3.7. PROJEKTOVANJE ZAVARENIH KONSTRUKCIJA – STATIČKO OPTEREĆENJE

1. Vrste zavarenih spojeva

U tab. 3.2.1. su date osnovne vrste zavarenih spojeva koje se proračunavaju prema DIN 18 800/ Deo 1, sa njihovim oznakama (simbolima) prema Din 1912/ Deo 5, a u tab. 3.2.2 proračunske debljine.

Tabela 3.2.1. Osnovne vrste zavarenih spojeva za proračun prema DIN 18 800

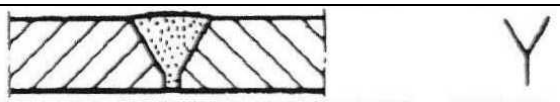
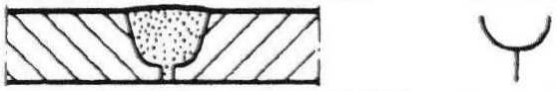
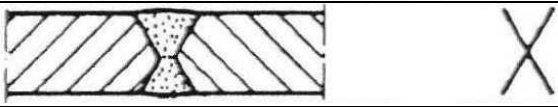
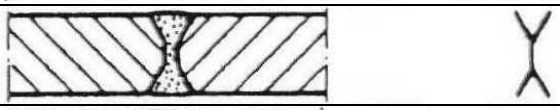
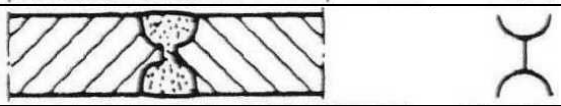
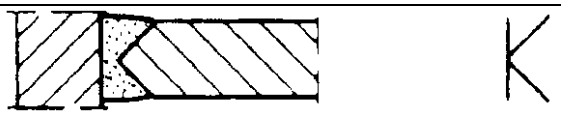
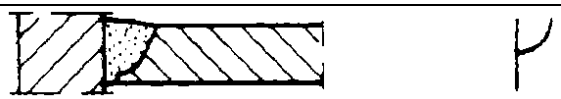
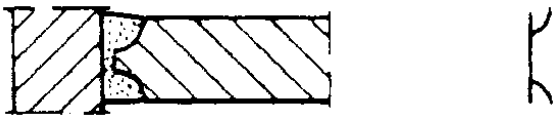
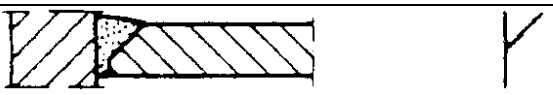
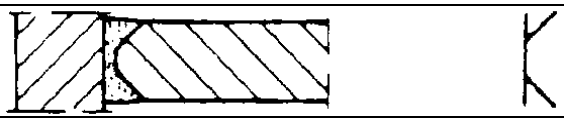
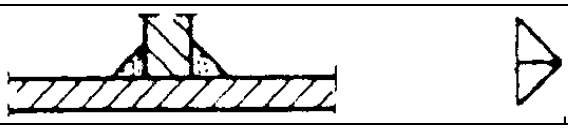
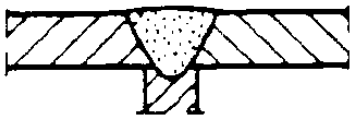
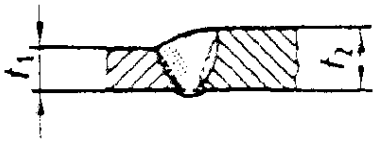
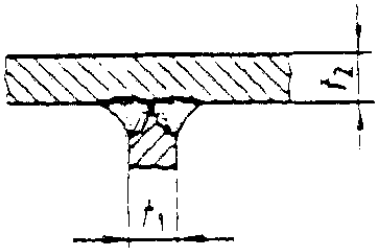
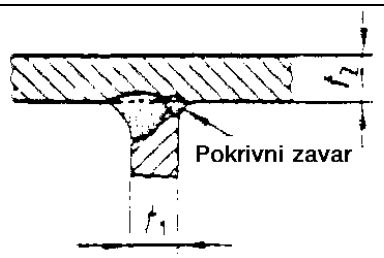
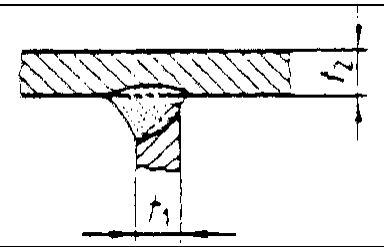
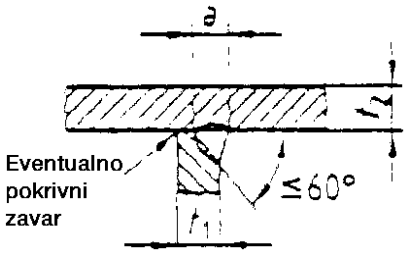
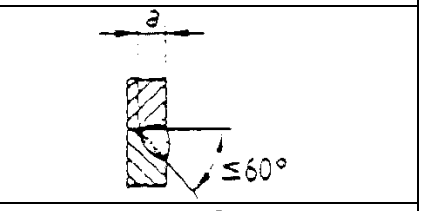
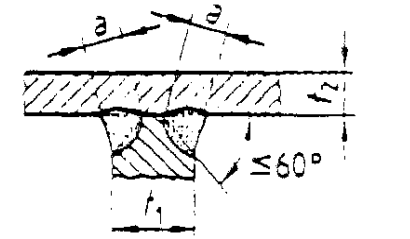
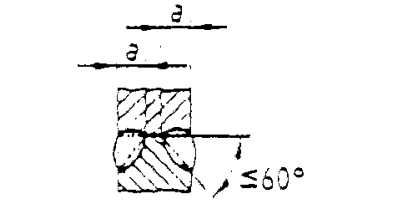
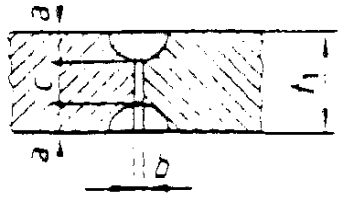
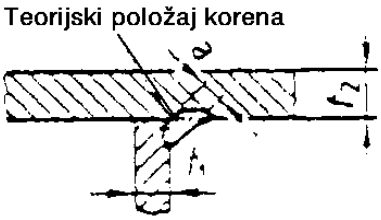
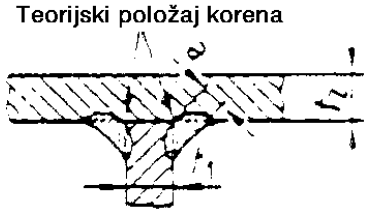
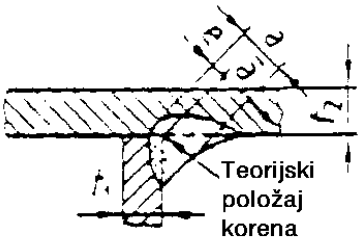
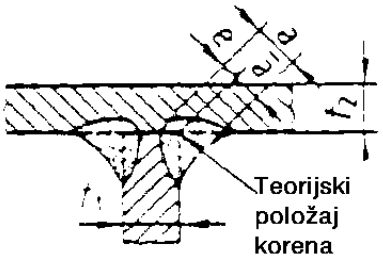
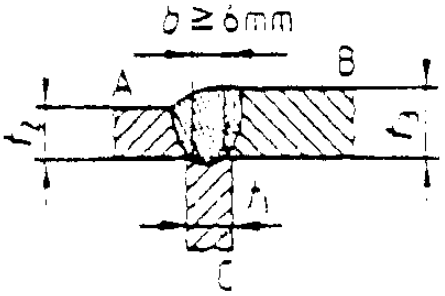
Redni broj	Vrsta spoja	Obeležavanje	Skica i simbol
1.	Sučeoni spoj, jednostrani ili obostrani	I	
2.		V	
3.		Y	
4.		U	
5.		DV (X)	
6.		DY	
7.		DU	
8.	Druge vrste spojeva, jednostrani ili dvostrani	HV	
9.		DHV	
10.		HU	
11.		DHU	
12.	Neprovareni spojevi	HY	
13.		DHY	
14.	Ugaoni spojevi	Ugaoni spoj	
15.		Dvostrani ugaoni spoj	
16.	T spoj sa tri elementa		

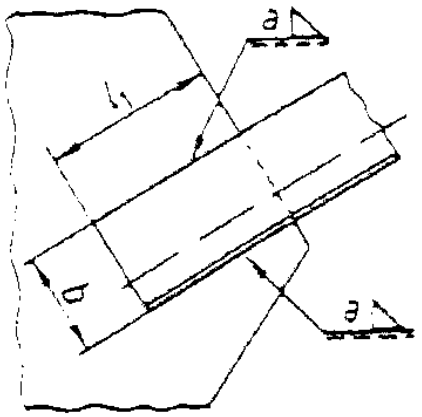
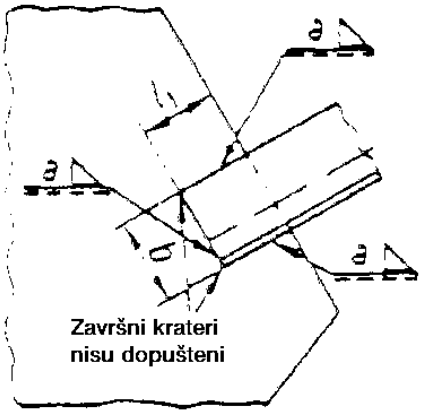
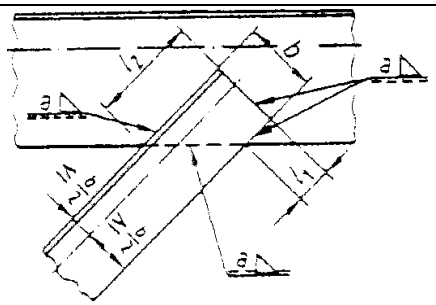
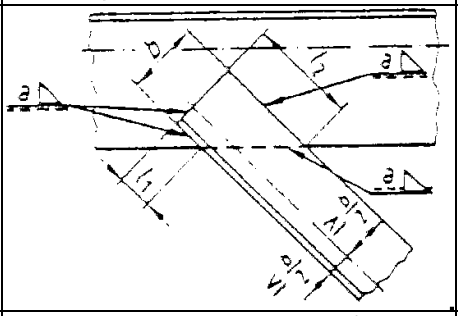
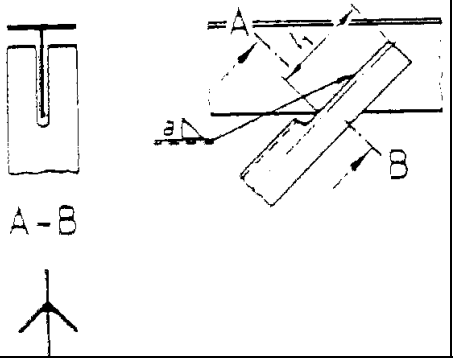
Tabela 3.2.2. Određivanje debljine zavarenih spojeva

Redni broj	Vrsta spoja			Skica	Proračunska debljina, a
1.	2.			3.	4.
1.	Jednostrani ili dvostrani šav	Sučeoni spoj			$a = t_1$
2.		DHV (K) šav			$a = t_1$
3.		HV šav	Pokrivni zavar sa druge strane		
4.			Provaren koren		
5.	Šavovi bez provara	HY šav ugaoni šav			Debljina šava *a* je jednaka rastojanju od teorijskog položaja korena do površine šava
6.		HY šav			
7.		DHY šav sa dvostranim ugaonim šavom			
8.		DHY šav			

<table>
<tr><th>1.</th><th colspan="3">2.</th><th>3.</th><th>4.</th></tr>
<tr><td>9.</td><td>Šavovi bez provara</td><td colspan="2">DHY šav bez pripreme šava</td><td>  </td><td>Debljina šava a se određuje prema procesu zavarivanja. Zazor b zavisi od procesa. Za EPP proces b=0</td></tr>
<tr><td>10.</td><td rowspan="5">Ugaoni šavovi</td><td colspan="2">Ugaoni šav</td><td>  </td><td rowspan="2">Debljina šava je jednaka izmerenoj visini upisanog ravnokrakog trougla do teorijskog položaja korena</td></tr>
<tr><td>11.</td><td colspan="2">Dvostrani ugaoni šav</td><td>  </td></tr>
<tr><td>12.</td><td>Ugaoni šav</td><td rowspan="2">Sa dubokim provarom</td><td>  </td><td rowspan="3">$a = \bar{a} + e$
$\bar{a}$ – odgovara debljini šava prema stavkama 10 i 11
e – određeno prema procesu zavarivanja (DIN 18 800/ Deo 7)</td></tr>
<tr><td>13.</td><td>Dvostrani ugaoni šav</td><td>  </td></tr>
<tr><td>14.</td><td rowspan="2">Ivični šav tri lima</td><td rowspan="2">Prenos sile</td><td>od A na B</td><td rowspan="2">  </td><td>$a = t_2$
za $t_2 < t_3$</td></tr>
<tr><td>15.</td><td>od C na A i B</td><td>$a = b$</td></tr>
<tr><td colspan="6">Za šavove pod r. br. 5. do 8. sa uglom žleba od 45° proračunska a veličina treba da se smanji za oko 2 mm ili da se utvrdi postupkom zavarivanja. Od toga se izuzimaju šavovi izvedeni u koritastom i horizontalnom položaju pri zavarivanju u zaštiti gasom.</td></tr>
</table>

U tab. 3.2.3. su date proračunske dužine ugaonih spojeva u direktnim vezama.

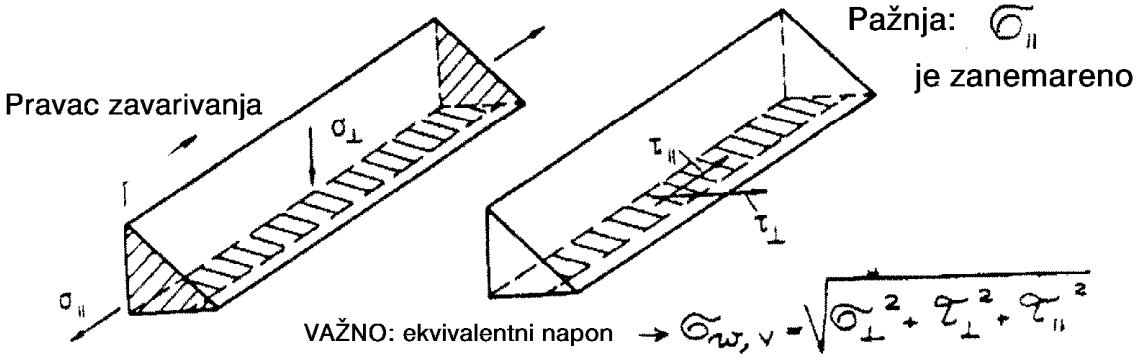
Tabela 3.2.3. Dužine ugaonih spojeva u direktnim vezama

Redni broj	Vrsta zavarenog spoja	Skica	Proračunska dužina šava $\sum l$
1.	Ugaoni šav ivica		$\sum l = 2l_1$
2.	Ugaoni šav ivica i čela		$\sum l = b + 2l_1$
3.	Ugaoni šav po obimu – težište bliže dužem šavu		$\sum l = l_1 + l_2 + 2b$
4.	Ugaoni šav po obimu – težište bliže kraćem šavu		$\sum l = 2l_1 + 2b$
5.	Ugaoni ili HV šav prorezanog ugaonika		$\sum l = 2l_1$

2. Proračun čvrstoće zavarenih spojeva

Osnove proračuna su iznete prema DIN 18 800/ Deo 1.

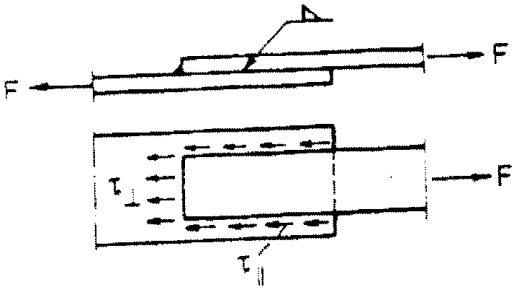
- Zavareni spojevi prenose:
  - normalno zatezanje (jedinični napon) → σ ($\sigma_\perp$ i $\sigma_\parallel$)
  - napon smicanja → τ ($\tau_\perp$ i $\tau_\parallel$)

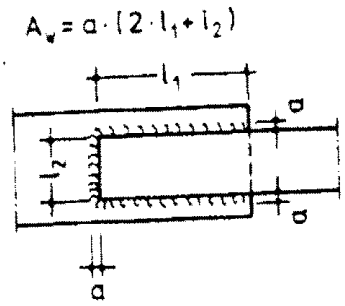


Pažnja: $\sigma_\parallel$ je zanemareno

VAŽNO: ekvivalentni napon → $\sigma_{w,v} = \sqrt{\sigma_\perp^2 + \tau_\perp^2 + \tau_\parallel^2}$

- Prenos sila smicanja



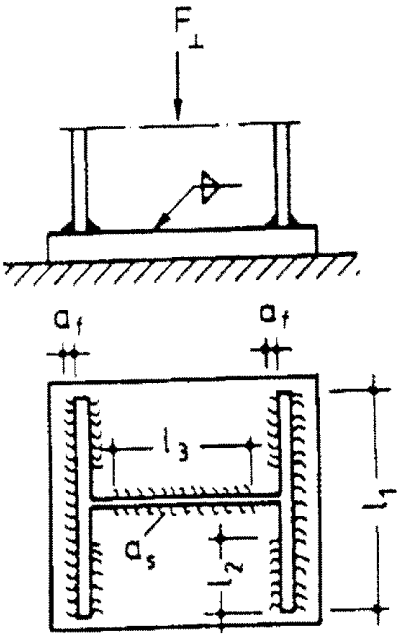


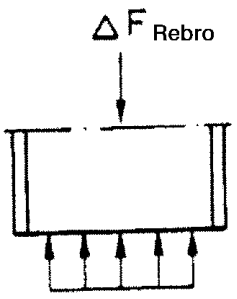
$$\tau_w = \frac{F}{A_w}$$

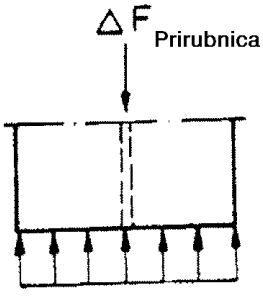
Načelno

$$A_w = \sum (a_w \cdot l_w)$$

- Prenos sila upravnih na spoj







$$A_{w,\,Prirubnica} = a_f \cdot (l_1 + 2 \cdot l_2)$$

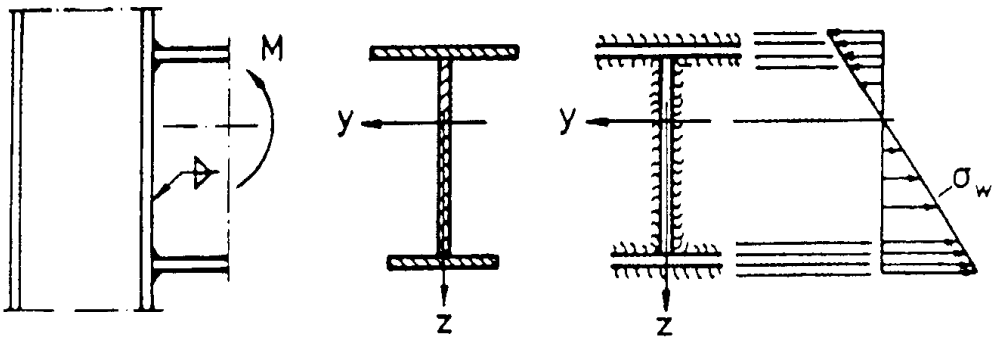
$$A_{w,\,Rebro} = a_s \cdot 2 \cdot l_3$$

$$\sigma_w = \frac{F_\perp}{A_w}$$

– gde je

$$A_w = \sum (a_w \cdot l_w)$$

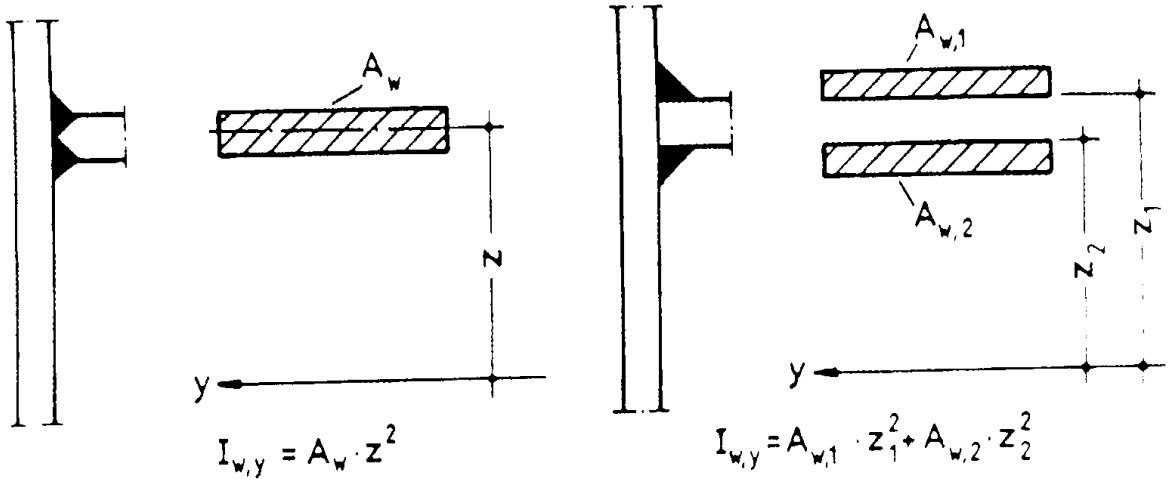
- Prenos momenata savijanja



$$\sigma_w = \frac{M_y}{I_{w,y}} \cdot z$$

Glavne ose napona se moraju poklapati sa glavnim osama šava

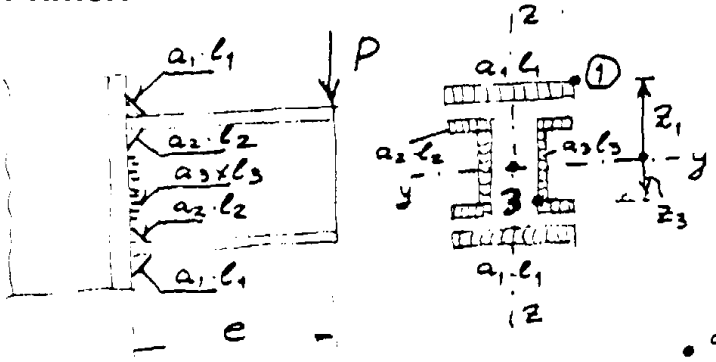
Proračun momenta inercije $I_{w,y}$ (drugog momenta površine) za šav prirubnice:



$$I_{w,y} = A_w \cdot z^2$$

$$I_{w,y} = A_{w,1} \cdot z_1^2 + A_{w,2} \cdot z_2^2$$

Primer:



- $\sigma_{w,1} = \frac{P \cdot e}{I_{w,y}} \cdot z_1$

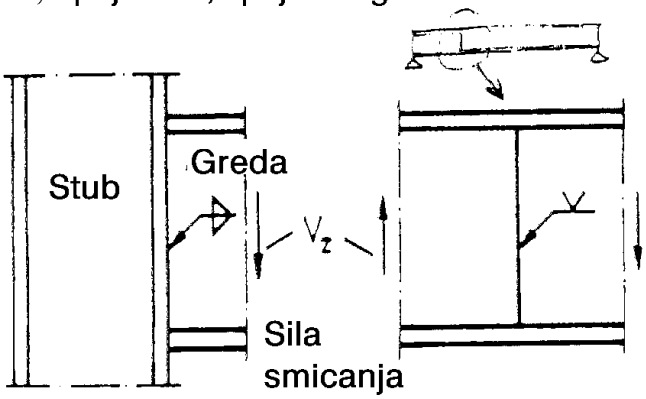
$I_{w,y}$ moment inercije svih šavova

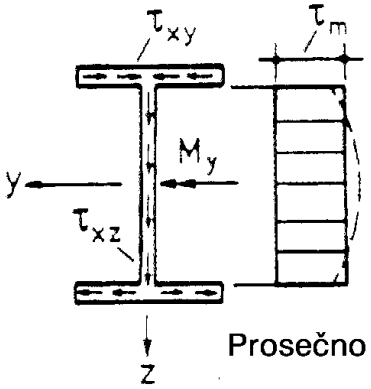
- Moment savijanja $M = P \cdot e$
- Sila smicanja $T = P$

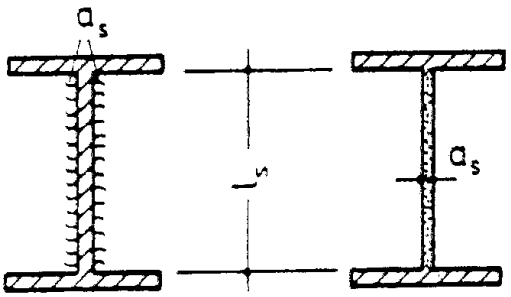
- $\tau_{w,m} = \frac{P}{2a_3 \cdot l_3}$ preuzima samo rebro
- $\sigma_{w,3} = \frac{P \cdot e \, z_3}{I_{w,y}}$
- $\sqrt{\sigma_{w,3}^2 + \tau_{w,m}^2}$

- Prenos sila smicanja

a.) Spoj rebra; spoj stub-greda





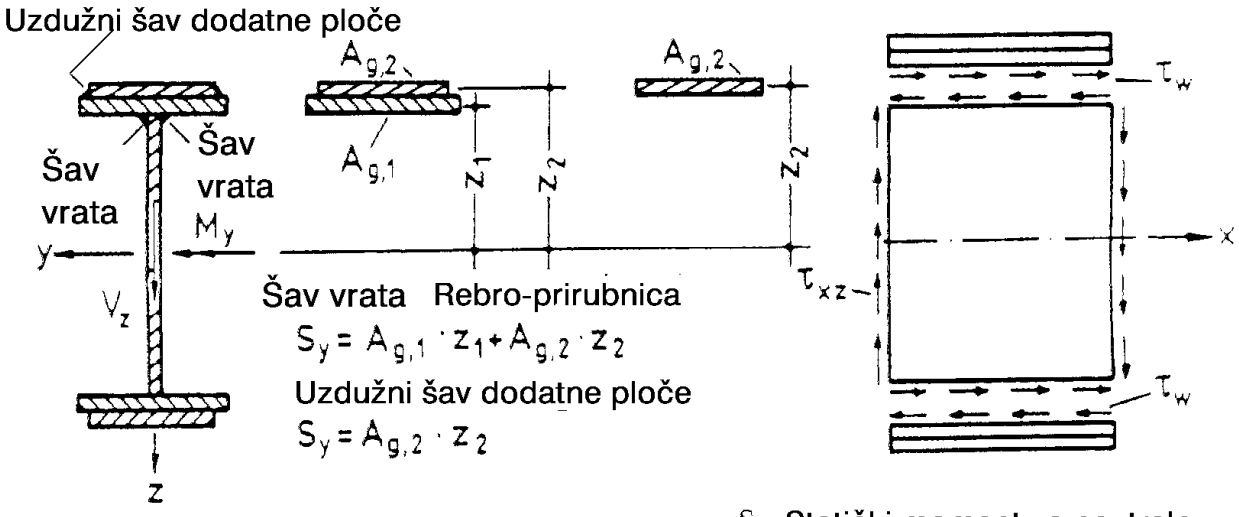


$$A_{w,V_z} = \sum (a_s \cdot l_s)$$

Zatezanje se prenosi samo preko rebra

$$\tau_{w,m} = V_z / A_{w\,V_z}$$

Uzdužni spoj rebra, spoj rebro-prirubnica



$$\tau_w = \frac{V_z \cdot S_y}{(\sum a_w) \cdot I_y}$$

Jednačina Mor - Žuravski

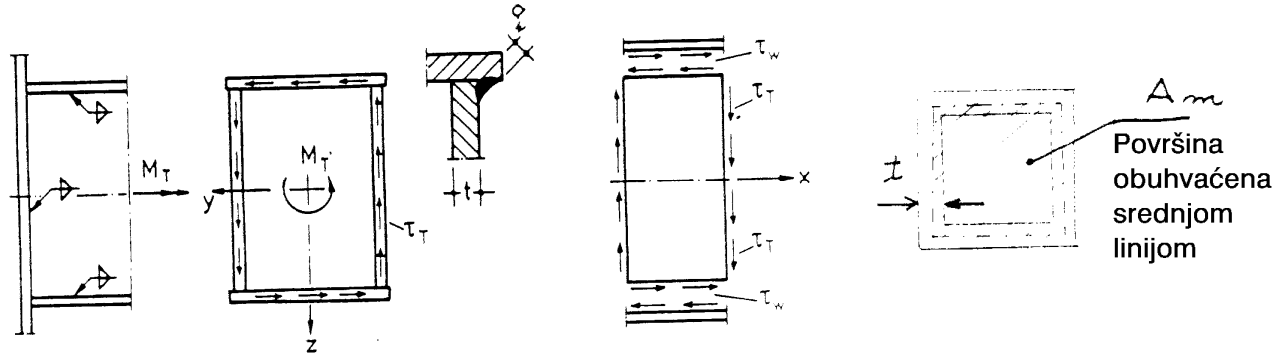
- S_y Statički moment za neutralnu osu dela preseka izloženog smicanju

I_y Moment inercije preseka

- **Prenos momenta torzije**

Moment torzije uvodi napon smicanja u zatvorenim presecima i njihovim spojevima (τ_t – Sen Venan). Odnos napona smicanja u šavu zavarenog spoja i u osnovnom preseku je τ_w / τ_T = t/a_w. Napon smicanja se računa po formuli Breta:

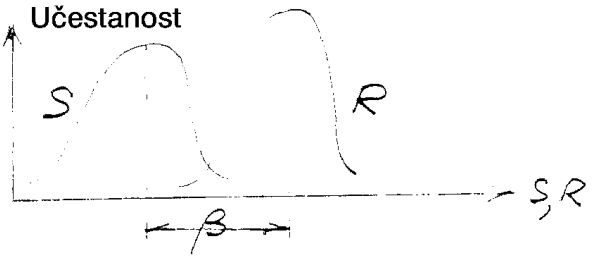
$$\tau_T = \frac{M_T}{2A_m t}$$



Analiza spoja prema DIN 18 800

Osnovna formula maksimalnog graničnog stanja za projektno stanje (indeks "*d*"):

$S_d/R_d \le 1$



Za zavareni spoj važi formula za uporedni napon (indeks "*v*")

$\sigma_{w,v} \le \sigma_{w,R,\,d}$

Konvencionalna vrednost normalnog napona je

$$\sigma_{w,v} = \sqrt{\sigma_{\perp}^2 + \tau_{\perp}^2 + \tau^2}$$

Projektni napon za šav čelika napona tečenja $f_{y,k}$:

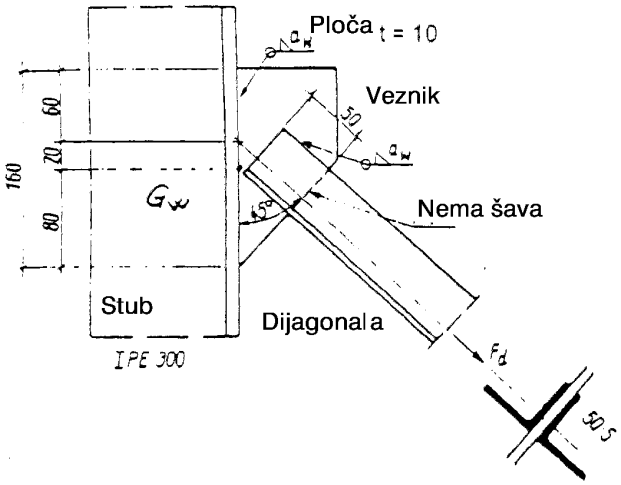
$\sigma_{w,R,\,d} = \alpha_w f_{y,k}/\gamma_M$

$f_{y,k}$ za čelik St 37 je 240 MPa, za St 52 je 360 MPa.

Koeficijent α_w koji zavisi od vrste spoja, kvaliteta šava i kvaliteta materijala, iznosi 0,80 do 1,00. Veličina γ_M je parcijalni stepen sigurnosti materijala.

Primer

Proveriti zavareni spoj između ugaonika i veznika i veznika i stuba na slici.



Podaci:

St37; γ_M = 1,1; a_w = 3 mm; F_d = 150 kN

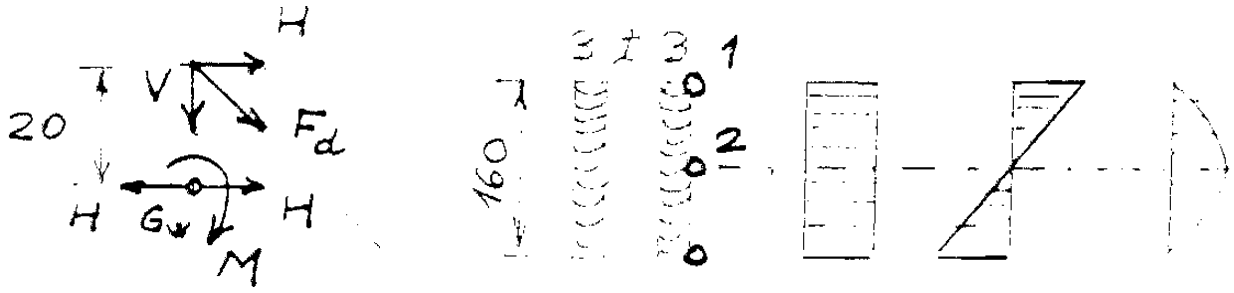
Dijagonalni šav – veznik (ploča):

- dužina šava $\Sigma l = b + 2l_1 = 50 + 2x50 = 150$ mm
- površina šava $A_w = 2x15x0,3 = 9$ cm^2
- napon smicanja $\tau_{||} = 150/9 = 15,7$ kN/ cm^2
- ekvivalentni napon $\sigma_{w,v} = \sqrt{}\ 16,7^2 = 16,7$ kN/ cm^2
- koeficijent $\alpha_w = 0,95$
- napon tečenja $f_y = 24$ kN/ cm^2
- projektni napon $\sigma_{w,R,\,d}$ =0,95x24/1,1=20,7 kN/cm^2
- provera prema DIN 18 800

$\sigma_{w,v}$ / $\sigma_{w,R,\,d}$ = 16,7/20,7 < 1

Spoj veznik – stub:

Prvi korak: sve sile treba redukovati na težište šava G_w, čija je ekscentričnost 20 mm, kako je prikazano na slici dole levo.



- Horizontalna i vertikalna komponenta sile F_d
  H = F_d × sin a = 150 × √2/2 = 106,1 kN
  V = F_d × sin a = 150 × √2/2 = 106,1 kN
- Moment M = 106,1 × 2 = 212,2 kNcm
- Karakteristike šava: l_w = 16 cm; A_w = 2 × 0,3 × 16 = 9,6 cm^2; I_w = 2 × (0,3 × 16^3)/12 = 205 cm^4

  <u>Provera gornje tačke (1) šava</u> (slika gore desno):
  $\sigma_\perp$ = 106,1/9,6 + (212,2/205) × 8 = 19,4 kN/cm^2 = $\sigma_{w,v}$; sa koeficijentom α_w = 0,95 i projektnim naponom $\sigma_{w,R,\,d}$ = 20,7 kN/cm^2 to daje $\sigma_{w,v}$ / $\sigma_{w,R,\,d}$ = 19,4/20,7 < 1

  <u>Provera sredine šava (tačka 2)</u>
- Statički moment S = 2 × 0,3 × 8 × 8/2 = 19,2 cm^2
- Napon smicanja (Mor–Žuravski): t = (106,1 × 19,2)/2 × 0,3 × 205) = 16,6 kN/cm^2
- Normalni napon $\sigma_\perp$ = 106,1/9,6 = 11,1 kN/cm^2
- Ekvivalentni napon $\sigma_{w,v} = \sqrt{16{,}6^2 + 11{,}1^2} = 20{,}0$ kN/cm^2

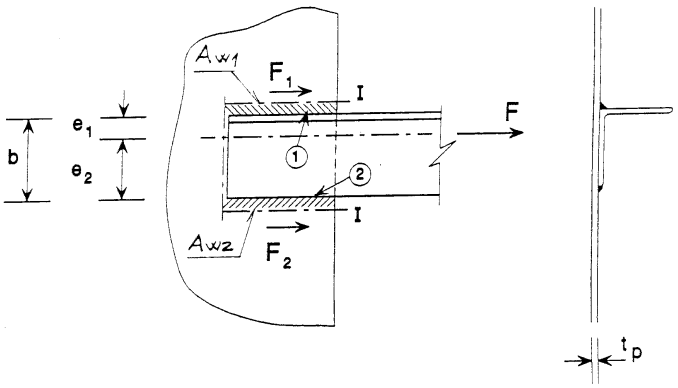
$\sigma_{w,v}$ / 20/20,7 < 1

Zaključak je da je otpornost šava zadovoljavajuća.

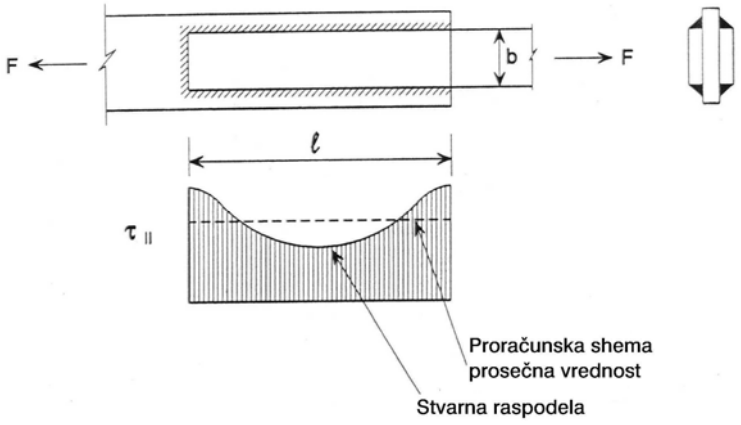
<u>Napomene</u>:

1. Izbor debljine ugaonog šava za t ≥ 3 mm je uslovljen sa
   2 mm ≤ a_w ≤ 0,7t, odnosno $a_w = \sqrt{t_{max}} - 0{,}5$, u mm.
2. Zavareni spoj je pod uglom u odnosu na veznik.

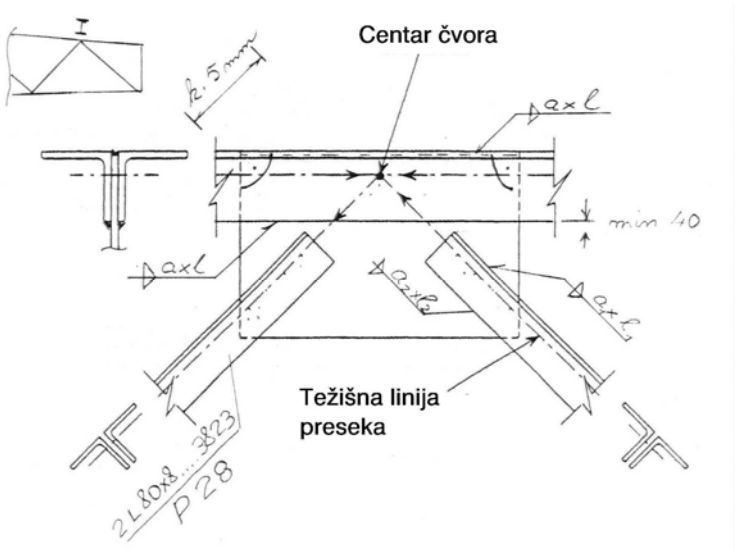
<u>Prvo rešenje</u>, preporučeno prema DIN 18 800 (prosto za izvođenje)
$A_{w1} = A_{w2} = a_w \times l$
<u>Drugo rešenje</u>
$A_{w1} \neq A_{w2}$ $(A_{w1} > A_{w2})$
$A_{w1} = a_{w1} \times l_1$
$A_{w2} = a_{w2} \times l_2$
$A_w = A_{w1} + A_{w2} = F/\sigma_{w,R,\,d}$
$A_{w1} \times e_1 = A_{w2} \times e_2$



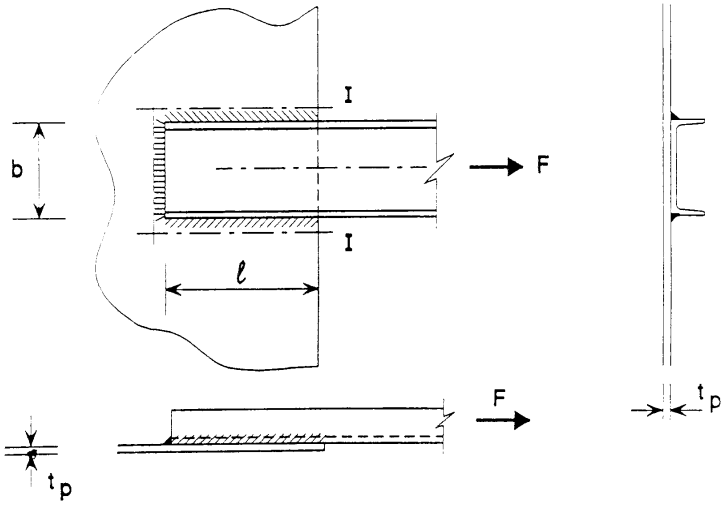
3. Neravnomerna raspodela napona smicanja $\tau_{||}$ u spoju duž ugaonog šava



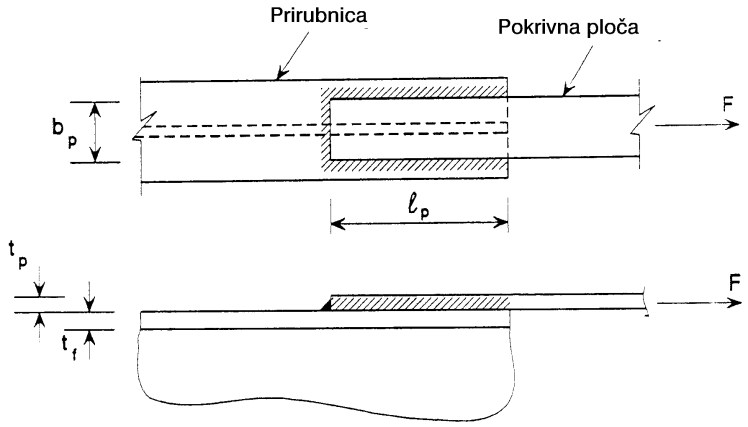
4. Spoj između krovne rešetke i veznika



5. Spoj tunelske sekcije sa veznikom

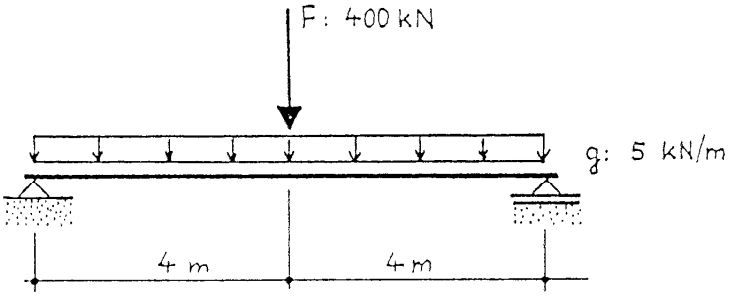


6. Zavarena pokrivna ploča

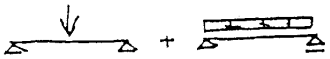


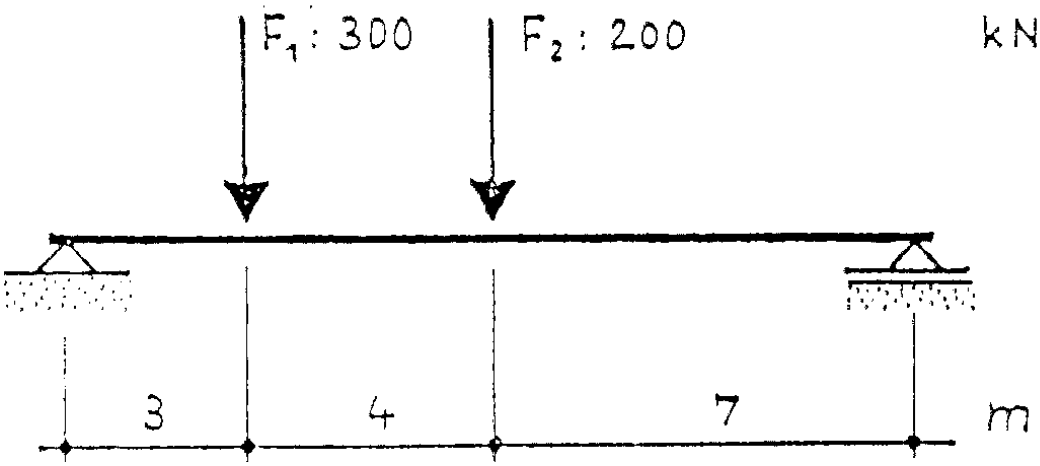
Zadaci za vežbu

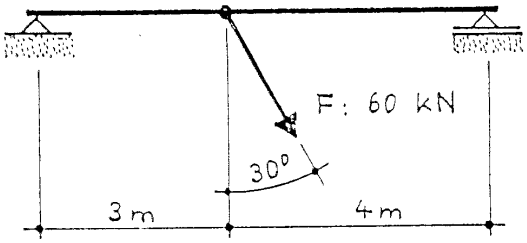
Za naredne konstrukcije odrediti dijagrame sila i momenata.



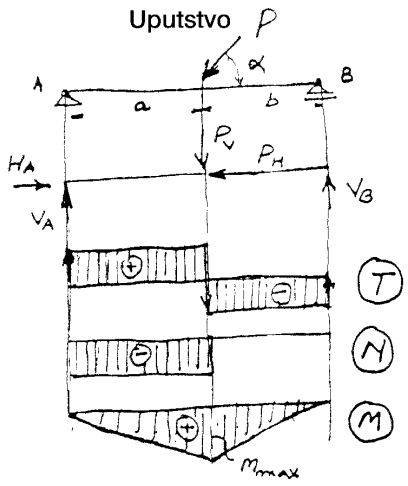
Uputstvo:
Treba koristiti pravilo super-pozicije

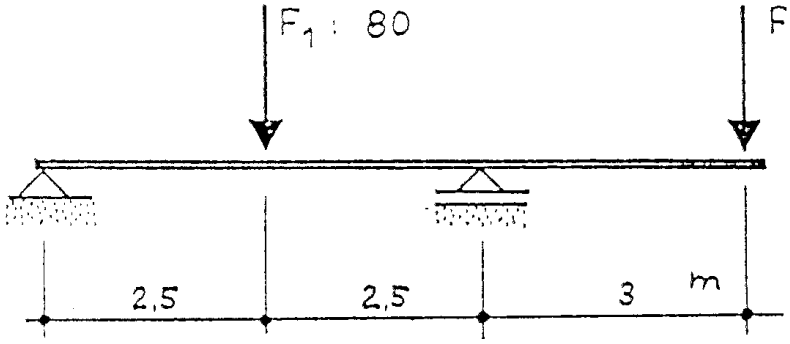




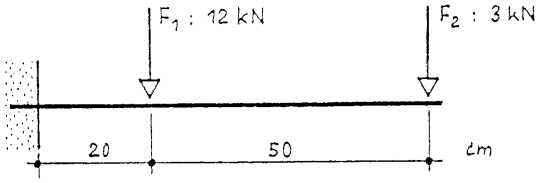


Uputstvo

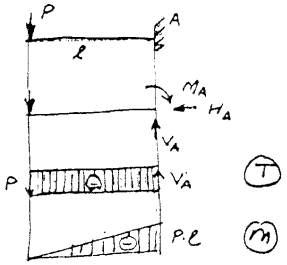


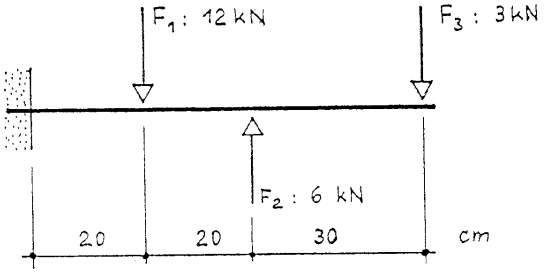


Uputstvo:
Treba koristiti princip super-pozicije

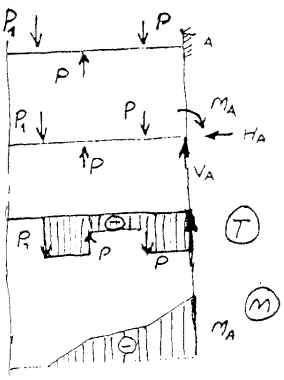


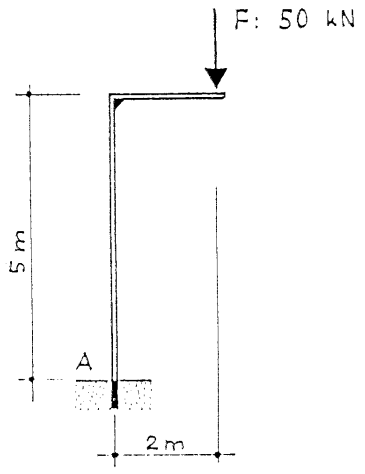
Uputstvo



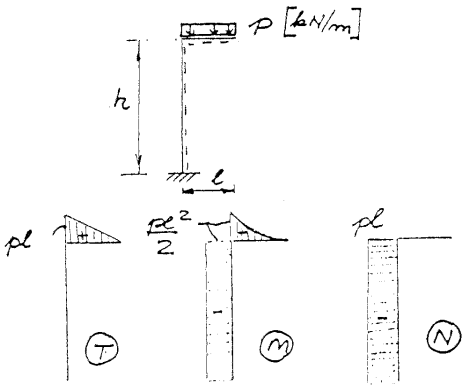


Uputstvo $P_1 > P$

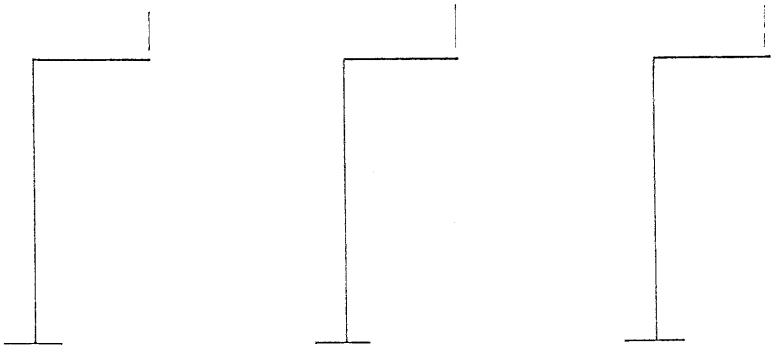




Nacrtati dijagrame sila i momenata ekscentrične grede



Primer razlaganja



N Aksijalna sila

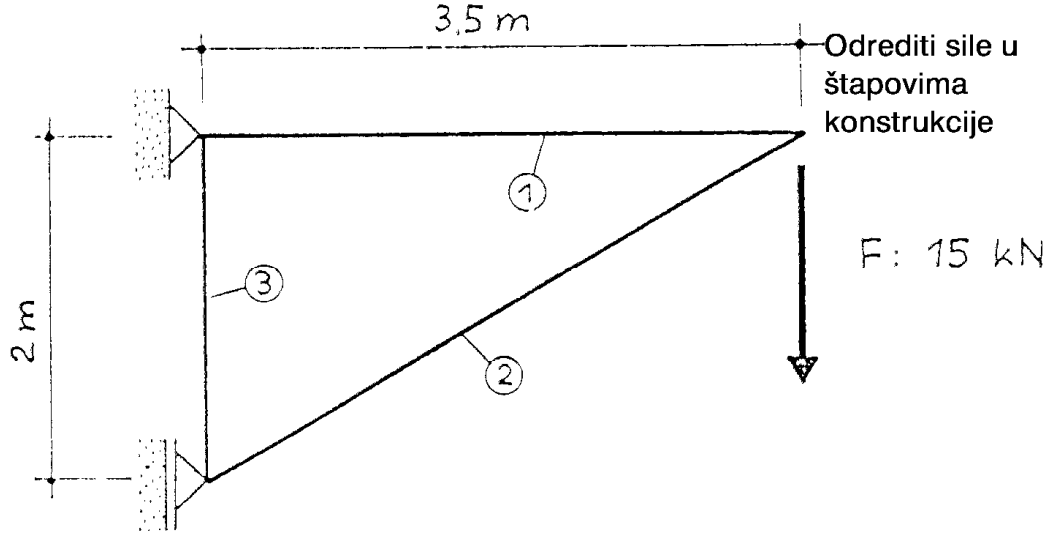
T Tangencijalna sila

M Moment

$V_A =$

H_A

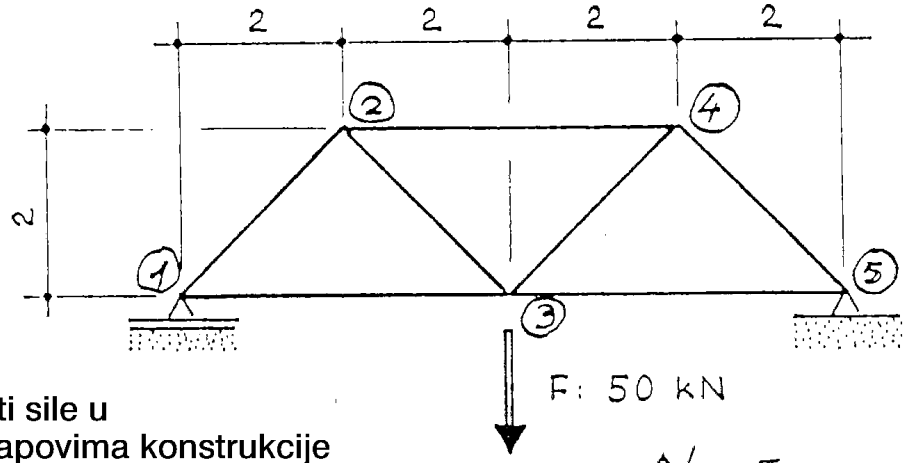
M_A



Odrediti sile u štapovima konstrukcije

Primeri za vežbu

1



Odrediti sile u svim štapovima konstrukcije

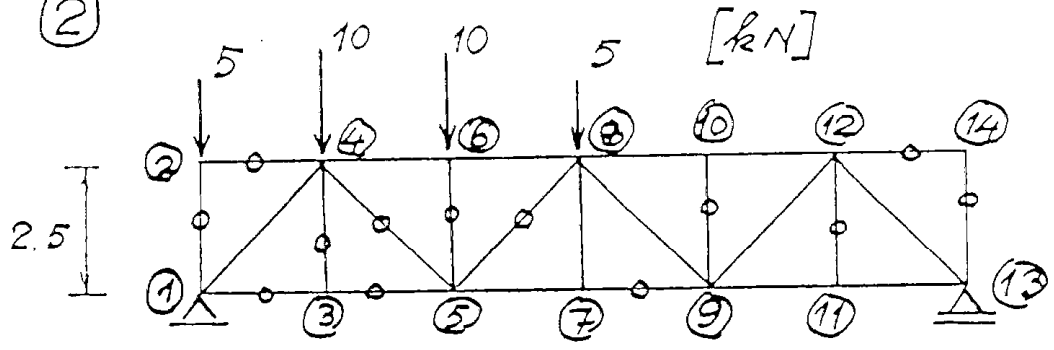
$V_1 =$ $N_{13} =$ $N_{12} =$

$V_5 =$ $N_{35} =$ $N_{23} =$

$N_{24} =$

2

Odrediti sile u označenim štapovima



$V_1 =$

$V_{13} =$

Proveriti geometrijske krutosti i statičku određenost

Formule za proračun napona

Zatezanje $\sigma_z = \frac{F}{A}$ $\sigma = \frac{N}{A}$

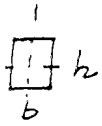
Pritisak $\sigma_{dl} = \frac{F}{A}$

Izvijanje $\sigma = \frac{N}{\varphi \cdot A}$; $\varphi \rightarrow \lambda = \frac{l_i}{i}$

Savijanje $\sigma_b = \frac{M_b}{W_b} = \frac{M_b \cdot c}{I}$

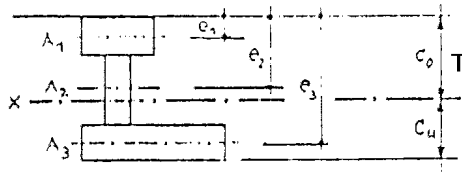
$W_{b\,\square} = \frac{b \cdot h^2}{6}$

$I_{b\,\square} = \frac{b \cdot h^3}{12}$

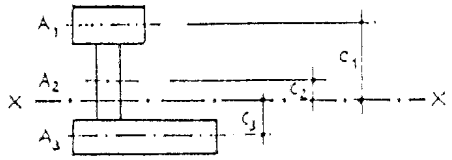


c = Rastojanje težišta u ravni je potrebno za σ_b

$c_0 = \frac{A_1 \cdot e_1 + A_2 \cdot e_2 + A_3 \cdot e_3}{A_1 + A_2 + A_3}$



$I_x = I_1 + A_1 \cdot c_1^2 + I_2 + A_2 \cdot c_2^2 + I_3 + A_3 \cdot c_3^2$



$\tau_{II} = \frac{F_Q \cdot S}{I_x \cdot \Sigma a}$

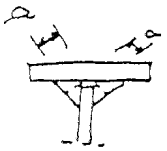
$\tau_{II} = \frac{T \cdot S}{2a\, I_x}$

τ_{II} = Tangencijalni napon

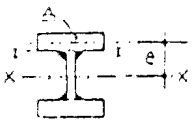
F_Q = Poprečna sila

S = Statički moment (Površina smicanja puta rastojanje težišta)

Σa = Debljina šava izložena smicanju



Presek

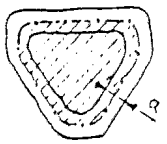


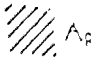
Smicanje $\tau_a = \frac{F}{A}$

Uvijanje $\tau_t = \frac{M_t}{W_p} \approx \frac{M_t}{2A_R \cdot a}$

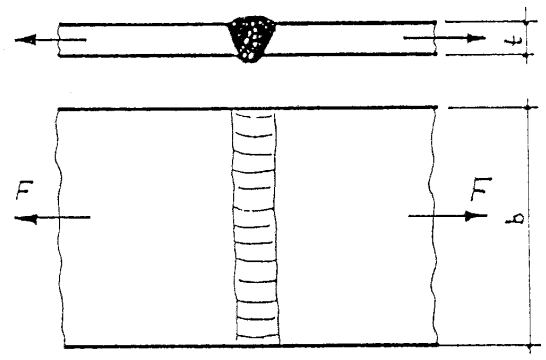
A_R = Od sredine profila obuhvaćena površina

a = Debljina profila/debljina šava u ravni, traži se za τ_t





Primeri za proračun napona i dimenzija



Spoj ploča (DIN 18 800)
F = 800 kN (Opterećenje tipa H)
Ploča 450 x 16 St 37-3
Kvalitet šava nepoznat
Napon ?

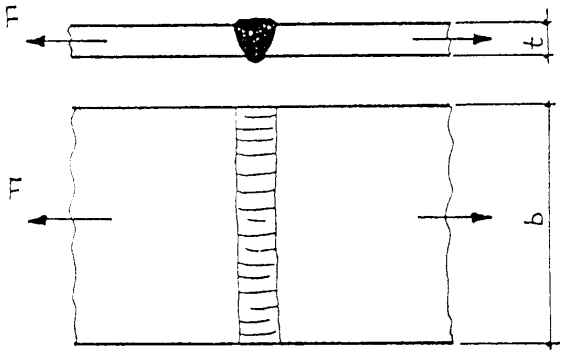
Uputstvo

$a = t_1$

$\sigma_{\perp} = \dots$

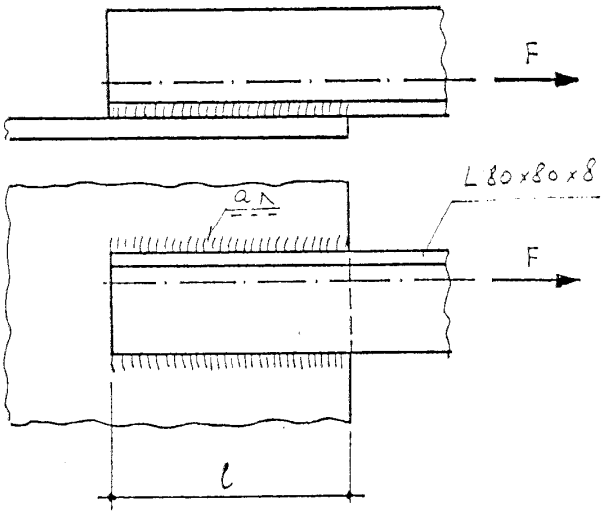
$\sigma_{w,R,d} = \alpha_w f_{y,k} / \gamma_M$

$\sigma_{w,R,d} = 0{,}95 \cdot 24/1{,}1 \ kN/cm^2$



Spoj ploča (DIN 18 800
F = 800 kN (Opterećenje tipa HZ)
Ploča debljine 16 mm; St 52-3
Kvalitet šava nepoznat
Širina ploče b ?

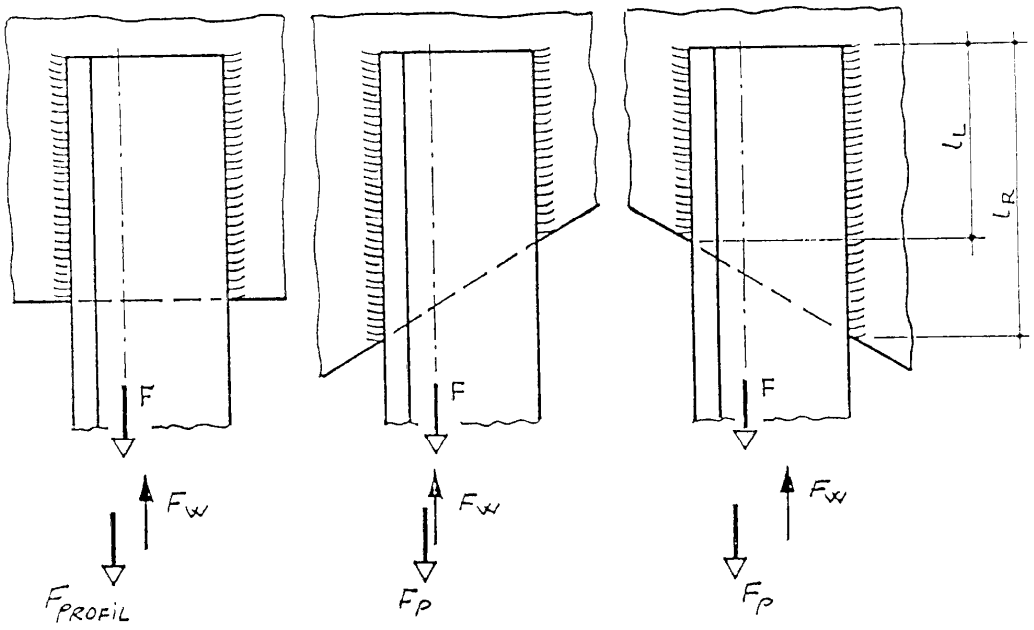
$\sigma_{w,R,d} = 1{,}0 \cdot 24/1{,}1 \ kN/cm^2$



Spoj ugaonika (DIN 18 800
F = 140 kN (Opterećenje tipa H)
Profil L 80X80X8; S235
Priključni lim 12 mm; S355
Debljina ugaonog šava ?
Dužina preklopa ?
Napon ?

Uputstvo

- $\tau_w = F / A_w$
- $\tau_w = 0{,}95 \cdot 24/1{,}1 \ daN/mm^2$

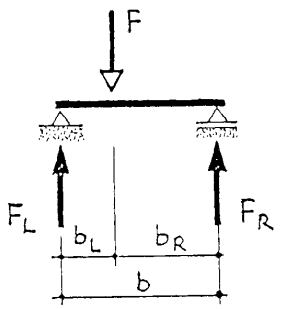


Moment savijanja se uzima

Moment savijanja se zanemaruje

Moment savijanja se uzima

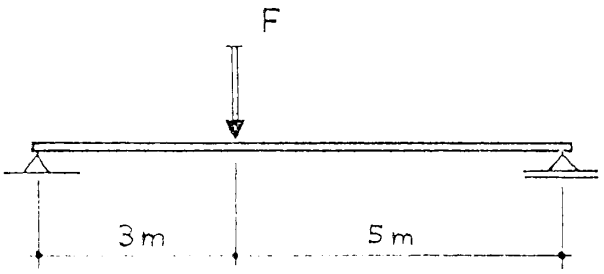
Slično sa

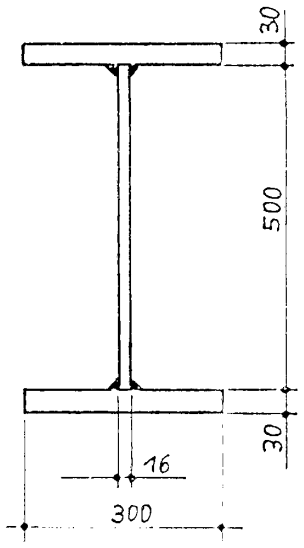


$$F_L = \frac{F \cdot b_R}{b}$$

$$\tau_{w,L} = \frac{F_L}{a_L \cdot l_L}$$

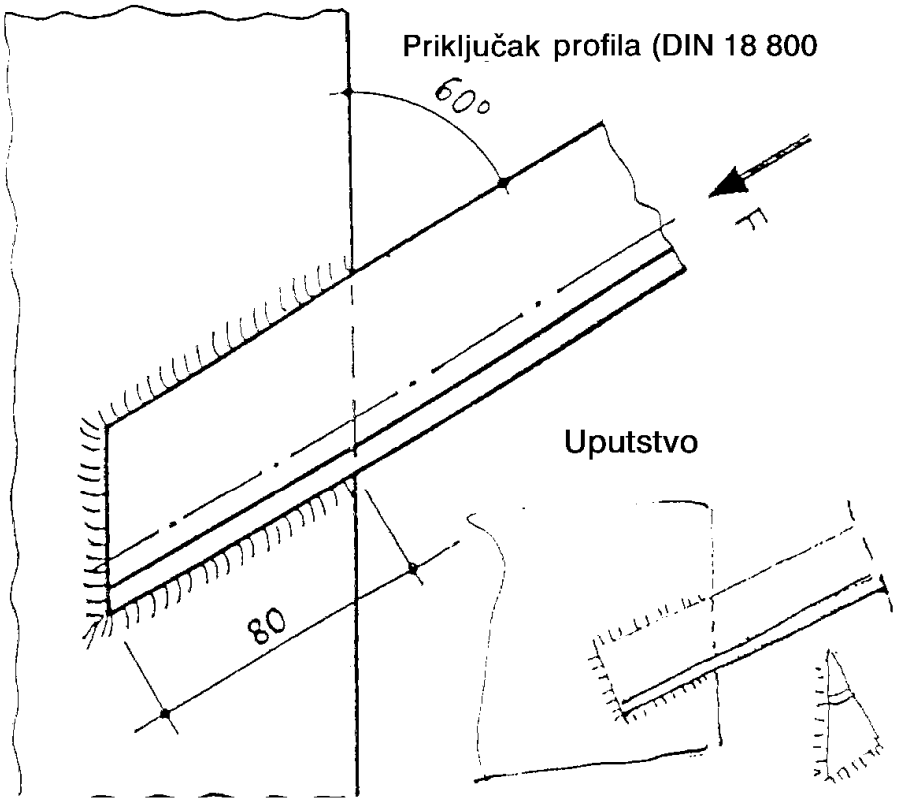
$$a_L = \frac{F_L}{\tau_{w,L} \, l_L}$$



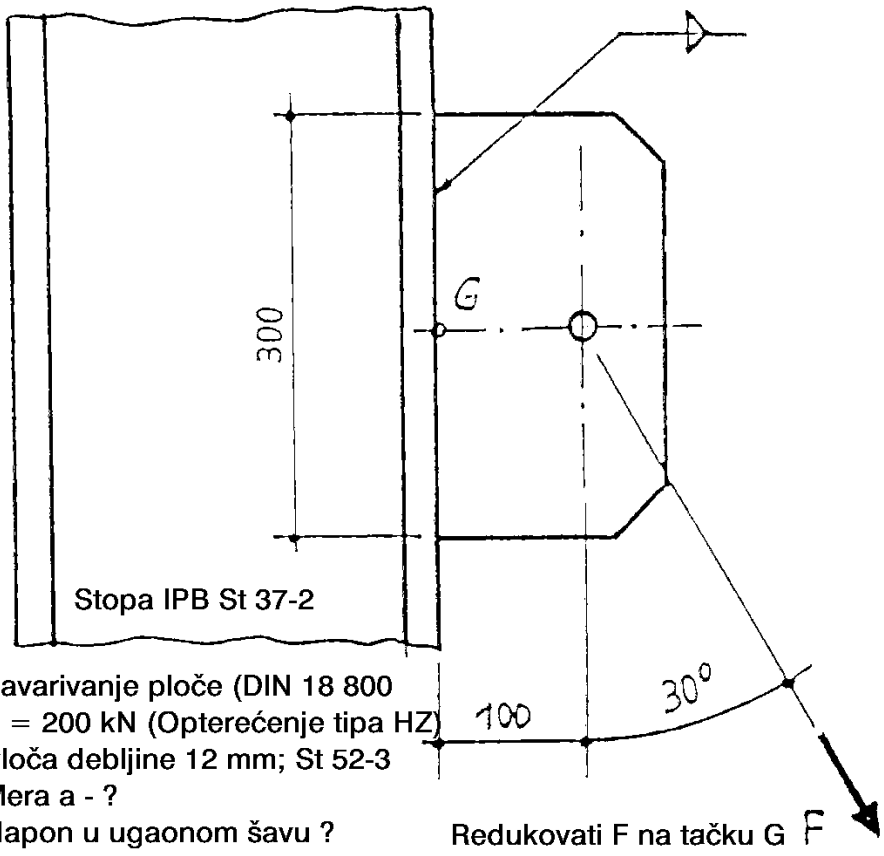


Zavarena greda (DIN 18 800
F = 320 kN (Opterećenje tipa H)
Profil - gornji i donji pojas 300X30; St 37-2
Rebro 500Z16; St 37-2
Mera a - minimalna
Napon u nosaču i u ugaonom spoju ?

Uputstvo: nacrati dijagrame M, T.

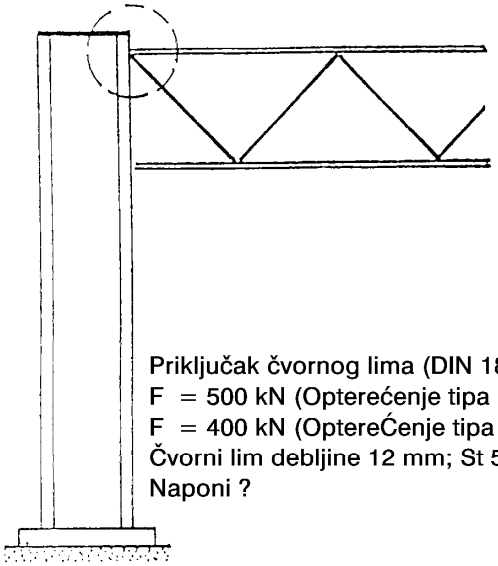


F = 200 kN (Opterećenje tipa H)
Profil L 100X100X12; St 37
Mera a - 6 mm
Napon u ugaonom šavu ?

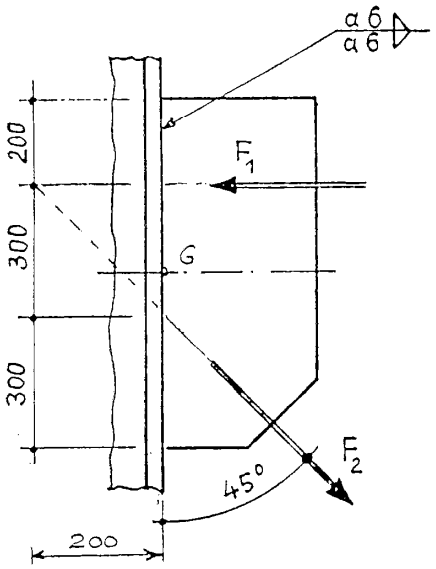


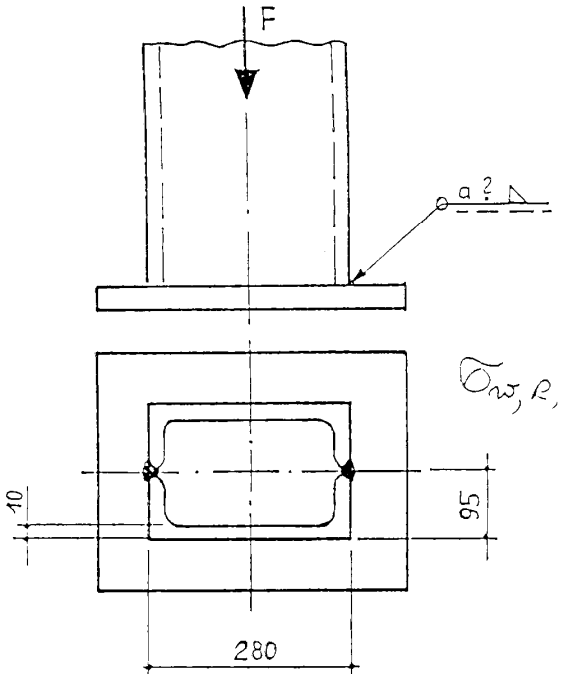
Zavarivanje ploče (DIN 18 800
F = 200 kN (Opterećenje tipa HZ)
Ploča debljine 12 mm; St 52-3
Mera a - ?
Napon u ugaonom šavu ?

Redukovati F na tačku G



Priključak čvornog lima (DIN 18 800)
F = 500 kN (Opterećenje tipa H)
F = 400 kN (OptereĆenje tipa H)
Čvorni lim debljine 12 mm; St 52 -3
Naponi ?

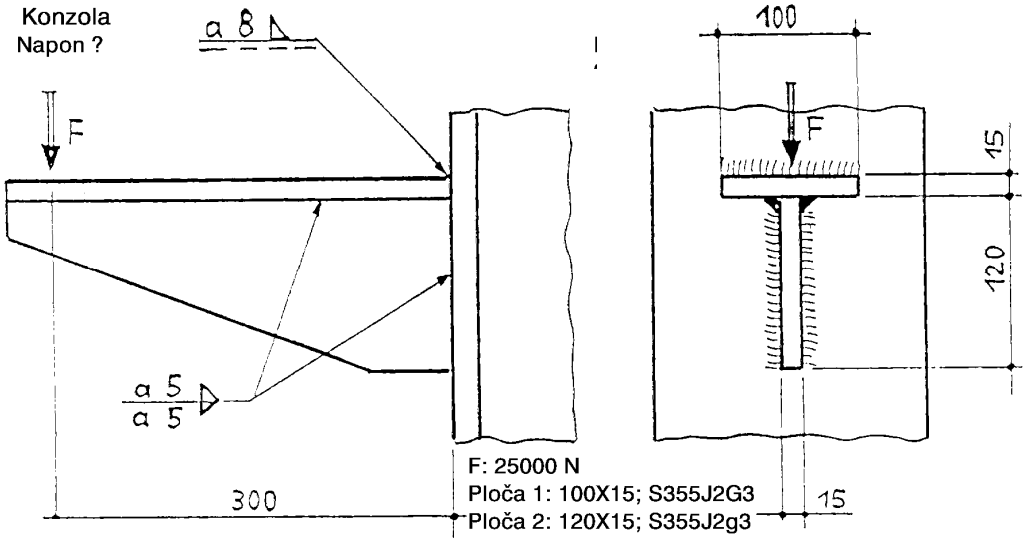




Oslona ploča (DIN 18 800)
F 500 kN (Opterećenje tipa H)
Profil 2[280X95X10; St 37 -2
a ?
Napon ?

$\sigma_{w,R,d} = 0{,}95 \cdot 24\ kN/mm^2$

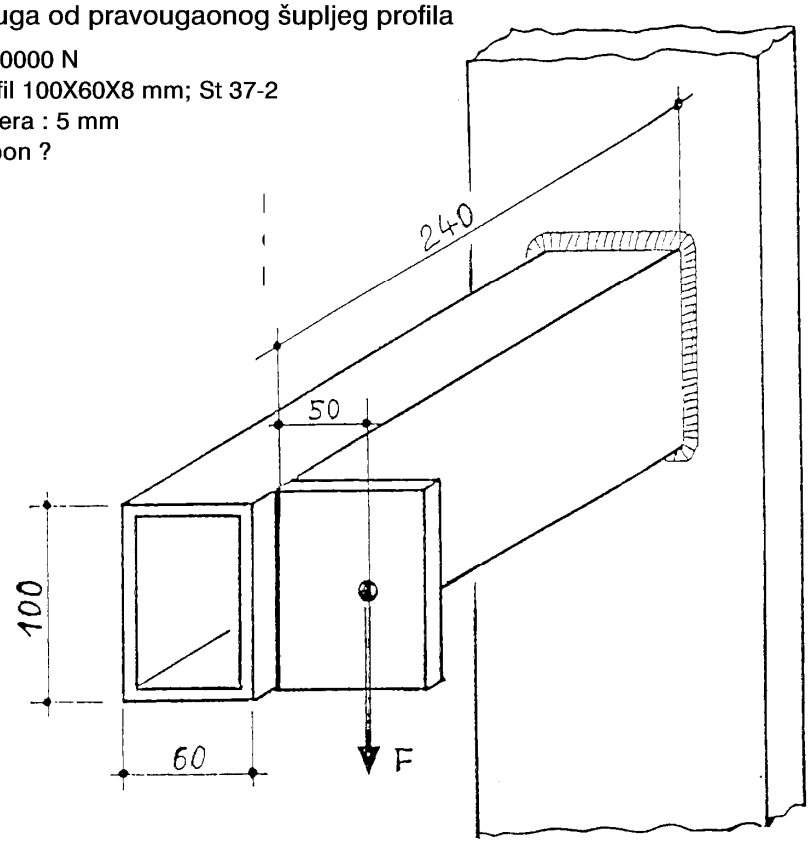
Konzola
Napon ?



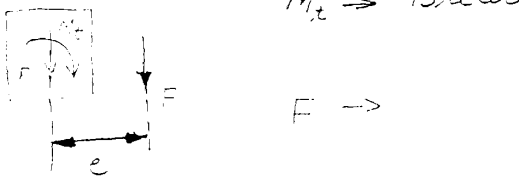
F: 25000 N
Ploča 1: 100X15; S355J2G3
Ploča 2: 120X15; S355J2g3

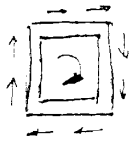
Poluga od pravougaonog šupljeg profila

F: 30000 N
Profil 100X60X8 mm; St 37-2
a mera : 5 mm
Napon ?

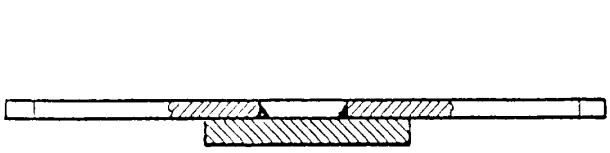


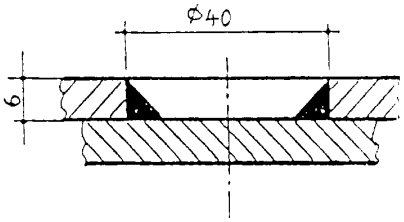
Uputstvo

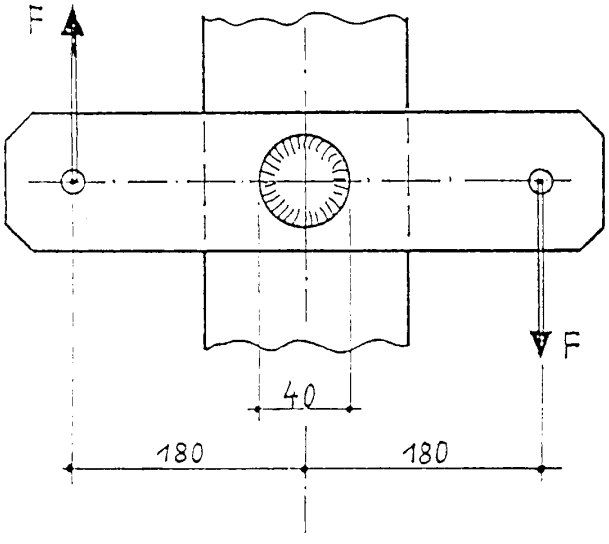




Formula
Bred



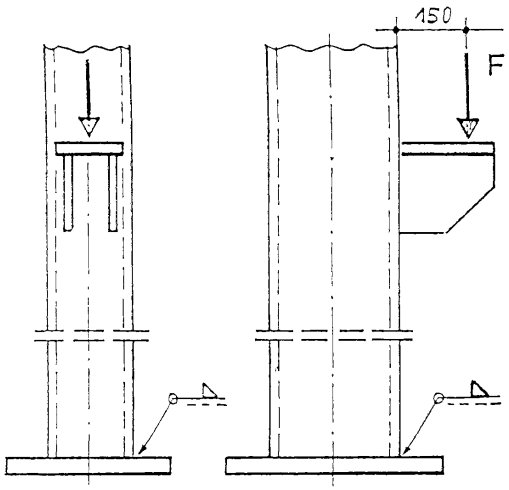




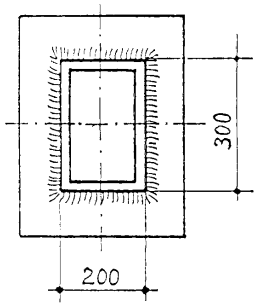
Zavarivanje čepa

F: 2,5 kN
Debljina lima 6 mm
Prečnik rupe 40 mm

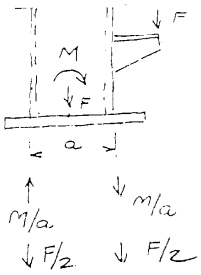
Koristiti formulu Breta



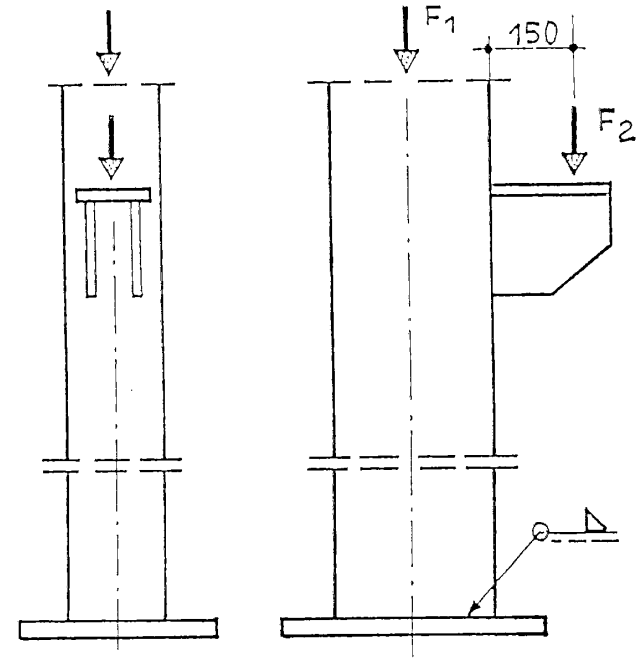
Oslona stopa (DIN 18 800)
F 160 kN
Potporni profil 300X200X12; S235
Osnovna ploča debljine 35 mm; S235
Debljin ugaonog šava a ?
Napon ?



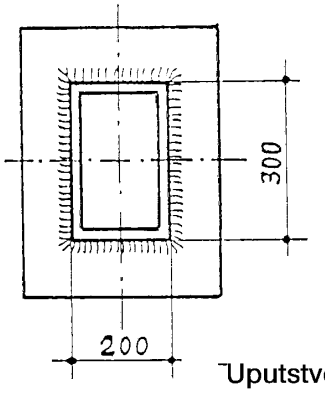
Uputstvo
Redukovati silu F
na težište spoja



$\sigma_{w,R,d} = 0{,}95 \cdot 24/1{,}1 \; kN/mm^2$



Oslona stopa
F1 200 kN
F2 100 kN
Potporni profil 300X200X12; S235
Osnovna ploča 35 mm; S235
Debljin ugaonog šava a ?
Napon ?



Uputstvo: vidi prethodni primer