

# Reinforced concrete arch calculation

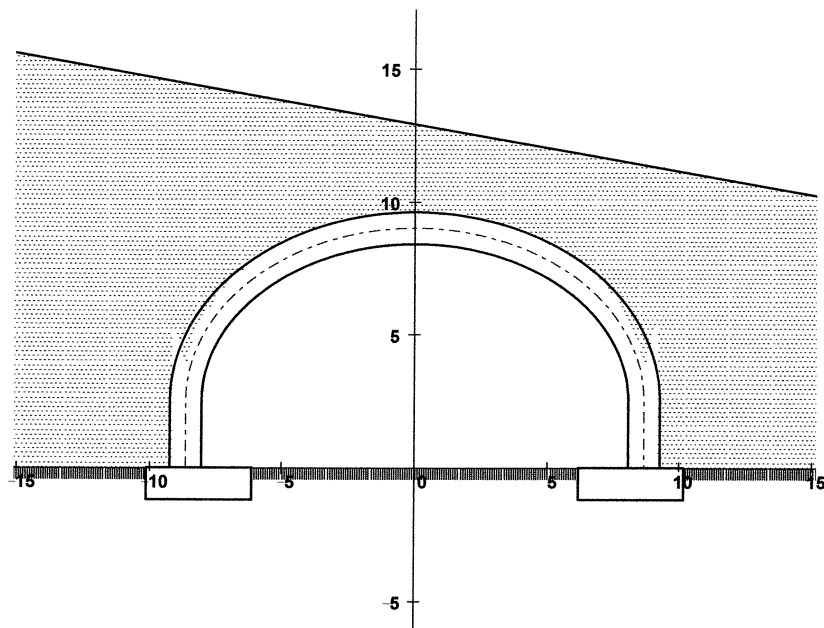
Arc shape : circle, ellipse, parabola

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Investitor :

Gradevina :

Broj projekta :



# PRORAČUN TUNELSKJE BETONSKJE OBLOGE

(a)

Pozicija : *Tunel* \_\_\_\_\_ Shema = 1

## *Kombinacija opterećenja 4*

- Kombinacija opterećenja :
1. Vlastita težina betonske obloge
  2. Skupljanje betona obloge
  3. Pad temperature ( $\Delta t = -30^{\circ}\text{C}$ )
  4. Mirni tlak tla

- Sadržaj proračuna :
1. ULAZNI PODACI,
  3. GEOMETRIJA BETONSKJE OBLOGE,
  4. STATIČKA SHEMA, PRORAČUNSKI DIAGRAM OPTEREĆENJA,
  5. REZNE SILE
    - 5.1 Momenti savijanja - zglobni i upeti oslonci,  
Anvelopa momenata savijanja,
    - 5.2 Poprečne sile - zglobni i upeti oslonci,  
Anvelopa poprečnih sila,
    - 5.3 Normalne sile - zglobni i upeti oslonci,  
Anvelopa normalnih sila,
    - 5.4 Glavni vlačni naponi - zglobni i upeti oslonci,  
Anvelopa glavnih vlačnih napona,
    - 5.5 Pregled reznih sila i reakcija u proračunskim točkama,  
Reakcije na osloncima  
Glavni vlačnih naponi u proračunskim točkama,
  6. DIMENZIONIRANJE ARMATURE,
    - 6.1 Ulazni podaci,
    - 6.2 Anvelopa potrebne armature i minimalna armatura,  
Pregled računski potrebne armatura, ekstremi
    - 6.3 Anvelopa deformacija betona po unutaršnjem i vanjskom rubu,  
Pregled rubnih deformacija betona
    - 6.4 Pokrivanje odabranom armaturom,  
Pregled potrebne i odabrane armatura u računskim točkama,
  7. PRORAČUN PUKOTINA U BETONU,
    - 7.1 Ulazni podaci,
    - 7.2 Granično stanje širina pukotina,
    - 7.3 Anvelope računskih širina pukotina,  
Pregled pukotina u proračunskim točkama i ekstremi,
  8. KONTROLA NAPONA U NEARMIRANOJ BETONSKOJ OBLOZI,
    - 8.1 Rubni naponi u betonu - zglobni oslonci,
    - 8.2 Rubni naponi u betonu - upeti oslonci,
    - 8.3 Rubni naponi u betonu u proračunskim točkama,

# 1. ULAZNI PODACI

(a)

Shema = 1.0

## 1.1 Geometrija luka

Linija luka (kružnica Fk, elipsa Fe, Parabola Fp) : Fk = 0 Fe = 1 Fp = 0

Raspon luka : L = 17.30 · m

Strelica luka : f = 6.50 · m

Visina stupa : h = 2.50 · m f + h = 9.00 · m

Debljina luka : dl = 1.20 · m

Debljina stupa : ds<sub>1</sub> = 1.20 · m

Računska širina svoda i stupa : bl = 1.00 · m

Zaštitni slojevi betona za luk i stupove : al = 0.10 · m

## 1.2 Geometrija temelja

### Lijevi temelj

Širina temelja : bt<sub>1</sub> = 4.00 · m

Visina temelja : ht<sub>1</sub> = 1.20 · m

Ekscentricitet temelja : et<sub>1</sub> = 0.50 · m

### Desni temelj

Širina temelja : bt<sub>2</sub> = 4.00 · m

Visina temelja : ht<sub>2</sub> = 1.20 · m

Ekscentricitet temelja : et<sub>2</sub> = -0.50 · m

## 1.3 Materijali

### Beton

Razred tlačne čvrstoće betona : C = 30.37

Karakteristična tlačna čvrstoća valjka : fck = 30.00 · MPa

Parcijalni koeficijent sigurnosti za beton : Usvojeno : γ<sub>c</sub> = 1.50

osnovna kombinacija : γ<sub>c</sub> = 1.5

izvanredne kombinacije (osim potresa) : γ<sub>c</sub> = 1.3

Proračunska čvrstoća betona : fcd = fck · γ<sub>c</sub><sup>-1</sup> fcd = 20.00 · MPa

Modul elastičnosti betona : E<sub>cm</sub> = 9500 ·  $\sqrt[3]{fck \cdot MPa^{-1} + 8 \cdot MPa}$  E<sub>cm</sub> = 31.94 · GPa

Prostorna težina betona : γ<sub>b</sub> = 25.00 · kN · m<sup>-3</sup>

Smičuća čvrstoća : τ<sub>rd</sub> = 0.34 · MPa (0.1 MPa za fazu skidanja oplata, MB 30)

Dopušteni središnji tlačni napon nearmiranog betona : σ<sub>dop</sub> = 6.00 · MPa (2 MPa za fazu skidanja oplata, MB 30)

Dopušteni rubni tlačni napon nearmiranog betona : σ<sub>rt</sub> = 8.00 · MPa (3 MPa za fazu skidanja oplata, MB 30)

Dopušteni vlačni napon nearmiranog betona : σ<sub>rv</sub> = 0.80 · MPa (0.3 MPa za fazu skidanja oplata, MB 30)

### Armaturni čelik

Granica razvlačenja čelika : R<sub>c</sub> = 500.00 · MPa (B500B)

Modul elastičnosti čelika : E<sub>s</sub> = 200.00 · GPa

Shema = 1.0

#### 1.4 Opterećenja

(a)

Koeficijent sigurnosti za dimenzioniranje :  $\gamma_u = 1.60$

Prostorna težina stijene :  $\gamma_n = 21.00 \cdot \text{kN} \cdot \text{m}^{-3}$

Visina sloja razlabavljene stijenske mase na duljini L :  $\text{hrs}_1 = 0.00 \cdot \text{m}$

Visina sloja razlabavljene stijenske mase na duljini L/2 :  $\text{hrs}_2 = 0.00 \cdot \text{m}$

Vlastita težina razlabavljene stijenske mase na duljini L :  $\text{gsm}_1 = \text{hrs}_1 \cdot \gamma_n$   $\text{gsm}_1 = 0.00 \cdot \text{kN} \cdot \text{m}^{-2}$

Vlastita težina razlabavljene stijenske mase na duljini L/2 :  $\text{gsm}_2 = \text{hrs}_2 \cdot \gamma_n$   $\text{gsm}_2 = 0.00 \cdot \text{kN} \cdot \text{m}^{-2}$

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Vlastita težina tunelske obloge :  $\text{gob} = \text{dl} \cdot \gamma_b$   $\text{gob} = 30.00 \cdot \text{kN} \cdot \text{m}^{-2}$

Prometno opterećenje na duljini L :  $\text{gpr}_1 = 5.00 \cdot \text{kN} \cdot \text{m}^{-2}$

Prometno opterećenje na duljini L/2 :  $\text{gpr}_2 = 10.00 \cdot \text{kN} \cdot \text{m}^{-2}$

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**UKUPNO**  $q_1 = \text{gob} + \text{gsm}_1 + \text{gpr}_1 = 35.00 \cdot \text{kN} \cdot \text{m}^{-2}$

**UKUPNO**  $q_2 = \text{gsm}_2 + \text{gpr}_2 = 10.00 \cdot \text{kN} \cdot \text{m}^{-2}$

#### Vertikalna opterećenja

Ravnomjerno kontinuirano po cijelom rasponu :  $q_1 = 70.00 \cdot \text{kN} \cdot \text{m}^{-1}$

Djelimično ravnomjerno kontinuirano :  $q_2 = 0.00 \cdot \text{kN} \cdot \text{m}^{-1}$

Početak ( $q_2$ ) :  $\text{bq}_2 = 0.000 \cdot \text{m}$

Duljina ( $q_2$ ) :  $\text{aq}_2 = 17.300 \cdot \text{m}$

Trokutno kontinuirano po cijelom rasponu :  $q_{11} = 80.00 \cdot \text{kN} \cdot \text{m}^{-1}$

#### Horizontalna opterećenja - lijevo

Ravnomjerno kontinuirano na luku, stupu :  $q_3 = 0.00 \cdot \text{kN} \cdot \text{m}^{-1}$   $q_5 = 130.00 \cdot \text{kN} \cdot \text{m}^{-1}$

Trokutno kontinuirano na luku, stupu :  $q_4 = 130.00 \cdot \text{kN} \cdot \text{m}^{-1}$   $q_6 = 25.00 \cdot \text{kN} \cdot \text{m}^{-1}$

#### Horizontalna opterećenja - desno

Ravnomjerno kontinuirano na luku, stupu :  $q_7 = 0.00 \cdot \text{kN} \cdot \text{m}^{-1}$   $q_9 = 55.00 \cdot \text{kN} \cdot \text{m}^{-1}$

Trokutno kontinuirano na luku, stupu :  $q_8 = 55.00 \cdot \text{kN} \cdot \text{m}^{-1}$   $q_{10} = 20.00 \cdot \text{kN} \cdot \text{m}^{-1}$

#### Vertikalne koncentrirane sile na kaloti

Simetrično na vertikalnu os. + dole.

Veličina sile (2 sile) :  $V = 0.00 \cdot \text{kN}$

Udaljenost između sile :  $\text{bV} = 0.00 \cdot \text{m}$

#### Horizontalne sile u vrhu stupa

Sile su usmjerene u unutrašnjost luka

Veličina sile :  $H = 0.00 \cdot \text{kN}$

Udaljenost sile od oslonca :  $\text{aH} = 0.00 \cdot \text{m}$

Shema = 1.0

## 1.5 Utjecaj temperature i skupljanja betona

(a)

### Temperatura

Koeficijent temperaturne promjene za beton :  $\epsilon_t = 1.00 \cdot 10^{-5}$

Promjena temperature (°Celsiusa) :  $\Delta t_i = -10$

Duljina raspona :  $L = 17.30 \cdot m$

Promjena duljine raspona :  $\Delta L_t = \epsilon_t \cdot \Delta t_i \cdot L$        $\Delta L_t = -1.73 \cdot mm$

### Skupljanje

Površina poprečnog presjeka :  $A_r = d_l \cdot b_l$        $A_r = 1.20 \cdot m^2$

Opseg poprečnog presjeka :  $O = 2 \cdot b_l$        $O = 2.00 \cdot m$

Srednja debljina presjeka elementa :  $d_m = \frac{2 \cdot A_r}{O}$        $d_m = 1.20 \cdot m$

Konačna vrijednost skupljanja betona za vlažnost 70% :  $\epsilon_{s\infty} = 0.03 \cdot \%$

Skupljanje u periodu eksploatacije  $\epsilon_s(t=28) - \epsilon_s(t=3 \text{ god.})$  :  $\epsilon_{st} = 0.63 - 0.08$        $\epsilon_{st} = 0.55$

$\epsilon_s = \epsilon_{s\infty} \cdot \epsilon_{st}$        $\epsilon_s = 0.017 \cdot \%$

Promjena duljine raspona :  $\Delta \epsilon = -\epsilon_s \cdot L$        $\Delta \epsilon = -2.9 \cdot mm$

### Ukupno temperatura + skupljanje

Ekvivalentni jednoliki pad temperature

$$\Delta t = \left( \Delta t_i + \frac{\Delta \epsilon}{\epsilon_t \cdot L} \right) \quad \Delta t = -26.50$$

## 1.6 Parametri grafike

Broj proračunskih točaka na luku i stupu :  $B_{tl} = 91$        $B_{ts} = 11$

Položaji diagrama :  $Y_{di} = 11.07 \cdot m$        $od_2 = 2.07 \cdot m$

$Y_{di} = 11.07 \cdot m$        $od_2 = 2.07 \cdot m$        $Bl_{am} = 0.10$

$Dot = 51.90 \cdot m$        $\Delta t_o = 0.17 \cdot m$        $\Delta x_t = 0.09 \cdot m$

$D_{mr} = 25.95 \cdot m$        $Re_1 = 5.00$        $Re_2 = 2.00$



## 2. Opterećenje mirnim tlakom tla

(b)

Shema = 1.0

### Parametri nasipa

Visina nadsloja iznad tjemena :  $H_{nt} = 3.30 \cdot m$

Računska širina sloja nasipa :  $B_n = 1.00 \cdot m$

Nagib površine terena :  $\beta_t = 10.00 \cdot deg$

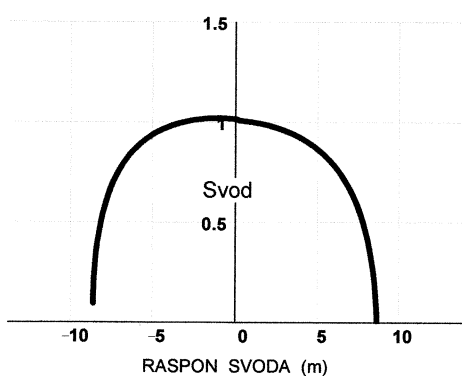
Prostorna težina nasipa :  $\gamma_n = 21.00 \cdot kN \cdot m^{-3}$

Kut unutrašnjeg trenja nasipa :  $\phi = 35.00 \cdot deg$

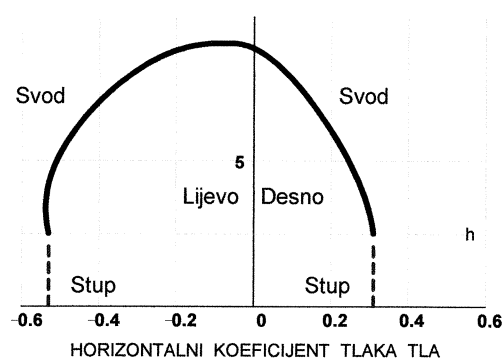
Kohezija :  $c_{oh} = 0 \cdot MPa$

### Koeficijenti mirnog tlaka tla (Jaky, Franke)

VERTIKALNI KOEFICIJENT TLAKA TLA



VISINA KONSTRUKCIJE (m)



### Diagrami mirnog tlaka tla

Luk

Visina nadsloja iznad točke  $x_l$  :  $y_n = (h + f + H_{nt} - y_l) + (0.5 \cdot L - x_l) \cdot \tan(\beta_t)$

Geostatički tlak iznad točke  $x_l$  + vlastita težina obloge :  $g_{vl} = y_n \cdot \gamma_n + d_l \cdot \gamma_b$

Vertikalna i horizontalna komponenta mirnog tlaka tla :  $E_{ov} = g_{vl} \cdot K_{ovl}$       $E_{oh} = g_{vl} \cdot K_{ohl}$

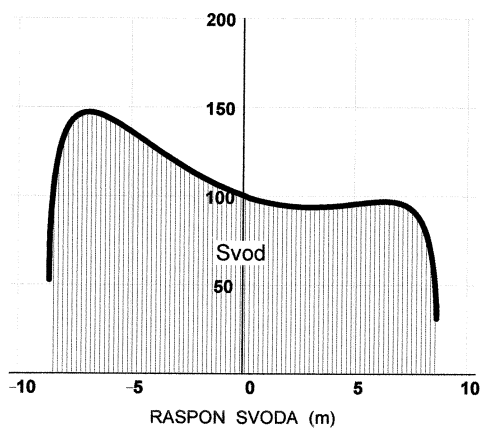
Stup

Visina nadsloja iznad točke  $x_s$  :  $y_n = h + f + H_{nt} - y_s + 0.5 \cdot L \cdot \tan(\beta_t)$

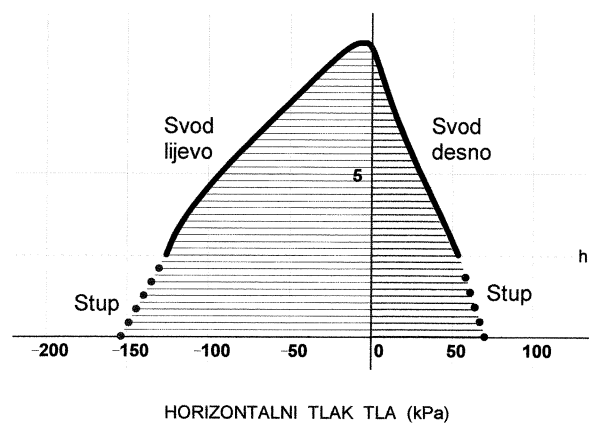
Geostatički tlak iznad točke  $x_s$  :  $g_{v2} = y_n \cdot \gamma_n$

Horizontalna komponenta mirnog tlaka tla :  $E_{oh} = g_{v2} \cdot K_{ohs1}$

VERTIKALNI TLAK TLA (kPa)

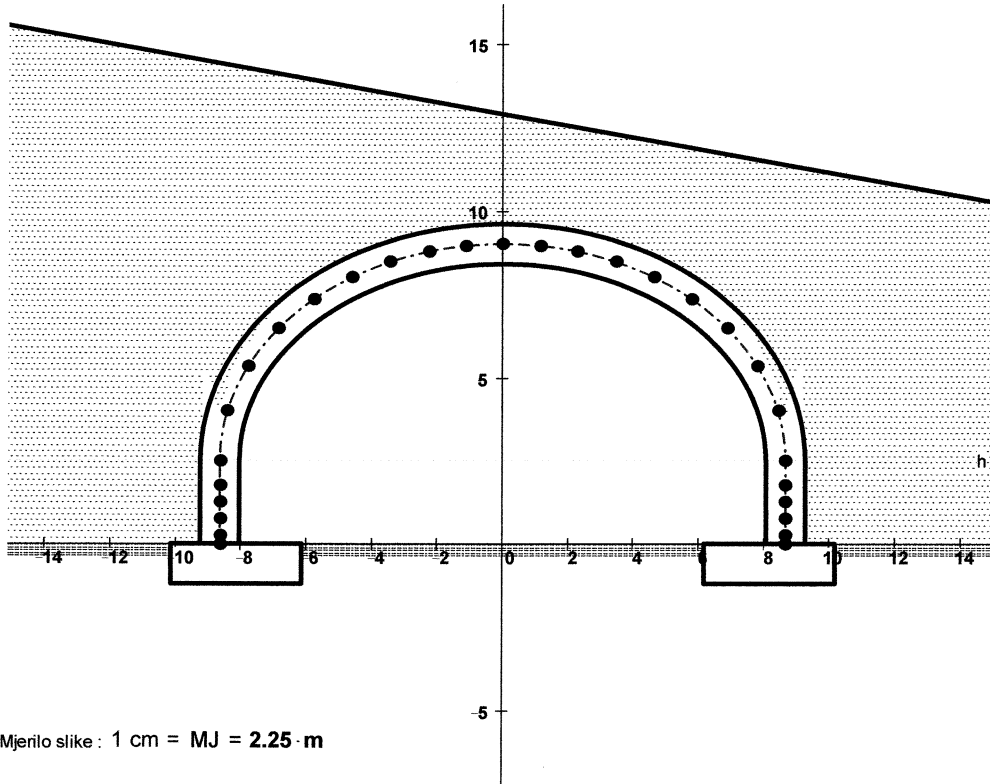


VISINA KONSTRUKCIJE (m)



### 3. Geometrija svoda

(b) Shema = 1.0

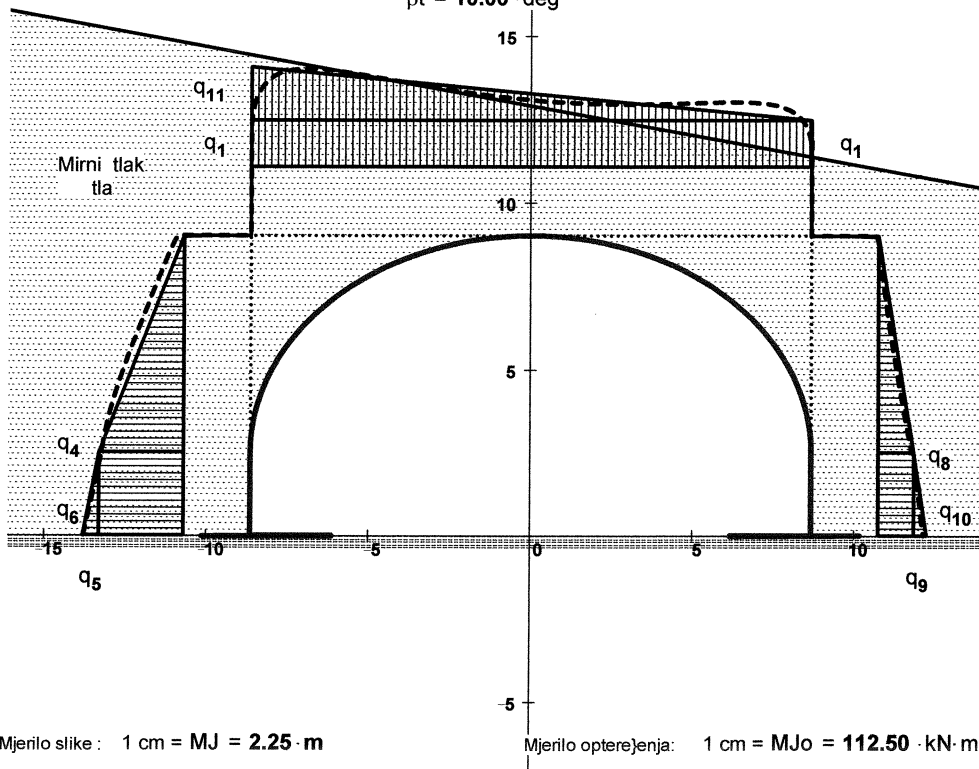


- $L = 17.30 \cdot \text{m}$
- $f = 6.50 \cdot \text{m}$
- $h = 2.50 \cdot \text{m}$
- $dl = 1.20 \cdot \text{m}$
- $ds_1 = 1.20 \cdot \text{m}$
- $bl = 1.00 \cdot \text{m}$
- $bt_1 = 4.00 \cdot \text{m}$
- $ht_1 = 1.20 \cdot \text{m}$
- $et_1 = 0.50 \cdot \text{m}$
- $bt_2 = 4.00 \cdot \text{m}$
- $ht_2 = 1.20 \cdot \text{m}$
- $et_2 = -0.50 \cdot \text{m}$
- $Hnt = 3.30 \cdot \text{m}$
- $\beta t = 10.00 \cdot \text{deg}$

Mjerilo slike : 1 cm = MJ = 2.25 · m

### 4. Statička shema, proračunski diagram opterećenja

$\beta t = 10.00 \cdot \text{deg}$



Temperatura +  
skupljanje  
 $\Delta t = 26.5$

Diagrami vanjskog  
opterećenja

$q =$	70	$\frac{\text{kN}}{\text{m}}$
	0	
	0	
	130	
	130	
	25	
	0	
	55	
	55	
	20	
	80	

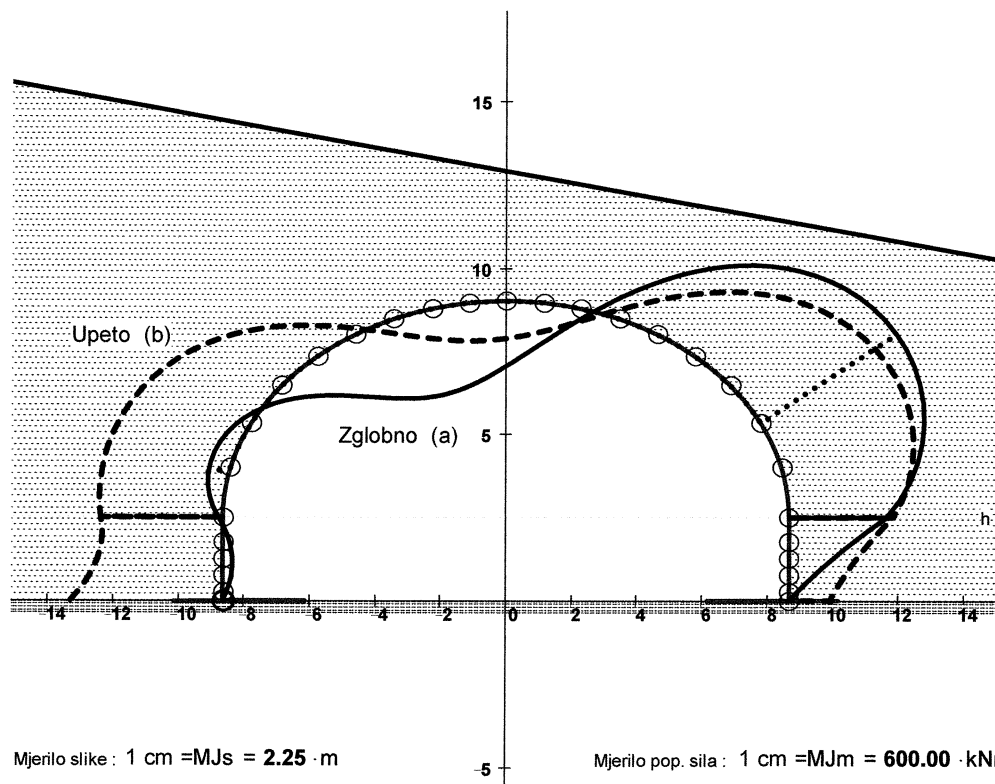
Mjerilo slike : 1 cm = MJ = 2.25 · m

Mjerilo opterećenja: 1 cm = MJ<sub>o</sub> = 112.50 · kN · m<sup>-1</sup>

|||||||

## 5.1 Momenti savijanja - zglobni i upeti oslonci

Shema = 1.0



### Zglobno (a)

Luk (1), stupovi (2), (3)

$$mxMa1 = 780.31 \cdot kNm$$

$$mnMa1 = -1484.57 \cdot kNm$$

$$mxMa2 = 88.14 \cdot kNm$$

$$mnMa2 = -39.86 \cdot kNm$$

$$mxMa3 = 0.00 \cdot kNm$$

$$mnMa3 = -893.99 \cdot kNm$$

### Upeto (b)

$$mxMb1 = 348.29 \cdot kNm$$

$$mnMb1 = -1284.40 \cdot kNm$$

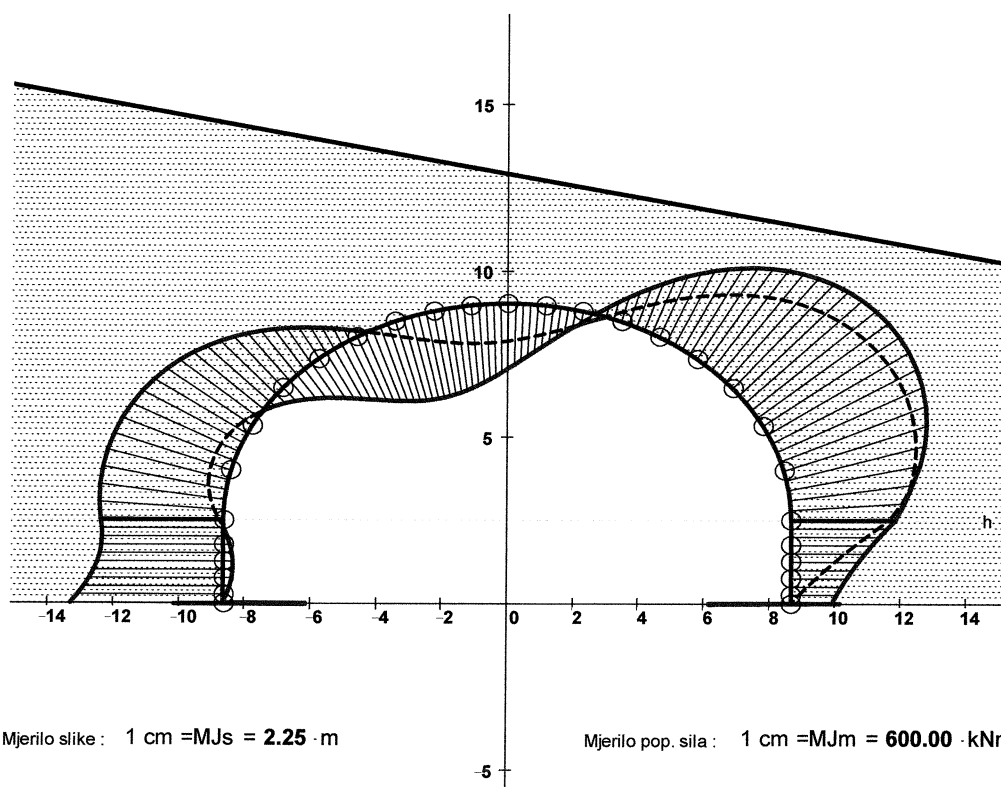
$$mxMb2 = -1.11 \cdot 10^3 \cdot kNm$$

$$mnMb2 = -1398.98 \cdot kNm$$

$$mxMb3 = -375.59 \cdot kNm$$

$$mnMb3 = -953.39 \cdot kNm$$

## Anvelopa momenata savijanja - zglobni i upeti oslonci



### Ekstremne vrijednosti

#### Luk (1)

$$mxM1 = 780.31 \cdot kNm$$

$$mnM1 = -1484.57 \cdot kNm$$

#### Stup (2)

$$mxM2 = 88.14 \cdot kNm$$

$$mnM2 = -1398.98 \cdot kNm$$

#### Stup (3)

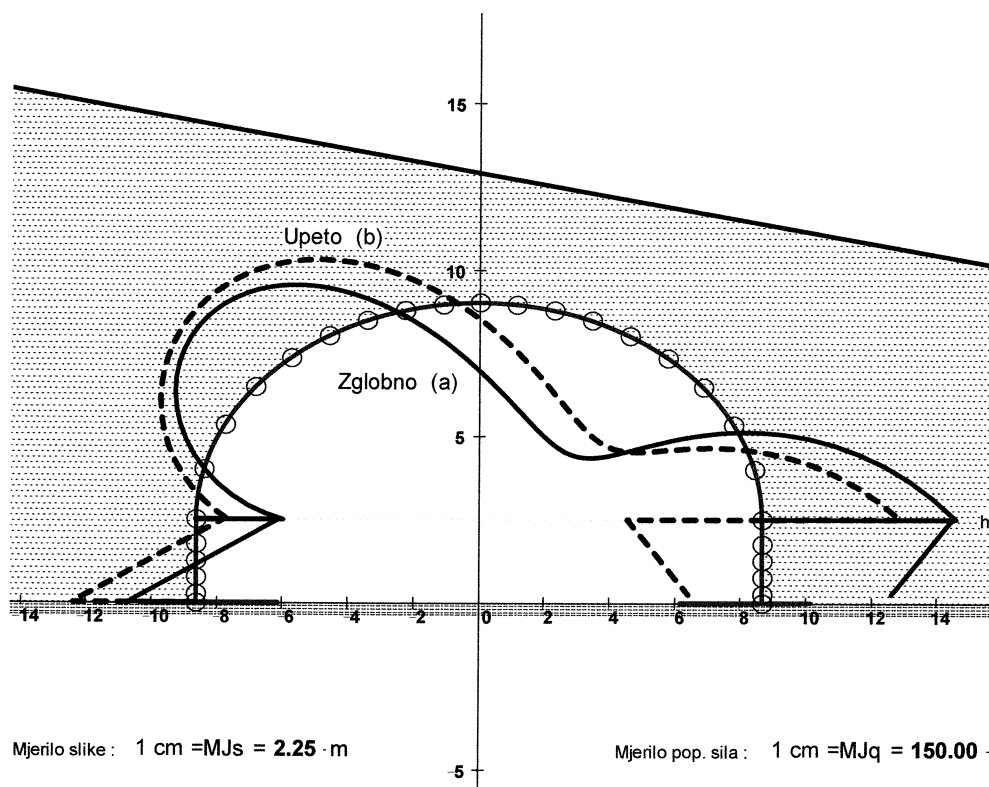
$$mxM3 = 0.00 \cdot kNm$$

$$mnM3 = -953.39 \cdot kNm$$



## 5.2 Poprečne sile - zglobni i upeti oslonci

Schema = 1.0



### Zglobno (a)

Luk (1), stupovi (2), (3)

$$m_x Q_{a1} = 444.22 \cdot \text{kN}$$

$$m_n Q_{a1} = -298.99 \cdot \text{kN}$$

$$m_x Q_{a2} = 156.97 \cdot \text{kN}$$

$$m_n Q_{a2} = -188.86 \cdot \text{kN}$$

$$m_x Q_{a3} = -280.51 \cdot \text{kN}$$

$$m_n Q_{a3} = -434.68 \cdot \text{kN}$$

### Upeto (b)

$$m_x Q_{b1} = 316.61 \cdot \text{kN}$$

$$m_n Q_{b1} = -243.40 \cdot \text{kN}$$

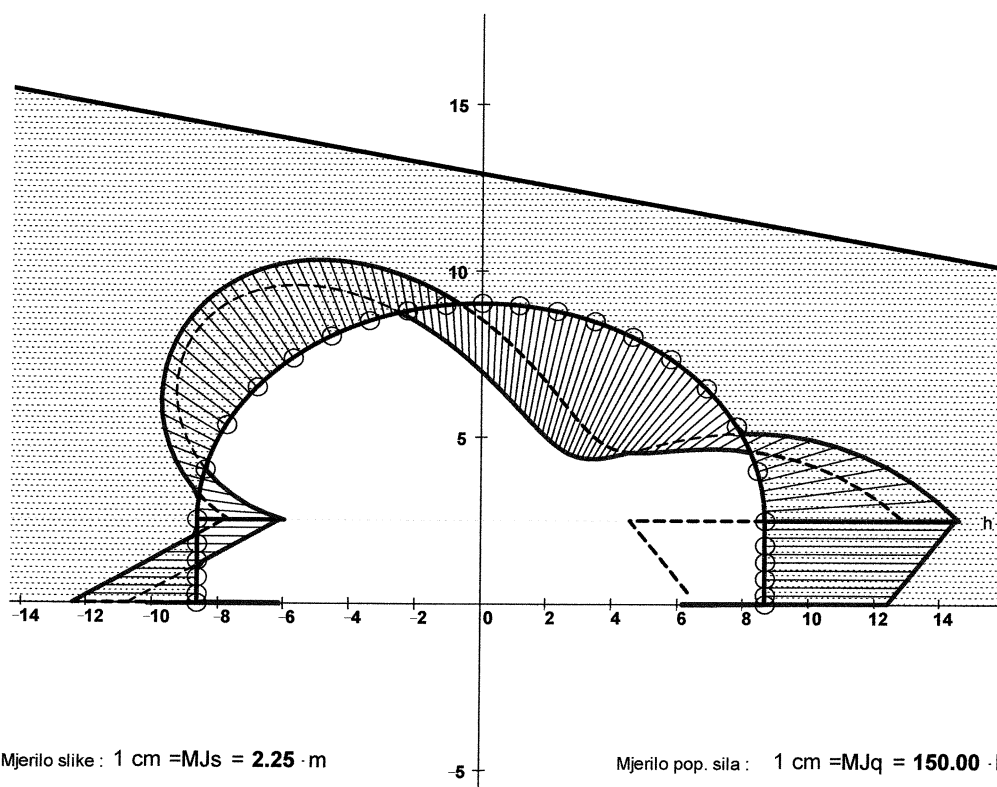
$$m_x Q_{b2} = 283.45 \cdot \text{kN}$$

$$m_n Q_{b2} = -62.38 \cdot \text{kN}$$

$$m_x Q_{b3} = -154.04 \cdot \text{kN}$$

$$m_n Q_{b3} = -308.20 \cdot \text{kN}$$

## Anvelopa poprečnih sila - zglobni i upeti oslonci



### Ekstremne vrijednosti

#### Luk (1)

$$m_x Q_1 = 444.22 \cdot \text{kN}$$

$$m_n Q_1 = -298.99 \cdot \text{kN}$$

#### Stup (2)

$$m_x Q_2 = 283.45 \cdot \text{kN}$$

$$m_n Q_2 = -188.86 \cdot \text{kN}$$

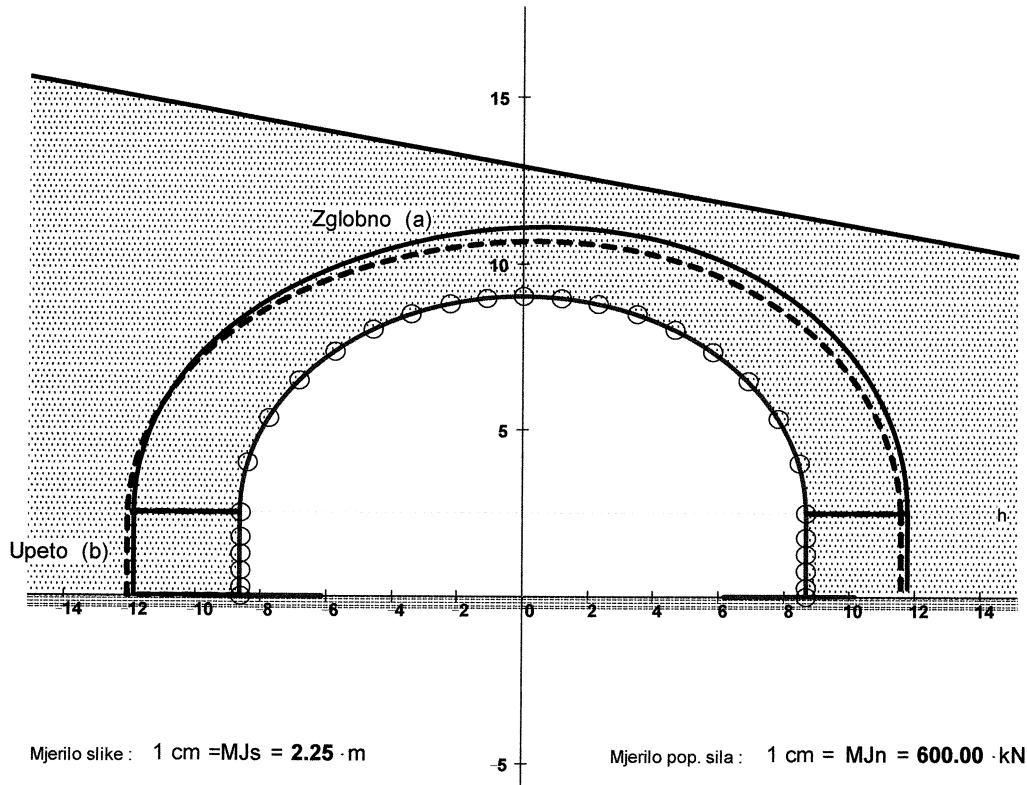
#### Stup (3)

$$m_x Q_3 = 0 \cdot \text{kN}$$

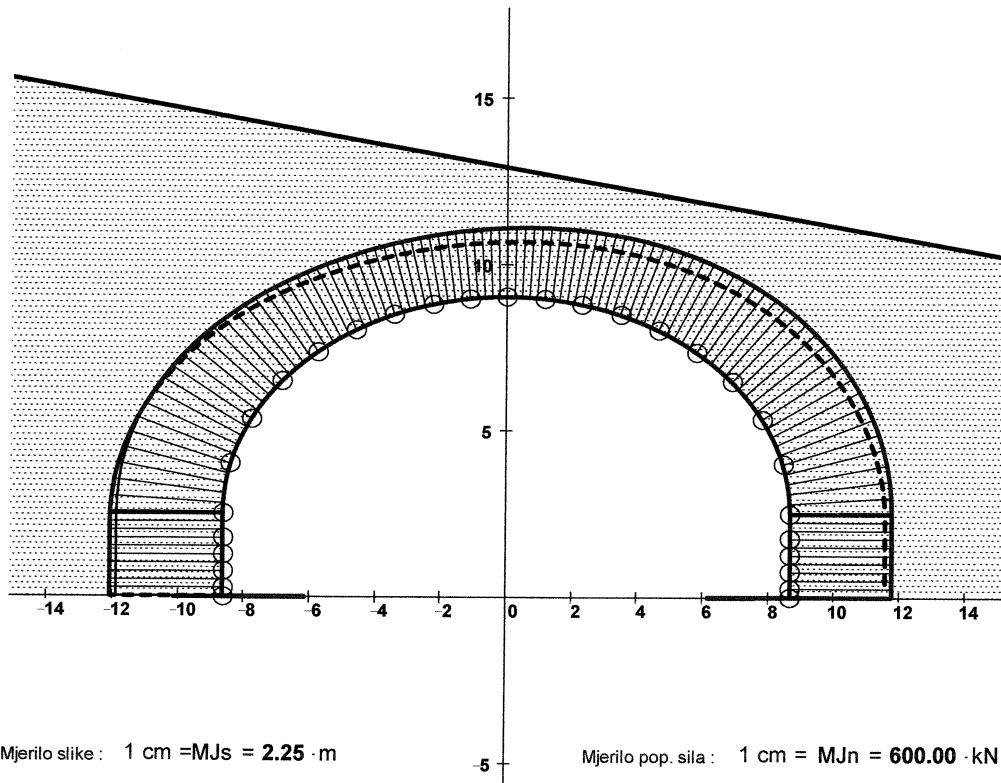
$$m_n Q_3 = -434.68 \cdot \text{kN}$$

### 5.3 Normalne sile - zglobni i upeti oslonci

Shema = 1.0

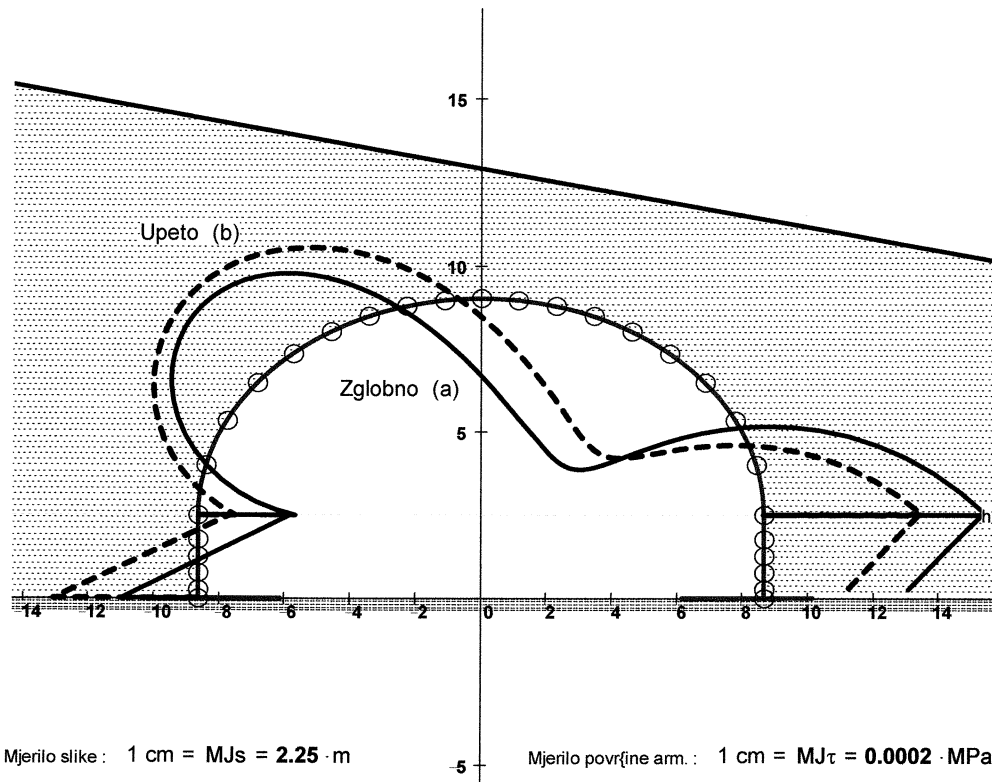


### Anvelopa normalnih sila - zglobni i upeti oslonci



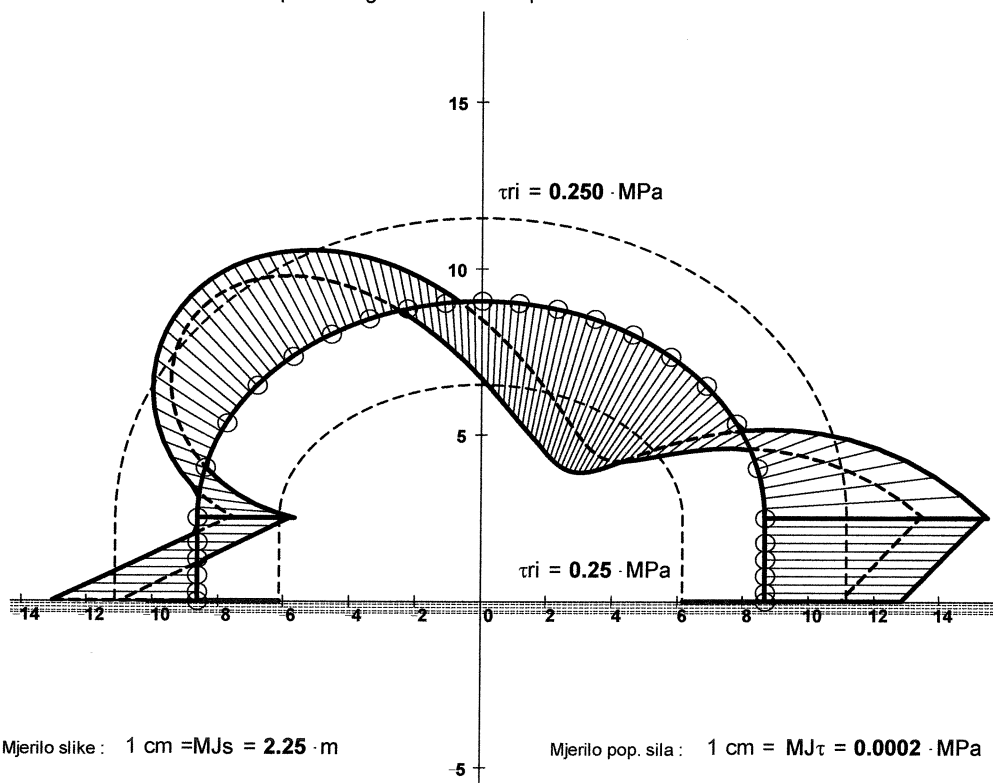
## 5.4 Glavni vlačni naponi - zglobni i upeti oslonci

Schema = 1.0



## Anvelopa glavnih vlačnih napona - zglobni i upeti oslonci

Dopušteni glavni vlačni napon :  $\tau_i = 0.25 \cdot \text{MPa}$



## 5.5 Pregled reznih sila i reakcija u proračunskim točkama

Schema = 1.0

Red. br. točke, min. (vani), max. (unutra)

### Momenti savijanja

Zglobno :

Luk :

$$M1a = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 & 16 & 17 & 18 & 19 & 20 \\ -38 & -38 & -189 & -80 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -233 & -607 & -988 & -1313 & -1481 & -1371 & -895 \\ 0 & 0 & 0 & 0 & 165 & 428 & 633 & 751 & 779 & 720 & 584 & 376 & 101 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \cdot \text{kNm} \begin{matrix} \text{vani} \\ \text{unutra} \end{matrix}$$

Upeto :

$$M1b = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 & 16 & 17 & 18 & 19 & 20 \\ -1123 & -1123 & -1122 & -934 & -643 & -334 & -63 & 0 & 0 & 0 & 0 & 0 & 0 & -99 & -376 & -698 & -1016 & -1242 & -1257 & -957 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0 & 144 & 279 & 343 & 336 & 261 & 116 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \cdot \text{kNm}$$

Anvelopa :

$$M1 = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 & 16 & 17 & 18 & 19 & 20 \\ -1123 & -1123 & -1122 & -934 & -643 & -334 & -63 & 0 & 0 & 0 & 0 & 0 & 0 & -233 & -607 & -988 & -1313 & -1481 & -1371 & -957 \\ 0 & 0 & 0 & 0 & 165 & 428 & 633 & 751 & 779 & 720 & 584 & 376 & 116 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \cdot \text{kNm}$$

Lijevi stup :

Desni stup :

$$\begin{matrix} \text{Zglobno :} \\ M2a = \end{matrix} \begin{pmatrix} 6 & -39.86 & 0 \\ 5 & 0 & 62.88 \\ 4 & 0 & 88.14 \\ 3 & 0 & 78.82 \\ 2 & 0 & 34.92 \\ 1 & 0 & 0 \end{pmatrix} \cdot \text{kNm} \quad \begin{matrix} M3a = \\ \end{matrix} \begin{pmatrix} 6 & 0 & -893.99 \\ 5 & 0 & -585.32 \\ 4 & 0 & -398.82 \\ 3 & 0 & -227.73 \\ 2 & 0 & -72.06 \\ 1 & 0 & 0 \end{pmatrix} \cdot \text{kNm}$$

$$\begin{matrix} \text{Upeto :} \\ M2b = \end{matrix} \begin{pmatrix} 6 & -1122.65 & 0 \\ 5 & -1114.77 & 0 \\ 4 & -1152.75 & 0 \\ 3 & -1225.3 & 0 \\ 2 & -1332.44 & 0 \\ 1 & -1398.98 & 0 \end{pmatrix} \cdot \text{kNm} \quad \begin{matrix} M3b = \\ \end{matrix} \begin{pmatrix} 6 & 0 & -953.39 \\ 5 & 0 & -739.58 \\ 4 & 0 & -616.31 \\ 3 & 0 & -508.46 \\ 2 & 0 & -416.02 \\ 1 & 0 & -375.59 \end{pmatrix} \cdot \text{kNm}$$

$$\begin{matrix} \text{Anvelopa :} \\ M2 = \end{matrix} \begin{pmatrix} 6 & -1122.65 & 0 \\ 5 & -1114.77 & 62.88 \\ 4 & -1152.75 & 88.14 \\ 3 & -1225.3 & 78.82 \\ 2 & -1332.44 & 34.92 \\ 1 & -1398.98 & 0 \end{pmatrix} \cdot \text{kNm} \quad \begin{matrix} M3 = \\ \end{matrix} \begin{pmatrix} 6 & 0 & -953.39 \\ 5 & 0 & -739.58 \\ 4 & 0 & -616.31 \\ 3 & 0 & -508.46 \\ 2 & 0 & -416.02 \\ 1 & 0 & -375.59 \end{pmatrix} \cdot \text{kNm}$$

Poprečne sile, anvelopa

Shema = 1.0

Luk :

Zglobno :

$$Q1a = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 & 16 & 17 & 18 & 19 & 20 \\ -198.9 & -198.9 & -2.9 & 0 & 0 & 0 & 0 & 0 & -14.2 & -86 & -152.8 & -212 & -259.9 & -291.2 & -297.8 & -267.9 & -185 & -33 & 0 & 0 \\ 0 & 0 & 0 & 134.8 & 188.6 & 176.8 & 126.6 & 58.9 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 189 & 444 \end{pmatrix}$$

Upeto :

$$Q1b = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 & 16 & 17 & 18 & 19 \\ -72.2 & -72.2 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -36 & -96.2 & -152.9 & -201.7 & -235.3 & -241.6 & -202.3 & -95.7 & 0 \\ 0 & 0 & 70.3 & 172.2 & 217.4 & 216.6 & 186.3 & 139.5 & 84.1 & 24.8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 87.7 \end{pmatrix}$$

Anvelopa :

$$Q1 = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 & 16 & 17 & 18 & 19 \\ -198.9 & -198.9 & -2.9 & 0 & 0 & 0 & 0 & 0 & -14.2 & -86 & -152.8 & -212 & -259.9 & -291.2 & -297.8 & -267.9 & -202.3 & -95.7 & 0 \\ 0 & 0 & 70.3 & 172.2 & 217.4 & 216.6 & 186.3 & 139.5 & 84.1 & 24.8 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 18 \end{pmatrix}$$

Lijevi stup :

Desni stup :

$$\text{Zglobno : } Q2a = \begin{pmatrix} 6 & -188.86 & 0 \\ 5 & -85.11 & 0 \\ 4 & -15.94 & 0 \\ 3 & 0 & 53.22 \\ 2 & 0 & 122.39 \\ 1 & 0 & 156.97 \end{pmatrix} \cdot \text{kN} \quad Q3a = \begin{pmatrix} 6 & -434.68 & 0 \\ 5 & -388.43 & 0 \\ 4 & -357.6 & 0 \\ 3 & -326.76 & 0 \\ 2 & -295.93 & 0 \\ 1 & -280.51 & 0 \end{pmatrix} \cdot \text{kN}$$

$$\text{Upeto : } Q2b = \begin{pmatrix} 6 & -62.38 & 0 \\ 5 & 0 & 41.37 \\ 4 & 0 & 110.53 \\ 3 & 0 & 179.7 \\ 2 & 0 & 248.87 \\ 1 & 0 & 283.45 \end{pmatrix} \cdot \text{kN} \quad Q3b = \begin{pmatrix} 6 & -308.2 & 0 \\ 5 & -261.95 & 0 \\ 4 & -231.12 & 0 \\ 3 & -200.29 & 0 \\ 2 & -169.45 & 0 \\ 1 & -154.04 & 0 \end{pmatrix} \cdot \text{kN}$$

$$\text{Anvelopa : } Q2 = \begin{pmatrix} 6 & -188.86 & 0 \\ 5 & -85.11 & 41.37 \\ 4 & -15.94 & 110.53 \\ 3 & 0 & 179.7 \\ 2 & 0 & 248.87 \\ 1 & 0 & 283.45 \end{pmatrix} \cdot \text{kN} \quad Q3 = \begin{pmatrix} 6 & -434.68 & 0 \\ 5 & -388.43 & 0 \\ 4 & -357.6 & 0 \\ 3 & -326.76 & 0 \\ 2 & -295.93 & 0 \\ 1 & -280.51 & 0 \end{pmatrix} \cdot \text{kN}$$

## Normalne sile, anelopa

Shema = 1.0

Luk :

$$\text{Zglobno : } N1a = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 & 16 & 17 & 18 & 19 & 20 \\ 972 & 972 & 942 & 862 & 773 & 701 & 651 & 622 & 610 & 611 & 622 & 641 & 667 & 700 & 740 & 785 & 835 & 884 & 921 & 931 \end{pmatrix} \cdot \text{kl}$$

$$\text{Upeto : } N1b = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 & 16 & 17 & 18 & 19 & 20 \\ 1031 & 1031 & 961 & 843 & 724 & 629 & 562 & 520 & 498 & 491 & 495 & 509 & 531 & 562 & 600 & 647 & 703 & 765 & 826 & 872 \end{pmatrix}$$

$$\text{Anelopa : } N1 = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 & 16 & 17 & 18 & 19 & 20 \\ 1031 & 1031 & 961 & 862 & 773 & 701 & 651 & 622 & 610 & 611 & 622 & 641 & 667 & 700 & 740 & 785 & 835 & 884 & 921 & 931 \end{pmatrix} \cdot \text{l}$$

Lijevi stup :

Desni stup :

$$\begin{array}{l} \text{Zglobno : } N2a = \begin{bmatrix} 6 & 971.68 \\ 5 & 971.68 \\ 4 & 971.68 \\ 3 & 971.68 \\ 2 & 971.68 \\ 1 & 971.68 \end{bmatrix} \cdot \text{kN} \end{array} \qquad \begin{array}{l} N3a = \begin{bmatrix} 6 & 931.32 \\ 5 & 931.32 \\ 4 & 931.32 \\ 3 & 931.32 \\ 2 & 931.32 \\ 1 & 931.32 \end{bmatrix} \cdot \text{kN} \end{array}$$

$$\begin{array}{l} \text{Upeto : } N2b = \begin{bmatrix} 6 & 1030.83 \\ 5 & 1030.83 \\ 4 & 1030.83 \\ 3 & 1030.83 \\ 2 & 1030.83 \\ 1 & 1030.83 \end{bmatrix} \cdot \text{kN} \end{array} \qquad \begin{array}{l} N3b = \begin{bmatrix} 6 & 872.17 \\ 5 & 872.17 \\ 4 & 872.17 \\ 3 & 872.17 \\ 2 & 872.17 \\ 1 & 872.17 \end{bmatrix} \cdot \text{kN} \end{array}$$

$$\begin{array}{l} \text{Anelopa : } N2 = \begin{bmatrix} 6 & 1030.83 \\ 5 & 1030.83 \\ 4 & 1030.83 \\ 3 & 1030.83 \\ 2 & 1030.83 \\ 1 & 1030.83 \end{bmatrix} \cdot \text{kN} \end{array} \qquad \begin{array}{l} N3 = \begin{bmatrix} 6 & 931.32 \\ 5 & 931.32 \\ 4 & 931.32 \\ 3 & 931.32 \\ 2 & 931.32 \\ 1 & 931.32 \end{bmatrix} \cdot \text{kN} \end{array}$$

## Reakcije na osloncima

	Lijevi oslonac	Desni oslonac	
<b>Vertikalne reakcije :</b>	Zglobno : $Va1 = 971.68 \cdot \text{kN}$	$Va2 = 931.32 \cdot \text{kN}$	( + gore)
	Upeto : $Vb1 = 1030.83 \cdot \text{kN}$	$Vb2 = 872.17 \cdot \text{kN}$	
<b>Horizontalne reakcije :</b>	Zglobno : $Ha1 = -156.97 \cdot \text{kN}$	$Ha2 = 280.51 \cdot \text{kN}$	( - unutra)
	Upeto : $Hb1 = -283.45 \cdot \text{kN}$	$Hb2 = 154.04 \cdot \text{kN}$	
<b>Reaktivni momenti :</b>	Zglobno : $Mra1 = 0.00 \cdot \text{kNm}$	$Mra2 = 0.00 \cdot \text{kNm}$	( - unutra)
	Upeto : $Mrb1 = -1398.98 \cdot \text{kNm}$	$Mrb2 = -375.59 \cdot \text{kNm}$	

## Glavni vlačni naponi

Dopušteni glavni vlačni napon :  $\tau_i = 0.25 \cdot \text{MPa}$

Luk :

Zglobno :

$$T1a = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 & 16 & 17 & 18 & 19 & 20 \\ -0.3 & -0.3 & 0 & 0 & 0 & 0 & 0 & 0 & -0.02 & -0.13 & -0.23 & -0.32 & -0.39 & -0.44 & -0.45 & -0.41 & -0.29 & -0.05 & 0 & 0 \\ 0 & 0 & 0 & 0.2 & 0.28 & 0.27 & 0.19 & 0.09 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.29 & 0.68 \end{pmatrix} \cdot \text{MPa}$$

Upeto :

$$T1b = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 & 16 & 17 & 18 & 19 & 20 \\ -0.11 & -0.11 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & -0.05 & -0.14 & -0.23 & -0.3 & -0.35 & -0.37 & -0.31 & -0.15 & 0 & 0 \\ 0 & 0 & 0.11 & 0.26 & 0.33 & 0.33 & 0.28 & 0.21 & 0.13 & 0.04 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.14 & 0.49 \end{pmatrix} \cdot \text{MPa}$$

Anvelopa :

$$T1 = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 & 16 & 17 & 18 & 19 & 20 \\ -0.3 & -0.3 & 0 & 0 & 0 & 0 & 0 & 0 & -0.02 & -0.13 & -0.23 & -0.32 & -0.39 & -0.44 & -0.45 & -0.41 & -0.31 & -0.15 & 0 & 0 \\ 0 & 0 & 0.11 & 0.26 & 0.33 & 0.33 & 0.28 & 0.21 & 0.13 & 0.04 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.29 & 0.68 \end{pmatrix} \cdot \text{MPa}$$

Lijevi stup :

Desni stup :

$$\begin{array}{l} \text{Zglobno :} \\ T2a = \begin{bmatrix} 6 & -0.28 & 0 \\ 5 & -0.13 & 0 \\ 4 & -0.02 & 0 \\ 3 & 0 & 0.08 \\ 2 & 0 & 0.18 \\ 1 & 0 & 0.23 \end{bmatrix} \cdot \text{MPa} \end{array} \quad \begin{array}{l} T3a = \begin{bmatrix} 6 & -0.67 & 0 \\ 5 & -0.59 & 0 \\ 4 & -0.54 & 0 \\ 3 & -0.49 & 0 \\ 2 & -0.44 & 0 \\ 1 & -0.42 & 0 \end{bmatrix} \cdot \text{MPa} \end{array}$$

$$\begin{array}{l} \text{Upeto :} \\ T2b = \begin{bmatrix} 6 & -0.1 & 0 \\ 5 & 0 & 0.06 \\ 4 & 0 & 0.17 \\ 3 & 0 & 0.28 \\ 2 & 0 & 0.39 \\ 1 & 0 & 0.44 \end{bmatrix} \cdot \text{MPa} \end{array} \quad \begin{array}{l} T3b = \begin{bmatrix} 6 & -0.47 & 0 \\ 5 & -0.4 & 0 \\ 4 & -0.35 & 0 \\ 3 & -0.3 & 0 \\ 2 & -0.26 & 0 \\ 1 & -0.23 & 0 \end{bmatrix} \cdot \text{MPa} \end{array}$$

$$\begin{array}{l} \text{Anvelopa :} \\ T2 = \begin{bmatrix} 6 & -0.28 & 0 \\ 5 & -0.13 & 0.06 \\ 4 & -0.02 & 0.17 \\ 3 & 0 & 0.28 \\ 2 & 0 & 0.39 \\ 1 & 0 & 0.44 \end{bmatrix} \cdot \text{MPa} \end{array} \quad \begin{array}{l} T3 = \begin{bmatrix} 6 & -0.67 & 0 \\ 5 & -0.59 & 0 \\ 4 & -0.54 & 0 \\ 3 & -0.49 & 0 \\ 2 & -0.44 & 0 \\ 1 & -0.42 & 0 \end{bmatrix} \cdot \text{MPa} \end{array}$$

## 6. DIMENZIONIRANJE ARMATURE

Shema = 1.0

### 6.1 Ulazni podaci

Koeficijent sigurnosti za stalno i pokretni opt. :  $\gamma_u = 1.60$

Greda (1) ili ploča (2) : Tip = 2

#### DIMENZIJE BETONSKOG PRESJEKA

Širina tlačnog dijela betonskog presjeka :  $b = 1.00 \cdot m$

Širina (rebra) za glavna vlačna naprezanja :  $b_r = 1.00 \cdot m$

Debljina luka :  $d_l = 1.20 \cdot m$

Debljina stupa :  $d_{s_1} = 1.20 \cdot m$

Zaštitni slojevi betona za luk i stupove :  $a_l = 0.10 \cdot m$

#### MATERIJALI

##### Beton

Razred tlačne čvrstoće betona :  $C = 30.37$

Karakteristična tlačna čvrstoća valjka :  $f_{ck} = 30.0 \cdot MPa$

Računska vlačna čvrstoća betona :  $\tau_i = 0.25 \cdot MPa$

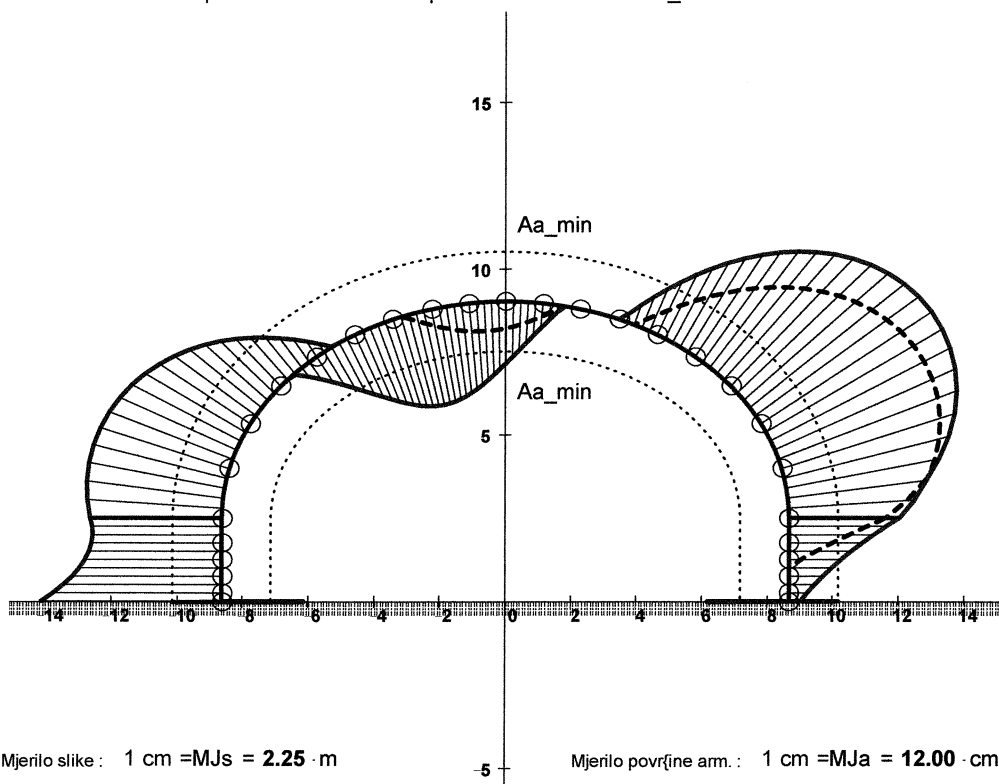
##### Armatura

Granica razvlačenja čelika :  $R_c = 500 \cdot MPa$

Deformacija armature (promila) :  $\epsilon_a = 10$

### 6.2 Anvelope potrebne armature i minimalna armatura

Min. površina armature :  $\mu_{min} = 0.075 \cdot \%$   $A_{a\_min} = 9.00 \cdot cm^2$





6.3 Pregled rubnih deformacija beton (prema anvelopi)  
(Red. br. točke, vani, unutra)

Shema = 1.0

Luk :

$$eb1 = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 & 16 & 17 & 18 & 19 & 20 \\ 0 & 0 & 0 & 0 & 0.83 & 1.1 & 1.29 & 1.39 & 1.42 & 1.36 & 1.23 & 1.02 & 0.71 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \\ 1.87 & 1.87 & 1.85 & 1.63 & 1.32 & 0.97 & 0.62 & 0 & 0 & 0 & 0 & 0 & 0 & 0.89 & 1.29 & 1.67 & 2 & 2.19 & 2.08 & 1.66 \end{pmatrix} \begin{matrix} \text{točka} \\ \text{vani} \\ \text{unutra} \end{matrix}$$

Lijevi stup : eb2 =

$$\begin{bmatrix} 6 & 0 & 1.87 \\ 5 & 0.79 & 1.86 \\ 4 & 0.82 & 1.9 \\ 3 & 0.8 & 1.97 \\ 2 & 0.75 & 2.08 \\ 1 & 0 & 2.15 \end{bmatrix}$$

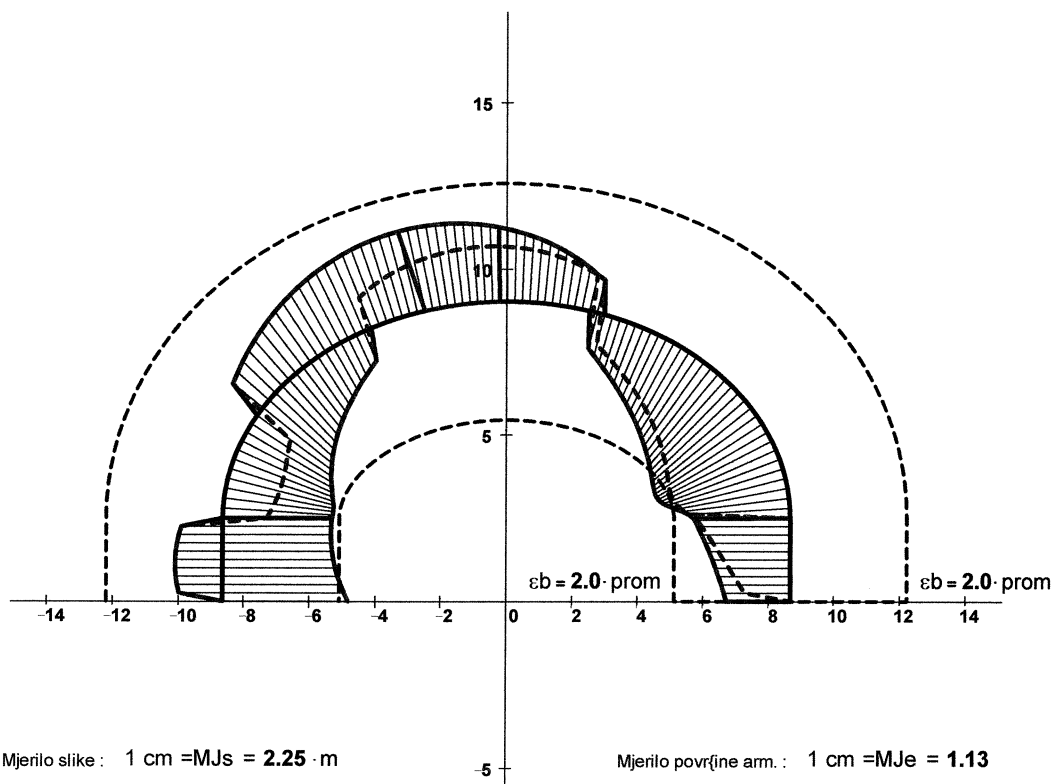
Desni stup : eb3 =

$$\begin{bmatrix} 6 & 1.66 & 0 \\ 5 & 1.46 & 0 \\ 4 & 1.34 & 0 \\ 3 & 1.23 & 0 \\ 2 & 1.14 & 0 \\ 1 & 1.1 & 0 \end{bmatrix}$$

Ekstremne vrijednosti površine armature

	Zglobno (a)	Upeto (b)	Anvelopa
Luk :	$mx\epsilon_{ba1} = 2.19$	$mx\epsilon_{bb1} = 1.96$	$\epsilon_{b1u} = 2.19$
	$mn\epsilon_{ba1} = 0.62$	$mn\epsilon_{bb1} = 0.52$	$\epsilon_{b1v} = 0.62$
Stup lijevo :	$mx\epsilon_{ba2} = 0.82$	$mx\epsilon_{bb2} = 2.15$	$\epsilon_{b2u} = 2.15$
	$mn\epsilon_{ba2} = 0.00$	$mn\epsilon_{bb2} = 0.00$	$\epsilon_{b2v} = 0.00$
Stup desno :	$mx\epsilon_{ba3} = 1.62$	$mx\epsilon_{bb3} = 1.66$	$\epsilon_{b3u} = 1.66$
	$mn\epsilon_{ba3} = 0.00$	$mn\epsilon_{bb3} = 0.00$	$\epsilon_{b3v} = 0.00$

Anvelopa deformacija betona po unutarnjem i vanjskom rubu



**Pregled računski potrebne armature (prema anvelopi)**  
(Red. br. točke, vani, unutra)

Shema = 1.0

Luk :

$$A1 = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 & 16 & 17 & 18 & 19 & 20 \\ 24 & 24 & 24.7 & 19.8 & 11.9 & 3.3 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 10.6 & 22.2 & 32.1 & 37.2 & 33.2 & 20.3 \\ 0 & 0 & 0 & 0 & 0 & 5.5 & 12.3 & 16.3 & 17.3 & 15.5 & 11.1 & 4.5 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \cdot \text{cm}^2 \begin{matrix} \text{vani} \\ \text{unutra} \end{matrix}$$

$$\text{Lijevi stup : } A2 = \begin{pmatrix} 6 & 24.02 & 0 \\ 5 & 23.77 & 0 \\ 4 & 25 & 0 \\ 3 & 27.36 & 0 \\ 2 & 30.86 & 0 \\ 1 & 33.06 & 0 \end{pmatrix} \cdot \text{cm}^2$$

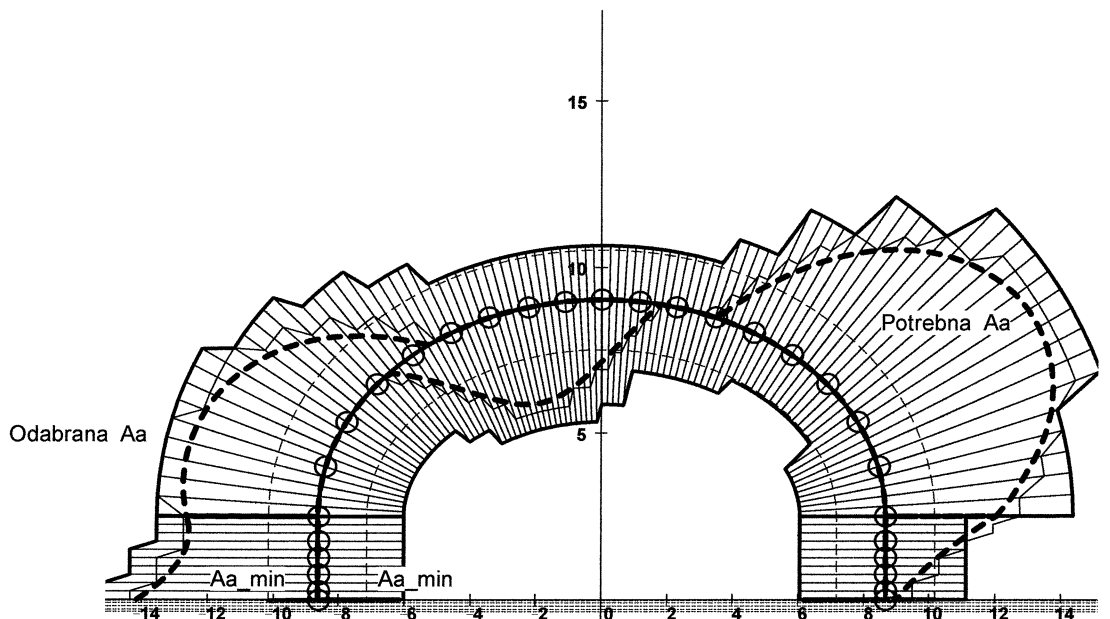
$$\text{Desni stup : } A3 = \begin{pmatrix} 6 & 0 & 20.18 \\ 5 & 0 & 13.41 \\ 4 & 0 & 9.55 \\ 3 & 0 & 6.2 \\ 2 & 0 & 3.34 \\ 1 & 0 & 2.09 \end{pmatrix} \cdot \text{cm}^2$$

**Ekstremne vrijednosti površine armature**

	Zglobno (a)	Upeto (b)	Anvelopa
Luk :	$mxAa1 = 17.35 \cdot \text{cm}^2$ $mnAa1 = 37.23 \cdot \text{cm}^2$	$mxAb1 = 5.22 \cdot \text{cm}^2$ $mnAb1 = 31.52 \cdot \text{cm}^2$	$mxA1 = 17.35 \cdot \text{cm}^2$ $mnA1 = 37.23 \cdot \text{cm}^2$
Stup lijevo :	$mxAa2 = 0.00 \cdot \text{cm}^2$ $mnAa2 = 0.00 \cdot \text{cm}^2$	$mxAb2 = 0.00 \cdot \text{cm}^2$ $mnAb2 = 33.06 \cdot \text{cm}^2$	$mxA2 = 0.00 \cdot \text{cm}^2$ $mnA2 = 33.06 \cdot \text{cm}^2$
Stup desno :	$mxAa3 = 0.00 \cdot \text{cm}^2$ $mnAa3 = 17.69 \cdot \text{cm}^2$	$mxAb3 = 0.00 \cdot \text{cm}^2$ $mnAb3 = 20.18 \cdot \text{cm}^2$	$mxA3 = 0.00 \cdot \text{cm}^2$ $mnA3 = 20.18 \cdot \text{cm}^2$

**6.4 Pokrivanje odabranom armaturom**

Min. površina armature :  $\mu_{\min} = 0.075 \cdot \%$      $Aa_{\min} = 9.00 \cdot \text{cm}^2$



Mjerilo slike : 1 cm = MJs = 2.25 · m

-5 Mjerilo površine armature : 1 cm = MJa = 12.00 · cm<sup>2</sup>

## Pregled potrebne i odabrane armature u računskim točkama

Shema = 1.0

### Luk vani

Profil :  $\phi_{v_1} = 25 \cdot \text{mm}$      $A\phi_1 = 4.91 \cdot \text{cm}^2$

Potrebno			Odabrano					
Aa (cm <sup>2</sup> )	br. $\phi$ kom		br. $\phi$ kom	b (cm)	Aa (cm <sup>2</sup> )			
P1 $\phi_v$ =	1	24	5	O1 $\phi_v$ =	1	6	16.7	29.5
	2	24	5		2	6	16.7	29.5
	3	24.7	6		3	6	16.7	29.5
	4	19.8	5		4	5	20	24.5
	5	11.9	3		5	4	25	19.6
	6	3.3	1		6	3	33.3	14.7
	7	0	0		7	2	50	9.8
	8	0	0		8	2	50	9.8
	9	0	0		9	2	50	9.8
	10	0	0		10	2	50	9.8
	11	0	0		11	2	50	9.8
	12	0	0		12	2	50	9.8
	13	0	0		13	2	50	9.8
	14	0	0		14	3	33.3	14.7
	15	10.6	3		15	5	20	24.5
	16	22.2	5		16	7	14.3	34.4
	17	32.1	7		17	9	11.1	44.2
	18	37.2	8		18	9	11.1	44.2
	19	33.2	7		19	7	14.3	34.4
	20	20.3	5		20	5	20	24.5

### Luk unutra

Profil :  $\phi_{u_1} = 20 \cdot \text{mm}$      $A\phi_4 = 3.14 \cdot \text{cm}^2$

Potrebno			Odabrano					
Aa (cm <sup>2</sup> )	br. $\phi$ kom		br. $\phi$ kom	b (cm)	Aa (cm <sup>2</sup> )			
P1 $\phi_u$ =	1	0	0	O1 $\phi_u$ =	1	5	20	15.7
	2	0	0		2	5	20	15.7
	3	0	0		3	5	20	15.7
	4	0	0		4	5	20	15.7
	5	0	0		5	5	20	15.7
	6	-5.5	2		6	6	16.7	18.8
	7	-12.3	4		7	7	14.3	22
	8	-16.3	6		8	7	14.3	22
	9	-17.3	6		9	7	14.3	22
	10	-15.5	5		10	7	14.3	22
	11	-11.1	4		11	6	16.7	18.8
	12	-4.5	2		12	4	25	12.6
	13	0	0		13	4	25	12.6
	14	0	0		14	4	25	12.6
	15	0	0		15	3	33.3	9.4
	16	0	0		16	3	33.3	9.4
	17	0	0		17	3	33.3	9.4
	18	0	0		18	5	20	15.7
	19	0	0		19	5	20	15.7
	20	0	0		20	5	20	15.7

### Stup lijevo - vani

Profil :  $\phi_{v_2} = 25 \cdot \text{mm}$      $A\phi_2 = 4.91 \cdot \text{cm}^2$

Potrebno			Odabrano					
Aa (cm <sup>2</sup> )	br. $\phi$ kom		br. $\phi$ kom	b (cm)	Aa (cm <sup>2</sup> )			
P2 $\phi_v$ =	1	33	7	O2 $\phi_v$ =	1	8	12.5	39.27
	2	31	7		2	8	12.5	39.27
	3	27	6		3	7	14.29	34.36
	4	25	6		4	7	14.29	34.36
	5	24	5		5	6	16.67	29.45
	6	24	5		6	6	16.67	29.45

### Stup desno - vani

Profil :  $\phi_{v_3} = 25 \cdot \text{mm}$      $A\phi_3 = 4.91 \cdot \text{cm}^2$

Potrebno			Odabrano					
Aa (cm <sup>2</sup> )	br. $\phi$ kom		br. $\phi$ kom	b (cm)	Aa (cm <sup>2</sup> )			
P3 $\phi_v$ =	1	2	1	O3 $\phi_v$ =	1	3	33.33	14.73
	2	3	1		2	3	33.33	14.73
	3	6	2		3	3	33.33	14.73
	4	10	2		4	3	33.33	14.73
	5	13	3		5	3	33.33	14.73
	6	20	5		6	3	33.33	14.73

## 7. PRORAČUN PUKOTINA U BETONU (prema EC-2)

### 7.1 Ulazni podaci Shema = 1.0

#### DIMENZIJE PRESJEKA

Širina i visina betonskog presjeka :  $b = 100.00 \cdot \text{cm}$   $d_p = 120 \cdot \text{cm}$   
Težište vlačne armature do vlačnog ruba i zaštitni sloj :  $a = 17.30 \cdot \text{m}$   $c_p = 4.50 \cdot \text{cm}$

#### MATERIJALI

Marka betona :  $C = 30.37$   
Karakteristična tlačna čvrstoća betonskog cilindra :  $f_{ck} = 30.0 \cdot \text{MPa}$   
Efektivna vlačna čvrstoća betona :  $f_{ct\_eff} = 2.60 \cdot \text{MPa}$   
Sekantni modul elastičnosti betona :  $E_{cm} = 31.94 \cdot \text{GPa}$   
Granica razvlačenja i modul elastičnosti čelika :  $R_c = 500 \cdot \text{MPa}$   $E_s = 200 \cdot \text{GPa}$

#### KOEFICIJENTI

Koeficijent puzanja betona  $f(\infty, t_0)$  :  $\psi_t = 2.50$   
Koeficijent raspodjele naprezanja po visini presjeka :  $k_c = 0.40$   
Koeficijent uravnoteženih nelinearnih naprezanja :  $k = 1.00$   
Utjecaj stupnja prijanjanja između armature i betona :  $k_1 = 0.80$   
Koeficijent raspodjele deformacija :  $k_2 = 0.50$   
Koeficijent odnosa prosječne širine pukotine :  $\beta_i = 1.70$   
Koeficijent vrste armature :  $\beta_1 = 1.00$   
Koeficijent trajanja opterećenja :  $\beta_2 = 0.50$

### 7.2 Granično stanje širina pukotina (osnovne formule)

$$\text{Težište armature na tlačni rub : } x_a = \frac{A_{s1} \cdot h_a + A_{s2} \cdot a}{A_{s1} + A_{s2}} \quad y_v = d_l - x_a$$

$$\text{Površina vlačne zone betona : } A_{ct} = b_3 \cdot y_v$$

$$\text{Minimalna armatura za ograničenje raspucavanja : } A_{mn} = k_c \cdot k \cdot f_{ct\_eff} \cdot \frac{A_{ct}}{\sigma_s}$$

$$\text{Moment savijanja pri pojavi prve pukotine : } M_{sr} = f_{ctm} \cdot b_3 \cdot \frac{d_l^2}{6}$$

$$\text{Vlačno naprezanje u armaturi pri pojavi prve pukotine : } \sigma_{sr} = \frac{M_{sr}}{A_{s1} \cdot 0.9 \cdot h_a}$$

$$\text{Srednja deformacija armature : } \epsilon_{sm} = \frac{\sigma_s}{E_s} \left[ 1 - \beta_1 \cdot \beta_2 \cdot \left( \frac{\sigma_{sr}}{\sigma_s} \right)^2 \right]$$

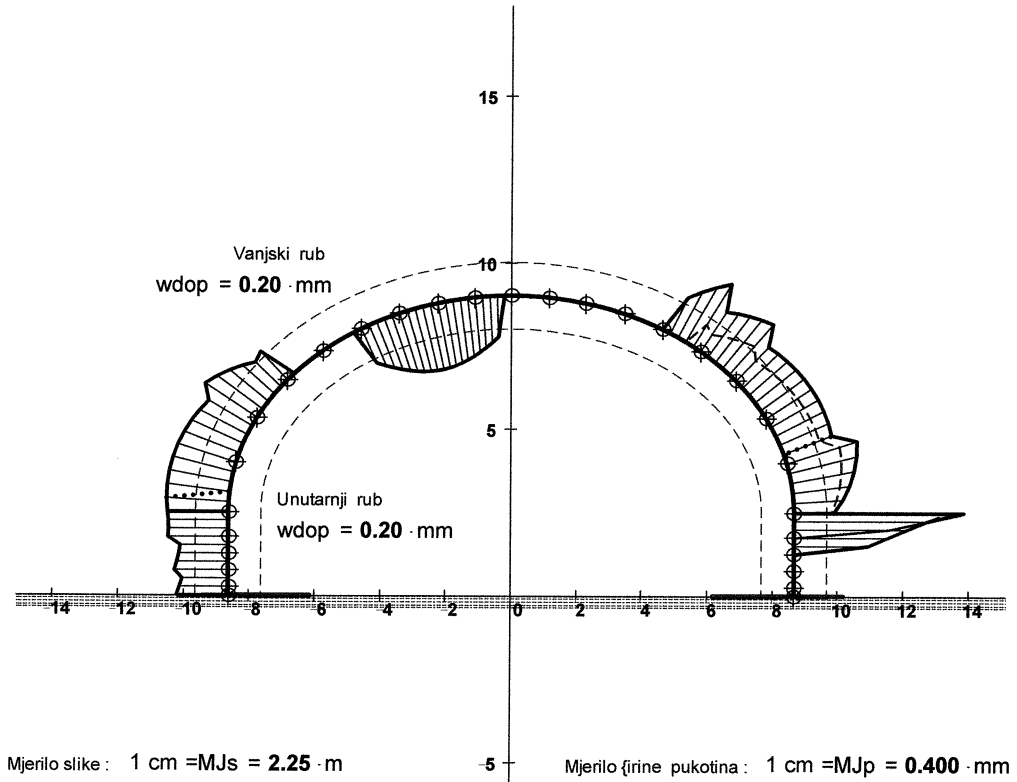
$$\text{Srednji razmak pukotina : } s_{rm} = 50 \cdot \text{mm} + 0.25 \cdot k_1 \cdot k_2 \cdot \frac{\phi_{sr}}{\rho_1}$$

$$\text{Granično stanje širina pukotina : } w_k = \beta_i \cdot s_{rm} \cdot \epsilon_{sm}$$

### 7.3 Anvelope računskih širina pukotina u betonu

Shema = 1.0

Max. dopuštena širina pukotine :  $w_{dop} = 0.20 \cdot \text{mm}$



### Pregled pukotina u proračunskim točkama i ekstremi

(Red. br. točke, vani, unutra)

Luk :

$$w1 = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 & 16 & 17 & 18 & 19 & 20 \\ 0.37 & 0.37 & 0.37 & 0.38 & 0.24 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0.29 & 0.28 & 0.33 & 0.45 & 0.24 \\ 0 & 0 & 0 & 0 & 0 & 0 & 0.23 & 0.36 & 0.39 & 0.33 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 \end{pmatrix} \cdot \text{mm}$$

vani  
unutra

$$\text{Lijevi stup : } w2 = \begin{pmatrix} 6 & 0.37 & 0 \\ 5 & 0.37 & 0 \\ 4 & 0.3 & 0 \\ 3 & 0.33 & 0 \\ 2 & 0.3 & 0 \\ 1 & 0.31 & 0 \end{pmatrix} \cdot \text{mm}$$

$$\text{Desni stup : } w3 = \begin{pmatrix} 6 & 0 & 1.04 \\ 5 & 0 & 0.57 \\ 4 & 0 & 0 \\ 3 & 0 & 0 \\ 2 & 0 & 0 \\ 1 & 0 & 0 \end{pmatrix} \cdot \text{mm}$$

### Ekstremne vrijednosti pukotina u betonu

	Zglobno (a)	Upeto (b)	Anvelopa
Luk :	$mxwa1 = 0.40 \cdot \text{mm}$	$mxwb1 = 0.00 \cdot \text{mm}$	$mxw1 = 0.40 \cdot \text{mm}$
	$mnwa1 = -0.45 \cdot \text{mm}$	$mnwb1 = -0.38 \cdot \text{mm}$	$mnw1 = -0.45 \cdot \text{mm}$
Stup lijevo :	$mxwa2 = 0.00 \cdot \text{mm}$	$mxwb2 = 0.00 \cdot \text{mm}$	$mxw2 = 0.00 \cdot \text{mm}$
	$mnwa2 = 0.00 \cdot \text{mm}$	$mnwb2 = -0.37 \cdot \text{mm}$	$mnw2 = -0.37 \cdot \text{mm}$
Stup desno :	$mxwa3 = 0.00 \cdot \text{mm}$	$mxwb3 = 0.00 \cdot \text{mm}$	$mxw3 = 0.00 \cdot \text{mm}$
	$mnwa3 = -1.04 \cdot \text{mm}$	$mnwb3 = -0.93 \cdot \text{mm}$	$mnw3 = -1.04 \cdot \text{mm}$

## 8. KONTROLA NAPONA U NEARMIRANOJ BETONSKOJ OBLOZI

a) Proračun prema dopuštenim naponima (pravilnik BAB 87, Sl. list 11/1987., članak 123.) Shema = 1.0

Proračunava se poprečni presjek od nerarmiranog betona opterećen ekscentričnom tlačnom silom na osi (y) koja je ujedno jedna od glavni težišnih osi (jednoosno savijanje bez izvijanja). Proračun vrijedi za presjeke izvan radnih reški.

Dimenzioniranje se provodi prema slijedećim uvjetima :

1. Stvarni središnji normalni TLAČNI napon u betonu ( $\sigma_{bs}$ ) mora biti manji od dopuštenog ( $\sigma_{dop}$ )

$$\sigma_{bs} = \frac{N}{Ab} < \sigma_{dop} = 6.00 \cdot \text{MPa}$$

2. Stvarni veći normalni rubni TLAČNI napon u betonu ( $\sigma_{b1}$ ) mora biti manji od dopuštenog ( $\sigma_{rt}$ )

$$\sigma_{b1} = \frac{N}{Ab} \left( 1 + \frac{6 \cdot e}{d} \right) < \sigma_{rt} = 8.00 \cdot \text{MPa}$$

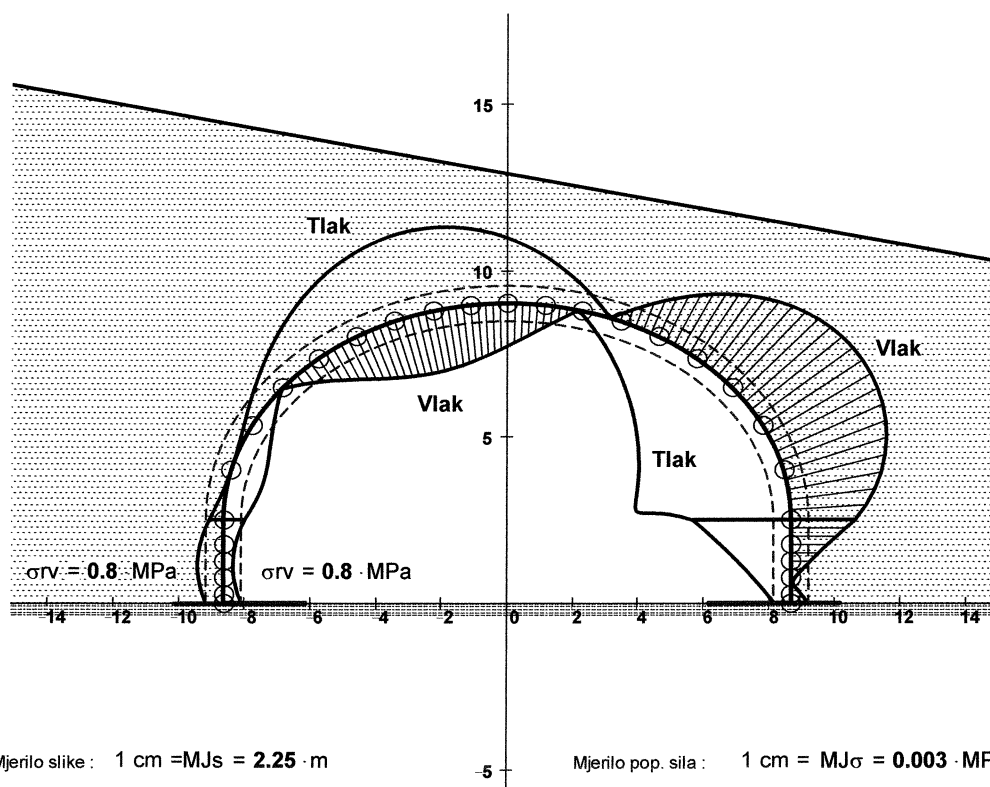
3. Stvarni normalni rubni VLAČNI napon u betonu ( $\sigma_{b2}$ ) mora po apsolutnoj vrijednosti biti :  
 - manji od 1/10 dopuštenog tlačnog napona ( $\sigma_{rt}$ ), ili  
 - manji od 1/5 istovremenog većeg rubnog normalnog tlačnog napona ( $\sigma_{b1}$ )

$$-\sigma_{b2} = \frac{N}{Ab} \left( 1 - \frac{6 \cdot e}{d} \right) \leq \begin{cases} \frac{\sigma_{rt}}{10} \\ \frac{\sigma_{b1}}{5} \end{cases} \quad \text{za } \sigma_{b2} < 0 \quad \frac{\sigma_{rt}}{10} = 0.80 \cdot \text{MPa}$$

Dopušteni rubni tlačni napon nearmiranog betona :  $\sigma_{rt} = 8.00 \cdot \text{MPa}$

Dopušteni vlačni napon nearmiranog betona :  $\sigma_{rv} = 0.80 \cdot \text{MPa}$

### 8.1 Rubni naponi u betonu - zglobni oslonci



Zglobno (a)

(-) tlak, (+) vlak

Luk (max, min)

mxσa1 = 5.44 · MPa

mnσa1 = -6.93 · MPa

Lijevi stup (max, min)

mxσa2 = 0.00 · MPa

mnσa2 = -1.18 · MPa

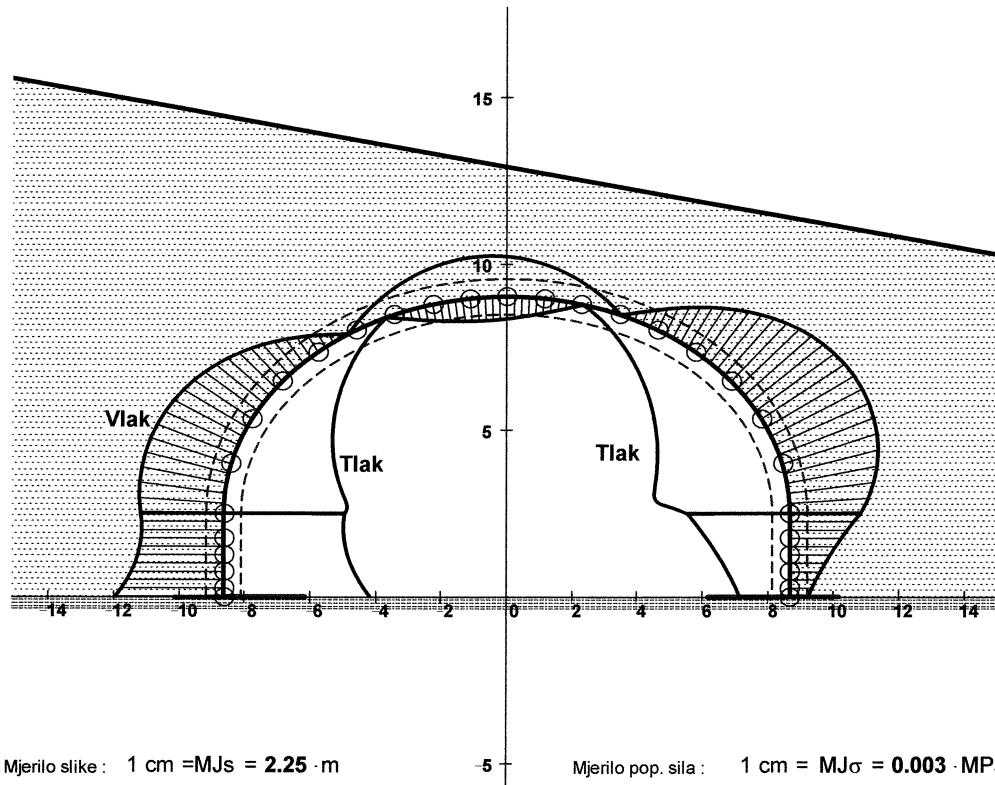
Desni stup (max, min)

mxσa3 = 2.95 · MPa

mnσa3 = -4.50 · MPa

## 8.2 Rubni naponi u betonu - upeti oslonci

Shema = 1.0



### Upeto (b)

(-) tlak, (+) vlak

### Luk (max, min)

$$m_{x\sigma b1} = 4.68 \cdot \text{MPa}$$

$$m_{n\sigma b1} = -6.02 \cdot \text{MPa}$$

### Lijevi stup (max, min)

$$m_{x\sigma b2} = 4.97 \cdot \text{MPa}$$

$$m_{n\sigma b2} = -6.69 \cdot \text{MPa}$$

### Desni stup (max, min)

$$m_{x\sigma b3} = 3.25 \cdot \text{MPa}$$

$$m_{n\sigma b3} = -4.70 \cdot \text{MPa}$$

## 8.3 Rubni naponi u betonu u proračunskim točkama, (-) tlak, (+) vlak

Dopušteni središnji tlačni napon :  $\sigma_{dop} = 6.00 \cdot \text{MPa}$  (2 MPa za fazu skidanja oplata, MB 30)

Dopušteni rubni tlačni napon :  $\sigma_{rt} = 8.00 \cdot \text{MPa}$  (3 MPa za fazu skidanja oplata, MB 30)

Dopušteni vlačni napon :  $\sigma_{rv} = 0.80 \cdot \text{MPa}$  (0.3 MPa za fazu skidanja oplata, MB 30)

Zglobno :

Luk

$$\sigma_{a1} = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 & 16 & 17 & 18 & 19 & 20 \\ 0.65 & 0.65 & 0 & -0.38 & -1.33 & -2.37 & -3.18 & -3.65 & -3.75 & -3.51 & -2.95 & -2.1 & -0.97 & 0.39 & 1.91 & 3.46 & 4.77 & 5.43 & 4.94 & 2.95 \\ 0.97 & 0.97 & -1.57 & -1.05 & 0.04 & 1.2 & 2.09 & 2.61 & 2.74 & 2.49 & 1.92 & 1.03 & -0.14 & -1.55 & -3.15 & -4.77 & -6.17 & -6.91 & -6.48 & -4.5 \end{pmatrix} \cdot \text{MPa}$$

Upeto :

$$\sigma_{b1} = \begin{pmatrix} 1 & 2 & 3 & 4 & 5 & 6 & 7 & 8 & 9 & 10 & 11 & 12 & 13 & 14 & 15 & 16 & 17 & 18 & 19 & 20 \\ 3.82 & 3.82 & 3.87 & 3.19 & 2.07 & 0.87 & -0.21 & -1.03 & -1.58 & -1.84 & -1.81 & -1.51 & -0.92 & -0.06 & 1.07 & 2.37 & 3.65 & 4.54 & 4.55 & 3.26 \\ 5.54 & 5.54 & 5.48 & 4.59 & -3.28 & -1.91 & -0.73 & 0.17 & 0.75 & 1.02 & 0.99 & 0.66 & 0.04 & -0.88 & -2.07 & -3.45 & -4.82 & -5.81 & -5.93 & -4.71 \end{pmatrix} \cdot \text{MPa}$$

Lijevi stup

Desni stup

$$\text{Zglobno : } \sigma_{a2} = \begin{pmatrix} 6 & -0.64 & -0.98 \\ 5 & -1.07 & -0.55 \\ 4 & -1.18 & -0.44 \\ 3 & -1.14 & -0.48 \\ 2 & -0.96 & -0.66 \\ 1 & -0.81 & -0.81 \end{pmatrix} \cdot \text{MPa}$$

$$\sigma_{a3} = \begin{pmatrix} 6 & -4.5 & 2.95 \\ 5 & -3.21 & 1.66 \\ 4 & -2.44 & 0.89 \\ 3 & -1.72 & 0.17 \\ 2 & -1.08 & -0.48 \\ 1 & -0.78 & -0.78 \end{pmatrix} \cdot \text{MPa}$$

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