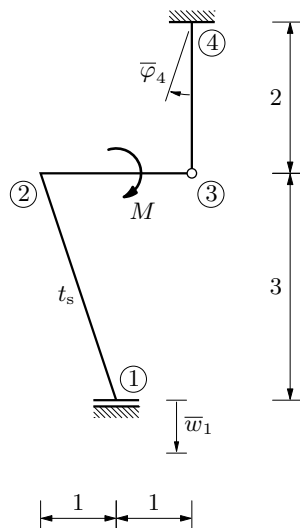


Inženjerska metoda pomakā

Primjer

Nacrtajte dijagram momenata savijanja!



$$\bar{w}_1 = 3 \text{ mm}$$

$$\bar{\varphi}_4 = 0,0006$$

$$M = 360 \text{ kNm}$$

$$t_s = 21^\circ \text{ C}$$

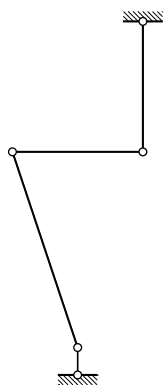
$$\alpha_t = 10^{-5} \text{ K}^{-1}$$

$$EI = 162\,000 \text{ kNm}^2$$

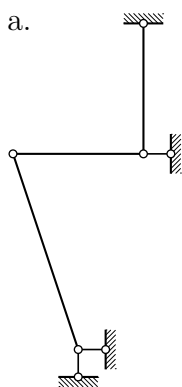
$$(EI)_{\{2,3\}} = (EI)_{\{3,4\}} = EI$$

$$(EI)_{\{1,2\}} = 2EI$$

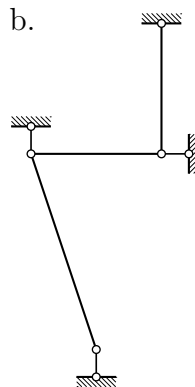
nepoznanice:



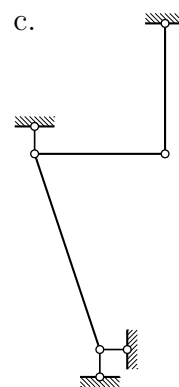
$$S_{\min} = 3 \cdot 2 - 4 \\ = 2$$



$$\varphi_2 \\ u_1, u_{\{2,3\}}$$



$$\varphi_2 \\ w_2, u_{\{2,3\}}$$



$$\varphi_2 \\ u_1, w_2$$

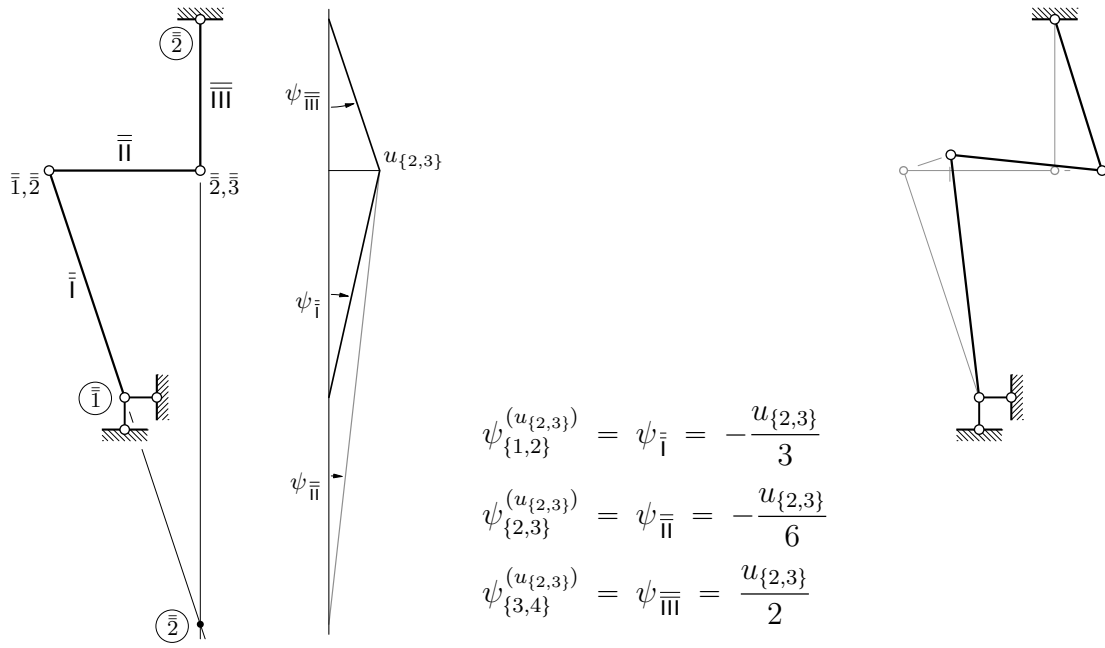
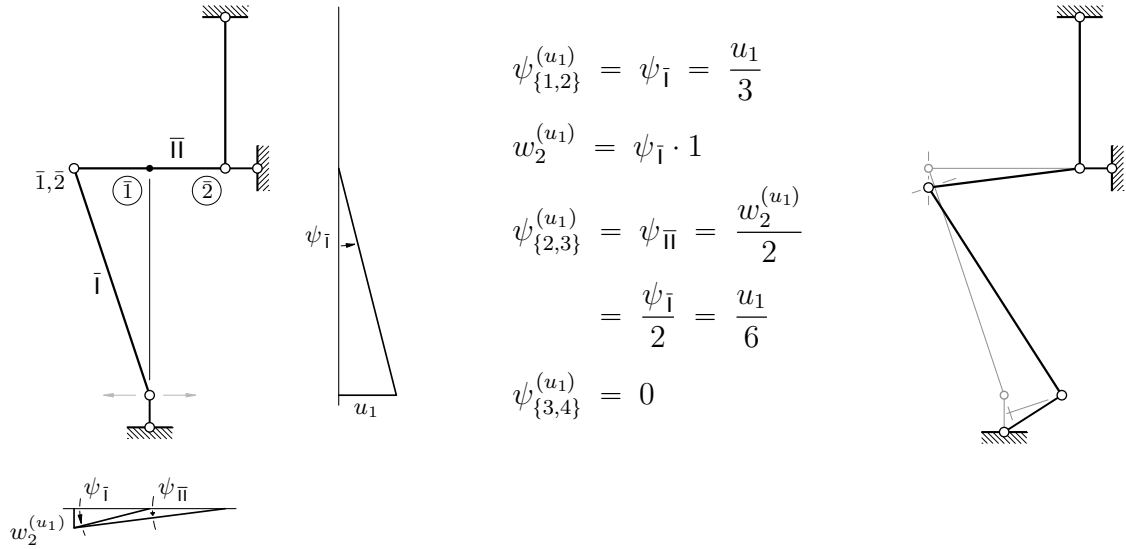
a.

$$M_{1,2} = 2k_{\{1,2\}}\varphi_2 - 6k_{\{1,2\}}\psi_{\{1,2\}}^{(u_1)} - 6k_{\{1,2\}}\psi_{\{1,2\}}^{(u_{\{2,3\}})} + \bar{M}_{1,2}$$

$$M_{2,1} = 4k_{\{1,2\}}\varphi_2 - 6k_{\{1,2\}}\psi_{\{1,2\}}^{(u_1)} - 6k_{\{1,2\}}\psi_{\{1,2\}}^{(u_{\{2,3\}})} + \bar{M}_{2,1}$$

$$M_{2,3} = M_{2,3}^c = 3k_{\{2,3\}}\varphi_2 - 3k_{\{2,3\}}\psi_{\{2,3\}}^{(u_1)} - 3k_{\{2,3\}}\psi_{\{2,3\}}^{(u_{\{2,3\}})} + \bar{M}_{2,3}^c$$

$$M_{4,3} = M_{4,3}^c = -3k_{\{3,4\}}\psi_{\{3,4\}}^{(u_1)} - 3k_{\{3,4\}}\psi_{\{3,4\}}^{(u_{\{2,3\}})} + \bar{M}_{4,3}^c$$



$$M_{1,2} = 2k_{\{1,2\}}\varphi_2 - 6k_{\{1,2\}}\frac{u_1}{3} - 6k_{\{1,2\}}\left(-\frac{u_{\{2,3\}}}{3}\right) + \bar{M}_{1,2}$$

$$= 2k_{\{1,2\}}\varphi_2 - 2k_{\{1,2\}}u_1 + 2k_{\{1,2\}}u_{\{2,3\}} + \bar{M}_{1,2}$$

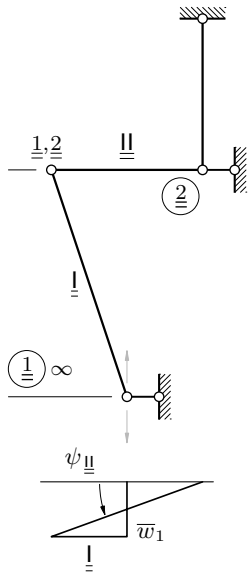
$$M_{2,1} = 4k_{\{1,2\}}\varphi_2 - 6k_{\{1,2\}}\frac{u_1}{3} - 6k_{\{1,2\}}\left(-\frac{u_{\{2,3\}}}{3}\right) + \bar{M}_{2,1}$$

$$= 4k_{\{1,2\}}\varphi_2 - 2k_{\{1,2\}}u_1 + 2k_{\{1,2\}}u_{\{2,3\}} + \bar{M}_{2,1}$$

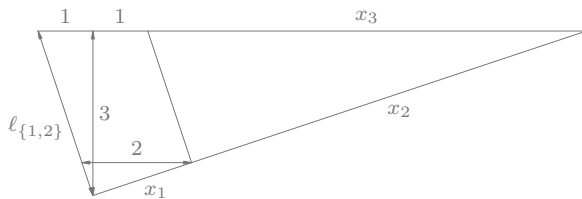
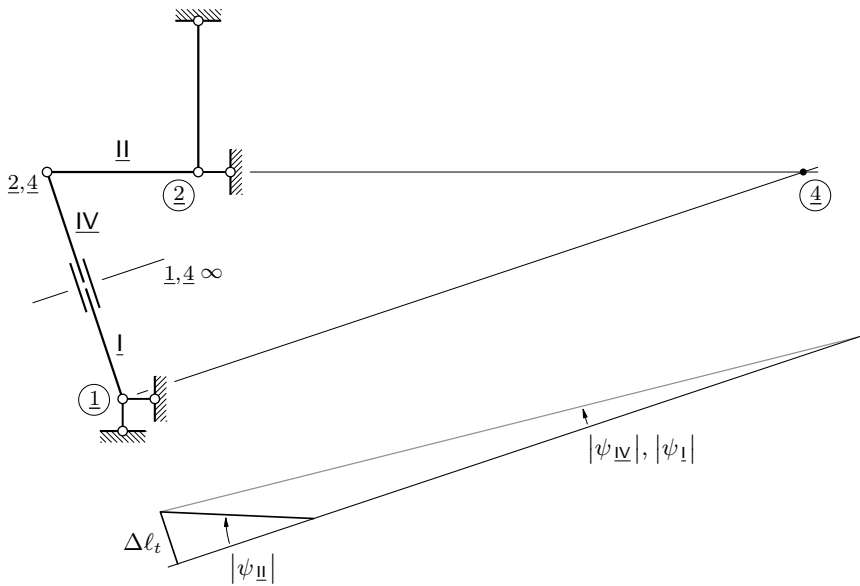
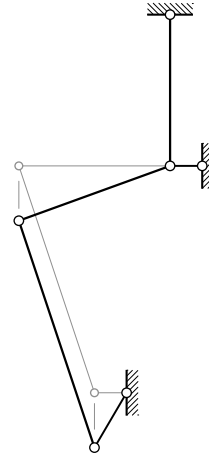
$$M_{2,3} = M_{2,3}^c = 3k_{\{2,3\}}\varphi_2 - 3k_{\{2,3\}}\frac{u_1}{6} - 3k_{\{2,3\}}\left(-\frac{u_{\{2,3\}}}{6}\right) + \bar{M}_{2,3}^c$$

$$= 3k_{\{2,3\}}\varphi_2 - \frac{1}{2}k_{\{2,3\}}u_1 + \frac{1}{2}k_{\{2,3\}}u_{\{2,3\}} + \bar{M}_{2,3}^c$$

$$M_{4,3} = M_{4,3}^c = -3k_{\{3,4\}} \cdot 0 - 3k_{\{3,4\}}\frac{u_{\{2,3\}}}{2} + \bar{M}_{4,3}^c = -\frac{3}{2}k_{\{3,4\}}u_{\{2,3\}} + \bar{M}_{4,3}^c$$



$$\begin{aligned} \psi_{\{1,2\}}^{(\bar{w}_1)} &= \psi_{\underline{I}} = 0 \\ \psi_{\{2,3\}}^{(\bar{w}_1)} &= \psi_{\underline{II}} = \frac{\bar{w}_1}{2} \\ &= \frac{0,003}{2} = 0,0015 \\ \psi_{\{3,4\}}^{(\bar{w}_1)} &= 0 \end{aligned}$$



$$l_{\{1,2\}} = \sqrt{1^2 + 9^2} = \sqrt{10} = 3,16 \text{ m}$$

$$\Delta l_t = \alpha_t t_s l_{\{1,2\}} = 10^{-5} \cdot 21 \cdot \sqrt{10} = 0,000664 \text{ m}$$

$$\frac{x_1}{2} = \frac{3}{l_{\{1,2\}}} \Rightarrow x_1 = \frac{6}{l_{\{1,2\}}} = \frac{6}{\sqrt{10}} = 1,90 \text{ m}$$

$$\begin{aligned}
\bar{M}_{1,2} &= \bar{M}_{1,2}^{(\bar{w}_1)} + \bar{M}_{1,2}^{(t_s)} = -6 k_{\{1,2\}} \psi_{\{1,2\}}^{(\bar{w}_1)} - 6 k_{\{1,2\}} \psi_{\{1,2\}}^{(t_s)} \\
&= -6 k_{\{1,2\}} \cdot 0 - 6 k_{\{1,2\}} \psi_{\{1,2\}}^{(t_s)} = -6 \cdot 102\,458 \cdot (-0,000\,07) = 43,03 \text{ kNm} \\
\bar{M}_{2,1} &= \bar{M}_{2,1}^{(\bar{w}_1)} + \bar{M}_{2,1}^{(t_s)} = -6 k_{\{1,2\}} \psi_{\{1,2\}}^{(\bar{w}_1)} - 6 k_{\{1,2\}} \psi_{\{1,2\}}^{(t_s)} = \bar{M}_{1,2} = 43,03 \text{ kNm} \\
\bar{M}_{2,3}^c &= {}^c\bar{M}_{2,3}^{(\bar{w}_1)} + {}^c\bar{M}_{2,3}^{(t_s)} + {}^c\bar{M}_{2,3}^{(M)} = {}^c\bar{M}_{2,3}^{(\bar{w}_1)} + {}^c\bar{M}_{2,3}^{(t_s)} + \left(\bar{M}_{2,3}^{(M)} - \frac{1}{2} \bar{M}_{3,2}^{(M)} \right) \\
&= -3 k_{\{2,3\}} \psi_{\{2,3\}}^{(\bar{w}_1)} - 3 k_{\{2,3\}} \psi_{\{2,3\}}^{(t_s)} + \left(\frac{M}{4} - \frac{1}{2} \frac{M}{4} \right) \\
&= -3 \cdot 81\,000 \cdot 0,001\,5 - 3 \cdot 81\,000 \cdot (-0,000\,35) + \frac{-360}{8} = -324,45 \text{ kNm} \\
\bar{M}_{4,3}^c &= {}^c\bar{M}_{4,3}^{(\bar{\varphi}_4)} = -3 k_{\{3,4\}} \bar{\varphi}_4 = -3 \cdot 81\,000 \cdot (-0,000\,6) = -145,80 \text{ kNm}
\end{aligned}$$

jednadžba ravnoteže momenata u čvoru 2:

$$\begin{aligned}
-M_{2,1} - M_{2,3} &= 0 \quad \Rightarrow \quad M_{2,1} + M_{2,3} = 0 \\
[4 k_{\{1,2\}} \varphi_2 - 2 k_{\{1,2\}} u_1 + 2 k_{\{1,2\}} u_{\{2,3\}} + \bar{M}_{2,1}] \\
+ \left[3 k_{\{2,3\}} \varphi_2 - \frac{1}{2} k_{\{2,3\}} u_1 + \frac{1}{2} k_{\{2,3\}} u_{\{2,3\}} + \bar{M}_{2,3}^c \right] &= 0 \\
(4 k_{\{1,2\}} + 3 k_{\{2,3\}}) \varphi_2 + \left(-2 k_{\{1,2\}} - \frac{1}{2} k_{\{2,3\}} \right) u_1 \\
+ \left(2 k_{\{1,2\}} + \frac{1}{2} k_{\{2,3\}} \right) u_{\{2,3\}} &= -\bar{M}_{2,1} - \bar{M}_{2,3}^c \\
652\,832 \cdot \varphi_2 - 245\,416 \cdot u_1 + 245\,416 \cdot u_{2,3} &= 281,42 \quad (\leftarrow)
\end{aligned}$$

jednadžba rada na virtualnom pomaku δu_1 (projekcije pomaka za u_1 uz dodani δ):

$$\begin{aligned}
(M_{1,2} + M_{2,1}) \delta \psi_{\{1,2\}}^{(\delta u_1)} + M_{2,3} \delta \psi_{\{2,3\}}^{(\delta u_1)} + M_{4,3} \delta \psi_{\{3,4\}}^{(\delta u_1)} + (-M) \delta \psi_{\{2,3\}}^{(\delta u_1)} &= 0 \\
(6 k_{\{1,2\}} \varphi_2 - 4 k_{\{1,2\}} u_1 + 4 k_{\{1,2\}} u_{2,3} + \bar{M}_{1,2} + \bar{M}_{2,1}) \frac{\delta u_1}{3} \\
+ \left(3 k_{\{2,3\}} \varphi_2 - \frac{1}{2} k_{\{2,3\}} u_1 + \frac{1}{2} k_{\{2,3\}} u_{2,3} + \bar{M}_{2,3}^c \right) \frac{\delta u_1}{6} + 0 - M \frac{\delta u_1}{6} &= 0 \\
\left(2 k_{\{1,2\}} + \frac{1}{2} k_{\{2,3\}} \right) \varphi_2 - \left(\frac{4}{3} k_{\{1,2\}} + \frac{1}{12} k_{\{2,3\}} \right) u_1 \\
+ \left(\frac{4}{3} k_{\{1,2\}} + \frac{1}{12} k_{\{2,3\}} \right) u_{2,3} &= -\frac{1}{3} (\bar{M}_{1,2} + \bar{M}_{2,1}) - \frac{1}{6} (\bar{M}_{2,3}^c - M) \\
245\,416 \varphi_2 - 143\,361 u_1 + 143\,361 u_{2,3} = 85,39 \quad | \quad \times (-1) \\
-245\,416 \varphi_2 + 143\,361 u_1 - 143\,361 u_{2,3} &= -85,39 \quad (\rightarrow)
\end{aligned}$$

jednadžba rada na virtualnom pomaku $\delta u_{2,3}$ (projekcije pomaka za $u_{2,3}$ uz dodani δ):

$$\begin{aligned}
 & (M_{1,2} + M_{2,1}) \delta\psi_{\{1,2\}}^{(\delta u_{\{2,3\}})} + M_{2,3} \delta\psi_{\{2,3\}}^{(\delta u_{\{2,3\}})} + M_{4,3} \delta\psi_{\{3,4\}}^{(\delta u_{\{2,3\}})} + (-M) \delta\psi_{\{2,3\}}^{(\delta u_{\{2,3\}})} = 0 \\
 & (6 k_{\{1,2\}} \varphi_2 - 4 k_{\{1,2\}} u_1 + 4 k_{\{1,2\}} u_{2,3} + \bar{M}_{1,2} + \bar{M}_{2,1}) \left(-\frac{\delta u_{2,3}}{3} \right) \\
 & + \left(3 k_{\{2,3\}} \varphi_2 - \frac{1}{2} k_{\{2,3\}} u_1 + \frac{1}{2} k_{\{2,3\}} u_{2,3} + \bar{M}_{2,3}^c \right) \left(-\frac{\delta u_{2,3}}{6} \right) \\
 & + \left(-\frac{3}{2} k_{\{3,4\}} u_{2,3} + \bar{M}_{4,3}^c \right) \frac{\delta u_{2,3}}{2} - M \left(-\frac{\delta u_{2,3}}{6} \right) = 0 \\
 & - \left(2 k_{\{1,2\}} + \frac{1}{2} k_{\{2,3\}} \right) \varphi_2 + \left(\frac{4}{3} k_{\{1,2\}} + \frac{1}{12} k_{\{2,3\}} \right) u_1 \\
 & - \left(\frac{4}{3} k_{\{1,2\}} + \frac{1}{12} k_{\{2,3\}} + \frac{3}{4} k_{\{3,4\}} \right) u_{2,3} \\
 & = \frac{1}{3} (\bar{M}_{1,2} + \bar{M}_{2,1}) + \frac{1}{6} (\bar{M}_{2,3}^c - M) - \frac{1}{2} \bar{M}_{4,3}^c \\
 & -245\,416 \varphi_2 + 143\,361 u_1 - 204\,111 u_{2,3} = -12,49 \quad | \quad \times (-1) \\
 & 245\,416 \varphi_2 - 143\,361 u_1 + 204\,111 u_{2,3} = 12,49 \quad (\text{✎})
 \end{aligned}$$

rješenje sustava jednadžbi (✎), (✎) \mathcal{E} (✎):

$$\varphi_2 = 0,000\,581\,2, \quad u_1 = -0,000\,8 \text{ m} \quad \mathcal{E} \quad u_{\{2,3\}} = -0,001\,2 \text{ m}$$

vrijednosti momenata na krajevima štapova:

$$\begin{aligned}
 M_{1,2} &= k_{\{1,2\}} (2 \varphi_2 - 2 u_1 + 2 u_{\{2,3\}}) + \bar{M}_{1,2} \\
 &= 102\,458 \cdot [2 \cdot 0,000\,581\,2 - 2 \cdot (-0,000\,8) + 2 \cdot (-0,001\,2)] + 43,03 \\
 &= 80,16 \text{ kNm}
 \end{aligned}$$

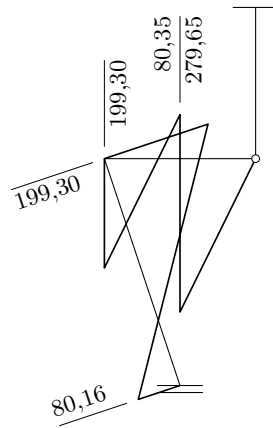
$$\begin{aligned}
 M_{2,1} &= k_{\{1,2\}} (4 \varphi_2 - 2 u_1 + 2 u_{\{2,3\}}) + \bar{M}_{2,1} \\
 &= 102\,458 \cdot [4 \cdot 0,000\,581\,2 - 2 \cdot (-0,000\,8) + 2 \cdot (-0,001\,2)] + 43,03 \\
 &= 199,26 \text{ kNm}
 \end{aligned}$$

$$\begin{aligned}
 M_{2,3} &= k_{\{2,3\}} \left(3 \varphi_2 - \frac{1}{2} u_1 + \frac{1}{2} u_{\{2,3\}} \right) + \bar{M}_{2,3}^c \\
 &= 81\,000 \cdot \left[3 \cdot 0,000\,581\,2 - \frac{1}{2} \cdot (-0,000\,8) + \frac{1}{2} \cdot (-0,001\,2) \right] - 324,45 \\
 &= -199,40 \text{ kNm}
 \end{aligned}$$

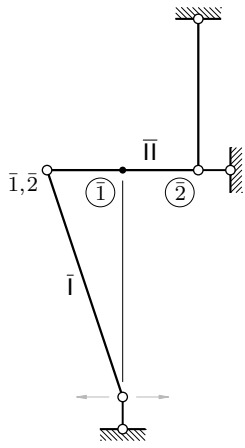
$$M_{4,3} = -\frac{3}{2} k_{\{3,4\}} u_{\{2,3\}} + \bar{M}_{4,3}^c = -\frac{3}{2} \cdot 81\,000 \cdot (-0,001\,2) - 145,80 = 0$$

(„neravnoteža” momenata u čvoru 2 posljedica je pogrešaka zaokruživanja)

momentni dijagram:



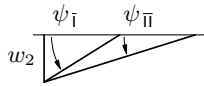
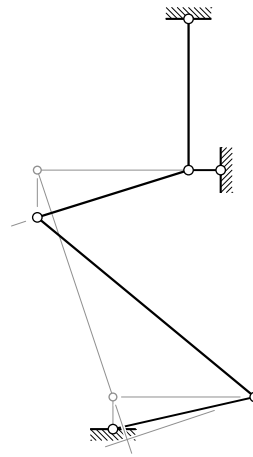
b.



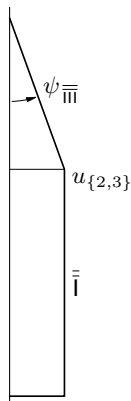
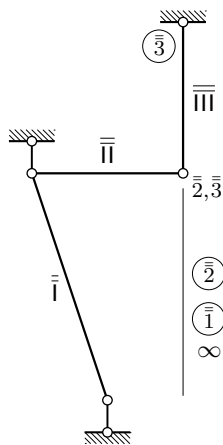
$$\psi_{\{1,2\}}^{(w_2)} = \psi_{\bar{I}} = \frac{w_2}{1}$$

$$\psi_{\{2,3\}}^{(w_2)} = \psi_{\bar{II}} = \frac{w_2}{2}$$

$$\psi_{\{3,4\}}^{(w_2)} = 0$$



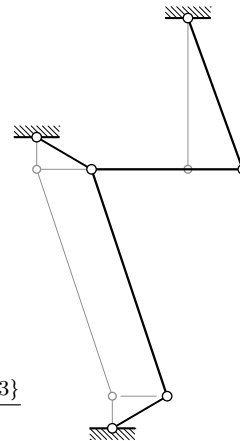
(isti mehanizam kao za \vec{u}_1 u a., ali je „vodeći” pomak sada \vec{w}_2)



$$\psi_{\{1,2\}}^{(u_{2,3})} = 0$$

$$\psi_{\{2,3\}}^{(u_{2,3})} = 0$$

$$\psi_{\{3,4\}}^{(u_{2,3})} = \psi_{\bar{III}} = \frac{u_{\{2,3\}}}{2}$$

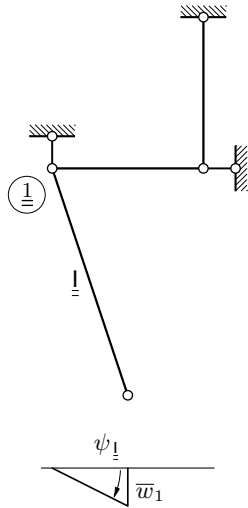


$$\begin{aligned}
M_{1,2} &= 2 k_{\{1,2\}} \varphi_2 - 6 k_{\{1,2\}} \psi_{\{1,2\}}^{(w_2)} - 6 k_{\{1,2\}} \psi_{\{1,2\}}^{(u_{\{2,3\}})} + \bar{M}_{1,2} \\
&= 2 k_{\{1,2\}} \varphi_2 - 6 k_{\{1,2\}} w_2 + \bar{M}_{1,2}
\end{aligned}$$

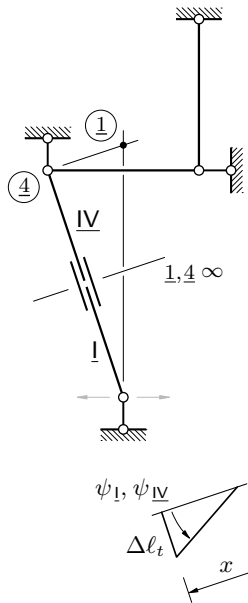
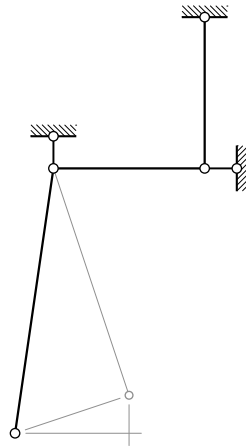
$$\begin{aligned}
M_{2,1} &= 4 k_{\{1,2\}} \varphi_2 - 6 k_{\{1,2\}} \psi_{\{1,2\}}^{(w_2)} - 6 k_{\{1,2\}} \psi_{\{1,2\}}^{(u_{\{2,3\}})} + \bar{M}_{2,1} \\
&= 4 k_{\{1,2\}} \varphi_2 - 6 k_{\{1,2\}} w_2 + \bar{M}_{2,1}
\end{aligned}$$

$$\begin{aligned}
M_{2,3} &= M_{2,3}^c = 3 k_{\{2,3\}} \varphi_2 - 3 k_{\{2,3\}} \psi_{\{2,3\}}^{(w_2)} - 3 k_{\{2,3\}} \psi_{\{2,3\}}^{(u_{\{2,3\}})} + \bar{M}_{2,3}^c \\
&= 3 k_{\{2,3\}} \varphi_2 - \frac{3}{2} k_{\{2,3\}} w_2 + \bar{M}_{2,3}^c
\end{aligned}$$

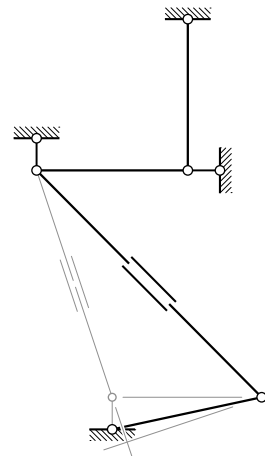
$$\begin{aligned}
M_{4,3} &= M_{4,3}^c = -3 k_{\{3,4\}} \psi_{\{3,4\}}^{(w_2)} - 3 k_{\{3,4\}} \psi_{\{3,4\}}^{(u_{\{2,3\}})} + \bar{M}_{4,3}^c \\
&= -\frac{3}{2} k_{\{3,4\}} u_{\{2,3\}} + \bar{M}_{4,3}^c
\end{aligned}$$



$$\begin{aligned}
\psi_{\{1,2\}}^{(\bar{w}_1)} &= \psi_{\underline{1}} = -\frac{\bar{w}_1}{1} \\
&= -0,003 \\
\psi_{\{2,3\}}^{(\bar{w}_1)} &= \psi_{\{3,4\}} = 0
\end{aligned}$$



$$\begin{aligned}
\frac{x}{1} &= \frac{\ell_{\{1,2\}}}{3} \Rightarrow x = \frac{\ell_{\{1,2\}}}{3} \\
\psi_{\{1,2\}}^{(t_s)} &= \psi_{\underline{1}} = \frac{\Delta \ell_t}{x} \\
&= \frac{3 \Delta \ell_t}{\ell_{\{1,2\}}} = 0,000630 \\
\psi_{\{2,3\}}^{(t_s)} &= \psi_{\{3,4\}} = 0
\end{aligned}$$



$$\begin{aligned}\bar{M}_{1,2} &= \bar{M}_{1,2}^{(\bar{w}_1)} + \bar{M}_{1,2}^{(t_s)} = -6 k_{\{1,2\}} \psi_{\{1,2\}}^{(\bar{w}_1)} - 6 k_{\{1,2\}} \psi_{\{1,2\}}^{(t_s)} \\ &= -6 \cdot 102\,458 \cdot (-0,003) - 6 \cdot 102\,458 \cdot 0,000\,63 = 1\,456,95 \text{ kNm}\end{aligned}$$

$$\bar{M}_{2,1} = \bar{M}_{1,2} = 1\,456,95 \text{ kNm}$$

$$\begin{aligned}\bar{M}_{2,3}^c &= {}^c\bar{M}_{2,3}^{(\bar{w}_1)} + {}^c\bar{M}_{2,3}^{(t_s)} + {}^c\bar{M}_{2,3}^{(M)} \\ &= -3 k_{\{2,3\}} \psi_{\{2,3\}}^{(\bar{w}_1)} - 3 k_{\{2,3\}} \psi_{\{2,3\}}^{(t_s)} + \frac{M}{8} = \frac{-360}{8} = -45 \text{ kNm}\end{aligned}$$

$$\bar{M}_{4,3}^c = {}^c\bar{M}_{4,3}^{(\bar{\varphi}_4)} = -3 k_{\{3,4\}} \bar{\varphi}_4 = -3 \cdot 81\,000 \cdot (-0,000\,6) = -145,80 \text{ kNm}$$

jednadžba ravnoteže momenata u čvoru 2:

$$-M_{2,1} - M_{2,3} = 0 \quad \Rightarrow \quad M_{2,1} + M_{2,3} = 0$$

$$\left[4 k_{\{1,2\}} \varphi_2 - 6 k_{\{1,2\}} w_2 + \bar{M}_{2,1} \right] + \left[3 k_{\{2,3\}} \varphi_2 - \frac{3}{2} k_{\{2,3\}} w_2 + \bar{M}_{2,3}^c \right] = 0$$

$$(4 k_{\{1,2\}} + 3 k_{\{2,3\}}) \varphi_2 + \left(-6 k_{\{1,2\}} - \frac{3}{2} k_{\{2,3\}} \right) w_2 = -\bar{M}_{2,1} - \bar{M}_{2,3}^c$$

$$652\,832 \cdot \varphi_2 - 736\,248 \cdot w_2 = -1\,411,95 \quad (\text{---b})$$

jednadžba rada na virtualnom pomaku δw_2 :

$$(M_{1,2} + M_{2,1}) \delta \psi_{\{1,2\}}^{(\delta w_2)} + M_{2,3} \delta \psi_{\{2,3\}}^{(\delta w_2)} + M_{4,3} \delta \psi_{\{3,4\}}^{(\delta w_2)} + (-M) \delta \psi_{\{2,3\}}^{(\delta w_2)} = 0$$

$$\begin{aligned}&(6 k_{\{1,2\}} \varphi_2 - 12 k_{\{1,2\}} w_2 + \bar{M}_{1,2} + \bar{M}_{2,1}) \delta w_2 \\ &+ \left(3 k_{\{2,3\}} \varphi_2 - \frac{3}{2} k_{\{2,3\}} w_2 + \bar{M}_{2,3}^c \right) \frac{\delta w_2}{2} - M \frac{\delta w_2}{2} = 0\end{aligned}$$

$$\left(6 k_{\{1,2\}} + \frac{3}{2} k_{\{2,3\}} \right) \varphi_2 - \left(12 k_{\{1,2\}} + \frac{3}{4} k_{\{2,3\}} \right) w_2 = -\bar{M}_{1,2} - \bar{M}_{2,1} - \frac{1}{2} (\bar{M}_{2,3}^c - M)$$

$$736\,248 \varphi_2 - 1\,290\,246 w_2 = -2\,711,4 \quad | \quad \times (-1)$$

$$-736\,248 \varphi_2 + 1\,290\,246 w_2 = 2\,711,4 \quad (\text{---b})$$

jednadžba rada na virtualnom pomaku $\delta u_{2,3}$:

$$(M_{1,2} + M_{2,1}) \delta \psi_{\{1,2\}}^{(\delta u_{2,3})} + M_{2,3} \delta \psi_{\{2,3\}}^{(\delta u_{2,3})} + M_{4,3} \delta \psi_{\{3,4\}}^{(\delta u_{2,3})} + (-M) \delta \psi_{\{2,3\}}^{(\delta u_{2,3})} = 0$$

$$\left(-\frac{3}{2} k_{\{3,4\}} u_{\{2,3\}} + \bar{M}_{4,3}^c \right) \frac{\delta u_{2,3}}{2} = 0$$

$$-60\,750 u_{\{2,3\}} = 72,9 \quad | \quad \times (-1)$$

$$60\,750 u_{\{2,3\}} = -72,9 \quad (\text{---b})$$

rješenje sustava jednažbi ($\overline{\mathbf{K}}_{1,2}$), ($\overline{\mathbf{K}}_{2,3}$) & ($\overline{\mathbf{K}}_{3,4}$):

$$\text{iz } (\overline{\mathbf{K}}_{2,3}): u_{\{2,3\}} = -0,0012 \text{ m}$$

$$\text{iz } (\overline{\mathbf{K}}_{1,2}) \text{ \& } (\overline{\mathbf{K}}_{2,3}): \varphi_2 = 0,0005812 \text{ \& } w_2 = 0,002433 \text{ m}$$

vrijednosti momenata na krajevima štapova:

$$\begin{aligned} M_{1,2} &= k_{\{1,2\}} (2\varphi_2 - 6w_2) + \overline{M}_{1,2} \\ &= 102458 \cdot (2 \cdot 0,0005812 - 6 \cdot 0,002433) + 1456,95 = 80,37 \text{ kNm} \end{aligned}$$

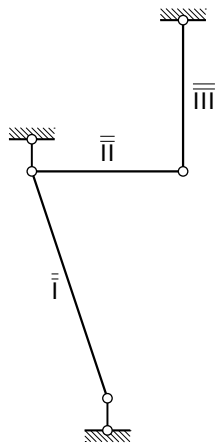
$$\begin{aligned} M_{2,1} &= k_{\{1,2\}} (4\varphi_2 - 6w_2) + \overline{M}_{1,2} \\ &= 102458 \cdot (4 \cdot 0,0005812 - 6 \cdot 0,002433) + 1456,95 = 199,46 \text{ kNm} \end{aligned}$$

$$\begin{aligned} M_{2,3} &= k_{\{2,3\}} \left(3\varphi_2 - \frac{3}{2}u_1 \right) + \overline{M}_{2,3}^c \\ &= 81000 \cdot \left(3 \cdot 0,0005812 - \frac{3}{2} \cdot 0,002433 \right) - 45 = -199,38 \text{ kNm} \end{aligned}$$

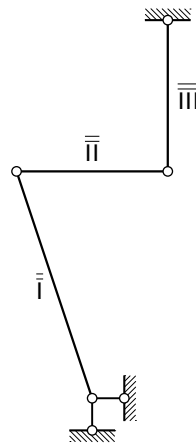
$$M_{4,3} = -\frac{3}{2} k_{\{3,4\}} u_{\{2,3\}} + \overline{M}_{4,3}^c = -\frac{3}{2} \cdot 81000 \cdot (-0,0012) - 145,80 = 0$$

momentni dijagram kao na stranici 7 (s neznatno drukčijim vrijednostima)

c.

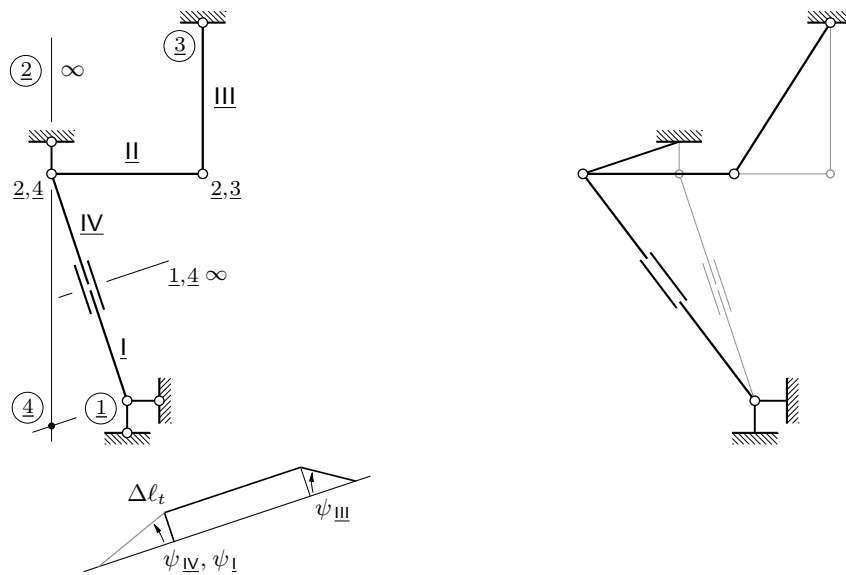
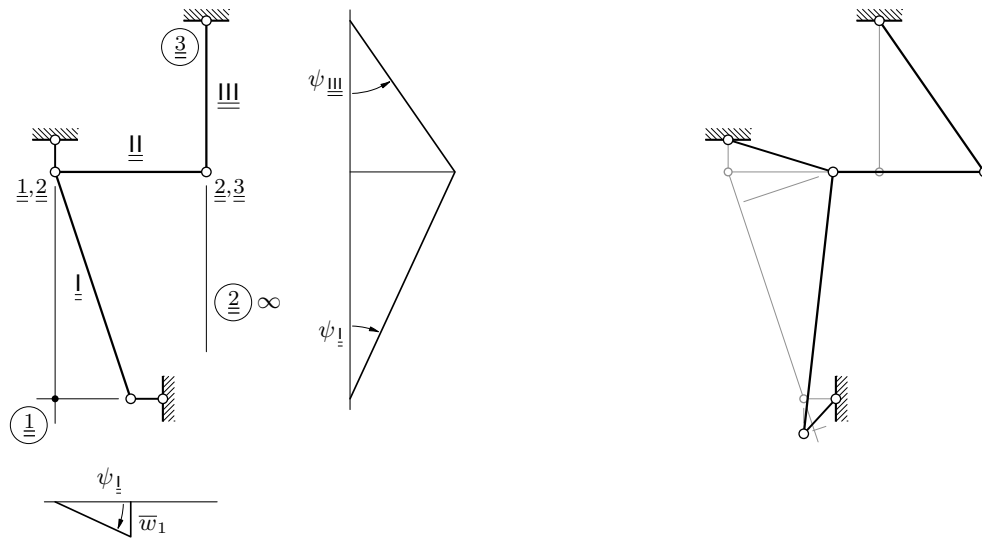


isti mehanizam kao za $\vec{u}_{\{2,3\}}$ u b.,
ali s drugim „vodećim” pomakom
— nastavite sami!



isti mehanizam kao za $\vec{u}_{\{2,3\}}$ u a.,
ali s drugim „vodećim” pomakom
— nastavite sami!

Prije no što okrenete stranicu, pokušajte sami nacrtati dijagrame projekcija pomakā i(li) planove pomakā za zadani prisilni pomak i za utjecaj promjene temperature!



Proračun provedite sami!