Univerza
v Ljubljani
Fakulteta
za gradbeništvo
in geodezijo

Katedra za metalne konstrukcije

JEKLENE KONSTRUKCIJE I

6.0 SPOJI

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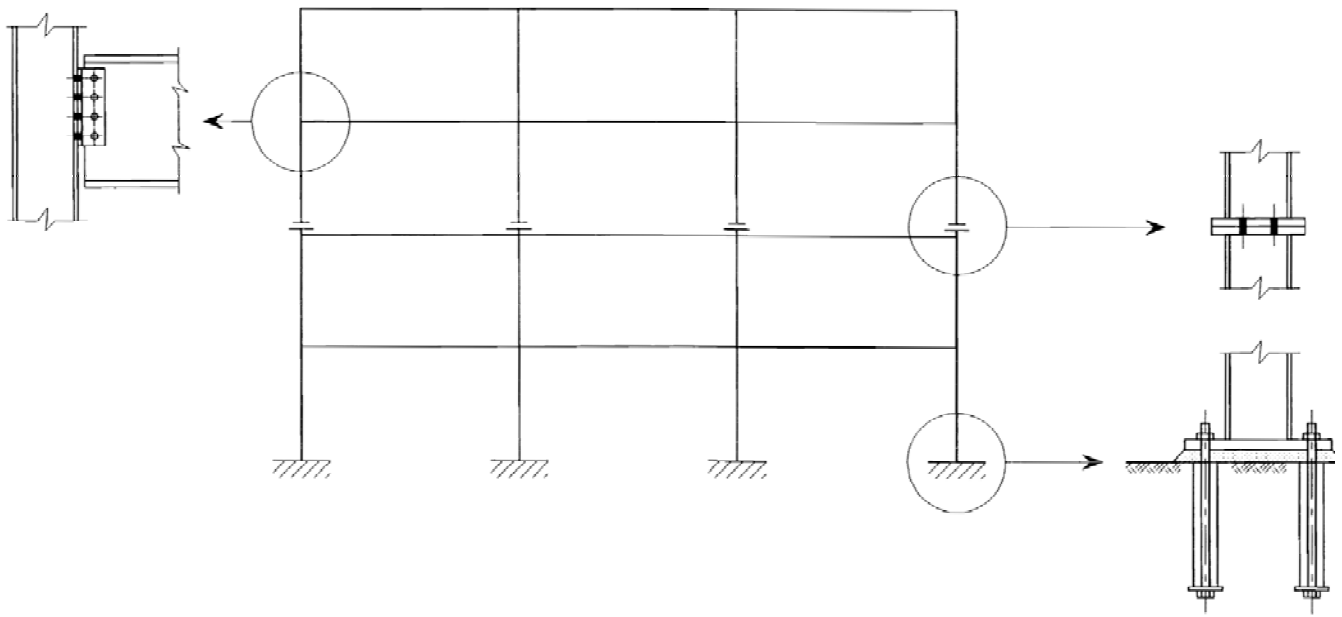
Sodelavec: Blaž Čermelj

Spoji

- Spoji so v jeklenih konstrukcijah zelo pomembni konstrukcijski elementi;
- so najdražji elementi nosilne konstrukcije (množica detajlov, zvari, vijaki – več vloženega dela);
- ključna je pravilna in čim bolj racionalna zasnova;



-Sprememba smeri elementa;

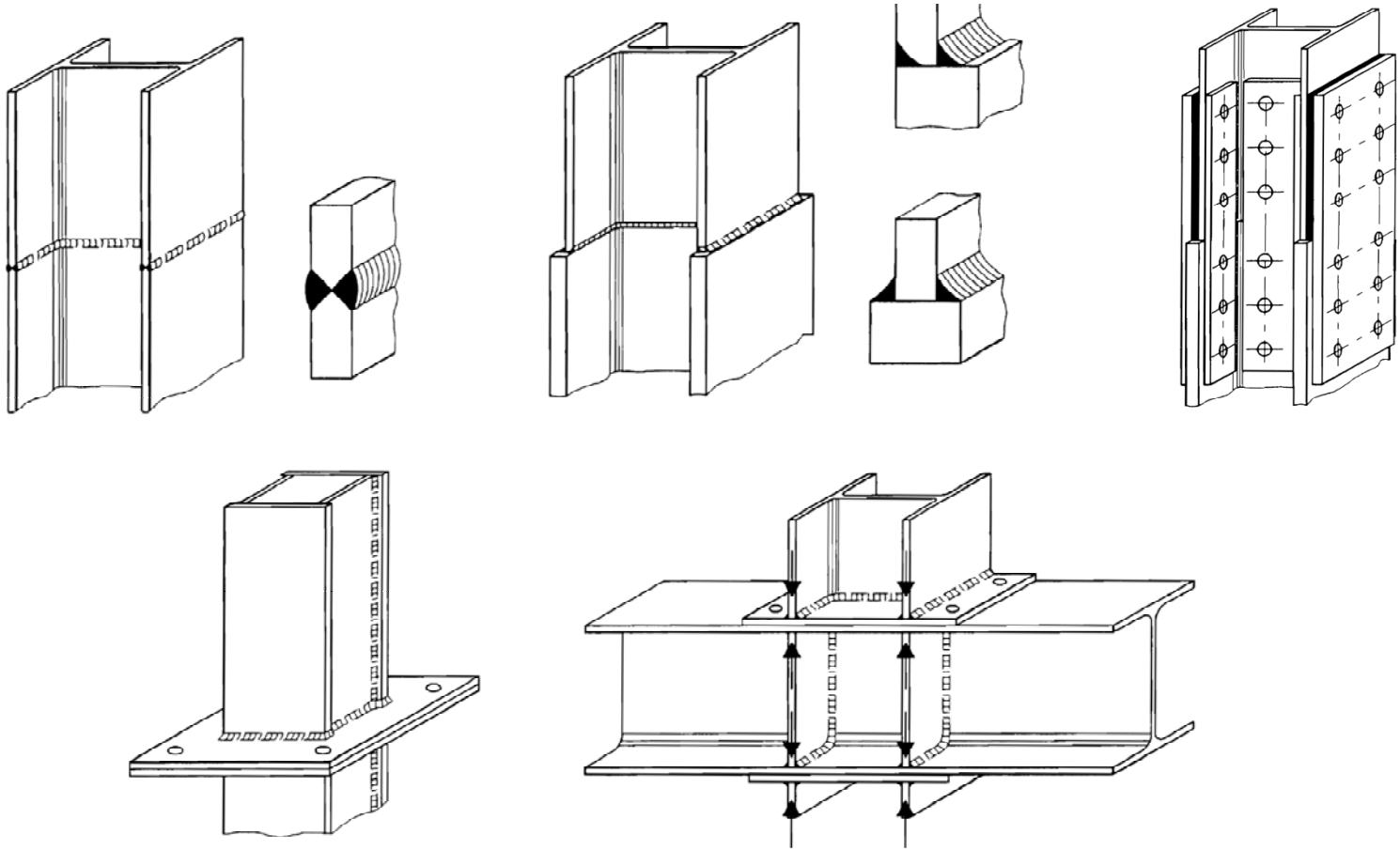
-montažni spoji (transport, montaža);

-sprememba nosilnega elementa: velikost prereza, material.

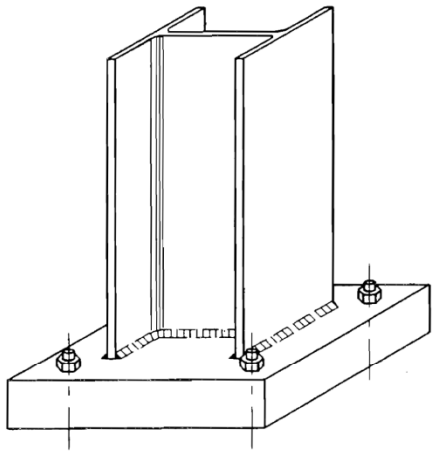
- kot vezna sredstva uporabljamo **zvare** in **vijake**, redkeje zakovice.

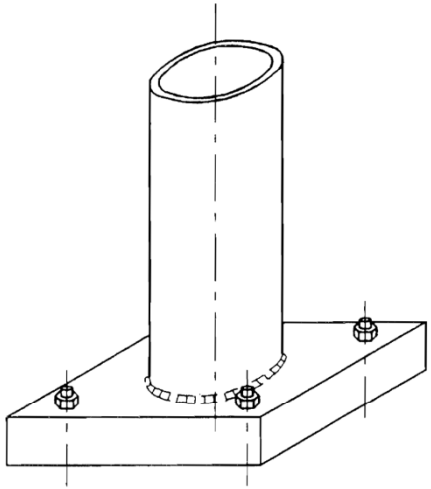
Glede na obliko in namen ločimo več vrst spojev:

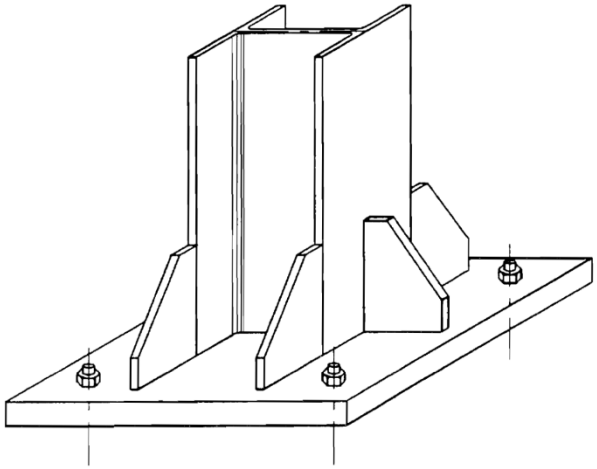
- Spoji v stebrih



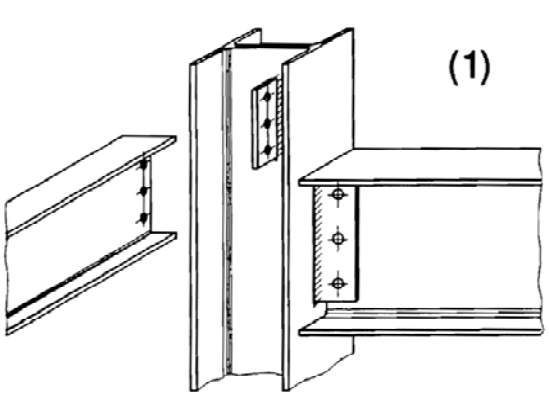
- Priključki na temelj

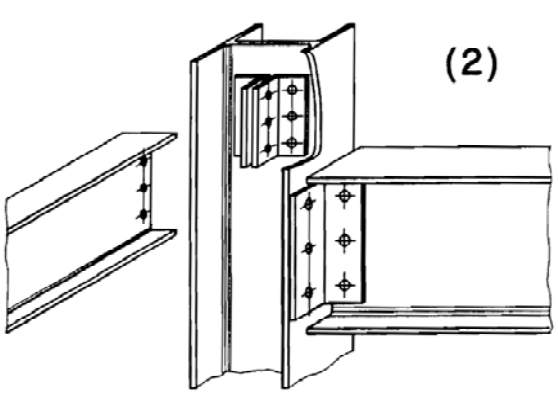


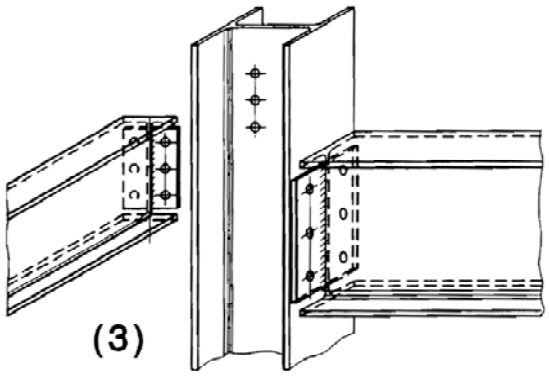


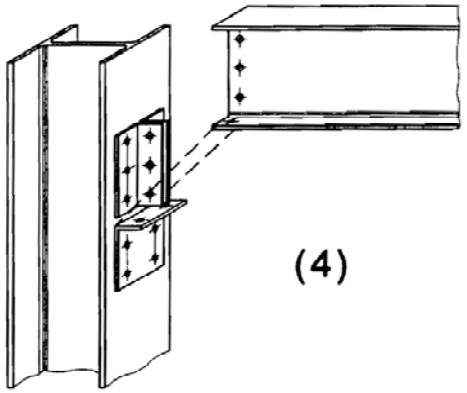


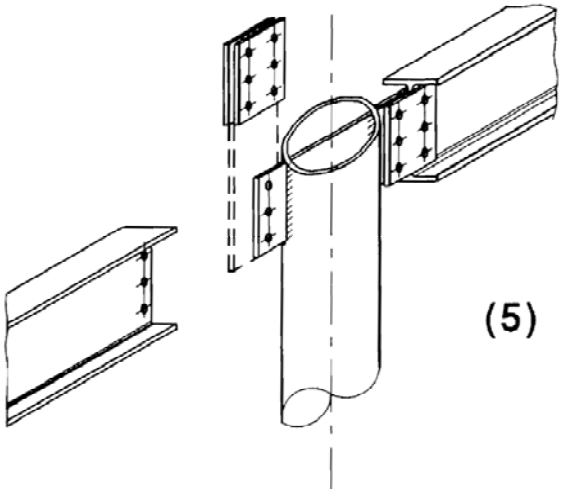
- Členkasti priključki greda - steber

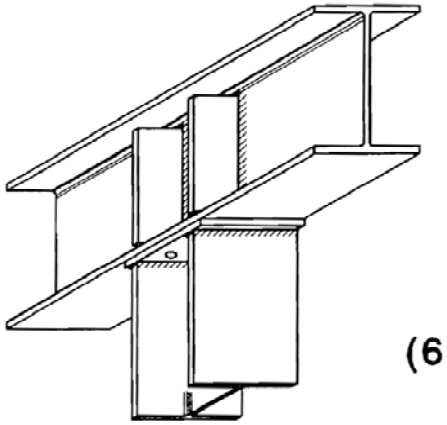




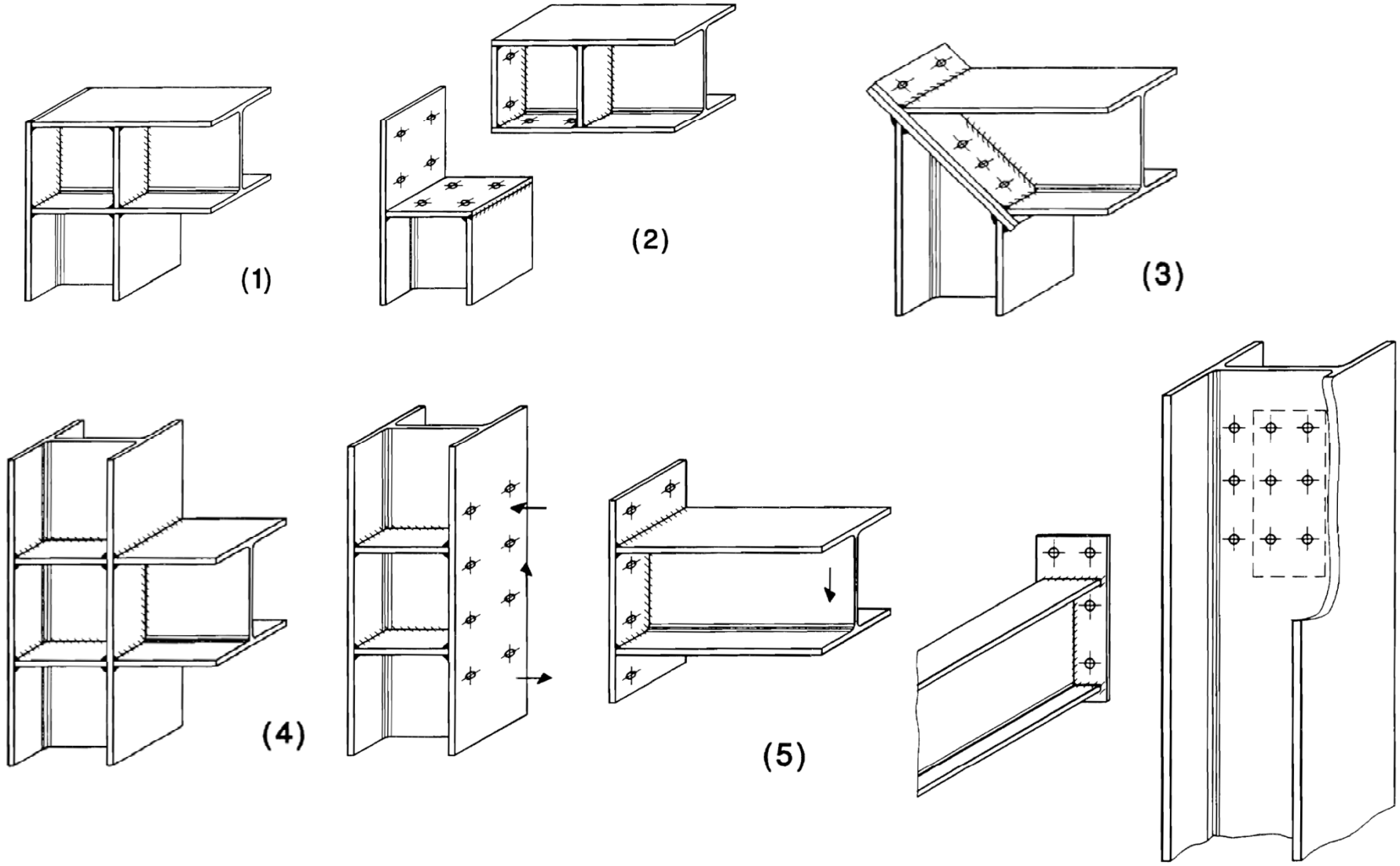




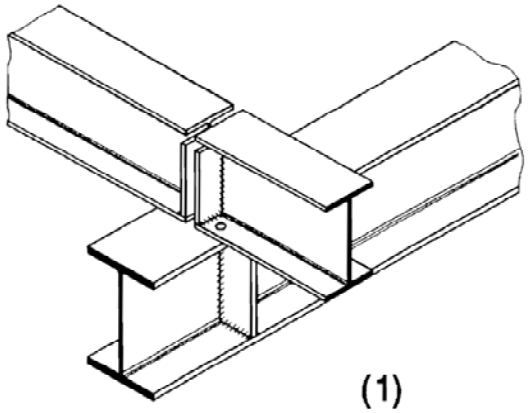


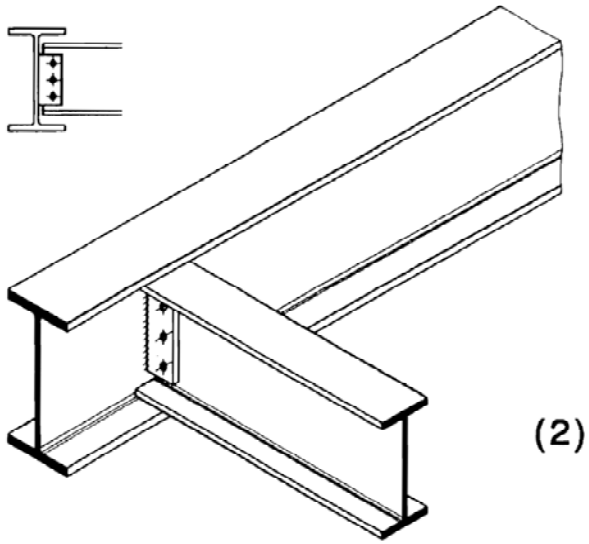


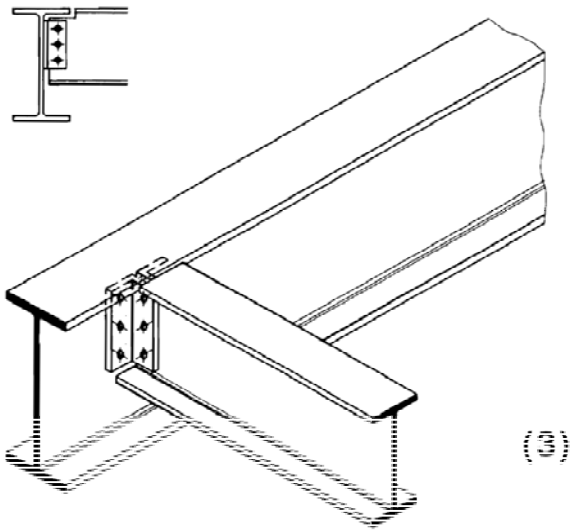
- Momentni priključki greda - steber

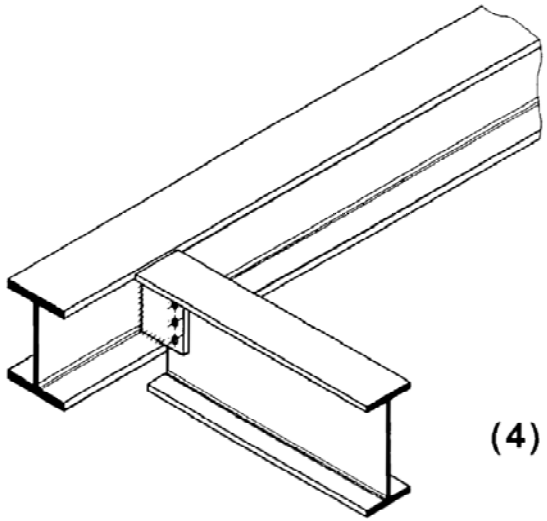


- Členkasti priključki greda - greda

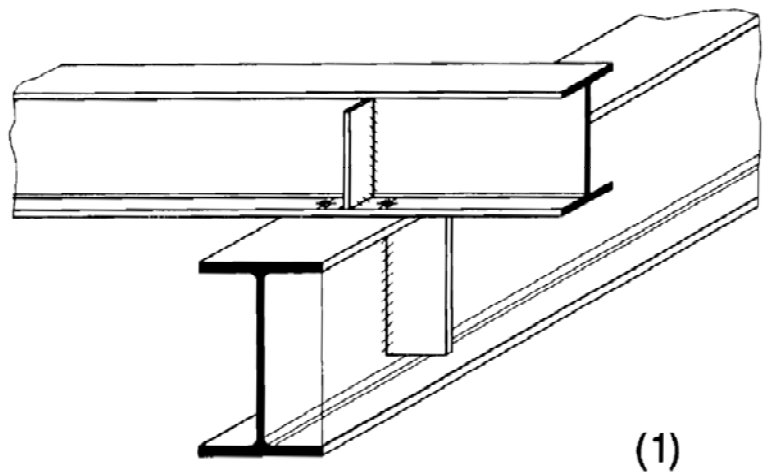


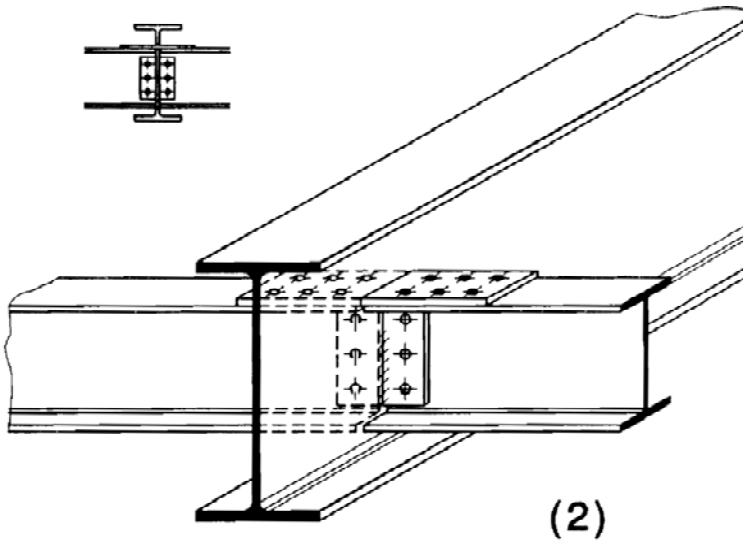


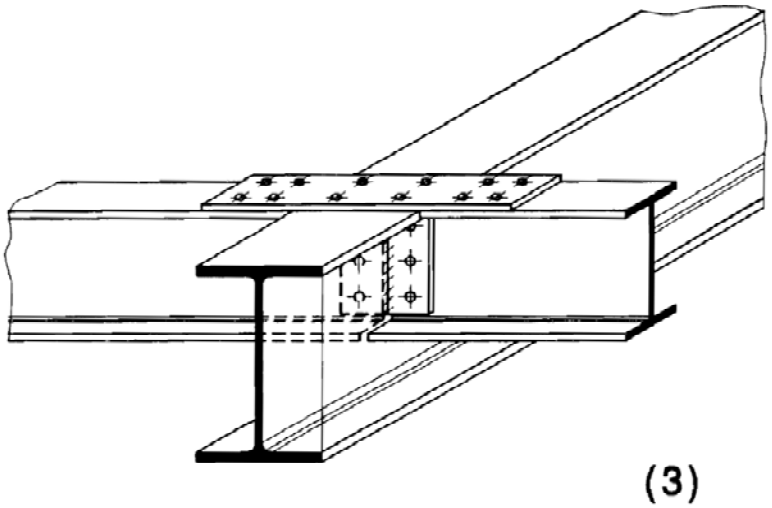


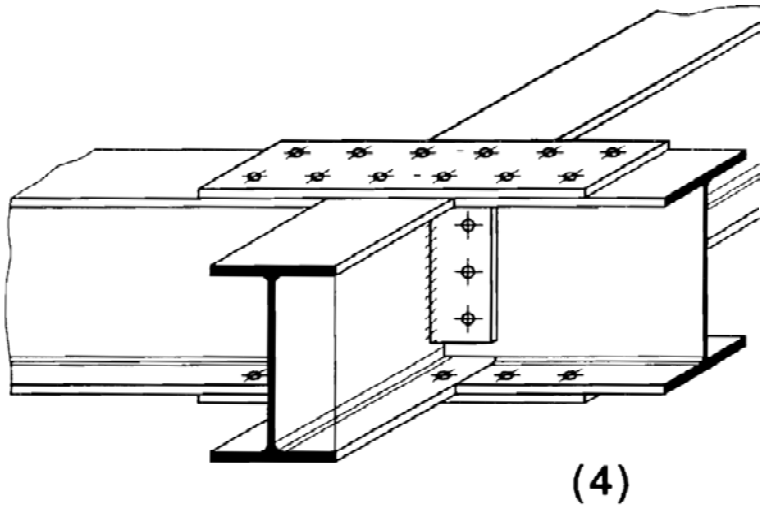


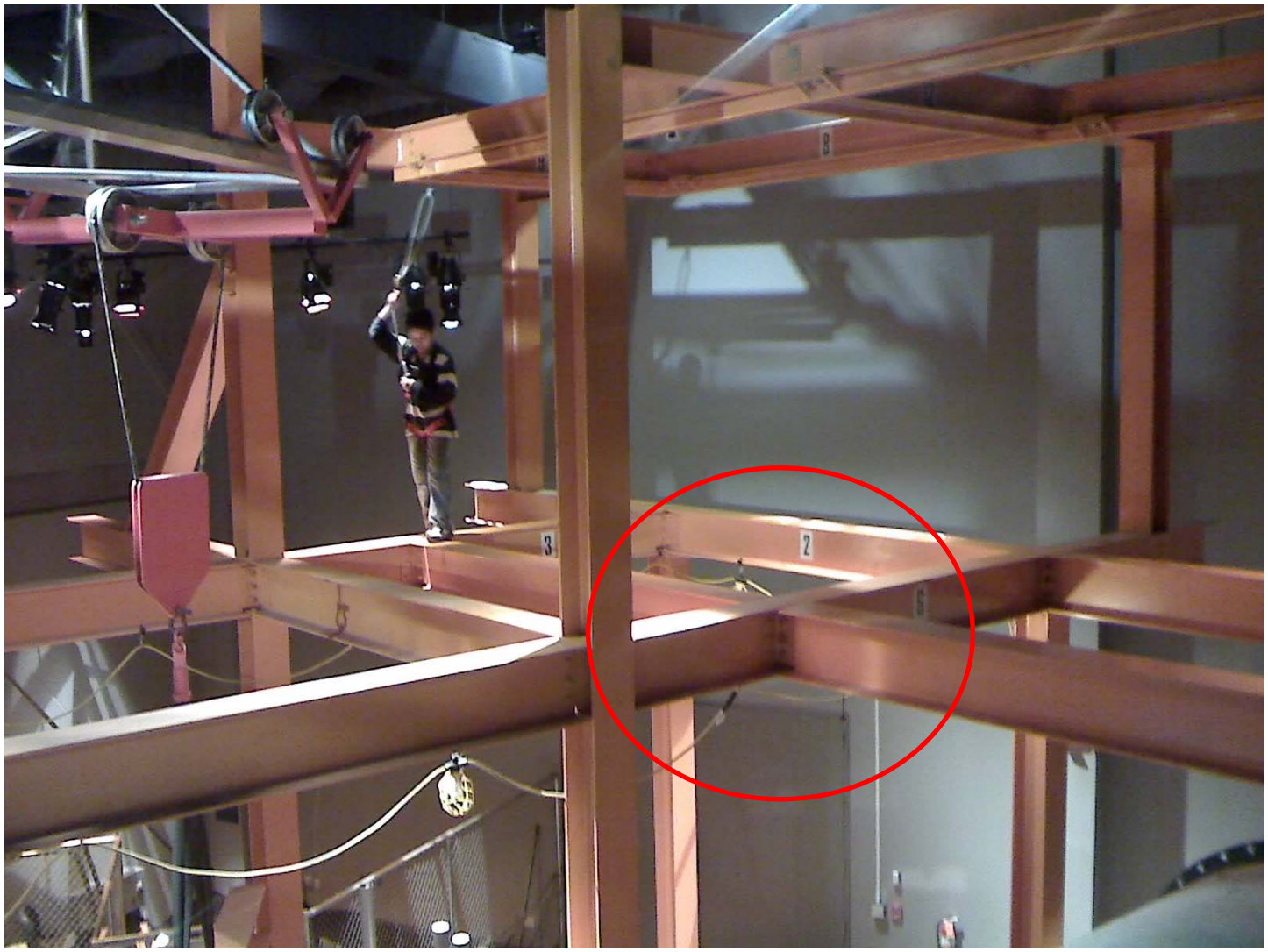
- Momentni priključki greda - greda



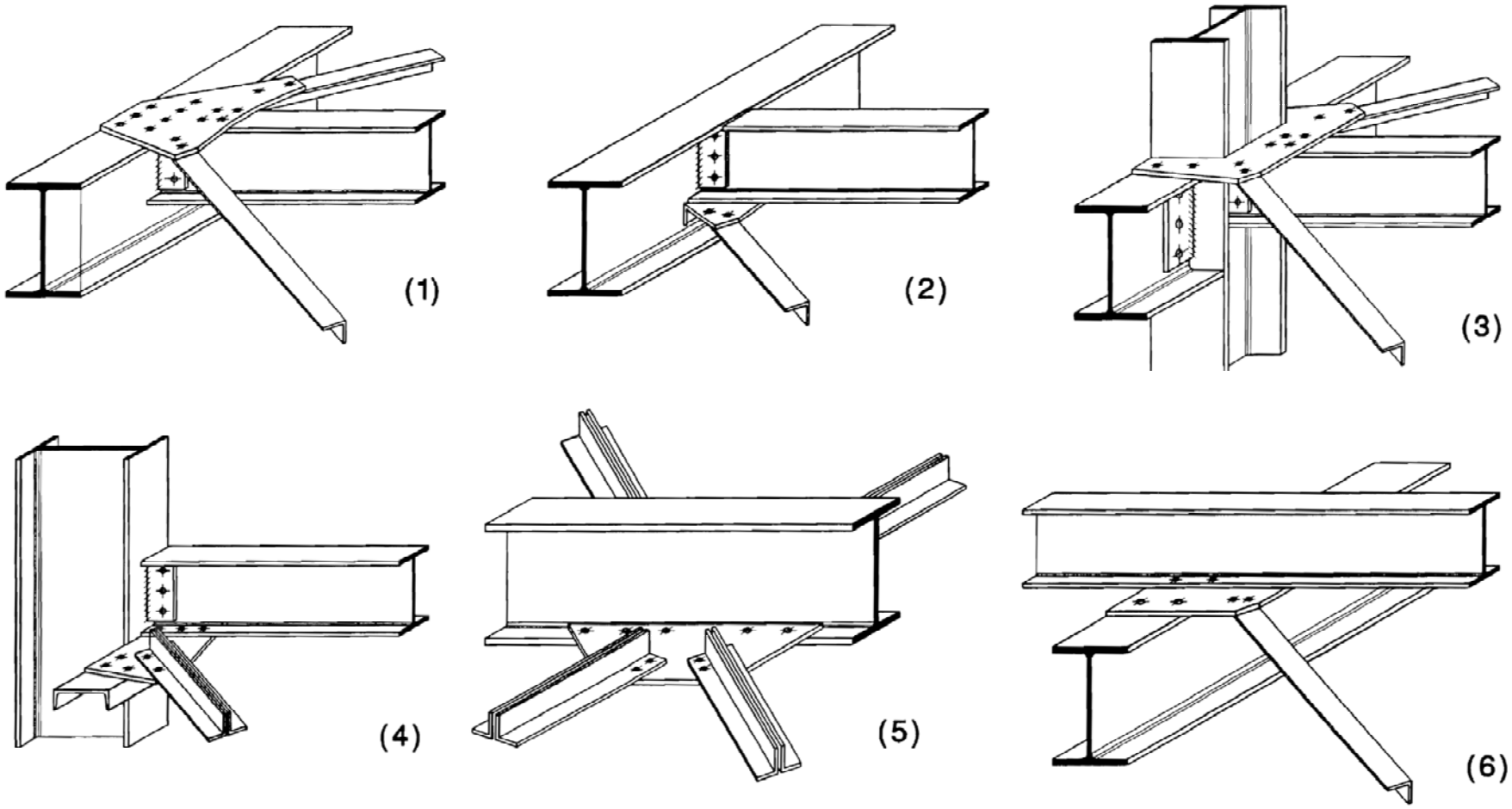




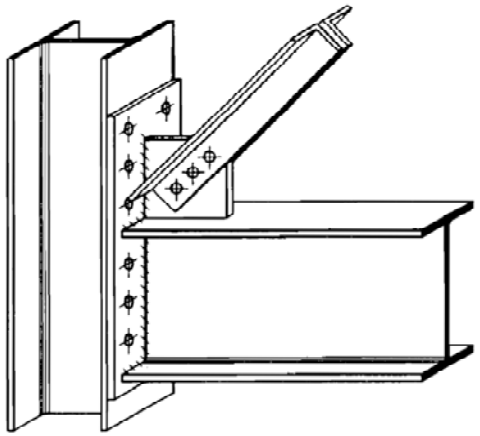



3
2

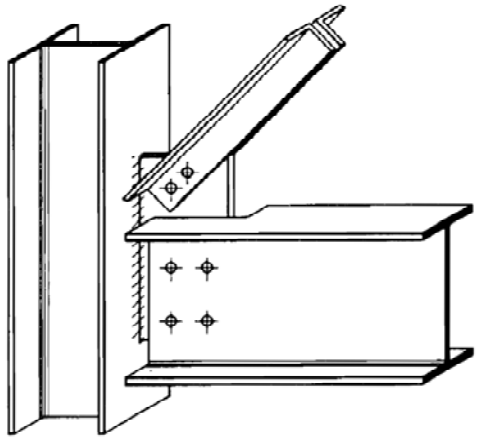
- Priključki horizontalnih povezij



- Priključki vertikalnih povezij



(1)



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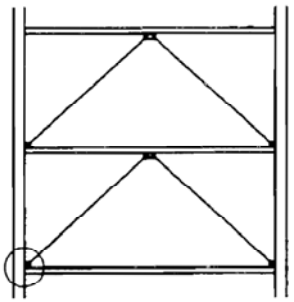

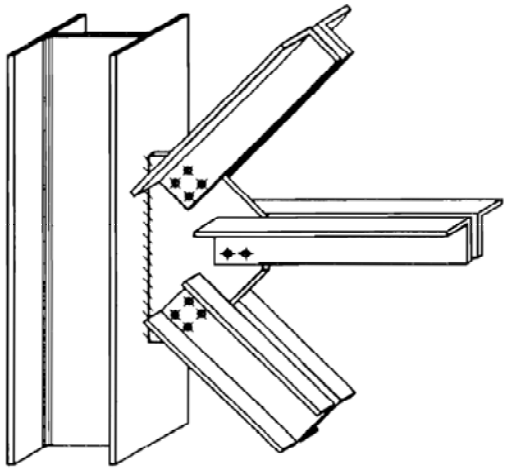

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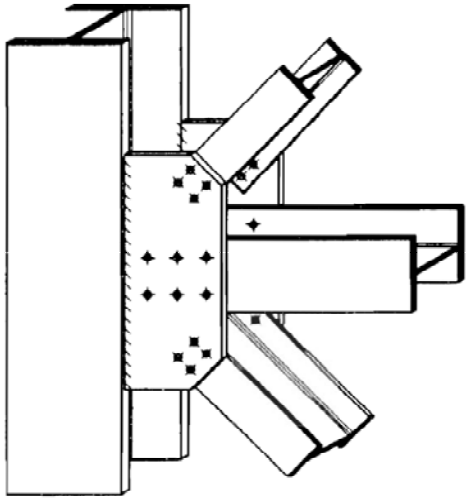

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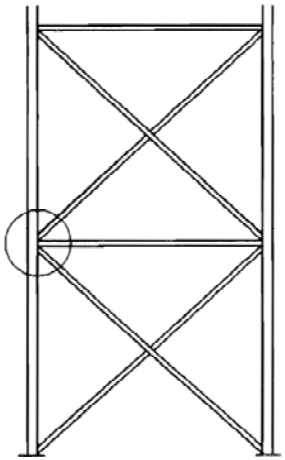
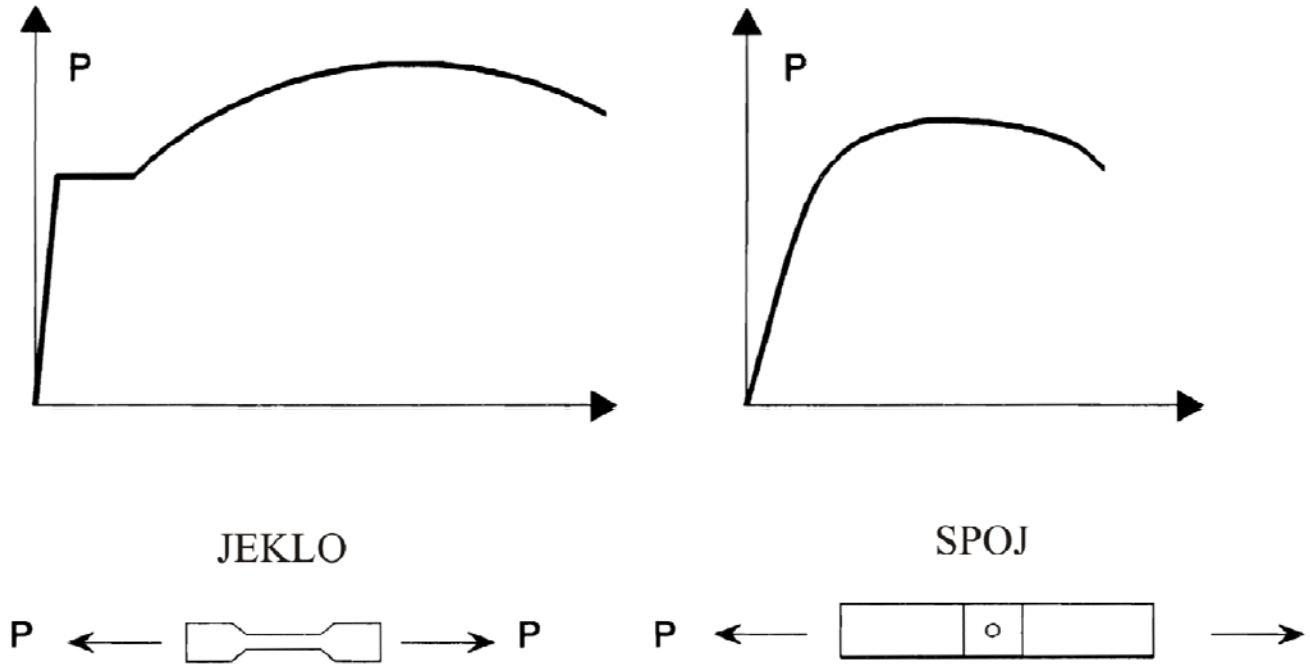
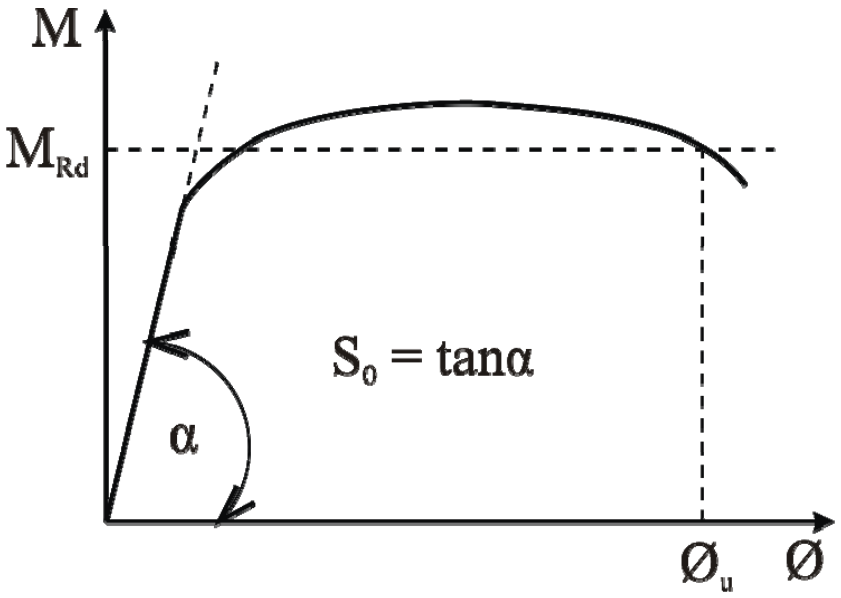


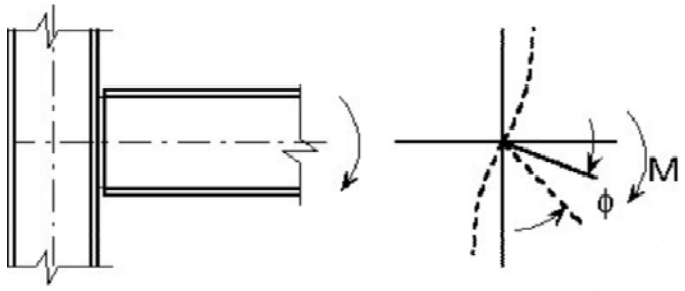
- Diagram obtežba – pomik za preizkušanec iz jekla in za spoj



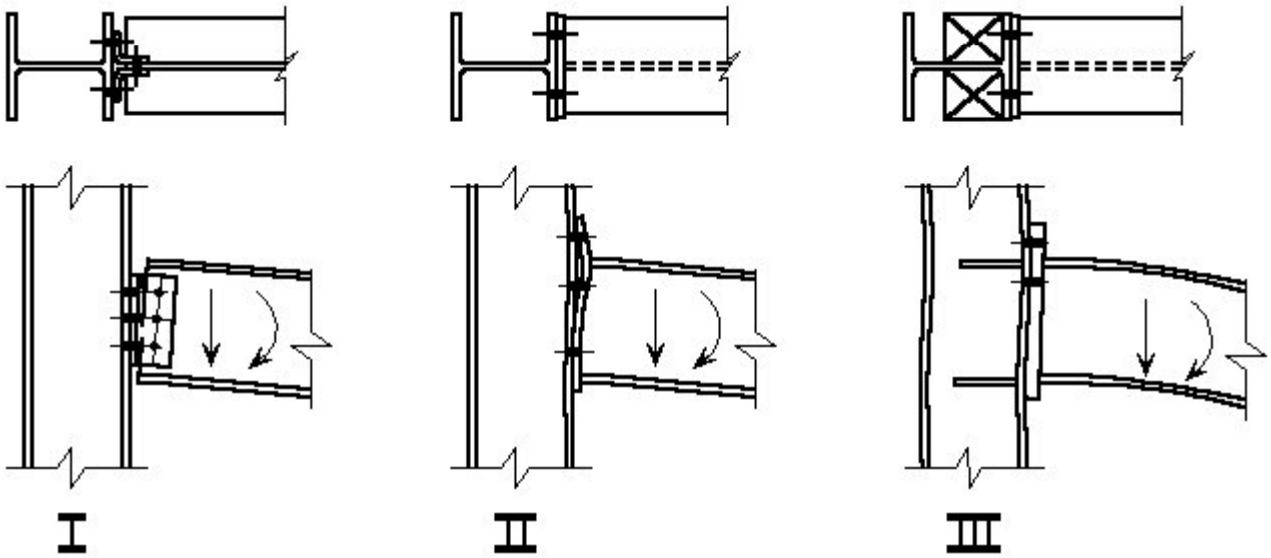
Glede na mehanske lastnosti spoje delimo po:

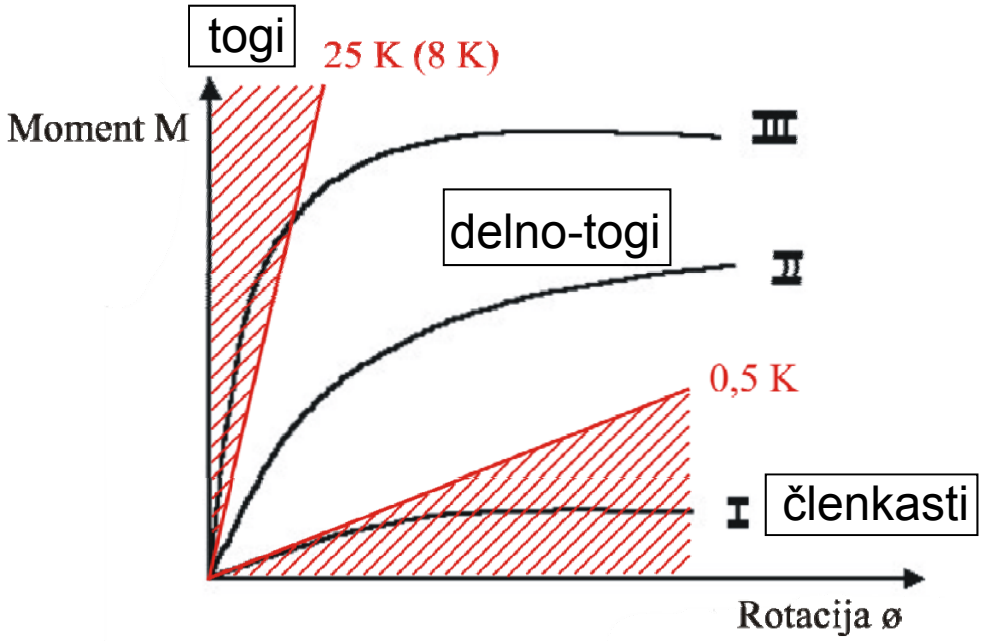
- TOGOSTI
- NOSILNOSTI
- DUKTILNOSTI

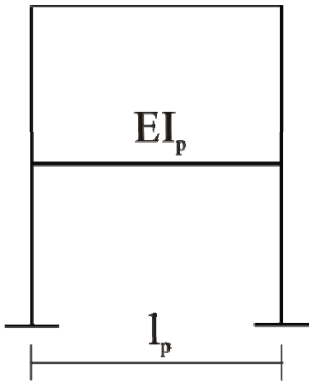




- Delitev po togosti





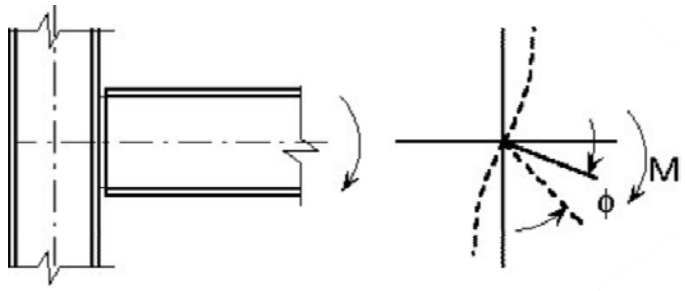


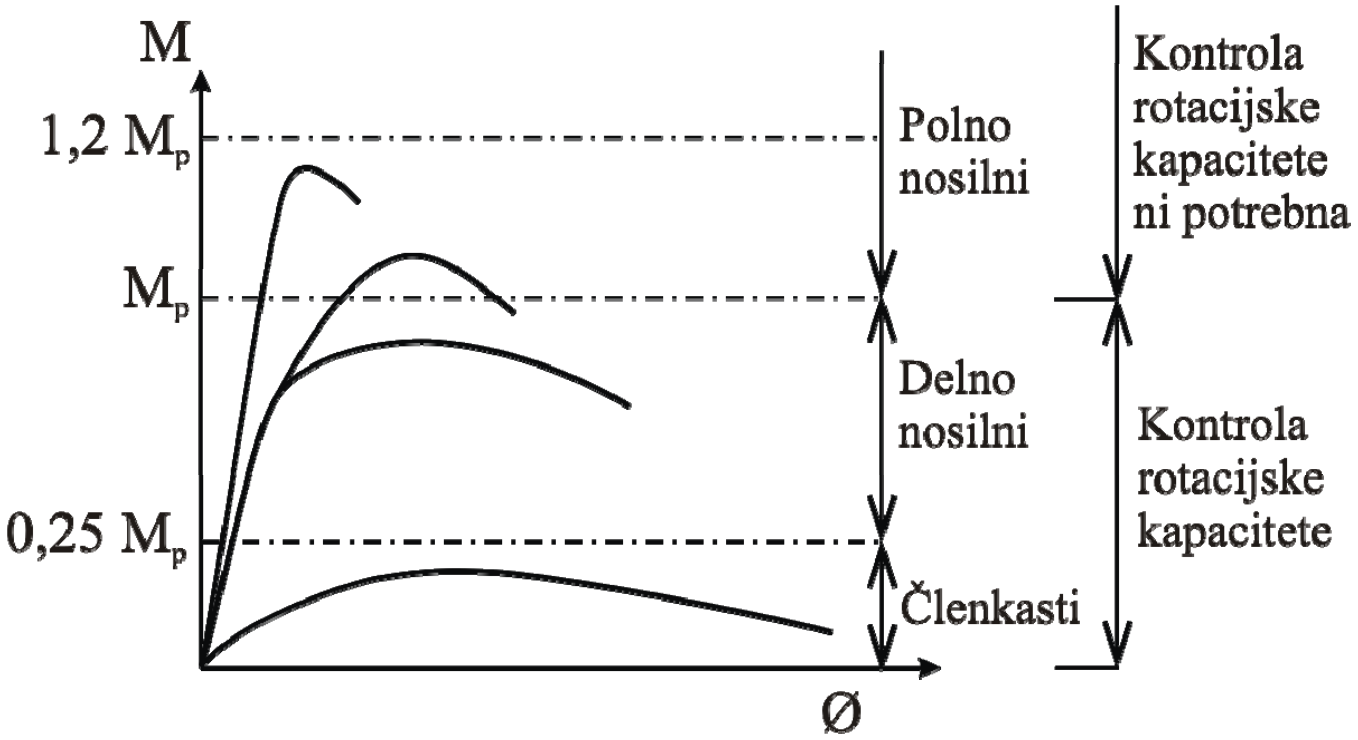
$$K = \frac{E\,I_p}{l_p}$$

- <u>Delitev po nosilnosti</u>

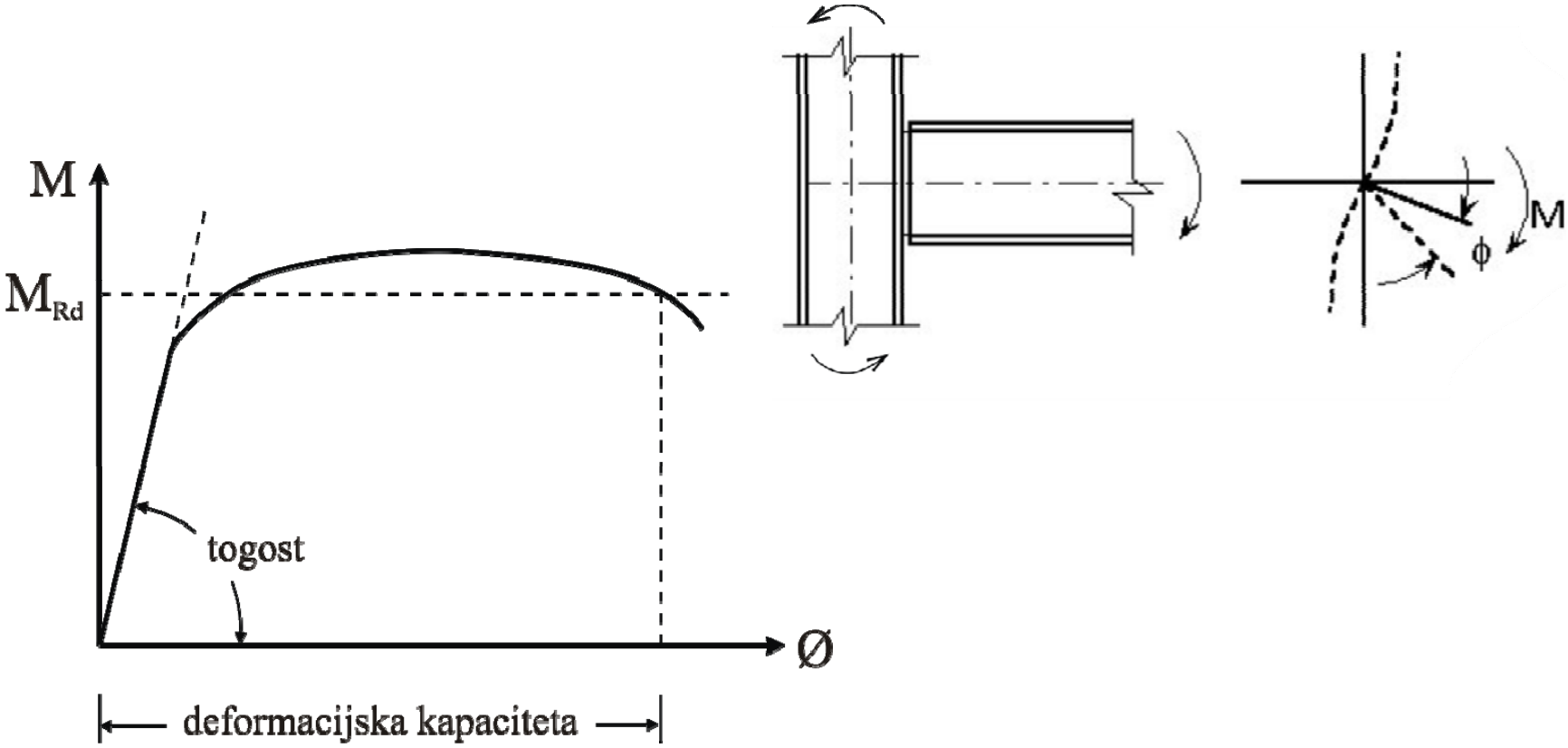
  - členkasti: $M < 0{,}25\ M_{pl}$;

  - polno nosilni: $M > M_{pl}$.





- <u>Rotacijska kapaciteta</u>

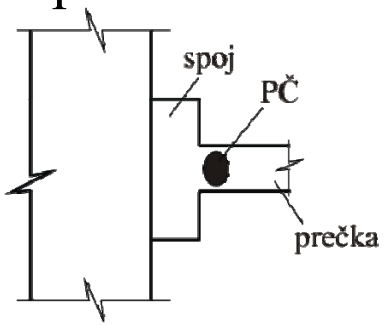


Delitev spojev

Duktilnost – rotacijska kapaciteta

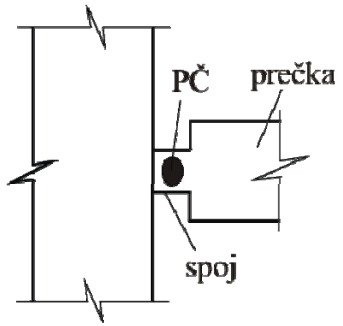
- Polnonosilni – **duktilnost ni potrebna**

Poškodbe se tvorijo v prečki in ne v spoju



- Delnonosilni - **obvezno duktilni**

Poškodbe se tvorijo v spoju



Spoji in priključki

Mehanizmi prenosa obtežbe:

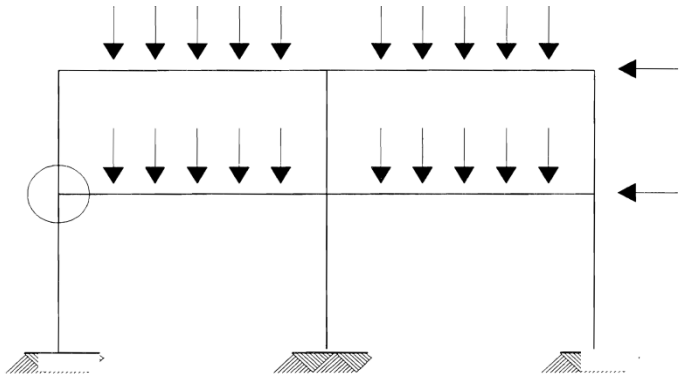
- Osnovna pravila:
  - predpostavljeni razpored notranjih sil v spoju mora biti v **ravnotežju** z delujočimi obremenitvami;
  - vsak sestavni del spoja mora biti **sposoben prevzeti obtežbo**, ki odpade nanj;
  - **deformacije** v spoju ne smejo presegati deformacijske kapacitete – duktilnosti – posameznih elementov spoja (zvari, vijaki, vezne pločevine).

Pri elastični analizi **obtežbo delimo** na posamezne elemente spoja v **razmerju togosti**.

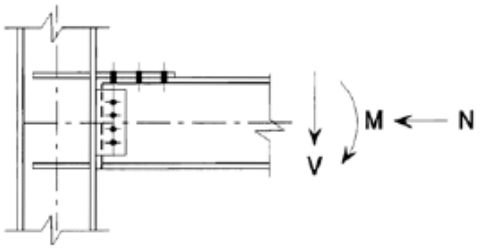
Primer:

Razdelitev obtežbe:

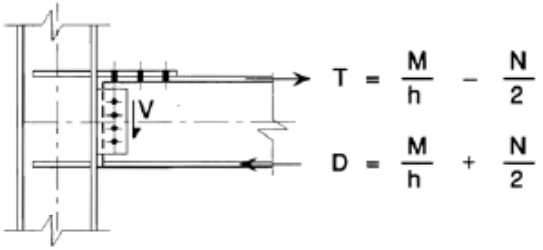
- pasnica → upogib
- stojina → strig



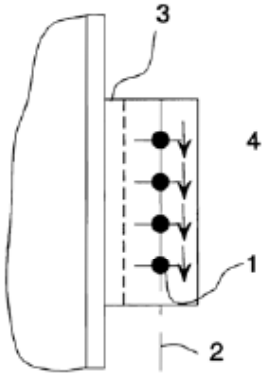
Shema konstrukciie



Spoj



Komponente spoja



1. Vijaki < bočni pritisk/prestrig
2. Neto prerez pločevine
3. Zvar
4. Stojina nosilca

Obtežba

↓

Notranje sile

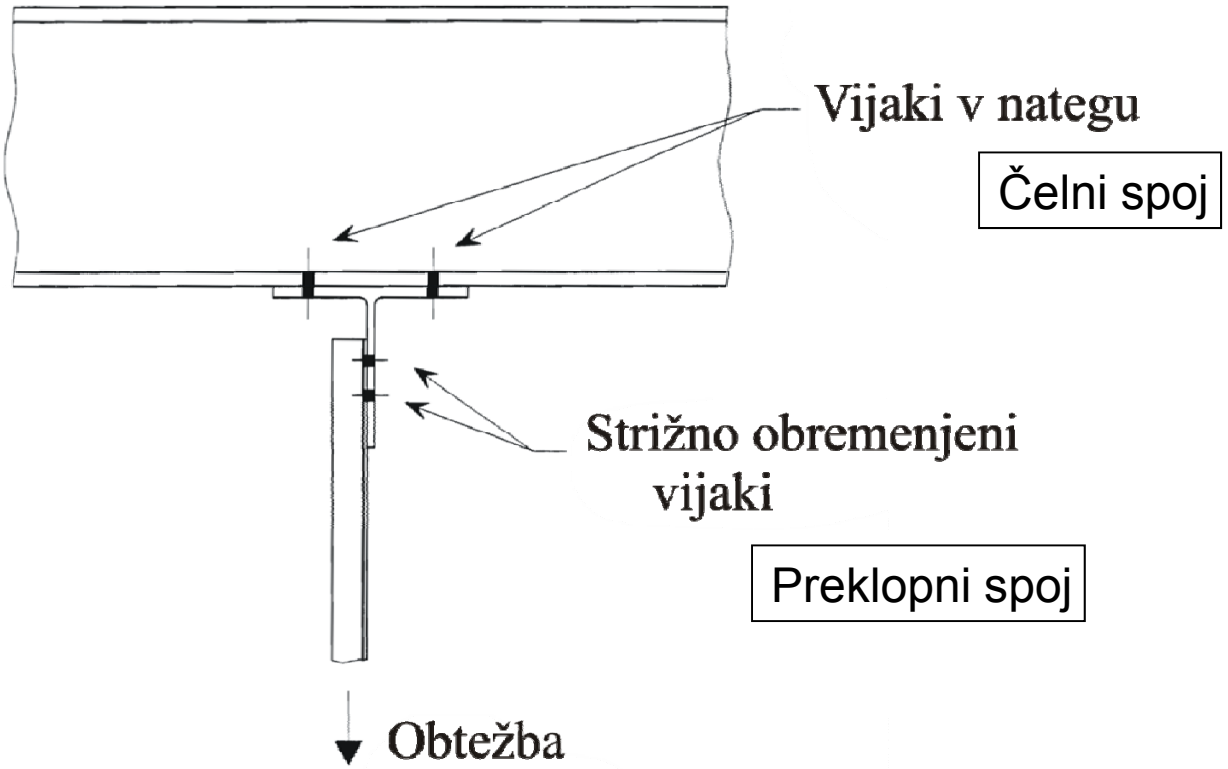
↓

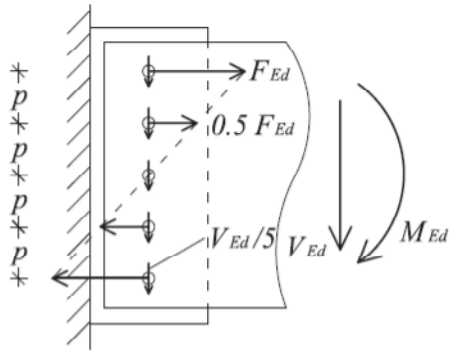
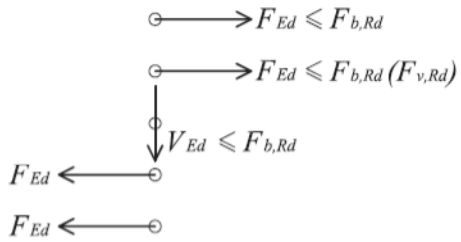
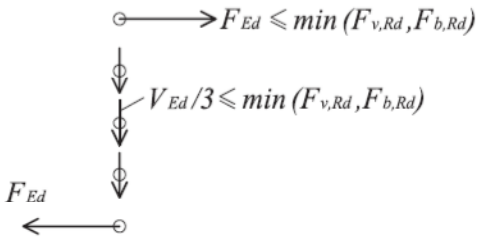
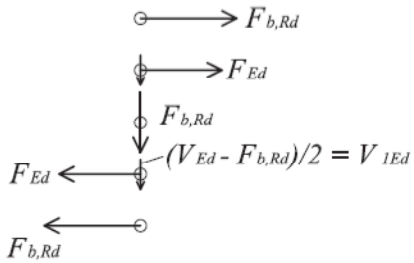
Sile v komponentah spoja

↓

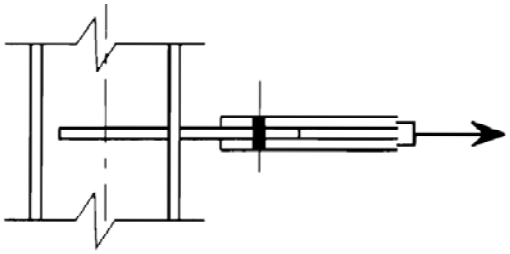
Zvari
Vijaki
Pločevine

Primer: Preklopni ↔ čelni spoj

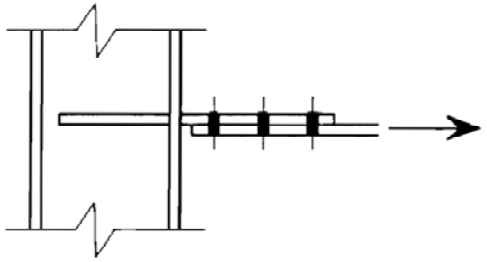


ELASTIČNO	PLASTIČNO
	
$F_{Ed} = \frac{M_{Ed}}{5p}$ $F_{Ed} = \sqrt{F_{Ed}^{\,2} + (V_{Ed}/5)^2} \leq \min(F_{v,Rd}, F_{b,Rd})$	$F_{Ed} = \frac{M_{Ed}}{6p}$
a) razporeditev sil v razmerju z oddaljenostjo od centra rotacije	b) plastičen razpored sil z enim vijakom za prevzem prečne sile in štirimi vijaki za prevzem momenta
	
$F_{Ed} = \frac{M_{Ed}}{4p}$	$F_{Ed} = \frac{M_{Ed}}{2p} - 2F_{b,Rd} \leq F_{b,Rd}(F_{v,Rd})$ $\sqrt{F_{Ed}^{\,2} + V_{1Ed}^{\,2}} \leq F_{b,Rd}(F_{v,Rd})$
c) plastičen razpored sil s tremi vijaki za prevzem prečne sile in dvema vijakoma za prevzem momenta	d) plastičen razpored sil s tremi vijaki za prevzem prečne sile in štirimi vijaki za prevzem momenta

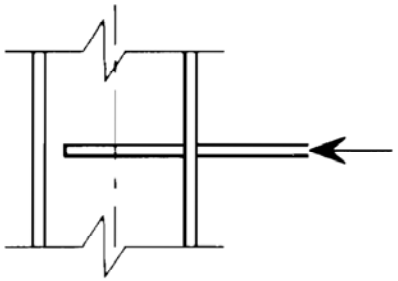
Osnovni primeri obtežbe: nateg, tlak, strig



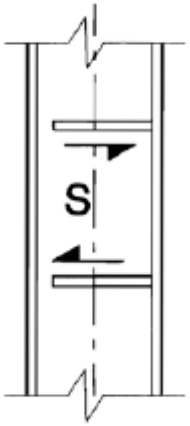
Natezna sila



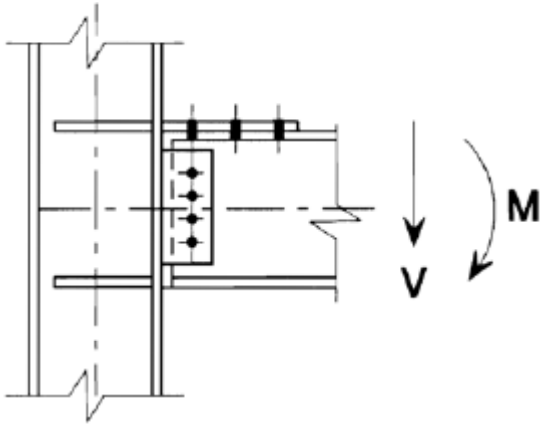
Natezna osna oz. tlačna sila



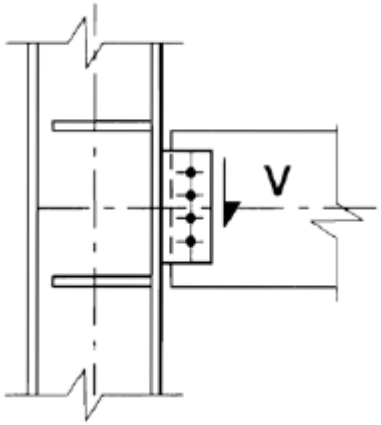
Tlačna sila



Panel v strigu



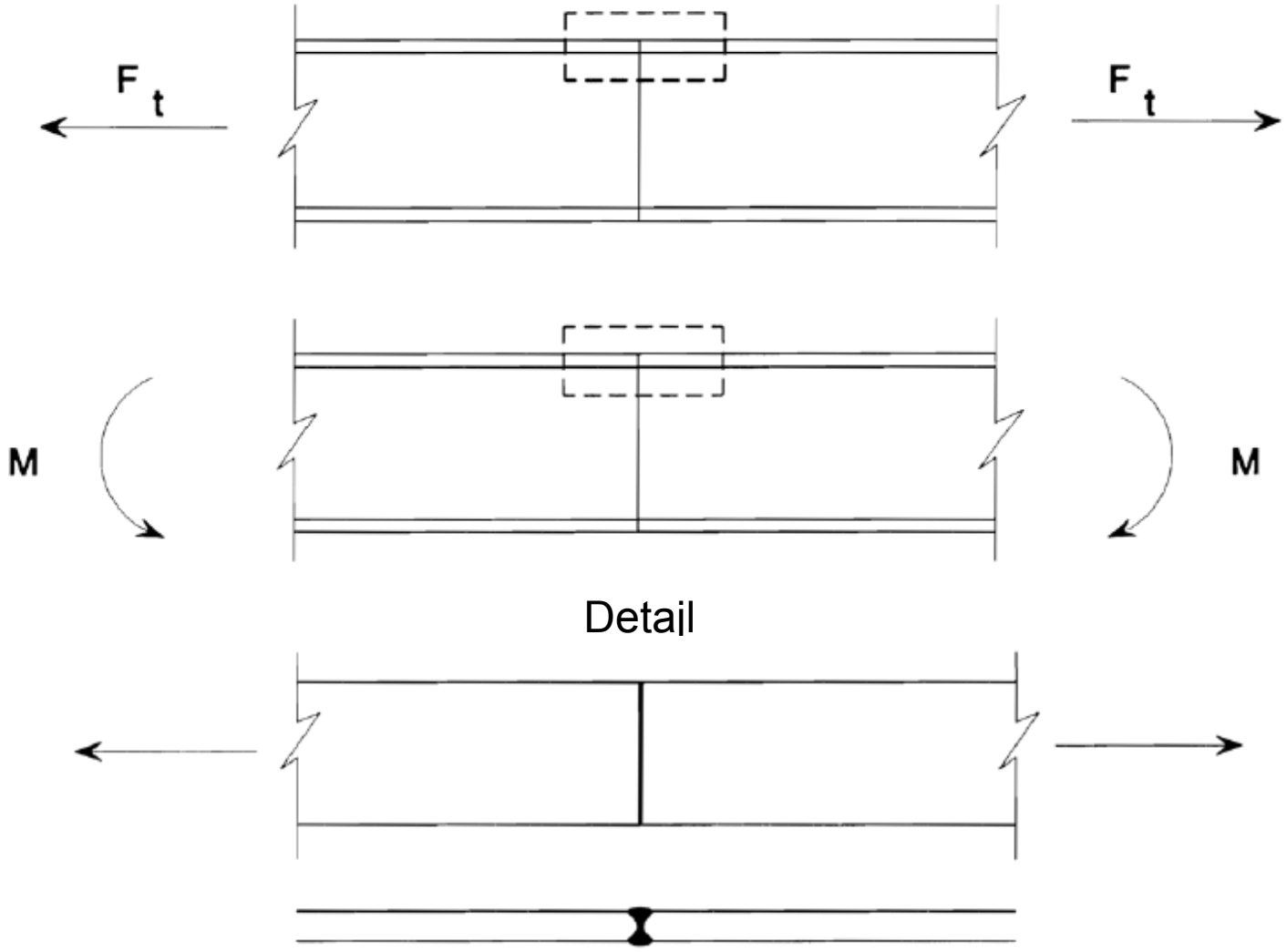
T - stik



Strig

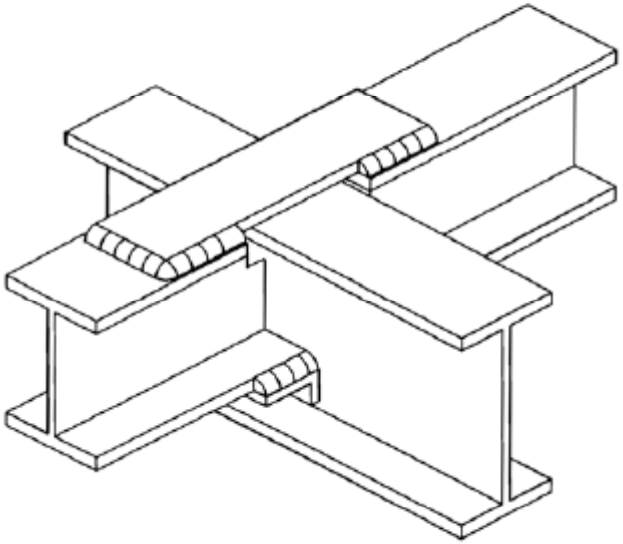
Natezni elementi v spoju

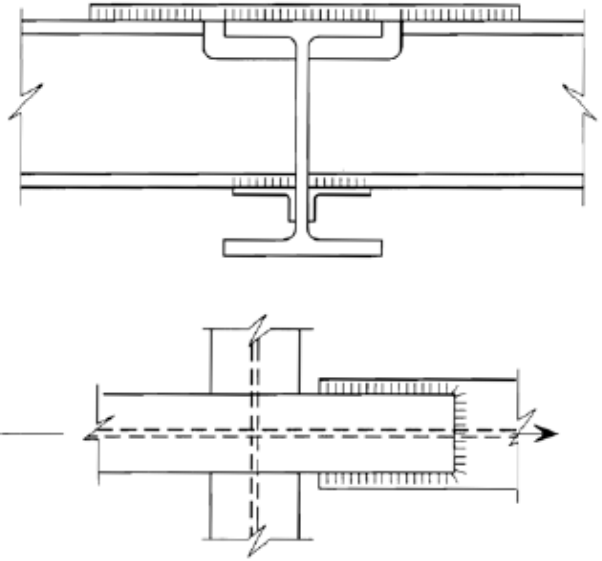
- Čelni zvari



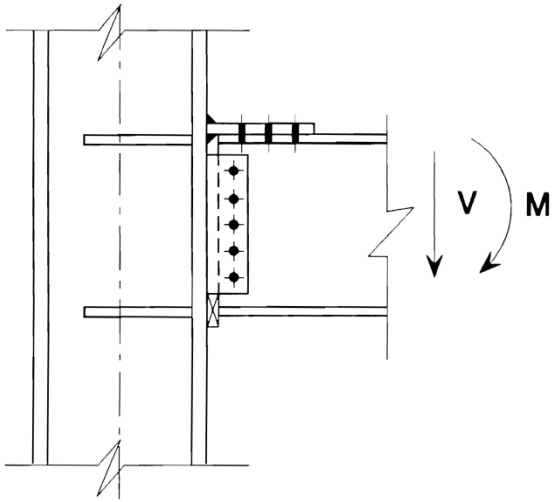
Natezni elementi v spoju

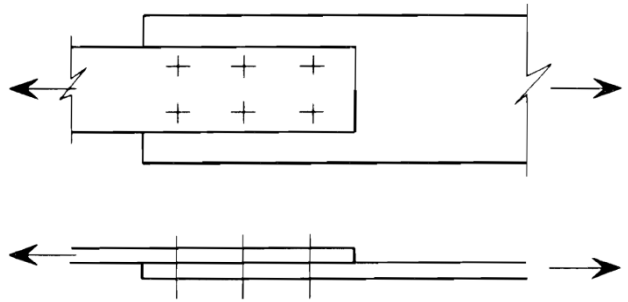
- Preklopni spoj – varjen, vijačen





Enostranska preklopna pločevina: varjena

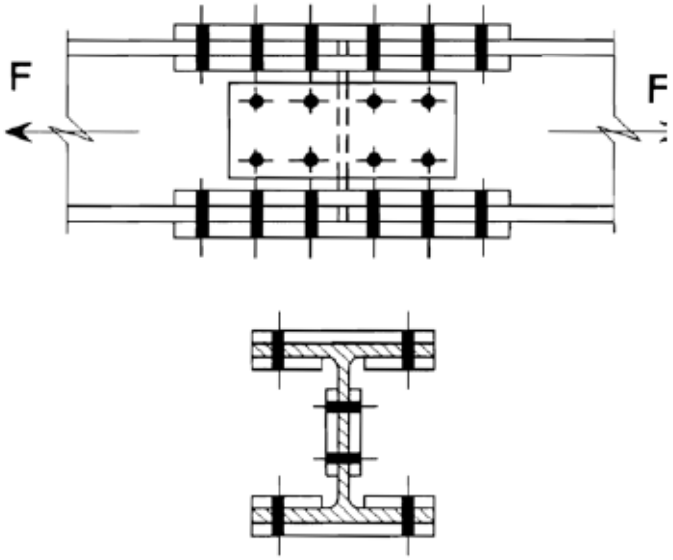


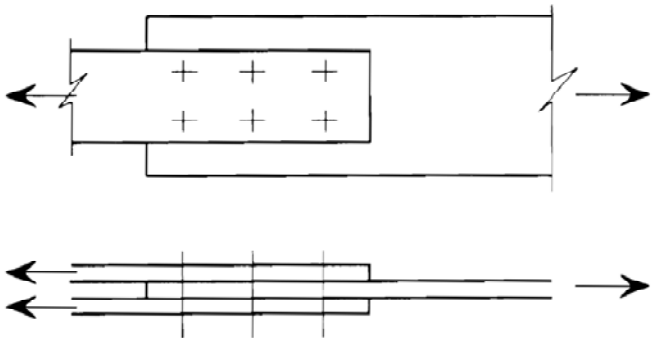


Enostranska preklopna pločevina: vijačena

Natezne palice

- Preklopni spoj – vijačen

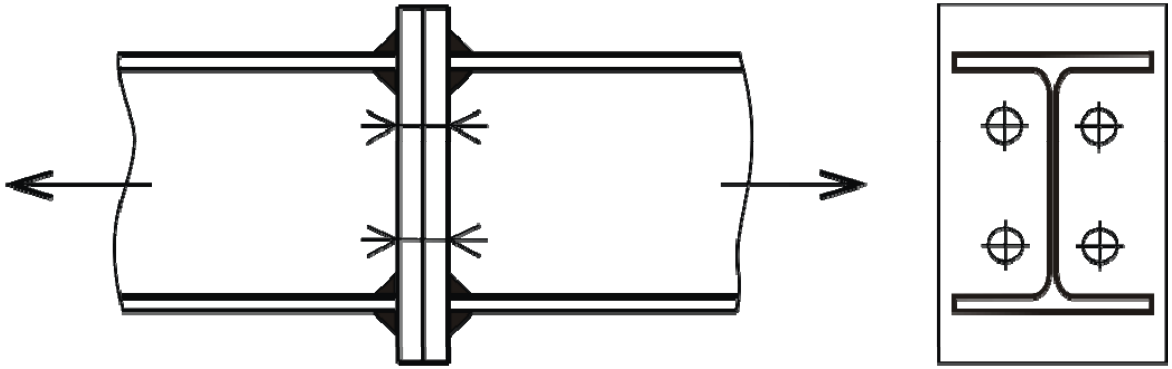




Obojestranska preklopna pločevina: vijačena

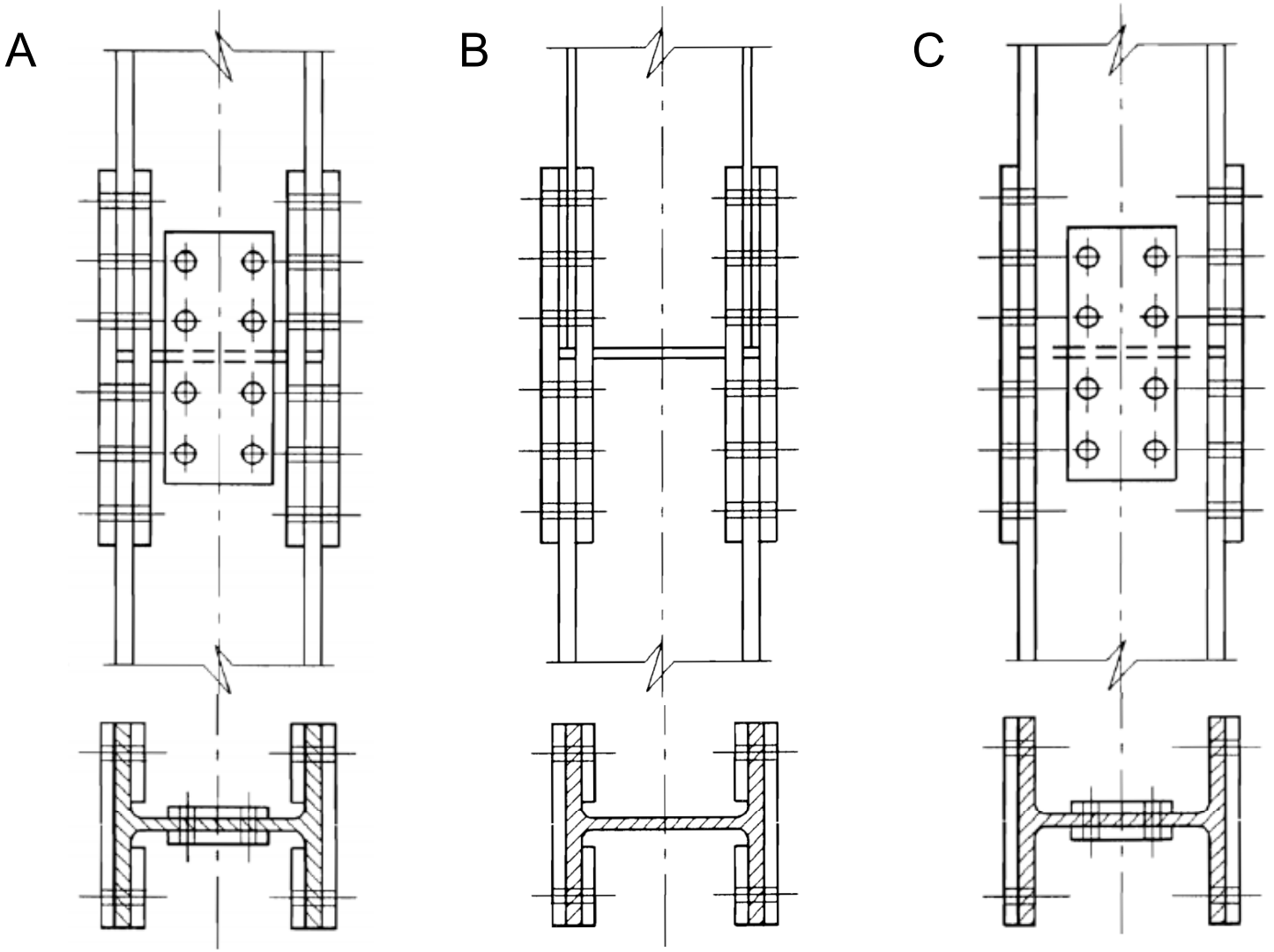
Natezne palice

- Čelni spoj – vijačen

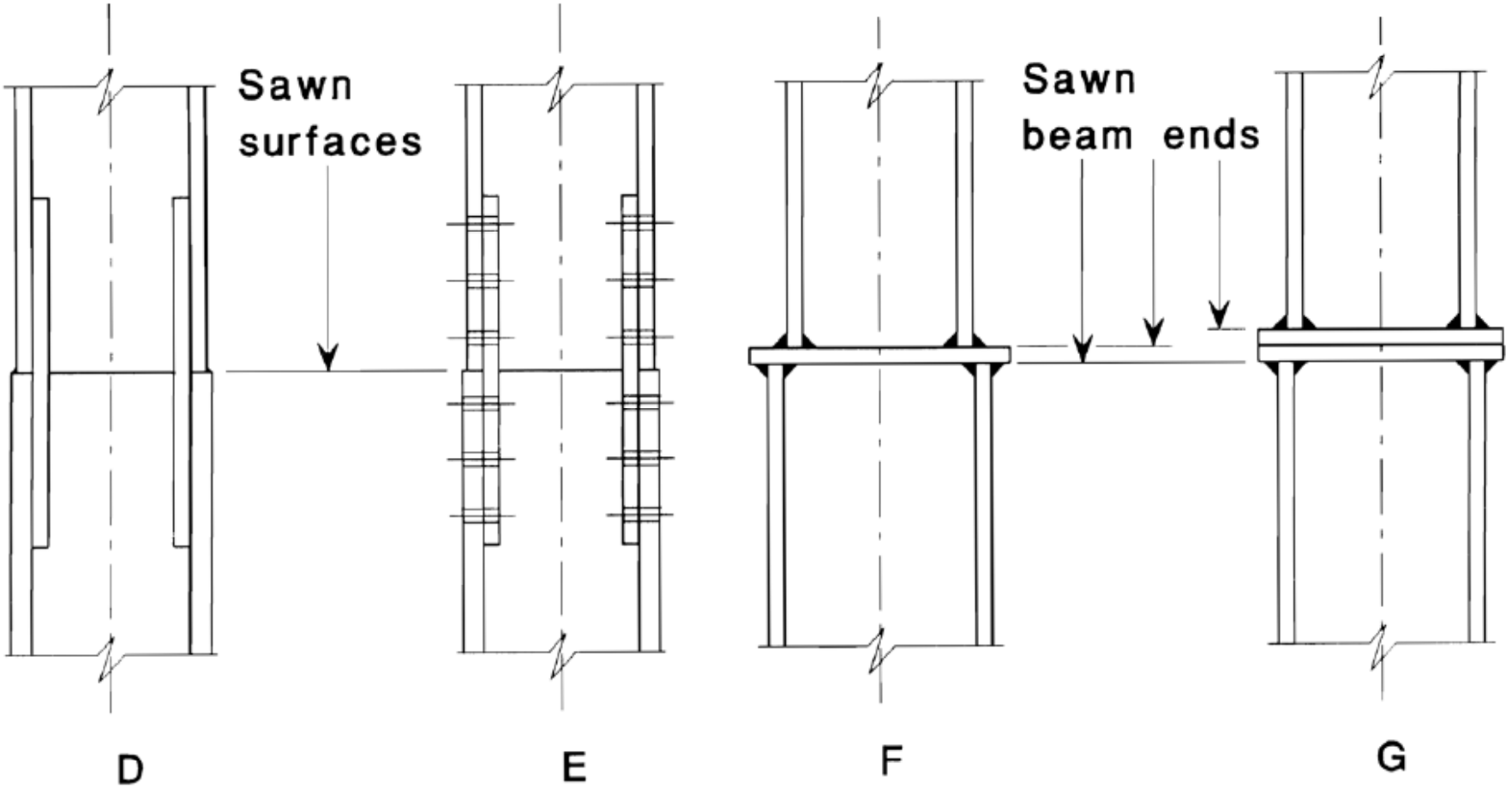


Tlačene palice

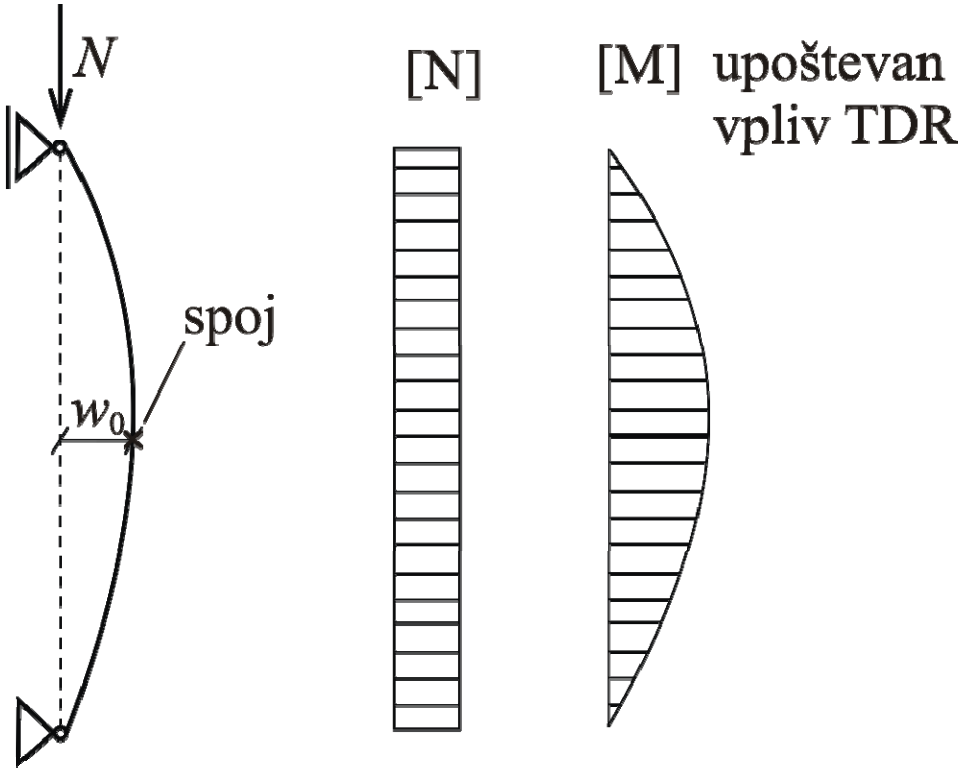
- Čelni in preklopni spoj



- Čelni in preklopni spoj (prenos s kontaktom – obdelane površine)



- Zaradi nevarnosti uklona in vplivov teorije drugega reda je potrebno zagotoviti upogibno togost in nosilnost.



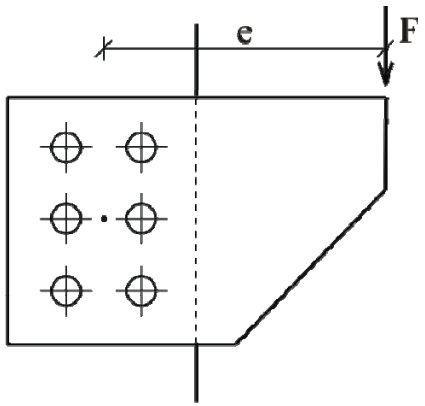
- Spoj v tlačeni palici je potrebno dimenzionirati še na:

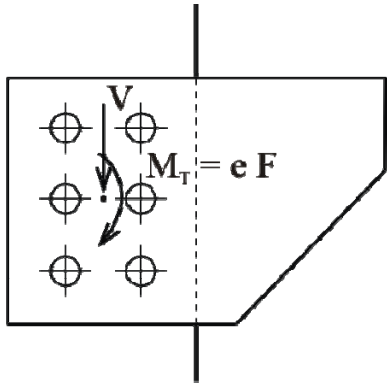
$$M_{Ed} > 0,25 M_{Rd} \left(\text{palice}\right)$$

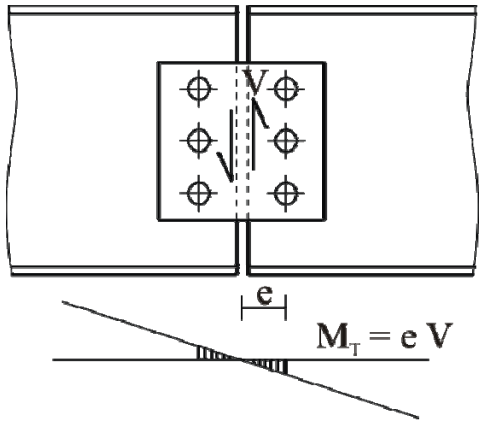
$$V_{Ed} > 0,025 N_{pl,Rd} \left(\text{palice}\right)$$

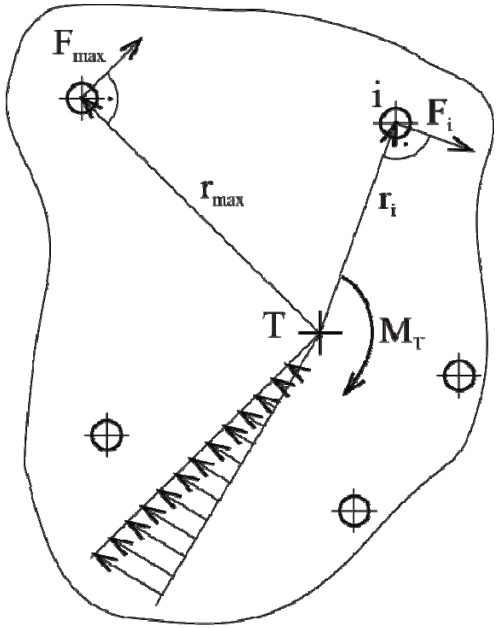
Torzijska obremenitev

- Vijaki









Toga šipa:

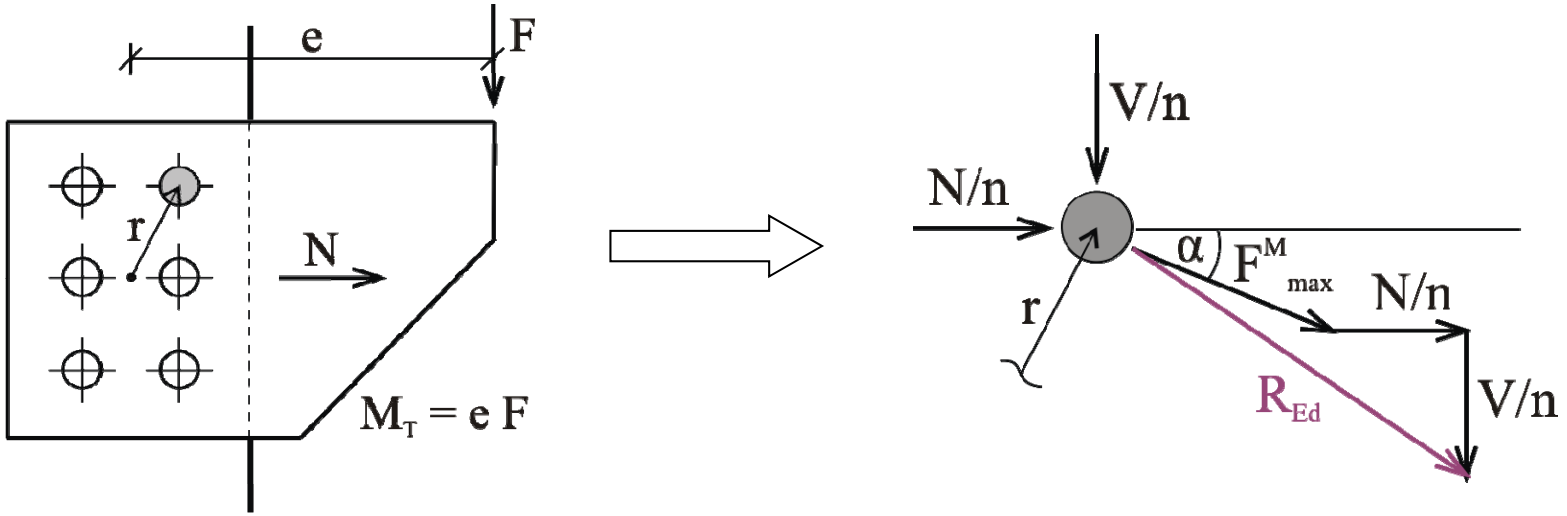
$$M_T = \sum_{i=1}^{n} r_i \cdot F_i$$

$$F_i = F_{\max} \cdot \frac{r_i}{r_{\max}}$$

$$M_T = \frac{F_{\max}}{r_{\max}} \cdot \sum_{i=1}^{n} r_i^2$$

$$F_{\max}^{M} = \frac{r_{\max} \cdot M_T}{\sum_{i=1}^{n} r_i^2}$$

Če na grupo vijakov deluje N, M, V:



$$R_{Ed} = \sqrt{\left(\frac{V}{n} + F^M_{\max} \cdot \sin\alpha\right)^2 + \left(\frac{N}{n} + F^M_{\max} \cdot \cos\alpha\right)^2} \le \min\begin{Bmatrix} F_{v,Rd} \\ F_{b,Rd} \end{Bmatrix}$$

Torzijska obremenitev

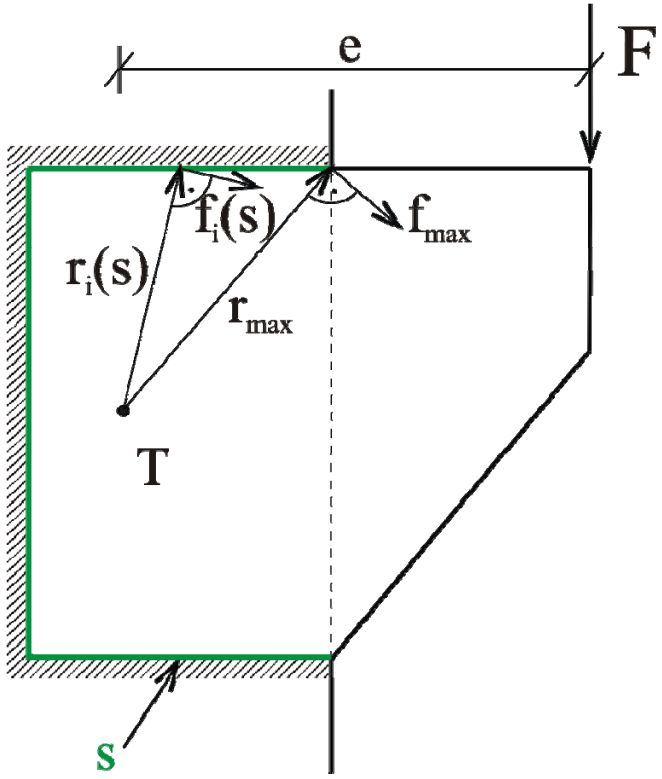
- Zvari

$$M_T = e \cdot F = \int_s r(s) \cdot f_w(s)\, ds$$

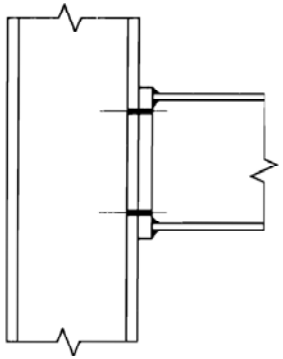
$$f_w(s) = f_{w,\max} \cdot \frac{r(s)}{r_{\max}}$$

$$M_T = \frac{f_{w,\max}}{r_{\max}} \cdot \int_s r^2\, ds$$

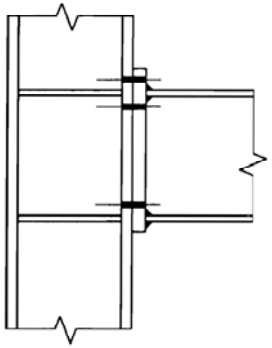
$$f_{\max}^{M} = \frac{M_T \cdot r_{\max}}{a \cdot \int_s r^2 ds}$$



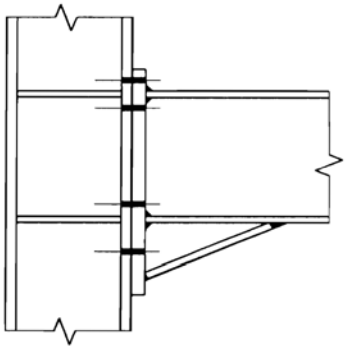
Upogibni spoji



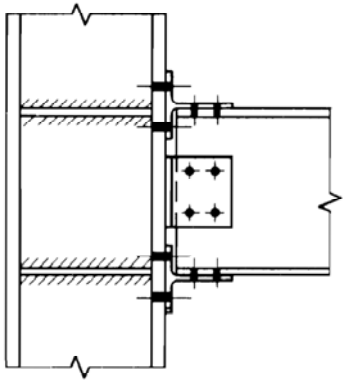
a) S čelno pločevino



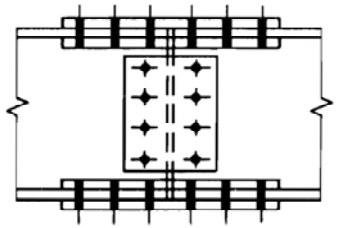
b) S podaljšano čelno pločevino



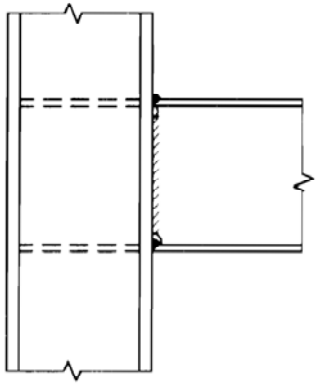
c) Z vuto



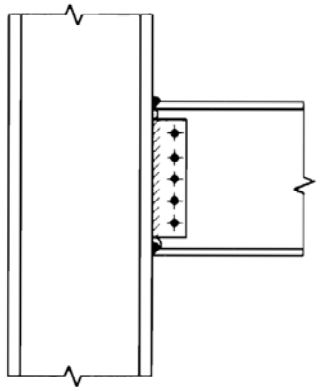
d) T – spoj s prednapetimi vijaki ob pasnici



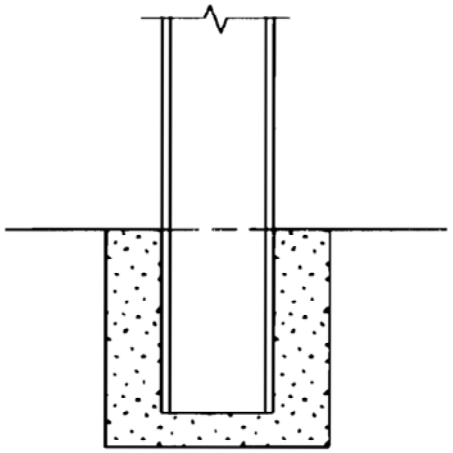
e) Preklopni



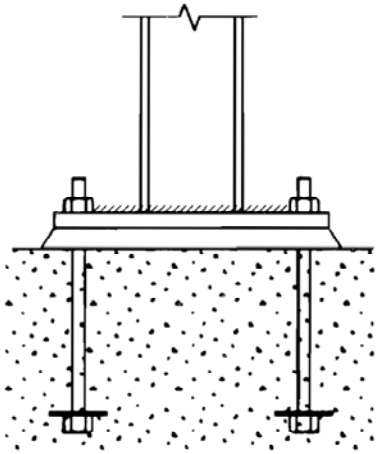
f) Varjen



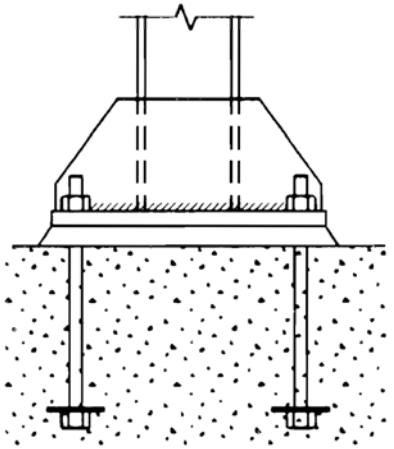
g) Varjen in vijačen



h) Časast temelj

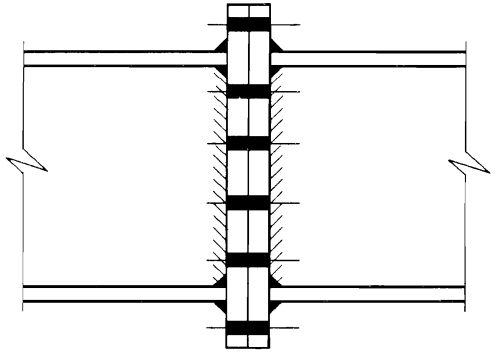


j) Neojačana ležiščna pločevina

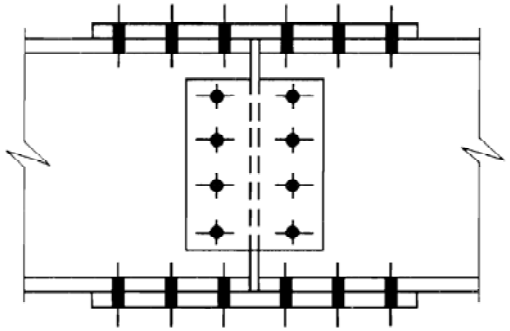


k) Ojačana ležiščna pločevina

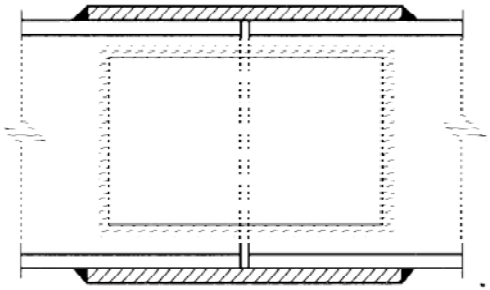
- Stikovanje prečk



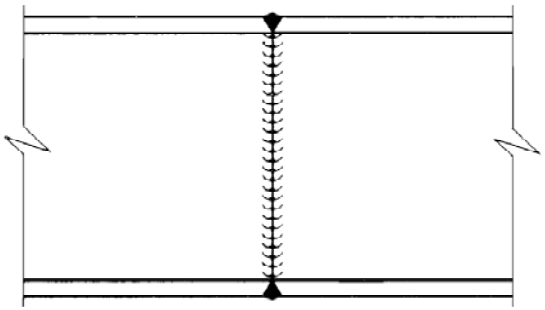
a) S čelno pločevino



b) S preklopno pločevino, vijaki

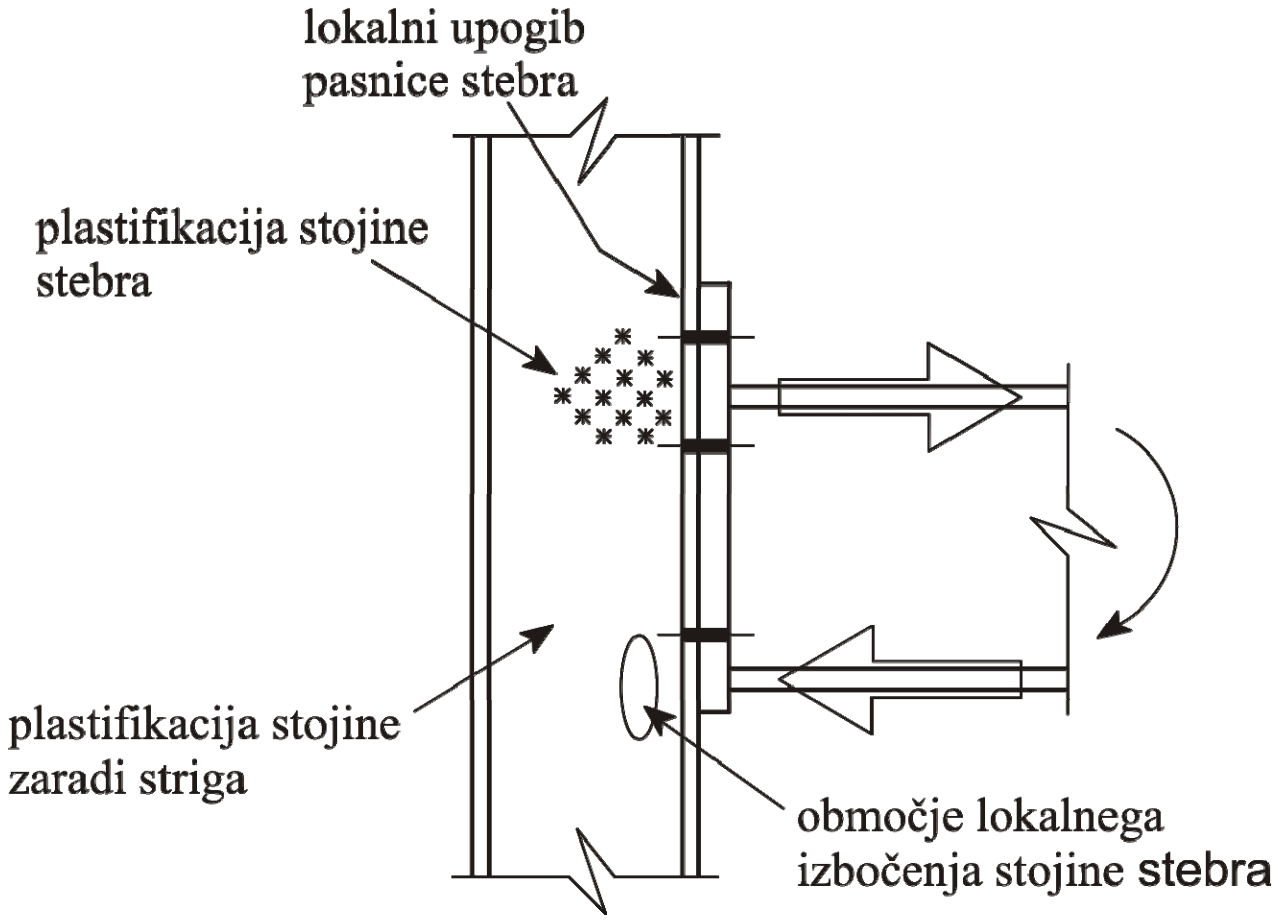


c) S preklopno pločevino, varjeno

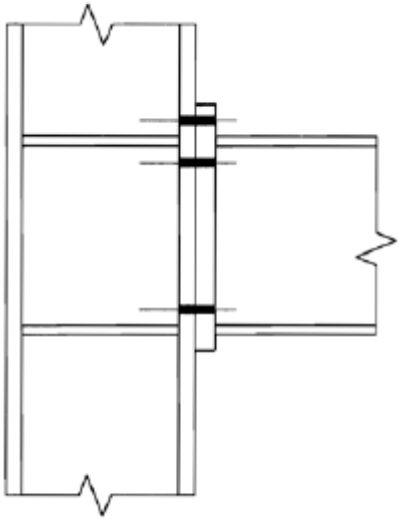


d) S čelnim zvarom

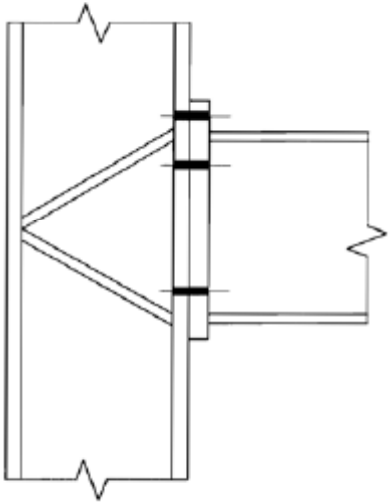
- Vnos koncentriranih sil



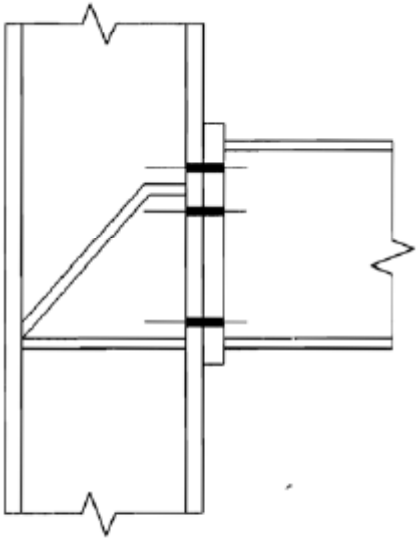
Upogibni spoji - ojačitve



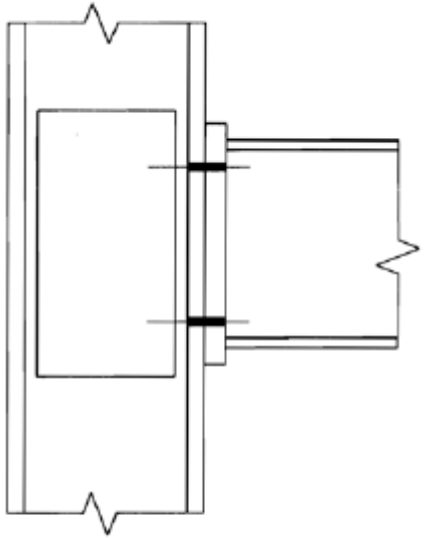
a) Horizontalne ojačitve



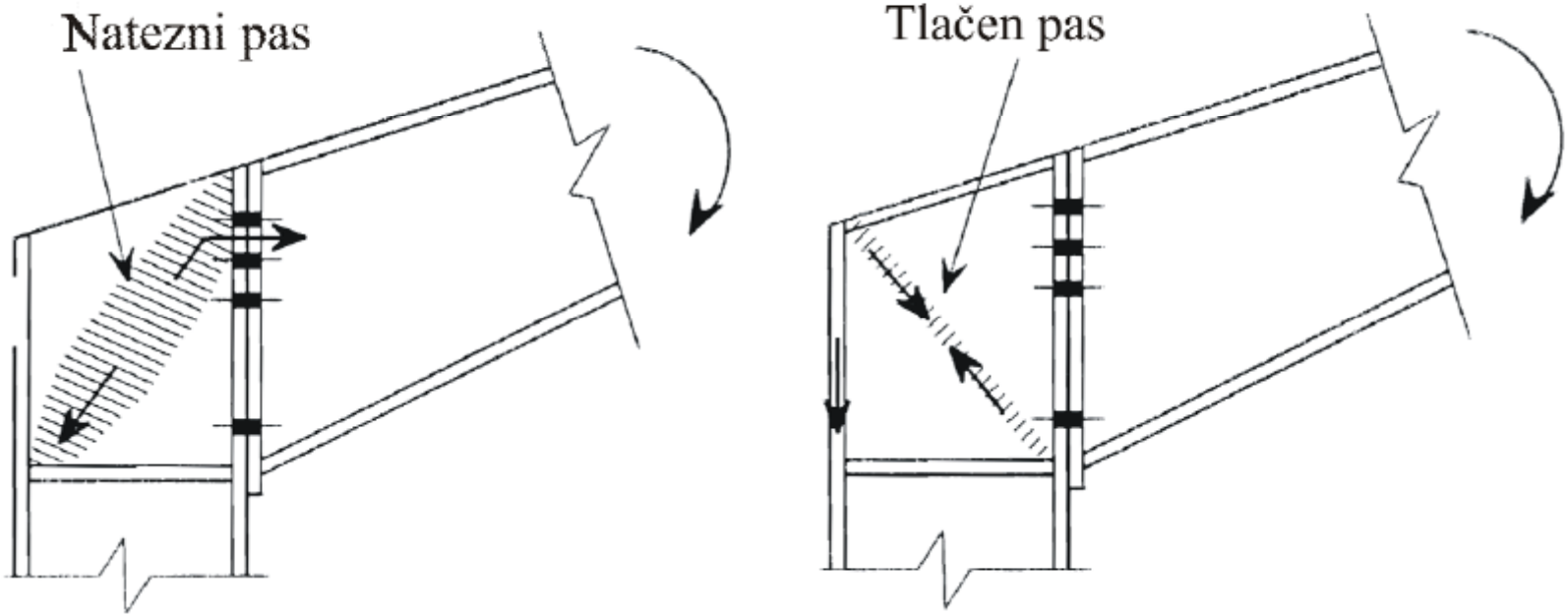
b) "K" ojačitev



c) Ojačitev tipa "Morris" (z ojačitvijo v tlaku)



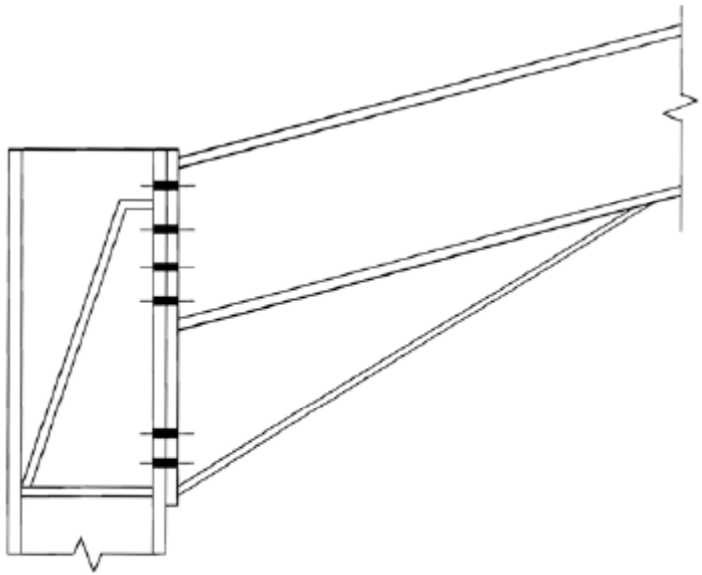
d) Dodatna pločevina ob stojini



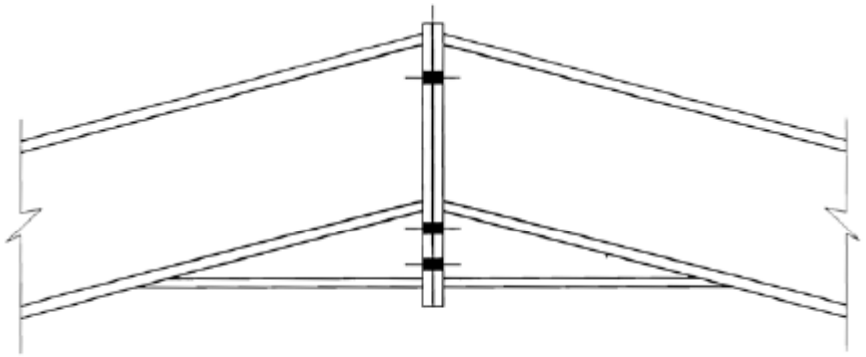
a) Neojačan stik

b) Ojačan stik

Upogibni spoji - Industrijske hale

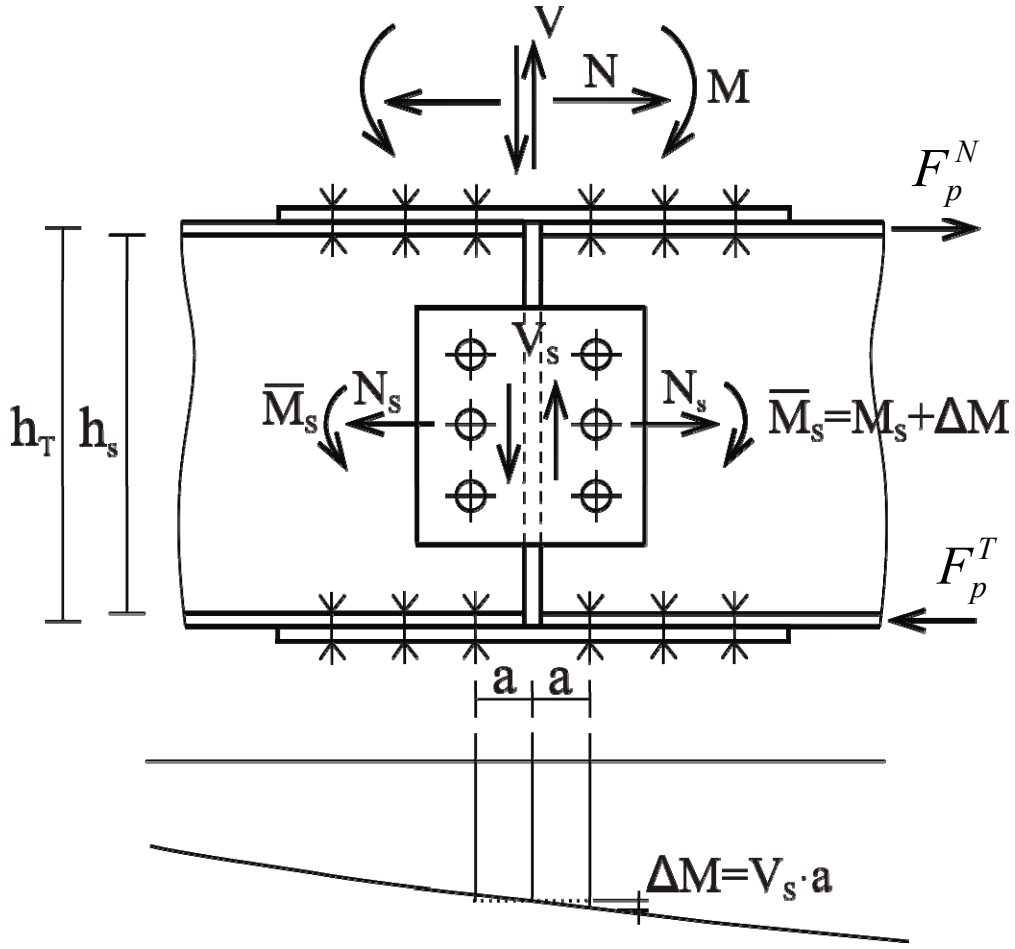


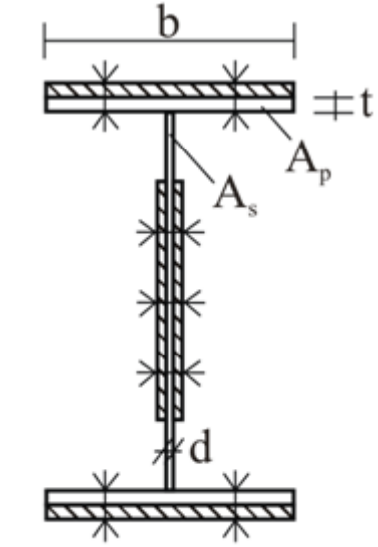
a) Spoj steber – strešni nosilec



b) Spoj v slemenu

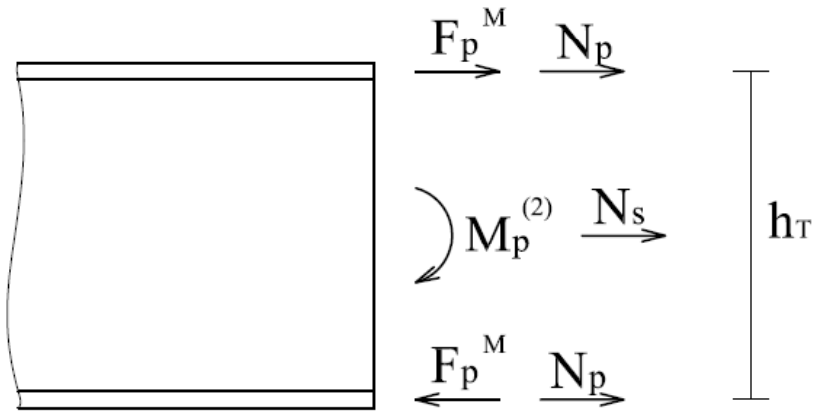
- Preklopni spoj





– razdelitev obremenitve (v razmerju togosti)

$$N_p = \frac{A_p}{A} \cdot N \qquad N_s = \frac{A_s}{A} \cdot N$$



$$I = I_p^{(2)} + I_s = \overbrace{A_p \cdot \frac{h_T^2}{2}}^{\text{obe pasnici}} + h_s^3 \cdot \frac{d}{12}$$

$$M_p^{(2)} = M \cdot \frac{I_p^{(2)}}{I}$$

$$M_s = M \cdot \frac{I_s}{I}$$

$$F_p^M = \frac{M_p^{(2)}}{h_T}$$

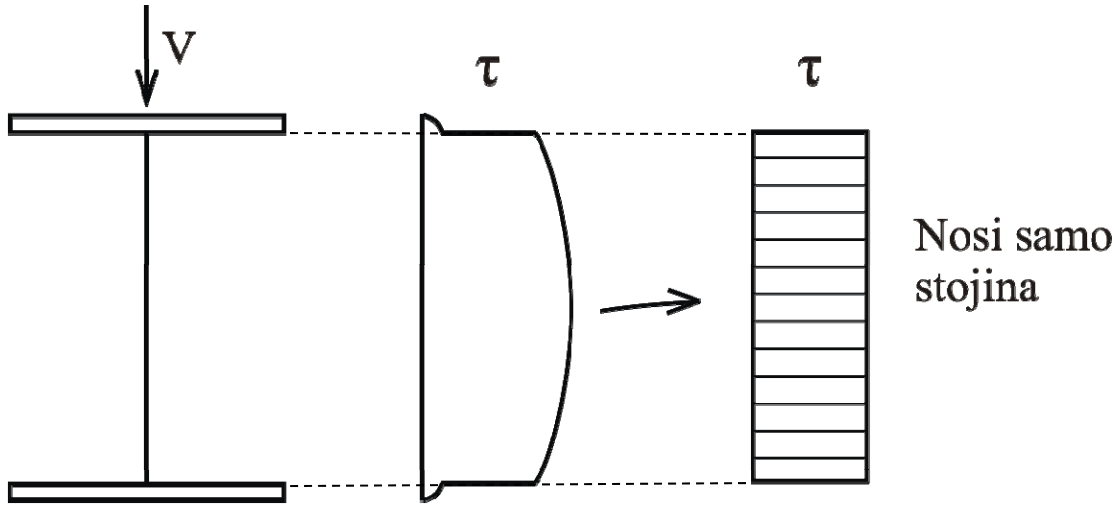
$$F_p^N = N_p + F_p^M$$

$$F_p^T = N_p - F_p^M$$

– razdelitev obremenitve (nadaljevanje)

$V_p = 0$

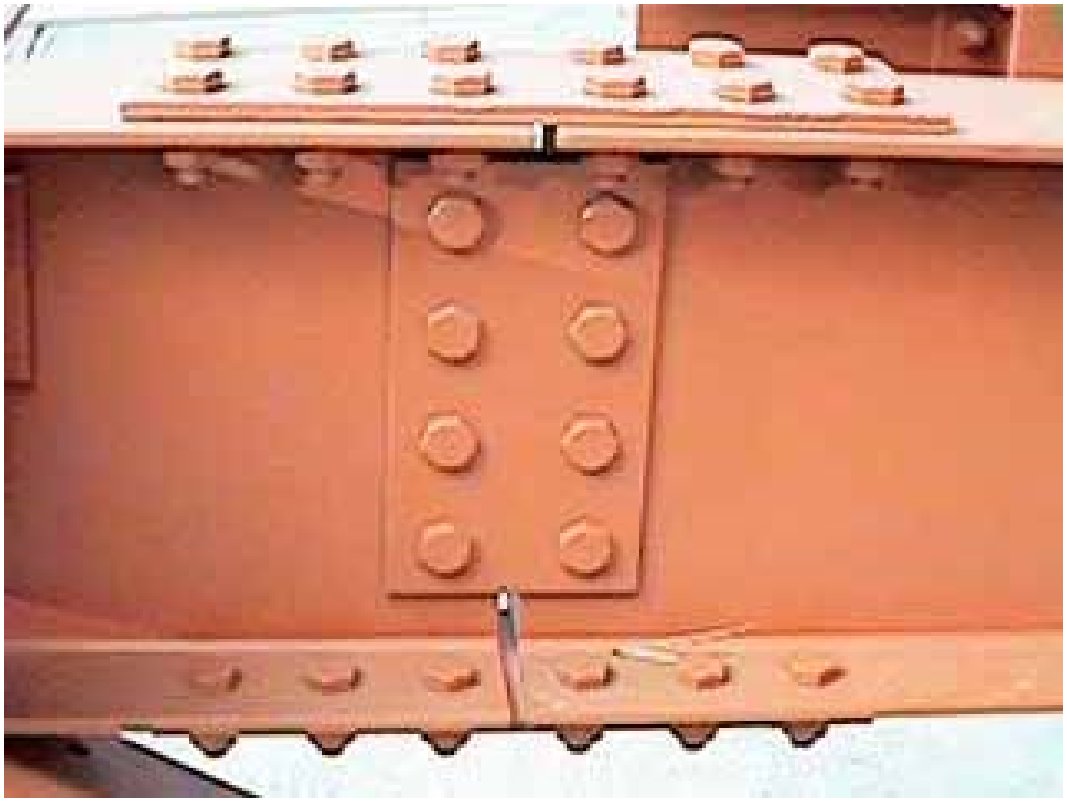
$V_s = V$



Pasnica: $F_p{}^N, F_p{}^T$ natezni stik

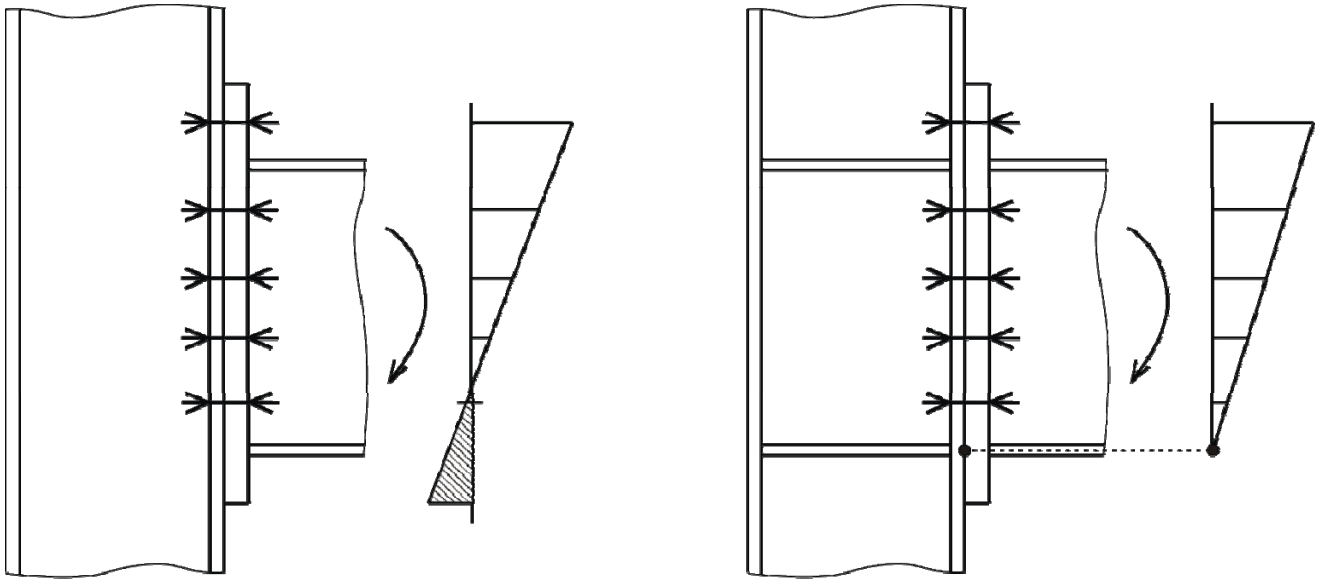
Stojina: $\bar{M}_s = M_s + \Delta M$, V_s } strig (prečna sila + torzijski moment)

N_s nateg



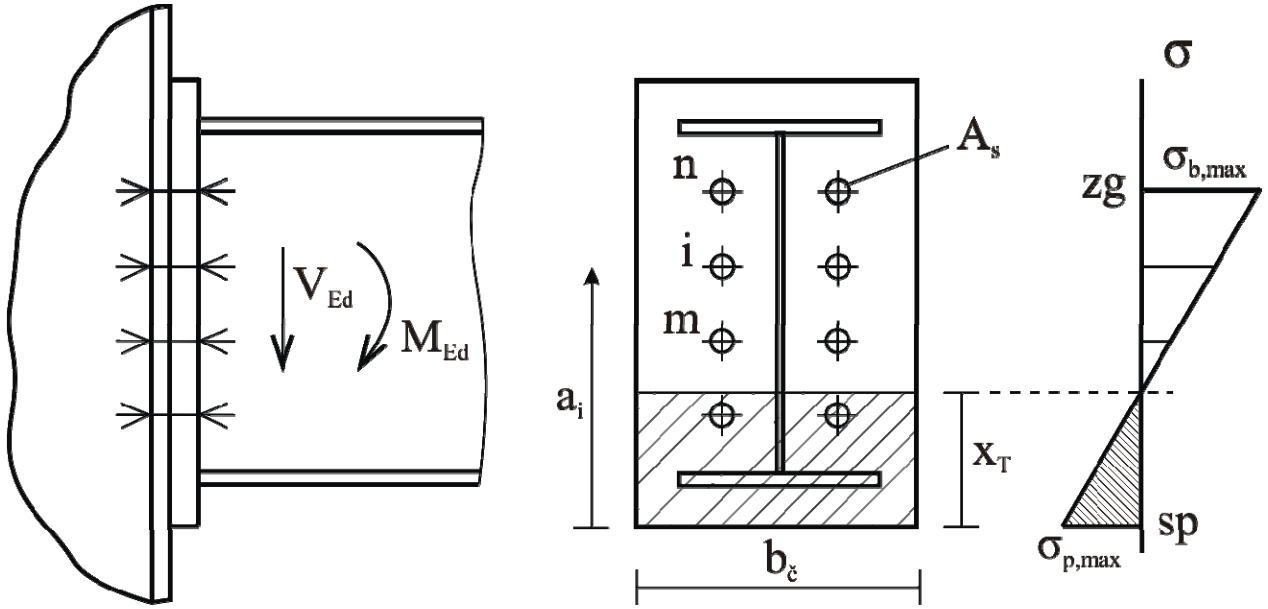
Čelni spoj

- razporeditev sil med vijaki



a) b)

Čelni spoj: PRIMER 1



m = 1 ali 2 (običajno)

Težišče x_T:

$$\frac{b_{č}\, x_T^{\,2}}{2} = \sum_{i=m}^{n} 2\, A_s \left(a_i - x_T\right) = \underbrace{2\, A_s \sum_{i=m}^{n} a_i}_{\beta} - \underbrace{2\, A_s x_T \sum_{i=m}^{n}}_{\alpha} \qquad ; \sum_{i=m}^{n} = n - m + 1$$

$$\alpha = 2\,A_s\left(n-m+1\right)$$

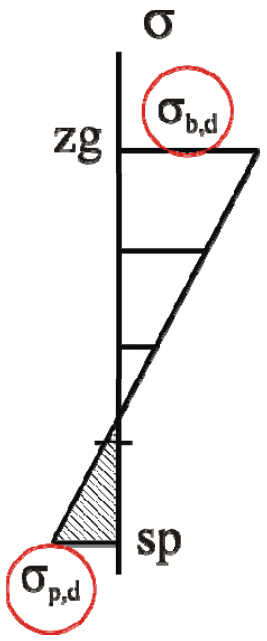
$$\beta = 2\,A_s\sum_{i=m}^{n} a_i$$

$$I_{sp} = \frac{b_{č}\,x_T^{\,3}}{3} + 2\,A_s\sum_{i=m}^{n}\left(a_i - x_T\right)^2$$

$$\frac{b_{č}\,x_T}{2} + \alpha\,x_T - \beta = 0$$

$$W_{zg} = \frac{I_{sp}}{a_n - x_T} \qquad W_{sp} = \frac{I_{sp}}{x_T}$$

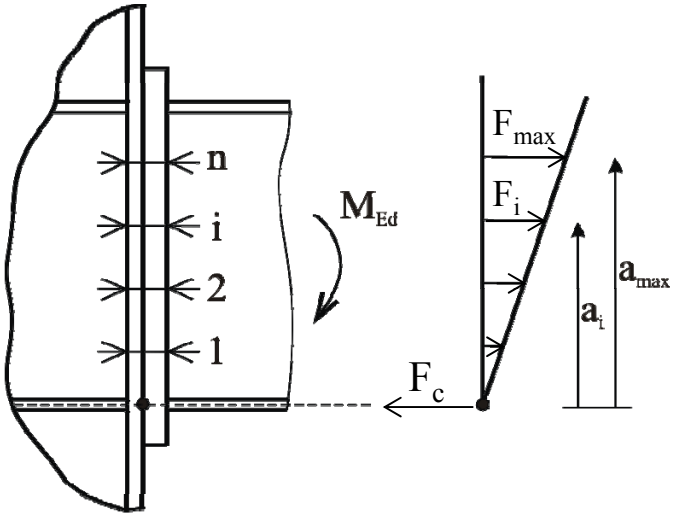
$$\rightarrow \quad x_T = \frac{\beta}{\frac{b_{č}}{2} + \alpha}$$



pločevina: $\sigma_{p,d} = \dfrac{M_{Ed}}{W_p} \le \dfrac{f_y}{\gamma_{M0}}$

vijaki: $\sigma_{b,d} = \dfrac{M_{Ed}}{W_{zg}} \quad \rightarrow \quad F_{t,Ed} = \sigma_{b,d}\cdot A_s < F_{t,Rd}$

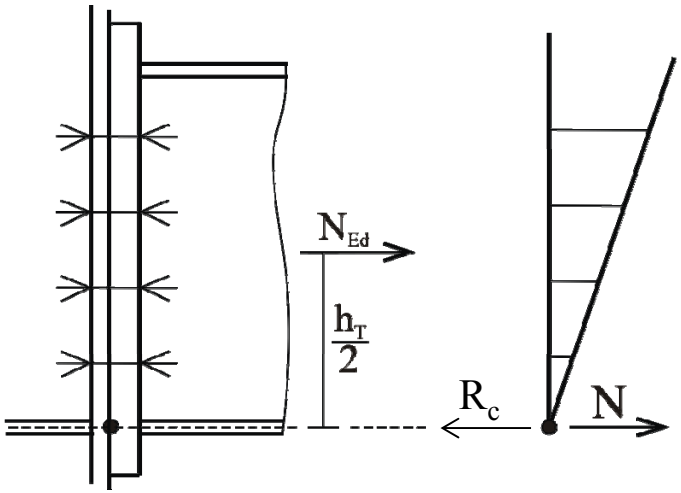
Čelni spoj: PRIMER 2



$$F_{\max} = \frac{M \cdot a_{\max}}{2\sum_{i=1}^{n} a_i^{\,2}}$$

$$F_c = \sum_{i=1}^{n} 2\,F_i$$

$$F_i = F_{\max} \cdot \frac{a_i}{a_{\max}}$$



$$\bar{M} = M + N \cdot \frac{h_T}{2}$$

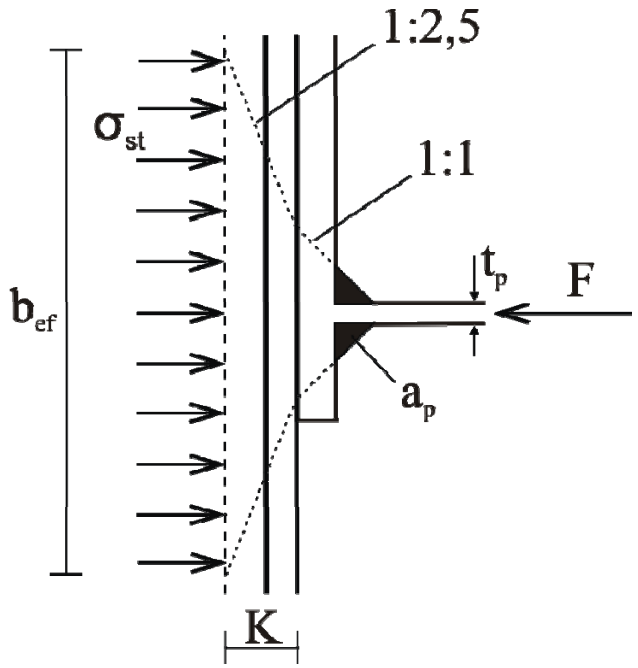
$$R_c = \sum_{i=1}^{n} 2\,F_i - N$$

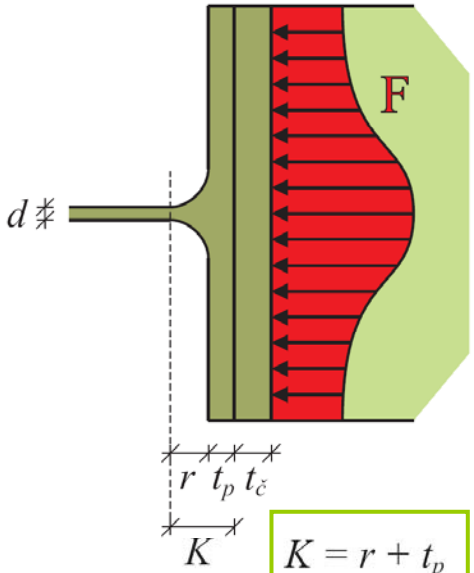
Čelni spoj – VNOS KONCENTRIRANIH SIL

$$b_{ef} = t_{ps} + \left(2\sqrt{2}\, a_p\right) + 5K$$

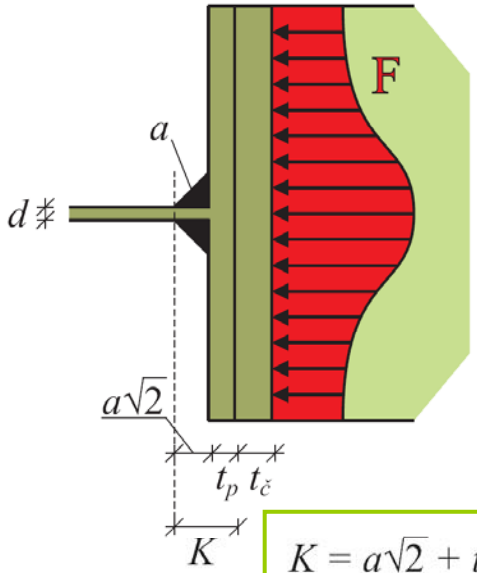
$$b_{ef} = l_0 + 5K$$

$$\sigma_{st} = \frac{F}{b_{ef} \cdot d}$$

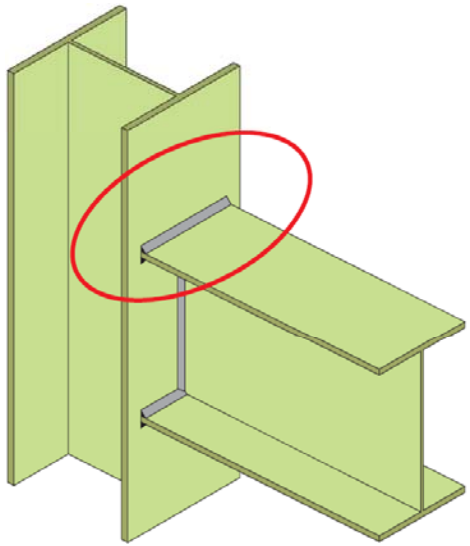


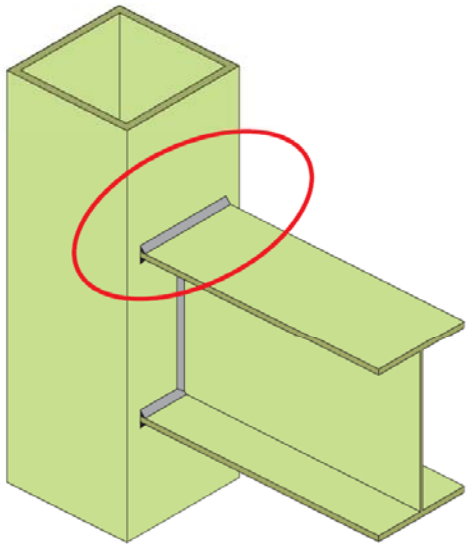


$K = r + t_p$



$K = a\sqrt{2} + t_p$





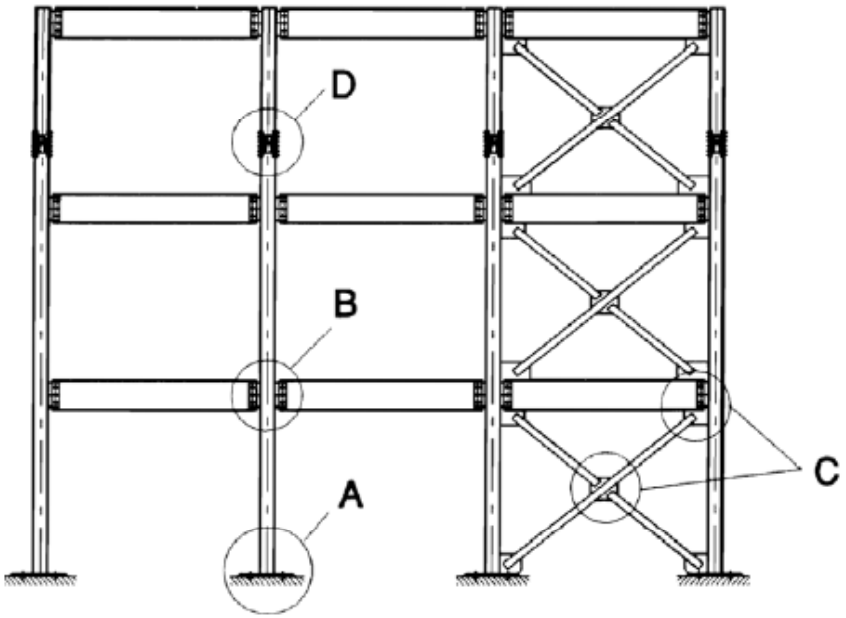
Členkasti spoji

- <u>Uporaba</u>

Prenašajo **samo strižno silo** in **nimajo** znatnejše **rotacijske togosti**.

- okvir podprt na togi nosilni element

a) Okvir z diagonalnim povezjem



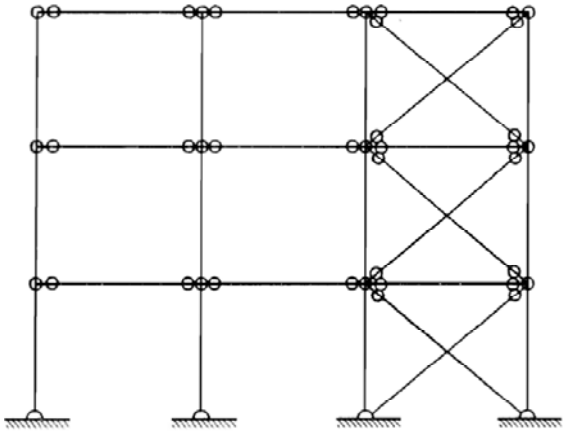
A – priključek stebra na temelj

B – spoj prečka – steber

C – spoj v povezju

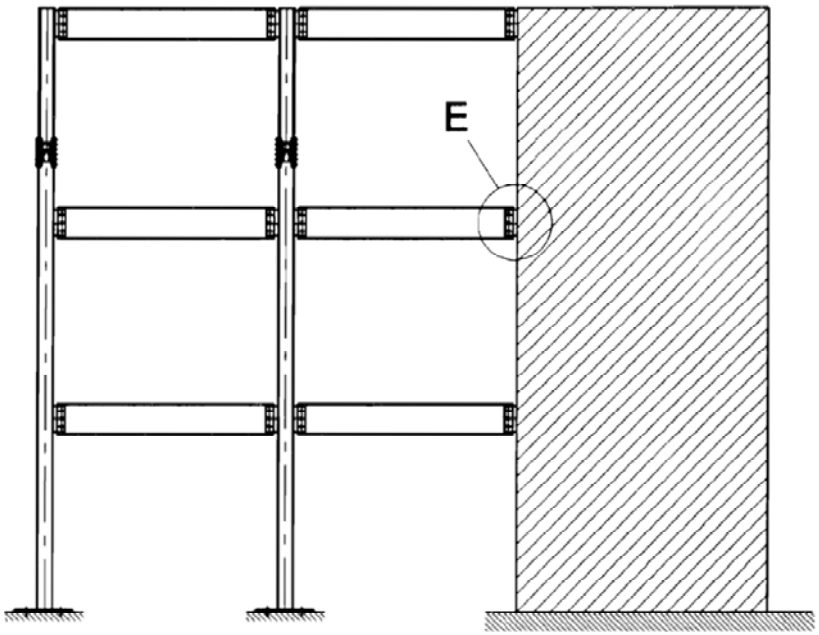
D – spoj na stebru

Idealizacija konstrukcije



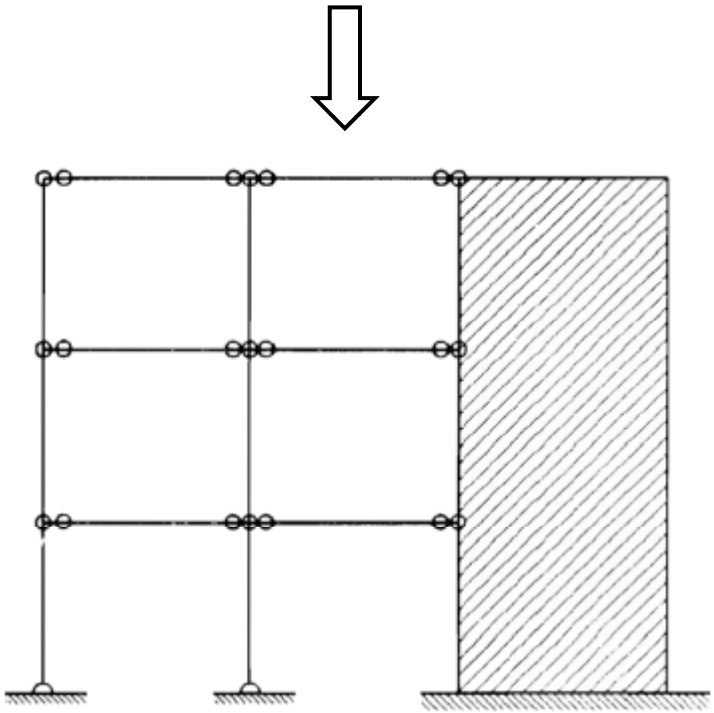
Členkasti spoji - uporaba

b) Okvir podprt z betonsko konstrukcijo



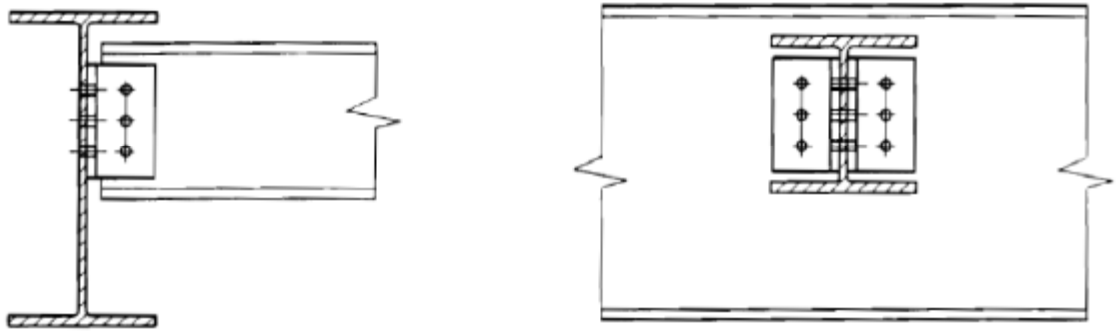
E – spoj z betonskim delom

Idealizacija konstrukcije

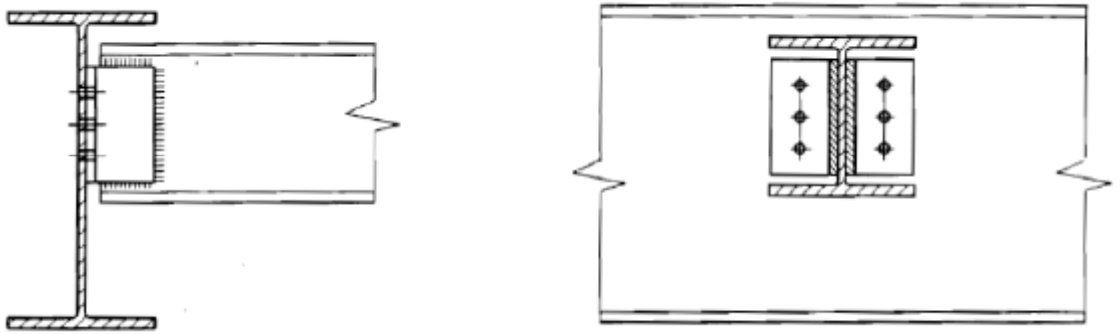


- členkasti spoji prečka - prečka

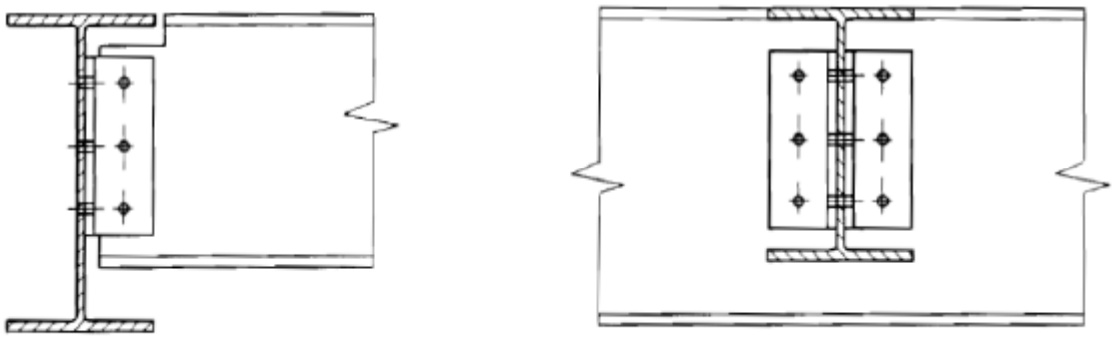
A



B

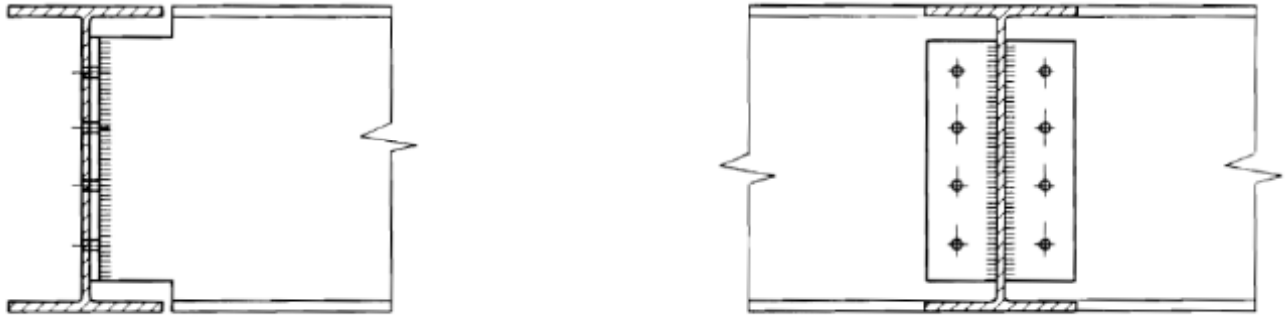


C

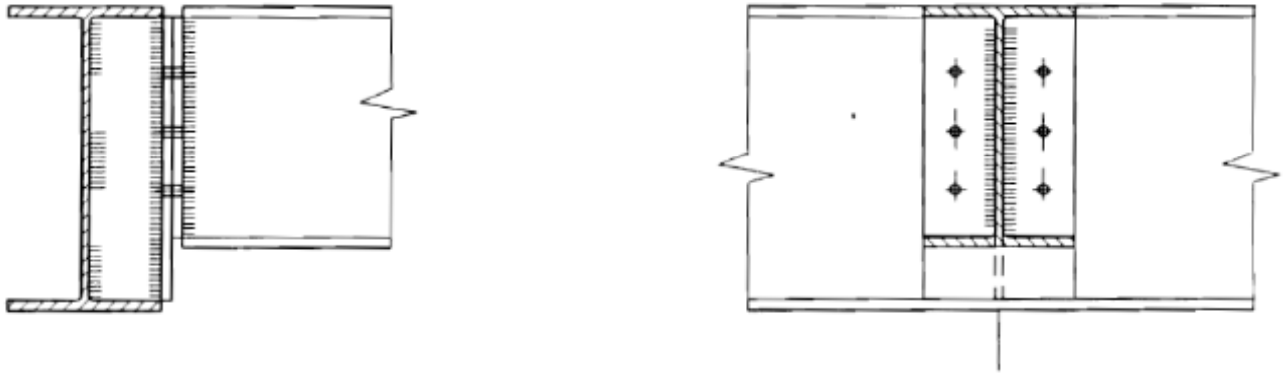


- členkasti spoji prečka – prečka (nadaljevanje)

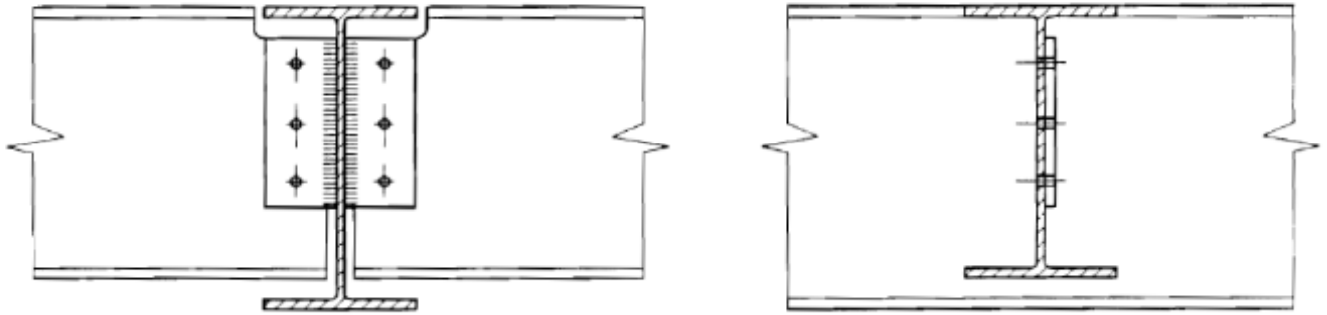
D



E

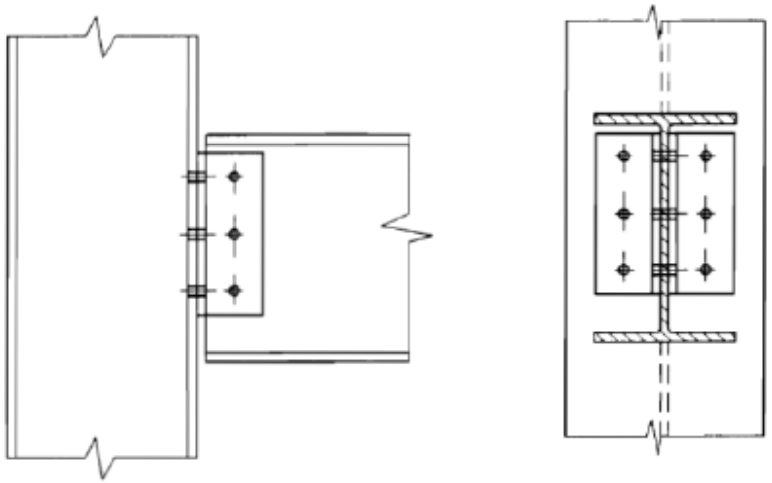


F

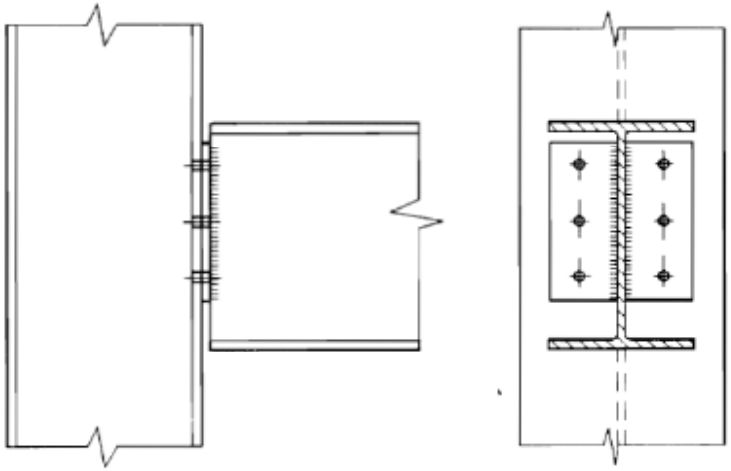


- členkasti spoji steber – prečka

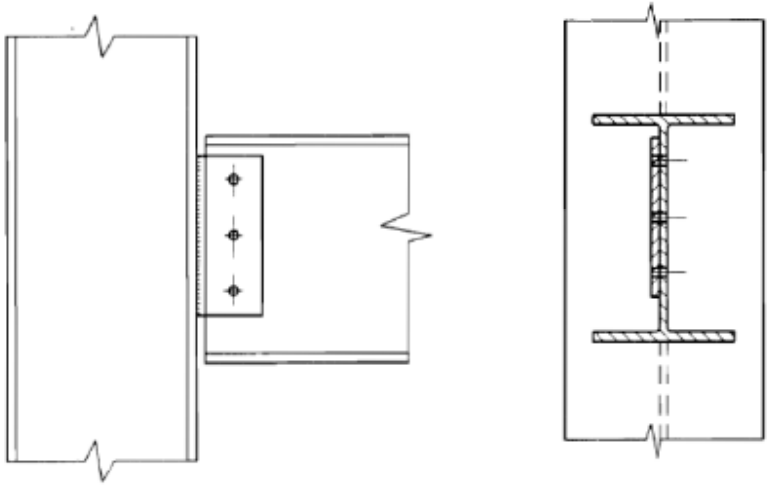
A



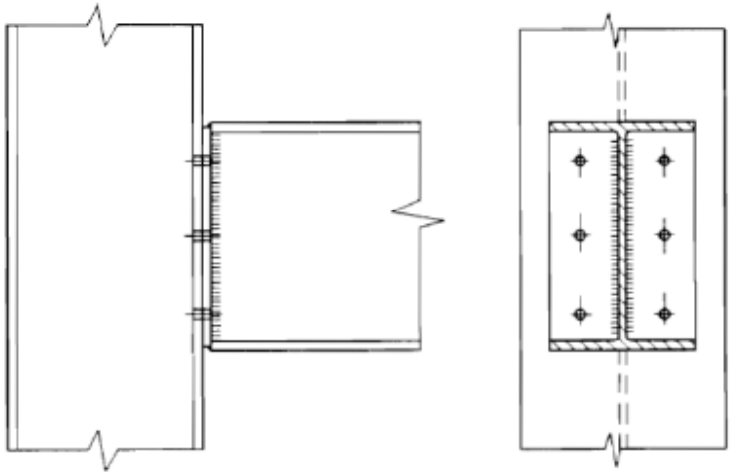
C



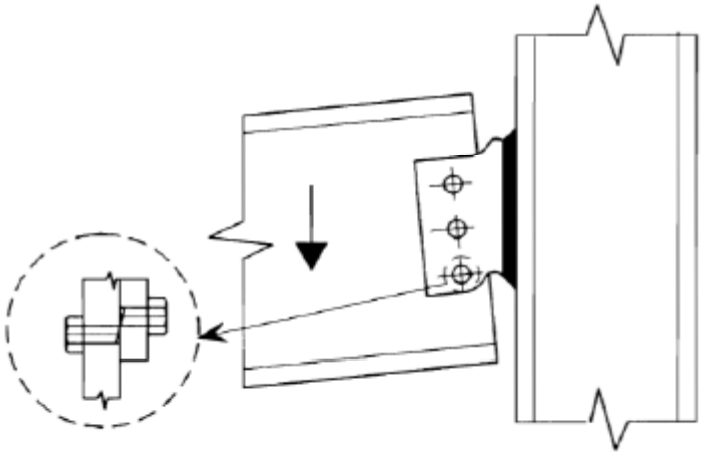
B



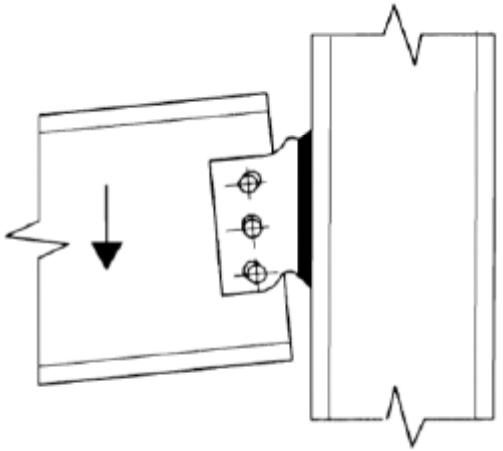
D



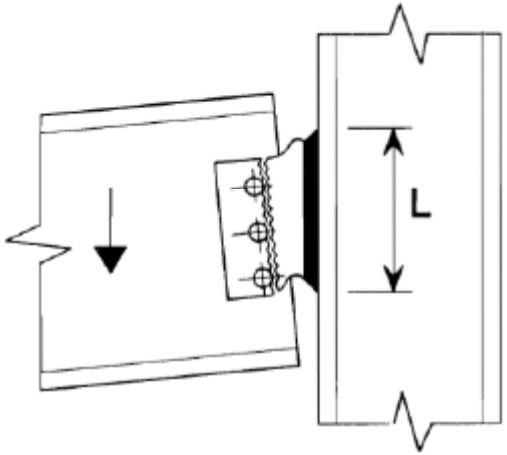
- možni načini porušitve



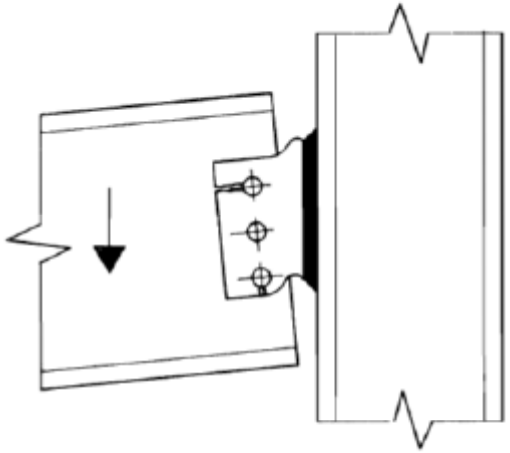
a) pretrg vijaka



b) porušitev na bočni pritisk

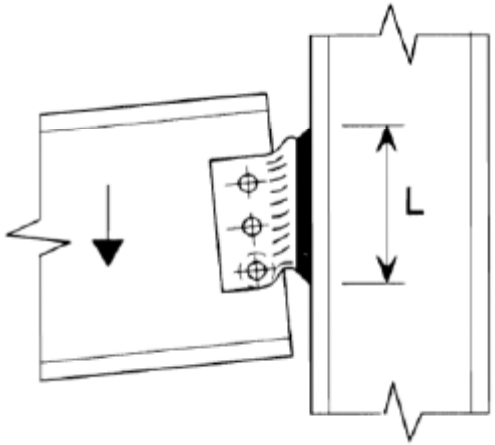


c) porušitev neto prereza

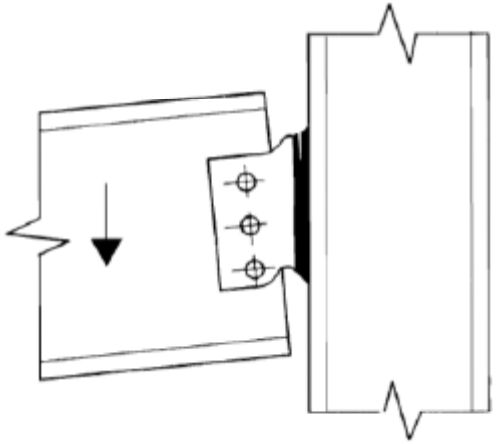


d) iztrg vijaka

- možni načini porušitve (nadaljevanje)

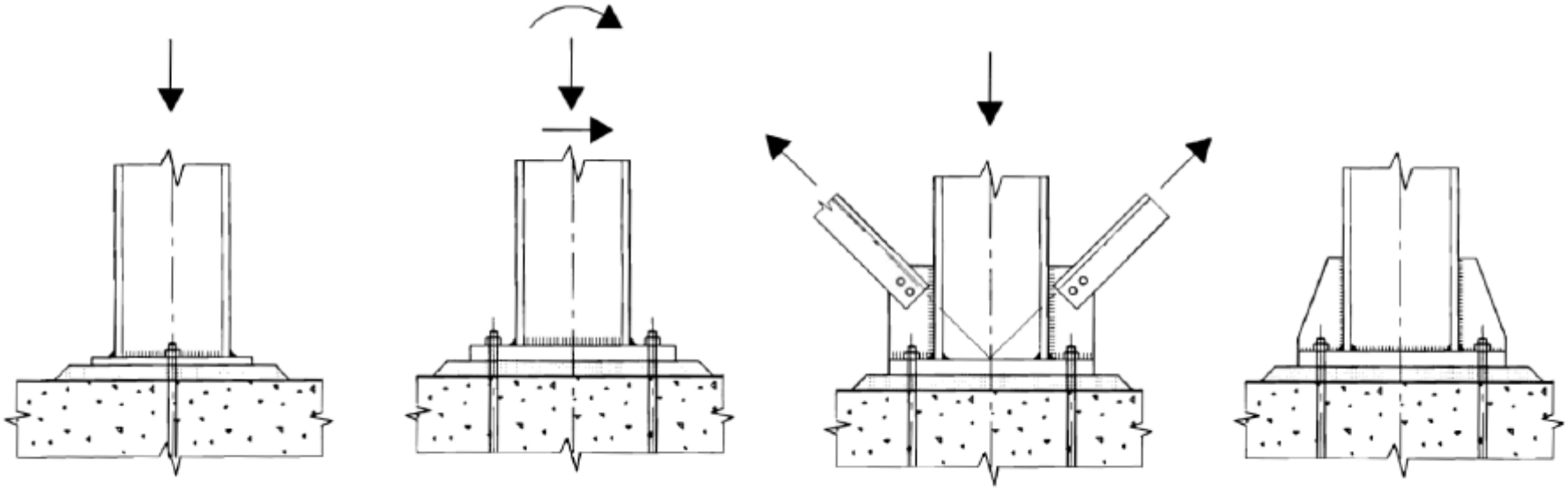


e) plastifikacija vezne pločevine



f) porušitev zvara

- priklujčki na temelj



a) Nominalno členkast priključek

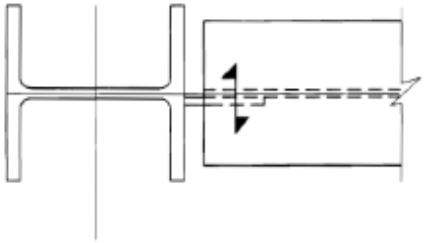
b)

c)

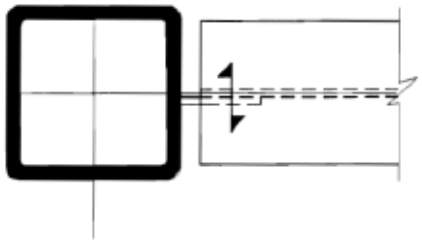
d)

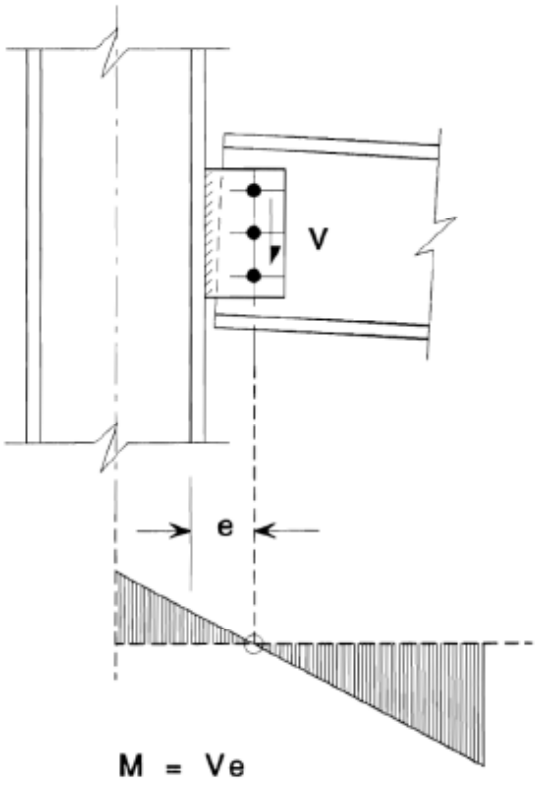
- Delitev

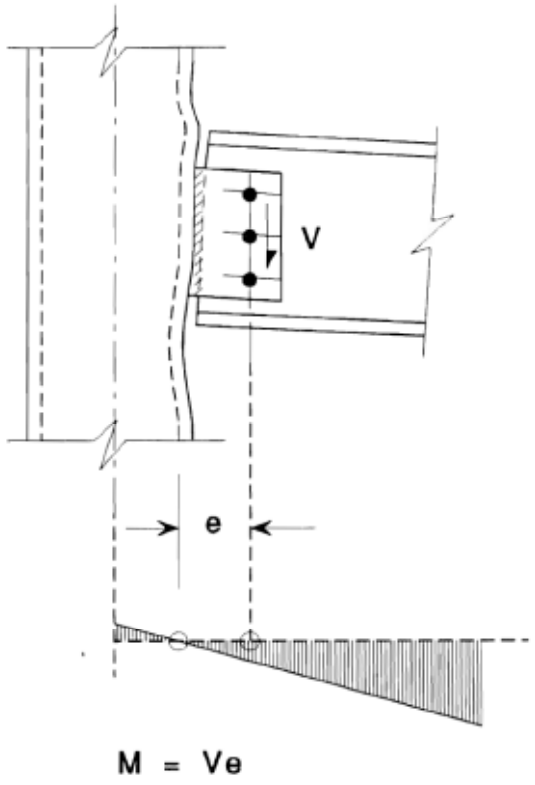
a) **toga podpora:**



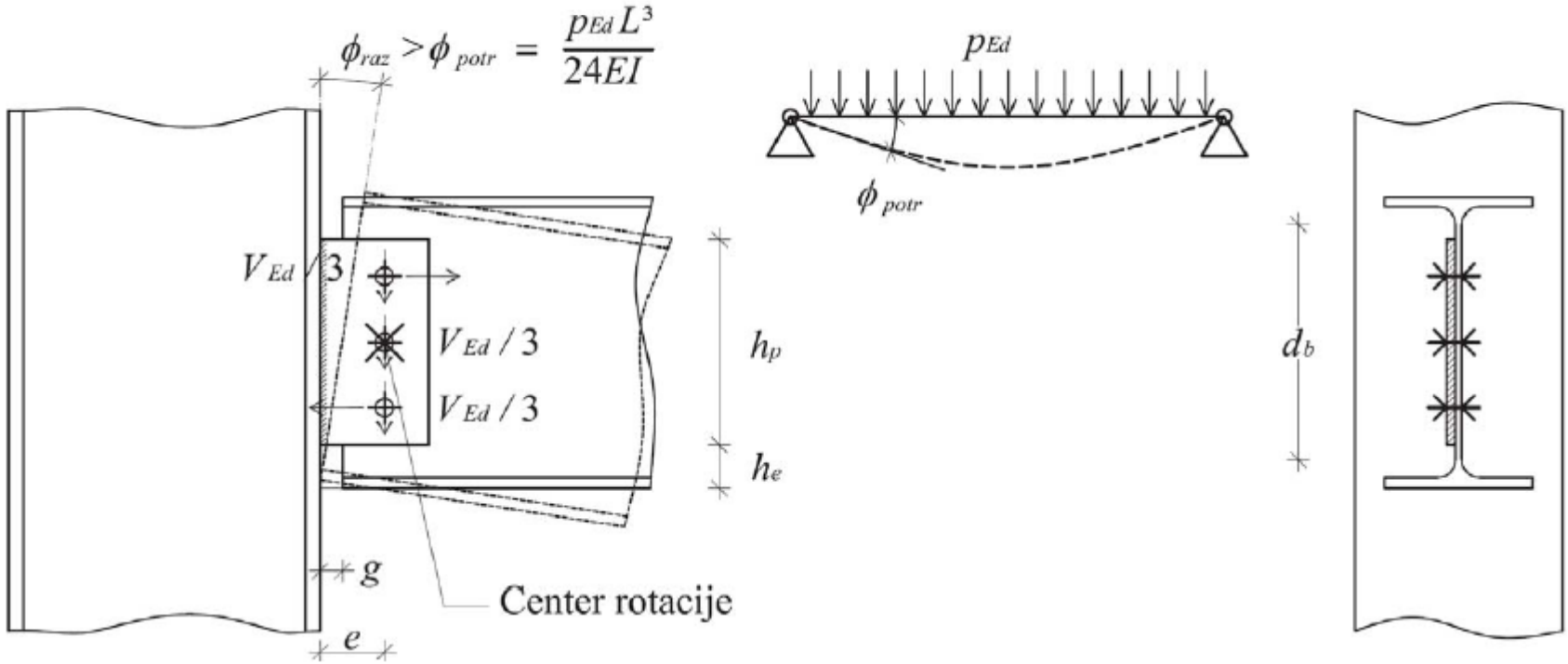
b) **podajna podpora:**







Členkasti spoj z vezno pločevino



Načela projektiranja:

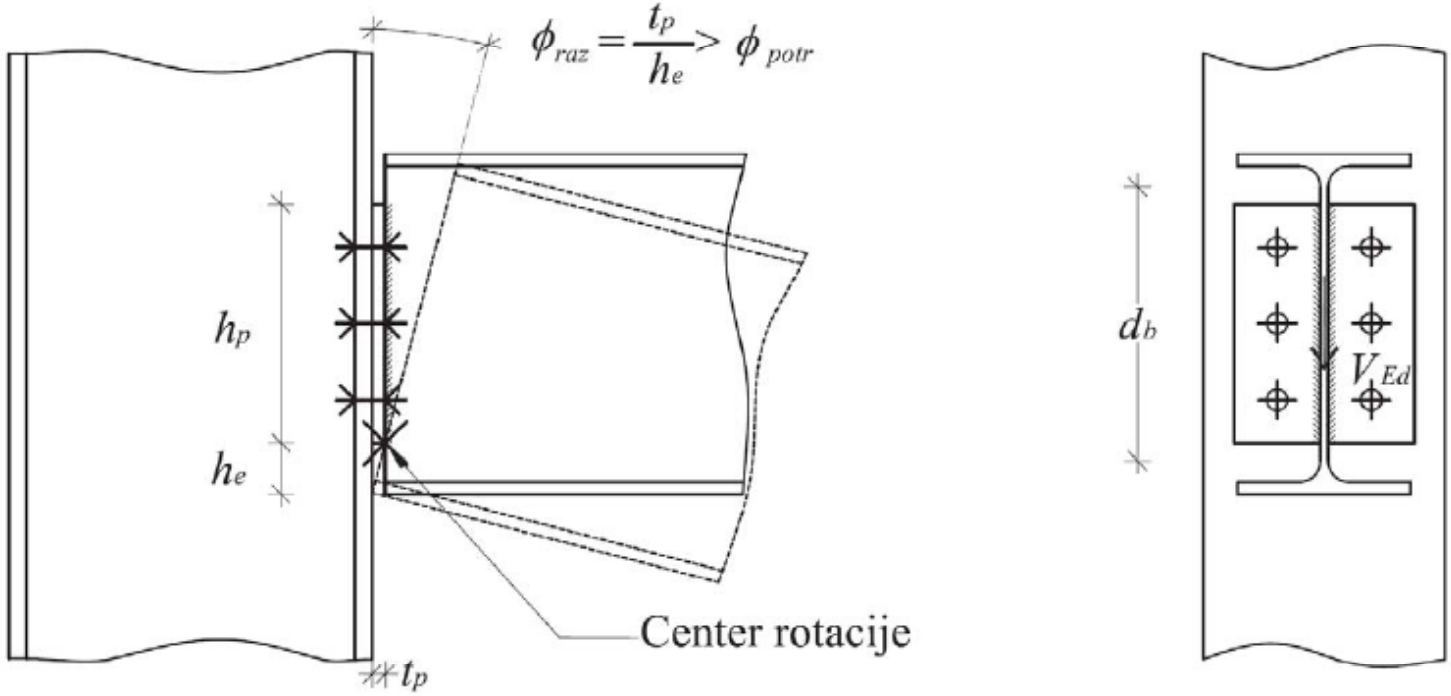
- dovolj velika rega $\boldsymbol{g} \rightarrow \phi_{raz} > \phi_{potr}$, $h_p < d_b$
- kontrola komponent spoja: V_{Ed}, $M_{Ed} = e \cdot V_{Ed}$
- zagotovitev duktilnega obnašanja (preprečene neduktilne porušitve)

Zagotavljanje duktilnega obnašanja:

- preprečene neduktilne porušitve (zvari, vijaki);
- polnonosilni zvari med stebrom in vezno pločevino;
- nosilnost na bočni pritisk v horizontalni smeri za vezno pločevino ali stojino nosilca mora biti manjša od strižne nosilnosti vijaka (morebitna preobremenitev zaradi upogibnega momenta).

Zadnji kriterij se uravnava z debelino vezne pločevine ali stojine nosilca (vsaj ena od debelin ustrezno majhna).

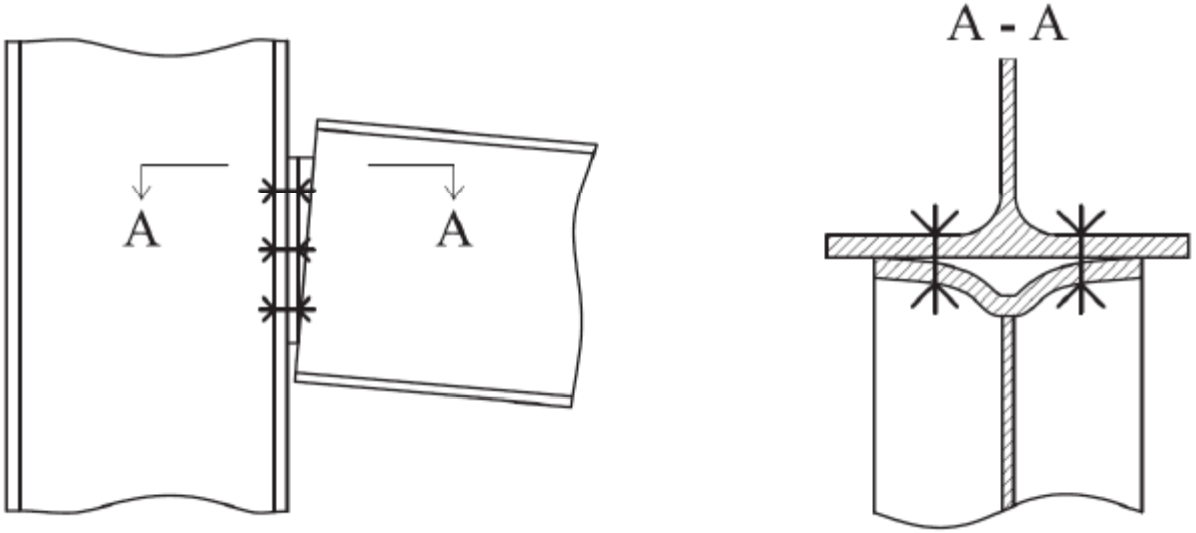
Členkasti spoj z delno čelno pločevino



Načela projektiranja:

- Debelina čelne pločevine $\boldsymbol{t_p}$ in dimenzija $\boldsymbol{h_e}$ omogočata $\phi_{raz} > \phi_{potr}$, $h_p < d_b$
- kontrola komponent spoja **samo na prečno silo** V_{Ed}
- zagotovitev duktilnega obnašanja → **polnonosilni zvari** ob čelni pločevini, **upogib čelne pločevine izven lastne ravnine**.

Upogib čelne pločevine izven lastne ravnine → **natezne sile v vijakih**



Preprečitev natezne porušitve vijakov:

- 80 % izkoriščena strižna nosilnost;
- kontrola **debeline čelne pločevine** (omejitev upogibne nosilnosti):

$$\frac{d}{t_p} \geq 2{,}8 \cdot \sqrt{\frac{f_{yp}}{f_{ub}}}$$

Kombiniranje različnih veznih sredstev

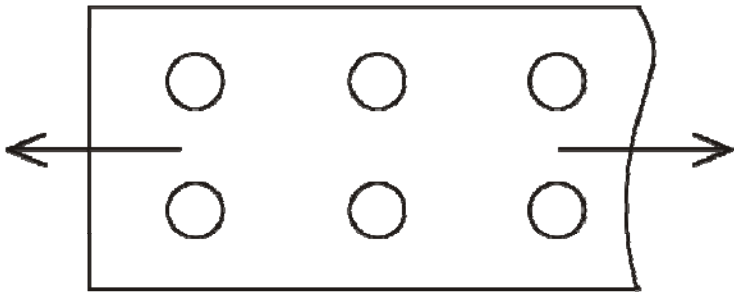
V **istem spoju** lahko kombiniramo le **taka vezna sredstva**, ki **imajo približno enako deformabilnost**:

Dovoljeno: ZVARI + PREDNAPETI VIJAKI

Prepovedano: ZVARI + OBIČAJNI VIJAKI

Skupine veznih sredstev

- Skupina vijakov



$F_{b,Rd,i}$, $F_{v,Rd,j}$

Če je: $F_{v,Rd,j} > F_{b,Rd,i} \rightarrow$ duktilno obnašanje

Nosilnost: $F_{Rd} = \sum F_{b,Rd,i}$

V nasprotnem primeru je nosilnost: $F_{Rd} = n \cdot \min\left(F_{b,Rd,i}, F_{v,Rd,i}\right)$

- Skupina zvarov