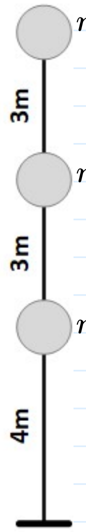
Primer-MDOF-Spektralna-analiza-odgovora

Podaci: E = 33 GPa, b/d = 30/100 cm, m_1 = 40 t, m_2 = 40 t, m_3 = 30 t, referentno maksimalno ubrzanje tla u horizontalnom pravcu a_{gR} = 0,1g, faktor ponašanja q = 1.5, tip tla C, tip elastičnog odgovora 1, faktor značaja γ_I=1.0, relativno prigušenje 5%.



$m_3 := 30.0$ $E := 33 \cdot 10^6$ $b := 0.3$ $d := 1.0$

$h_3 := 3$

Napomena: pri analizi će se koristiti homogene karakteristike poprečnih preseka

$m_2 := 40.0$

$A := b \cdot d = 0.30$ $I := \dfrac{b \cdot d^3}{12} = 0.0250$

$h_2 := 3$

$m_1 := 40.0$

Projektno maksimalno ubrzanje tla u horizontalnom pravcu a_g

$\gamma_I := 1.0$ $a_{gR} := 0.1 \cdot 9.81 = 0.981$ $a_g := \gamma_I \cdot a_{gR} = 0.981$

$h_1 := 4$

$q := 1.5$ $tipTla := \text{“C”}$ $\eta := 1$

Statički i dinamički model

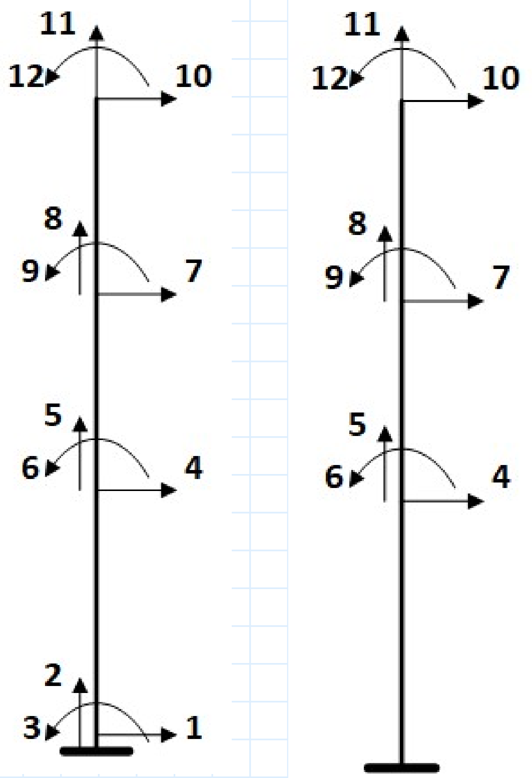
Napomena: analizira se samo mogućnost vibracija u horizontalnom pravcu

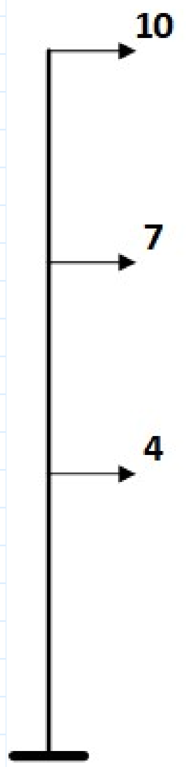
Statički model

Stepeni slobode: 1, 2, 3, 4, 5, 6, 7, 8, 9, 10, 11 i 12

Dinamički model

Stepeni slobode: 4, 7 i 10





Matrica krutosti i matrica transformacije

Štap tipa *k* (funkcija za matricu krutosti i matricu transformacije)

$$m_{k\_k}(E,L,A,I) := \frac{E \cdot I}{L^3} \cdot \begin{bmatrix} \frac{A \cdot L^2}{I} & 0 & 0 & -\frac{A \cdot L^2}{I} & 0 & 0 \\ 0 & 12 & 6 \cdot L & 0 & -12 & 6 \cdot L \\ 0 & 6 \cdot L & 4 \cdot L^2 & 0 & -6 \cdot L & 2 \cdot L^2 \\ -\frac{A \cdot L^2}{I} & 0 & 0 & \frac{A \cdot L^2}{I} & 0 & 0 \\ 0 & -12 & -6 \cdot L & 0 & 12 & -6 \cdot L \\ 0 & 6 \cdot L & 2 \cdot L^2 & 0 & -6 \cdot L & 4 \cdot L^2 \end{bmatrix}$$

$$T_k(\alpha) := \begin{bmatrix} \cos(\alpha) & \sin(\alpha) & 0 & 0 & 0 & 0 \\ -\sin(\alpha) & \cos(\alpha) & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 0 & 0 & 0 & \cos(\alpha) & \sin(\alpha) & 0 \\ 0 & 0 & 0 & -\sin(\alpha) & \cos(\alpha) & 0 \\ 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix}$$

Štap 1

$L_1 := h_1$ $\quad T_1 := T_k(90\ deg)$ $\quad m_{k\_1\_LKS} := m_{k\_k}(E, L_1, A, I)$ $\quad m_{k\_1\_GKS} := {T_1}^T \cdot m_{k\_1\_LKS} \cdot T_1$

1 2 3 4 5 6

$$m_{k\_1\_GKS} = \begin{bmatrix} 154687.5 & 0.0 & -309375.0 & -154687.5 & 0.0 & -309375.0 \\ 0.0 & 2475000.0 & 0.0 & 0.0 & -2475000.0 & 0.0 \\ -309375.0 & 0.0 & 825000.0 & 309375.0 & 0.0 & 412500.0 \\ -154687.5 & 0.0 & 309375.0 & 154687.5 & 0.0 & 309375.0 \\ 0.0 & -2475000.0 & 0.0 & 0.0 & 2475000.0 & 0.0 \\ -309375.0 & 0.0 & 412500.0 & 309375.0 & 0.0 & 825000.0 \end{bmatrix} \begin{bmatrix} 1 \\ 2 \\ 3 \\ 4 \\ 5 \\ 6 \end{bmatrix}$$

Vektor stepeni slobode: $ss_1 := [1\ \ 2\ \ 3\ \ 4\ \ 5\ \ 6]^T$

Štap 2

$L_2 := h_2$ $\quad T_2 := T_k(90\ deg)$ $\quad m_{k\_2\_LKS} := m_{k\_k}(E, L_2, A, I)$ $\quad m_{k\_2\_GKS} := {T_2}^T \cdot m_{k\_2\_LKS} \cdot T_2$

4 5 6 7 8 9

$$m_{k\_2\_GKS} = \begin{bmatrix} 366666.7 & 0.0 & -550000.0 & -366666.7 & 0.0 & -550000.0 \\ 0.0 & 3300000.0 & 0.0 & 0.0 & -3300000.0 & 0.0 \\ -550000.0 & 0.0 & 1100000.0 & 550000.0 & 0.0 & 550000.0 \\ -366666.7 & 0.0 & 550000.0 & 366666.7 & 0.0 & 550000.0 \\ 0.0 & -3300000.0 & 0.0 & 0.0 & 3300000.0 & 0.0 \\ -550000.0 & 0.0 & 550000.0 & 550000.0 & 0.0 & 1100000.0 \end{bmatrix} \begin{bmatrix} 4 \\ 5 \\ 6 \\ 7 \\ 8 \\ 9 \end{bmatrix}$$

Vektor stepeni slobode: $ss_2 := [4\ \ 5\ \ 6\ \ 7\ \ 8\ \ 9]^T$

Štap 3

$L_3 := h_3 \qquad T_3 := T_k(90\ deg) \qquad m_{k\_3\_LKS} := m_{k\_k}(E, L_3, A, I) \qquad m_{k\_3\_GKS} := {T_3}^{\mathrm{T}} \cdot m_{k\_3\_LKS} \cdot T_3$

$$
\begin{matrix} & 7 & 8 & 9 & 10 & 11 & 12 \end{matrix}
$$

$$
m_{k\_3\_LKS} = \begin{bmatrix} 3300000.0 & 0.0 & 0.0 & -3300000.0 & 0.0 & 0.0 \\ 0.0 & 366666.7 & 550000.0 & 0.0 & -366666.7 & 550000.0 \\ 0.0 & 550000.0 & 1100000.0 & 0.0 & -550000.0 & 550000.0 \\ -3300000.0 & 0.0 & 0.0 & 3300000.0 & 0.0 & 0.0 \\ 0.0 & -366666.7 & -550000.0 & 0.0 & 366666.7 & -550000.0 \\ 0.0 & 550000.0 & 550000.0 & 0.0 & -550000.0 & 1100000.0 \end{bmatrix} \begin{bmatrix} 7 \\ 8 \\ 9 \\ 10 \\ 11 \\ 12 \end{bmatrix}
$$

Vektor stepeni slobode: $ss_3 := \begin{bmatrix} 7 & 8 & 9 & 10 & 11 & 12 \end{bmatrix}^{\mathrm{T}}$

Kondenzovana matrica krutosti

Pasivni stepeni slobode: 1, 2 i 3 Aktivni stepeni slobode: 4, 5, 6, 7, 8, 9, 10, 11 i 12

Bitni stepeni slobode: 4, 7 i 10 $b_s := \begin{bmatrix} 4 & 7 & 10 \end{bmatrix}^{\mathrm{T}}$

Nebitni stepeni slobode: 5, 6, 8, 9, 11 i 12 $n_s := \begin{bmatrix} 5 & 6 & 8 & 9 & 11 & 12 \end{bmatrix}^{\mathrm{T}}$

$$
niz_{ss} := \begin{bmatrix} ss_1 \\ ss_2 \\ ss_3 \end{bmatrix} \qquad niz_{mk} := \begin{bmatrix} m_{k\_1\_GKS} \\ m_{k\_2\_GKS} \\ m_{k\_3\_GKS} \end{bmatrix}
$$

Funkcija za formiranje matrice sistema povezanih štapova koristeći brojeve stepeni slobode štapova i matrice krutosti štapova

```
K(niz_ss, niz_mk, ssv, ssk) := | K[last(ssv), last(ssk)] ← 0
                               | for m ∈ 0 .. last(niz_ss)
                               |   | SSstap ← niz_ss[m]
                               |   | for i ∈ 0 .. last(SSstap)
                               |   |   | for j ∈ 0 .. last(ssv)
                               |   |   |   | if SSstap[i] = ssv[j]
                               |   |   |   |   | for k ∈ 0 .. last(SSstap)
                               |   |   |   |   |   | for l ∈ 0 .. last(ssk)
                               |   |   |   |   |   |   | if SSstap[k] = ssk[l]
                               |   |   |   |   |   |   |   | MK ← niz_mk[m]
                               |   |   |   |   |   |   |   | K[j,l] ← K[j,l] + MK[i,k]
                               | return K
```

$Kbb := K\left(niz_{ss}, niz_{mk}, b_s, b_s\right)$ $Kbn := K\left(niz_{ss}, niz_{mk}, b_s, n_s\right)$

$Knb := K\left(niz_{ss}, niz_{mk}, n_s, b_s\right)$ $Knn := K\left(niz_{ss}, niz_{mk}, n_s, n_s\right)$

$$Kbb = \begin{bmatrix} 521354.2 & -366666.7 & 0.0 \\ -366666.7 & 733333.3 & -366666.7 \\ 0.0 & -366666.7 & 366666.7 \end{bmatrix} \quad \text{columns: } 4,\ 7,\ 10 \quad \begin{bmatrix} 4 \\ 7 \\ 10 \end{bmatrix}$$

$$Kbn = \begin{bmatrix} 0.0 & -240625.0 & 0.0 & -550000.0 & 0.0 & 0.0 \\ 0.0 & 550000.0 & 0.0 & 0.0 & 0.0 & -550000.0 \\ 0.0 & 0.0 & 0.0 & 550000.0 & 0.0 & 550000.0 \end{bmatrix} \quad \text{columns: } 5,\ 6,\ 8,\ 9,\ 11,\ 12 \quad \begin{bmatrix} 4 \\ 7 \\ 10 \end{bmatrix}$$

$$Knb = \begin{bmatrix} 0.0 & 0.0 & 0.0 \\ -240625.0 & 550000.0 & 0.0 \\ 0.0 & 0.0 & 0.0 \\ -550000.0 & 0.0 & 550000.0 \\ 0.0 & 0.0 & 0.0 \\ 0.0 & -550000.0 & 550000.0 \end{bmatrix} \quad \text{columns: } 4,\ 7,\ 10 \quad \begin{bmatrix} 5 \\ 6 \\ 8 \\ 9 \\ 11 \\ 12 \end{bmatrix}$$

$\text{if}\left(Knb = Kbn^{T}, \text{“OK”}, \text{“NO OK”}\right) = \text{“OK”}$

$$Knn = \begin{bmatrix} 5775000.0 & 0.0 & -3300000.0 & 0.0 & 0.0 & 0.0 \\ 0.0 & 1925000.0 & 0.0 & 550000.0 & 0.0 & 0.0 \\ -3300000.0 & 0.0 & 6600000.0 & 0.0 & -3300000.0 & 0.0 \\ 0.0 & 550000.0 & 0.0 & 2200000.0 & 0.0 & 550000.0 \\ 0.0 & 0.0 & -3300000.0 & 0.0 & 3300000.0 & 0.0 \\ 0.0 & 0.0 & 0.0 & 550000.0 & 0.0 & 1100000.0 \end{bmatrix} \quad \text{columns: } 5,\ 6,\ 8,\ 9,\ 11,\ 12 \quad \begin{bmatrix} 5 \\ 6 \\ 8 \\ 9 \\ 11 \\ 12 \end{bmatrix}$$

$Kc := Kbb - Kbn \cdot Knn^{-1} \cdot Knb$

$$Kc = \begin{bmatrix} 360269.1 & -265833.3 & 74861.1 \\ -265833.3 & 293333.3 & -110000.0 \\ 74861.1 & -110000.0 & 48888.9 \end{bmatrix} \quad \text{columns: } 4,\ 7,\ 10 \quad \begin{bmatrix} 4 \\ 7 \\ 10 \end{bmatrix}$$

Matrica mase

$$Mc := \begin{bmatrix} m_1 & 0 & 0 \\ 0 & m_2 & 0 \\ 0 & 0 & m_3 \end{bmatrix} = \begin{bmatrix} 40.0 & 0.0 & 0.0 \\ 0.0 & 40.0 & 0.0 \\ 0.0 & 0.0 & 30.0 \end{bmatrix} \quad \text{columns: } 4,\ 7,\ 10 \quad \begin{bmatrix} 4 \\ 7 \\ 10 \end{bmatrix}$$

Periodi svojstvenih vibracija

$$Trac := \frac{2 \cdot \pi}{\sqrt{\text{eigenvals}\left(Mc^{-1} \cdot Kc\right)}} = \begin{bmatrix} 0.04991 \\ 0.13817 \\ 0.84654 \end{bmatrix}$$

$T_{ton\_1} := Trac_2 = 0.84654$ $T_{ton\_2} := Trac_1 = 0.13817$ $T_{ton\_3} := Trac_0 = 0.04991$

Oblici svojstvenih vibracija

$$Arac := \text{eigenvecs}\left(Mc^{-1} \cdot Kc\right) = \begin{bmatrix} -0.70651 & 0.63972 & 0.1884 \\ 0.64535 & 0.50467 & 0.49297 \\ -0.29045 & -0.57972 & 0.8494 \end{bmatrix}$$

Ton 1: $Arac\_1 := Arac^{\langle 2 \rangle} = \begin{bmatrix} 0.1884 \\ 0.49297 \\ 0.8494 \end{bmatrix}$ Ton 2: $Arac\_2 := Arac^{\langle 1 \rangle} = \begin{bmatrix} 0.63972 \\ 0.50467 \\ -0.57972 \end{bmatrix}$

Ton 3: $Arac\_3 := -Arac^{\langle 0 \rangle} = \begin{bmatrix} 0.70651 \\ -0.64535 \\ 0.29045 \end{bmatrix}$

Ortonormiranje svojstvenih oblika

Ton 1

$Mgen\_1 := Arac\_1^{T} \cdot Mc \cdot Arac\_1 = 32.78514$

$$\phi_1 := \frac{1}{\sqrt{Mgen\_1}} \cdot Arac\_1 = \begin{bmatrix} 0.03290 \\ 0.08610 \\ 0.14835 \end{bmatrix}$$

$M_1 := \phi_1^{T} \cdot Mc \cdot \phi_1 = 1.00000$

Ton 2

$Mgen\_2 := Arac\_2^{T} \cdot Mc \cdot Arac\_2 = 36.63930$

$$\phi_2 := \frac{1}{\sqrt{Mgen\_2}} \cdot Arac\_2 = \begin{bmatrix} 0.10569 \\ 0.08337 \\ -0.09577 \end{bmatrix}$$

$M_2 := \phi_2^{T} \cdot Mc \cdot \phi_2 = 1.00000$

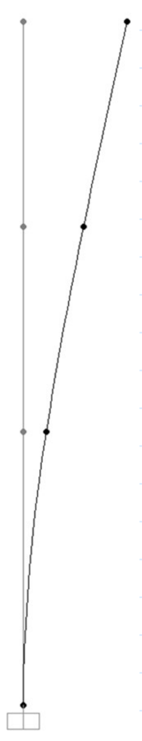
Ton 3

$Mgen\_3 := Arac\_3^{T} \cdot Mc \cdot Arac\_3 = 39.15640$

$$\phi_3 := \frac{1}{\sqrt{Mgen\_3}} \cdot Arac\_3 = \begin{bmatrix} 0.11291 \\ -0.10313 \\ 0.04642 \end{bmatrix}$$

$M_3 := \phi_3^{T} \cdot Mc \cdot \phi_3 = 1.00000$

$T_{ton\_1} = 0.847$

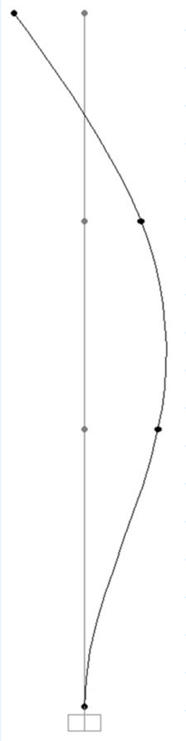


$\phi_{1_2} = 0.1483$

$\phi_{1_1} = 0.0861$

$\phi_{1_0} = 0.0329$

$T_{ton\_2} = 0.138$

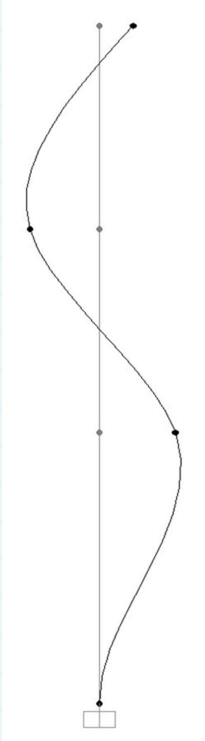


$\phi_{2_2} = -0.0958$

$\phi_{2_1} = 0.0834$

$\phi_{2_0} = 0.1057$

$T_{ton\_3} = 0.050$



$\phi_{3_2} = 0.0464$

$\phi_{3_1} = -0.1031$

$\phi_{3_0} = 0.1129$

Elastični i projektni spektar odgovora za horizontalan pravac

Tip 1 elastičnog odgovora

$$parametri\_tip\_1(tipTla) := \begin{array}{l} \text{if } tipTla = \text{"A"} \\ \quad [1.00\ \ 0.15\ \ 0.4\ \ 2.0] \\ \text{if } tipTla = \text{"B"} \\ \quad [1.20\ \ 0.15\ \ 0.5\ \ 2.0] \\ \text{if } tipTla = \text{"C"} \\ \quad [1.15\ \ 0.20\ \ 0.6\ \ 2.0] \\ \text{if } tipTla = \text{"D"} \\ \quad [1.35\ \ 0.20\ \ 0.8\ \ 2.0] \\ \text{if } tipTla = \text{"E"} \\ \quad [1.40\ \ 0.15\ \ 0.5\ \ 2.0] \end{array}$$

$$niz := parametri\_tip\_1(tipTla) = [1.15\ \ 0.2\ \ 0.6\ \ 2]$$

$Ss := niz_{0,0} = 1.15$ $\quad Tb := niz_{0,1} = 0.2$ $\quad Tc := niz_{0,2} = 0.6$ $\quad Td := niz_{0,3} = 2$

$$Se(T_{ton}) := \begin{cases} a_g \cdot Ss \cdot \left(1 + \frac{T_{ton}}{Tb} \cdot (\eta \cdot 2.5 - 1)\right) & \text{if } 0 \le T_{ton} \le Tb \\ a_g \cdot Ss \cdot \eta \cdot 2.5 & \text{if } Tb < T_{ton} \le Tc \\ a_g \cdot Ss \cdot \eta \cdot 2.5 \cdot \frac{Tc}{T_{ton}} & \text{if } Tc < T_{ton} \le Td \\ a_g \cdot Ss \cdot \eta \cdot 2.5 \cdot \frac{Tc \cdot Td}{T_{ton}^2} & \text{if } Td < T_{ton} \le 4 \end{cases}$$

$$Sd(T_{ton}, q) := \begin{cases} a_g \cdot Ss \cdot \left(\frac{2}{3} + \frac{T_{ton}}{Tb} \cdot \left(\frac{2.5}{q} - \frac{2}{3}\right)\right) & \text{if } 0 \le T_{ton} \le Tb \\ a_g \cdot Ss \cdot \frac{2.5}{q} & \text{if } Tb < T_{ton} \le Tc \\ a_g \cdot Ss \cdot \frac{2.5}{q} \cdot \frac{Tc}{T_{ton}} & \text{if } Tc < T_{ton} \le Td \\ a_g \cdot Ss \cdot \frac{2.5}{q} \cdot \frac{Tc \cdot Td}{T_{ton}^2} & \text{if } Td < T_{ton} \end{cases}$$

Projektno spektralno ubrzanje

$Sa11 := Sd(T_{ton\_1}, q) = 1.333$ $Sa22 := Sd(T_{ton\_2}, q) = 1.531$

$Sa33 := Sd(T_{ton\_3}, q) = 1.034$ $\beta := 0.2$ $\beta \cdot a_g = 0.196$

Ograničenje projektnog spektralnog ubrzanja:

$$Sa(Spa) := \begin{cases} \text{return } \beta \cdot a_g & \text{if } Spa < \beta \cdot a_g \\ \text{return } Spa & \text{else} \end{cases}$$

$Sa1 := Sa(Sa11) = 1.333$

$Sa2 := Sa(Sa22) = 1.531$

$Sa3 := Sa(Sa33) = 1.034$

Faktor "participacije"

Vektor uticajnih koeficijenata: $s := \begin{bmatrix} 1 \\ 1 \\ 1 \end{bmatrix}$

$\Gamma_1 := \frac{\phi_1^{T} \cdot Mc \cdot s}{M_1} = 9.210$ $\Gamma_2 := \frac{\phi_2^{T} \cdot Mc \cdot s}{M_2} = 4.689$ $\Gamma_3 := \frac{\phi_3^{T} \cdot Mc \cdot s}{M_3} = 1.783$

Efektivna masa

Ukupna masa dinamičkog modela:

$$Mukupno := \left| \begin{array}{l} suma \leftarrow 0 \\ \text{for } i \in 0..\text{last}\left(Mc^{\langle 0 \rangle}\right) \\ \quad suma \leftarrow suma + Mc_{i,i} \\ \text{return } suma \end{array} \right. = 110.0$$

Efektivna masa za T1:

$L1 := \phi_1^{T} \cdot Mc \cdot s = 9.210$ $Mef\_1 := \frac{L1^2}{M_1} = 84.83$ $\frac{Mef\_1}{Mukupno} = 0.771$

Efektivna masa za T2:

$L2 := \phi_2^{T} \cdot Mc \cdot s = 4.689$ $Mef\_2 := \frac{L2^2}{M_2} = 21.99$ $\frac{Mef\_2}{Mukupno} = 0.200$

Efektivna masa za T3:

$L3 := \phi_3^{T} \cdot Mc \cdot s = 1.783$ $Mef\_3 := \frac{L3^2}{M_3} = 3.18$ $\frac{Mef\_3}{Mukupno} = 0.029$

$Mef\_1 + Mef\_2 + Mef\_3 = 110.0$

$\frac{Mef\_1 + Mef\_2 + Mef\_3}{Mukupno} = 1$

Seizmičke sile

Ton 1: $S1 := \Gamma_1 \cdot Mc \cdot \phi_1 \cdot Sa1 = \begin{bmatrix} 16.15492 \\ 42.27061 \\ 54.62535 \end{bmatrix}$ Ton 2: $S2 := \Gamma_2 \cdot Mc \cdot \phi_2 \cdot Sa2 = \begin{bmatrix} 30.35893 \\ 23.94970 \\ -20.63348 \end{bmatrix}$

Ton 3: $S3 := \Gamma_3 \cdot Mc \cdot \phi_3 \cdot Sa3 = \begin{bmatrix} 8.32540 \\ -7.60471 \\ 2.56694 \end{bmatrix}$

Dijagram momenata savijanja (SRSS pravilo)

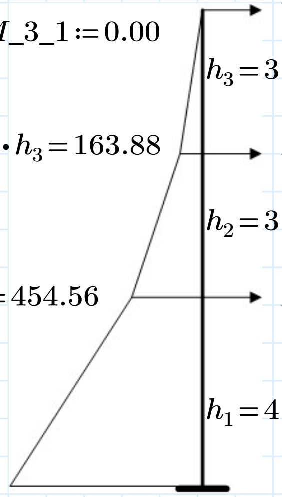
Ton 1

$S1 = \begin{bmatrix} 16.15 \\ 42.27 \\ 54.63 \end{bmatrix}$

$M\_3\_1 := 0.00$

$M\_2\_1 := S1_2 \cdot h_3 = 163.88$

$M\_1\_1 := S1_2 \cdot (h_2 + h_3) + S1_1 \cdot h_2 = 454.56$



$S1_2 = 54.63$

$h_3 = 3.0$

$S1_1 = 42.27$

$h_2 = 3.0$

M1 [kNm]

$S1_0 = 16.15$

$h_1 = 4.0$

$M\_0\_1 := S1_2 \cdot (h_1 + h_2 + h_3) + S1_1 \cdot (h_1 + h_2) + S1_0 \cdot h_1 = 906.77$

Ton 2

$$S2=\begin{bmatrix}30.36\\23.95\\-20.63\end{bmatrix}$$

$S2_2=-20.63$

$M\_3\_2:=0.00$

$h_3=3.0$

$M\_2\_2:=S2_2\cdot h_3=-61.90$

$S2_1=23.95$

$h_2=3.0$

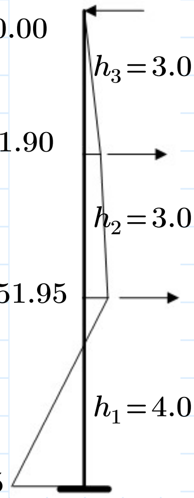
M2 [kNm]

$M\_1\_2:=S2_2\cdot(h_2+h_3)+S2_1\cdot h_2=-51.95$

$S2_0=30.36$

$h_1=4.0$

$M\_0\_2:=S2_2\cdot(h_1+h_2+h_3)+S2_1\cdot(h_1+h_2)+S2_0\cdot h_1=82.75$



Ton 3

$$S3=\begin{bmatrix}8.33\\-7.60\\2.57\end{bmatrix}$$

$S3_2=2.57$

$M\_3\_3:=0.00$

$h_3=3.0$

$M\_2\_3:=S3_2\cdot h_3=7.70$

$S3_1=-7.60$

$h_2=3.0$

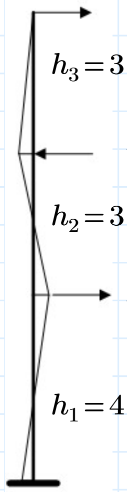
M3 [kNm]

$M\_1\_3:=S3_2\cdot(h_2+h_3)+S3_1\cdot h_2=-7.41$

$S3_0=8.33$

$h_1=4.0$

$M\_0\_3:=S3_2\cdot(h_1+h_2+h_3)+S3_1\cdot(h_1+h_2)+S3_0\cdot h_1=5.74$



Ukupni dijagram M (SRSS pravilo)

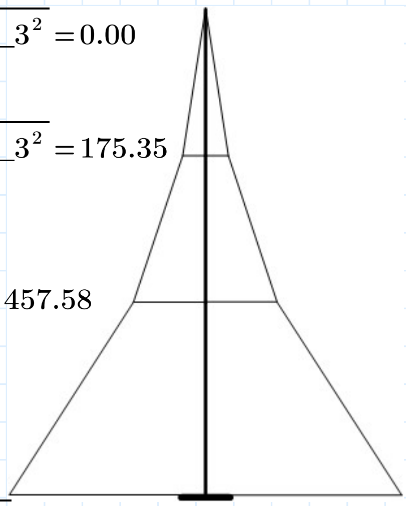
$\sqrt{M\_3\_1^2+M\_3\_2^2+M\_3\_3^2}=0.00$

$\sqrt{M\_2\_1^2+M\_2\_2^2+M\_2\_3^2}=175.35$

Mukupno [kNm]

$\sqrt{M\_1\_1^2+M\_1\_2^2+M\_1\_3^2}=457.58$

$\sqrt{M\_0\_1^2+M\_0\_2^2+M\_0\_3^2}=910.55$

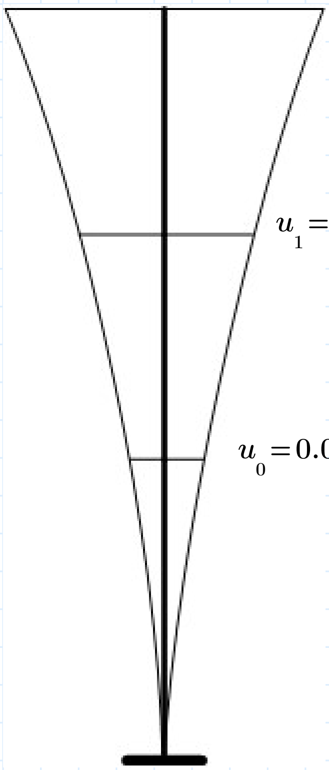


Relativno horizontalno pomeranje u nivou masa (SRSS pravilo)

Određeno na osnovu elastičnog spektra odgovora

$$u1 := \Gamma_1 \cdot \phi_1 \cdot \frac{Se\left(T_{ton\_1}\right)}{\left(\frac{2 \cdot \pi}{T_{ton\_1}}\right)^2} = \begin{bmatrix} 0.01100 \\ 0.02877 \\ 0.04958 \end{bmatrix} \qquad u2 := \Gamma_2 \cdot \phi_2 \cdot \frac{Se\left(T_{ton\_2}\right)}{\left(\frac{2 \cdot \pi}{T_{ton\_2}}\right)^2} = \begin{bmatrix} 0.00055 \\ 0.00043 \\ -0.00050 \end{bmatrix}$$

$$u3 := \Gamma_3 \cdot \phi_3 \cdot \frac{Se\left(T_{ton\_3}\right)}{\left(\frac{2 \cdot \pi}{T_{ton\_3}}\right)^2} = \begin{bmatrix} 0.00002 \\ -0.00002 \\ 0.00001 \end{bmatrix} \qquad u := \begin{bmatrix} \sqrt{\left(u1_0\right)^2 + \left(u2_0\right)^2 + \left(u3_0\right)^2} \\ \sqrt{\left(u1_1\right)^2 + \left(u2_1\right)^2 + \left(u3_1\right)^2} \\ \sqrt{\left(u1_2\right)^2 + \left(u2_2\right)^2 + \left(u3_2\right)^2} \end{bmatrix} = \begin{bmatrix} 0.01101 \\ 0.02878 \\ 0.04958 \end{bmatrix}$$



Određeno na osnovu projektnog spektra odgovora

$$u1 := \Gamma_1 \cdot \phi_1 \cdot \frac{Sd\left(T_{ton\_1}, q\right)}{\left(\frac{2 \cdot \pi}{T_{ton\_1}}\right)^2} \cdot q = \begin{bmatrix} 0.01100 \\ 0.02877 \\ 0.04958 \end{bmatrix} \qquad u2 := \Gamma_2 \cdot \phi_2 \cdot \frac{Sd\left(T_{ton\_2}, q\right)}{\left(\frac{2 \cdot \pi}{T_{ton\_2}}\right)^2} \cdot q = \begin{bmatrix} 0.00055 \\ 0.00043 \\ -0.00050 \end{bmatrix}$$

$$u3 := \Gamma_3 \cdot \phi_3 \cdot \frac{Sd\left(T_{ton\_3}, q\right)}{\left(\frac{2 \cdot \pi}{T_{ton\_3}}\right)^2} \cdot q = \begin{bmatrix} 0.00002 \\ -0.00002 \\ 0.00001 \end{bmatrix} \qquad u := \begin{bmatrix} \sqrt{\left(u1_0\right)^2 + \left(u2_0\right)^2 + \left(u3_0\right)^2} \\ \sqrt{\left(u1_1\right)^2 + \left(u2_1\right)^2 + \left(u3_1\right)^2} \\ \sqrt{\left(u1_2\right)^2 + \left(u2_2\right)^2 + \left(u3_2\right)^2} \end{bmatrix} = \begin{bmatrix} 0.01101 \\ 0.02878 \\ 0.04958 \end{bmatrix} \text{ [m]}$$