Politechnika Poznańska
Wydział Architektury Budownictwa
i Inżynierii Środowiska

ĆWICZENIE NR 4

OBLICZENIE RAMY METODĄ PRZEMIESZCZEŃ

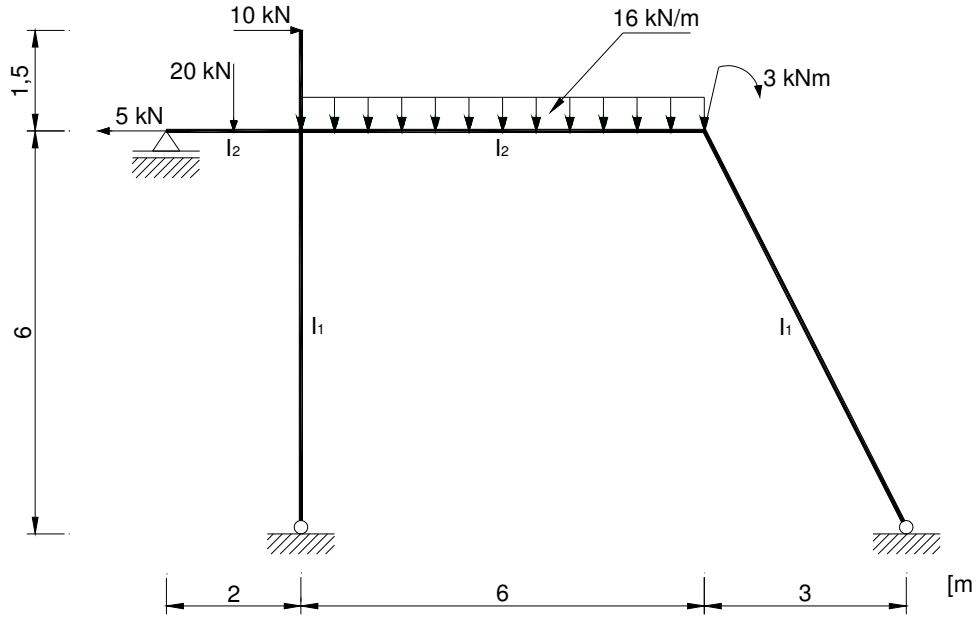
(wpływ obciążenia zewnętrznego)

Sierocki Damian
rok studiów: III
semestr: VI
gr. 8

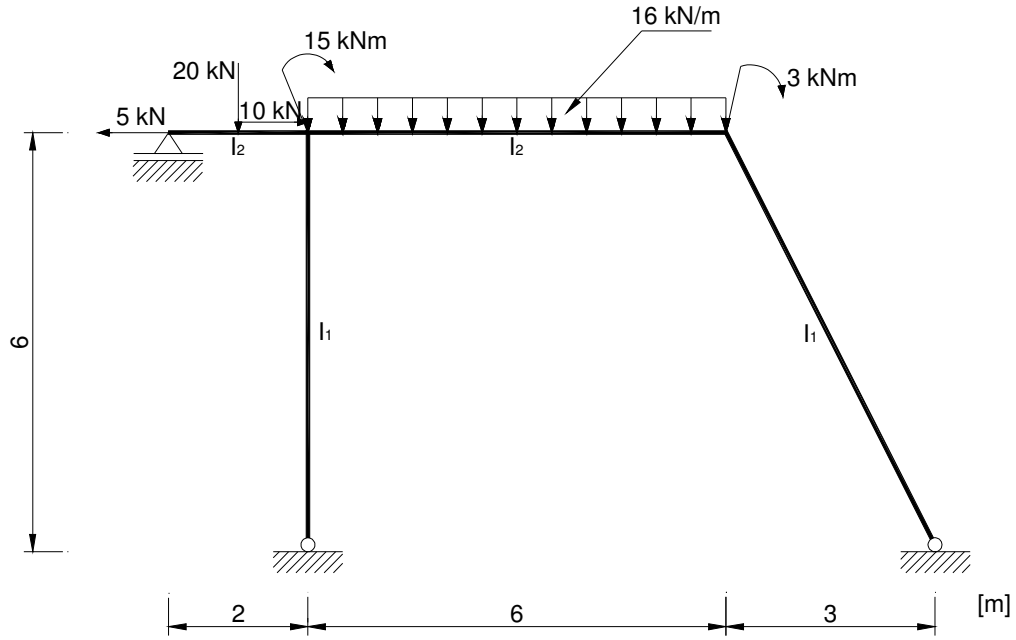
Poznań 2005

METODA PRZEMIESZCZEŃ – OBCIĄŻENIE ZEWNĘTRZNE

SCHEMAT KONSTRUKCJI



Sprowadzenie układu wyjściowego do równoważnego układu zastępczego:



STOPIEŃ GEOMETRYCZNEJ NIEWYZNACZALNOŚCI UKŁADU:

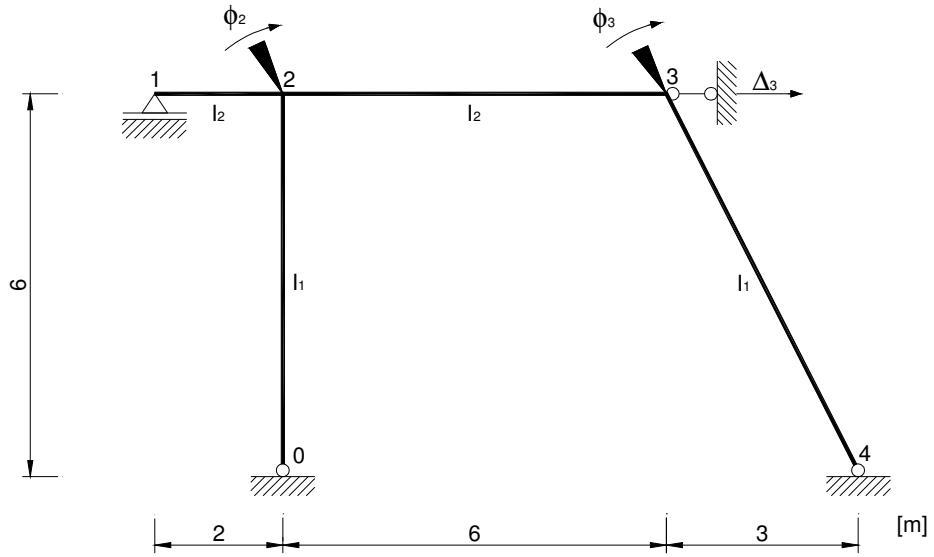
$$SGN = \sum \Delta + \sum \varphi$$

$\sum \Delta = 1$

$\sum \varphi = 2$

$$SGN = 1 + 2 = 3$$

UKŁAD PODSTAWOWY



UKŁAD RÓWNAŃ KANONICZNYCH

$$\begin{cases} r_{11} \cdot z_1 + r_{12} \cdot z_2 + r_{13} \cdot z_3 + r_{1P} = 0 \\ r_{21} \cdot z_1 + r_{22} \cdot z_2 + r_{23} \cdot z_3 + r_{2P} = 0 \\ r_{31} \cdot z_1 + r_{32} \cdot z_2 + r_{33} \cdot z_3 + r_{3P} = 0 \end{cases}$$

Niewiadome: $\varphi_2, \varphi_3, \Delta_3$

$\varphi_2 = z_1$
$\varphi_3 = z_2$
$\Delta_3 = z_3$

WSPÓŁCZYNNIK PORÓWNAWCZY SZTYWNOŚCI

I_1 - I220 $(W_x = 278.18\ cm^3, I_x = 3060\ cm^4)$

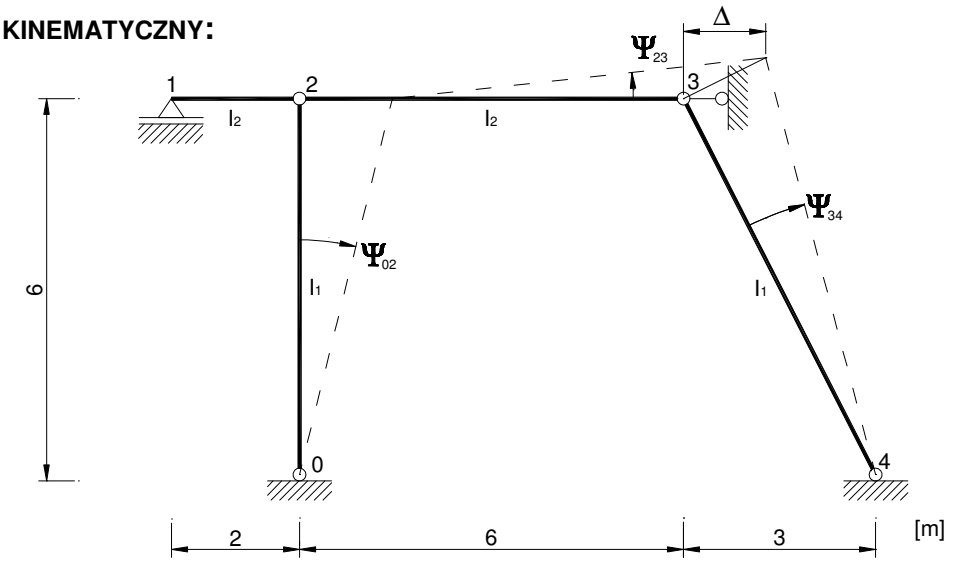
I_2 - I260 $(W_x = 441.54\ cm^3, I_x = 5740\ cm^4)$

$EI_1 = 205 \cdot 10^6 \cdot 3060 \cdot 10^{-8} = 6273\ kN/m$

$EI_2 = 205 \cdot 10^6 \cdot 5740 \cdot 10^{-8} = 11767\ kN/m$

Przyjęto współczynnik porównawczy sztywności $EI_0 = EI_2$ ➔ $EI_1 = 0.5331\, EI_0$

ŁAŃCUCH KINEMATYCZNY:



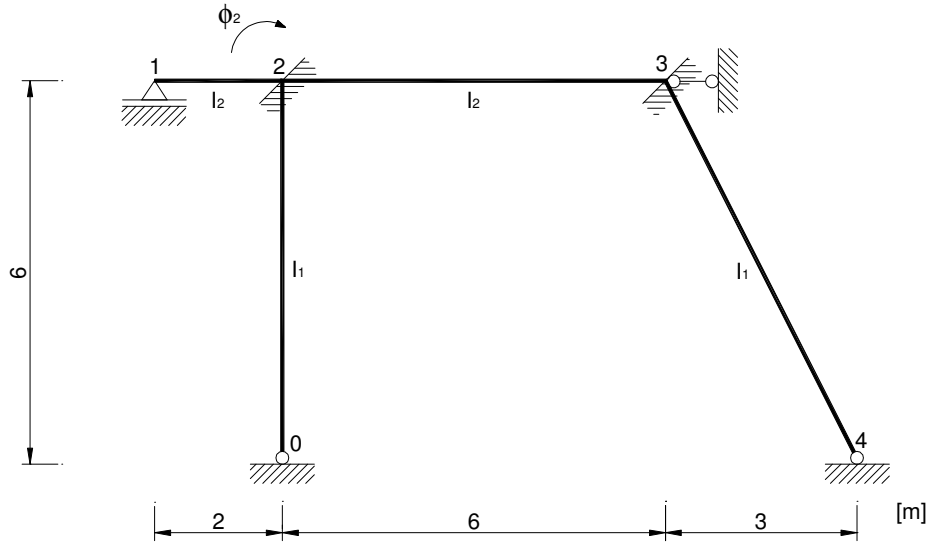
$\rightarrow 023 \quad 6\cdot\Psi_{02}=\Delta \quad\Rightarrow\quad \Psi_{02}=\dfrac{\Delta}{6}$

$\rightarrow 0234 \quad 6\cdot\Psi_{02}-6\cdot\Psi_{34}=0 \quad\Rightarrow\quad \Psi_{02}=\Psi_{34} \quad\Rightarrow\quad \Psi_{34}=\dfrac{\Delta}{6}$

$\downarrow 0234 \quad 6\cdot\Psi_{23}-3\cdot\Psi_{34}=0 \quad\Rightarrow\quad \Psi_{34}=-2\Psi_{23}\Rightarrow \quad \Psi_{23}=-\dfrac{\Delta}{12}$

$\downarrow 021 \quad 2\cdot\Psi_{12}=0 \quad\Rightarrow\quad \Psi_{12}=0$

Stan $z_1=1 \quad (\varphi_2=1)$



$M_{12}=0$

$M_{21}=\dfrac{3EI_0}{l}(\varphi_2-\Psi_{12})=\dfrac{3EI_0}{2}(1-0)=1.5000\,EI_0$

$M_{23}=\dfrac{2EI_0}{l}(2\varphi_2+\varphi_3-3\Psi_{23})=\dfrac{2EI_0}{6}(2\cdot 1+0-3\cdot 0)=0.6667\,EI_0$

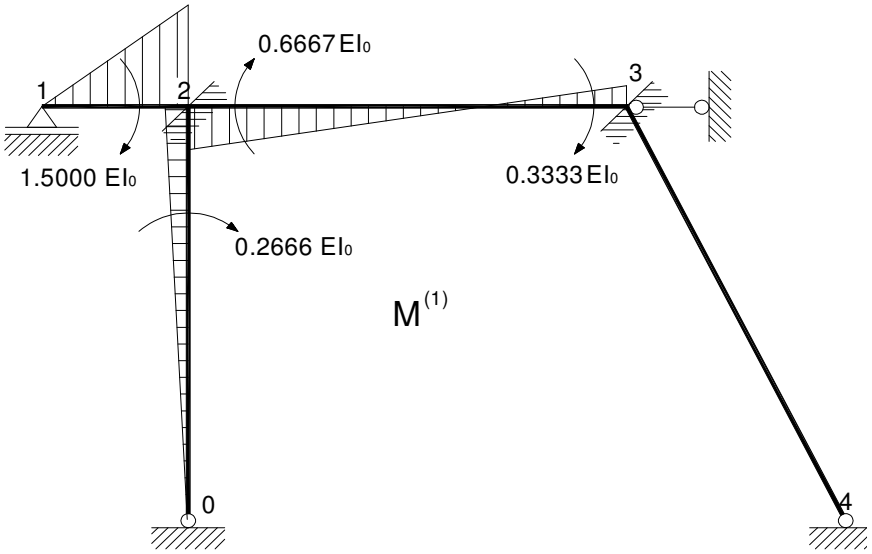
$M_{32}=\dfrac{2EI_0}{l}(\varphi_2+2\varphi_3-3\Psi_{23})=\dfrac{2EI_0}{6}(1+2\cdot 0-3\cdot 0)=0.3333\,EI_0$

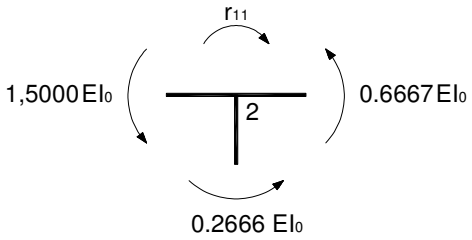
$M_{34}=\dfrac{3EI_0}{l}(\varphi_3-\Psi_{34})=\dfrac{3\cdot 0.5331\cdot EI_0}{6.7082}(0-0)=0{,}0\,EI_0$

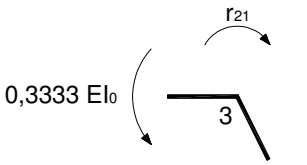
$M_{43}=0$

$M_{02}=0$

$M_{20}=\dfrac{3EI_0}{l}(\varphi_2-\Psi_{02})=\dfrac{3\cdot 0.5331\cdot EI_0}{6}(1-0)=0.2666\,EI_0$



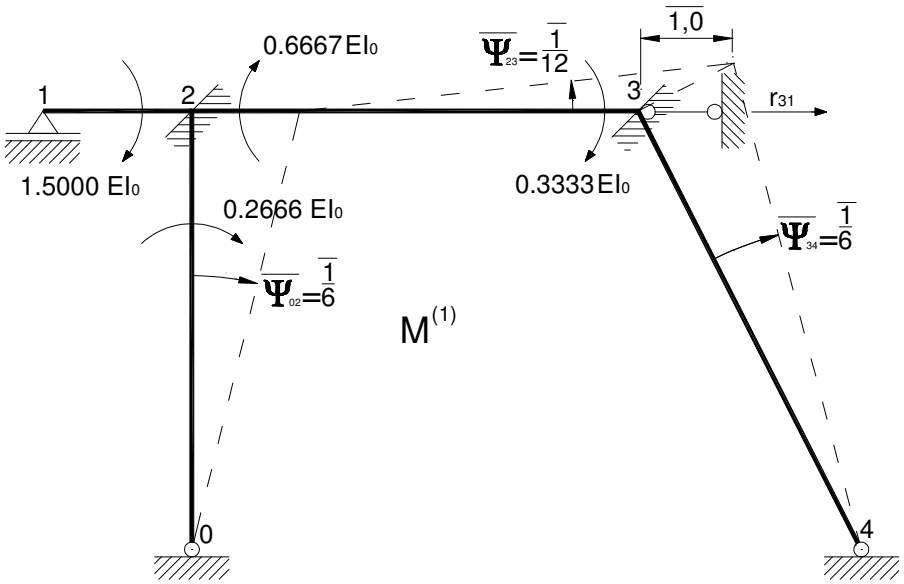




$r_{21} = 0.3333\ EI_0$

$r_{11} = 1.5000 + 0.2666 + 0.6667$

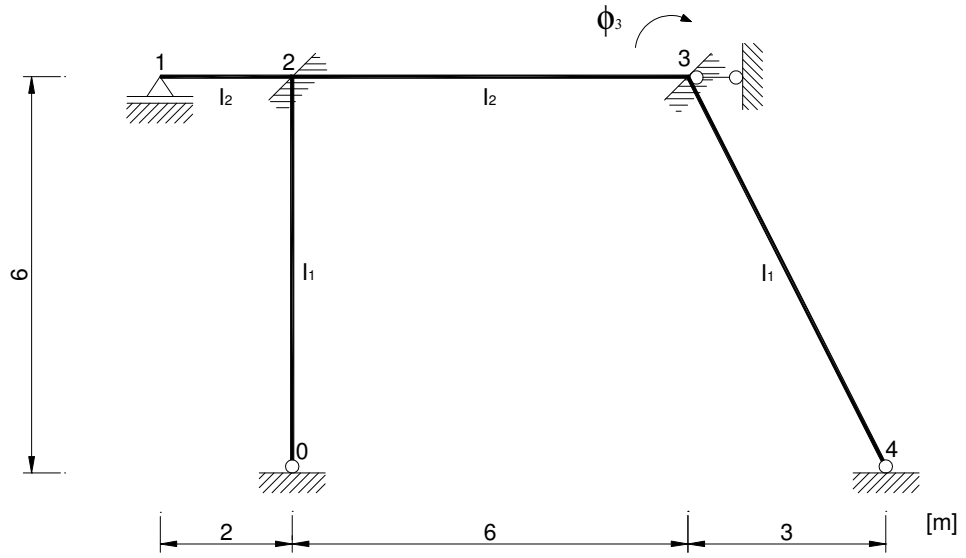
$r_{11} = 2.4332\ EI_0$



R.P.W.

$$\overline{1,0} \cdot r_{31} + 0.2666 EI_0 \cdot \frac{\overline{1,0}}{6} - (0.6667 + 0.3333) EI_0 \cdot \frac{\overline{1,0}}{12} = 0 \quad \rightarrow \quad r_{31} = 0.0389\ EI_0$$

Stan $z_2 = 1 \;\; (\varphi_3 = 1)$



$M_{12} = 0$

$$M_{21} = \frac{3EI_0}{l}(\varphi_2 - \Psi_{12}) = \frac{3EI_0}{2}(0-0) = 0\,0$$

$$M_{23} = \frac{2EI_0}{l}(2\varphi_2 + \varphi_3 - 3\Psi_{23}) = \frac{2EI_0}{6}(2\cdot 0 + 1 - 3\cdot 0) = 0.3333\,EI_0$$

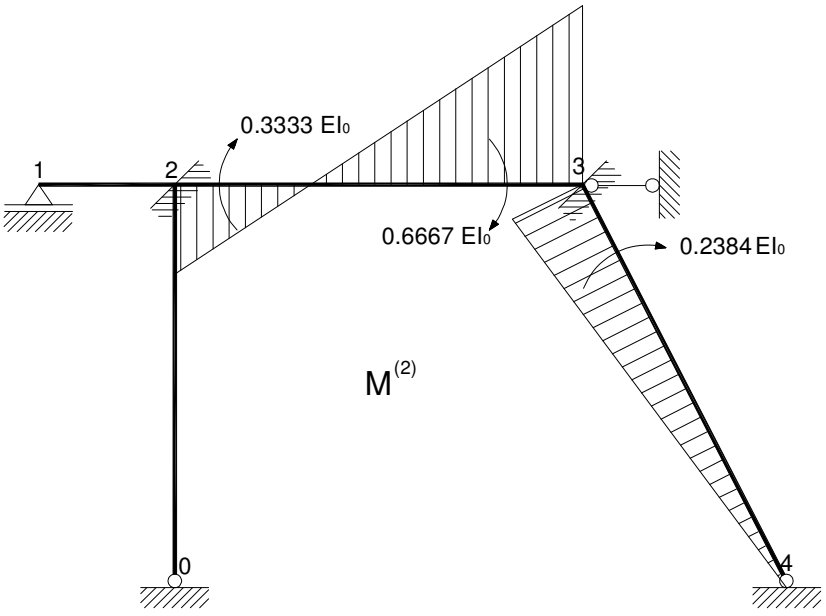
$$M_{32} = \frac{2EI_0}{l}(\varphi_2 + 2\varphi_3 - 3\Psi_{23}) = \frac{2EI_0}{6}(0 + 2\cdot 1 - 3\cdot 0) = 0.6667\,EI_0$$

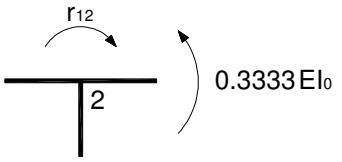
$$M_{34} = \frac{3EI_0}{l}(\varphi_3 - \Psi_{34}) = \frac{3\cdot 0.5331\cdot EI_0}{6.7082}(1-0) = 0.2384\,EI_0$$

$M_{43} = 0$

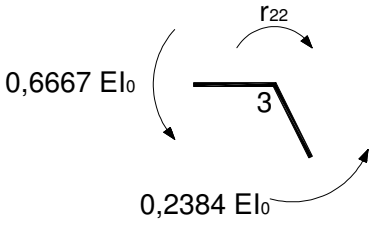
$M_{02} = 0$

$$M_{20} = \frac{3EI_0}{l}(\varphi_2 - \Psi_{02}) = \frac{3\cdot 0.5331\cdot EI_0}{6}(0-0) = 0{,}0$$





$r_{12} = 0{,}3333\;EI_0$



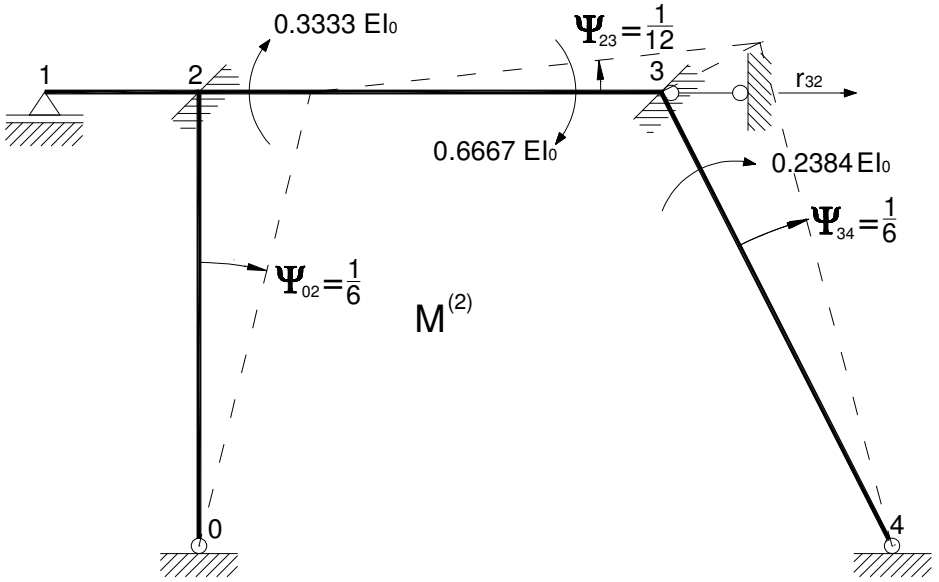
$r_{22} = 0.6667 + 0.2384$

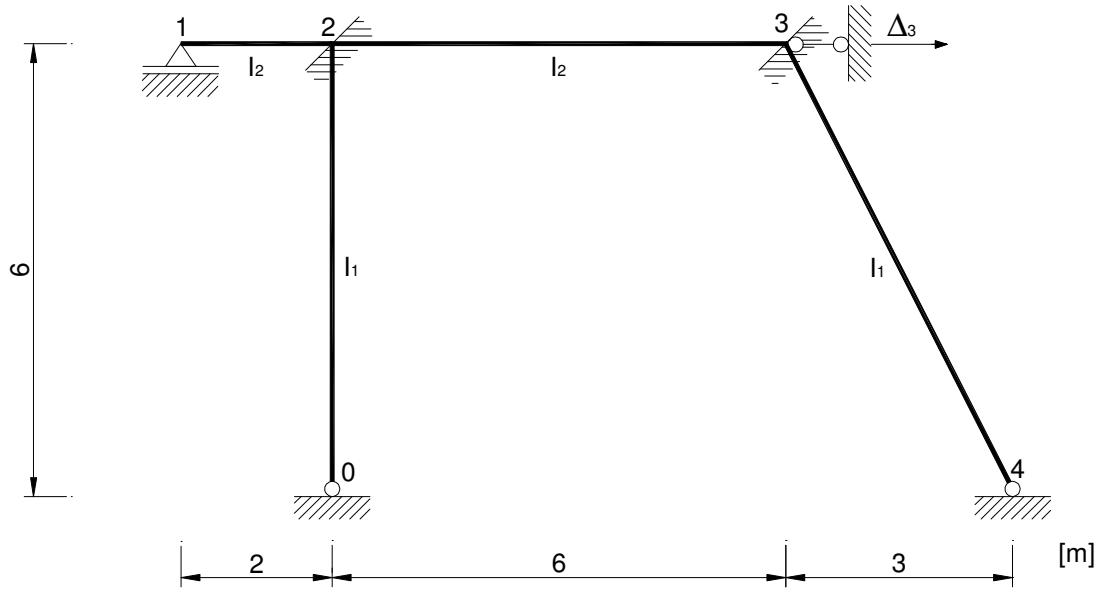
$r_{22} = 0.9051\;EI_0$

R.P.W

$$\overline{1{,}0}\cdot r_{32} - (0.6667 + 0.3333)EI_0 \cdot \frac{\overline{1{,}0}}{12} + 0.2384EI_0 \cdot \frac{\overline{1{,}0}}{6} = 0 \quad \rightarrow \quad r_{32} = 0.0436\,EI_0$$

Stan $z_3 = 1 \quad (\Delta_3 = 1)$





$M_{12} = 0$

$$M_{21} = \frac{3EI_0}{l}(\varphi_2 - \Psi_{12}) = \frac{3EI_0}{2}(0-0) = 0$$

$$M_{23} = \frac{2EI_0}{l}(2\varphi_2 + \varphi_3 - 3\Psi_{23}) = \frac{2EI_0}{6}\left(2\cdot 0 + 0 - 3\cdot\frac{1}{12}\right) = 0.0833\,EI_0$$

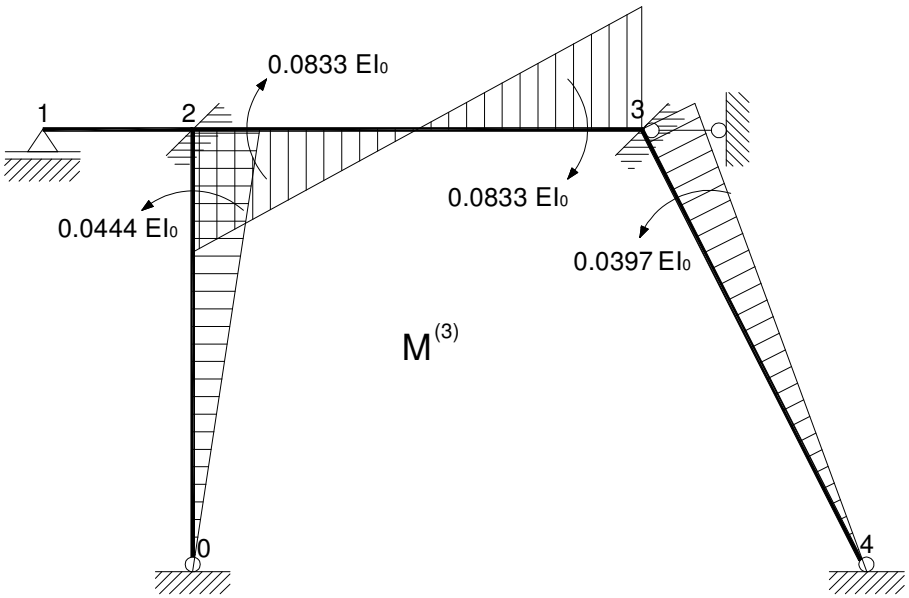
$$M_{32} = \frac{2EI_0}{l}(\varphi_2 + 2\varphi_3 - 3\Psi_{23}) = \frac{2EI_0}{6}\left(0 + 2\cdot 0 - 3\cdot\frac{1}{12}\right) = 0.0833\,EI_0$$

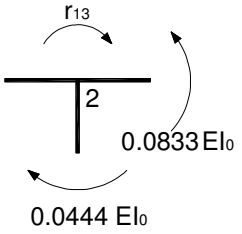
$$M_{34} = \frac{3EI_0}{l}(\varphi_3 - \Psi_{34}) = \frac{3\cdot 0.5331\cdot EI_0}{6.7082}\left(0 - \frac{1}{6}\right) = -0.0397\,EI_0$$

$M_{43} = 0$

$M_{02} = 0$

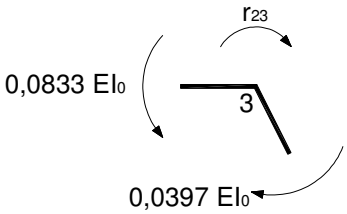
$$M_{20} = \frac{3EI_0}{l}(\varphi_2 - \Psi_{02}) = \frac{3\cdot 0.5331\cdot EI_0}{6}\left(0 - \frac{1}{6}\right) = -0.0444\,EI_0$$





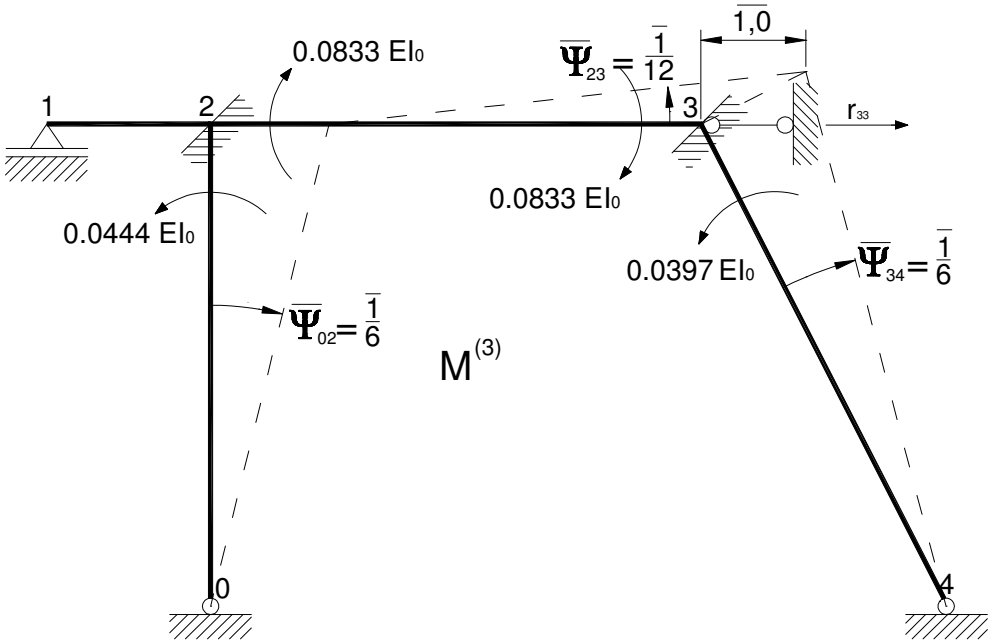
$r_{13} = -0.0444 + 0.0833$

$r_{13} = 0.0389\ EI_0$



$r_{23} = 0.0833 - 0.0397$

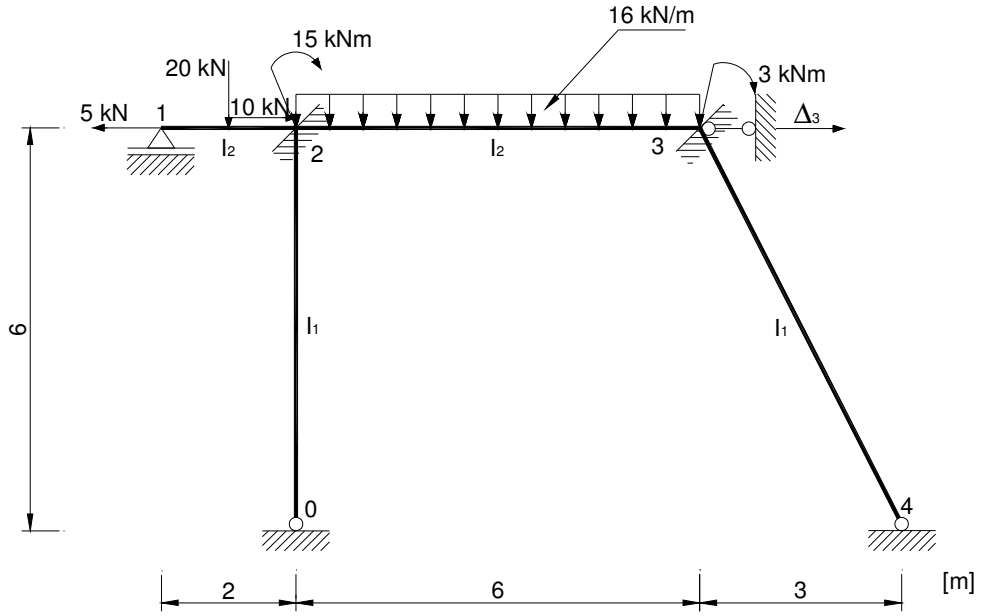
$r_{23} = 0.0436\ EI_0$



R.P.W.

$$\overline{1,0} \cdot r_{33} - 0.0444 EI_0 \cdot \frac{\overline{1,0}}{6} - (0.0833 + 0.0833) EI_0 \cdot \frac{\overline{1,0}}{12} - 0.0397 EI_0 \cdot \frac{\overline{1,0}}{6} = 0 \quad \rightarrow \quad r_{33} = 0.0279\ EI_0$$

Stan „P”



$M_{12} = 0$

$M_{21} = \frac{3}{16}Pl = \frac{3}{16} \cdot 20 \cdot 2 = 7.50\ \text{kNm}$

$M_{23} = -\frac{ql^2}{12} = \frac{16 \cdot 6^2}{12} = \text{-}48.00\ \text{kNm}$

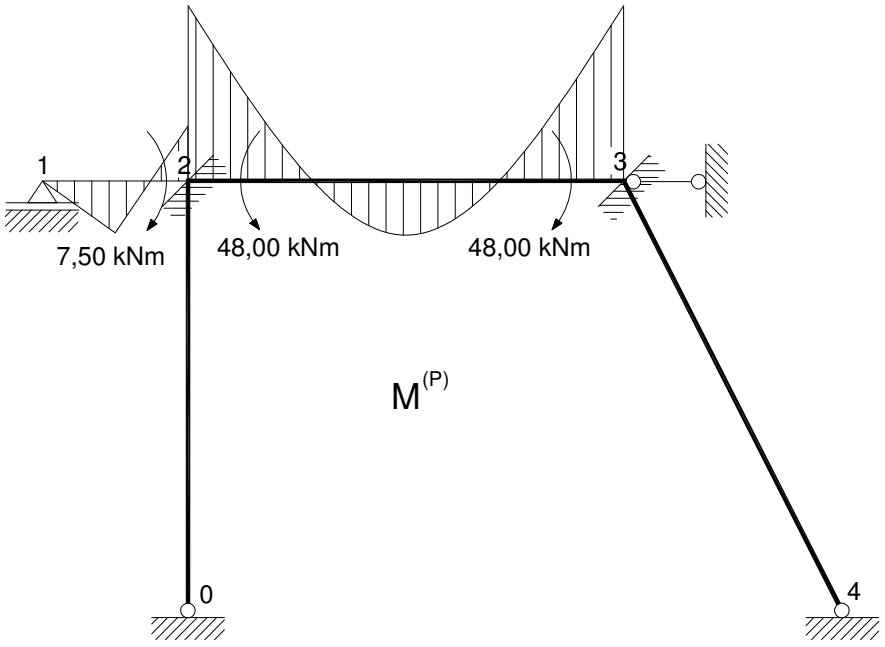
$M_{32} = \frac{ql^2}{12} = \frac{16 \cdot 6^2}{12} = 48.00\ \text{kNm}$

$M_{34} = 0$

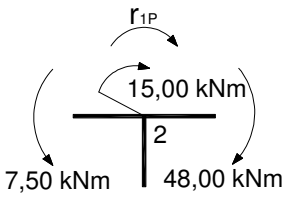
$M_{43} = 0$

$M_{02} = 0$

$M_{20} = 0$

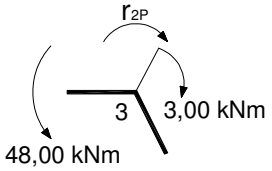


$M^{(P)}$



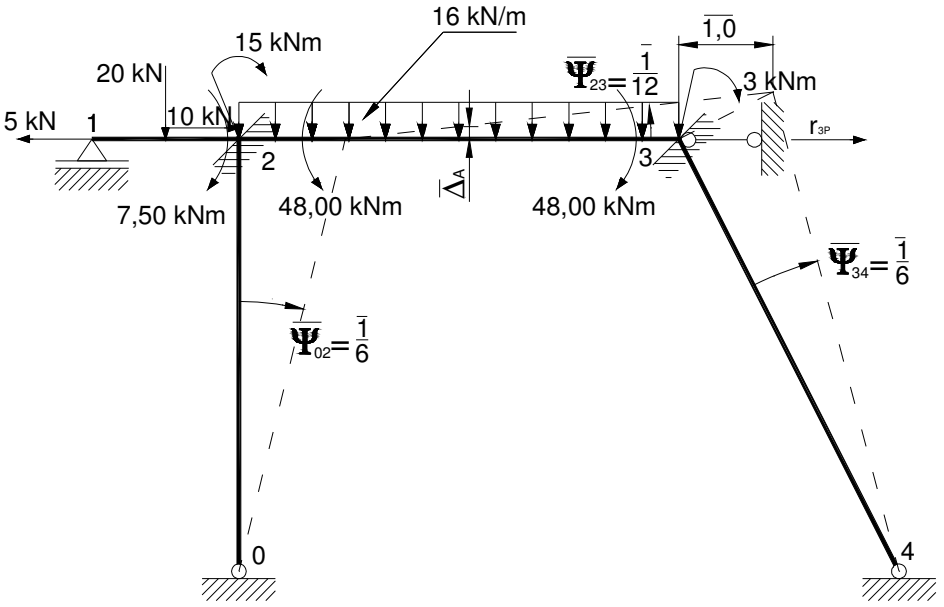
$r_{1P} = 7{,}50 - 15{,}00 - 48{,}00$

$r_{1P} = \text{-}55.50\ \text{kNm}$



$r_{2P} = 48.00 - 3{,}00$

$r_{2P} = 45.00\ \text{kNm}$



$$\downarrow 023 \quad 3\cdot\overline{\Psi}_{23}=\overline{\Delta}_A \quad\Rightarrow\quad \overline{\Delta}_A=3\cdot\frac{\overline{1,0}}{12} \quad\Rightarrow\quad \overline{\Delta}_A=\frac{\overline{1,0}}{4}$$

R.P.W.

$$\overline{1,0}\cdot r_{3P}+(48,0-48,0)\cdot\frac{\overline{1,0}}{12}-6\cdot 16\cdot\overline{\Delta}_A - 5,0\cdot\overline{1,0}+10\cdot\overline{1,0}=0 \quad\rightarrow\quad r_{3P}=19.00\,\text{kN}$$

ROZWIĄZANIE UKŁADU RÓWNAŃ KANONICZNYCH

$$\begin{cases} r_{11}\cdot z_1+r_{12}\cdot z_2+r_{13}\cdot z_3+r_{1P}=0 \\ r_{21}\cdot z_1+r_{22}\cdot z_2+r_{23}\cdot z_3+r_{2P}=0 \\ r_{31}\cdot z_1+r_{32}\cdot z_2+r_{33}\cdot z_3+r_{3P}=0 \end{cases}$$

$$\begin{cases} 2.4332EI_0\cdot z_1+0.3333EI_0\cdot z_2+0.0389EI_0\cdot z_3=55.50 \\ 0.3333EI_0\cdot z_1+0.9051EI_0\cdot z_2+0.0436EI_0\cdot z_3=-45.00 \\ 0.0389EI_0\cdot z_1+0.0436EI_0\cdot z_2+0.0279EI_0\cdot z_3=-19.00 \end{cases}$$

$$z_1=\frac{37.9757}{EI_0} \quad\Rightarrow\quad \varphi_2=\frac{37.9757}{EI_0}$$
$$z_2=\frac{-30.6778}{EI_0} \quad\Rightarrow\quad \varphi_3=\frac{-30.6778}{EI_0}$$
$$z_3=\frac{-685.6412}{EI_0} \quad\Rightarrow\quad \Delta_3=\frac{-685.6412}{EI_0}$$

WYZNACZENIE WARTOŚCI MOMENTÓW ZGINAJĄCYCH – METODA SUPERPOZYCJI:

$$M_P^{(n)}=M_1\cdot Z_1+M_2\cdot Z_2+M_3\cdot Z_3+M_P$$

$$M_{12}=0$$

$$M_{21}=1.50EI_0\cdot\frac{37.9757}{EI_0}+0\cdot\frac{-30.6778}{EI_0}+0\cdot\frac{-685.6412}{EI_0}+7.50=64.4635\,\text{kNm}$$

$$M_{23}=0.6667EI_0\cdot\frac{37.9757}{EI_0}+0.3333EI_0\cdot\frac{-30.6778}{EI_0}+0.0833EI_0\cdot\frac{-685.6412}{EI_0}-48.00=-90.0456\,\text{kNm}$$

$$M_{32} = 0.3333EI_0 \cdot \frac{37.9757}{EI_0} + 0.6667EI_0 \cdot \frac{-30.6778}{EI_0} + 0.0833EI_0 \cdot \frac{-685.6412}{EI_0} + 48.00 = -16.9301\,\text{kNm}$$

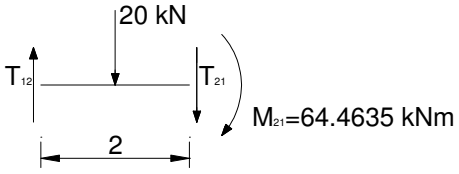
$$M_{34} = 0 \cdot \frac{37.9757}{EI_0} + 0.2384EI_0 \cdot \frac{-30.6778}{EI_0} - 0.0397EI_0 \cdot \frac{-685.6412}{EI_0} + 0 = 19.9301\,\text{kNm}$$

$$M_{43} = 0$$

$$M_{02} = 0$$

$$M_{20} = 0.2666EI_0 \cdot \frac{37.9757}{EI_0} + 0 \cdot \frac{-30.6778}{EI_0} - 0.0444EI_0 \cdot \frac{-685.6412}{EI_0} + 0 = 140.5821\,\text{kNm}$$

WYZNACZENIE WARTOŚCI SIŁ TNĄCYCH:



$$\sum M_1 = 0$$

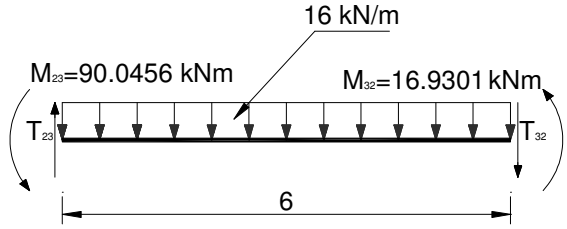
$$20 \cdot 1 + T_{21} \cdot 2 + 64.4635 = 0$$

$$T_{21} = -42.2317\,\text{kN}$$

$$\sum M_2 = 0$$

$$T_{12} \cdot 2 - 20 \cdot 1 + 64.4635 = 0$$

$$T_{12} = -22.2317\,\text{kN}$$



$$\sum M_2 = 0$$

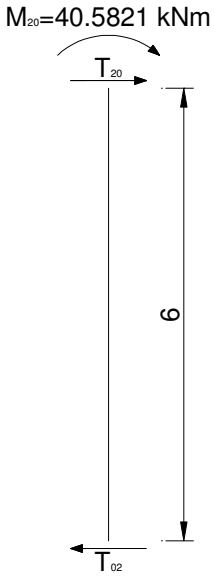
$$16 \cdot 6 \cdot 3 + T_{32} \cdot 6 - 90.0456 - 16.9301 = 0$$

$$T_{32} = -30.1707\,\text{kN}$$

$$\sum M_3 = 0$$

$$T_{23} \cdot 6 - 16 \cdot 6 \cdot 3 - 90.0456 - 16.9301 = 0$$

$$T_{23} = 65.8293\,\text{kN}$$

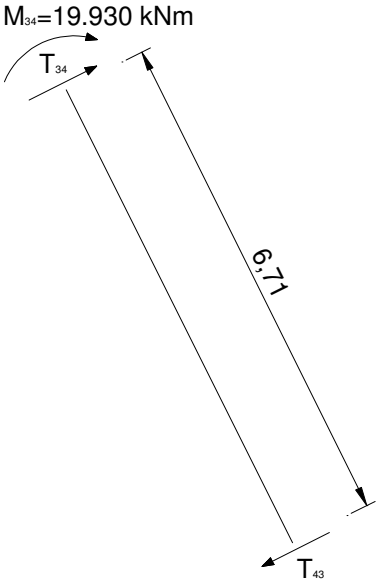


$$\sum M_0 = 0$$

$$T_{20} \cdot 6 + 40.5821 = 0$$

$$T_{20} = -6.764\,\text{kN}$$

$$T_{02} = T_{20} = -6.764\,\text{kN}$$



$$\sum M_3 = 0$$

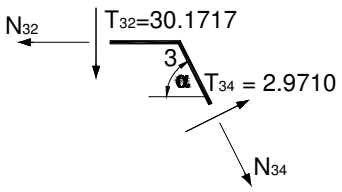
$$T_{43} \cdot 6.7082 + 19.9301 = 0$$

$$T_{43} = -2.9710\,\text{kN}$$

$$T_{34} = T_{43} = -2.9710\,\text{kN}$$

WYZNACZENIE WARTOŚCI SIŁ NORMALNYCH:

$\sin\alpha = 0.8944$; $\cos\alpha = 0.4472$



$\sum Y = 0$

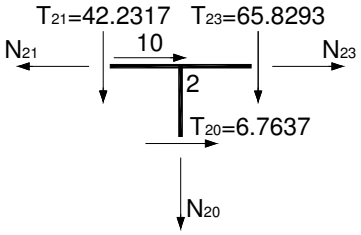
$-N_{34} \cdot \sin\alpha - 30.1707 + 2.9710 \cdot \cos\alpha = 0$

$N_{34} = -32.2464$ kN

$\sum X = 0$

$-N_{32} + 2.9710 \cdot \sin\alpha + N_{34} \cdot \cos\alpha = 0$

$N_{32} = -11.7637$ kN



$\sum Y = 0$

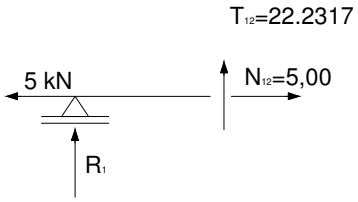
$-N_{20} - 42.2317 - 65.8293 = 0$

$N_{20} = -108.0610$ kN

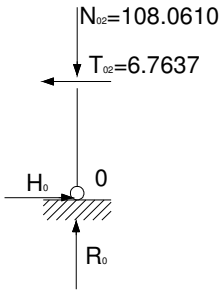
$\sum X = 0$

$-N_{21} + 6.7637 + N_{23} = 0$

$N_{21} = 5.00$ kN

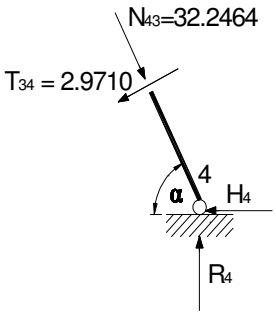


$R_1 = -22.2317$ kN



$R_0 = 108.0610$ kN

$H_0 = 6.7637$ kN



$\sum Y = 0$

$R_4 - 2.9710 \cdot \cos\alpha - 32.2464 \cdot \sin\alpha = 0$

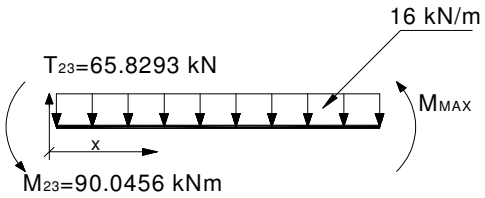
$R_4 = 30.1707$ kN

$\sum X = 0$

$-H_4 - 2.9710 \cdot \sin\alpha + 32.2464 \cdot \cos\alpha = 0$

$H_4 = 11.7637$ kN

WYZNACZENIE M_{max}

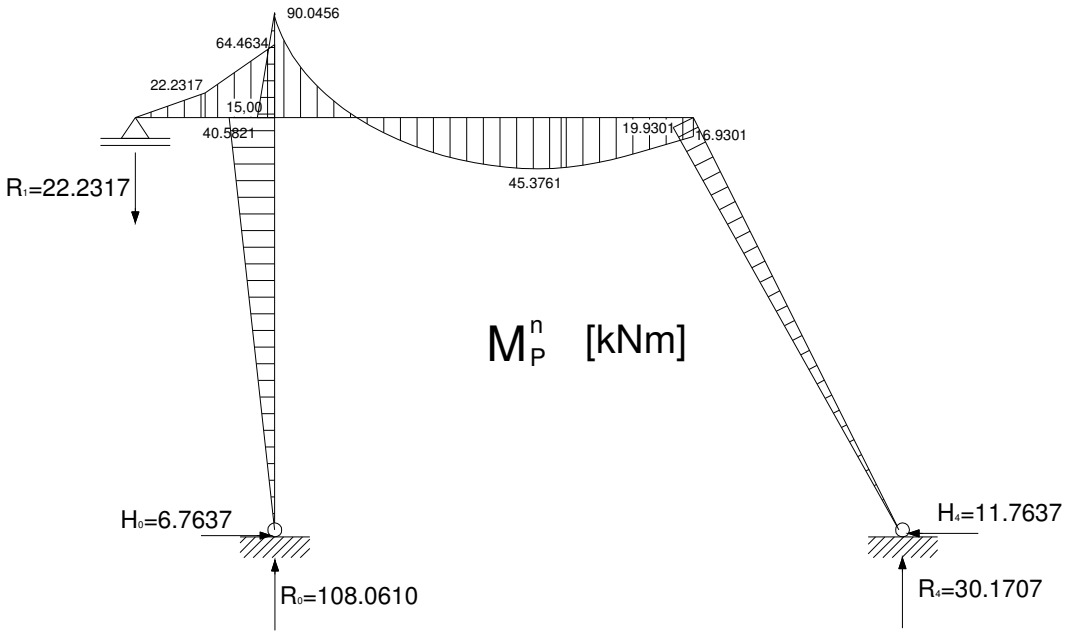


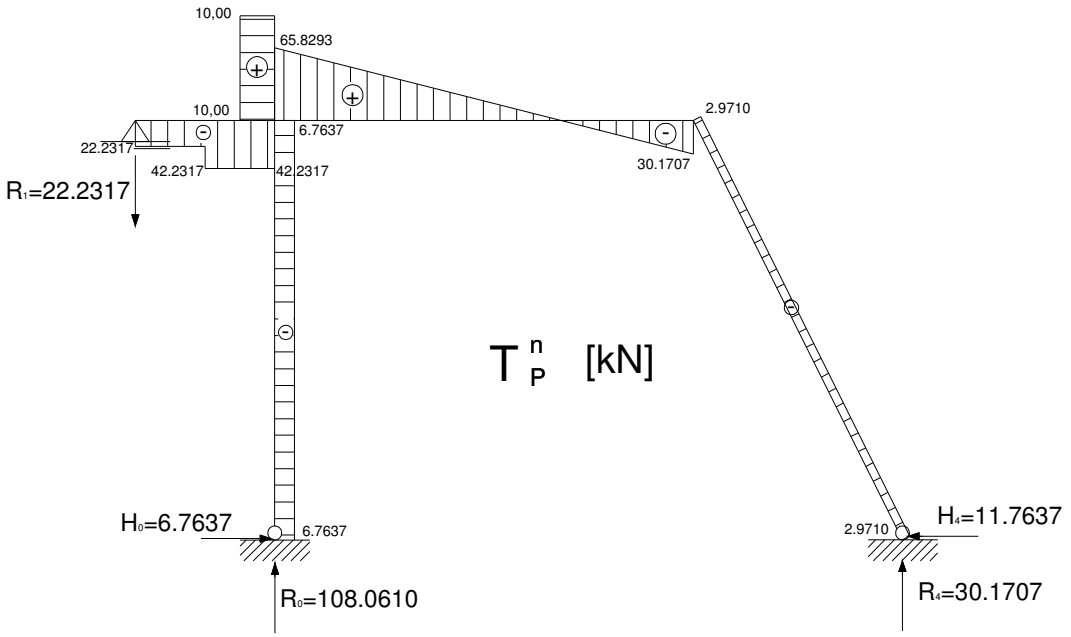
$\sum Y = 0$

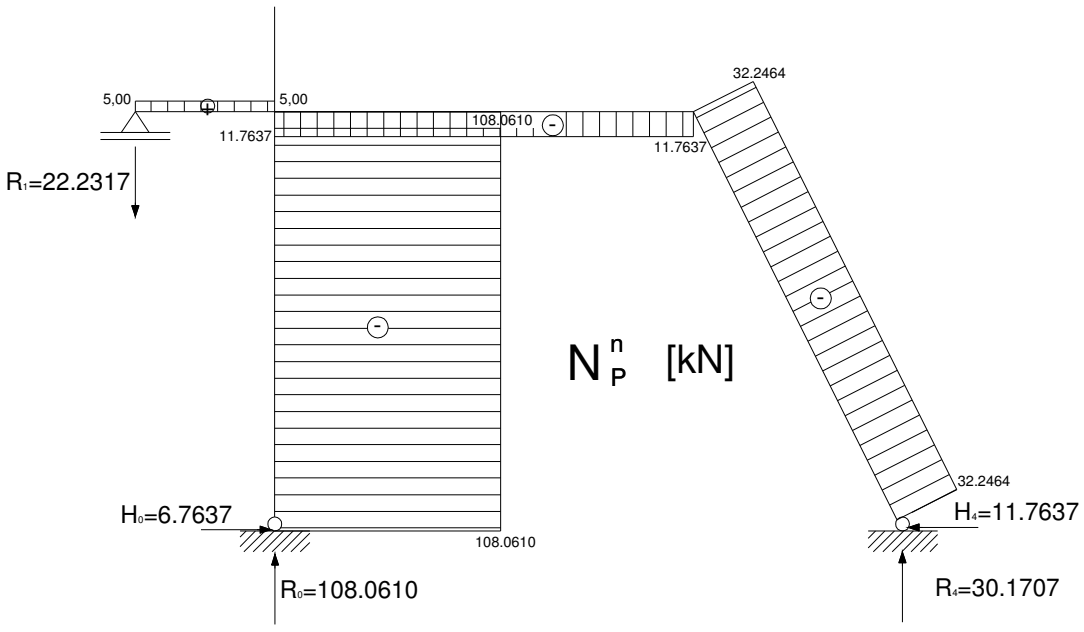
$65.8293 - 16 \cdot x = 0 \quad \Rightarrow \quad x = 45.3761$m

$M_{max} = -90.0456 + 65.8293 \cdot x - 16 \cdot \frac{x^2}{2}$

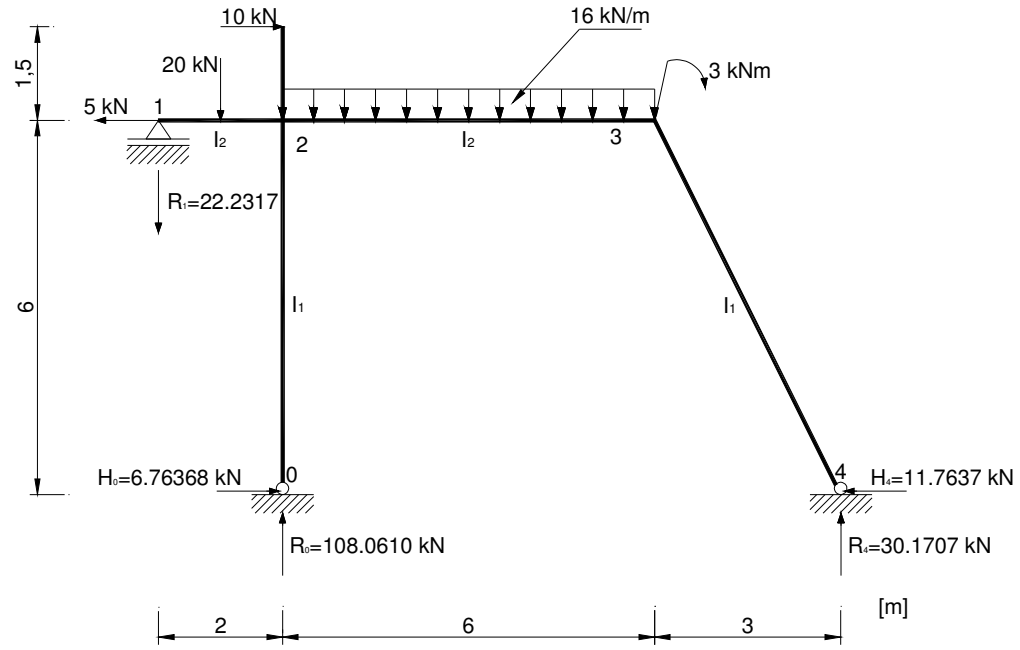
$M_{max} = 45.3761$ kNm


90.0456
64.4634
22.2317
15,00
40.5821
19.9301
16.9301
45.3761
R₁=22.2317
M_P^n [kNm]
H₀=6.7637
H₄=11.7637
R₀=108.0610
R₄=30.1707


10,00
65.8293
10,00
6.7637
2.9710
22.2317
42.2317
42.2317
30.1707
R₁=22.2317
T_P^n [kN]
H₀=6.7637
6.7637
2.9710
H₄=11.7637
R₀=108.0610
R₄=30.1707


32.2464
5,00
5,00
108.0610
11.7637
11.7637
R₁=22.2317
N_P^n [kN]
32.2464
H₀=6.7637
H₄=11.7637
108.0610
R₀=108.0610
R₄=30.1707

KONTROLA STATYCZNA



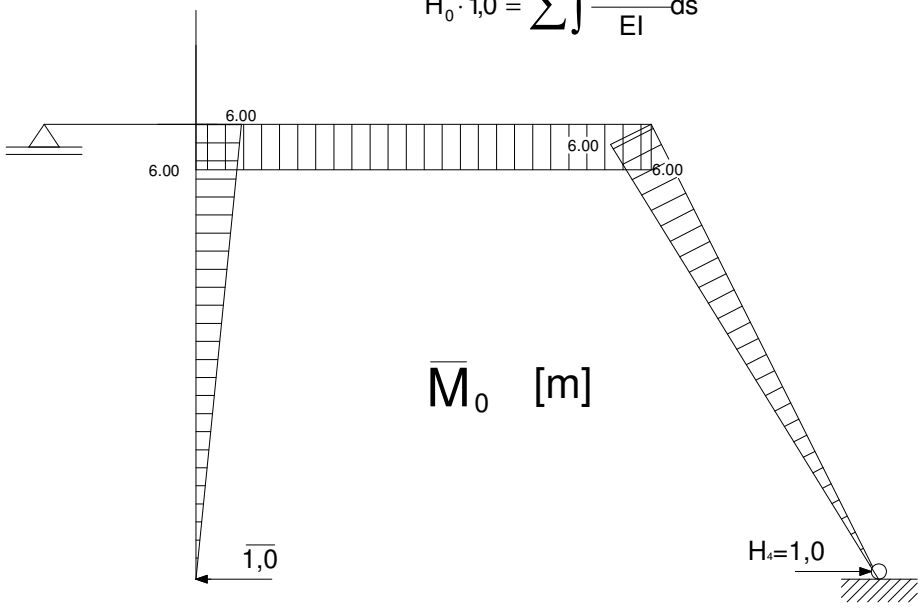
$\sum X = 0 \qquad -5 + 10 + 6.7637 - 11.7637 = 0 \quad \Rightarrow \quad \underline{0 = 0}$

$\sum X = 0 \qquad -22.2317 - 20 + 108.0610 - 16 \cdot 6 + 30.1707 = 0 \quad \Rightarrow \quad \underline{0 = 0}$

$\sum M_0 = 0 \qquad -5 \cdot 6 - 22.2317 \cdot 2 - 20 \cdot 1 + 10 \cdot 7{,}5 + 16 \cdot 6 \cdot 3 + 3 - 30.1707 \cdot 9 = 0 \quad \Rightarrow \quad \underline{0 = 0}$

KONTROLA KINEMATYCZNA

$$H_0 \cdot \overline{1{,}0} = \sum \int \frac{M_P^n \cdot \overline{M}}{EI} ds$$



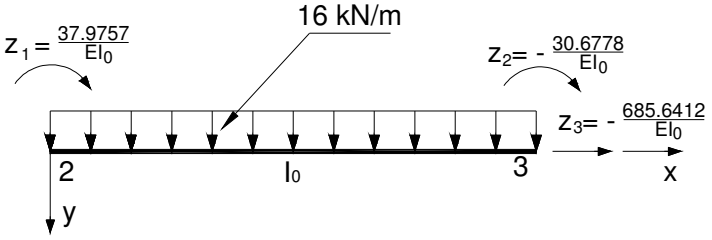
$$H_0 \cdot \overline{1{,}0} = \frac{1}{EI_0}\left[-\frac{1}{2} \cdot 6 \cdot 90.0456 \cdot 6 + \frac{1}{2} \cdot 6 \cdot 16.9301 \cdot 6 + \frac{2}{3} \cdot 6 \cdot \frac{16 \cdot 6^2}{8} \cdot 6\right] +$$

$$+ \frac{1}{0.5331EI_0}\left[-\frac{1}{2} \cdot 6 \cdot 40.5821 \cdot \frac{2}{3} \cdot 6 + \frac{1}{2} \cdot 6.7082 \cdot 19.9301 \cdot \frac{2}{3} \cdot 6\right]$$

$$H_0 \cdot \overline{1{,}0} = \frac{411.920613}{EI_0} + \frac{-219.595}{0.5331EI_0} = 0.0350 - 0.0350 = 1.38778E - 17 \approx 0{,}0$$

RÓWNANIE RÓŻNICZKOWE LINII UGIĘCIA

Równanie różniczkowe linii ugięcia dla pręta 2-3, q(x) = 16 kN/m



$$EI_0 \frac{d^4y}{dx^4} = q(x) \quad \Rightarrow \quad EI_0 \frac{d^4y}{dx^4} = 16$$

$$EI_0 \frac{d^3y}{dx^3} = -T(x) \quad \Rightarrow \quad EI_0 \frac{d^3y}{dx^3} = 16x + C$$

$$EI_0 \frac{d^2y}{dx^2} = -M(x) \quad \Rightarrow \quad EI_0 \frac{d^2y}{dx^2} = \frac{16}{2}x^2 + Cx + D$$

$$EI_0 \frac{dy}{dx} = \varphi(x) \quad \Rightarrow \quad EI_0 \frac{dy}{dx} = \frac{16}{2 \cdot 3}x^3 + \frac{1}{2}Cx^2 + Dx + E$$

$$EI_0 y = w(x) \quad \Rightarrow EI_0 y = \frac{16}{2 \cdot 3 \cdot 4}x^4 + \frac{1}{2 \cdot 3}Cx^3 + \frac{1}{2}Dx^2 + Ex + F$$

Warunki brzegowe:

1. $x = 0 \quad \varphi_2 = z_1 \quad z_1 = \frac{37.9757}{EI_0}$
2. $x = 0 \quad y_2 = 0$
3. $x = 0 \quad \varphi_3 = z_2 \quad z_2 = \frac{-30.6778}{EI_0}$
4. $x = 0 \quad y_3 = \Psi_{23} \cdot 6$

$$\Psi_{23} = -\frac{z_3}{12} \Rightarrow \Psi_{23} = \frac{-57.1368}{EI_0}$$

$$y_3 = \frac{-57.1368}{EI_0} \cdot 6 \Rightarrow y_3 = \frac{-342.8206}{EI_0}$$

$$37.9757 = \frac{16}{2 \cdot 3} \cdot 0^3 + \frac{1}{2}C \cdot 0^2 + D \cdot 0 + E \quad \Rightarrow \quad E = 37.9757$$

$$0 = \frac{16}{2 \cdot 3 \cdot 4}0^4 + \frac{1}{2 \cdot 3}C \cdot 0^3 + \frac{1}{2}D \cdot 0^2 + E \cdot 0 + F \quad \Rightarrow \quad F = 0$$

$$-30.6778 = \frac{16}{2 \cdot 3}6^3 + \frac{1}{2} \cdot 6^2 \cdot C + 6 \cdot D + 37.9757 \quad \Rightarrow \quad 18C + 6D = -644.6534$$

$$-342.8206 = \frac{16}{2 \cdot 3 \cdot 4} \cdot 6^4 + \frac{1}{2 \cdot 3} \cdot 6^3 \cdot C + \frac{1}{2} \cdot 6^2 D + 37.9757 \cdot 6 + 0 \quad \Rightarrow \quad 36C + 18D = -749.0333$$

$$18C + 6D = -644.6534 \quad \Rightarrow \quad C = -65.8293$$
$$36C + 18D = -749.0333 \quad \Rightarrow \quad D = 90.04559$$

$$M(0) = -\left(\frac{16}{2} \cdot 0^2 + -65.8293 \cdot 0 + 90.04559\right) = -90.0456 \text{ kN}$$

- rozciągane włókna górne

$$M(6) = -\left(\frac{16}{2} \cdot 6^2 - 65.8293 \cdot 6 + 90.04559\right) = 16.9301 \text{ kNm}$$

- rozciągane włókna dolne

Znakowanie wg zasady metody przemieszczeń

$M_{23} = -90.0456$ kNm - rozciągane włókna górne

$M_{32} = -16.9301$ kNm - rozciągane włókna dolne

$T(0) = -(16 \cdot 0 - 65.8293) = 65.8293\ kN$ $\quad T_{23} = 65.8293\ kN$

$T(6) = -(16 \cdot 6 - 65.8293) = -30.17072\ kN$ $\quad T_{32} = -30.1707\ kN$

SPRAWDZENIE NAPRĘŻEŃ NORMALNYCH WYWOŁANYCH MOMENTEM ZGINAJĄCYM

$$\sigma_{max} \le \sigma_{dop}$$

$$\sigma_{max} = \frac{M_{max}}{W} \le \sigma_{dop} = 205MPa$$

Pręty grupy 1 I220 $(W_x = 278.18\ cm^3, I_x = 3060\ cm^4)$

$$M_{max} = 40.5821\,kNm$$

$$\sigma_{max} = \frac{4058.21}{278.18} = 14.5884\ kN/cm^2$$

$$\sigma_{max} = 14.5884\,kN/cm^2 \le \sigma_{dop} = 20{,}5kN/cm^2$$

Pręty grupy 2 I260 $(W_x = 441.54\ cm^3, I_x = 5740\ cm^4)$

$$M_{max} = 90.0456\ kNm$$

$$\sigma_{max} = \frac{9004.56}{441.54} = 20.3935\ kN/cm^2$$

$$\sigma_{max} = 20.3935kN/cm^2 \le \sigma_{dop} = 20{,}5kN/cm^2$$