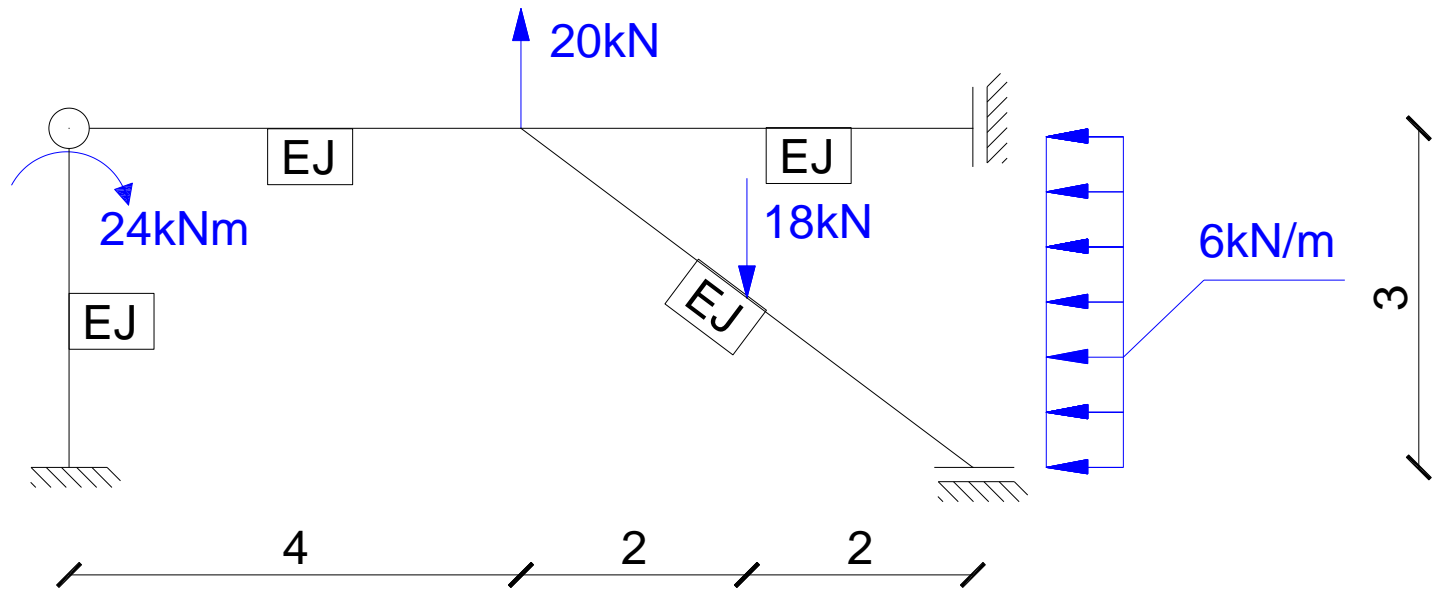
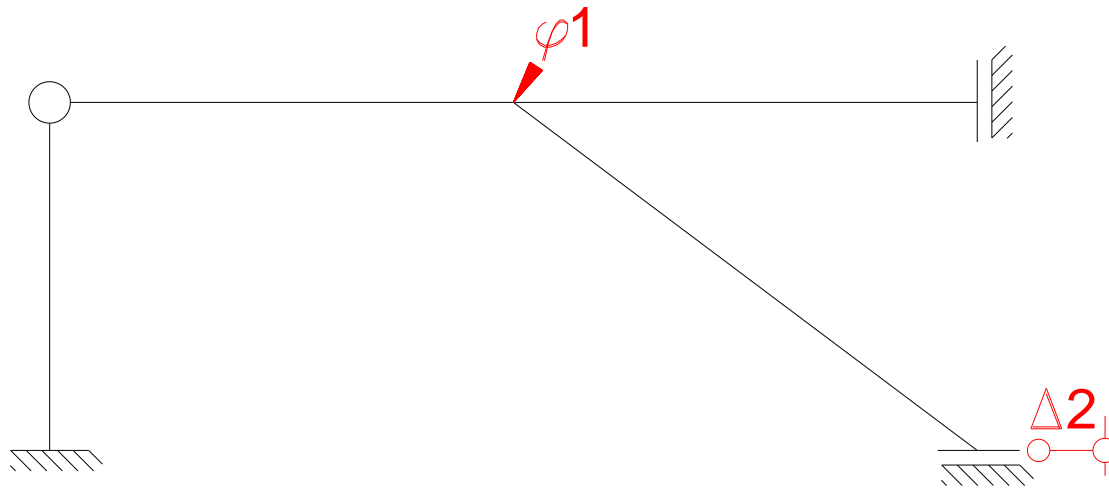


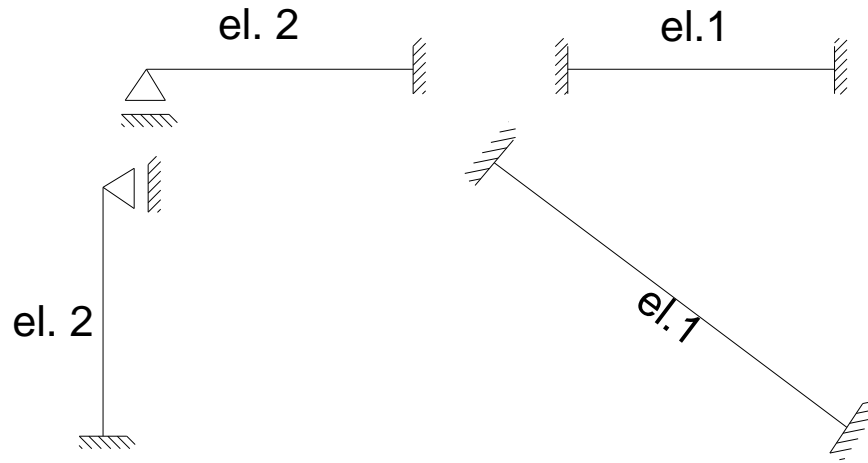
Wyznaczanie wykresów sił N,T,M dla ramy statycznie niewyznaczalnej z prętem ukośnym metodą przemieszczeń.



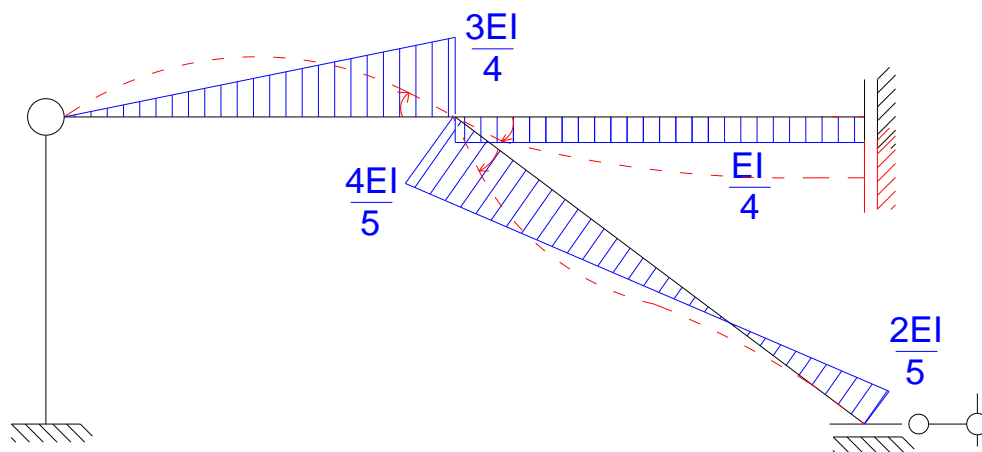
Schemat podstawowy i podział na elementy:



$$n_g = 2(\varphi_1, \Delta_2)$$

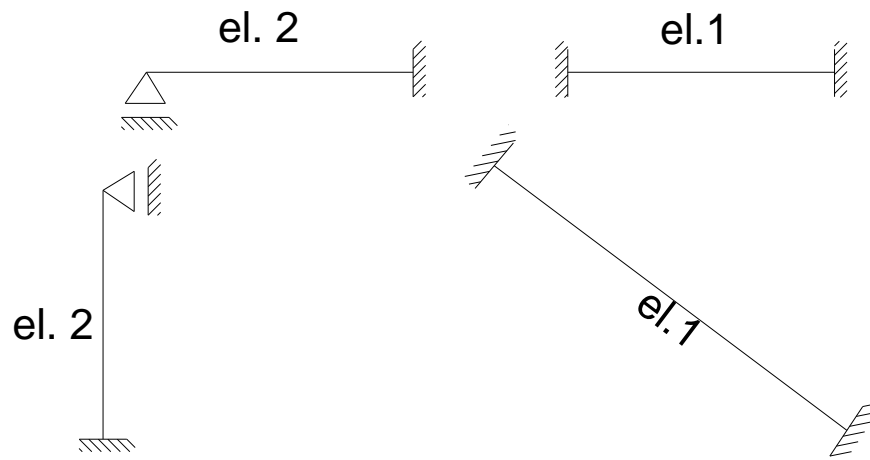


Stan $\varphi_1=1$

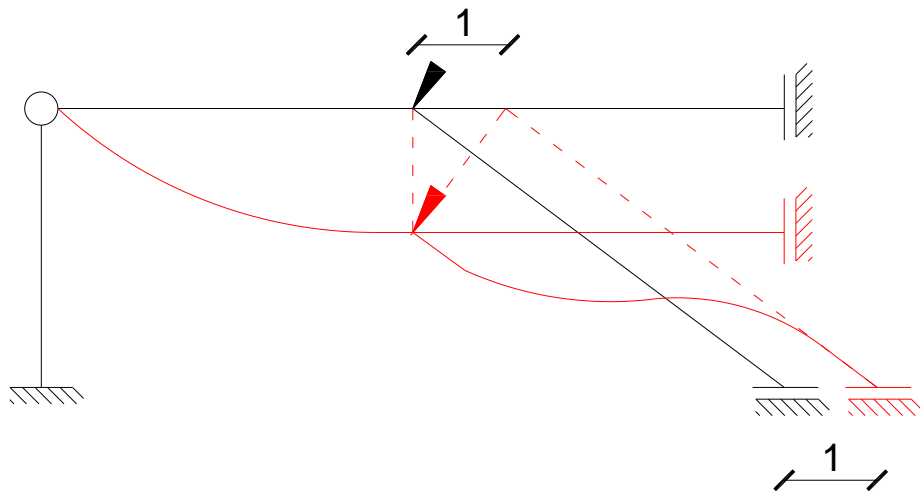


$$k_{11} = \frac{9EI}{5}$$

$$k_{21} = \frac{3EI}{20}$$

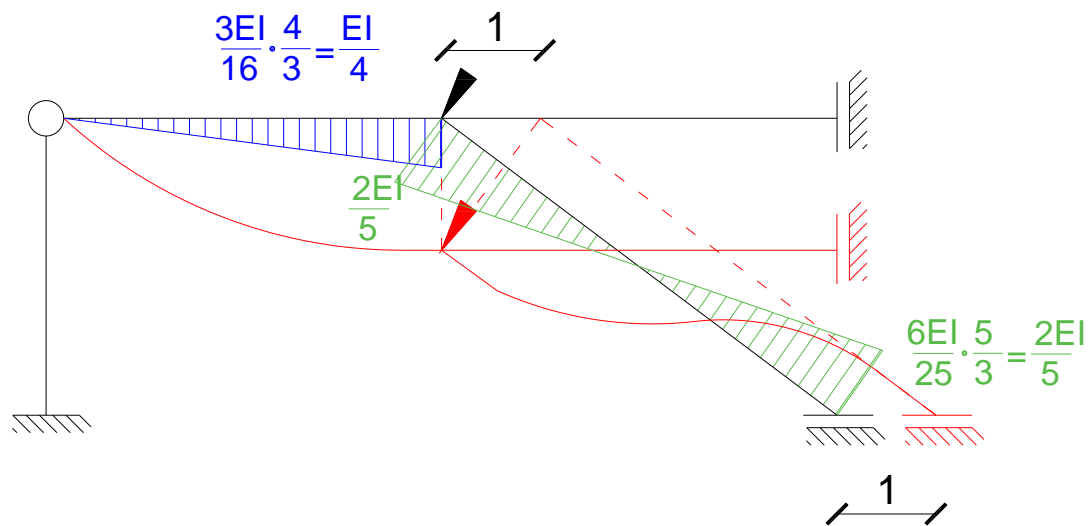
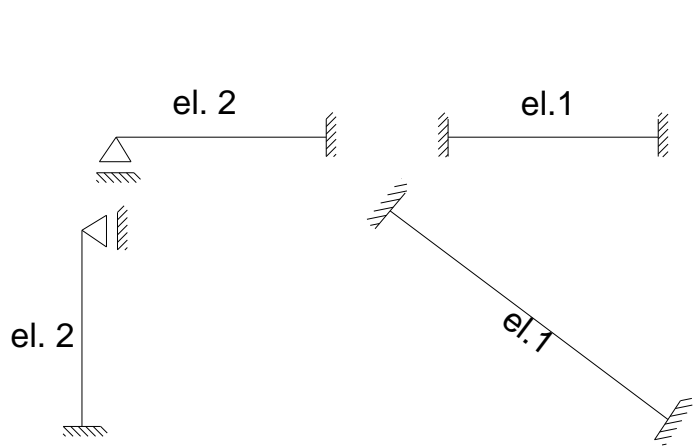


Stan $\Delta 2=1$

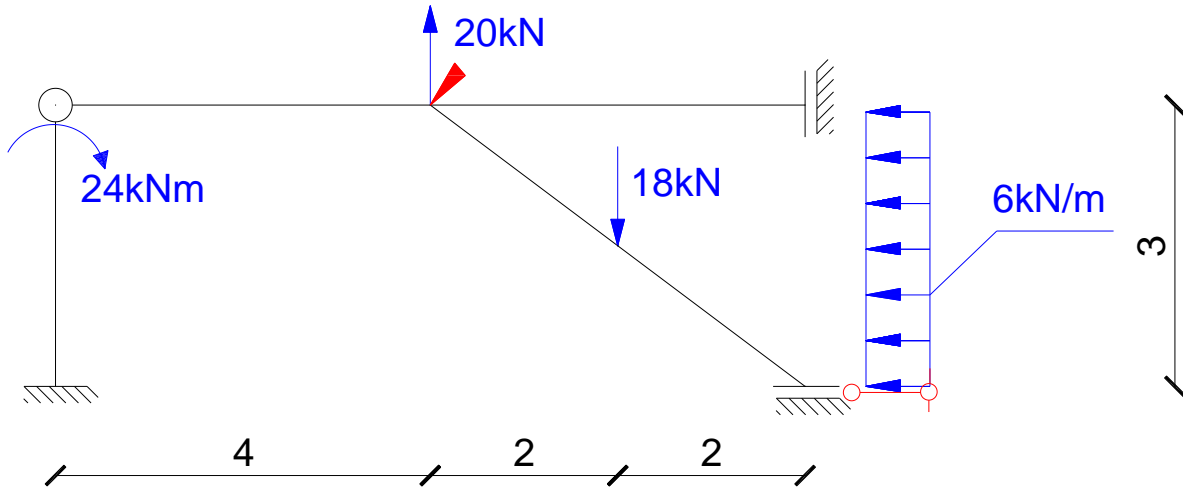


$$k_{22} = \frac{7EI}{20}$$

$$k_{12} = \frac{3EI}{20}$$

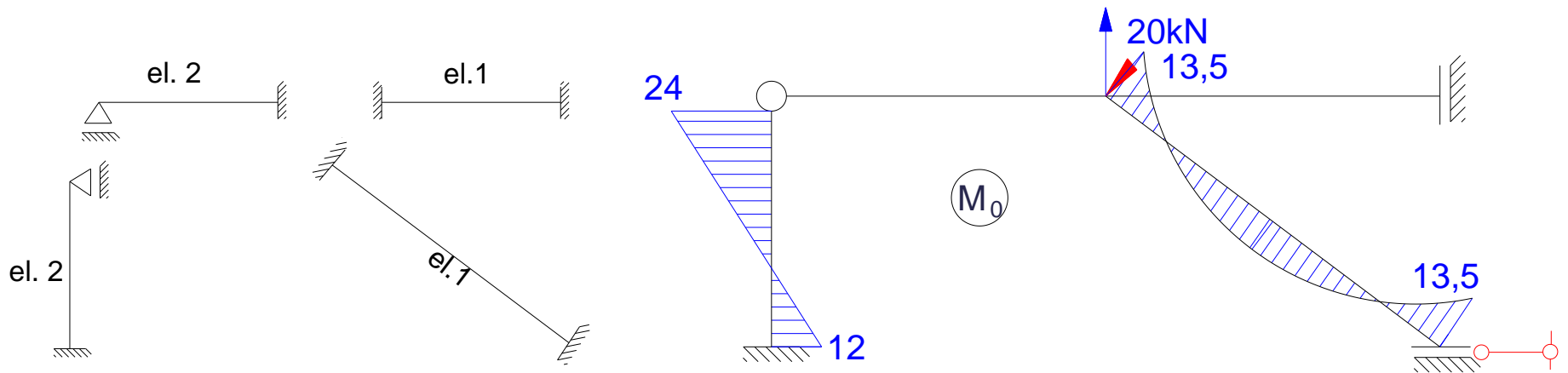


Obciążenie zewnętrzne



$$k_{10} = -13,5 \text{ kNm}$$

$$k_{20} = \frac{71}{3} \text{ kN}$$



Układ równań kanonicznych metody przemieszczeń:

$$k_{11} \cdot \varphi_1 + k_{12} \cdot \Delta_2 + k_{10} = 0$$

$$k_{21} \cdot \varphi_1 + k_{22} \cdot \Delta_2 + k_{20} = 0$$

$$\frac{9EI}{5} \cdot \varphi_1 + \frac{3EI}{20} \cdot \Delta_2 - 13,5 = 0$$

$$\frac{3EI}{20} \cdot \varphi_1 + \frac{7EI}{20} \cdot \Delta_2 + \frac{71}{3} = 0$$



$$\varphi_1 = \frac{13,62}{EI}$$

$$\Delta_2 = -\frac{73,46}{EI}$$

Wyznaczenie końcowego wykresu momentów:

$$M_i = M_i^{\varphi_1=1} \cdot \varphi_1 + M_i^{\Delta_1=1} \cdot \Delta_2 + M_{i0}$$

Końcowy wykres momentów:

$$k_{11} \cdot \varphi_1 + k_{12} \cdot \Delta_2 + k_{10} = 0$$

$$k_{21} \cdot \varphi_1 + k_{22} \cdot \Delta_2 + k_{20} = 0$$

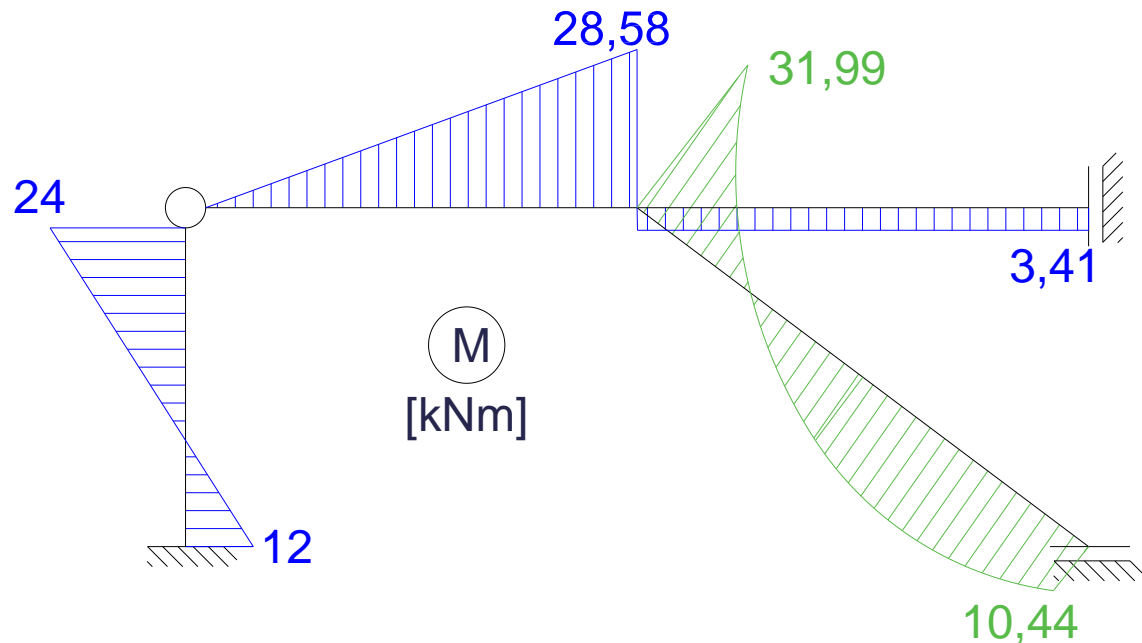
$$\frac{9EI}{5} \cdot \varphi_1 + \frac{3EI}{20} \cdot \Delta_2 - 13,5 = 0$$

$$\frac{3EI}{20} \cdot \varphi_1 + \frac{7EI}{20} \cdot \Delta_2 + \frac{71}{3} = 0$$



$$\varphi_1 = \frac{13,62}{EI}$$

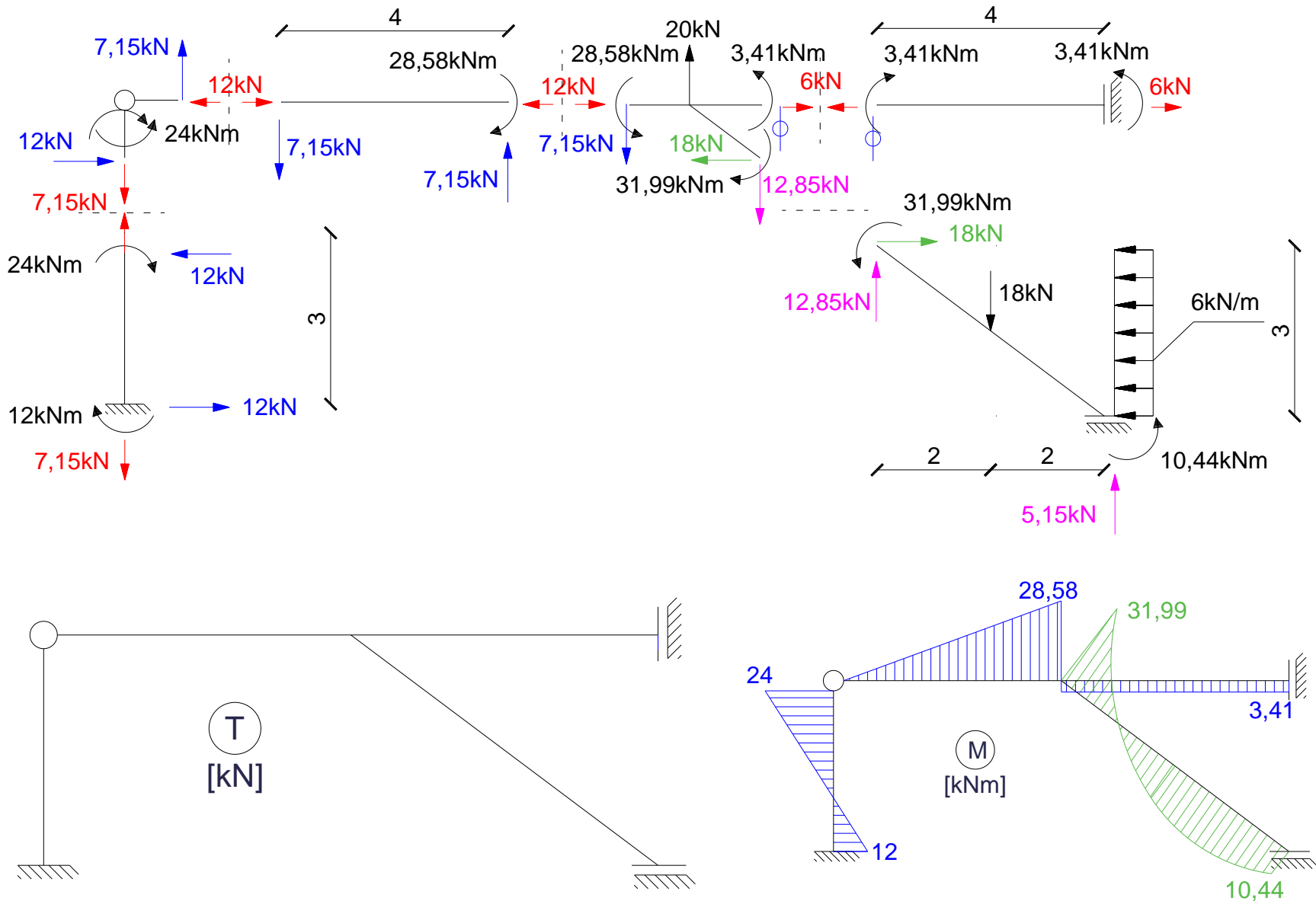
$$\Delta_2 = -\frac{73,46}{EI}$$



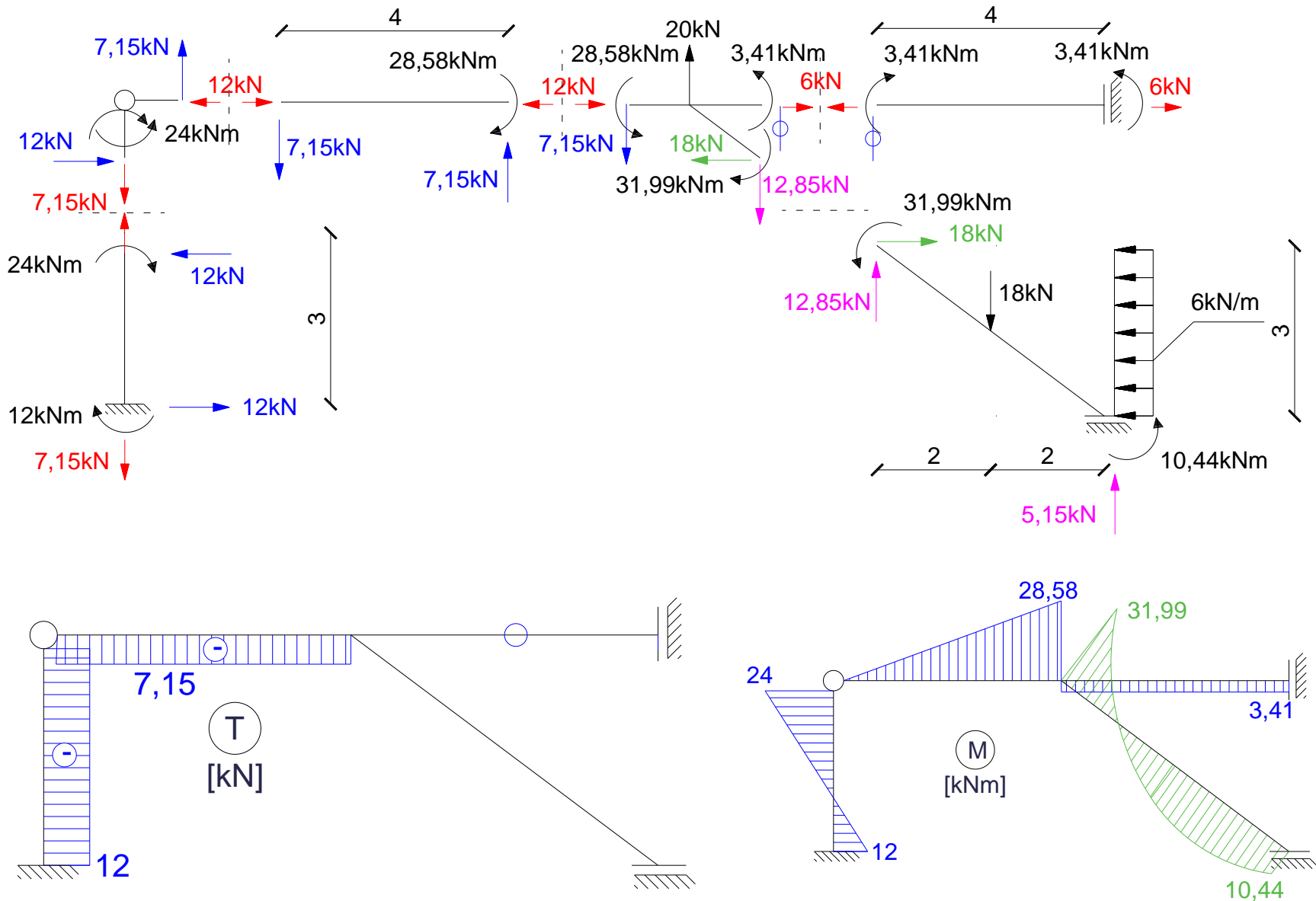
Wyznaczenie końcowego wykresu momentów:

$$M_i = M_i^{\varphi_1=1} \cdot \varphi_1 + M_i^{\Delta_1=1} \cdot \Delta_2 + M_{i0}$$

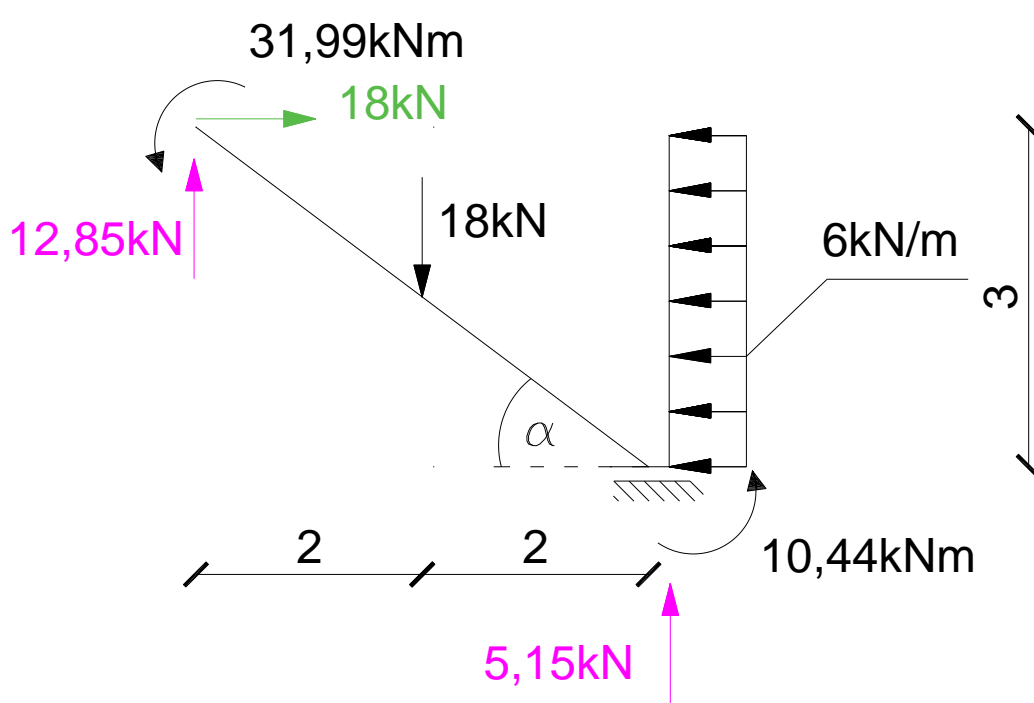
Wyznaczenie wykresu sił T i N na podstawie wykresu M



Wyznaczenie wykresu sił T i N na podstawie wykresu M

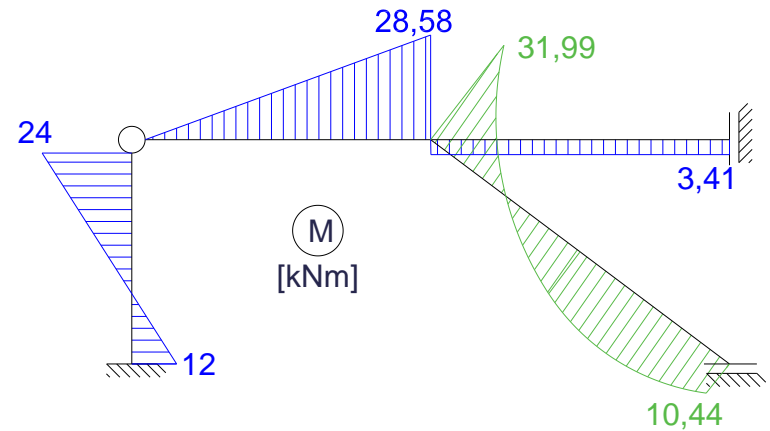
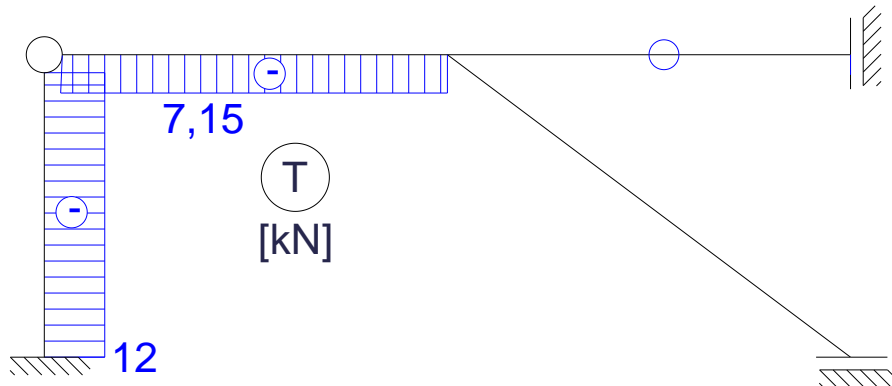


Wyznaczenie wykresu sił T i N na podstawie wykresu M

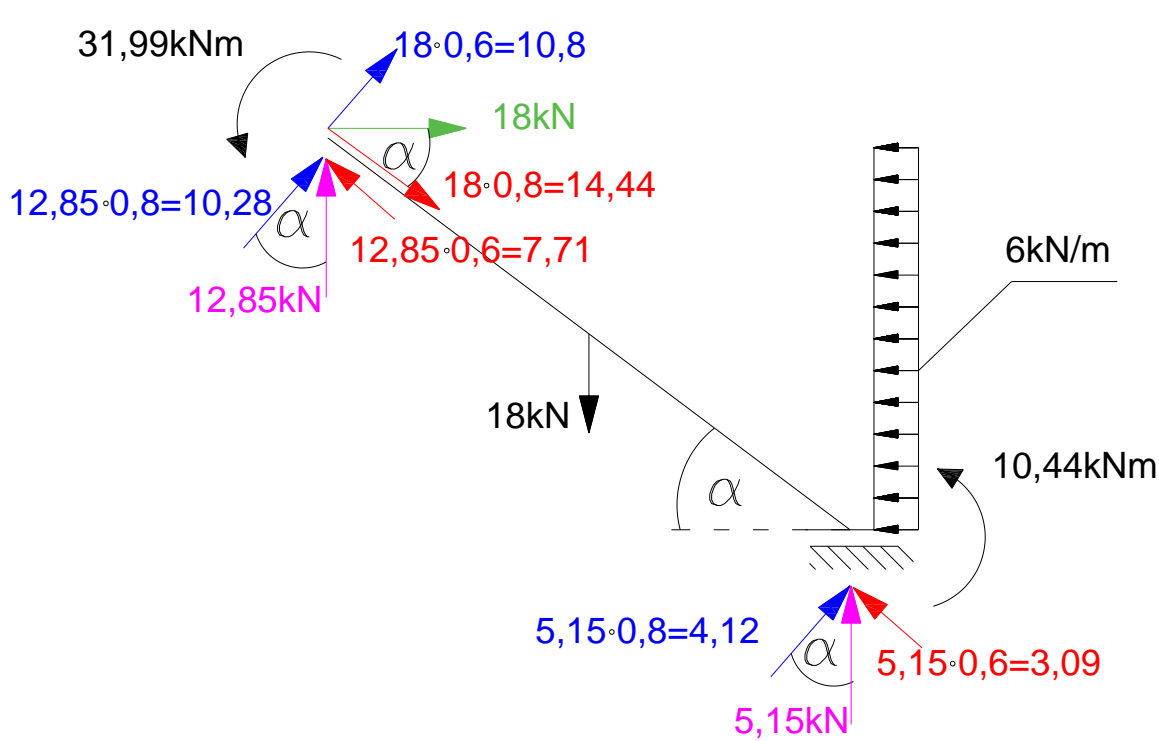


$$\cos \alpha = \frac{4}{5} = 0,8$$

$$\sin \alpha = \frac{3}{5} = 0,6$$

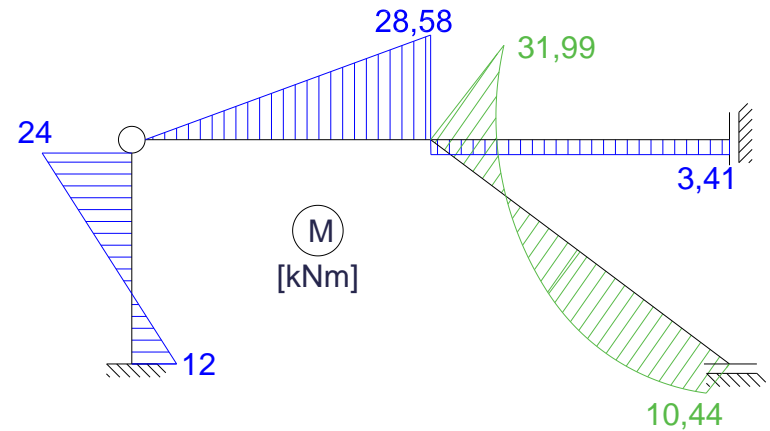
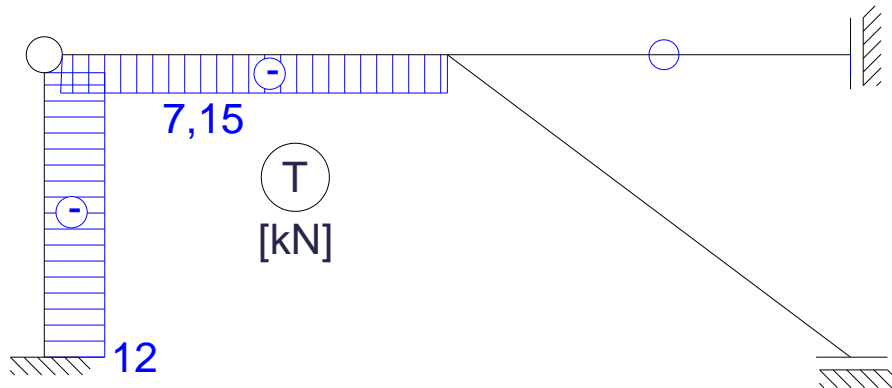


Wyznaczenie wykresu sił T i N na podstawie wykresu M

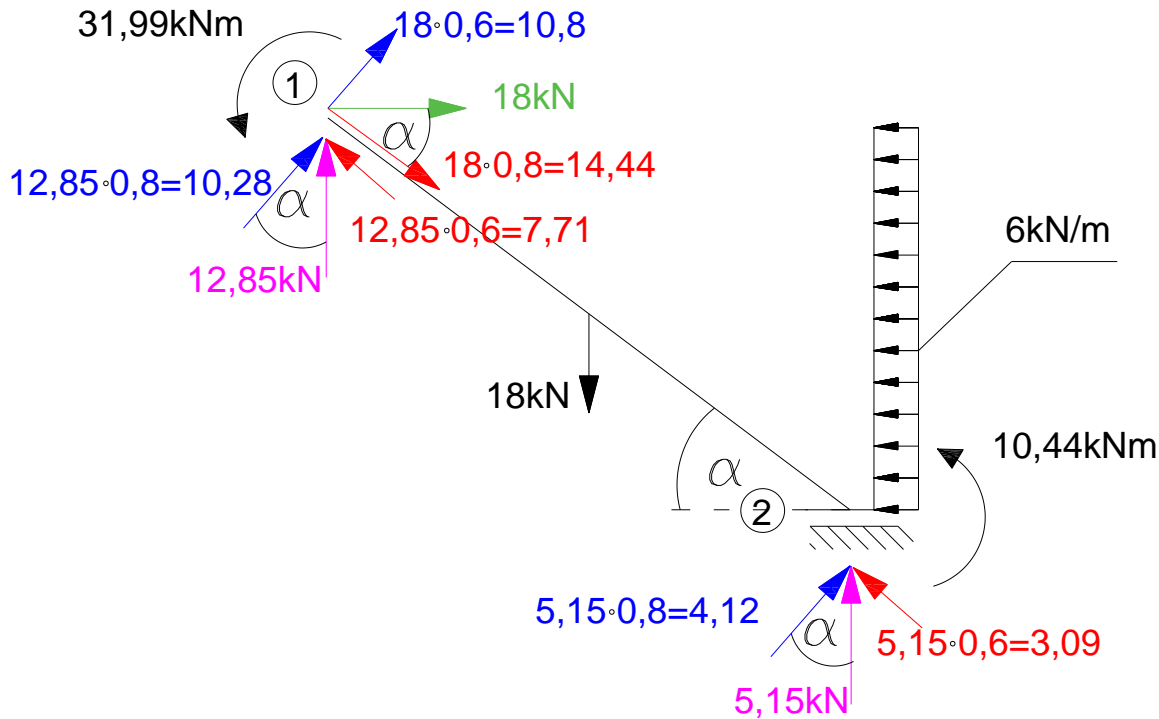


$$\cos \alpha = \frac{4}{5} = 0,8$$

$$\sin \alpha = \frac{3}{5} = 0,6$$



Wyznaczenie wykresu sił T i N na podstawie wykresu M

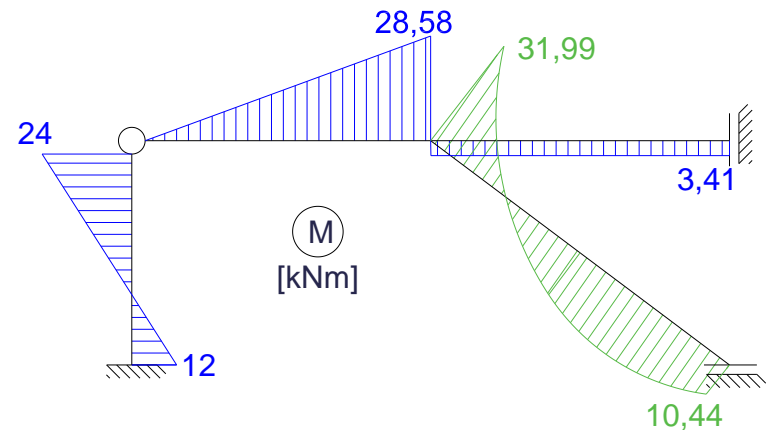
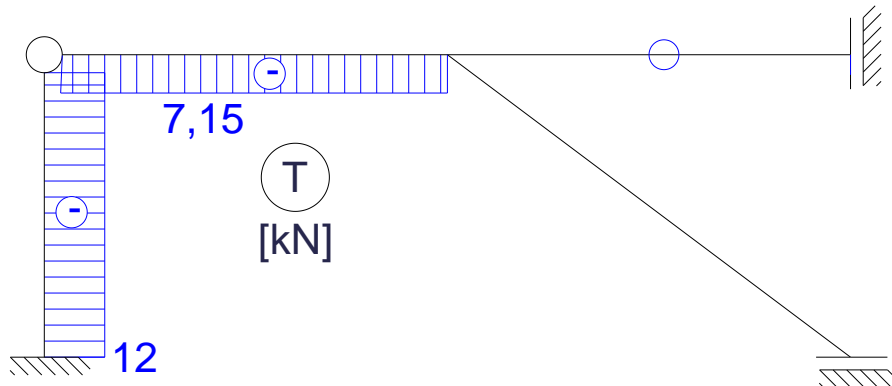


$$T_1 = 10,28 + 10,8 = 21,08 \text{ kN}$$

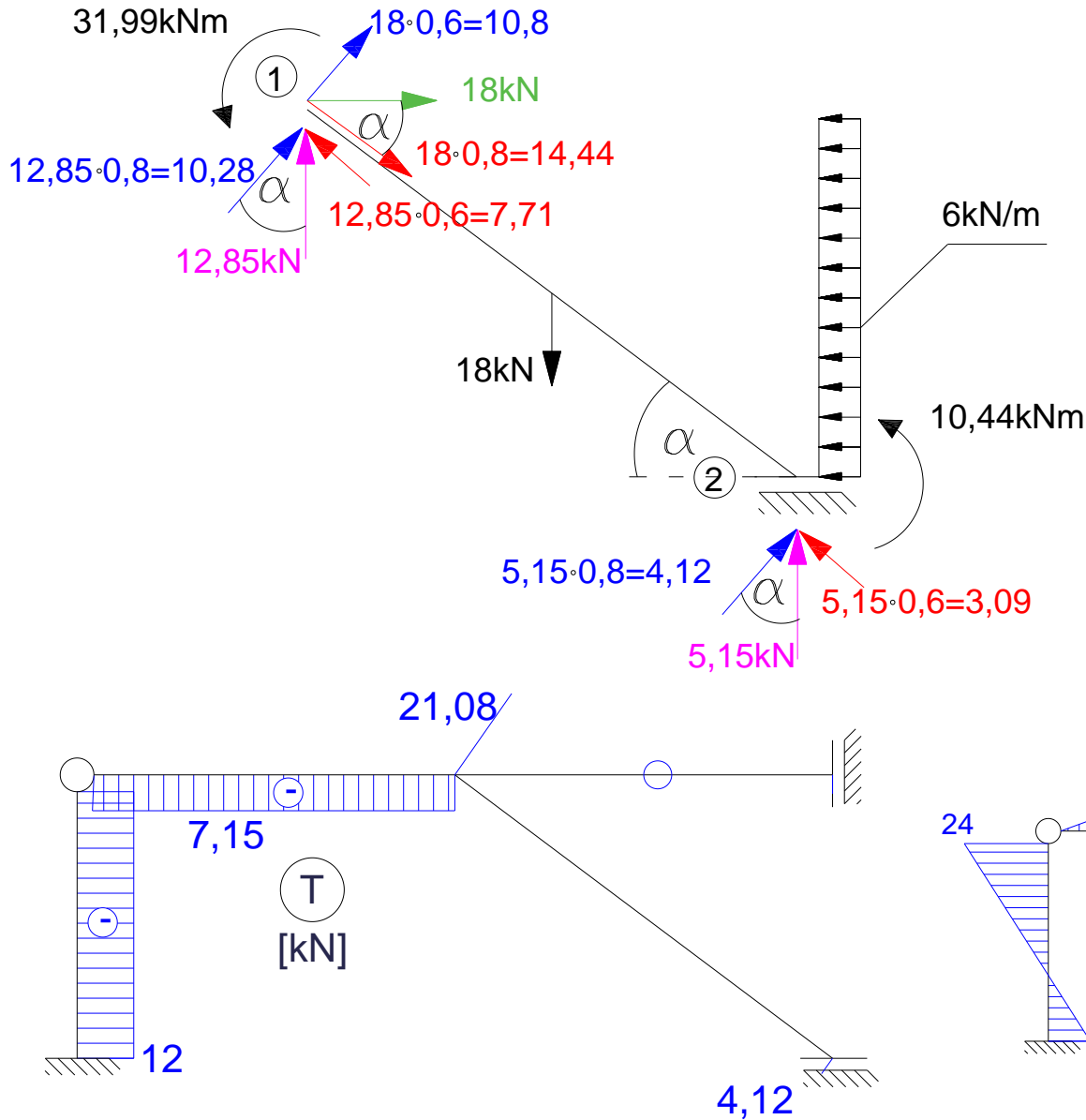
$$N_1 = 7,71 - 14,44 = -6,69 \text{ kN}$$

$$T_2 = -4,12 \text{ kN}$$

$$N_2 = -3,09 \text{ kN}$$



Wyznaczenie wykresu sił T i N na podstawie wykresu M

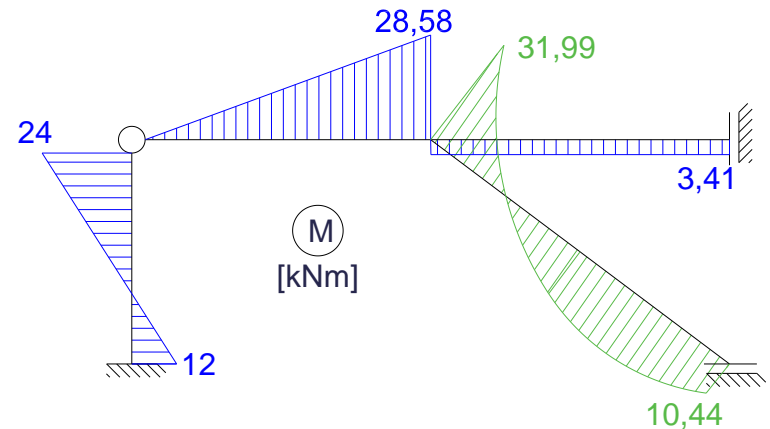


$$T_1 = 10,28 + 10,8 = 21,08 \text{ kN}$$

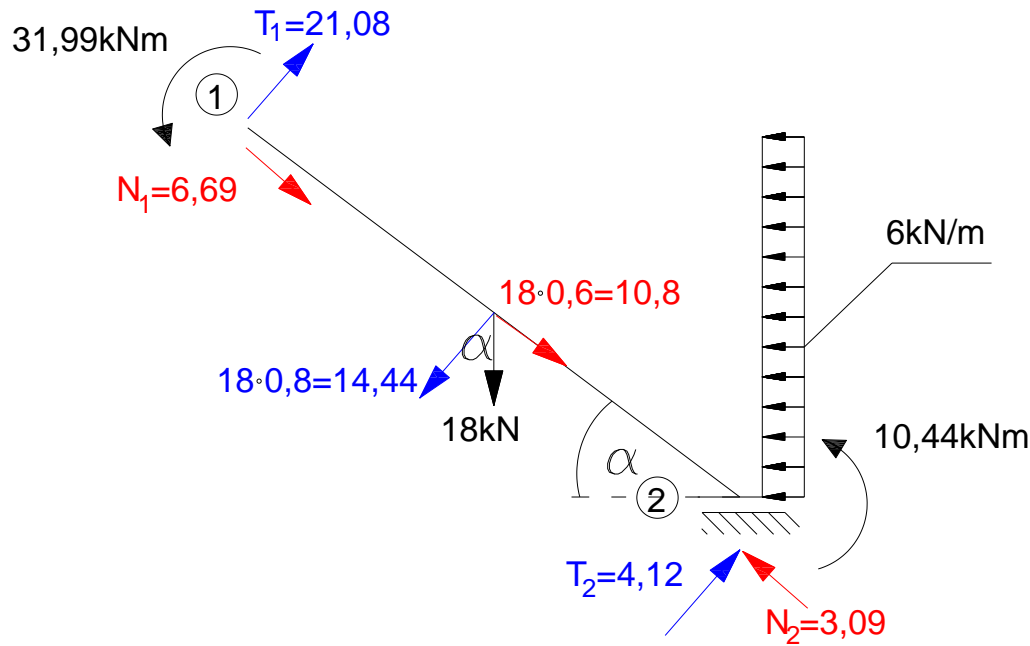
$$N_1 = 7,71 - 14,44 = -6,69 \text{ kN}$$

$$T_2 = -4,12 \text{ kN}$$

$$N_2 = -3,09 \text{ kN}$$



Wyznaczenie wykresu sił T i N na podstawie wykresu M

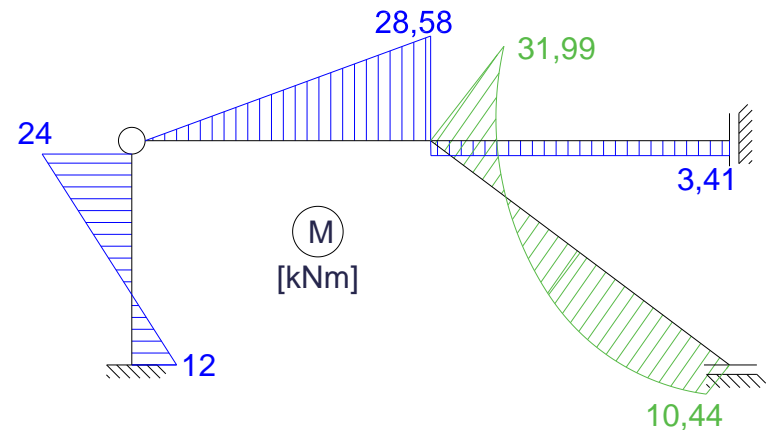
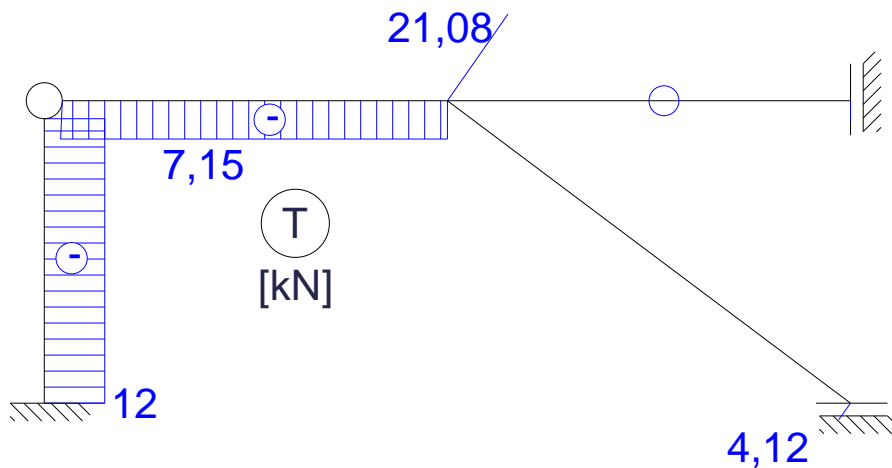


$$T_1 = 10,28 + 10,8 = 21,08 \text{ kN}$$

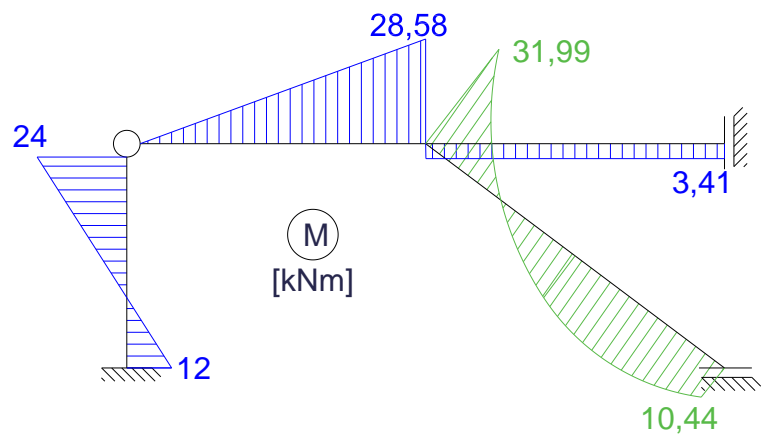
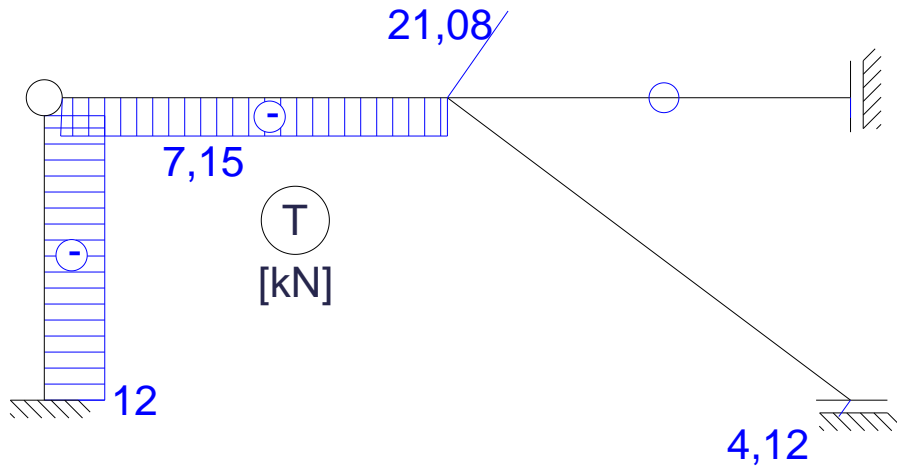
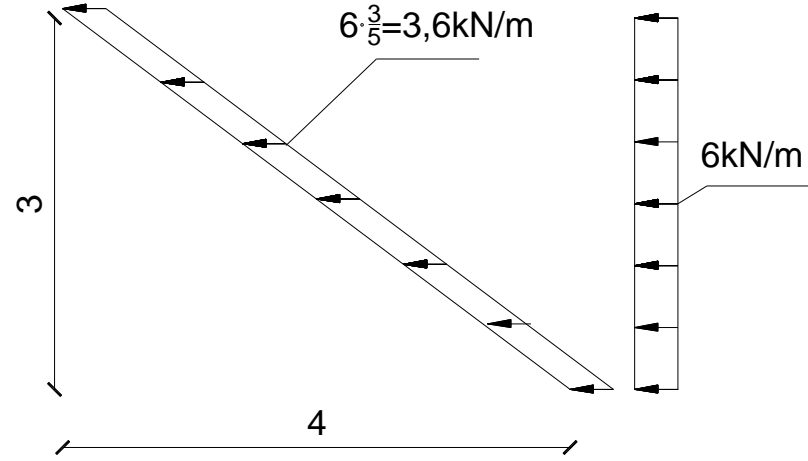
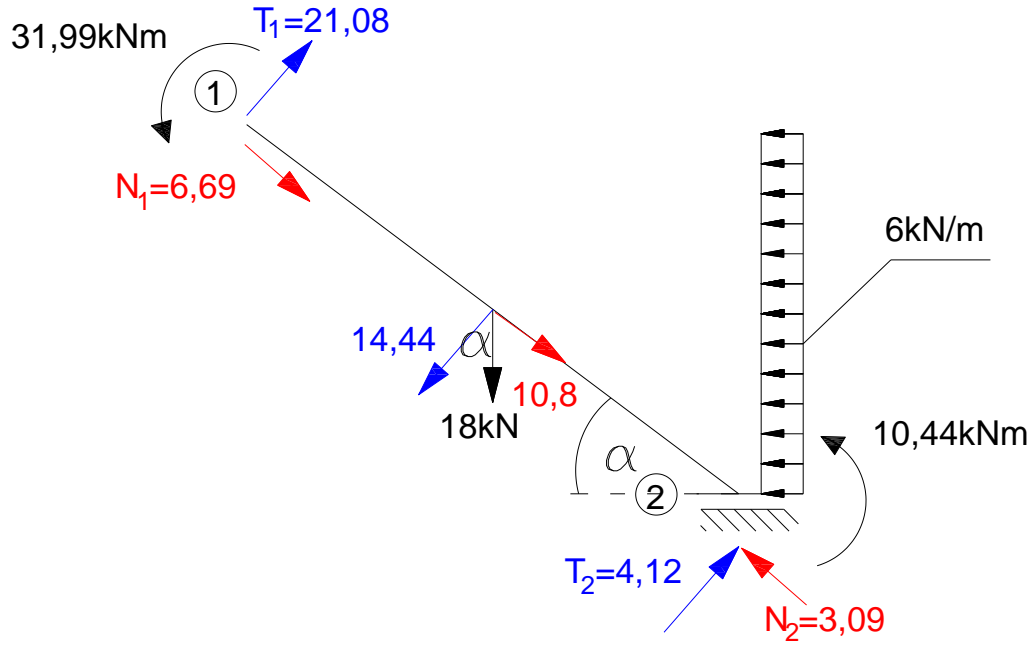
$$N_1 = 7,71 - 14,44 = -6,69 \text{ kN}$$

$$T_2 = -4,12 \text{ kN}$$

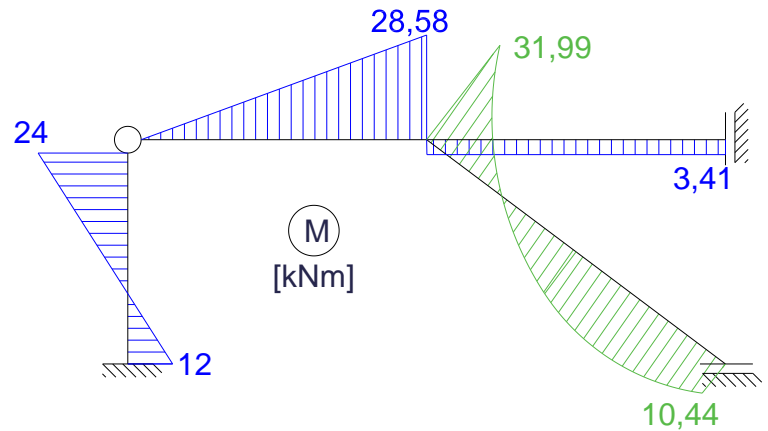
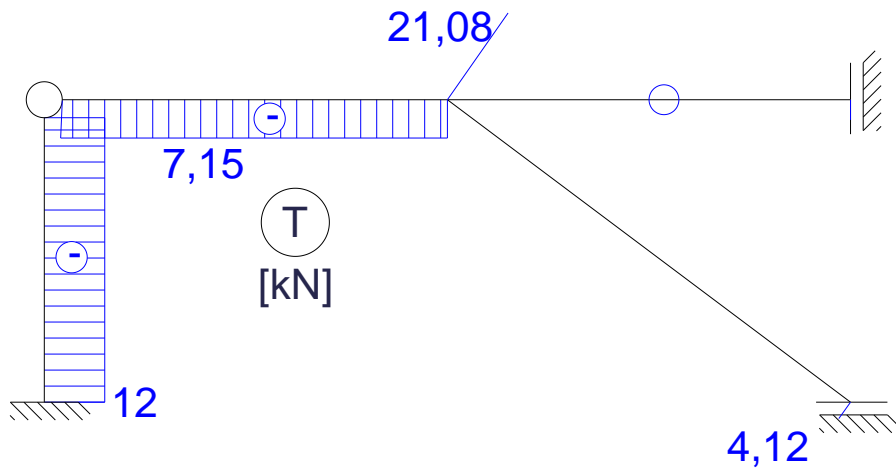
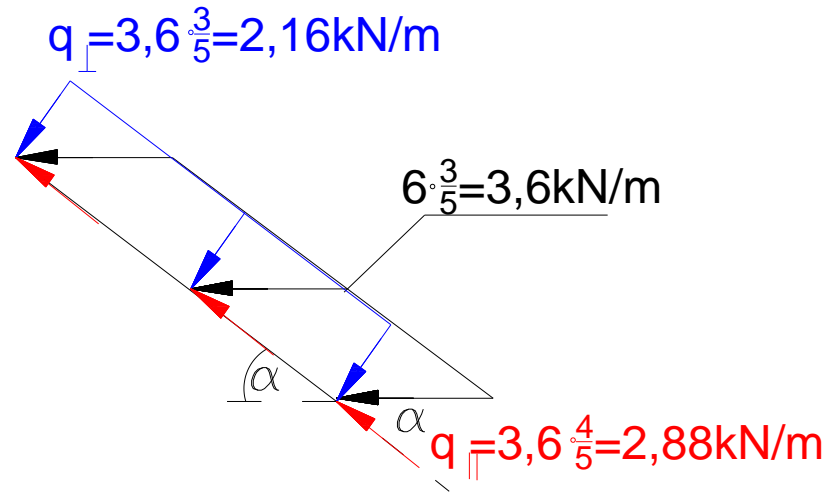
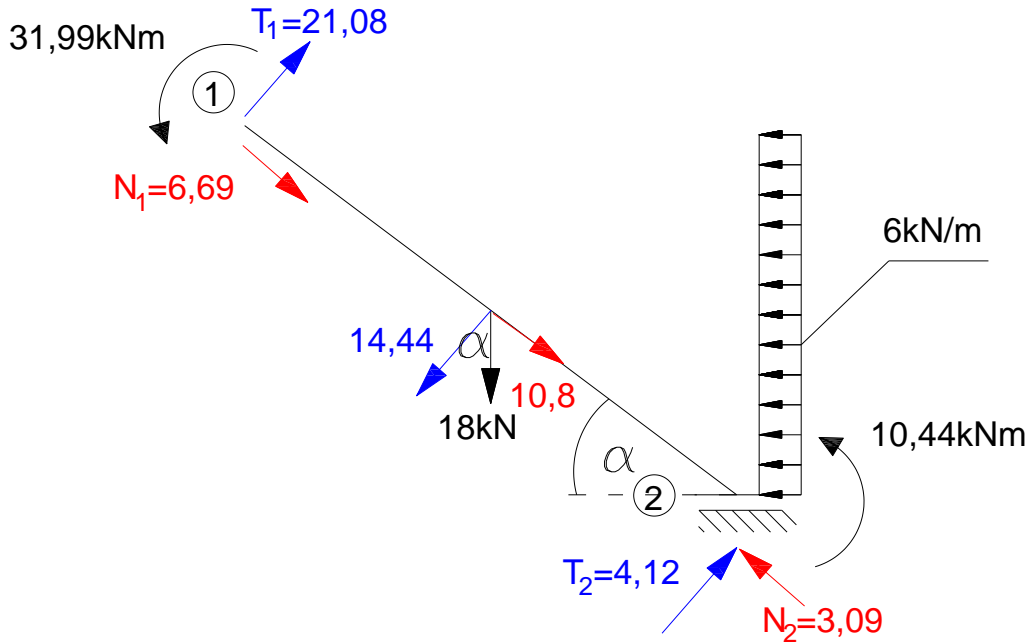
$$N_2 = -3,09 \text{ kN}$$



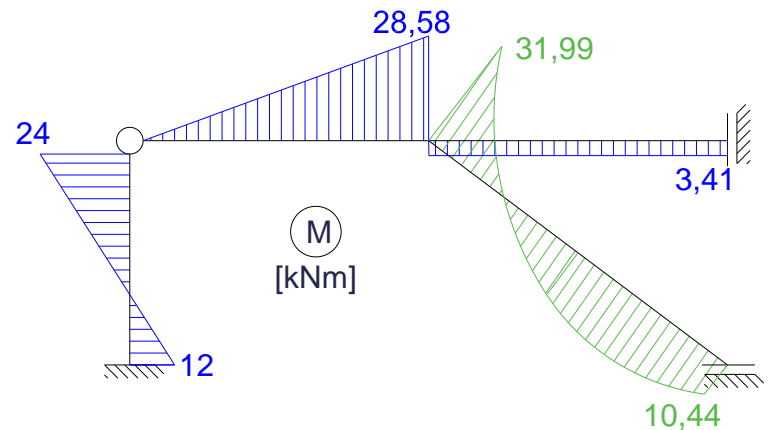
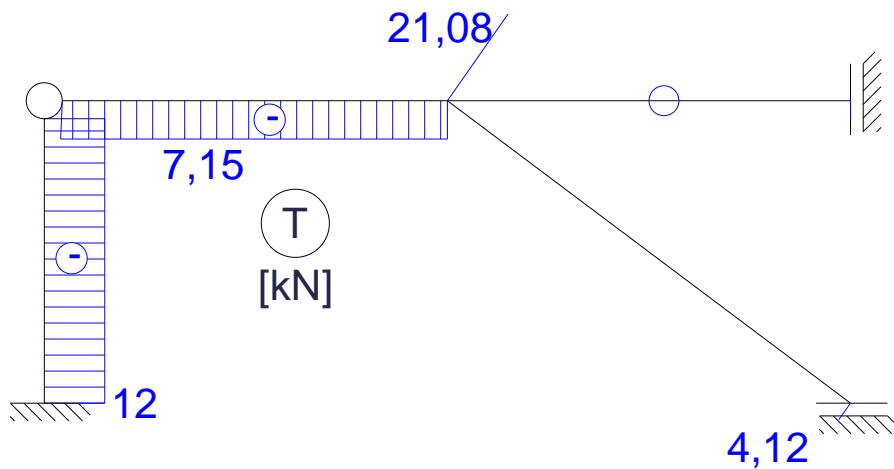
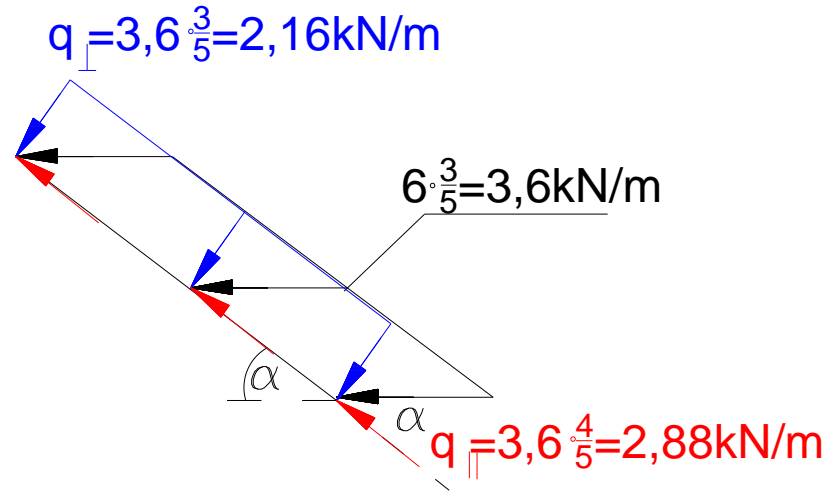
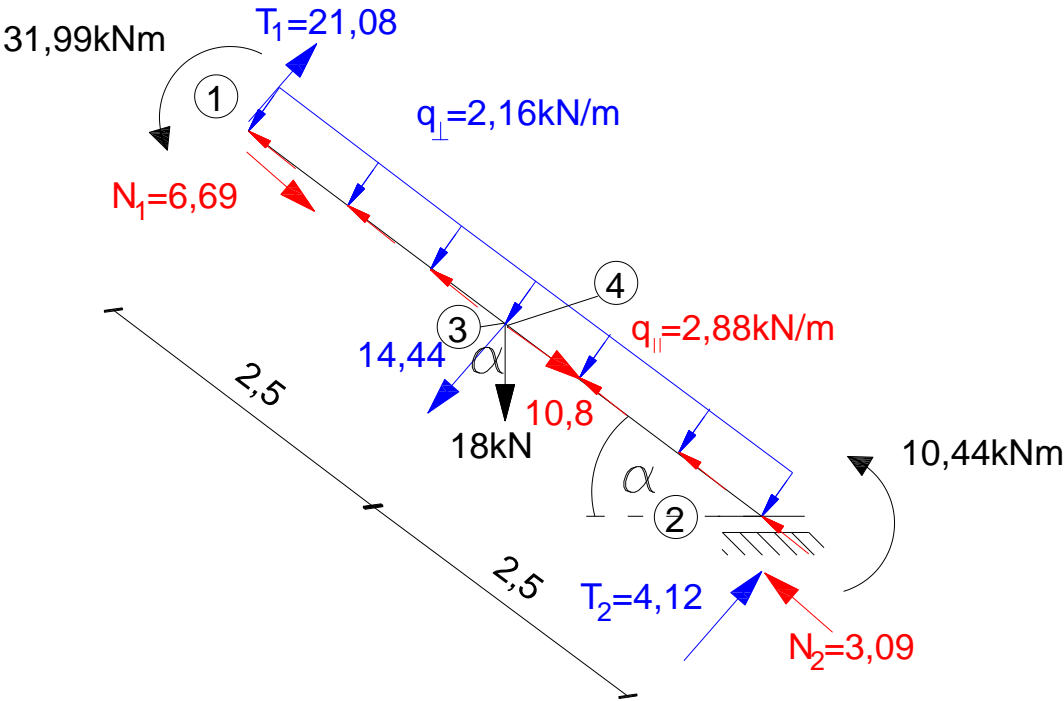
Wyznaczenie wykresu sił T i N na podstawie wykresu M



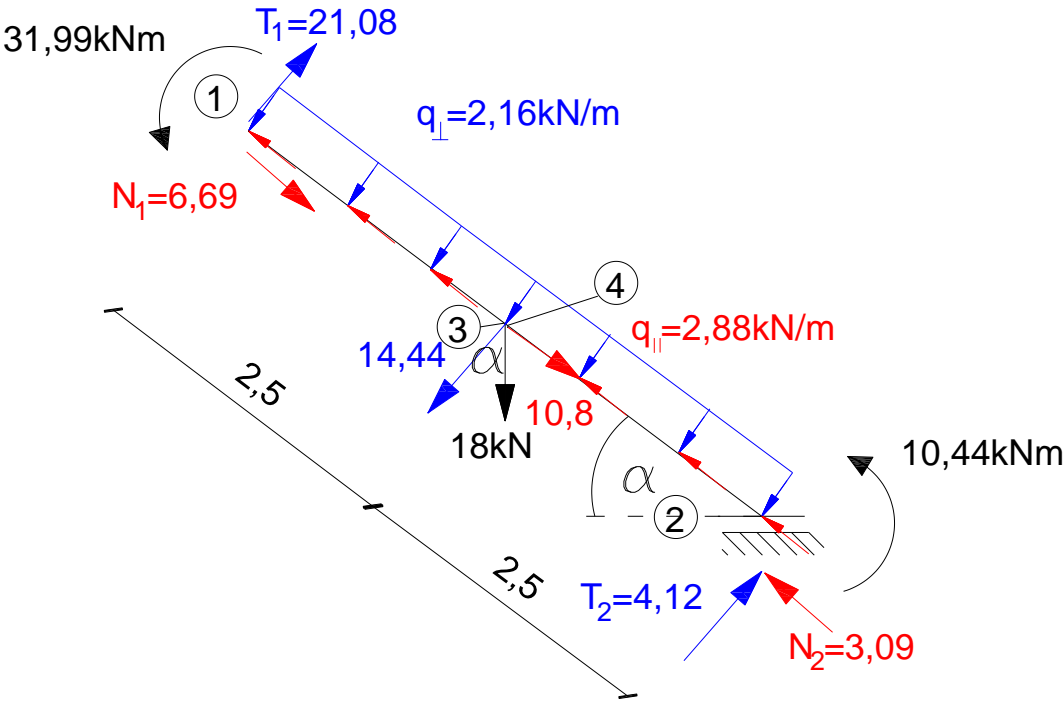
Wyznaczenie wykresu sił T i N na podstawie wykresu M



Wyznaczenie wykresu sił T i N na podstawie wykresu M



Wyznaczenie wykresu sił T i N na podstawie wykresu M



$$T_1 = 10,28 + 10,8 = 21,08 \text{ kN}$$

$$N_1 = 7,71 - 14,44 = -6,69 \text{ kN}$$

$$T_2 = -4,12 \text{ kN}$$

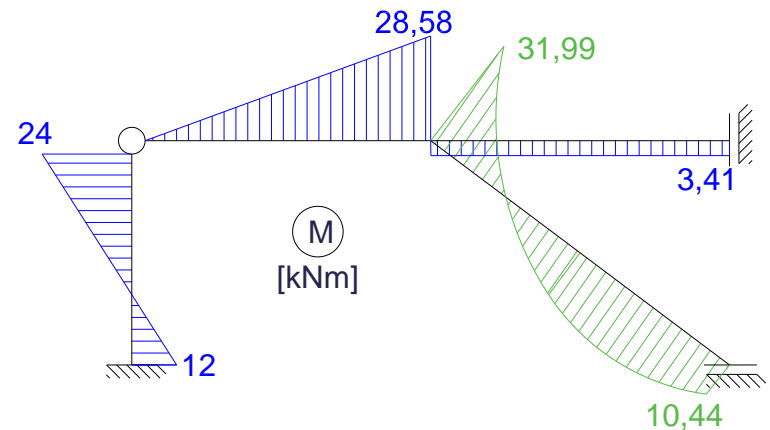
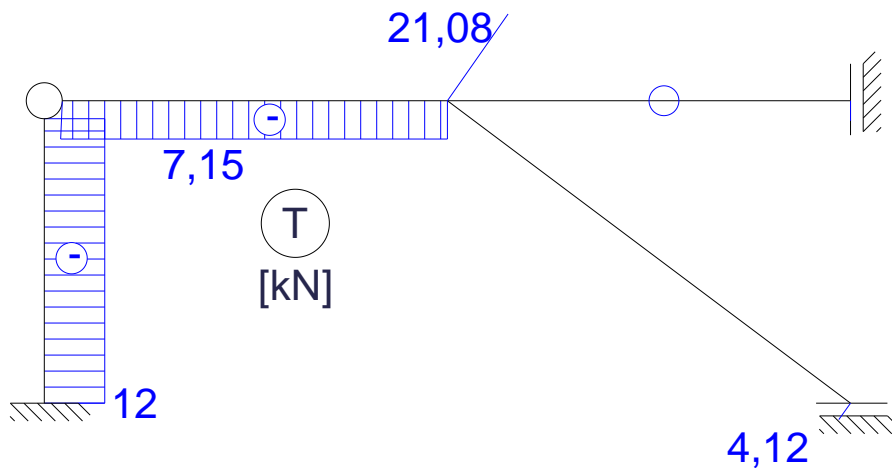
$$N_2 = -3,09 \text{ kN}$$

$$T_3 = 21,08 - 2,16 \cdot 2,5 = 15,68 \text{ kN}$$

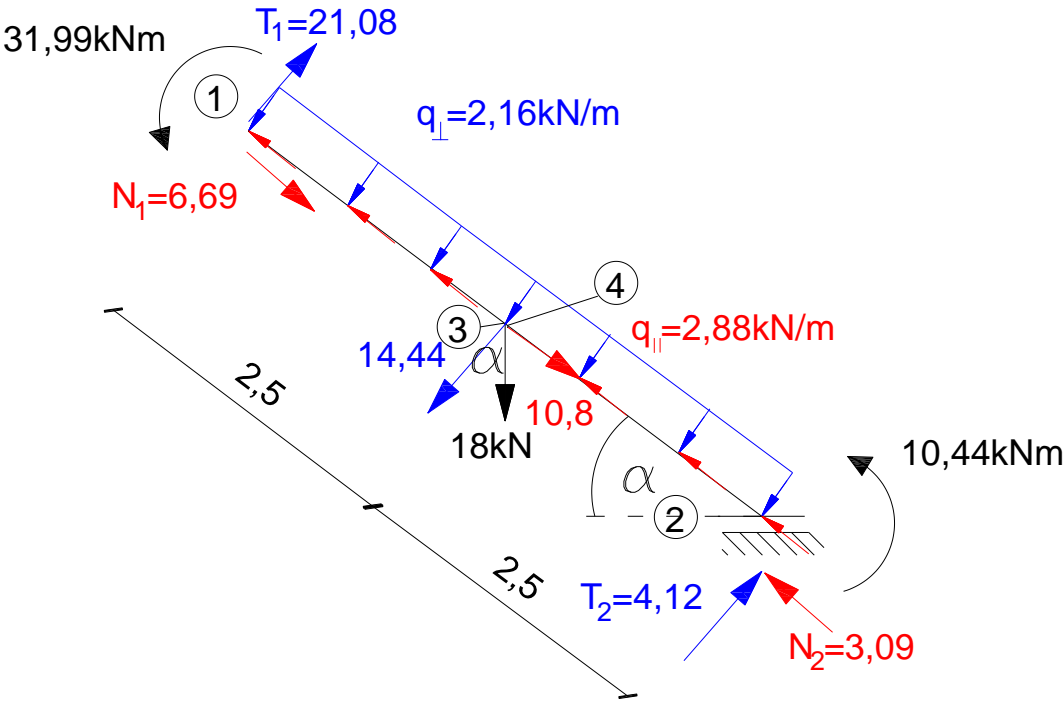
$$T_4 = 15,68 - 14,44 = 1,28 \text{ kN}$$

$$N_3 = -6,69 + 2,88 \cdot 2,5 = 0,51 \text{ kN}$$

$$N_4 = 0,51 - 10,8 = -10,29 \text{ kN}$$



Wyznaczenie wykresu sił T i N na podstawie wykresu M



$$T_1 = 10,28 + 10,8 = 21,08 \text{ kN}$$

$$N_1 = 7,71 - 14,44 = -6,69 \text{ kN}$$

$$T_2 = -4,12 \text{ kN}$$

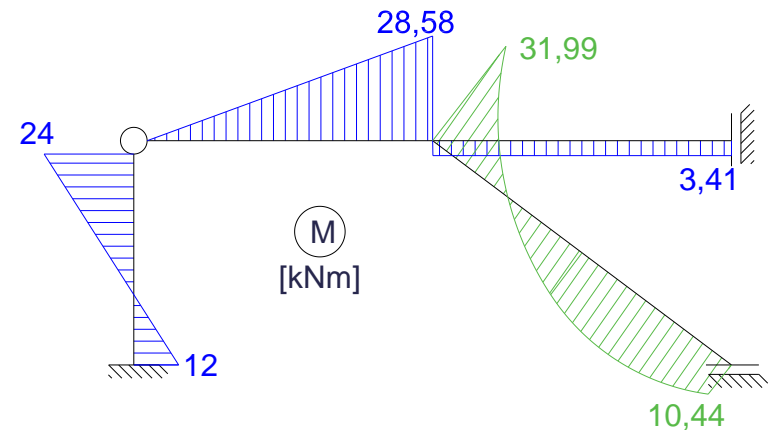
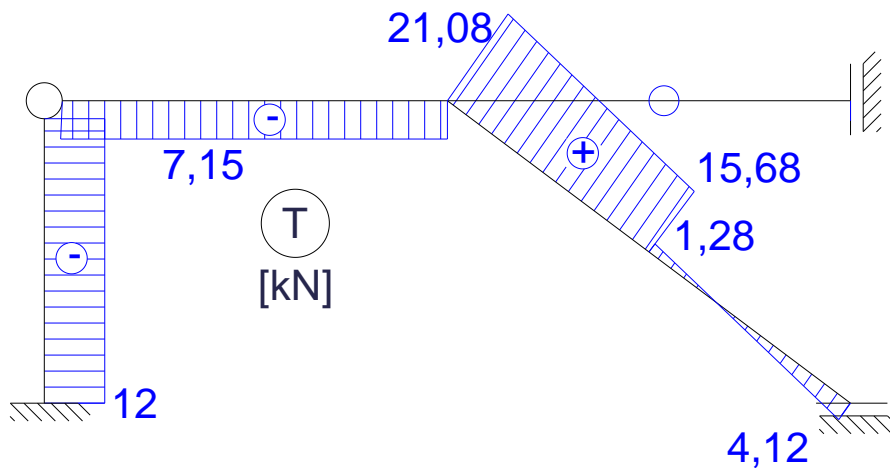
$$N_2 = -3,09 \text{ kN}$$

$$T_3 = 21,08 - 2,16 \cdot 2,5 = 15,68 \text{ kN}$$

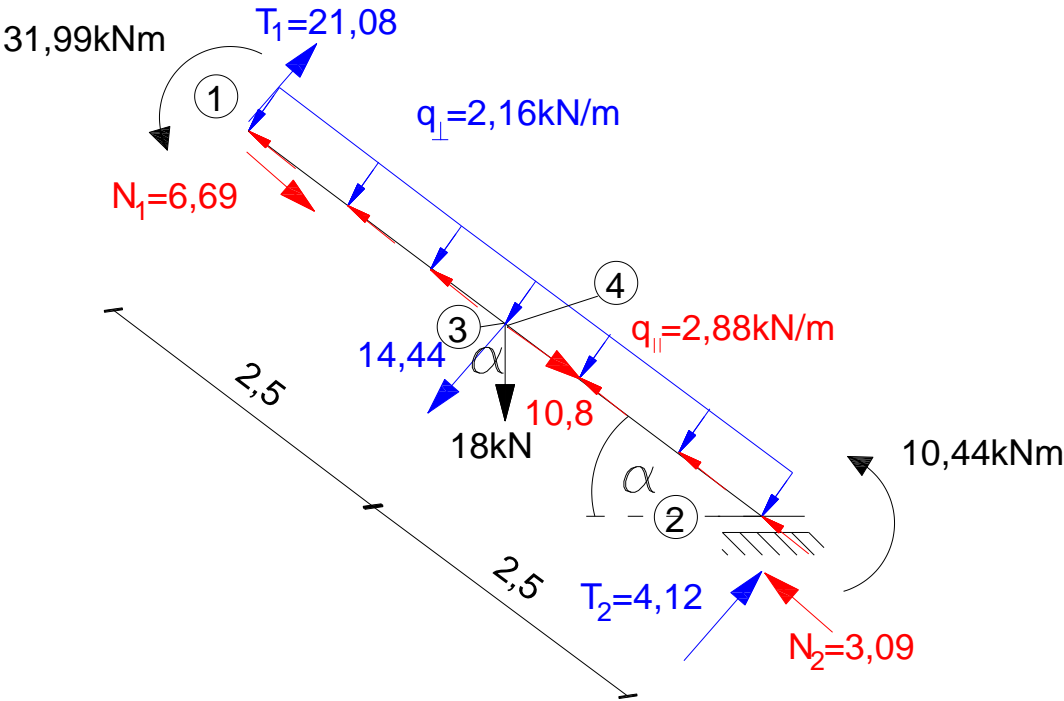
$$T_4 = 15,68 - 14,44 = 1,28 \text{ kN}$$

$$N_3 = -6,69 + 2,88 \cdot 2,5 = 0,51 \text{ kN}$$

$$N_4 = 0,51 - 10,8 = -10,29 \text{ kN}$$



Wyznaczenie wykresu sił T i N na podstawie wykresu M



$$T_1 = 10,28 + 10,8 = 21,08 \text{ kN}$$

$$N_1 = 7,71 - 14,44 = -6,69 \text{ kN}$$

$$T_2 = -4,12 \text{ kN}$$

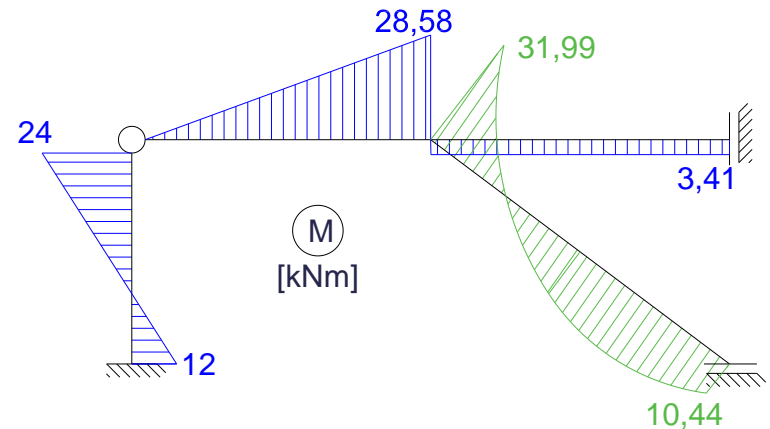
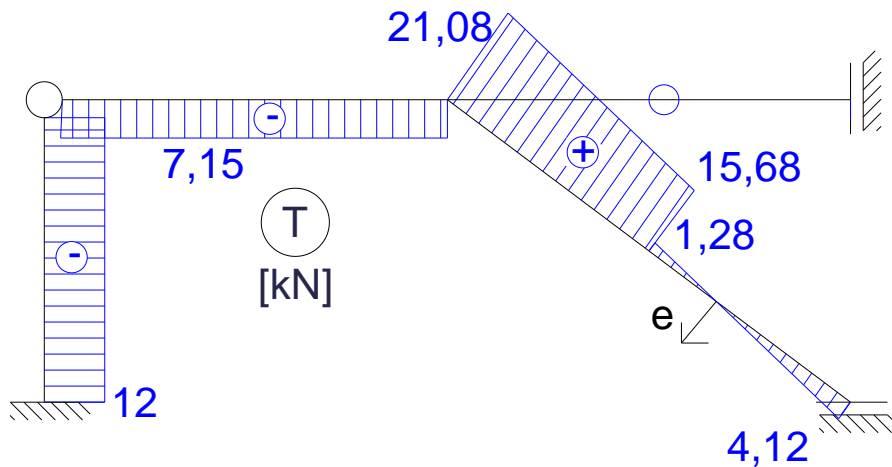
$$N_2 = -3,09 \text{ kN}$$

$$T_3 = 21,08 - 2,16 \cdot 2,5 = 15,68 \text{ kN}$$

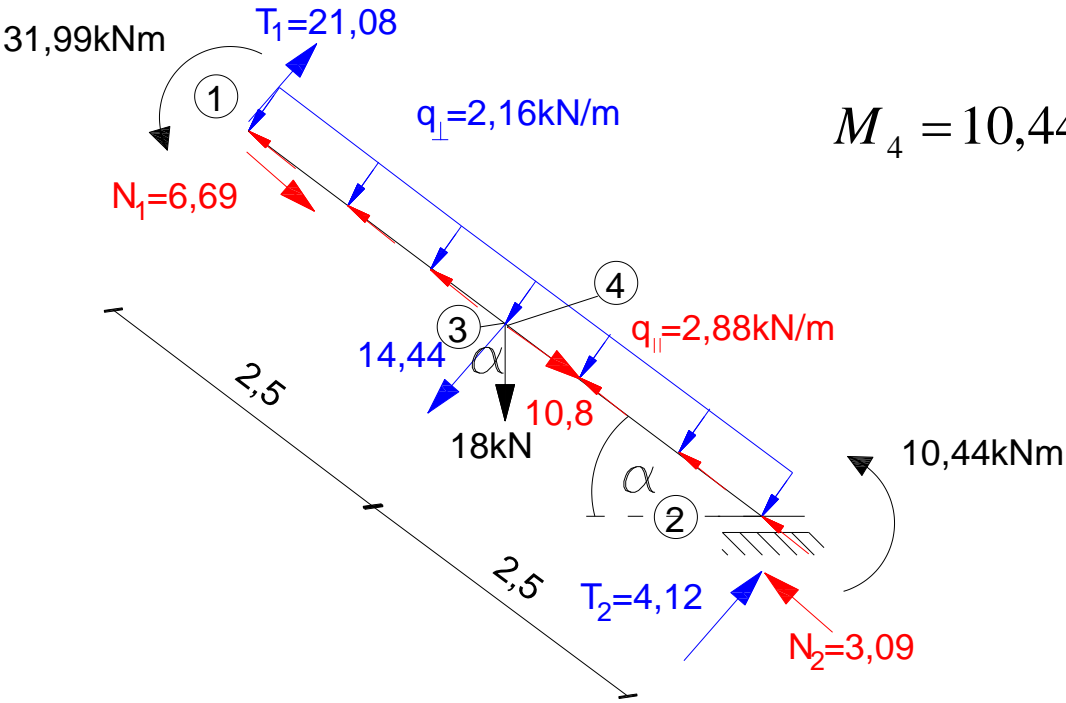
$$T_4 = 15,68 - 14,44 = 1,28 \text{ kN}$$

$$N_3 = -6,69 + 2,88 \cdot 2,5 = 0,51 \text{ kN}$$

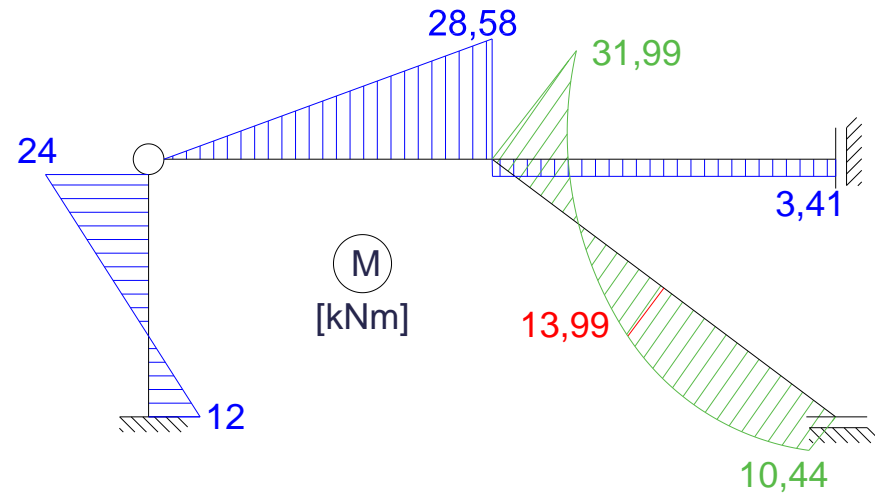
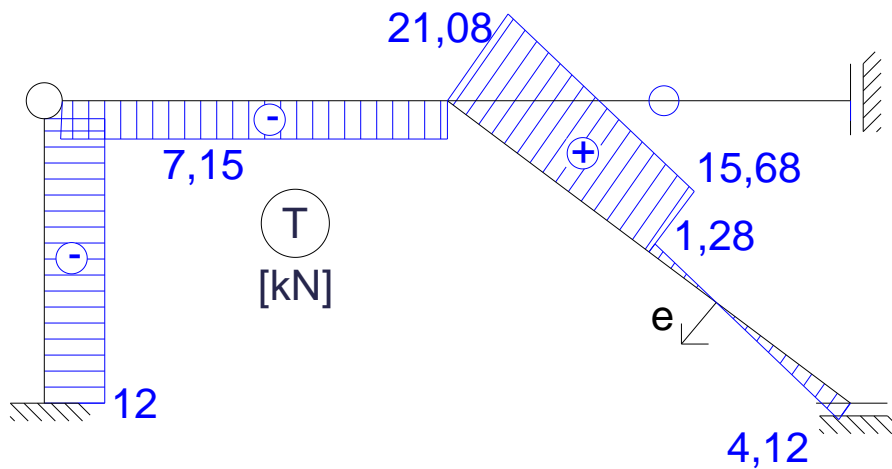
$$N_4 = 0,51 - 10,8 = -10,29 \text{ kN}$$



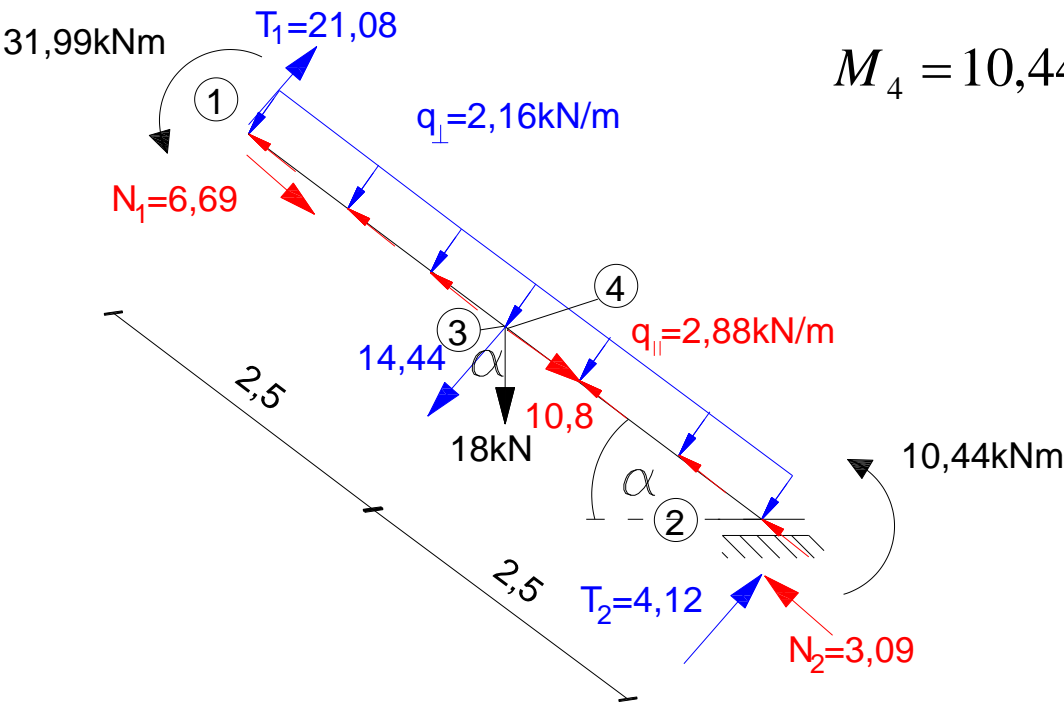
Wyznaczenie wykresu sił T i N na podstawie wykresu M



$$M_4 = 10,44 + 4,12 \cdot 2,5 - 2,16 \cdot \frac{2,5^2}{2} = 13,99 \text{ kNm}$$



Wyznaczenie wykresu sił T i N na podstawie wykresu M



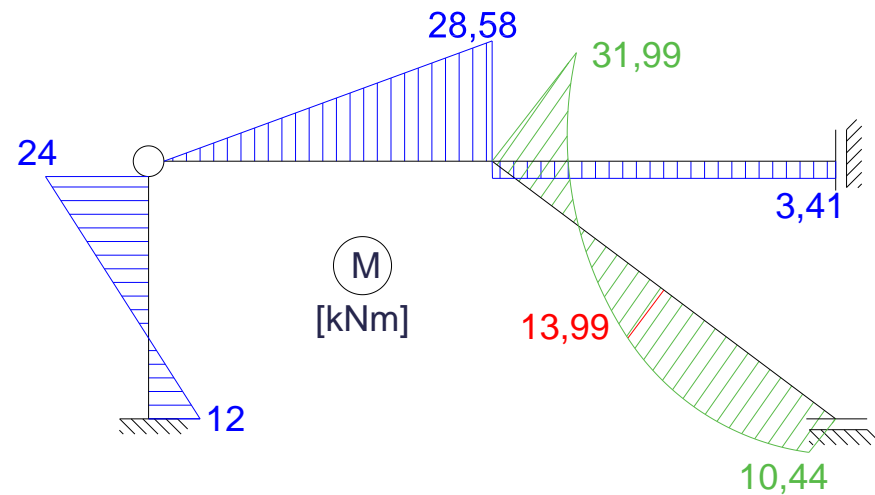
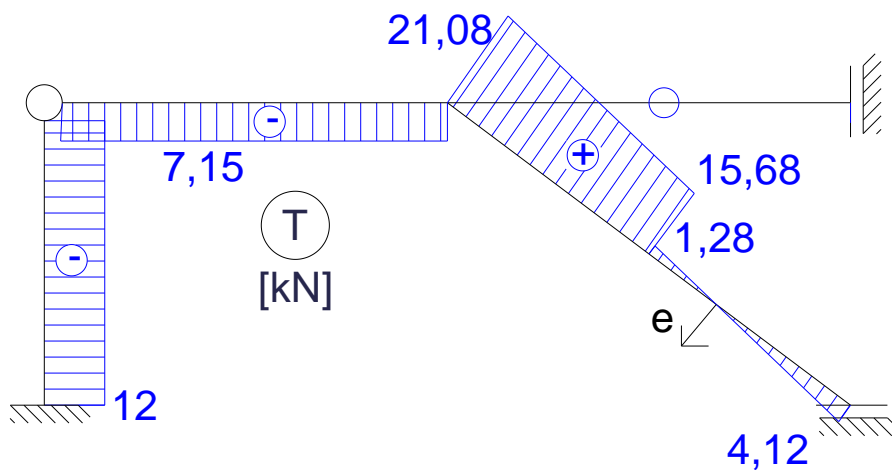
$$M_4 = 10,44 + 4,12 \cdot 2,5 - 2,16 \cdot \frac{2,5^2}{2} = 13,99 \text{ kNm}$$

$$T[x] = -4,12 + 2,16x = 0$$

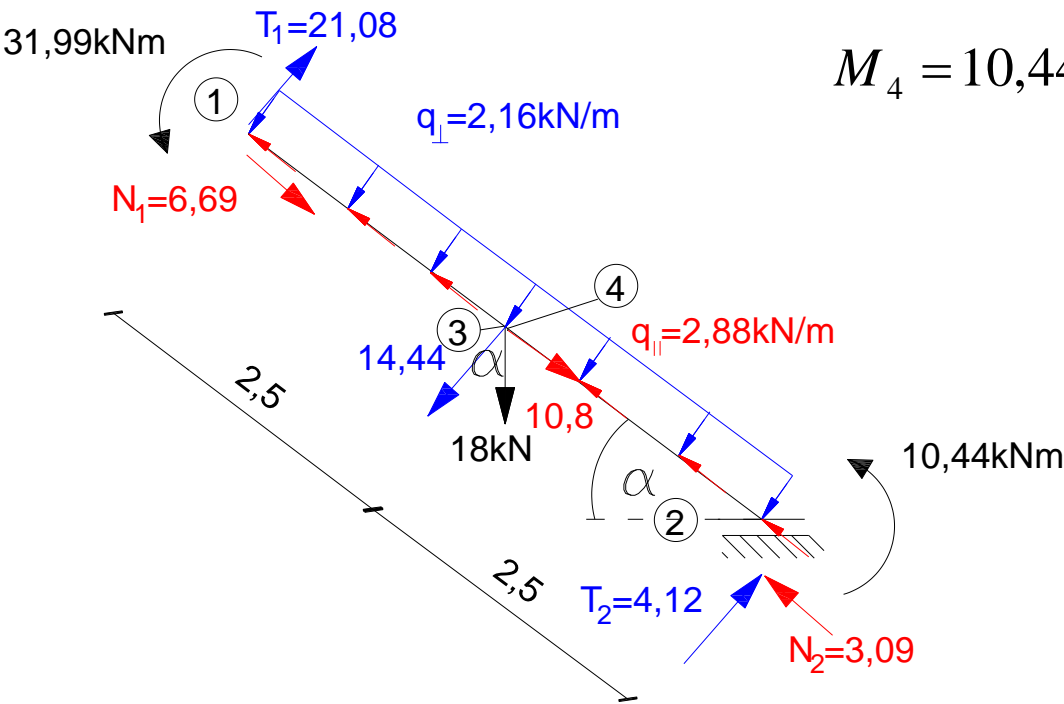
↓

$$x = \frac{4,12}{2,16} = 1,91 \text{ m}$$

$$M_{ekstr.} = 10,44 + 4,12 \cdot 1,91 - 2,16 \cdot \frac{1,91^2}{2} = 14,37 \text{ kNm}$$



Wyznaczenie wykresu sił T i N na podstawie wykresu M



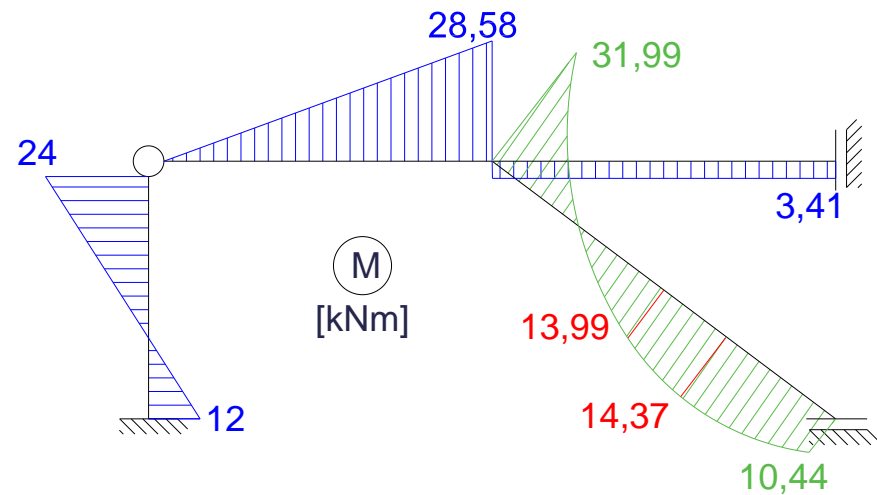
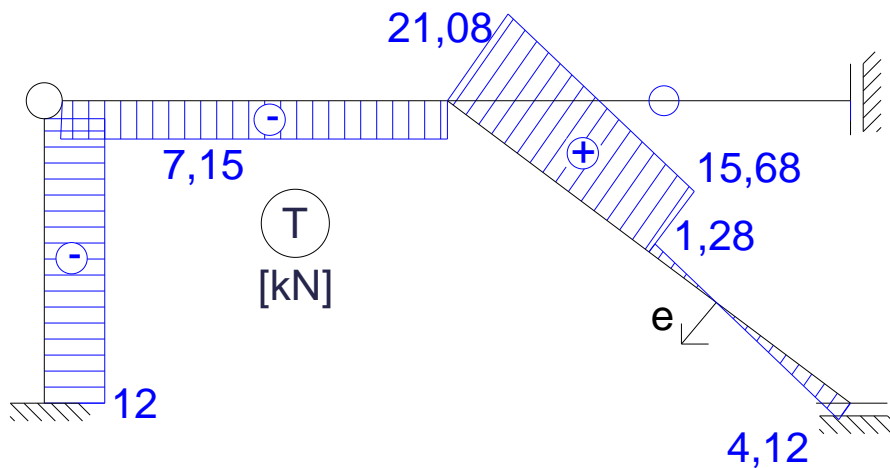
$$M_4 = 10,44 + 4,12 \cdot 2,5 - 2,16 \cdot \frac{2,5^2}{2} = 13,99 \text{ kNm}$$

$$T[x] = -4,12 + 2,16x = 0$$

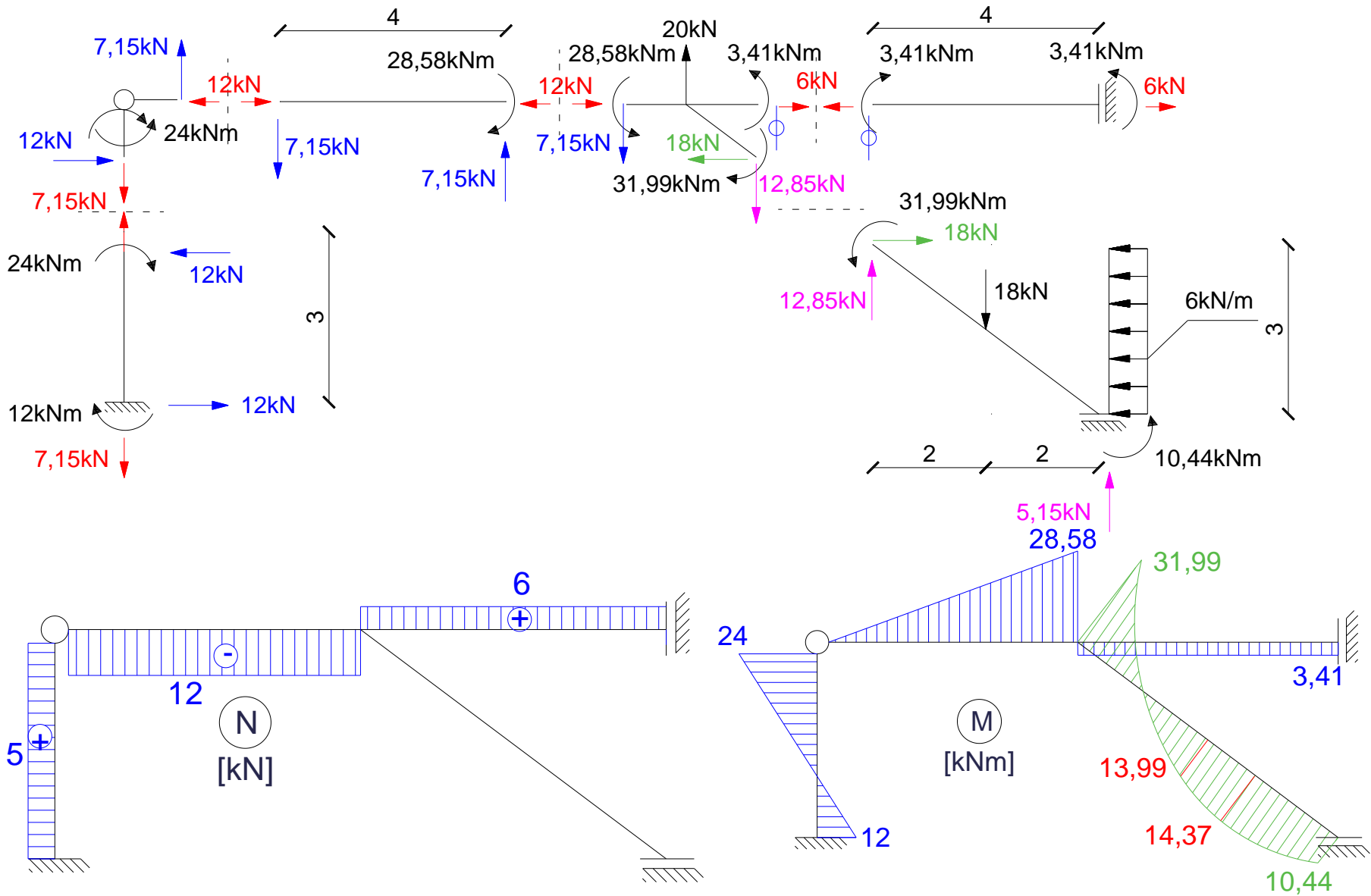
↓

$$x = \frac{4,12}{2,16} = 1,91 \text{ m}$$

$$M_{ekstr.} = 10,44 + 4,12 \cdot 1,91 - 2,16 \cdot \frac{1,91^2}{2} = 14,37 \text{ kNm}$$



Wyznaczenie wykresu sił T i N na podstawie wykresu M



Wyznaczenie wykresu sił T i N na podstawie wykresu M

