

Statični izračun

## **Kotalna zapornica B1**

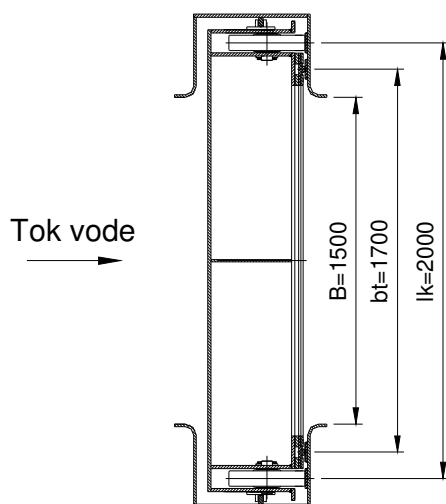
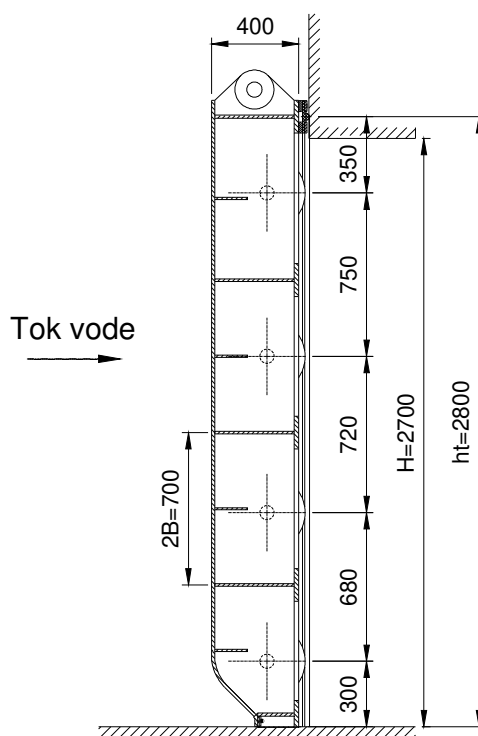
Konstrukcija

## KAZALO

|             |   |           |
|-------------|---|-----------|
| <b>1.0</b>  | <b>UVOD .....</b>                                 | <b>3</b>  |
| <b>2.0</b>  | <b>DOPUSTNE NAPETOSTI .....</b>                   | <b>4</b>  |
| <b>3.0</b>  | <b>OBREMENITEV .....</b>                          | <b>4</b>  |
| 3.1         | KOLESNI PRITISKI .....                            | 5         |
| 3.2         | NOTRANJE SILE IN MOMENTI V BOČNEM NOSILCU .....   | 5         |
| <b>4.0</b>  | <b>GLAVNI NOSILEC .....</b>                       | <b>6</b>  |
| 4.1         | STATIČNE VREDNOSTI .....                          | 7         |
| 4.2         | NAPETOSTI .....                                   | 8         |
| 4.3         | POVES .....                                       | 8         |
| <b>5.0</b>  | <b>SEKUNDARNA REBRA .....</b>                     | <b>9</b>  |
| 5.1         | STATIČNE VREDNOSTI .....                          | 9         |
| 5.2         | NAPETOSTI .....                                   | 9         |
| <b>6.0</b>  | <b>ZAJEZNA PLOČEVINA .....</b>                    | <b>10</b> |
| 6.1         | LOKALNE NAPETOSTI .....                           | 10        |
| 6.2         | PRIMERJALNE NAPETOSTI .....                       | 10        |
| <b>7.0</b>  | <b>BOČNI NOSILEC .....</b>                        | <b>11</b> |
| 7.1         | STATIČNE VREDNOSTI .....                          | 11        |
| 7.2         | NAPETOSTI .....                                   | 11        |
| <b>8.0</b>  | <b>KOLESNI SKLOP .....</b>                        | <b>13</b> |
| 8.1         | OS KOLESA .....                                   | 13        |
| 8.2         | HERTZOVA NAPETOST .....                           | 14        |
| 8.3         | SAMOMAZALNI LEŽAJ .....                           | 14        |
| <b>9.0</b>  | <b>TIRNICA .....</b>                              | <b>15</b> |
| 9.1         | STATIČNE VREDNOSTI .....                          | 15        |
| 9.2         | NAPETOSTI V TIRNICI .....                         | 16        |
| 9.3         | NAPETOST V BETONU .....                           | 16        |
| <b>10.0</b> | <b>SILE DVIGANJA IN SPUŠČANJA ZAPORNICE .....</b> | <b>17</b> |
| 10.1        | DVIGOVANJE .....                                  | 17        |
| 10.2        | SPUŠČANJE .....                                   | 17        |
| <b>11.0</b> | <b>LITERATURA .....</b>                           | <b>19</b> |

## 1.0 UVOD

Kotalna zapornica B1 zapira vhod v temeljni izpust dimenzij B x H=1,5 m x 2,7 m. Izdelana je iz jekla S235J2. Dvigniti jo je možno pod polnim enostranskim pritiskom, spustiti pa v poln pretok. Gibanje zapornice je izvedeno z elektromotornim vitlom, tesnila se nahajajo na dolvodni strani. Osnovni geometrijski podatki zapornice so razvidni iz sl. 1.



Slika 1

## 2.0 DOPUSTNE NAPETOSTI

$$\sigma_{dop} = \frac{f_y}{\gamma_F \cdot \gamma_M}$$

$$\tau_{dop} = \frac{\sigma_{dop}}{\sqrt{3}}$$

$f_y$  ..... meja plastičnosti

$\lambda_F = 1,35$  ..... faktor obremenitve

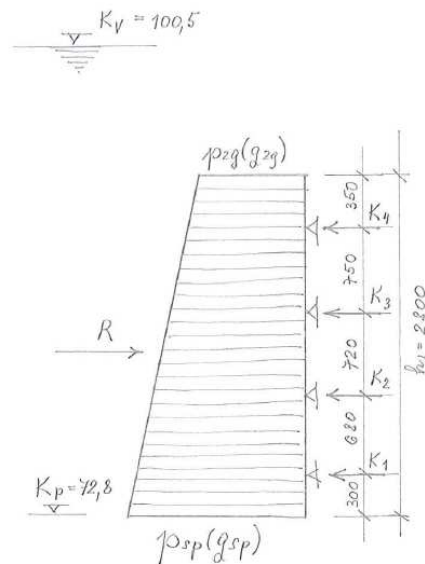
$\gamma_M = 1,1$  ..... faktor materiala

Za jeklo S235 J2,  $f_y = 235 \text{ N/mm}^2$

$$\sigma_{dop} = \frac{235}{1,35 \cdot 1,1} = 158 \text{ N/mm}^2$$

$$\tau_{dop} = \frac{158}{\sqrt{3}} = 91 \text{ N/mm}^2$$

## 3.0 OBREMENITEV



Slika 2

$$R = \frac{(p_{zg} + p_{sp})}{2} \cdot h_t \cdot b_t = \frac{(0,249 + 0,277)}{2} \cdot 2800 \cdot 1700 = 1,252 \cdot 10^6 \text{ N} = 1252 \text{ kN}$$

$$K \approx \frac{R}{8} = \frac{1252}{8} = 156,5 \text{ kN}$$

$$p_{sp} = K_v - K_p = 100,5 - 72,8 = 27,7 \text{ m v.s.}$$

$$p_{zg} = p_{sp} - h_t = 27,7 - 2,8 = 24,9 \text{ m v.s.}$$

$$q_{sp} = \frac{p_{sp} \cdot b_t}{2} = \frac{0,277 \cdot 1700}{2} = 235,5 \text{ N/mm}$$

$$q_{zg} = \frac{p_{zg} \cdot b_t}{2} = \frac{0,249 \cdot 1700}{2} = 211,7 \text{ N/mm}$$

### 3.1 Kolesni pritiski

Kolesni pritiski so izračunani s programom Tower 7 po obremenitveni shemi na sl.2

$$K_1 = 151 \text{ kN}$$

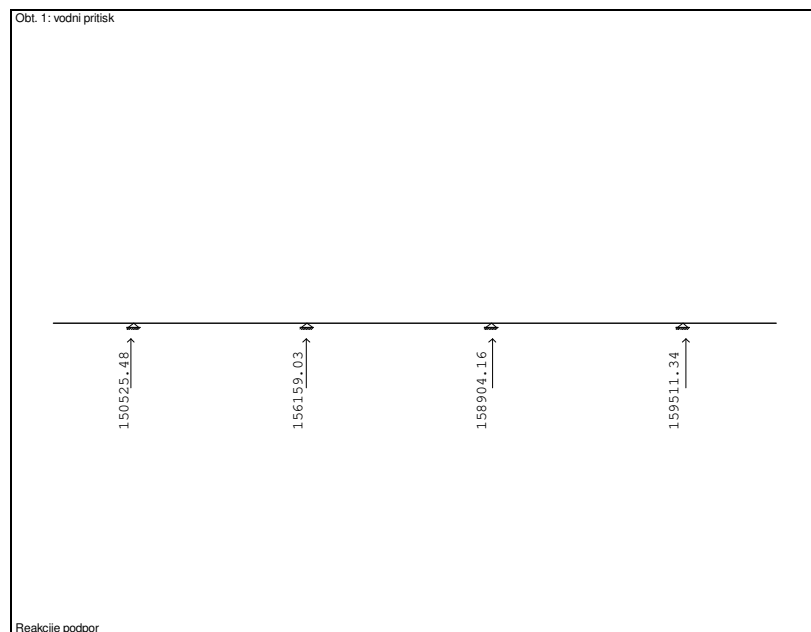
$$K_2 = 156 \text{ kN}$$

$$K_3 = 159 \text{ kN}$$

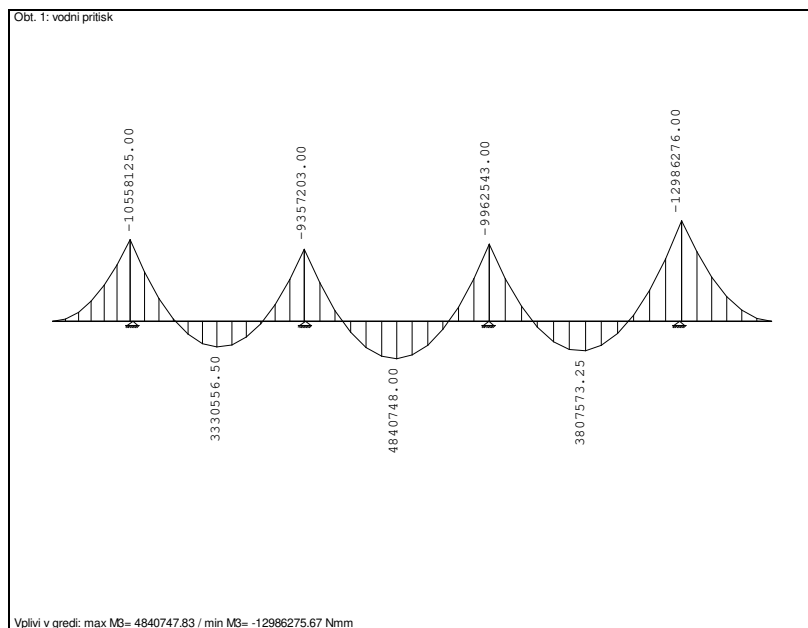
$$K_4 = 160 \text{ kN} = K_{\max}$$

### 3.2 Notranje sile in momenti v bočnem nosilcu

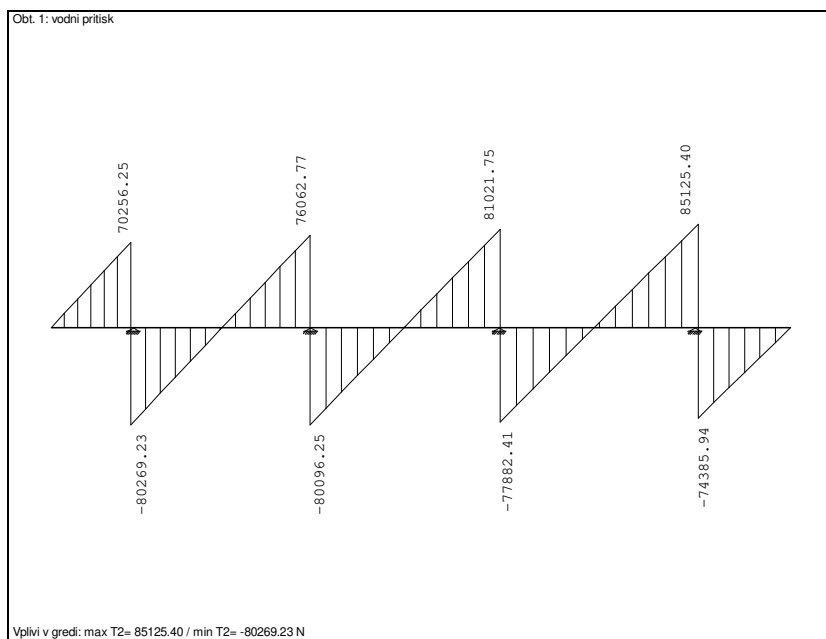
Račun je izvršen s programom Tower 7. Reakcije podpor ter diagram prečnih sil in momentov je prikazan na sl.2a, 2b in 2c.



Slika 2a



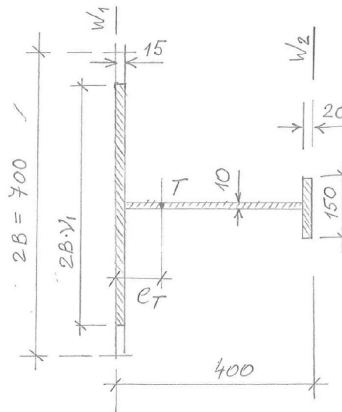
Slika 2b



Slika 2c

#### 4.0 GLAVNI NOSILEC

#### 4.1 Statične vrednosti



### Slika 3

$$\frac{L}{B} = \frac{2000 \cdot 2}{700} = 5,7 \rightarrow v_I = 0,82$$

$$2B \cdot v_I = 700 \cdot 0,82 = 574 \text{ mm}$$

$$A = 574 \cdot 15 + 365 \cdot 10 + 150 \cdot 20 = 15260 \text{ mm}^2$$

$$e_T = \frac{574 \cdot 15 \cdot 7,5 + 365 \cdot 10 \cdot 197,5 + 150 \cdot 20 \cdot 390}{15260} = 128 \text{ mm}$$

$$I = 574 \cdot 15 \cdot 120,5^2 + \frac{10 \cdot 365^3}{12} + 365 \cdot 10 \cdot 69,5^2 + 150 \cdot 20 \cdot 262^2 = 3,891 \cdot 10^8 \text{ mm}^4$$

$$W_1 = \frac{3,891 \cdot 10^8}{128} = 3,040 \cdot 10^6 \text{ mm}^3$$

$$W_2 = \frac{3,891 \cdot 10^8}{272} = 1,431 \cdot 10^6 \text{ mm}^3$$

$$A_{str} = (365 - 2 \cdot 25) \cdot 10 = 3150 \text{ mm}^2$$

## 4.2 Napetosti

$$\sigma_1 = -\frac{M}{W_1} = -\frac{9,700 \cdot 10^7}{3,040 \cdot 10^6} = -31,9 \text{ N/mm}^2$$

$$\sigma_2 = \frac{M}{W_2} = \frac{9,700 \cdot 10^7}{1,431 \cdot 10^6} = 67,8 \text{ N/mm}^2 < \sigma_{dop} = 158 \text{ N/mm}^2$$

$$\tau = \frac{Q}{A_{str}} = \frac{1,649 \cdot 10^5}{3150} = 52,3 \text{ N/mm}^2 < \tau_{dop} = 91 \text{ N/mm}^2$$

$$M = \frac{q \cdot l_k^2}{8} = \frac{194 \cdot 2000^2}{8} = 9,700 \cdot 10^7 \text{ Nmm}$$

$$Q = \frac{q \cdot b_t}{2} = \frac{194 \cdot 1700}{2} = 1,649 \cdot 10^5 \text{ N}$$

$$q = 2B \cdot p_{sp} = 700 \cdot 0,277 = 194 \text{ N/mm}$$

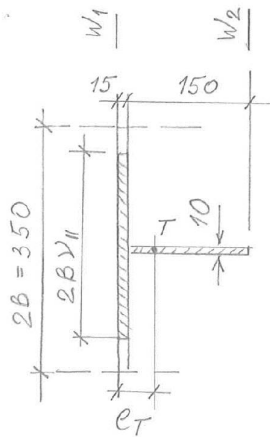
## 4.3 Poves

$$f = \frac{5 \cdot q \cdot l_k^4}{384 \cdot E \cdot I} = \frac{5 \cdot 194 \cdot 2000^4}{384 \cdot 2,1 \cdot 10^5 \cdot 3,891 \cdot 10^8} = 0,5 \text{ mm}$$



## 5.0 SEKUNDARNA REBRA

### 5.1 Statične vrednosti



Slika 4

$$\frac{L_I}{B} \cong \frac{650 \cdot 2}{350} = 3,7 \rightarrow v_{II} = 0,65$$

$$2B \cdot v_{II} = 350 \cdot 0,65 = 228 \text{ mm}$$

$$A = 228 \cdot 15 + 150 \cdot 10 = 4920 \text{ mm}^2$$

$$e_T = \frac{228 \cdot 15 \cdot 7,5 + 150 \cdot 10 \cdot 90}{4920} = 33 \text{ mm}$$

$$I = 228 \cdot 15 \cdot 25,5^2 + \frac{10 \cdot 150^3}{12} + 10 \cdot 150 \cdot 57^2 = 9,910 \cdot 10^6 \text{ mm}^4$$

$$W_1 = \frac{9,910 \cdot 10^6}{33} = 3,003 \cdot 10^5 \text{ mm}^3$$

$$W_2 = \frac{9,910 \cdot 10^6}{132} = 7,508 \cdot 10^4 \text{ mm}^3$$

$$A_{str} = (150 - 25) \cdot 10 = 1250 \text{ mm}^2$$

### 5.2 Napetosti

$$\sigma_{o1} = -\frac{M}{W_1} = -\frac{5,836 \cdot 10^6}{3,003 \cdot 10^5} = -19,4 \text{ N/mm}^2$$

$$\sigma_{o2} = \frac{M}{W_2} = \frac{5,836 \cdot 10^6}{7,508 \cdot 10^4} = 77,7 \text{ N/mm}^2 < \sigma_{dop} = 158 \text{ N/mm}^2$$

$$\tau = \frac{Q}{A_{str}} = \frac{5,608 \cdot 10^4}{1250} = 44,9 \text{ N/mm}^2 < \tau_{dop} = 91 \text{ N/mm}^2$$

$$M = \frac{9 \cdot q \cdot l_o^2}{128} = \frac{9 \cdot 97 \cdot 925^2}{128} = 5,836 \cdot 10^6 \text{ Nmm}$$

$$q = p_{sp} \cdot 2B = 0,277 \cdot 350 = 97 \text{ N/mm}$$

$$Q = 0,625 \cdot q \cdot l_o = 0,625 \cdot 97 \cdot 925 = 5,608 \cdot 10^4 \text{ N}$$

## 6.0 ZAJEZNA PLOČEVINA

Računa se kot trak širine 1 mm, ki poteka preko horizontalnih nosilcev

### 6.1 Lokalne napetosti

$$\sigma_y = \pm \frac{M}{W} = \pm \frac{2828}{37,5} = \pm 75,4 \text{ N/mm}^2$$

$$M = \frac{q \cdot l_o^2}{12} = \frac{0,277 \cdot 350^2}{12} = 2828 \text{ Nmm}$$

$$q = p_{sp} \cdot 1 \text{ mm} = 0,277 \cdot 1 = 0,277 \text{ N/mm}$$

$$W = \frac{1 \cdot 15^2}{6} = 37,5 \text{ cm}^3$$

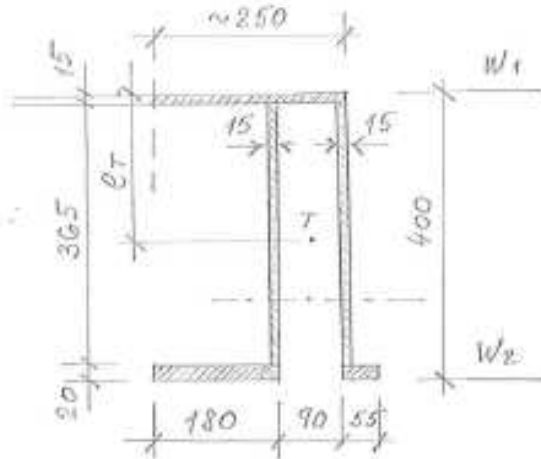
### 6.2 Primerjalne napetosti

$$\sigma_{pr} = \sqrt{\sigma_x^2 + \sigma_y^2 - \sigma_x \cdot \sigma_y} = \sqrt{51,3^2 + 75,4^2 + 51,3 \cdot 75,4} = 110 \text{ N/mm}^2 < \sigma_{dop} = 158 \text{ N/mm}^2$$

$$\sigma_x = \sigma_1 + \sigma_{ol} = -31,9 - 19,4 = -51,3 \text{ N/mm}^2$$

## 7.0 BOČNI NOSILEC

### 7.1 Statične vrednosti



Slika 5

$$A = 250 \cdot 15 + 2 \cdot 365 \cdot 15 + (180 + 55) \cdot 20 = 1,94 \cdot 10^4 \text{ mm}^2$$

$$e_T = \frac{250 \cdot 15 \cdot 7,5 + 2 \cdot 365 \cdot 15 \cdot 197,5 + (180 + 55) \cdot 20 \cdot 390}{1,94 \cdot 10^4} = 207 \text{ mm}$$

$$I = 250 \cdot 15 \cdot 199,5^2 + 2 \cdot \frac{15 \cdot 365^3}{12} + 2 \cdot 365 \cdot 15 \cdot 9,5^2 + (180 + 55) \cdot 20 \cdot 183^2 = 4,292 \cdot 10^8 \text{ mm}^4$$

$$W_1 = \frac{4,292 \cdot 10^8}{207} = 2,073 \cdot 10^6 \text{ mm}^3$$

$$W_2 = \frac{4,292 \cdot 10^8}{193} = 2,224 \cdot 10^6 \text{ mm}^3$$

$$A_{str} = 2 \cdot 365 \cdot 15 = 1,095 \cdot 10^4 \text{ mm}^2$$

### 7.2 Napetosti

$$\sigma_1 = \frac{M_{\max}}{W_1} = \frac{1,299 \cdot 10^7}{2,073 \cdot 10^6} = 6,3 \text{ N/mm}^2 < \sigma_{dop} = 158 \text{ N/mm}^2$$

$$\sigma_2 = -\frac{M_{\max}}{W_2} = -\frac{1,299 \cdot 10^7}{2,224 \cdot 10^6} = -5,8 \text{ N/mm}^2 < \sigma_{dop} = 158 \text{ N/mm}^2$$

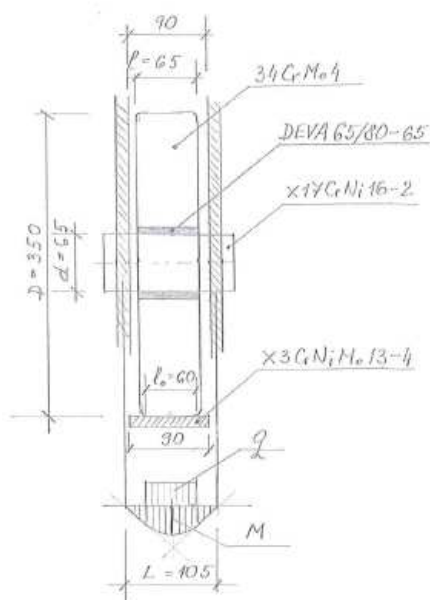
$$\tau = \frac{Q_{\max}}{A_{str}} = \frac{8,513 \cdot 10^4}{1,095 \cdot 10^4} = 7,8 \text{ N/mm}^2 < \tau_{dop} = 91 \text{ N/mm}^2$$

$M_{\max} = 1,299 \cdot 10^7 \text{ Nmm}$  .....glej točko 3.2

$Q_{\max} = 8,513 \cdot 10^4 \text{ N}$  .....glej točko 3.2

## 8.0 KOLESNI SKLOP

Kolesni sklop je prikazan na sl.6



### Slika 6

## 8.1 Os kolesa

Os  $d=65$  mm je izdelana iz nerjavnega jekla X17CrNi16-2 po EN10088, z mejo plastičnosti  $f_y = 550 \text{ N/mm}^2$

$$\sigma = \frac{M}{W} = \frac{3,00 \cdot 10^6}{2,696 \cdot 10^4} = 111 \text{ N/mm}^2 < \sigma_{dop} = 272 \text{ N/mm}^2$$

$$W = \frac{\pi \cdot d^3}{32} = \frac{\pi \cdot 65^3}{32} = 2,696 \cdot 10^4 \text{ mm}^3$$

$$M = \frac{q \cdot l_o^2}{8} + \frac{q \cdot l_o}{2} \cdot \frac{(L - l_o)}{2} = \frac{2667 \cdot 60^2}{8} + \frac{2667 \cdot 60}{2} \cdot \frac{(105 - 60)}{2} = 3,00 \cdot 10^6 \text{ N mm}$$

$$q = \frac{K_{\max}}{l_o} = \frac{160000}{60} = 2667 \text{ N/mm}$$

$$K_{\max} = 160 \text{ kN} \dots \text{glej tč. 3.1}$$

$$\tau = 1,33 \cdot \frac{Q_{\max} \cdot 4}{\pi \cdot d^2} = 1,33 \cdot \frac{80000 \cdot 4}{\pi \cdot 65^2} = 32,1 \text{ N/mm}^2 < \tau_{dop} = 91 \text{ N/mm}^2$$

$$Q_{\max} = \frac{K_{\max}}{2} = \frac{160}{2} = 80 \text{ kN}$$

Dopustne napetosti za X17CrNi16-2

$$\sigma_{dop} = \frac{f_y}{\gamma_F \cdot \gamma_M} = \frac{550}{1,35 \cdot 1,5} = 272 \text{ N/mm}^2$$

$$\tau_{dop} = \frac{\sigma_{dop}}{\sqrt{3}} = 157 \text{ N/mm}^2$$

$f_y = 550 \text{ N/mm}^2$  .....meja plastičnosti

$\gamma_F = 1,35$  .....faktor obremenitve

$\gamma_M = 1,5$  .....faktor materiala

## 8.2 Hertzova napetost

Kotalna površina je izdelana iz nerjavnega jekla X3CrNiMo13-4 po EN10088-2 z mejo plastičnosti  $f_y = 650 \text{ N/mm}^2$ , kolo pa iz jekla 34CrMo4 z mejo plastičnosti  $f_y = 550 \text{ N/mm}^2$ .

$$\sigma_H = 0,418 \cdot \sqrt{\frac{K_{\max} \cdot E}{l_o \cdot R}} = 0,418 \cdot \sqrt{\frac{160000 \cdot 2,1 \cdot 10^5}{60 \cdot 175}} = 748 \text{ N/mm}^2 < \sigma_{H,dop} = 937 \text{ N/mm}^2$$

$$\sigma_{H,dop} = \frac{2,3 \cdot f_y}{\gamma_F} = \frac{2,3 \cdot 550}{1,35} = 937 \text{ N/mm}^2$$

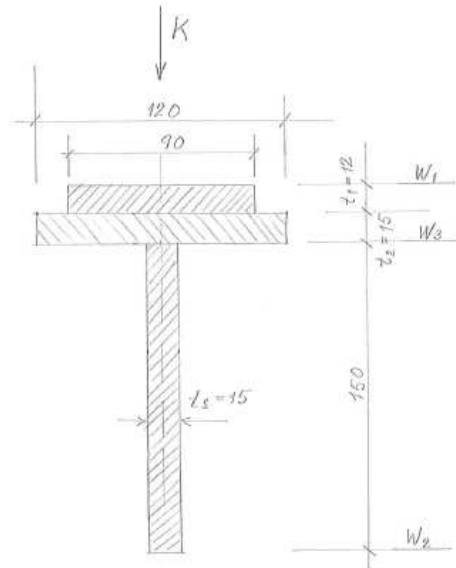
## 8.3 Samomazalni ležaj

Uporabljeni so samomazalni drsni ležaji DEVA d/D-l=65/80-65.

$$p = \frac{K_{\max}}{d \cdot l} = \frac{160000}{65 \cdot 65} = 38 \text{ N/mm}^2 < p_{dop} = 40 \text{ N/mm}^2$$

## 9.0 TIRNICA

Tirnica je prikazana na sl.7



Slika 7.

### 9.1 Statične vrednosti

Cel prerez tirnice:

$$A = 90 \cdot 12 + 120 \cdot 15 + 150 \cdot 15 = 5130 \text{ mm}^2$$

$$e_T = \frac{90 \cdot 12 \cdot 6 + 120 \cdot 15 \cdot 19,5 + 150 \cdot 15 \cdot 102}{5130} = 53 \text{ mm}$$

$$I = 90 \cdot 12 \cdot 47^2 + 120 \cdot 15 \cdot 33,5^2 + \frac{15 \cdot 150^3}{12} + 150 \cdot 15 \cdot 49^2 = 1,403 \cdot 10^7 \text{ mm}^4$$

$$W_1 = \frac{1,403 \cdot 10^7}{53} = 2,647 \cdot 10^5 \text{ mm}^3$$

$$W_2 = \frac{1,403 \cdot 10^7}{124} = 1,131 \cdot 10^5 \text{ mm}^3$$

$$W_3 = \frac{1,403 \cdot 10^7}{26} = 5,396 \cdot 10^5 \text{ mm}^3$$

Pasnica tirnice:

$$A_p = 90 \cdot 12 + 120 \cdot 15 = 2880 \text{ mm}^2$$

$$e_{T,p} = \frac{90 \cdot 12 \cdot 6 + 120 \cdot 15 \cdot 19,5}{2880} = 14 \text{ mm}$$

$$I_p = \frac{90 \cdot 12^3}{12} + 90 \cdot 12 \cdot 8^2 + \frac{120 \cdot 15^3}{12} + 120 \cdot 15 \cdot 5,5^2 = 1,703 \cdot 10^5 \text{ mm}^4$$

## 9.2 Napetosti v tirnici

Pritisk na zgornji rob stojine:

$$\sigma_y = \frac{0,3 \cdot K}{t_s} \cdot \sqrt[3]{\frac{t_s}{I_p}} = \frac{0,3 \cdot 160000}{15} \cdot \sqrt[3]{\frac{15}{1,703 \cdot 10^5}} = 142 \text{ N/mm}^2 < \sigma_{dop} = 158 \text{ N/mm}^2$$

Upogibne napetosti v profilu:

$$\sigma_2 = 0,5 \cdot \frac{K}{W_2} \cdot \sqrt[3]{\frac{E_j \cdot I}{E_b \cdot b_l}} = 0,5 \cdot \frac{160000}{1,131 \cdot 10^5} \cdot \sqrt[3]{\frac{2,1 \cdot 10^5 \cdot 1,403 \cdot 10^7}{3 \cdot 10^4 \cdot 114}} = 67,3 \text{ N/mm}^2 < \sigma_{dop} = 158 \text{ N/mm}^2$$

$$b_l = l_o + 2 \cdot (t_1 + t_2) = 60 + 2 \cdot (12 + 15) = 114 \text{ mm}$$

$$\sigma_1 = -\sigma_2 \cdot \frac{W_2}{W_1} = -67,3 \cdot \frac{1,131 \cdot 10^5}{2,647 \cdot 10^5} = -28,8 \text{ N/mm}^2$$

$$\sigma_3 = -\sigma_2 \cdot \frac{W_2}{W_3} = -67,3 \cdot \frac{1,131 \cdot 10^5}{5,396 \cdot 10^5} = -14,1 \text{ N/mm}^2$$

$$E_j = 2,1 \cdot 10^5 \text{ N/mm}^2 \dots\dots\dots \text{elastični modul jekla}$$

$$E_b = 3,0 \cdot 10^4 \text{ N/mm}^2 \dots\dots\dots \text{elastični modul betona}$$

Primerjalne napetosti v zgornjem robu stojine:

$$\sigma_{pr} = \sqrt{\sigma_y^2 + \sigma_3^2 - \sigma_y \cdot \sigma_3} = \sqrt{142^2 + 14,1^2 - 142 \cdot 14,1} = 136 \text{ N/mm}^2 < \sigma_{dop} = 158 \text{ N/mm}^2$$

## 9.3 Napetost v betonu

$$\sigma_2 = 0,2813 \cdot K \cdot \sqrt[3]{\frac{E_b}{E_j \cdot I \cdot b_l^2}} = 0,2813 \cdot 160000 \cdot \sqrt[3]{\frac{3,0 \cdot 10^4}{2,1 \cdot 10^5 \cdot 1,403 \cdot 10^7 \cdot 114^2}} = 4,1 \text{ N/mm}^2 < \sigma_{b,dop} = 12 \text{ N/mm}^2$$

Dopustne napetosti za beton C25/30

$$\sigma_{b,dop} = \frac{f_{ck}}{\gamma_F \cdot \gamma_M} = \frac{25}{1,35 \cdot 1,5} = 12 \text{ N/mm}^2$$



## 10.0 SILE DVIGANJA IN SPUŠČANJA ZAPORNICE

### 10.1 Dviganje

$$F_{dv} = f \cdot (G_z + F_{h,din} + \Sigma F_{tr}) = 1,5 \cdot (29 + 151,9 + 56,54) = 356 kN \rightarrow F_{dv} = 400 kN$$

$$f = 1,5 \dots\dots\dots \text{varnostni faktor}$$

$$G_z = 29 kN \dots\dots\dots \text{teža zapornice}$$

$$F_{h,din} \dots\dots\dots \text{hidrodinamična sila}$$

$$\Sigma F_{tr} \dots\dots\dots \text{vsota trenjskih sil}$$

Trenje v tesnilih ( $F_{tr,t}$ ):

$$F_{tr,t} = \mu_t \cdot [(p \cdot b + f_{pr}) \cdot (2 \cdot h_t + b_t)] = 0,23 \cdot [(2,63 \cdot 3 + 5) \cdot (2 \cdot 280 + 170)] = 2164 daN = 21,64 kN$$

$$\mu_t = 0,23 \dots\dots\dots \text{koeficient trenja v TCT tesnilih}$$

$$f_{pr} = 5 daN / cm \dots\dots\dots \text{sila prednapetja tesnil}$$

$$p = \frac{p_{sp} + p_{zg}}{2} = \frac{27,7 + 24,9}{2} = 26,3 mv.s. = 2,63 daN / cm^2$$

Trenje v kolesih ( $F_{tr,k}$ ):

$$F_{tr,k} = \mu_k \cdot \frac{R \cdot d}{D} = 0,15 \cdot \frac{1252 \cdot 65}{350} = 34,9 kN$$

$$R = 1252 kN \dots\dots\dots \text{glej tč. 3.0}$$

$$\Sigma F_{tr} = F_{tr,t} + F_{tr,k} = 21,64 + 34,9 = 56,54 kN$$

Hidrodinamične sile ( $F_{zhd}$ ;  $F_{shd}$ ):

$$F_{h,din} = F_{zhd} - F_{shd} = 19900 - 4710 = 15190 daN = 151,9 kN$$

$$F_{zhd} = p_{zg} \cdot d_z \cdot b_t = 2,49 \cdot 47 \cdot 170 = 19900 daN$$

$$F_{shd} = \frac{p_{sp}}{2} \cdot d_s \cdot b_t = \frac{2,77}{2} \cdot 20 \cdot 170 = 4710 daN$$

### 10.2 Spuščanje

Za varno spuščanje zapornice mora biti izpolnjen pogoj:

$$G_z + F_{zhs} - 1,25 \cdot (\Sigma F_{tr} + F_{shs}) > 0$$

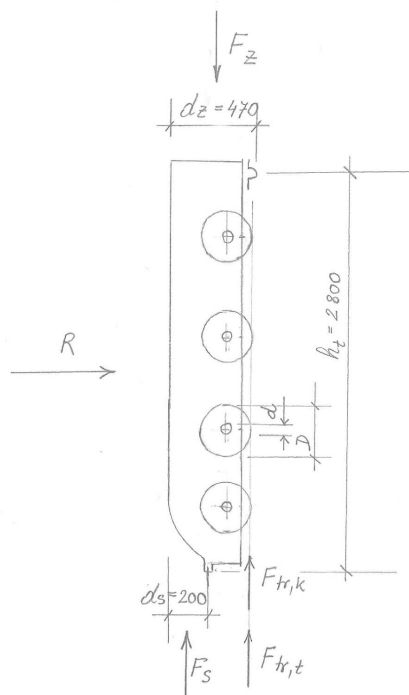
$$29 + 199 - 1,25 \cdot (56,54 + 94,2) = 39,6 kN > 0$$

Pogoj je izpolnjen.

Hidrostaticne sile ( $F_{zhs}$ ;  $F_{shs}$ ):

$$F_{zhs} \cong F_{zd} = 19900 \text{ daN} = 199 \text{ kN}$$

$$F_{shs} = p_{sp} \cdot d_s \cdot b_t = 2,77 \cdot 20 \cdot 170 = 9420 \text{ daN} = 94,2 \text{ kN}$$



Slika 8

## 11.0 LITERATURA

- (1) Strojniški priročnik, B. Kraut, Ljubljana 1987
- (2) DIN 19704, 19705, September 1976  
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- (3) SIST EN 10025, SIST EN 10088, SIST EN 10083

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