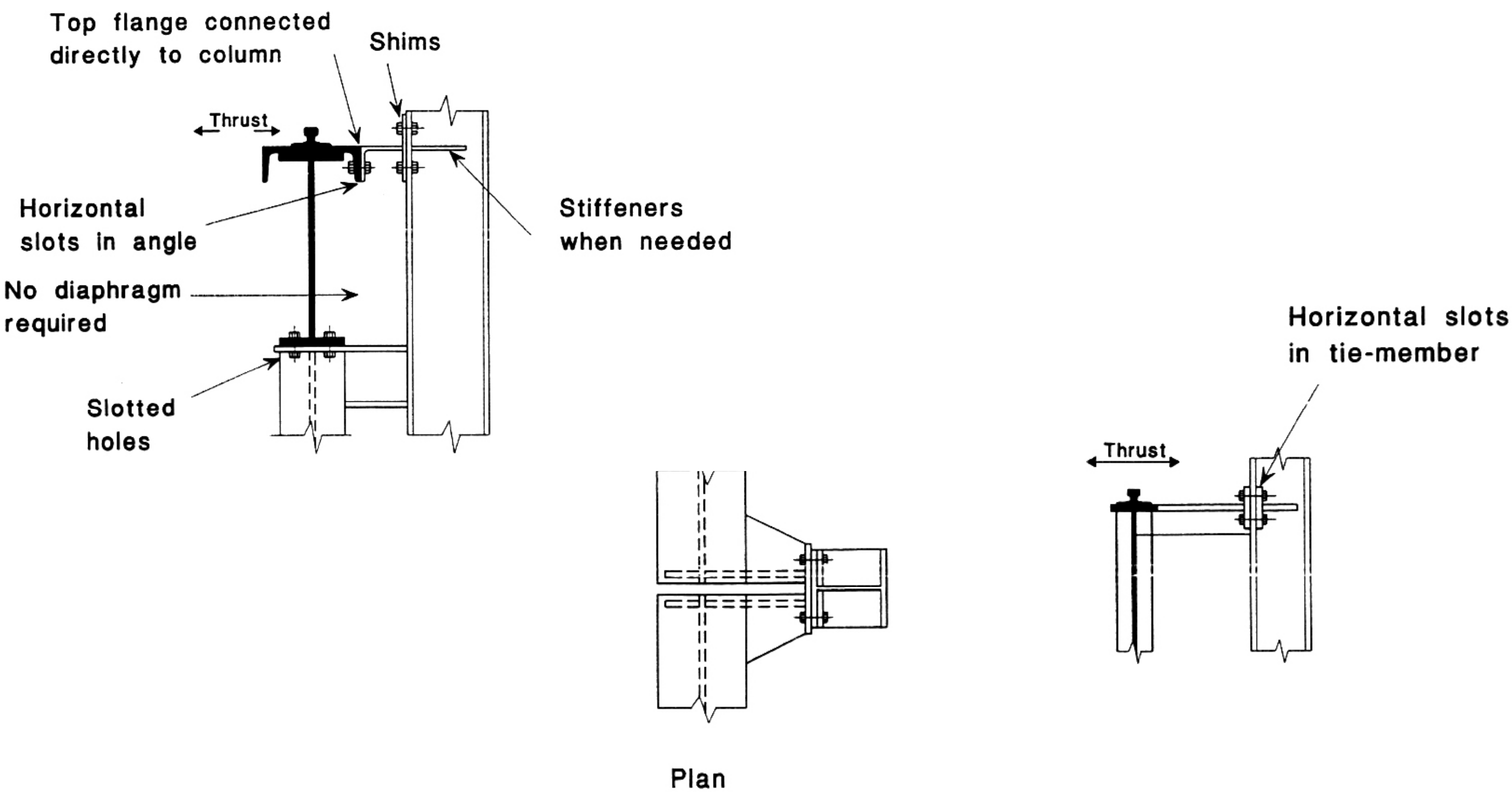
l_{eff} …efektivna širina

t_f …debelina zgornje pasnice



Konstrukcijski detajli

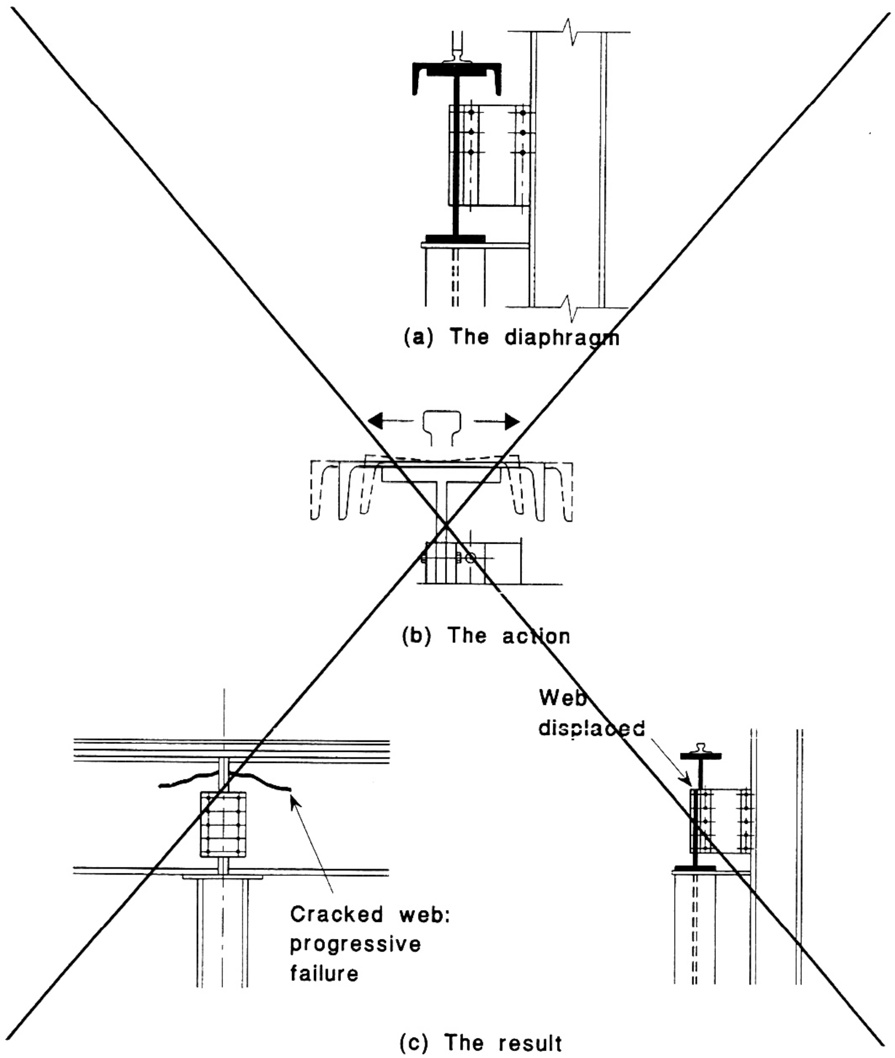
- Bočne podpore



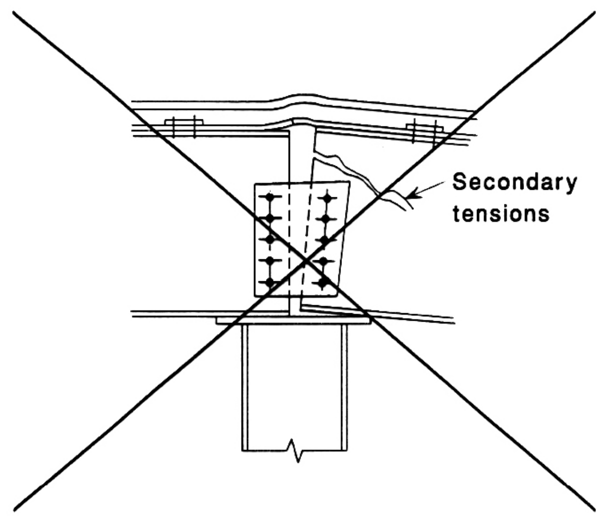
Povezava bočna podpora - steber

Konstrukcijski detajli

- Bočne podpore

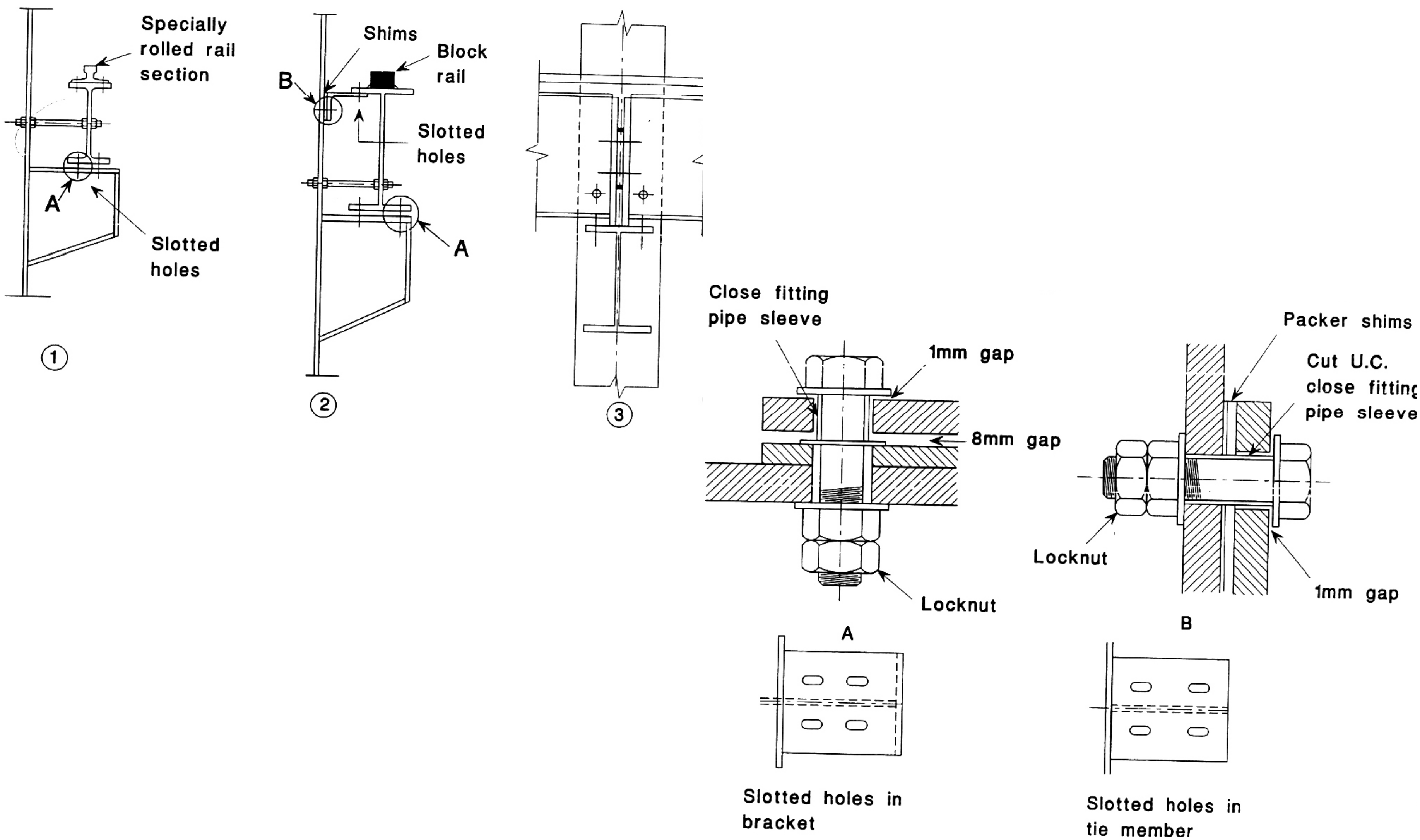


SLABA IZVEDBA BOČNE PODPORE!



Konstrukcijski detajli

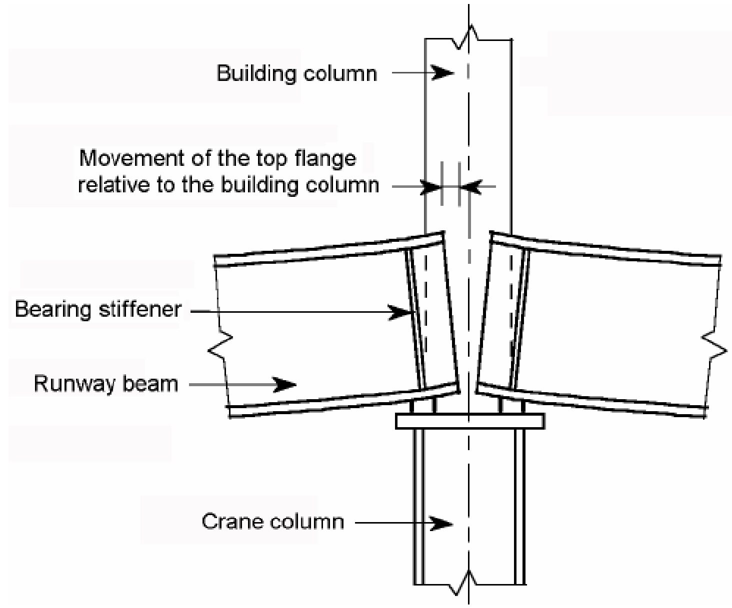
- Ležišče nosilca žerjavne proge



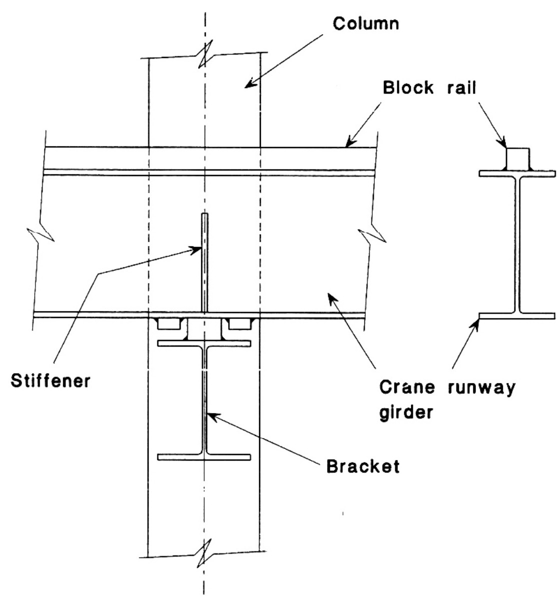
Konstrukcijski detajli

❑Vertikalne podpore

•Prostoležeči nosilec

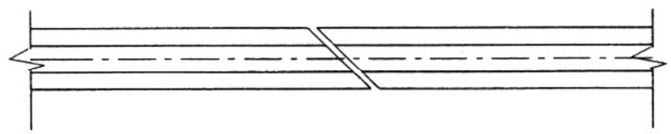


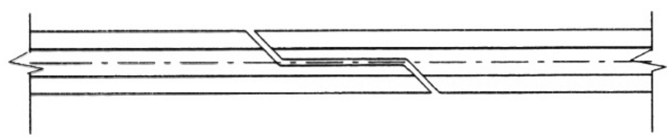
•Kontinuirni nosilec



Izvedba

- Tirnice
  - Odpornost na obrabo
  - Velika upogibna togost (zaradi večjega raznosa obtežbe)
  - Stikovanje
    - Podaljševanje – varjenje
    - Dilatacije – usklajene z dilatacijami nosilca (zvezni prehod dosežemo s preklopom)

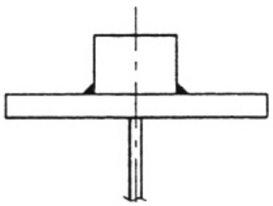




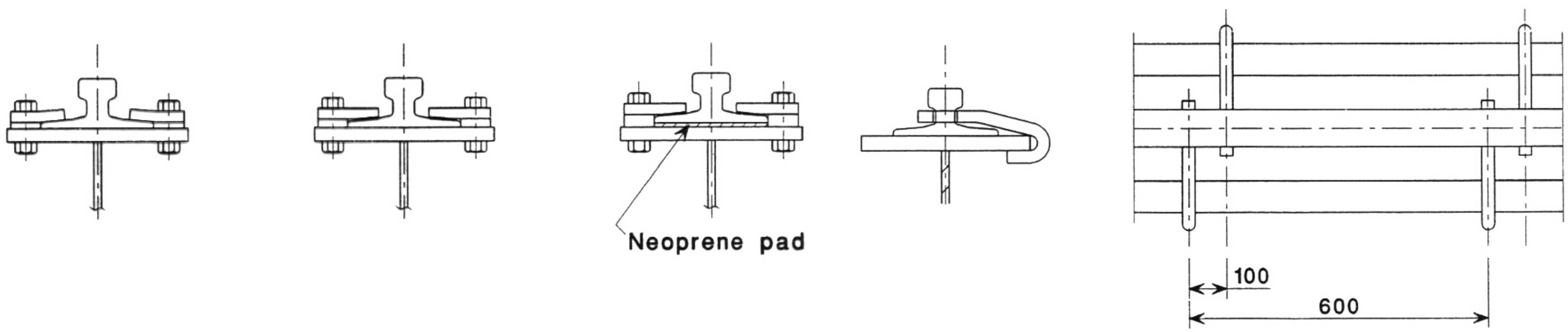
Izvedba

- Pritrjevanje

  -varjenje (težja prenova, prostoležeči nosilci – dilatacija ob vsaki podpori, koncentracije napetosti)

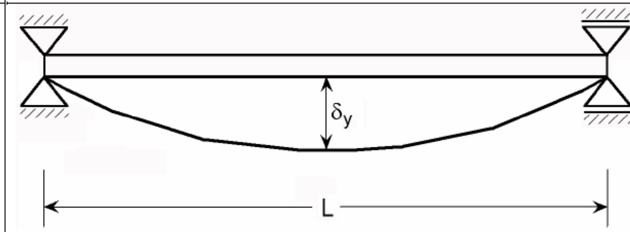
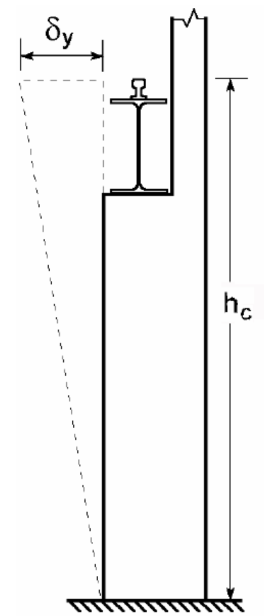


  -elastično pritrjevanje (bočno in vertikalno pridržano, vzdolžno pomično)



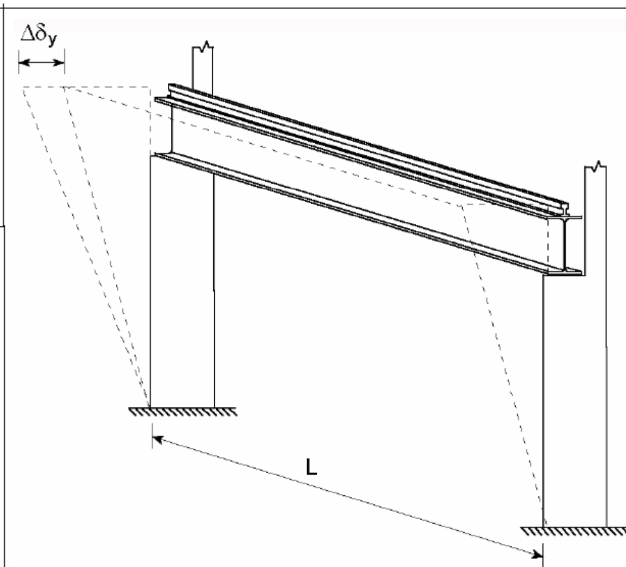
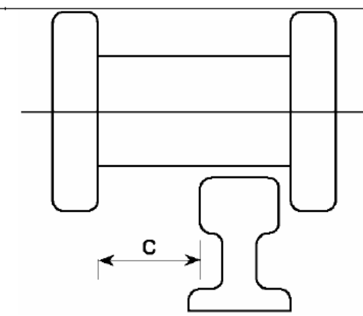
MSU

- Omejitev horizontalnih pomikov

Description of deflection (deformation or displacement)	Diagram
a) Horizontal deformation δ_y of a runway beam, measured at the level of the top of the crane rail: $\delta_y \leq L/600$	
b) Horizontal displacement δ_y of a frame (or of a column) at crane support level, due to crane loads: $\delta_y \leq h_c/400$ where: h_c is the height to the level at which the crane is supported (on a rail or on a flange)	

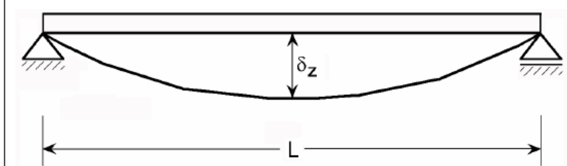
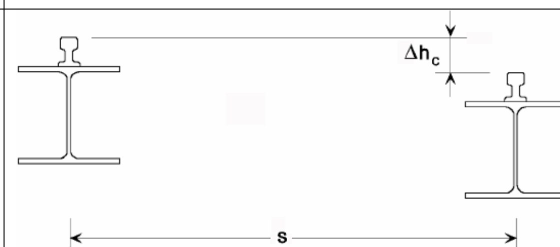
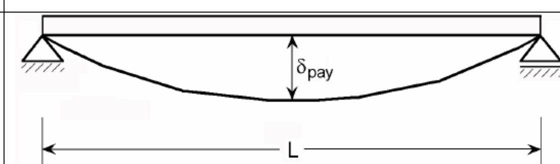
MSU

… nadaljevanje tabele “Omejitev horizontalnih pomikov”

c) Difference $\Delta\delta_y$ between the horizontal displacements of adjacent frames (or columns) supporting the beams of an indoor crane runway: $\Delta\delta_y \leq L/600$	
d) Difference $\Delta\delta_y$ between the horizontal displacements of adjacent columns (or frames) supporting the beams of an outdoor crane runway: - due to the combination of lateral crane forces and the in-service wind load: $\Delta\delta_y \leq L/600$ - due to the out-of-service wind load $\Delta\delta_y \leq L/400$	
e) Change of spacing Δs between the centres of crane rails, including the effects of thermal changes: $\Delta s \leq 10$ mm [see Note]	
NOTE: Horizontal deflections and deviations of crane runways are considered together in crane design. Acceptable deflections and tolerances depend on the details and clearances in the guidance means. Provided that the clearance c between the crane wheel flanges and the crane rail (or between the alternative guidance means and the crane beam) is also sufficient to accommodate the necessary tolerances, larger deflection limits can be specified for each project if agreed with the crane supplier and the client.	

MSU

❑Omejitev vertikalnih pomikov

Description of deflection (deformation or displacement)	Diagram
a) Vertical deformation δ_z of a runway beam: $\delta_z \leq L/600$ and $\delta_z \leq 25$ mm The vertical deformation δz should be taken as the total deformation due to vertical loads, less the possible pre-camber, as for δmax in figure A1.1 of EN 1990.	
b) Difference Δh_c between the vertical deformations of two beams forming a crane runway: $\Delta h_c \leq s/600$	
c) Vertical deformation δ_{pay} of a runway beam for a monorail hoist block, relative to its supports, due to the payload only: $\delta_{pay} \leq L/500$	

MSU

- Omejitev lokalnega izbočenja stojine v MSU

$$\sqrt{\left(\frac{\sigma_{x,Ed,ser}}{\sigma_{cr}}\right)^2 + \left(\frac{1,1 \cdot \tau_{Ed,ser}}{\tau_{cr}}\right)^2} \leq 1.1$$

σ_{cr} …elastična kritična normalna napetost

τ_{cr} …elastična kritična strižna napetost

MSU

- Omejitev napetosti

$$\sigma_{\mathrm{Ed,ser}} \leq f_{\mathrm{y}} / \gamma_{\mathrm{M,ser}}$$

$$\tau_{\mathrm{Ed,ser}} \leq \frac{f_{\mathrm{y}}}{\sqrt{3}\,\gamma_{\mathrm{M,ser}}}$$

$$\sqrt{\left(\sigma_{\mathrm{x,Ed,ser}}\right)^2 + 3\left(\tau_{\mathrm{Ed,ser}}\right)^2} \leq f_{\mathrm{y}} / \gamma_{\mathrm{M,ser}}$$

$$\sqrt{\left(\sigma_{\mathrm{x,Ed,ser}}\right)^2 + \left(\sigma_{\mathrm{y,Ed,ser}}\right)^2 - \left(\sigma_{\mathrm{x,Ed,ser}}\right)\left(\sigma_{\mathrm{y,Ed,ser}}\right) + 3\left(\tau_{\mathrm{Ed,ser}}\right)^2} \leq f_{\mathrm{y}} / \gamma_{\mathrm{M,ser}}$$

$$\sqrt{\left(\sigma_{\mathrm{x,Ed,ser}}\right)^2 + \left(\sigma_{\mathrm{z,Ed,ser}}\right)^2 - \left(\sigma_{\mathrm{x,Ed,ser}}\right)\left(\sigma_{\mathrm{z,Ed,ser}}\right) + 3\left(\tau_{\mathrm{Ed,ser}}\right)^2} \leq f_{\mathrm{y}} / \gamma_{\mathrm{M,ser}}$$

$\sigma_{\mathrm{x,Ed,ser}}$ …normalna napetost v vzdolžni smeri

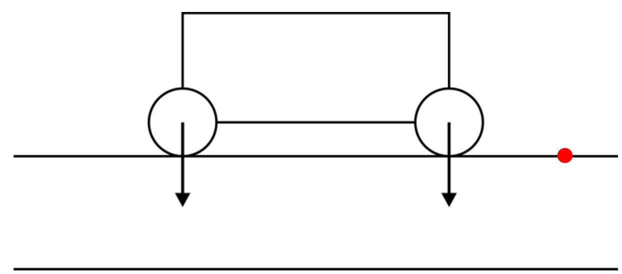
$\sigma_{\mathrm{y,Ed,ser}}$ …normalna napetost v horizontalni smeri

$\sigma_{\mathrm{z,Ed,ser}}$ … normalna napetost v vertikalni smeri

$\tau_{\mathrm{Ed,ser}}$ … strižna napetost

Utrujanje

•V pasnici kontroliramo globalni vpliv. V stojini tik pod pasnico s tirnico pa kontroliramo globalni in lokalni vpliv. Za lokalni vpliv je značilno, da moramo upoštevati 2 × več cikov.



$$\gamma_{\mathrm{Ff}} = 1.0$$

$$\gamma_{\mathrm{Mf}} = 1.0 - 1.35$$

(glej SIST EN 1993-1-9)

Določimo ekvivalentno obtežbo pri 2×10^6 ciklov:

$$Q_{\mathrm{e}} = \varphi_{\mathrm{fat}}\, \lambda_{\mathrm{i}}\, Q_{\mathrm{max,i}}\ ,$$

$$\left.\begin{aligned} \Delta\sigma_{\mathrm{E2}} &= \left|\sigma_{\mathrm{max}} - \sigma_{\mathrm{min}}\right| \\ \Delta\tau_{\mathrm{E2}} &= \left|\tau_{\mathrm{max}} - \tau_{\mathrm{min}}\right| \end{aligned}\right\} Q_{\mathrm{e}}$$

$Q_{\mathrm{max,i}}$ …maksimalna vrednost karakteristične vertikalne obtežbe kolesa i

Utrujanje

λ_i …faktor poškodb ekvivalenten pri N = 2×10^6 ciklov

Classes S	S_0	S_1	S_2	S_3	S_4	S_5	S_6	S_7	S_8	S_9
normal stresses	0,198	0,250	0,315	0,397	0,500	0,630	0,794	1,00	1,260	1,587
shear stresses	0,379	0,436	0,500	0,575	0,660	0,758	0,871	1,00	1,149	1,320

NOTE 1: In determining the λ-values standardized spectra with a gaussian distribution of the load effects, the Miner rule and fatigue strength S-N lines with a slope m = 3 for normal stresses and m = 5 for shear stress have been used.

NOTE 2: In case the crane classification is not included in the specification documents of the crane indications are given in Annex B.

φ_{fat} …dinamični faktor poškodb ekvivalenten pri N = 2×10^6 ciklov

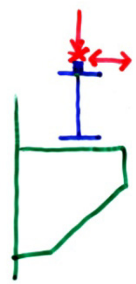
$$\varphi_{fat} = \max\left(\varphi_{fat,1},\ \varphi_{fat,2}\right)$$

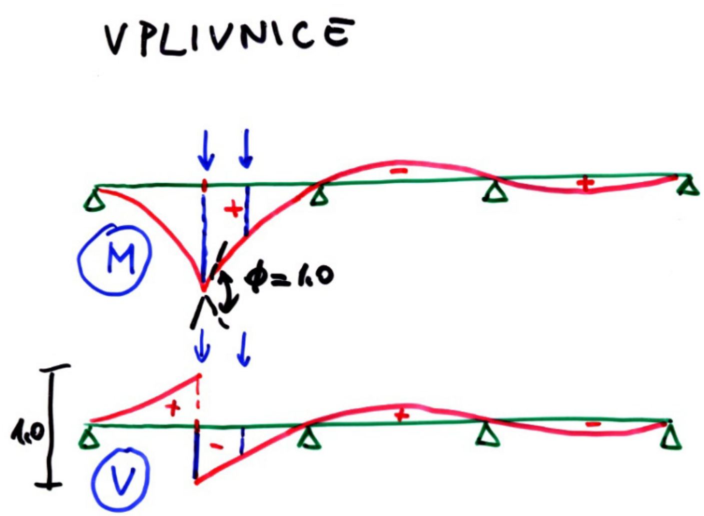
$$\varphi_{fat,1} = \frac{1+\varphi_1}{2}$$

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

Utrujanje

- Vplivnice M,Q





Utrujanje

- Kontrola odpornosti na utrujanje

•Pasnica

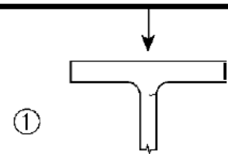
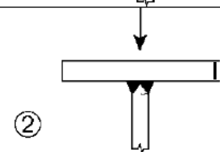
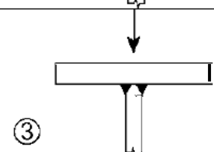
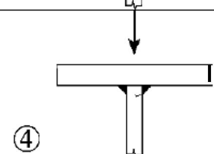
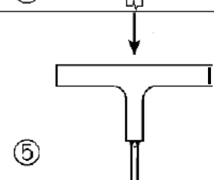
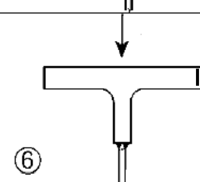
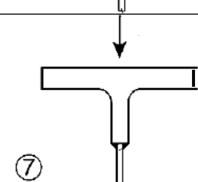
$$\left[\frac{\gamma_{\mathrm{Ff}}\Delta\sigma_{\mathrm{E2,i}}}{\Delta\sigma_{C}/\gamma_{\mathrm{Mf}}}\right]^{3}+\left[\frac{\gamma_{\mathrm{Ff}}\Delta\tau_{\mathrm{E2,i}}}{\Delta\tau_{C}/\gamma_{\mathrm{Mf}}}\right]^{5}\leq 1.0$$

•Stojina

$$\left[\frac{\gamma_{\mathrm{Ff}}\Delta\sigma_{\mathrm{z,E2,i}}}{\Delta\sigma_{C}/\gamma_{\mathrm{Mf}}}\right]^{3}+\left[\frac{\gamma_{\mathrm{Ff}}\Delta\tau_{\mathrm{E2,i}}}{\Delta\tau_{C}/\gamma_{\mathrm{Mf}}}\right]^{5}+2\left[\frac{\gamma_{\mathrm{Ff}}\Delta\sigma_{\mathrm{lok,z,E2,i}}}{\Delta\sigma_{C}/\gamma_{\mathrm{Mf}}}\right]^{3}+2\left[\frac{\gamma_{\mathrm{Ff}}\Delta\tau_{\mathrm{lok,E2,i}}}{\Delta\tau_{C}/\gamma_{\mathrm{Mf}}}\right]^{5}\leq 1.0$$

Utrujanje

Kategorije detajlov – vrednosti σ_C

Detail category	Constructional detail	Description	Requirements
160		1) Rolled I- or H-sections	1) Vertical compressive stress range $\Delta\sigma_{vert.}$ in web due to wheel loads
71		2) Full penetration tee-butt weld	2) Vertical compressive stress range $\Delta\sigma_{vert.}$ in web due to wheel loads
36*		3) Partial penetration tee-butt welds, or effective full penetration tee-butt weld conforming with EN 1993-1-8	3) Stress range $\Delta\sigma_{vert.}$ in weld throat due to vertical compression from wheel loads
36*		4) Fillet welds	4) Stress range $\Delta\sigma_{vert.}$ in weld throat due to vertical compression from wheel loads
71		5) T-section flange with full penetration tee-butt weld	5) Vertical compressive stress range $\Delta\sigma_{vert.}$ in web due to wheel loads
36*		6) T-section flange with partial penetration tee-butt weld, or effective full penetration tee-butt weld conforming with EN 1993-1-8	6) Stress range $\Delta\sigma_{vert.}$ in weld throat due to vertical compression from wheel loads
36*		7) T-section flange with fillet welds	7) Stress range $\Delta\sigma_{vert.}$ in weld throat due to vertical compression from wheel loads