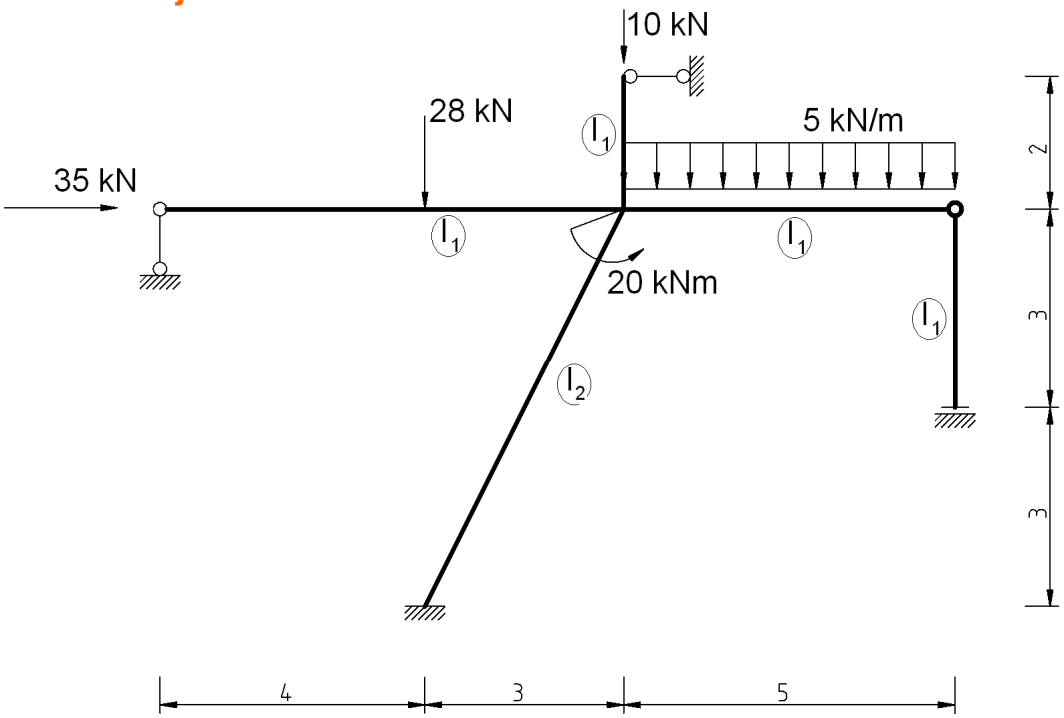
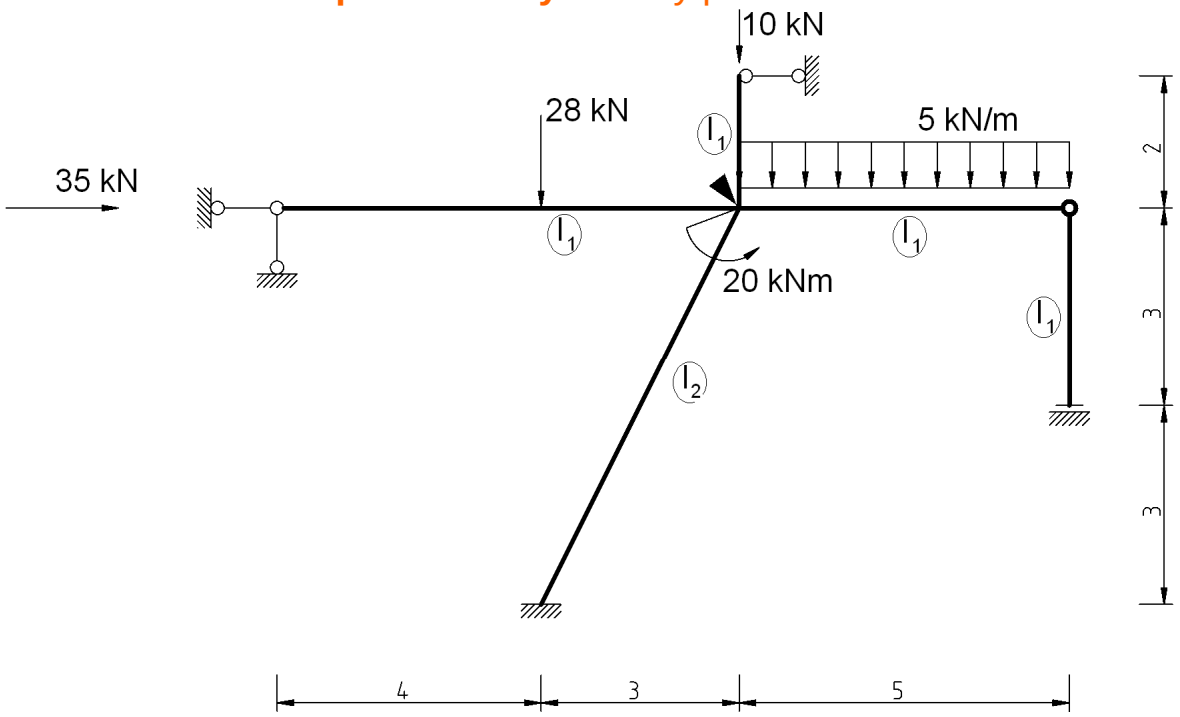
Metoda przemieszczeń

Wpływ obciążenia siłami

Schemat konstrukcji:



układ podstawowy metody przemieszczeń



SGN = 1 +1 = 2

Układ równań kanonicznych:

$$\begin{bmatrix} r_{11} & r_{12} \\ r_{21} & r_{22} \end{bmatrix} \cdot \begin{bmatrix} \varphi_1 \\ \Delta_2 \end{bmatrix} + \begin{bmatrix} r_{1p} \\ r_{2p} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

Współczynnik porównawczy sztywności
Przyjęto: I_1= I220 PE, I_2= I240 PE

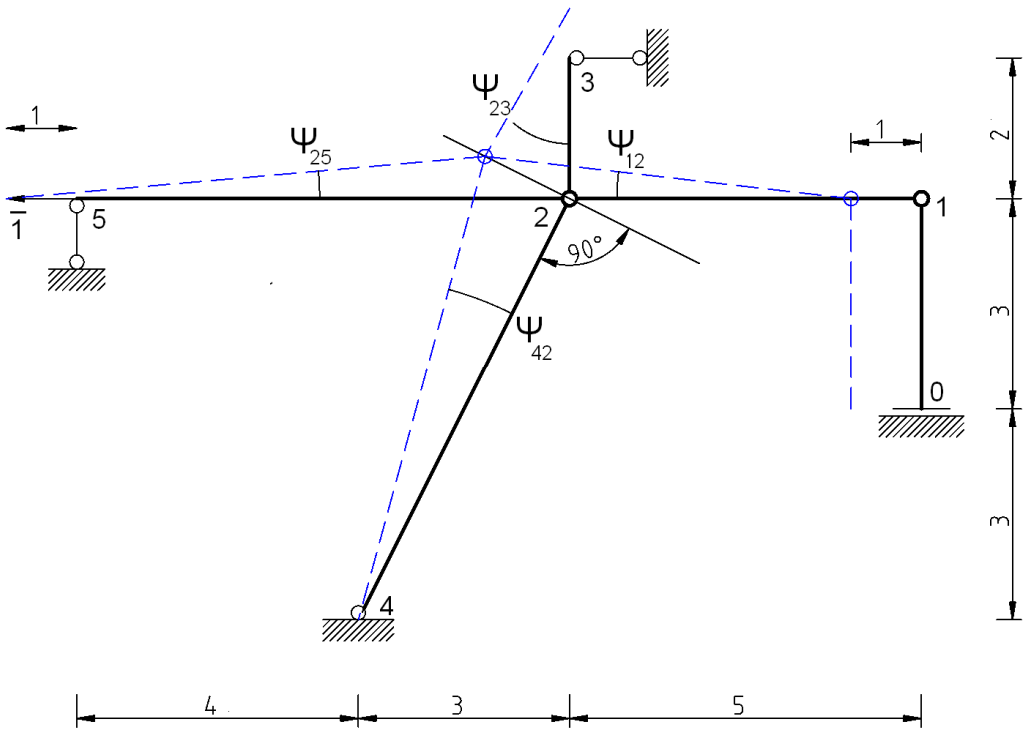
	h	b_f	t_w	t_f	r	A	G	I_x	$W_{el.x}$
	mm	mm	mm	mm	mm	cm^2	kg/m	cm^4	cm^3
I 220PE	220	110	5,9	9,2	12	33,40	26,2	2770,0	252,0
I 240PE	240	120	6,2	9,8	15	39,10	30,7	3890,0	324,0

$$EI_1 = 205 \cdot 10^5 \cdot 2770 \cdot 10^{-8} = 5678{,}5\ \mathrm{kNm}^2$$

$$EI_2 = 205 \cdot 10^5 \cdot 3890 \cdot 10^{-8} = 7974{,}5\ \mathrm{kNm}^2$$

$EI = EI_1 \quad \rightarrow \quad EI_2 = 1{,}404332EI$

Łańcuch kinematyczny:



$$\underline{\rightarrow 425} \quad 0 + 6 \cdot \Psi_{42} = -1 \quad \Rightarrow \quad \Psi_{42} = -\frac{1}{6}$$

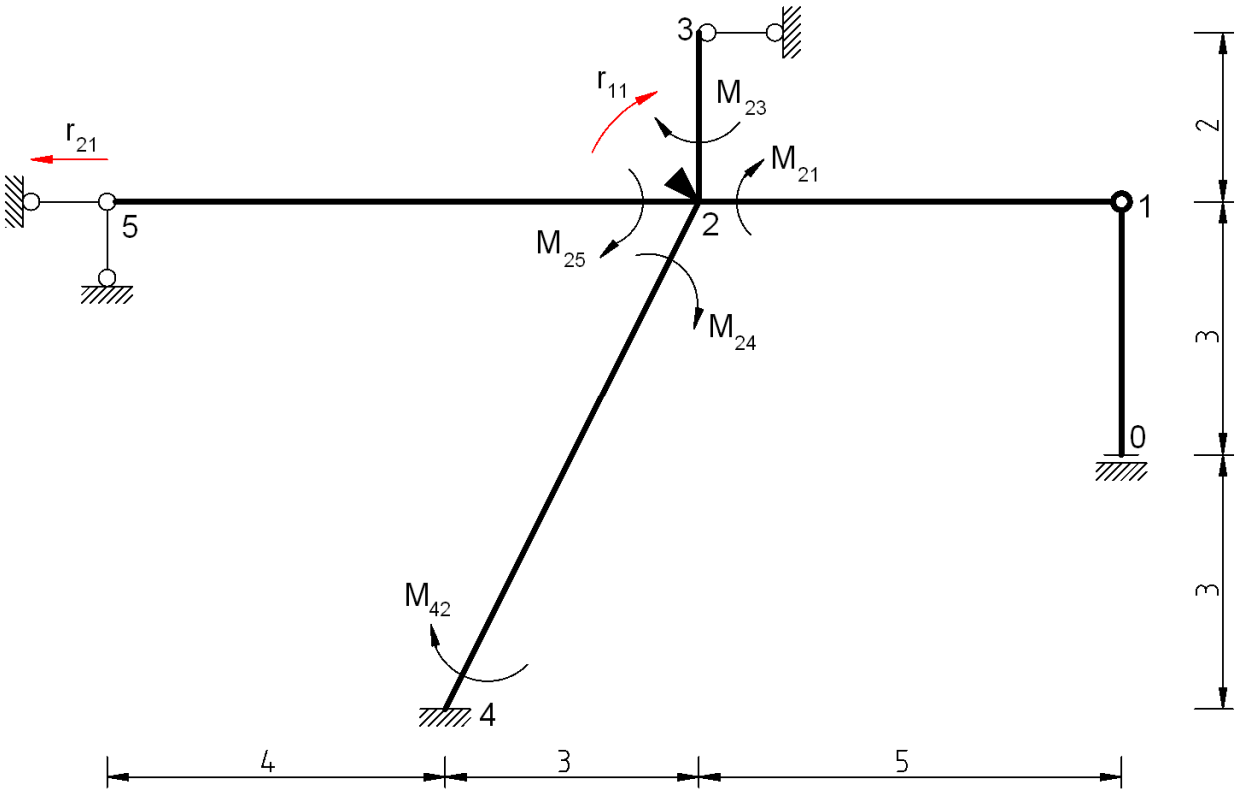
$$\underline{\rightarrow 325} \quad 0 - 2 \cdot \Psi_{23} = -1 \quad \Rightarrow \quad \Psi_{23} = \frac{1}{2}$$

$$\underline{\downarrow 425} \quad 0 + 3 \cdot \Psi_{42} - 7 \cdot \Psi_{25} = 0 \quad \Rightarrow \quad \Psi_{25} = -\frac{1}{14}$$

$$\underline{\downarrow 4210} \quad 0 + 3 \cdot \Psi_{42} + 5 \cdot \Psi_{12} = 0 \quad \Rightarrow \quad \Psi_{12} = \frac{1}{10}$$

$$\Psi_{01} = 0$$

Stan $\varphi_1 = 1$



$$M_{42} = \frac{2EI_2}{l} = \frac{2EI}{\sqrt{45}} = 0{,}41863EI$$

$$M_{24} = \frac{4EI_2}{l} = \frac{4EI}{\sqrt{45}} = 0{,}83727EI$$

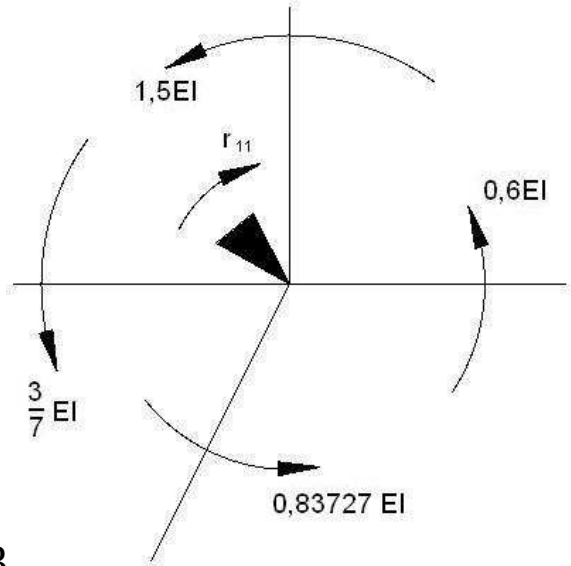
$$M_{25} = \frac{3EI_1}{l} = \frac{3}{7}EI$$

$$M_{23} = \frac{3EI_1}{l} = \frac{3}{2}EI$$

$$M_{21} = \frac{3EI_1}{l} = \frac{3}{5}EI$$

$$M_{01} = 0$$

Węzeł 2:



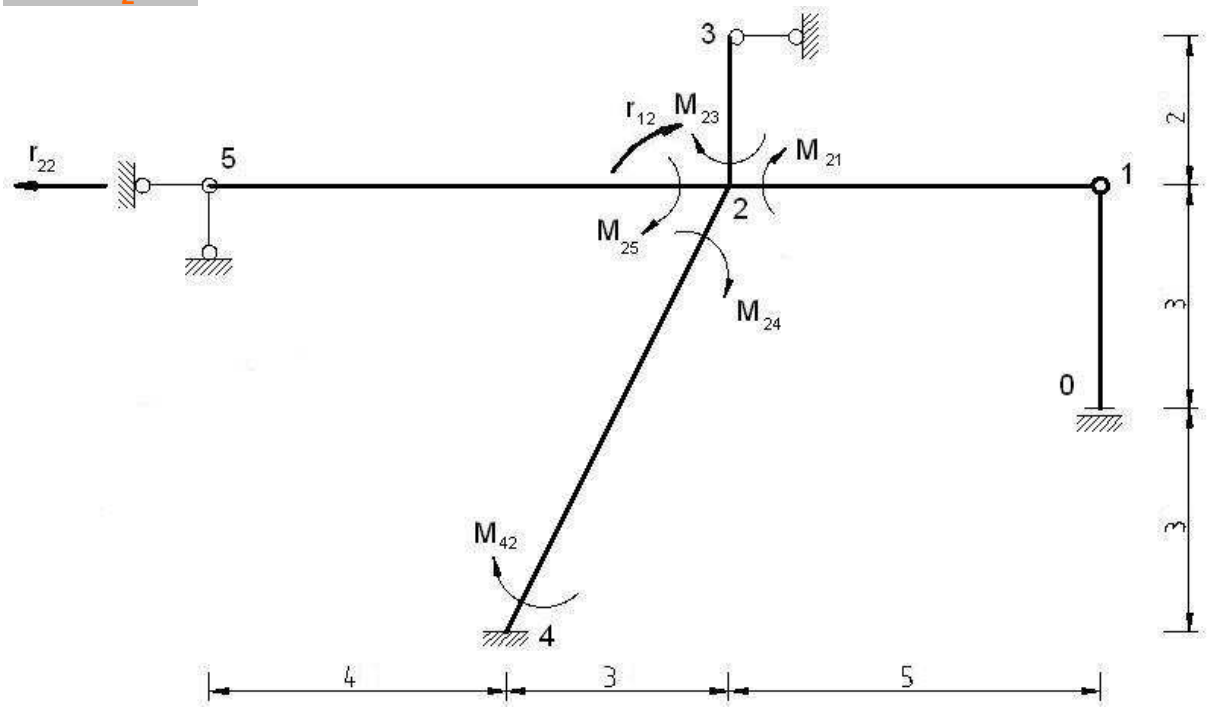
$$r_{11} = 1{,}5EI + 0{,}6EI + 0{,}83727EI + \frac{3}{7}EI = 3{,}36584EI$$

RPW

$$\overline{1} \cdot r_{21} + M_{23} \cdot \overline{\Psi}_{23} + M_{21} \cdot \overline{\Psi}_{12} + M_{24} \cdot \overline{\Psi}_{42} + M_{42} \cdot \overline{\Psi}_{42} + M_{25} \cdot \overline{\Psi}_{25} = 0$$

$$r_{21} = -0{,}57007EI$$

Stan $\Delta_2 = 1$



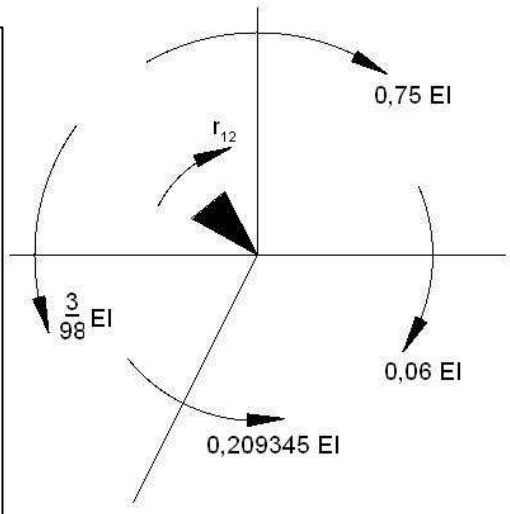
$$M_{23} = \frac{-3EI_1}{l} \cdot \Psi_{23} = \frac{-3}{2} \cdot \frac{1}{2} EI = -0{,}75EI$$

$$M_{21} = \frac{-3EI_1}{l} \cdot \Psi_{12} = \frac{-3}{5} \cdot \frac{1}{10} EI = -0{,}06EI$$

$$M_{25} = \frac{-3EI_1}{l} \cdot \Psi_{25} = \frac{-3}{7}\left(-\frac{1}{14}\right) EI = \frac{3}{98} EI$$

$$M_{24} = \frac{-6EI_2}{l} \cdot \Psi_{24} = \frac{-6}{\sqrt{45}} \cdot \frac{-1{,}404332}{6} EI = 0{,}2093454EI$$

$$M_{42} = \frac{-6EI_2}{l} \cdot \Psi_{24} = \frac{-6}{\sqrt{45}} \cdot \frac{-1{,}404332}{6} EI = 0{,}2093454EI$$



RPW

$$1 \cdot r_{22} + M_{23} \cdot \overline{\Psi}_{23} + M_{21} \cdot \overline{\Psi}_{12} + M_{24} \cdot \overline{\Psi}_{42} + M_{42} \cdot \overline{\Psi}_{42} + M_{25} \cdot \overline{\Psi}_{25} = 0$$

$$r_{22} + \frac{-3}{4} \cdot \frac{1}{2} EI + \frac{-3}{50} \cdot \frac{1}{10} EI + 2 \cdot 0{,}2093454 \cdot \left(-\frac{1}{6} EI\right) + \frac{3}{98} \cdot \left(-\frac{1}{14}\right) = 0$$

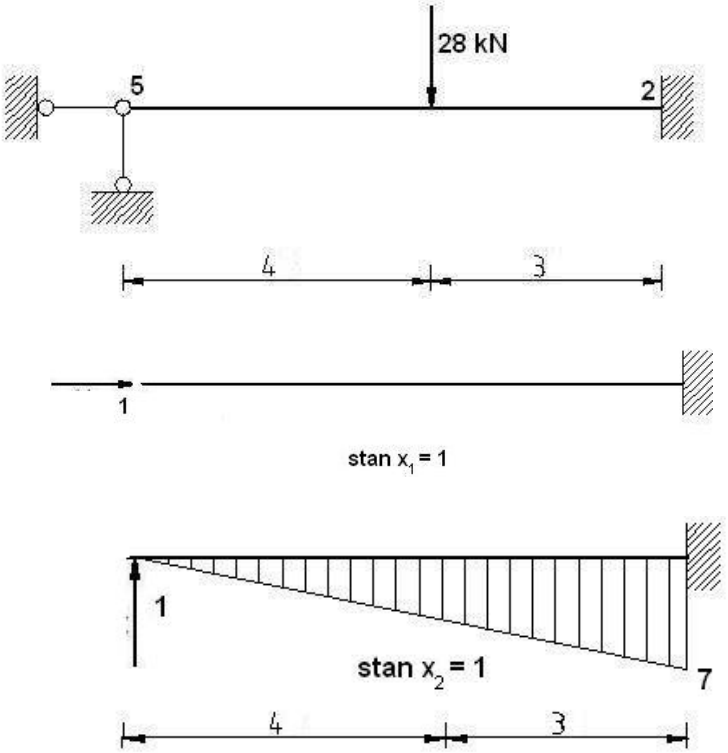
$$r_{22} = 0{,}452968\, EI$$

$$r_{12} = -0{,}75EI - 0{,}06EI + 0{,}209345\, EI + \frac{3}{98} EI = -0{,}57004\, EI$$

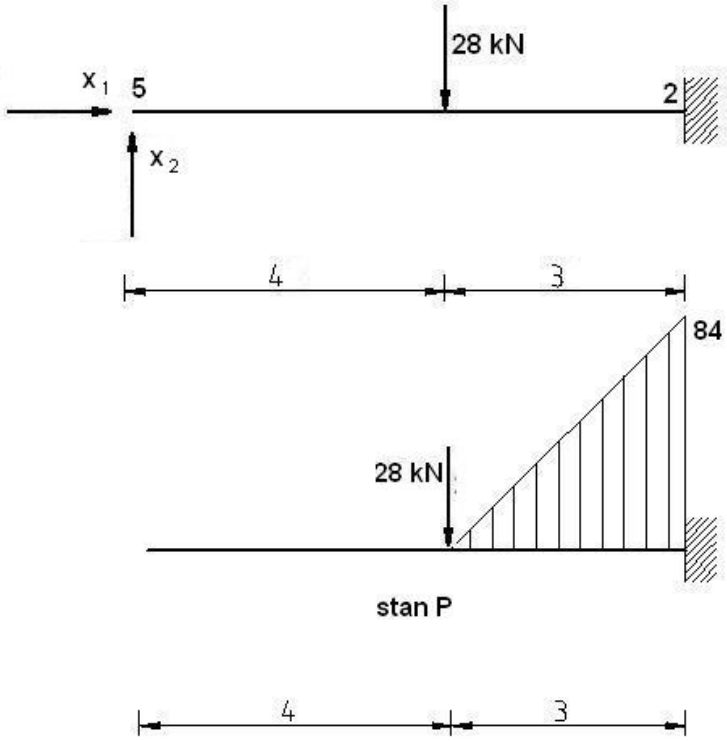
Stan p

a) Obliczenie belki 5-2 statycznie niewyznaczalnej z siłą skupioną nie znajdującą się w środku ciężkości (metodą sił):

U.RZ.



U.P.



$$\delta_{11} \cdot x_1 + \delta_{12} \cdot x_2 + \delta_{1p} = 0$$

$$\delta_{21} \cdot x_1 + \delta_{22} \cdot x_2 + \delta_{2p} = 0$$

$$\delta_{11} = \sum \int_x \frac{M_1^2}{EI} dx = 0$$

$$\delta_{12} = \sum \int_x \frac{M_1 \cdot M_2}{EI} dx = 0$$

$$\delta_{21} = \sum \int_x \frac{M_2 \cdot M_1}{EI} dx = \delta_{12} = 0$$

$$\delta_{22} = \sum \int_x \frac{M_2^2}{EI} dx = \frac{1}{EI}\left(\frac{1}{2} \cdot 7 \cdot 7 \cdot \frac{2}{3} \cdot 7\right) = \frac{114{,}333}{EI}$$

$$\delta_{1p} = \sum \int_x \frac{M_1 \cdot M_p}{EI} dx = 0$$

$$\delta_{2p} = \sum \int_x \frac{M_2 \cdot M_p}{EI} dx = \frac{1}{EI}\left[-\frac{1}{2} \cdot 84 \cdot 3 \cdot \left(\frac{1}{3} \cdot 4 + \frac{2}{3} \cdot 7\right)\right] = \frac{-756}{EI}$$

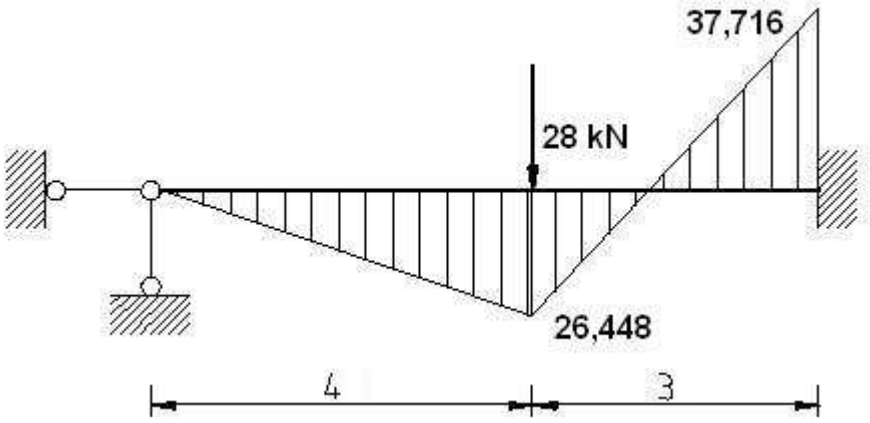
$$\delta_{11} \cdot x_1 + \delta_{12} \cdot x_2 + \delta_{1p} = 0$$

$$\delta_{21} \cdot x_1 + \delta_{22} \cdot x_2 + \delta_{2p} = 0$$

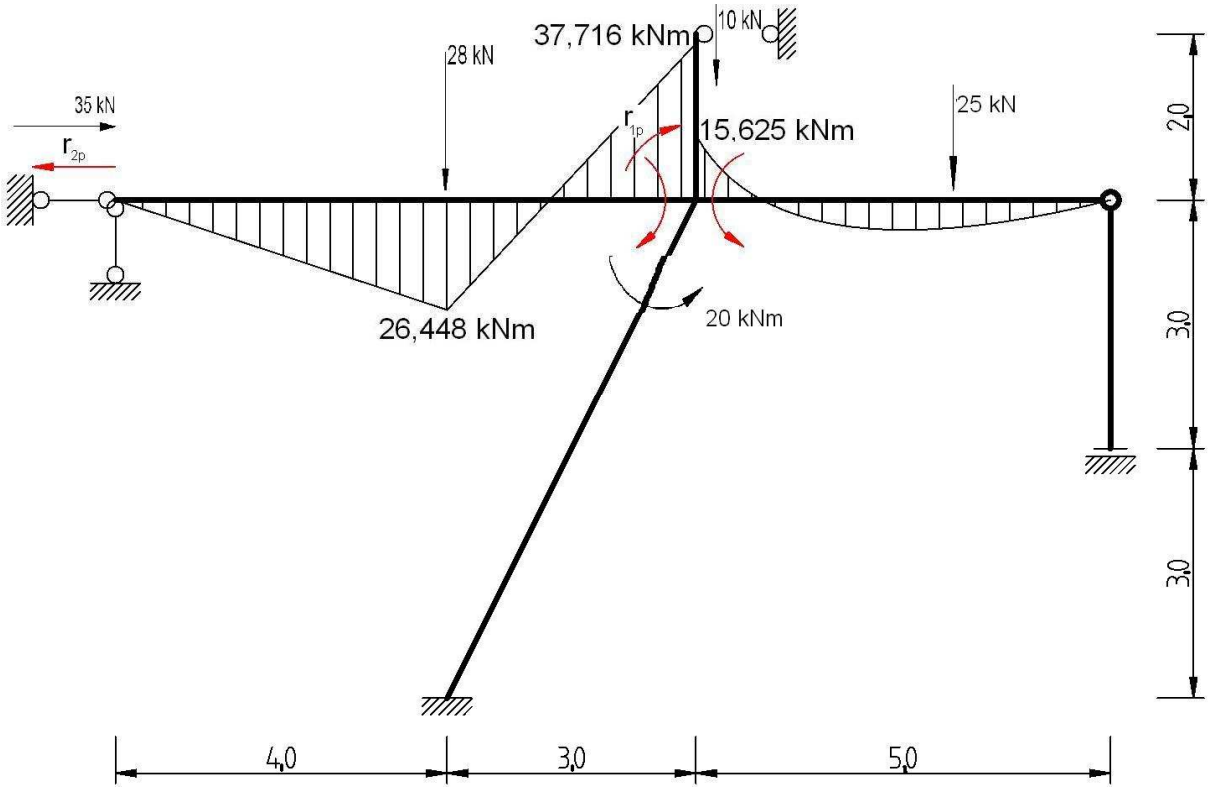
$$x_1 = 0$$

$$x_2 = 6{,}612 \text{ kN}$$

Wykres momentów zginających na belce 5-2

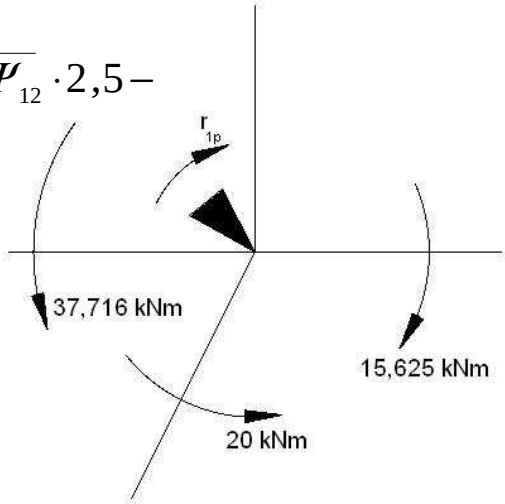


Wykres stanu „p" metody przemieszczeń:



RPW

$$\overline{1}\cdot r_{2p} - 15,625\cdot\overline{\Psi}_{12} + 37,716\cdot\overline{\Psi}_{25} - 35\cdot 1 - 25\cdot\overline{\Psi}_{12}\cdot 2,5 -$$
$$-10\cdot\overline{\Psi}_{12}\cdot 5 - 28\cdot\overline{\Psi}_{25}\cdot 4 = 0$$
$$r_{2p} = 58,5065 \quad \text{kN}$$



$$r_{1p} + 15,625 - 20 - 37,716 = 0$$
$$r_{1p} = 42,091\,\text{kNm}$$

Rozwiązanie układu równań kanonicznych

$$\begin{bmatrix} r_{11} & r_{12} \\ r_{21} & r_{22} \end{bmatrix} \cdot \begin{bmatrix} \varphi_1 \\ \Delta_2 \end{bmatrix} + \begin{bmatrix} r_{1p} \\ r_{2p} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} 3{,}36584 & -0{,}57007 \\ -0{,}57007 & 0{,}452968 \end{bmatrix} EI \cdot \begin{bmatrix} \varphi_1 \\ \Delta_2 \end{bmatrix} + \begin{bmatrix} 42{,}091 \\ 58{,}5065 \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$\varphi_1 = \frac{-43.695412}{EI} rad$$

$$\Delta_2 = \frac{-184.15416}{\mathrm{EI}} \mathrm{m}$$

Wyznaczenie momentów zginających metodą superpozycji

$$M_p^{(n)} = M_1 \cdot \varphi_1 + M_2 \cdot \Delta_2 + M_p$$

$$M_{01} = 0$$

$$M_{21} = \frac{3}{5} EI \cdot \frac{-43.695412}{EI} - 0{,}06 EI \cdot \frac{-184.15416}{\mathrm{EI}} - 15{,}625 = -30{,}793 \,\mathrm{kNm}$$

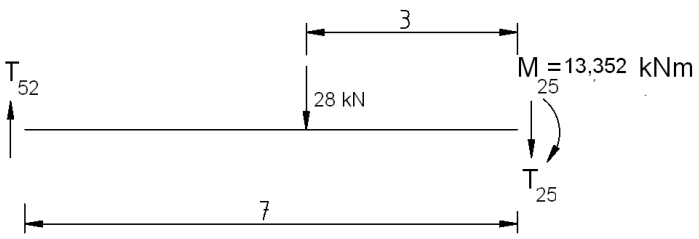
$$M_{23} = \frac{3}{2} EI \cdot \frac{-43.695412}{EI} - 0{,}75 EI \cdot \frac{-184.15416}{\mathrm{EI}} = 72{,}573 \,\mathrm{kNm}$$

$$M_{25} = \frac{3}{7} EI \cdot \frac{-43.695412}{EI} + \frac{3}{98} EI \cdot \frac{-184.15416}{\mathrm{EI}} + 37{,}716 = 13{,}352 \,\mathrm{kNm}$$

$$M_{24} = 0{,}83727 EI \cdot \frac{-43.695412}{EI} + 0{,}2093454 EI \cdot \frac{-184.15416}{\mathrm{EI}} = -75{,}136 \,\mathrm{kNm}$$

$$M_{42} = 0{,}41863 EI \cdot \frac{-43.695412}{EI} + 0{,}2093454 EI \cdot \frac{-184.15416}{\mathrm{EI}} = -56{,}844 \,\mathrm{kNm}$$

WYZNACZENIE WARTOŚCI SIŁ TNĄCYCH



$$\sum M_2 = 0$$

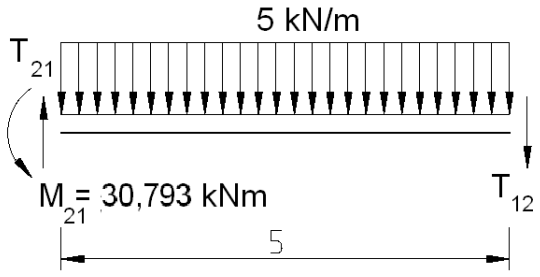
$$T_{52} \cdot 7 - 28 \cdot 3 + 13{,}352 = 0$$

$$T_{52} = 10{,}093 \,\mathrm{kN}$$

$$\sum \mathrm{Y} = 0$$

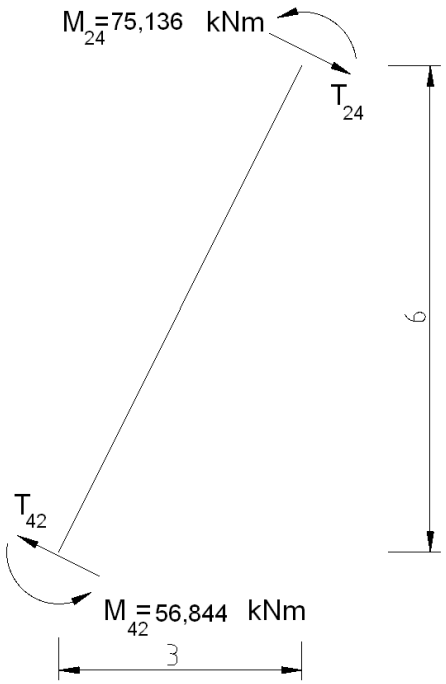
$$T_{52} - 28 - T_{25} = 0$$

$$T_{25} = -17{,}907 \,\mathrm{kN}$$

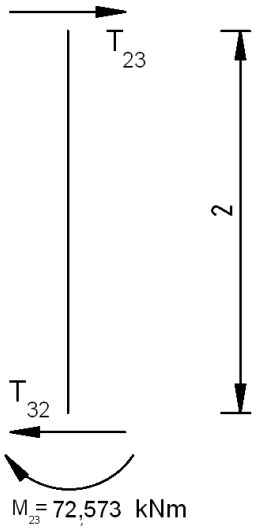


$$\sum M_1 = 0$$
$$T_{21} \cdot 5 - 30{,}793 - 5 \cdot 5 \cdot 2{,}5 = 0$$
$$T_{21} = 18{,}6586 \text{ kN}$$

$$\sum M_2 = 0$$
$$T_{12} \cdot 5 - 30{,}793 + 5 \cdot 5 \cdot 2{,}5 = 0$$
$$T_{12} = -6{,}3414 \text{ kN}$$



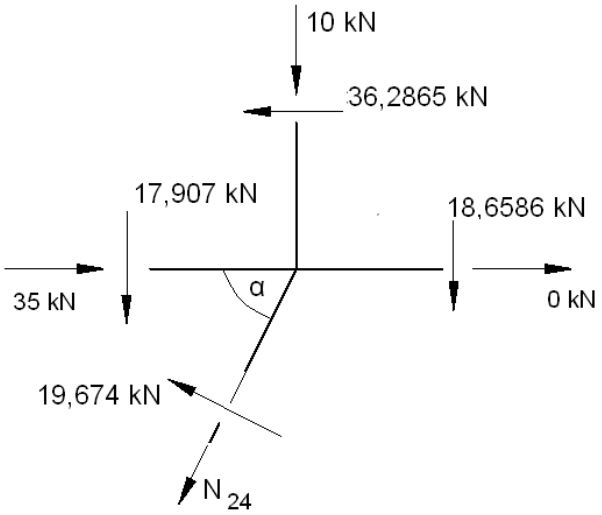
$$\sum M_2 = 0$$
$$75{,}136 + 56{,}844 - T_{42} \cdot \sqrt{45} = 0$$
$$T_{42} = 19{,}674 \text{ kN}$$
$$T_{24} = T_{42} = 19{,}674 \text{ kN}$$



$$\sum M_3 = 0$$
$$72{,}573 + T_{23} \cdot 2 = 0$$
$$T_{23} = -36{,}2865 \text{ kN}$$
$$T_{32} = T_{23} = -36{,}2865 \text{kN}$$

WYZNACZENIE SIŁ NORMALNYCH

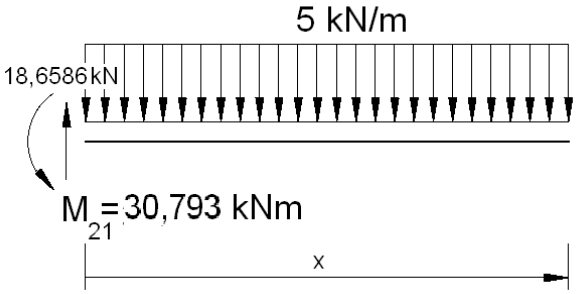
Z równowagi węzła „3” wynika że N_{32} = -10 kN, $N_{23}=N_{32}$= -10 kN
Z równowagi węzła „5” wynika że N_{52} = -35 kN, $N_{25}=N_{52}$= -35 kN



$$\sin\alpha = 0{,}89442$$
$$\cos\alpha = 0{,}447213$$

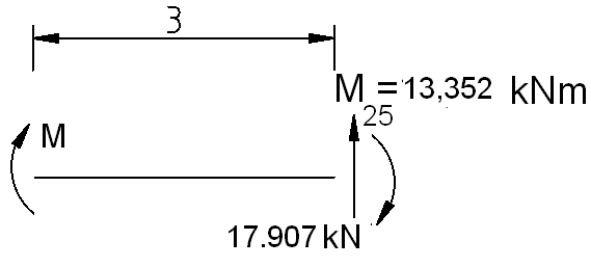
$$\sum Y = 0$$
$$10 + 17{,}907 + 18{,}6586 - 19{,}674 \cdot \cos\alpha -$$
$$- N_{24} \cdot \sin\alpha = 0$$
$$N_{24} = 42{,}2253 kN$$
$$N_{42} = N_{24} = 42{,}2253 kN$$

Wyznaczenie momentu maksymalnego pod obciążeniem ciągłym

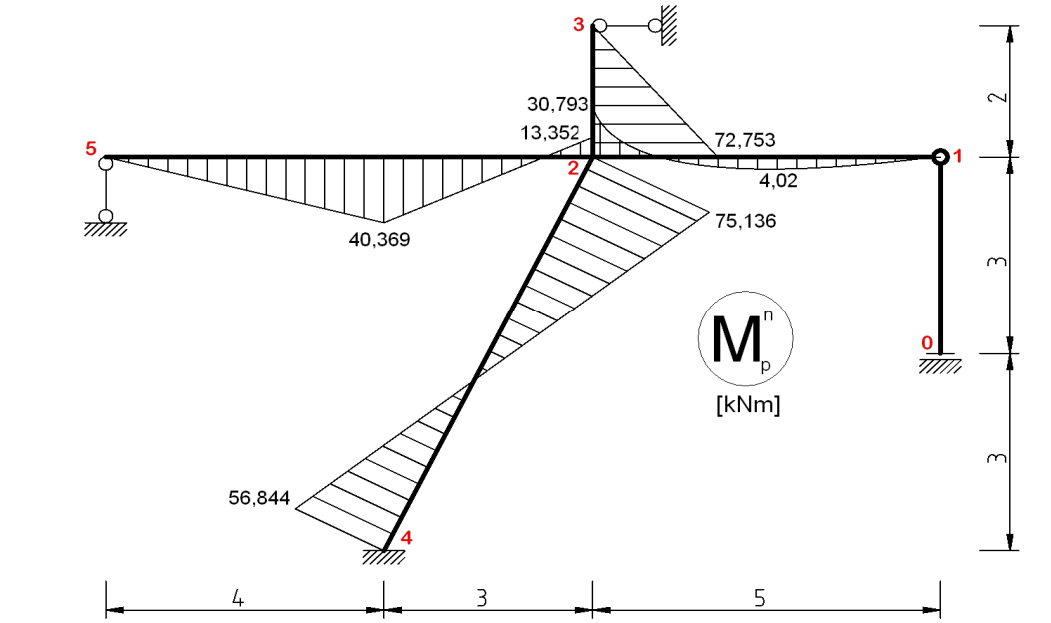


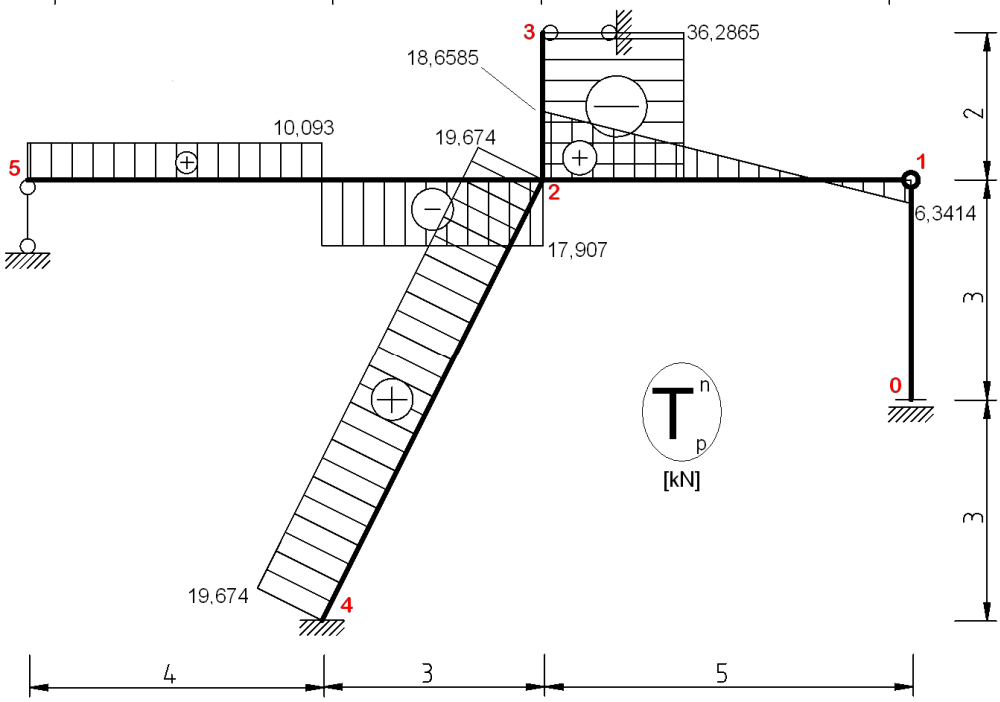
$$T(x) = 18{,}6586 - 5 \cdot x$$
$$18{,}6586 - 5 \cdot x = 0$$
$$x = 3{,}73172 m$$
$$-5 \cdot \frac{x^2}{2} + 18{,}6586 \cdot x - 30{,}793 = M(x)$$
$$M_{max} = 4{,}0213 \text{ kNm}$$

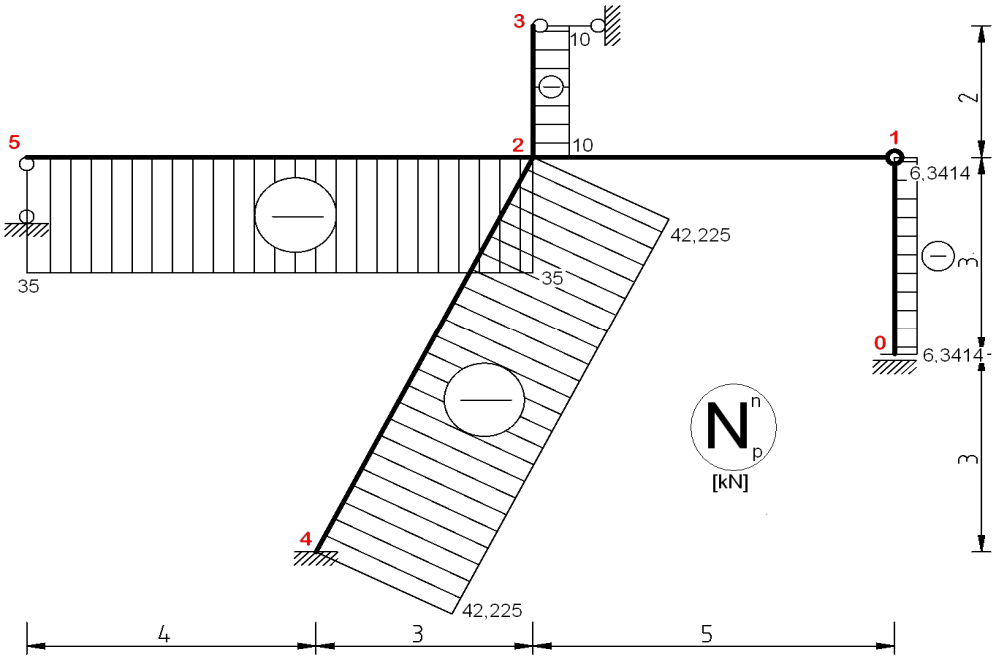
Wyznaczenie momentu pod siłą skupioną dla belki 2-5



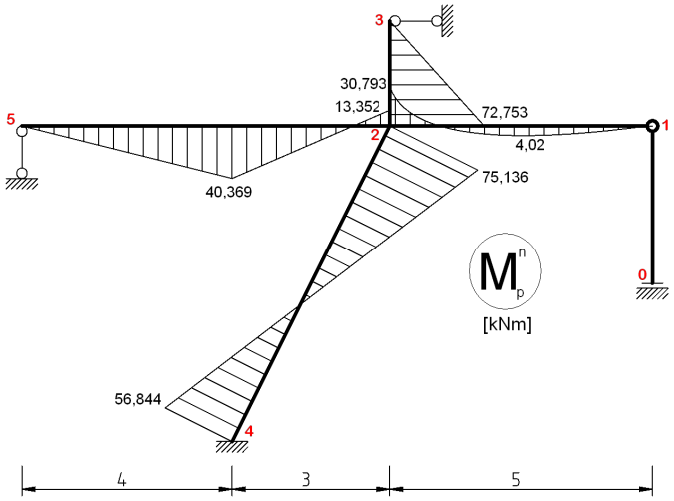
$$M = 13{,}352 - 17{,}907 \cdot 3 =$$
$$= -40{,}369 \text{ kNm}$$

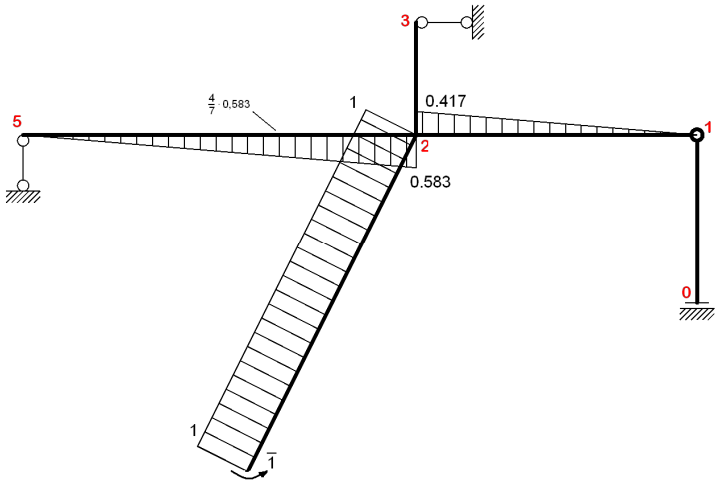

3
30,793
13,352
72,753
4,02
5
2
1
40,369
75,136
0
56,844
4
2
3
3
4
3
5
M
n
p
[kNm]


3
36,2865
18,6585
10,093
19,674
5
1
2
6,3414
17,907
0
19,674
4
2
3
3
4
3
5
T
n
p
[kN]


3
10
5
2
10
1
6,3414
42,225
35
35
0
6,3414
4
42,225
2
3
3
4
3
5
N
n
p
[kN]

Sprawdzenie kinematyczne





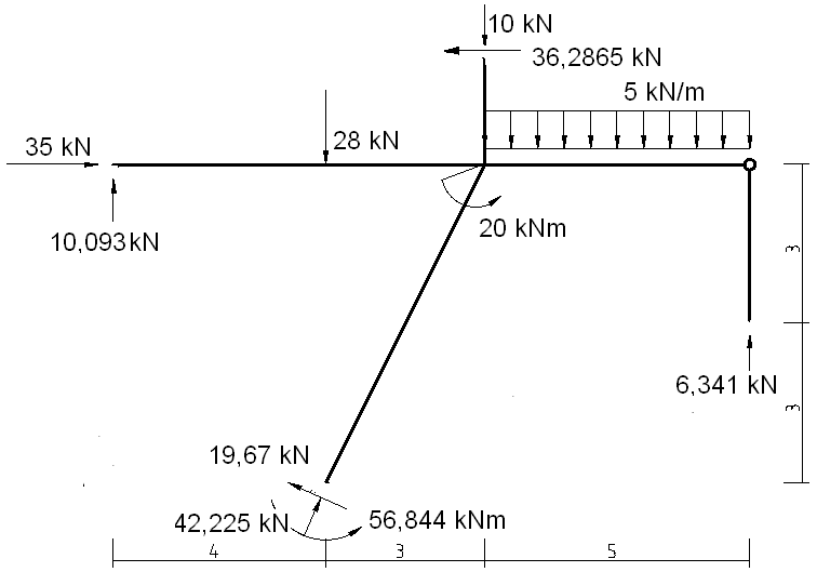
$$\bar{1}\cdot\delta = \frac{1}{EI_2}\left[\frac{1}{2}\cdot\sqrt{45}\cdot 56{,}844\cdot 1-\frac{1}{2}\cdot 75{,}136\cdot\sqrt{45}\cdot 1\right]+$$

$$\frac{1}{EI}\left[\frac{1}{2}\cdot 40{,}369\cdot 4\cdot\frac{2}{3}\cdot\left(\frac{4}{7}\cdot 0{,}583\right)+\frac{1}{2}\cdot 40{,}369\cdot 3\cdot\left(\frac{2}{3}\cdot\frac{4}{7}\cdot 0{,}583+\frac{1}{3}\cdot 0{,}583\right)-\right.$$

$$\left.-\frac{1}{2}\cdot 13{,}352\cdot 3\cdot\left(\frac{1}{3}\cdot\frac{4}{7}\cdot 0{,}583+\frac{2}{3}\cdot 0{,}583\right)+\frac{1}{2}\cdot 30{,}794\cdot 5\cdot\frac{2}{3}\cdot 0{,}417-\frac{2}{3}\cdot\frac{5\cdot 5^2}{8}5\cdot\frac{1}{2}\cdot 0{,}417\right]=$$

$$=\frac{-61{,}353}{1{,}404332\,EI}+\frac{43{,}75886}{EI}=\frac{0{,}07}{EI}\approx 0$$

Sprawdzenie statyczne



$$\sum X = 0$$

$$35-36{,}2865-19{,}67\cdot 0{,}89442+42{,}225\cdot 0{,}447213=0{,}0038\approx 0$$

$$\sum Y = 0$$

$$10{,}093-28-10-5\cdot 5+6{,}341+42{,}225\cdot 0{,}89442+19{,}67\cdot 0{,}447213=0{,}0024\approx 0$$

$$\sum M_4 = 0$$

$$35\cdot 6+10{,}093\cdot 4+10\cdot 3-36{,}28\cdot 8+25\cdot 5{,}5-6{,}341\cdot 8-56{,}844-20=0$$

Sprawdzenie naprężeń normalnych wywołanych momentem zginającym

a) M_{max} = 72,8 kNm dla zaprojektowanego **I_1** o W = 194 cm^3 (IPE200)

$$\frac{7275{,}3\,\text{kNcm}}{194\,\text{cm}^3} = 37{,}5015\,\frac{\text{kN}}{\text{cm}^2}$$
$$\delta_{\max} = 375\,\text{MPa} \geq \delta_{\text{dop}} = 205\,\text{MPa}$$

b) M_{max} = 75,1 kNm dla zaprojektowanego **I_2** o W = 324 cm^3 (IPE240)

$$\frac{7513{,}6\,\text{kNcm}}{324\,\text{cm}^3} = 23{,}19\,\frac{\text{kN}}{\text{cm}^2}$$
$$\delta_{\max} = 232\,\text{MPa} \geq \delta_{\text{dop}} = 205\,\text{MPa}$$

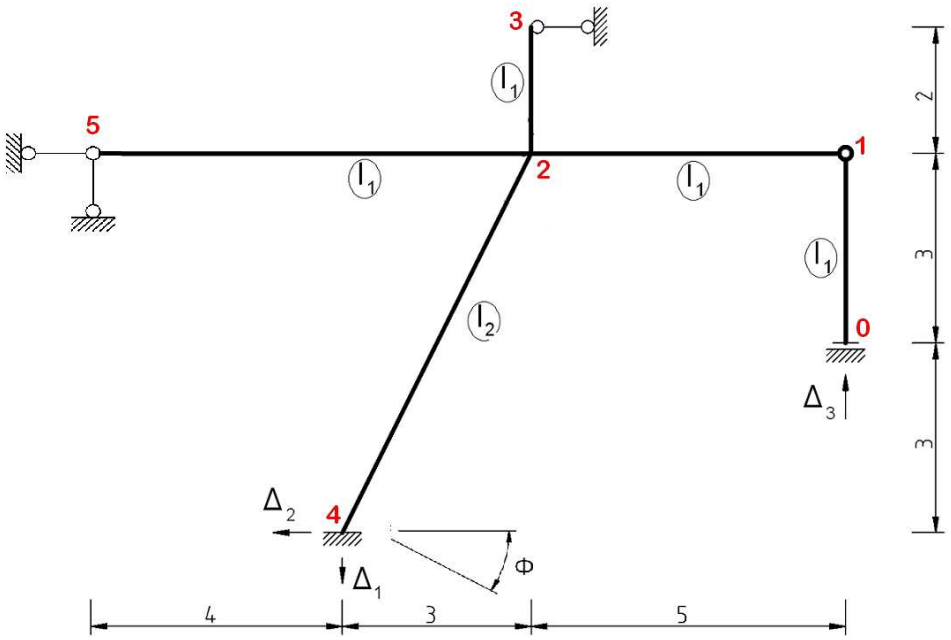
Wnioski:

- Oba przekroje okazały się zbyt małe dla danego obciążenia zewnętrznego.
- Należałoby wprowadzić przekroje znaczenie większe (np. IPE 280) i ponownie obliczyć układ statycznie niewyznaczalny.
- Jeżeli zostawimy wybrane przekroje prawdopodobnie doprowadzi to do katastrofy budowlanej.
- Dla obciążenia wypadkowego od osiadania oraz sił oczywiście dane przekroje również nie wystarczą.

Wpływ osiadania podpór

$$K = \begin{bmatrix} 3{,}36584 & -0{,}57007 \\ -0{,}57007 & 0{,}452968 \end{bmatrix} EI$$

Stan Δ



Δ_1 = 0,7 cm
Δ_2 = 1,1 cm
Δ_3 = 1,4 cm
$\Phi = 1{,}5^0$ =
=0,0261799 rad

$\rightarrow 524 \qquad 0 - \Psi_{24}^{\Delta} \cdot 6 = -0{,}011 \qquad \Psi_{24}^{\Delta} = 0{,}0018333\ rad$

$\rightarrow 423 \qquad -0{,}011 + \Psi_{24}^{\Delta} \cdot 6 + \Psi_{23}^{\Delta} \cdot 2 = 0 \qquad \Psi_{23}^{\Delta} = 0\ rad$

$\downarrow 4210 \qquad 0{,}007 + \Psi_{24}^{\Delta} \cdot 3 + \Psi_{21}^{\Delta} \cdot 5 = -0{,}014 \qquad \Psi_{21}^{\Delta} = -0{,}0053\ rad$

$\downarrow 5210 \qquad 0 + \Psi_{52}^{\Delta} \cdot 7 + \Psi_{21}^{\Delta} \cdot 5 = -0{,}014 \qquad \Psi_{52}^{\Delta} = 0{,}0017857\ rad$

$$M_{01} = 0$$

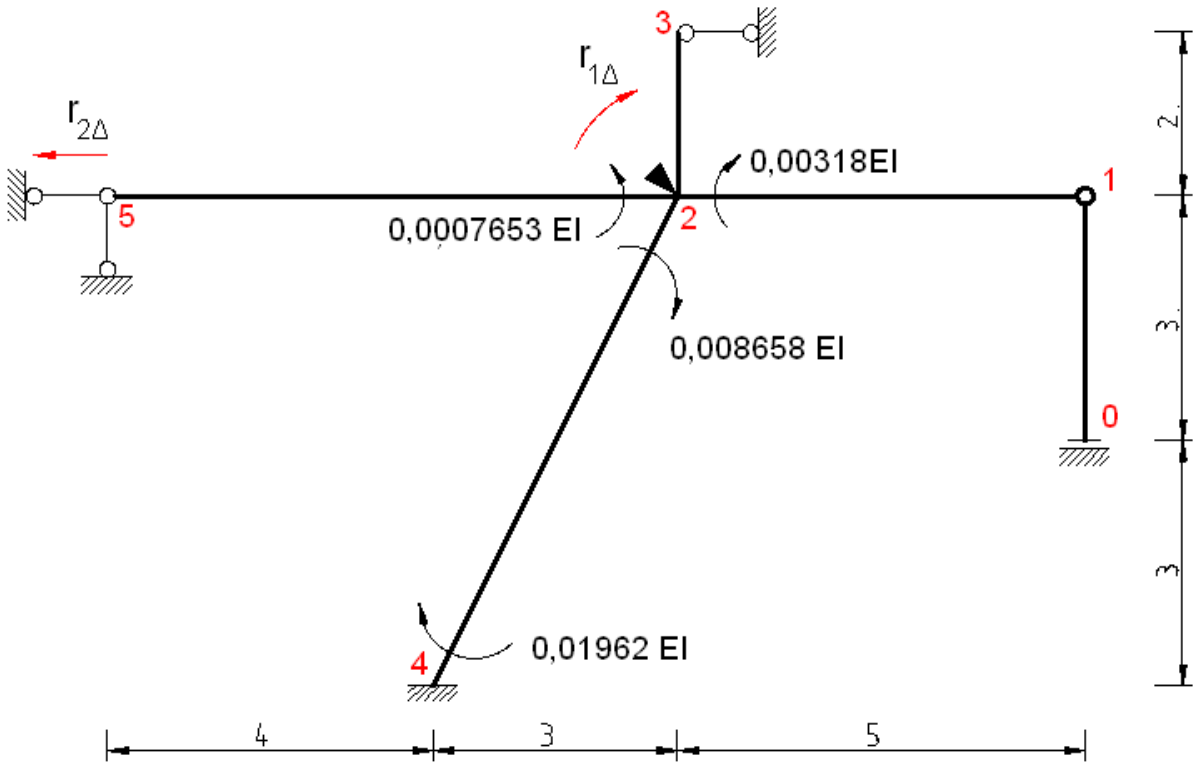
$$M_{21} = \frac{3EI}{5}(0{,}0053) = 0{,}00318EI$$

$$M_{23} = \frac{3EI}{2}(0) = 0$$

$$M_{25} = \frac{3EI}{7}(-0{,}0017857) = -0{,}0007653EI$$

$$M_{24} = \frac{2 \cdot 1{,}404332EI}{\sqrt{45}}(0{,}0261799 - 3 \cdot 0{,}0018333) = 0{,}008658EI$$

$$M_{42} = \frac{2 \cdot 1{,}404332EI}{\sqrt{45}}(2 \cdot 0{,}0261799 - 3 \cdot 0{,}0018333) = 0{,}01962EI$$



$$r_{1\Delta} = 0{,}00318EI - 0{,}0007652EI + 0{,}008658EI = 0{,}011073EI$$

RPW

$$1 \cdot r_{2\Delta} + M_{21} \cdot \overline{\Psi}_{12} + M_{24} \cdot \overline{\Psi}_{42} + M_{42} \cdot \overline{\Psi}_{42} + M_{25} \cdot \overline{\Psi}_{25} = 0$$

$$r_{2\Delta} + 0{,}00318EI \cdot 0{,}1 + 0{,}008658EI \cdot \left(-\frac{1}{6}\right) + 0{,}01962EI \cdot \left(-\frac{1}{6}\right) + \left(-0{,}0007653EI\right) \cdot \left(-\frac{1}{14}\right) = 0$$

$$r_{2\Delta} = 0{,}0043403EI$$

$$\begin{bmatrix} r_{11} & r_{12} \\ r_{21} & r_{22} \end{bmatrix} \cdot \begin{bmatrix} \varphi_1 \\ \Delta_2 \end{bmatrix} + \begin{bmatrix} r_{1\Delta} \\ r_{2\Delta} \end{bmatrix} = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$\begin{bmatrix} 3{,}36584 & -0{,}57007 \\ -0{,}57007 & 0{,}452968 \end{bmatrix} EI \cdot \begin{bmatrix} \varphi_1 \\ \Delta_2 \end{bmatrix} + \begin{bmatrix} 0{,}011073 \\ 0{,}0043403 \end{bmatrix} EI = \begin{bmatrix} 0 \\ 0 \end{bmatrix}$$

$$\varphi_1 = -0.0062435\ rad$$

$$\Delta_2 = -0.0174395\ \mathrm{m}$$

$$M_p^{(\Delta)} = M_1 \cdot \varphi_1 + M_2 \cdot \Delta_2 + M_\Delta$$

$$M_{01} = 0$$

$$M_{21} = \frac{3}{5} EI \cdot (-0.0062435) - 0{,}06EI \cdot (-0.0174395) + 0{,}00318EI = 2{,}724\,\text{kNm}$$

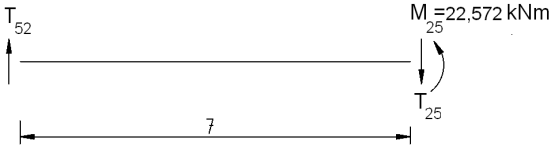
$$M_{23} = \frac{3}{2} EI \cdot (-0.0062435) - 0{,}75EI \cdot (-0.0174395) = 21{,}092\,\text{kNm}$$

$$M_{25} = \frac{3}{7} EI \cdot (-0.0062435) + \frac{3}{98} EI \cdot (-0.0174395) - 0{,}0007653EI = -22{,}572\,\text{kNm}$$

$$M_{24} = 0{,}83727EI \cdot (-0.0062435) + 0{,}2093454EI \cdot (-0.0174395) + 0{,}008658EI =$$
$$= -1{,}251\,\text{kNm}$$

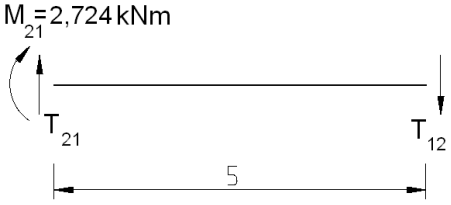
$$M_{42} = 0{,}41863EI \cdot (-0.0062435) + 0{,}2093454EI \cdot (-0.0174395) + 0{,}01962EI =$$
$$= 75{,}839\,\text{kNm}$$

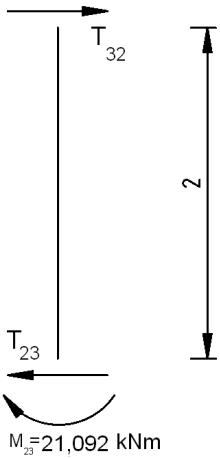
WYZNACZENIE WARTOŚCI SIŁ TNĄCYCH



$$\sum M_2 = 0$$
$$T_{52} \cdot 7 - 22{,}572 = 0$$
$$T_{52} = 3{,}22457\ \text{kN}$$
$$\sum Y = 0$$
$$T_{52} - T_{25} = 0$$
$$T_{25} = 3{,}22457\ \text{kN}$$

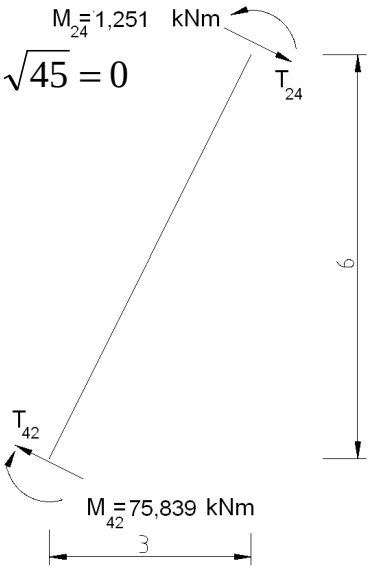
$$\sum M_1 = 0$$
$$T_{21} \cdot 5 + 2{,}724 = 0$$
$$T_{21} = -0{,}5448\ \text{kN}$$
$$T_{21} = T_{12}$$





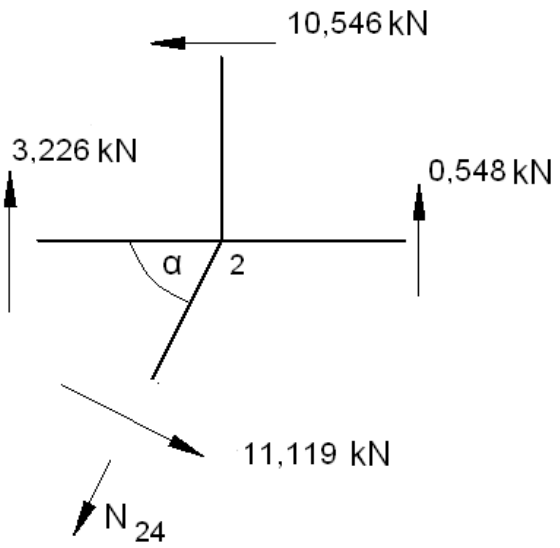
$$\sum M_3 = 0$$
$$21{,}092 + T_{23} \cdot 2 = 0$$
$$T_{23} = -10{,}546\ \text{kN}$$
$$T_{32} = T_{23} = -10{,}546\text{kN}$$

$$\sum M_2 = 0$$
$$-1{,}251 + 75{,}839 + T_{42} \cdot \sqrt{45} = 0$$
$$T_{42} = -11{,}119\ \text{kN}$$
$$T_{24} = T_{42} = -11{,}119\ \text{kN}$$



WYZNACZENIE SIŁ NORMALNYCH

Z równowagi węzła „3” wynika że $N_{32} = 0$, $N_{23} = N_{32} = 0$
Z równowagi węzła „5” wynika że $N_{52} = 0$, $N_{25} = N_{52} = 0$
Z równowagi węzła „1” >> $\Sigma X = 0$ > $N_{12} = 0$
>> $\Sigma y = 0$ > $N_{10} =$ -0,538 kN, $N_{01}=N_{10}$=-0,538 kN



$$\sin\alpha = 0{,}89442$$

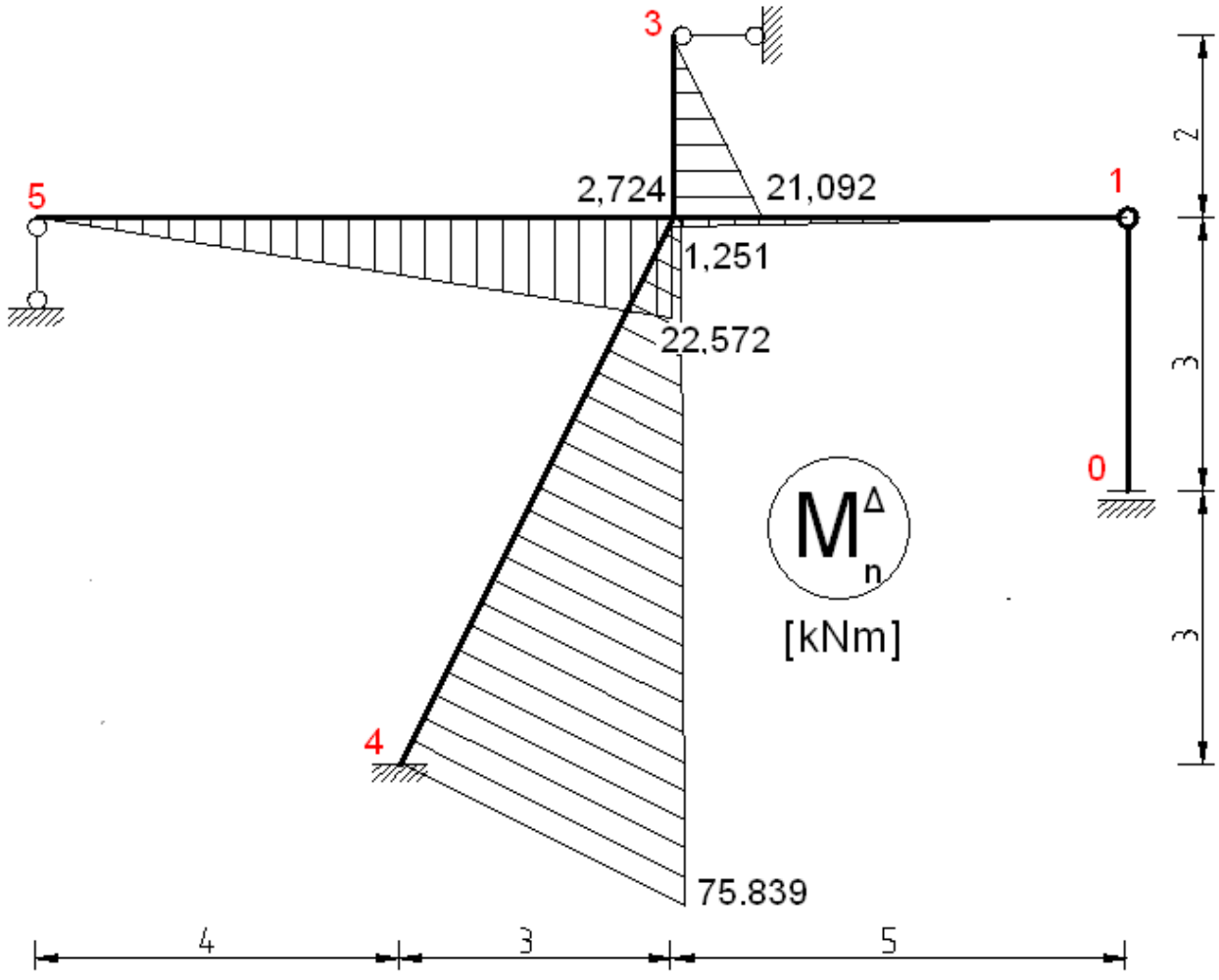
$$\cos\alpha = 0{,}447213$$

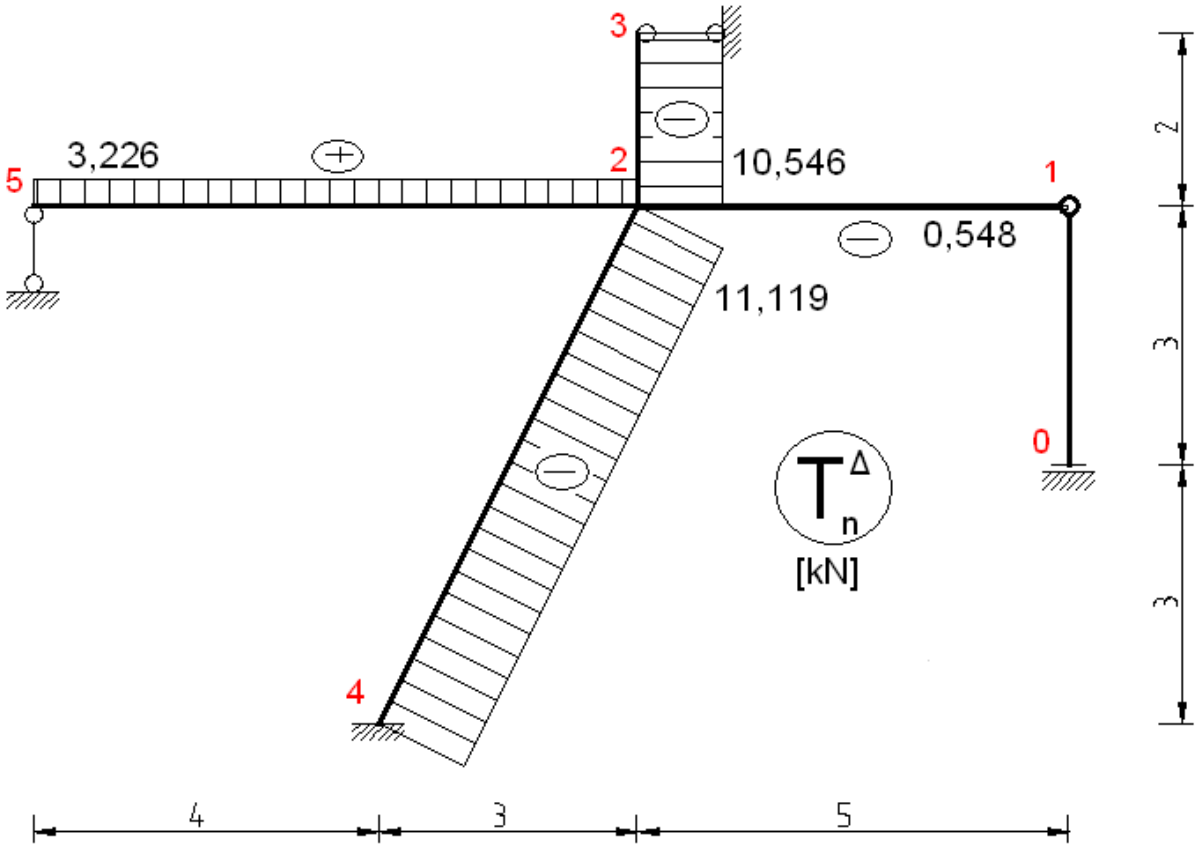
$$\sum Y = 0$$

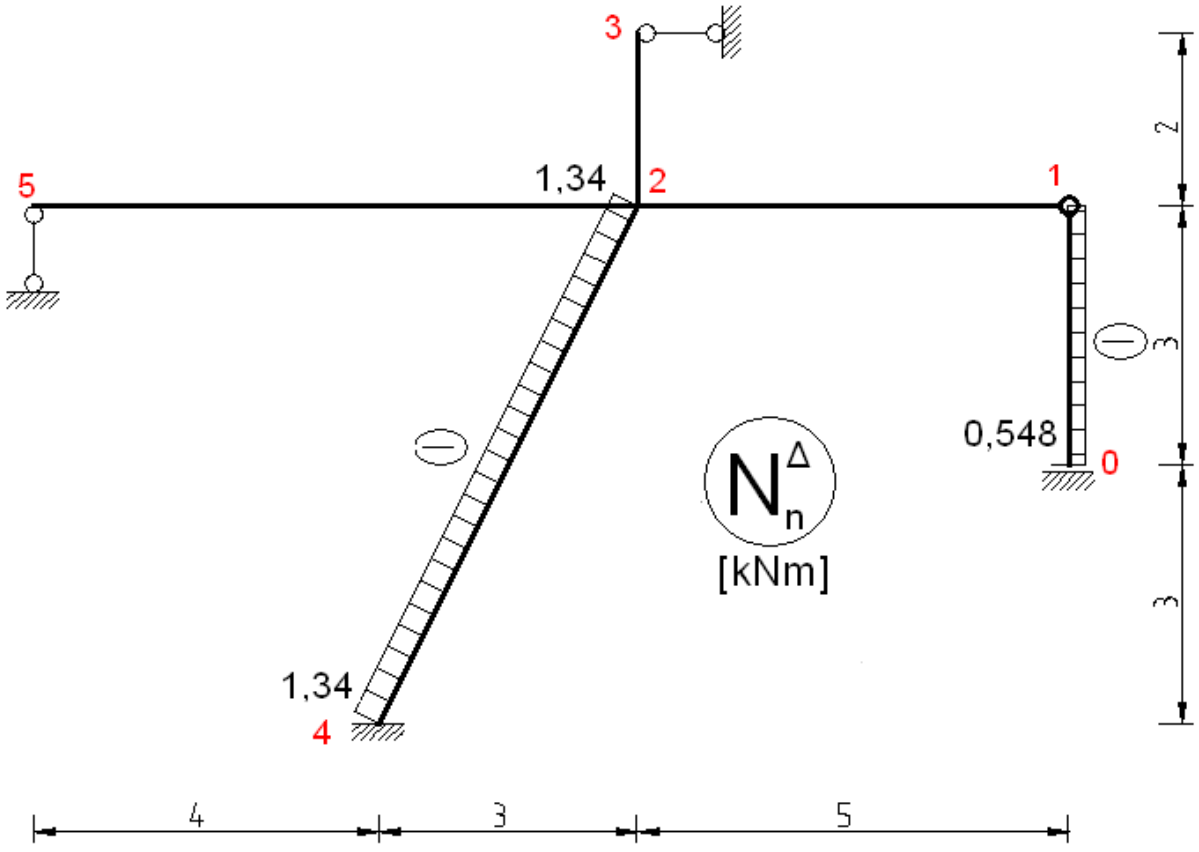
$$3{,}226 + 0{,}548 - 11{,}119 \cdot \cos\alpha -$$

$$+ N_{24.} \cdot \sin\alpha = 0$$

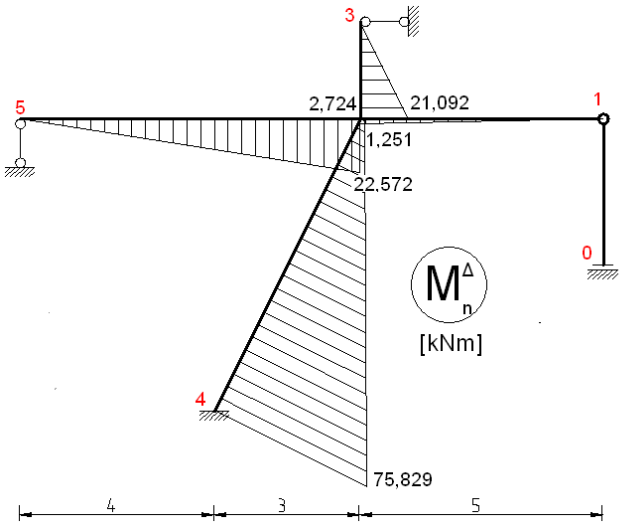
$$N_{24} = -1{,}34\text{kN}$$

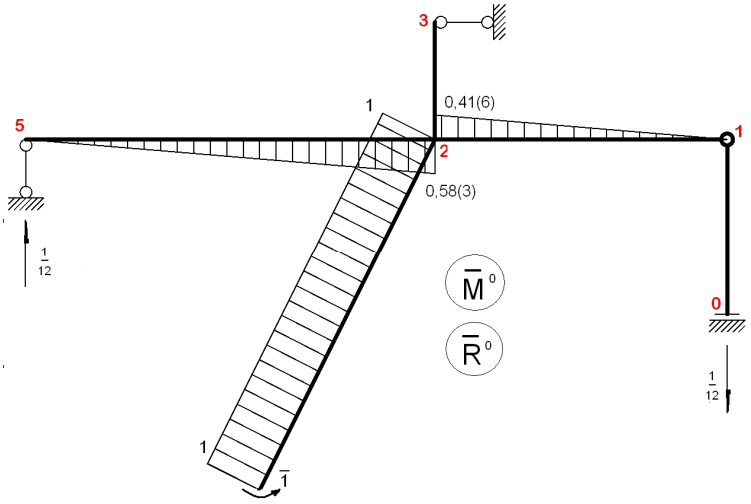



3
2
1
5
4
0
3,226
10,546
0,548
11,119
T_n^{Δ}
[kN]
2
3
3
4
3
5


3
2
1
5
4
0
1,34
1,34
0,548
N_n^{Δ}
[kNm]
2
3
3
4
3
5

Sprawdzenie kinematyczne





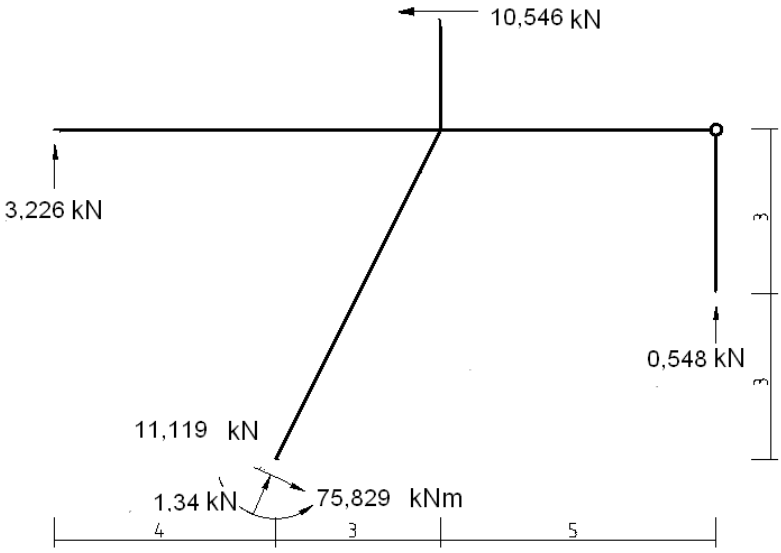
$$1 \cdot \varphi_4 = \sum \int_x \frac{M_n^{\Delta} \cdot \bar{M}_0}{EI} dx - \sum \bar{R}^0 \cdot \Delta$$

$$\bar{1} \cdot \varphi_4 = \frac{1}{EI_2}\left[-\frac{1}{2}\cdot(75{,}829+1{,}251)\cdot\sqrt{45}\cdot 1\right]+$$

$$+\frac{1}{EI}\left[\frac{1}{2}\cdot 22{,}572\cdot 7\cdot\frac{2}{3}\cdot(0{,}583)-\frac{1}{2}\cdot 2{,}7272\cdot 5\cdot\left(\frac{2}{3}\cdot 0{,}417\right)\right]-\left(-\frac{1}{12}\cdot 0{,}014\right)=$$

$$=\frac{-258{,}5679}{1{,}404332\,EI}+\frac{28{,}8287}{EI}-\frac{0{,}014}{12}=\frac{-157{,}77102}{EI}=-0{,}0261809\,rad=-1{,}5°$$

Sprawdzenie statyczne



$$\sum X = 0$$

$$10{,}546 - 11{,}119 \cdot 0{,}89442 - 1{,}34 \cdot 0{,}447213 = 0{,}001678 \approx 0$$

$$\sum Y = 0$$

$$3{,}226 + 0{,}548 + 1{,}34 \cdot 0{,}89442 - 11{,}119 \cdot 0{,}447213 = -0{,}0000385 \approx 0$$

$$\sum M_4 = 0$$

$$75{,}829 + 3{,}226 \cdot 4 - 10{,}546 \cdot 8 - 0{,}548 \cdot 8 = 0{,}019 \approx 0$$