

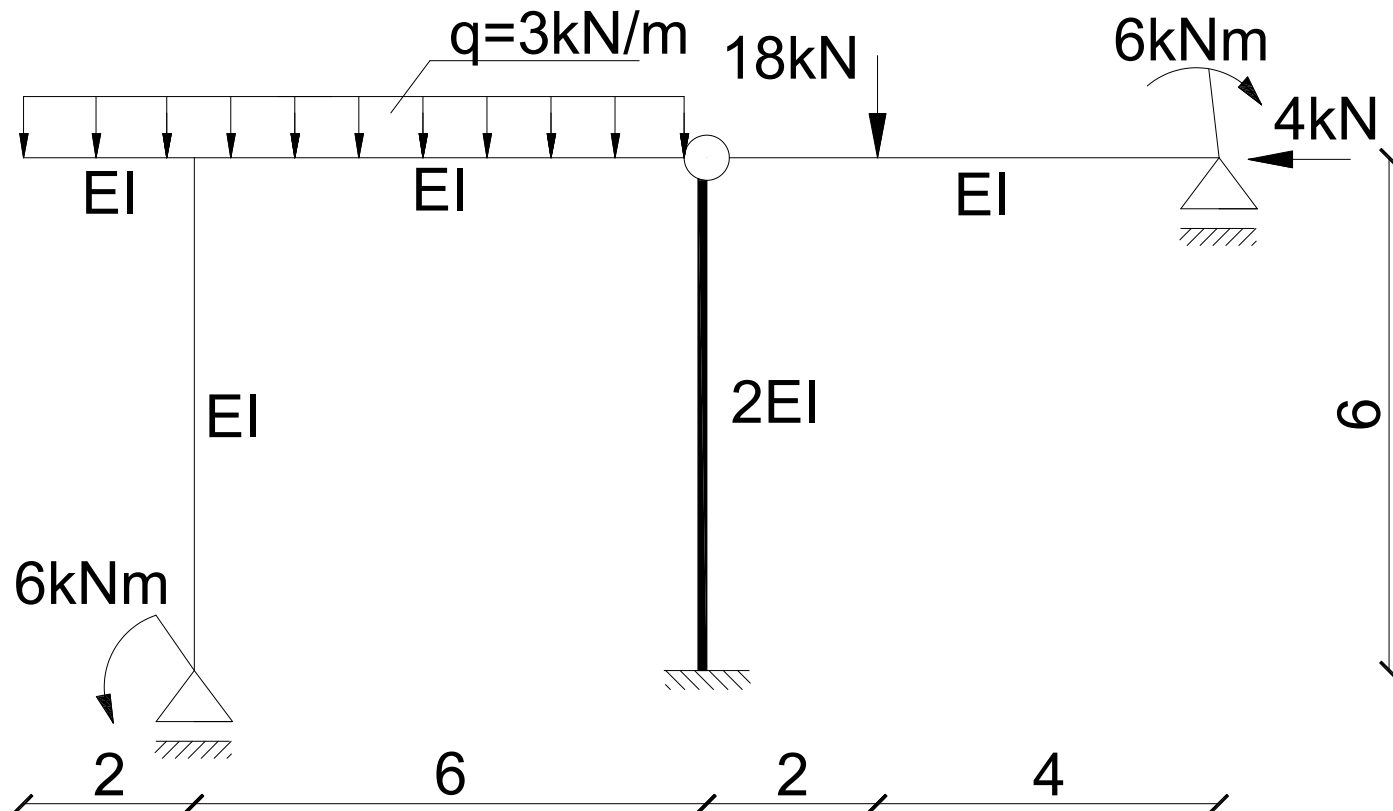
Wykład nr 3

Z Mechaniki Budowli

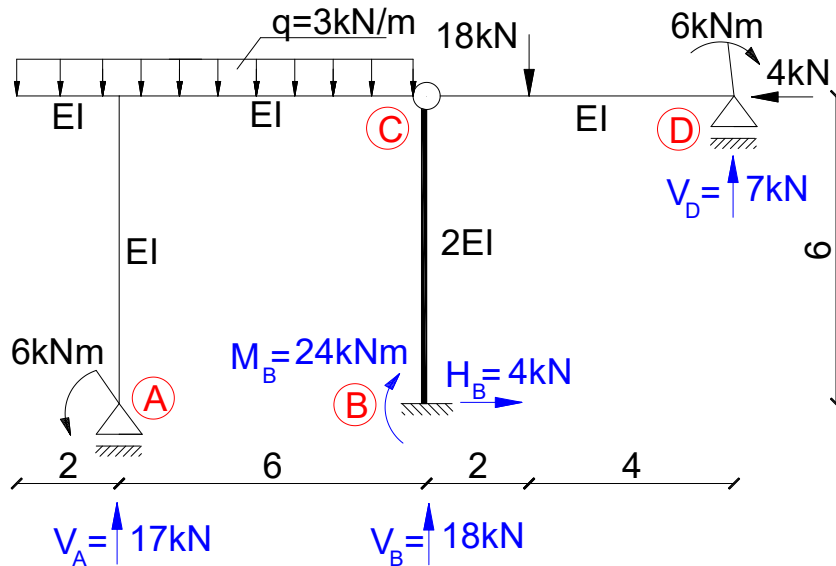
Liczenie przemieszczeń

z Zasady Prac Wirtualnych

Obliczenia przemieszczeń z zasady prac wirtualnych:



Wyznaczenie reakcji:



$$\sum R_Y = 17 - 3 \cdot 8 + V_B - 18 + 7 = 0$$

$$\downarrow$$

$$V_B = 18 \text{ kN}$$

$$\sum M_C^D = -4 \cdot 6 + M_B = 0 \rightarrow M_B = 24 \text{ kNm}$$

$$\sum R_x = -4 + H_B = 0 \rightarrow H_B = 4 \text{ kN}$$

$$\sum M_C^P = 18 \cdot 2 + 6 - 6V_D = 0$$

$$\downarrow$$

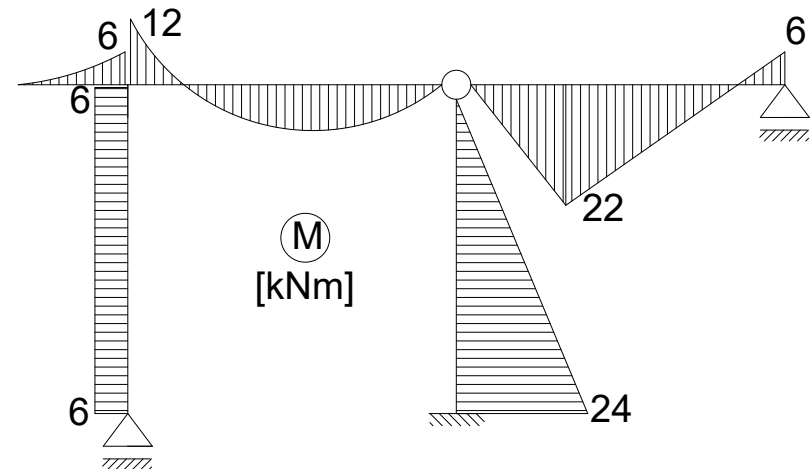
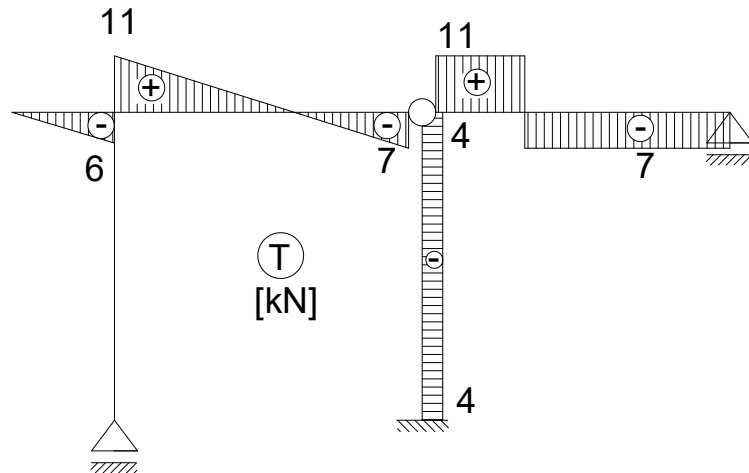
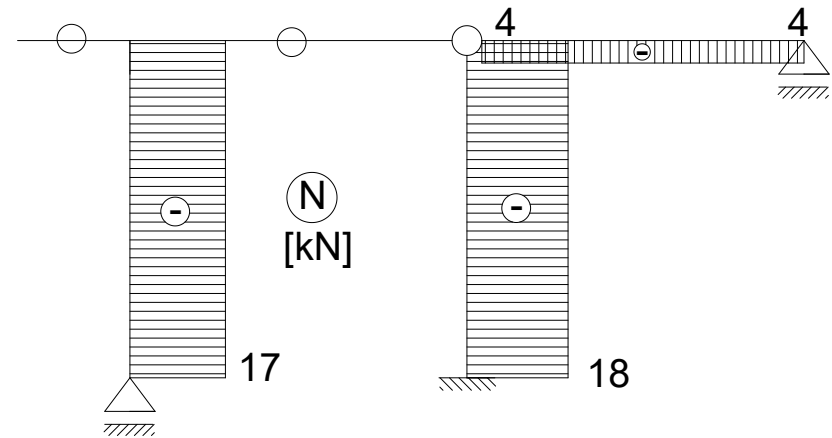
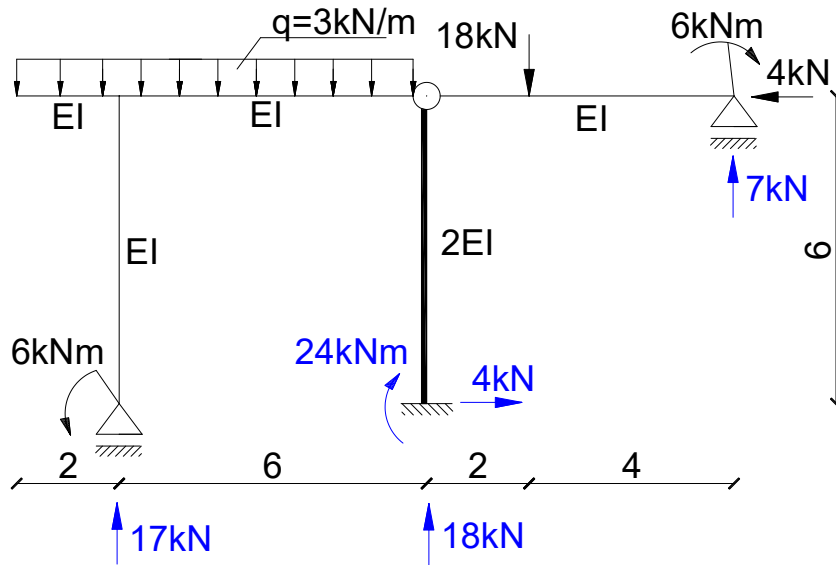
$$V_D = \frac{36 + 6}{6} = 7 \text{ kN}$$

$$\sum M_C^L = -3 \cdot 8 \cdot 4 - 6 + 6V_A = 0$$

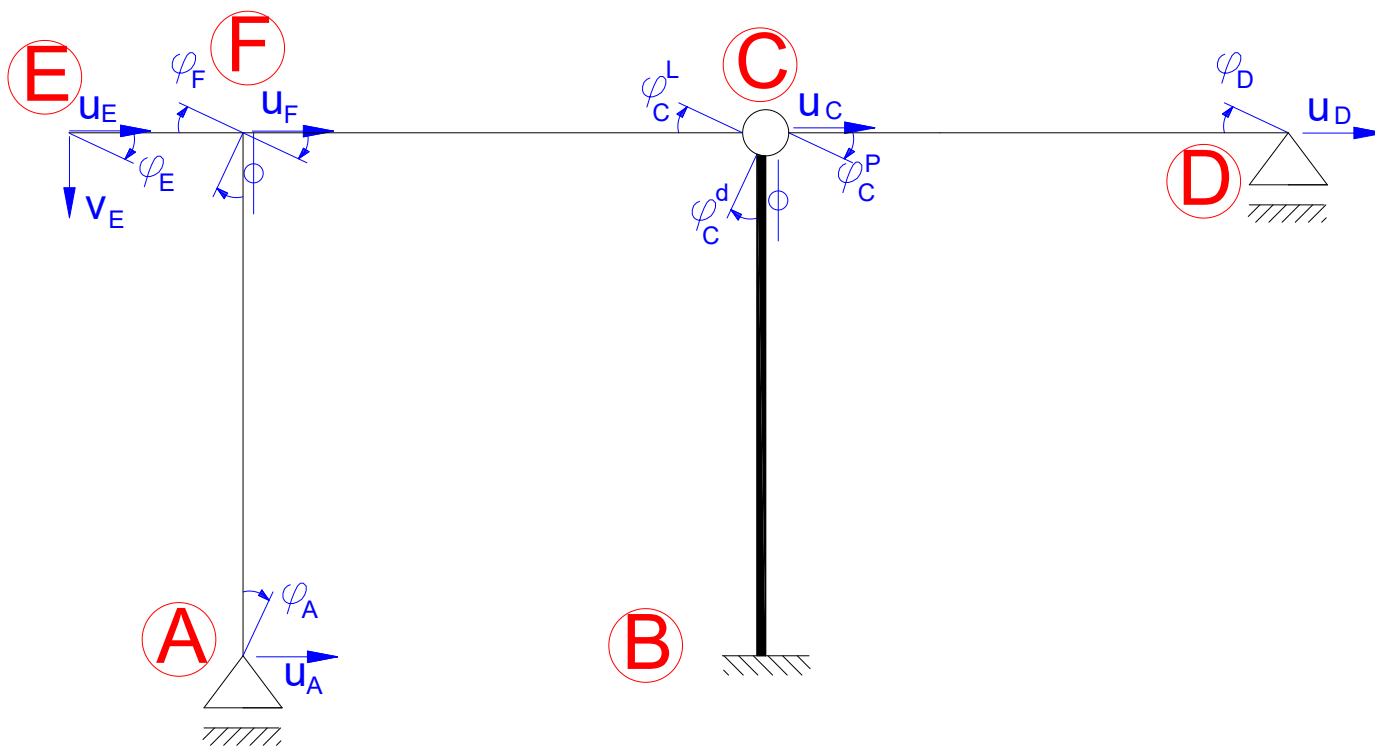
$$\downarrow$$

$$V_A = \frac{96 + 6}{6} = 17 \text{ kN}$$

Wykresy sił wewnętrznych:

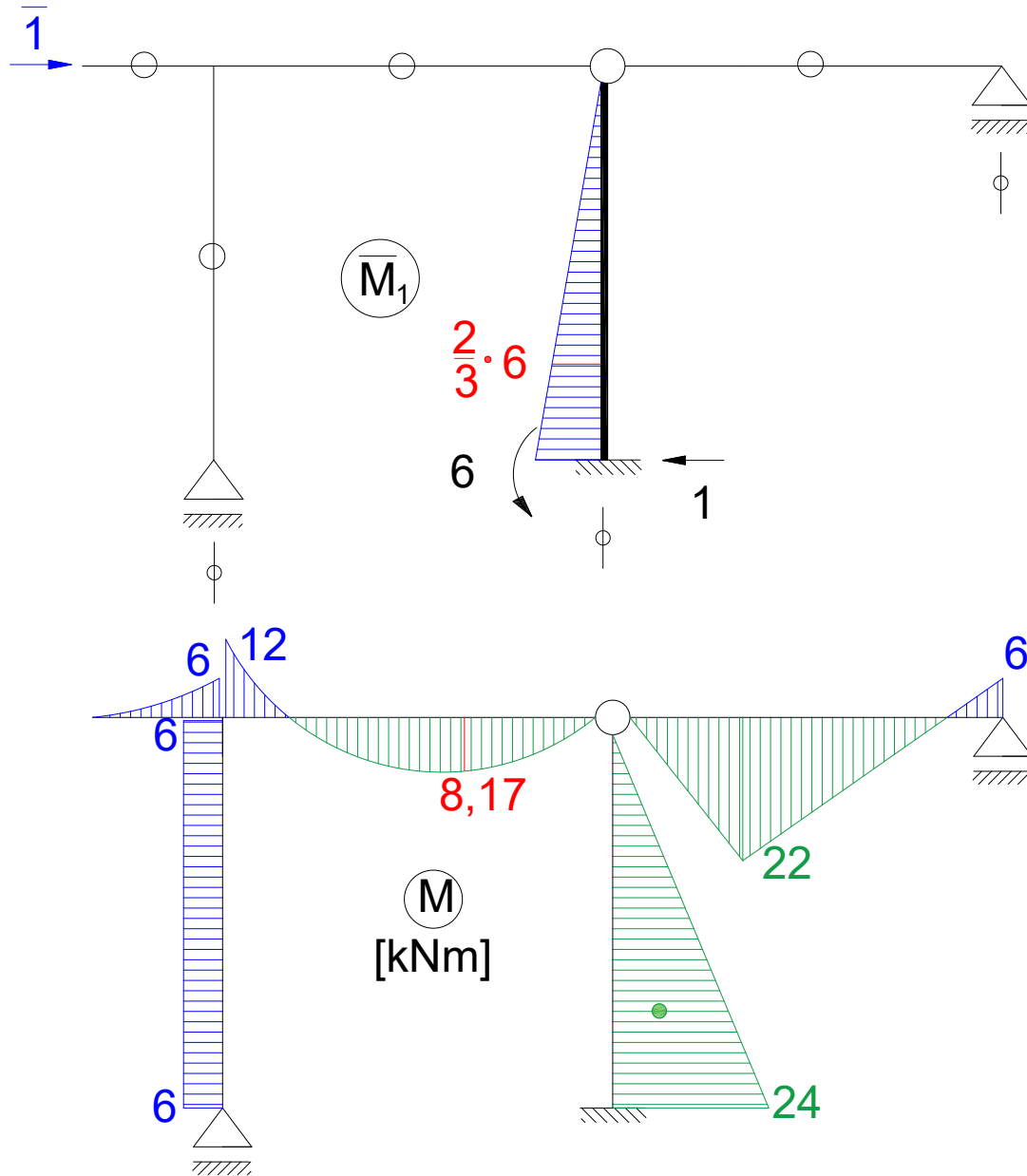


Obliczenia przemieszczeń z zasady prac wirtualnych:



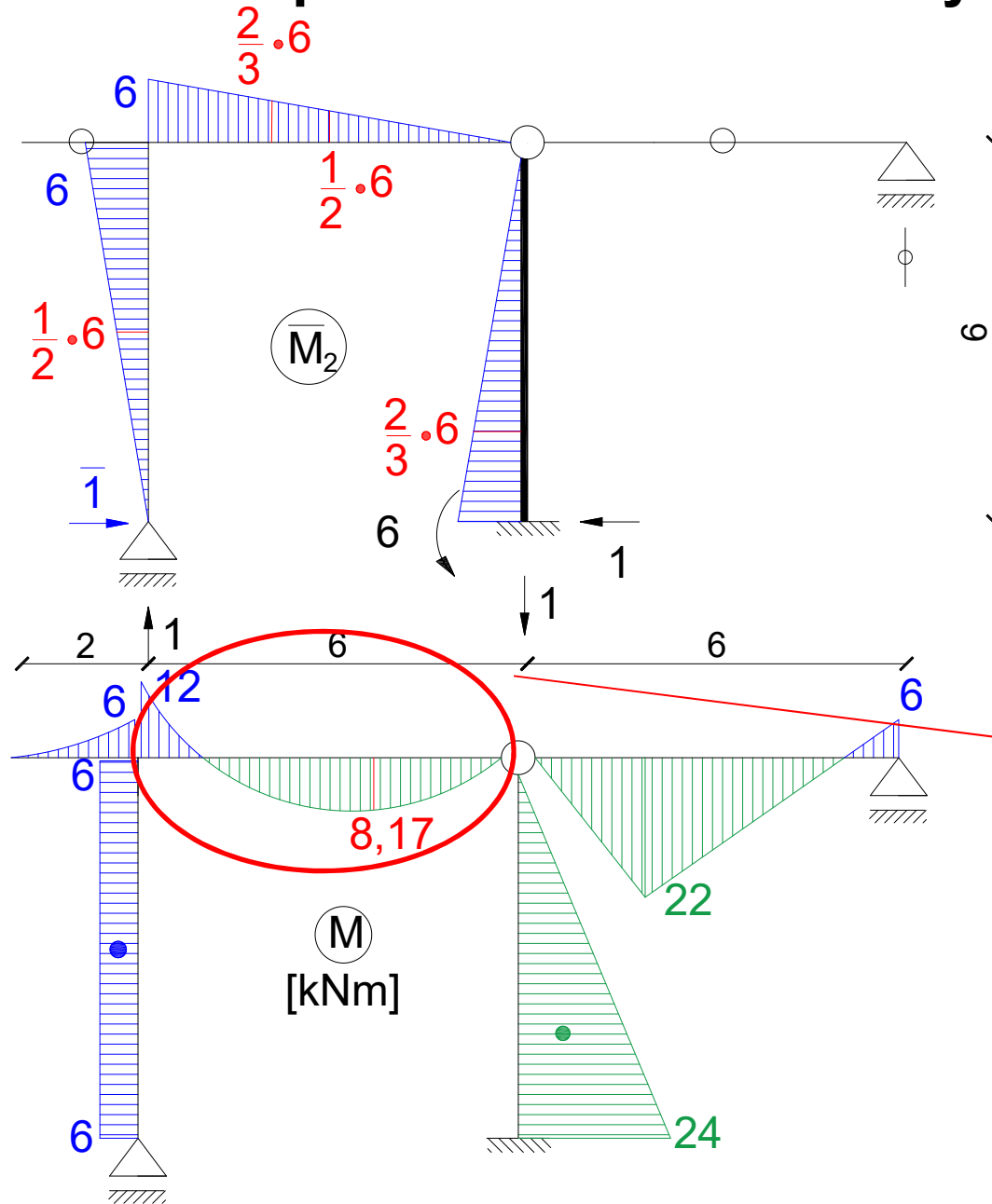
$$u_E = u_F = u_C = u_D$$

Obliczenia przemieszczeń z zasady prac wirtualnych:

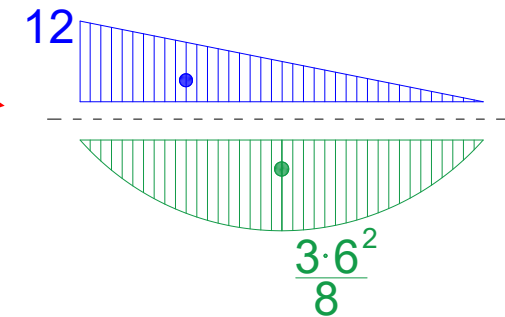


$$u_E = \frac{1}{2EI} \left(-\frac{1}{2} \cdot 24 \cdot 6 \cdot \frac{2}{3} \cdot 6 \right) = -\frac{144}{EI}$$

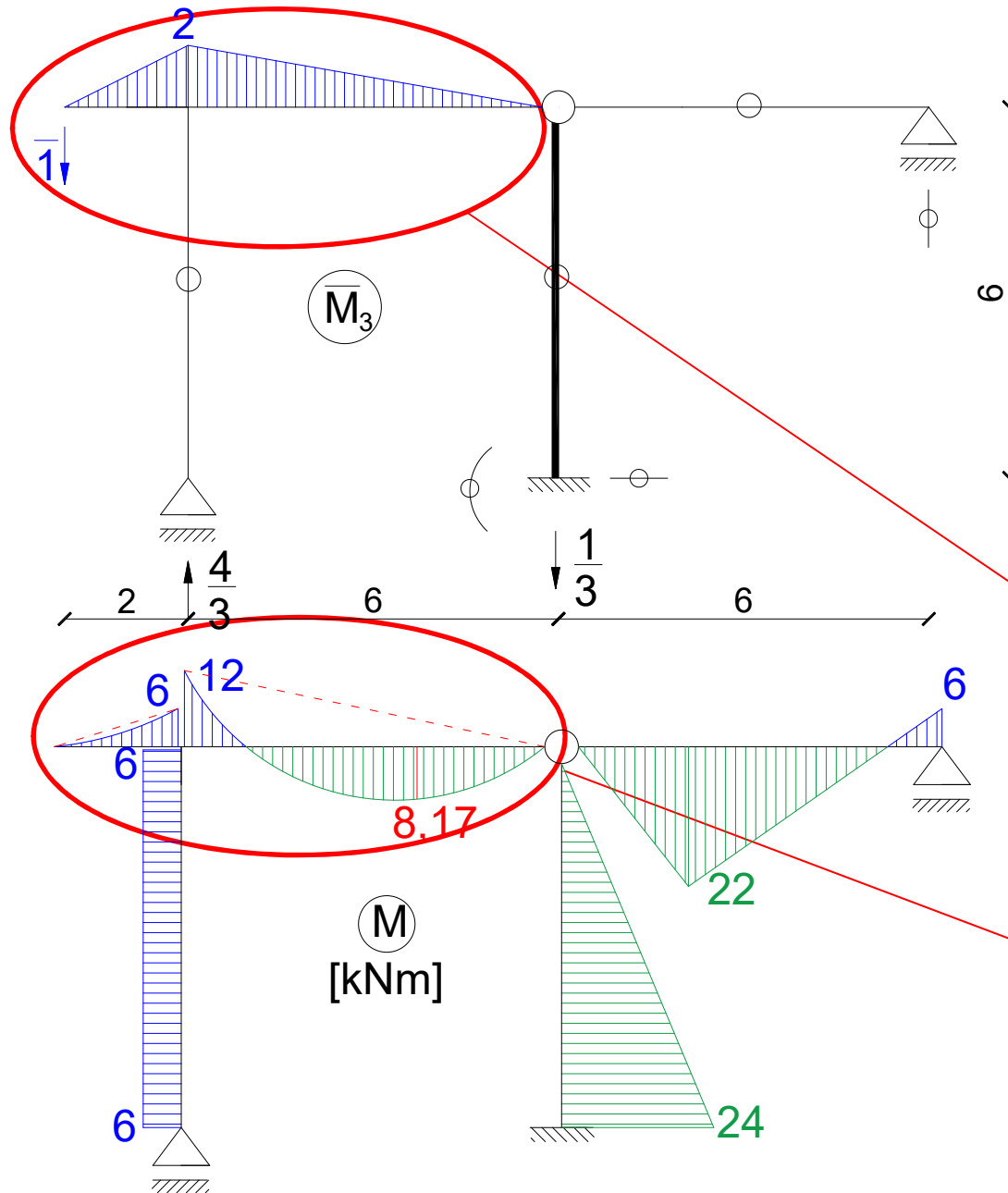
Obliczenia przemieszczeń z zasady prac wirtualnych:



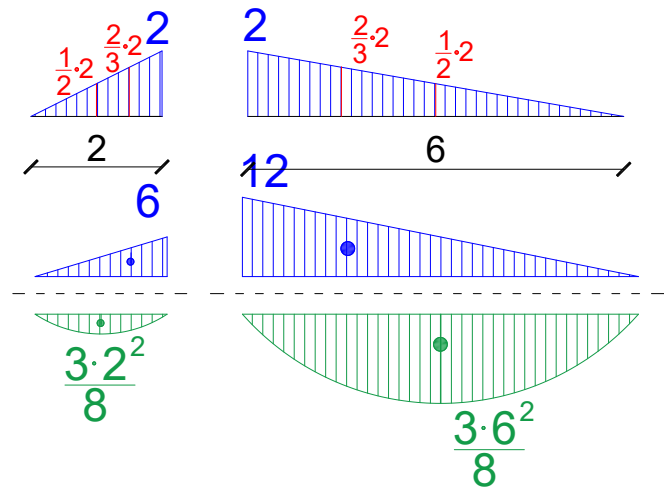
$$\begin{aligned}
 u_A &= -\frac{144}{EI} + \frac{1}{EI} \left(6 \cdot 6 \cdot \frac{1}{2} \cdot 6 \right) \\
 &+ \frac{1}{EI} \left(\frac{1}{2} \cdot 12 \cdot 6 \cdot \frac{2}{3} \cdot 6 \right) \\
 &- \frac{1}{EI} \left(\frac{2}{3} \cdot \frac{3 \cdot 6^2}{8} \cdot 6 \cdot \frac{1}{2} \cdot 6 \right) \\
 &= -\frac{54}{EI}
 \end{aligned}$$



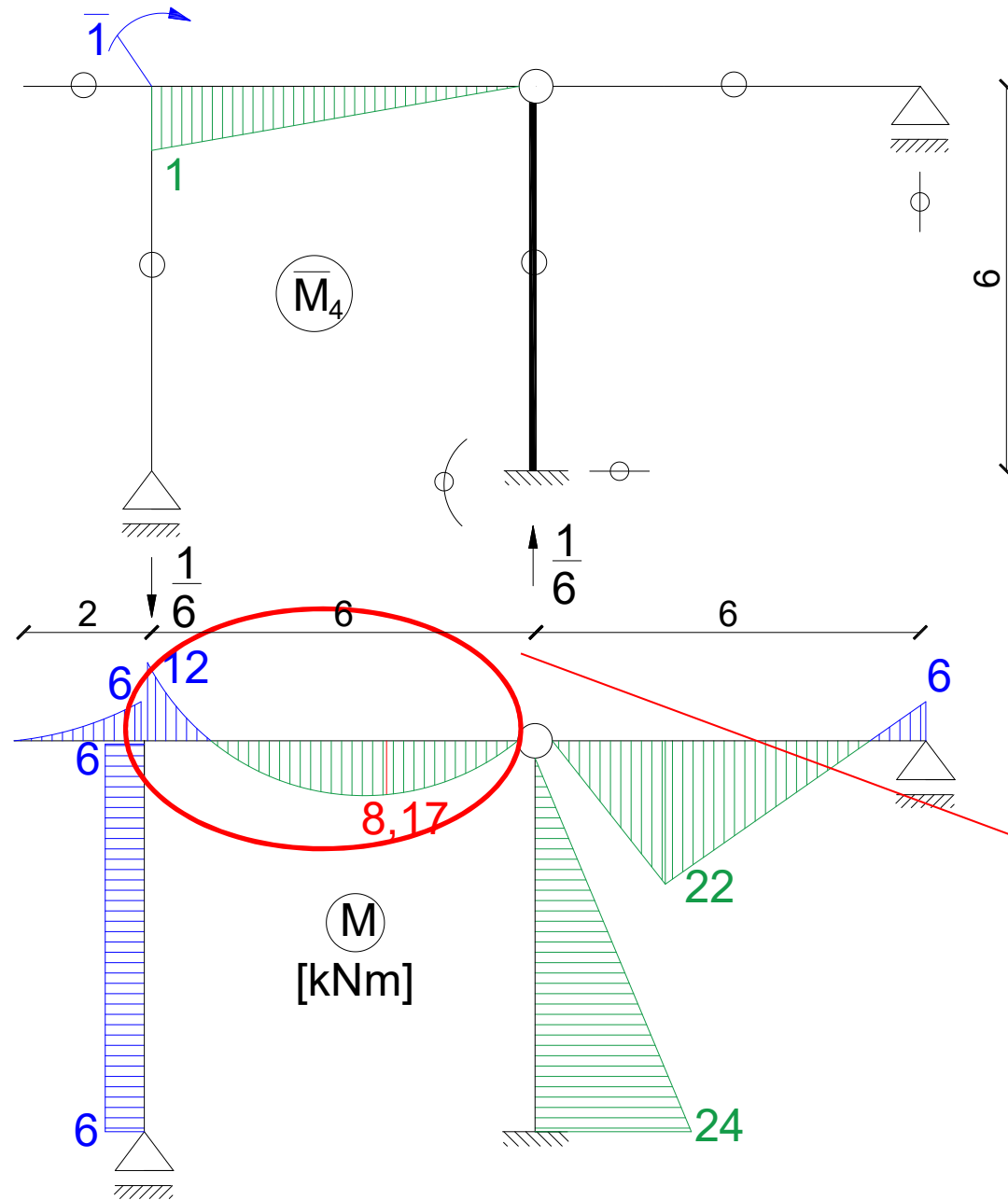
Obliczenia przemieszczeń z zasady prac wirtualnych:



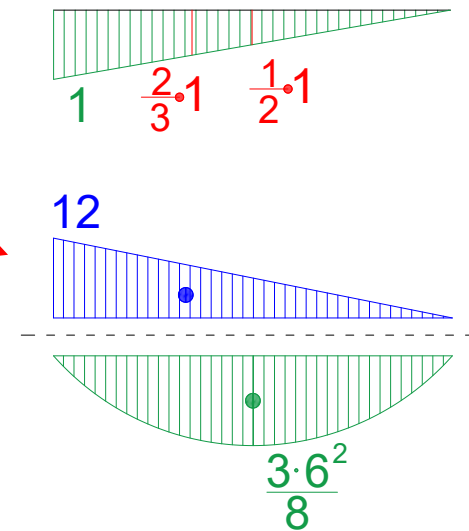
$$v_E = \frac{1}{EI} \left(\frac{1}{2} \cdot 6 \cdot 2 \cdot \frac{2}{3} \cdot 2 \right) - \frac{1}{EI} \left(\frac{2}{3} \cdot \frac{3 \cdot 2^2}{8} \cdot 2 \cdot \frac{1}{2} \cdot 2 \right) + \frac{1}{EI} \left(\frac{1}{2} \cdot 12 \cdot 6 \cdot \frac{2}{3} \cdot 2 \right) - \frac{1}{EI} \left(\frac{2}{3} \cdot \frac{3 \cdot 6^2}{8} \cdot 6 \cdot \frac{1}{2} \cdot 2 \right) = \frac{0}{EI}$$



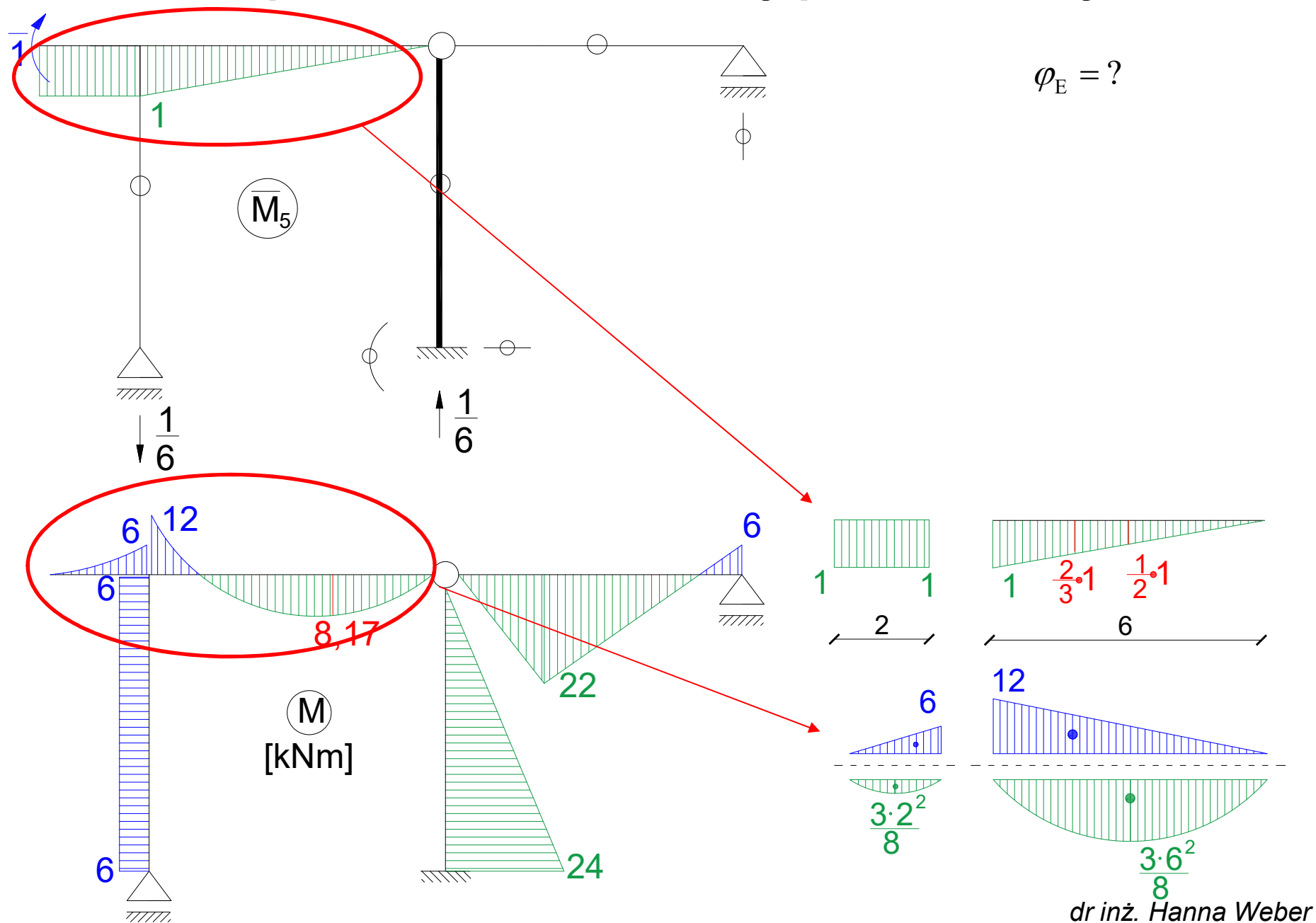
Obliczenia przemieszczeń z zasady prac wirtualnych:



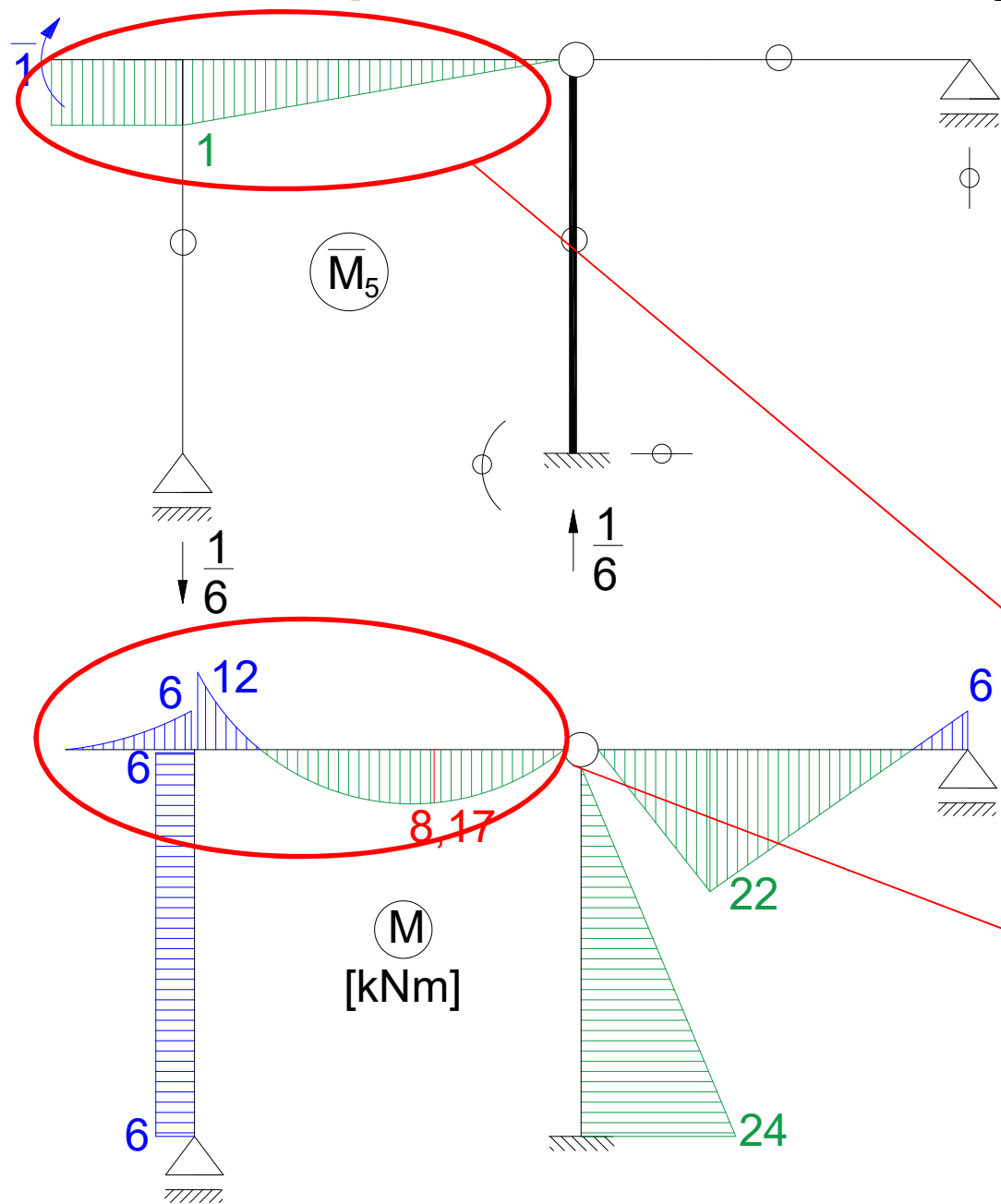
$$\varphi_F = -\frac{1}{EI} \left(\frac{1}{2} \cdot 12 \cdot 6 \cdot \frac{2}{3} \cdot 1 \right) + \frac{1}{EI} \left(\frac{2}{3} \cdot \frac{3 \cdot 6^2}{8} \cdot 6 \cdot \frac{1}{2} \cdot 1 \right) = \frac{3}{EI}$$



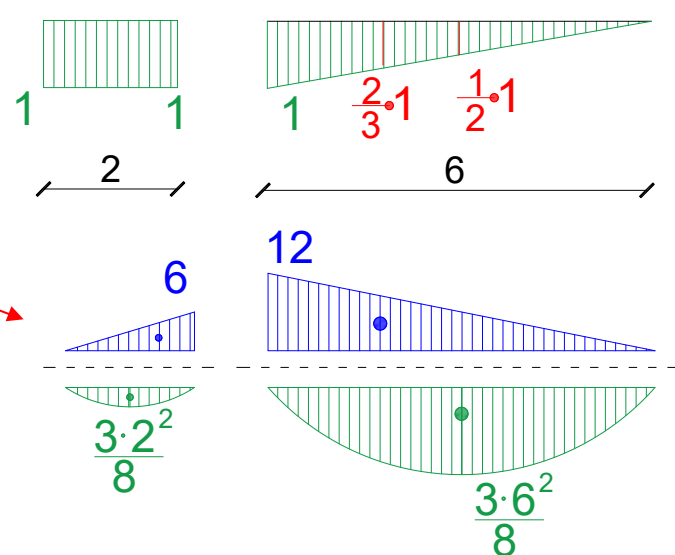
Obliczenia przemieszczeń z zasady prac wirtualnych:



Obliczenia przemieszczeń z zasady prac wirtualnych:

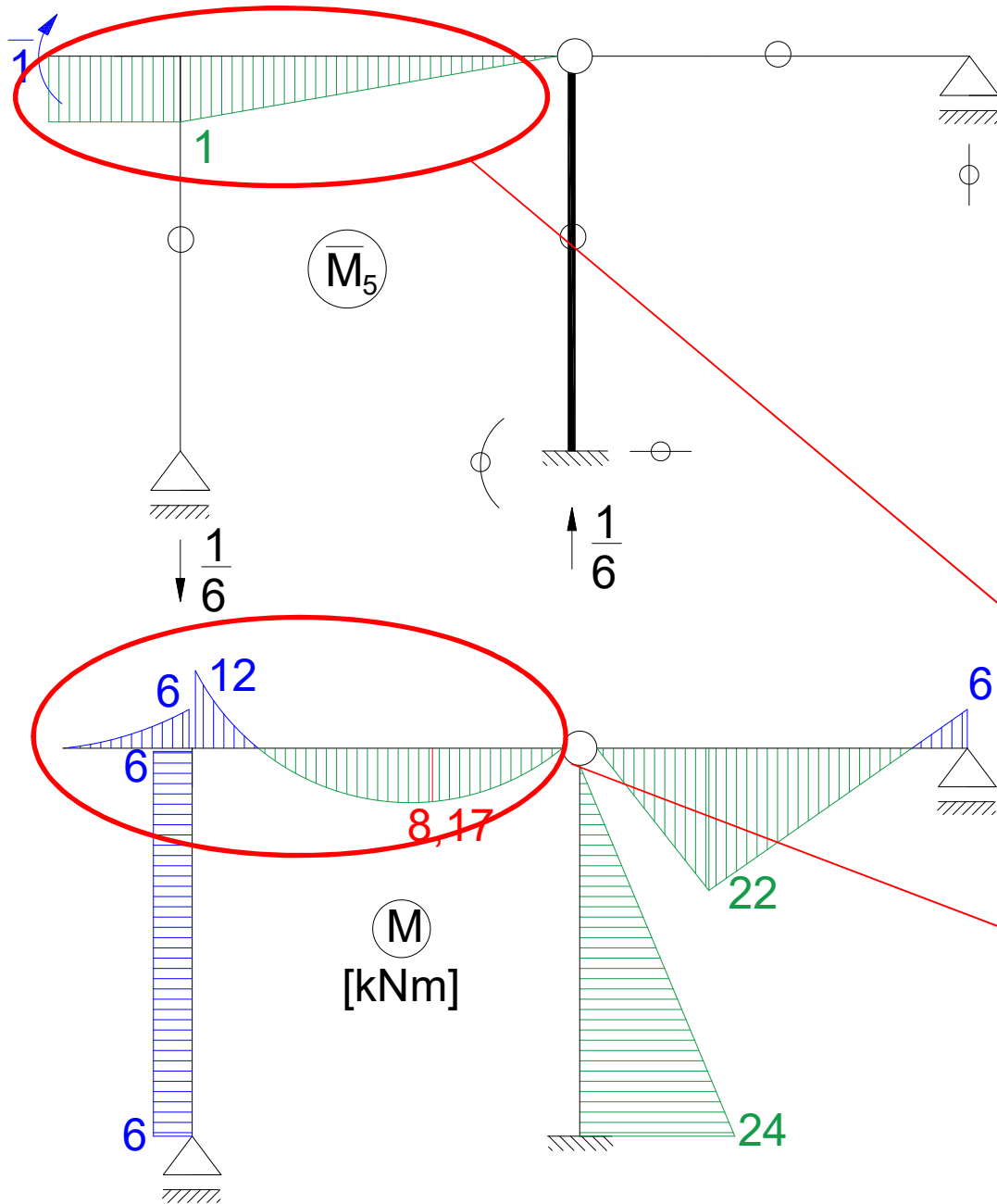


$$\varphi_E = \frac{1}{EI} \left(-\frac{1}{2} \cdot 6 \cdot 2 \cdot 1 \right)$$

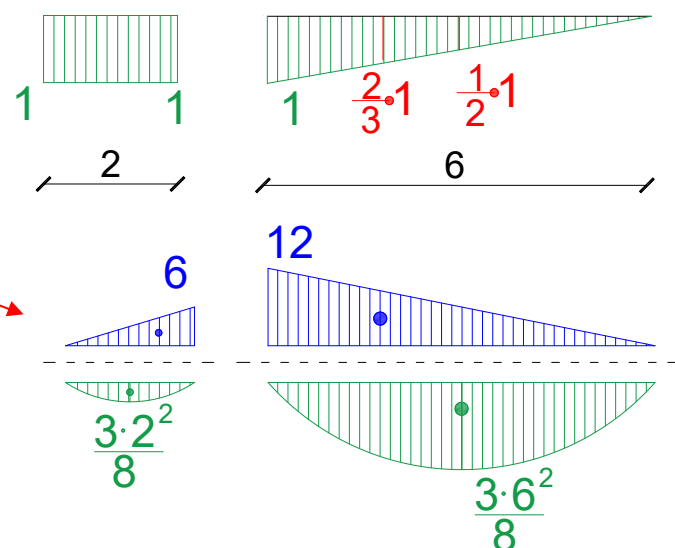


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Obliczenia przemieszczeń z zasady prac wirtualnych:

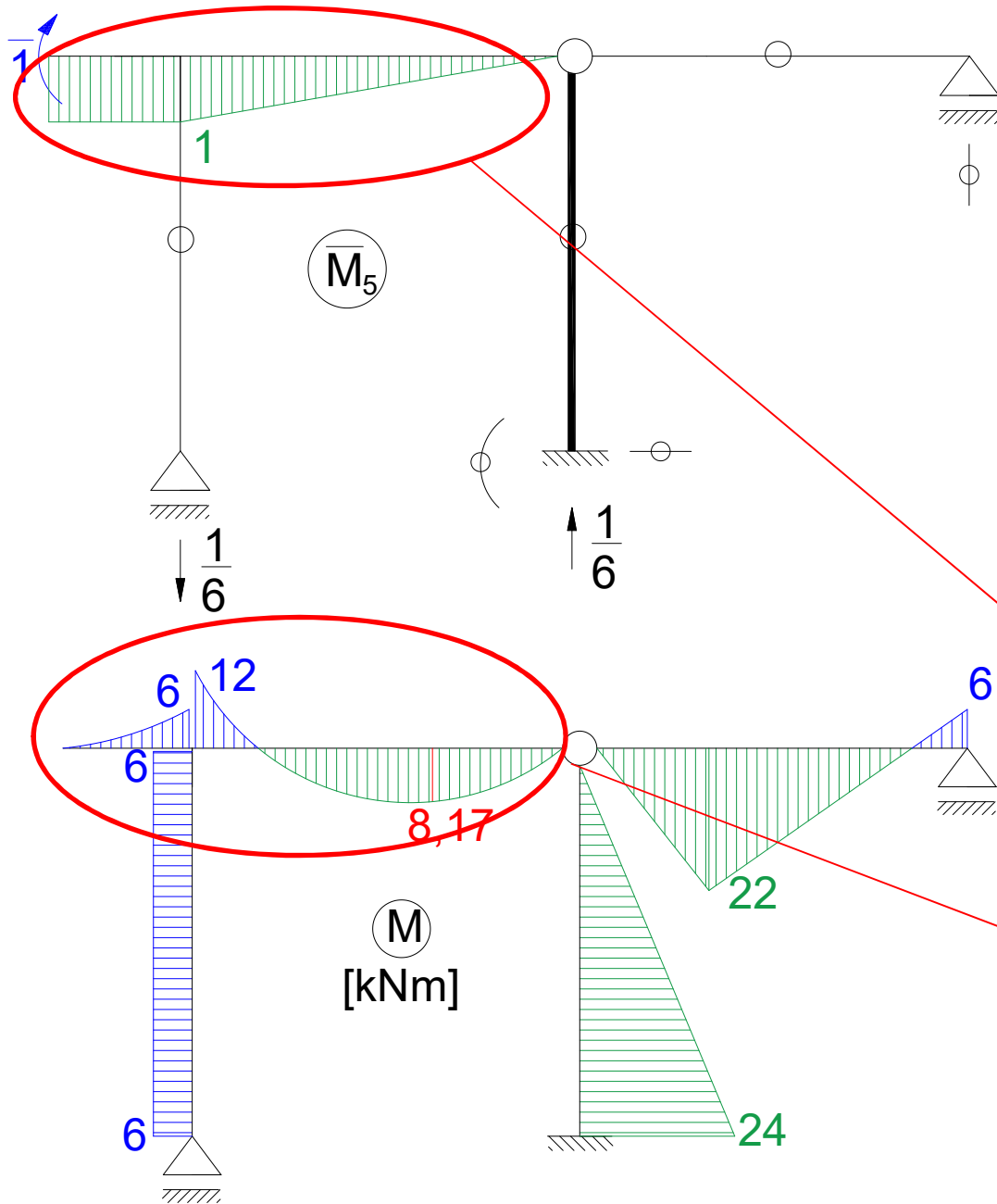


$$\varphi_E = \frac{1}{EI} \left(-\frac{1}{2} \cdot 6 \cdot 2 \cdot 1 \right) + \frac{1}{EI} \left(\frac{2}{3} \cdot \frac{3 \cdot 2^2}{8} \cdot 2 \cdot 1 \right)$$

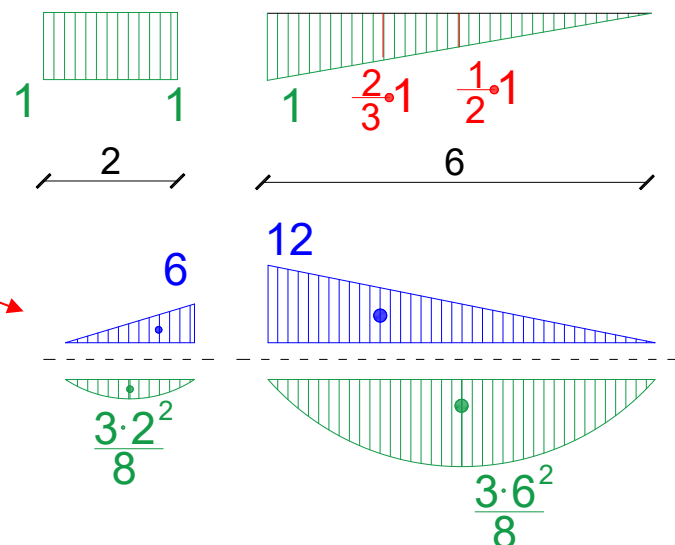


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Obliczenia przemieszczeń z zasady prac wirtualnych:

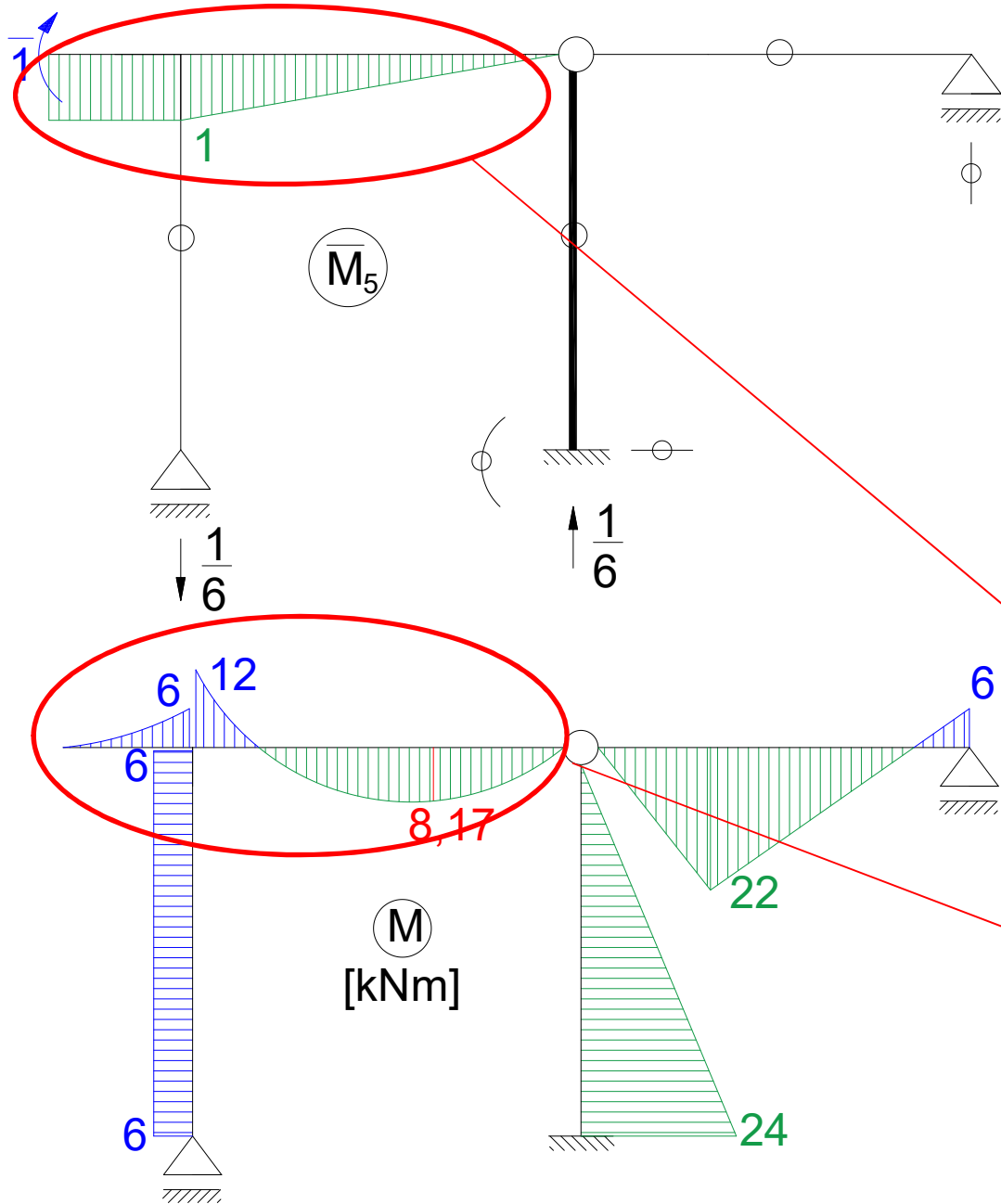


$$\begin{aligned} \varphi_E = & \frac{1}{EI} \left(-\frac{1}{2} \cdot 6 \cdot 2 \cdot 1 \right) \\ & + \frac{1}{EI} \left(\frac{2}{3} \cdot \frac{3 \cdot 2^2}{8} \cdot 2 \cdot 1 \right) \\ & - \frac{1}{EI} \left(\frac{1}{2} \cdot 12 \cdot 6 \cdot \frac{2}{3} \cdot 1 \right) \end{aligned}$$

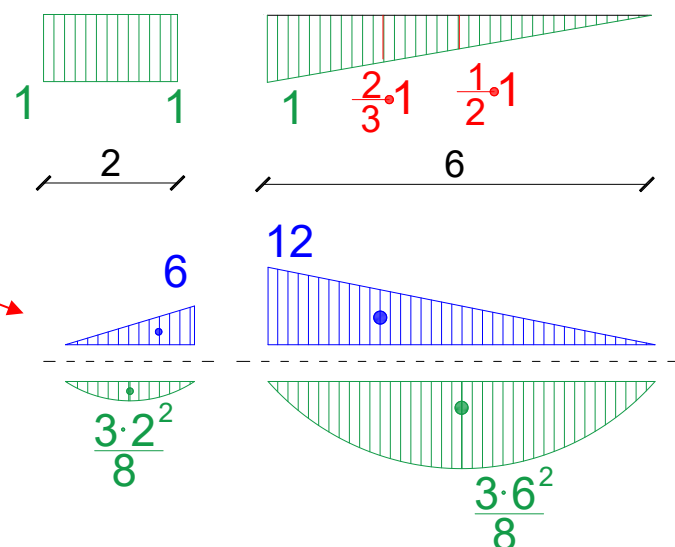


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Obliczenia przemieszczeń z zasady prac wirtualnych:

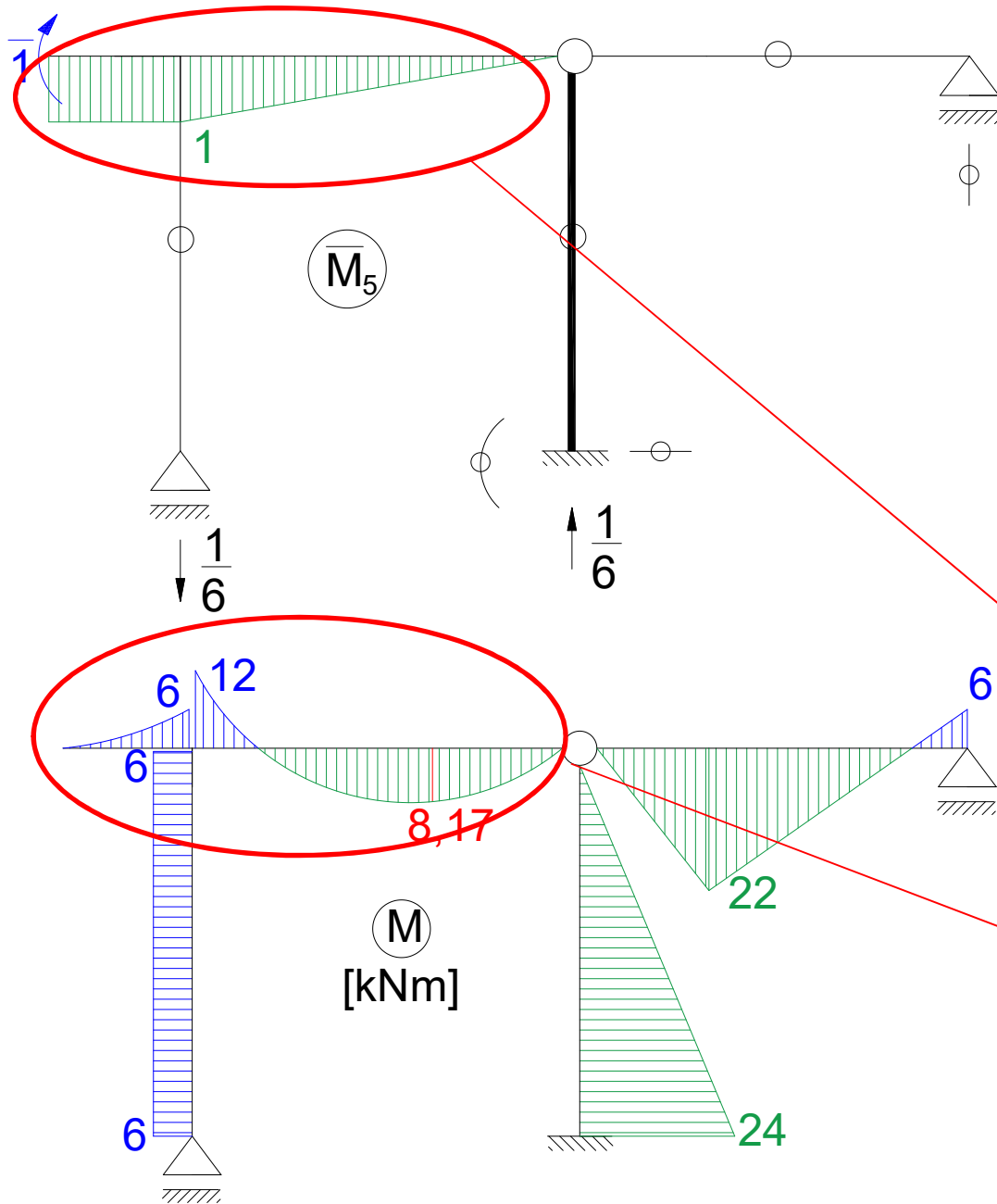


$$\begin{aligned}\varphi_E = & \frac{1}{EI} \left(-\frac{1}{2} \cdot 6 \cdot 2 \cdot 1 \right) \\ & + \frac{1}{EI} \left(\frac{2}{3} \cdot \frac{3 \cdot 2^2}{8} \cdot 2 \cdot 1 \right) \\ & - \frac{1}{EI} \left(\frac{1}{2} \cdot 12 \cdot 6 \cdot \frac{2}{3} \cdot 1 \right) \\ & + \frac{1}{EI} \left(\frac{2}{3} \cdot \frac{3 \cdot 6^2}{8} \cdot 6 \cdot \frac{1}{2} \cdot 1 \right)\end{aligned}$$

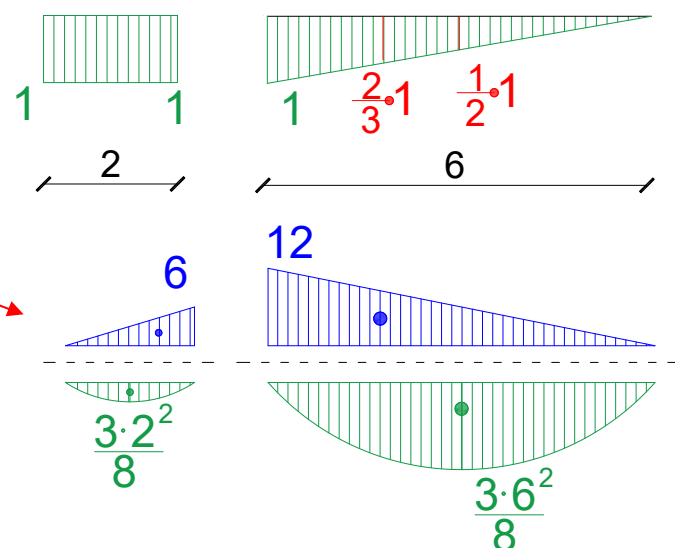


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Obliczenia przemieszczeń z zasady prac wirtualnych:

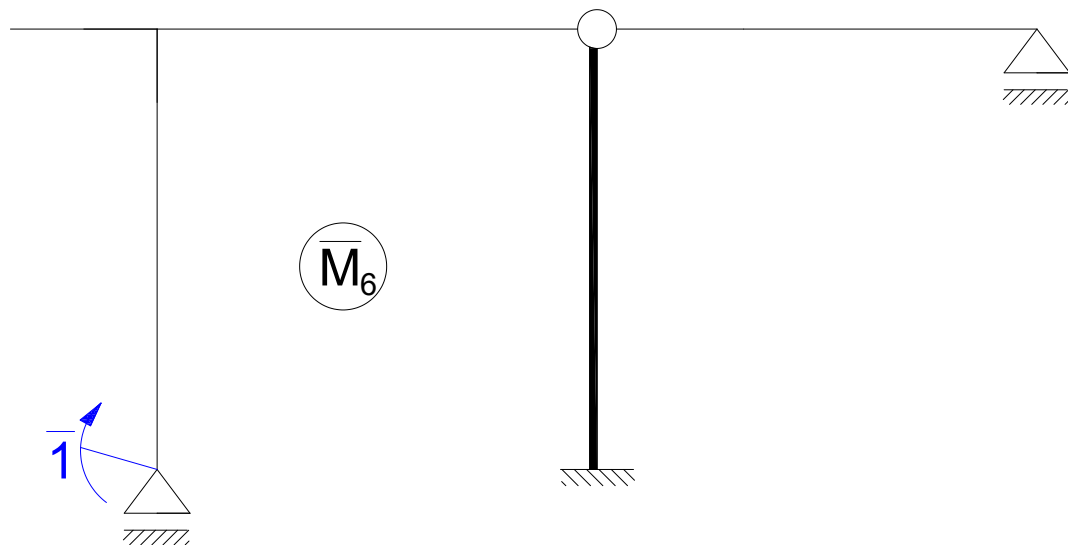


$$\begin{aligned} \varphi_E &= \frac{1}{EI} \left(-\frac{1}{2} \cdot 6 \cdot 2 \cdot 1 \right) \\ &+ \frac{1}{EI} \left(\frac{2}{3} \cdot \frac{3 \cdot 2^2}{8} \cdot 2 \cdot 1 \right) \\ &- \frac{1}{EI} \left(\frac{1}{2} \cdot 12 \cdot 6 \cdot \frac{2}{3} \cdot 1 \right) \\ &+ \frac{1}{EI} \left(\frac{2}{3} \cdot \frac{3 \cdot 6^2}{8} \cdot 6 \cdot \frac{1}{2} \cdot 1 \right) = -\frac{1}{EI} \end{aligned}$$

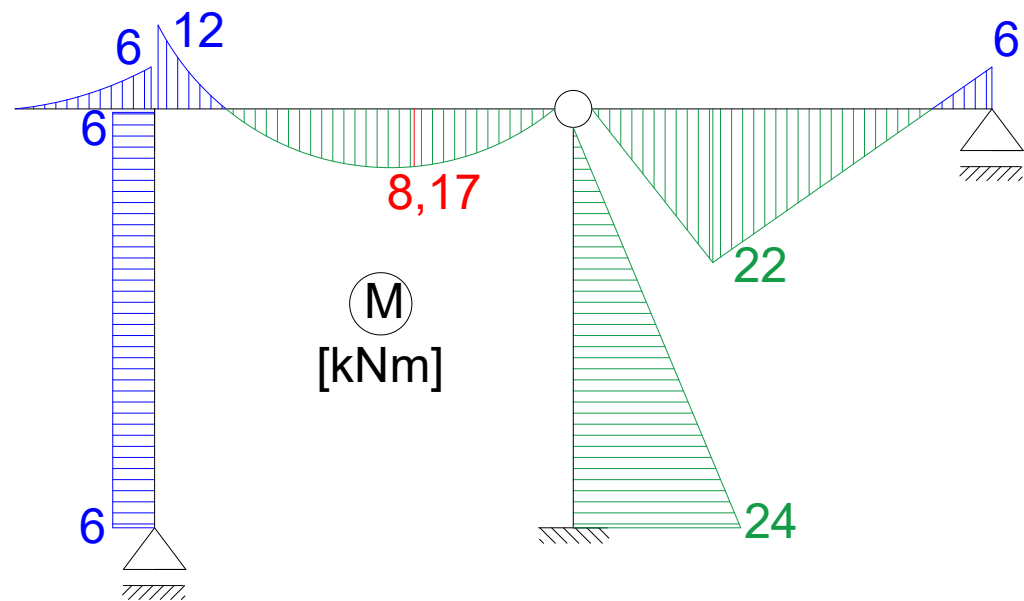


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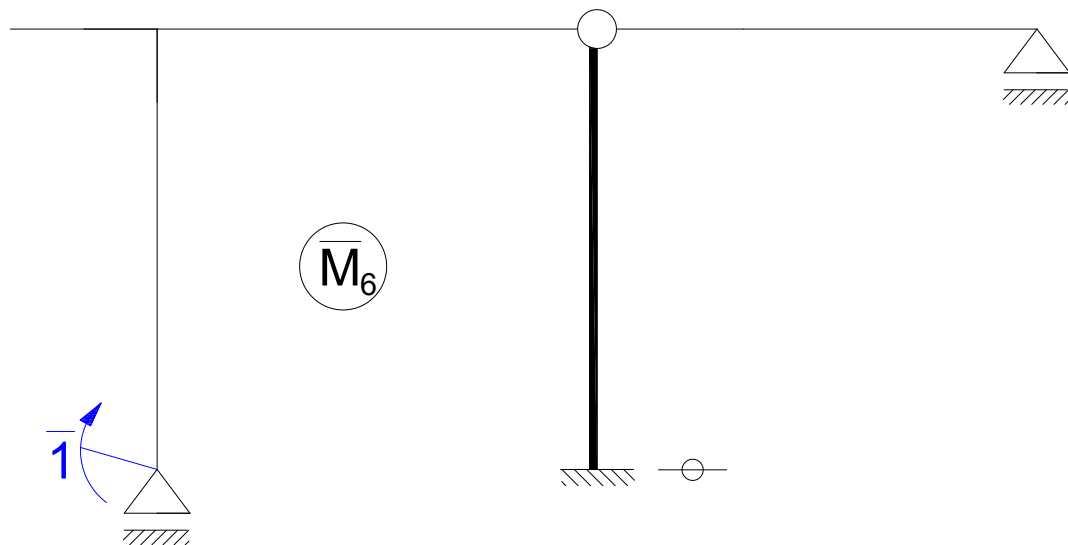
Obliczenia przemieszczeń z zasady prac wirtualnych:



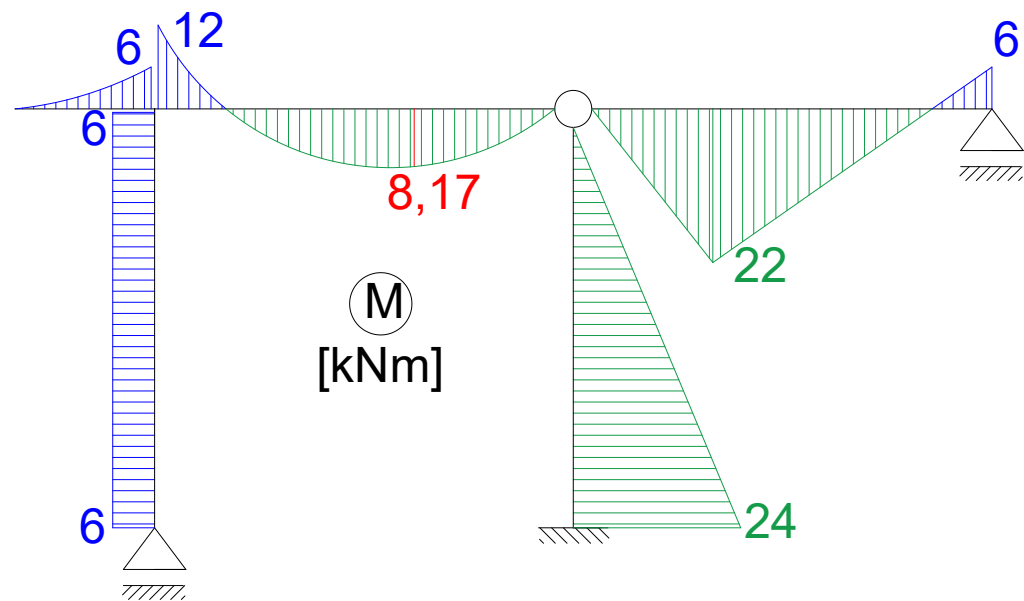
$$\varphi_A = ?$$



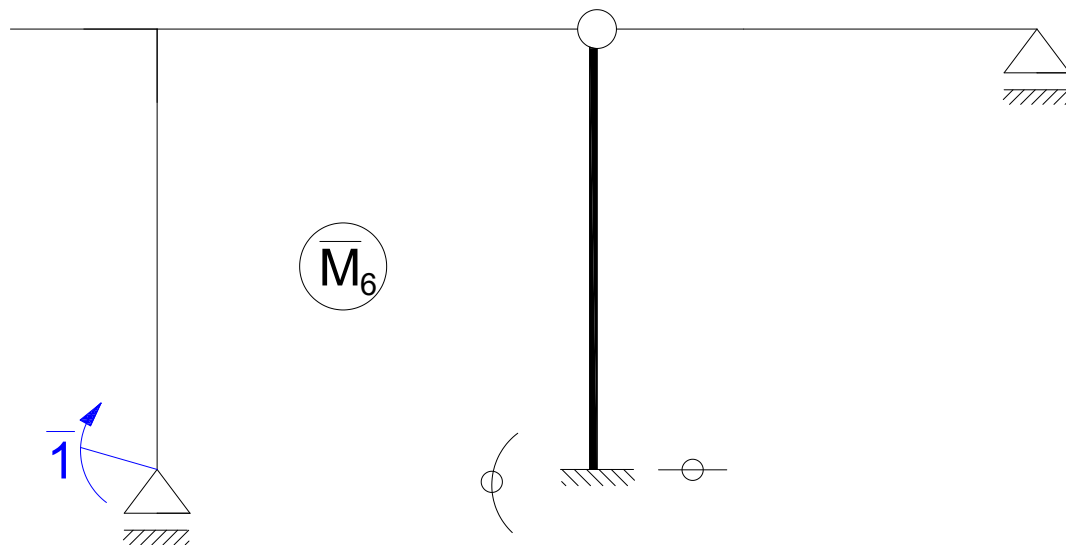
Obliczenia przemieszczeń z zasady prac wirtualnych:



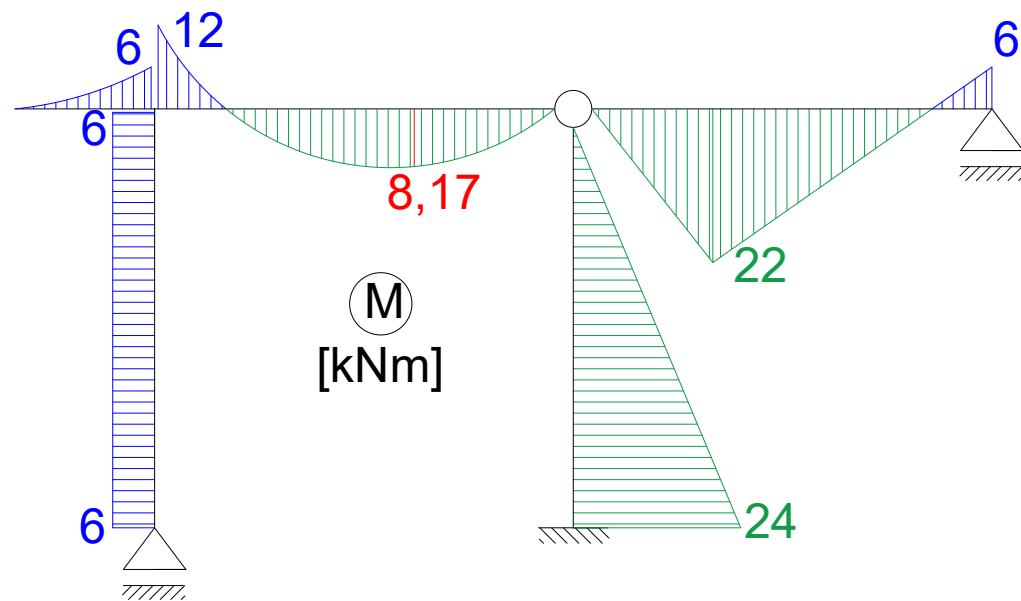
$$\varphi_A = ?$$



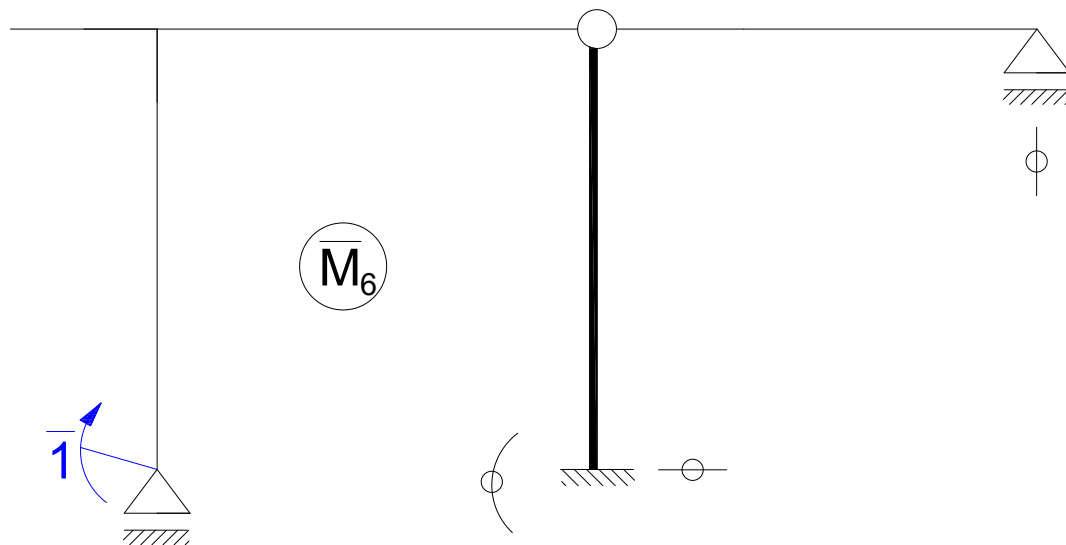
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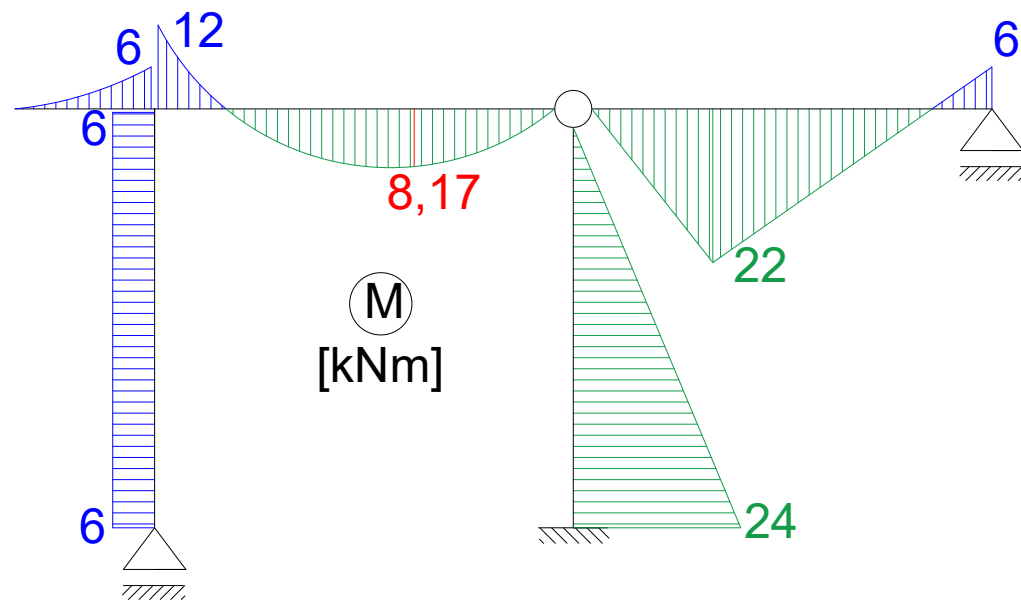
$$\varphi_A = ?$$



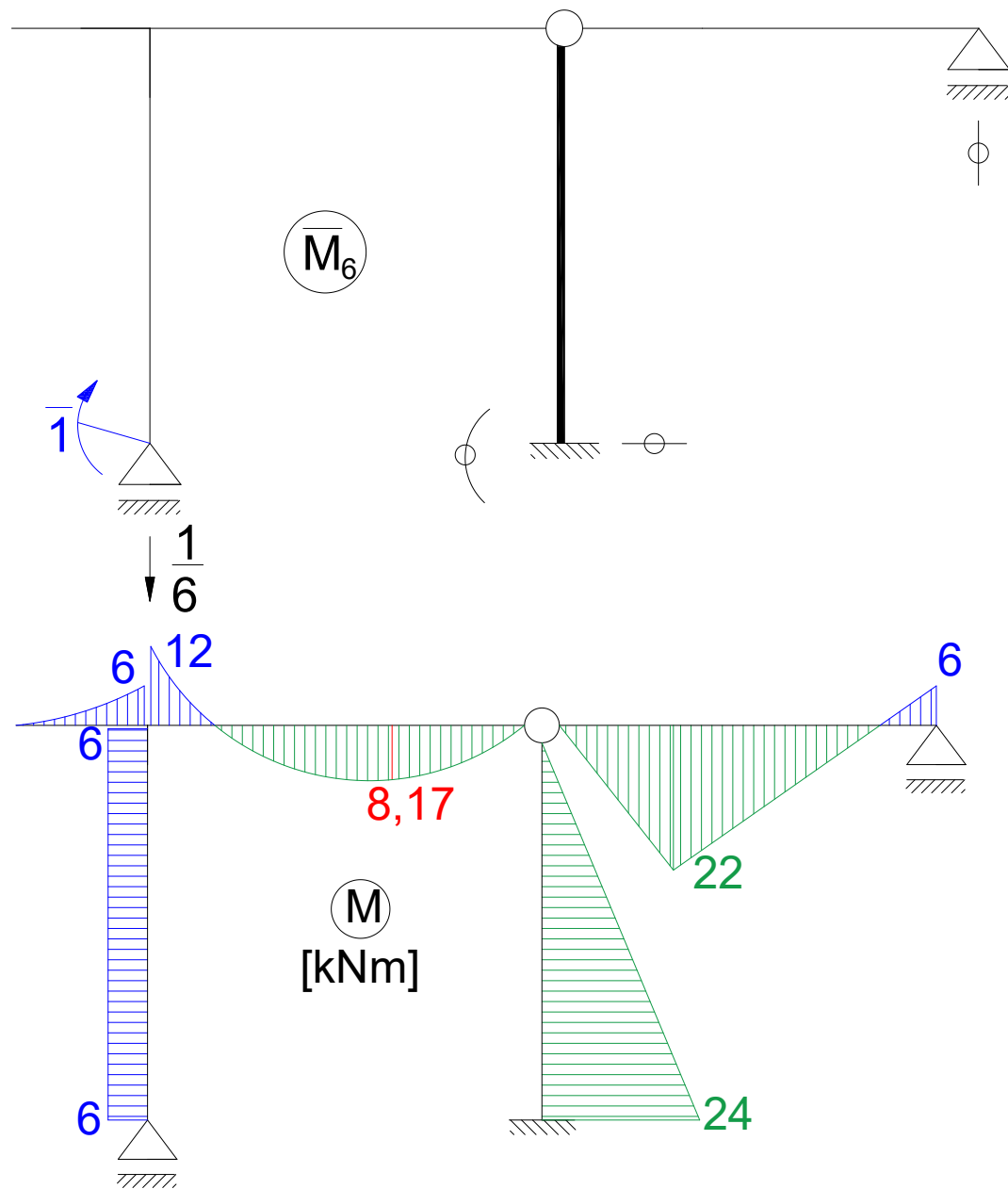
Obliczenia przemieszczeń z zasady prac wirtualnych:



$$\varphi_A = ?$$

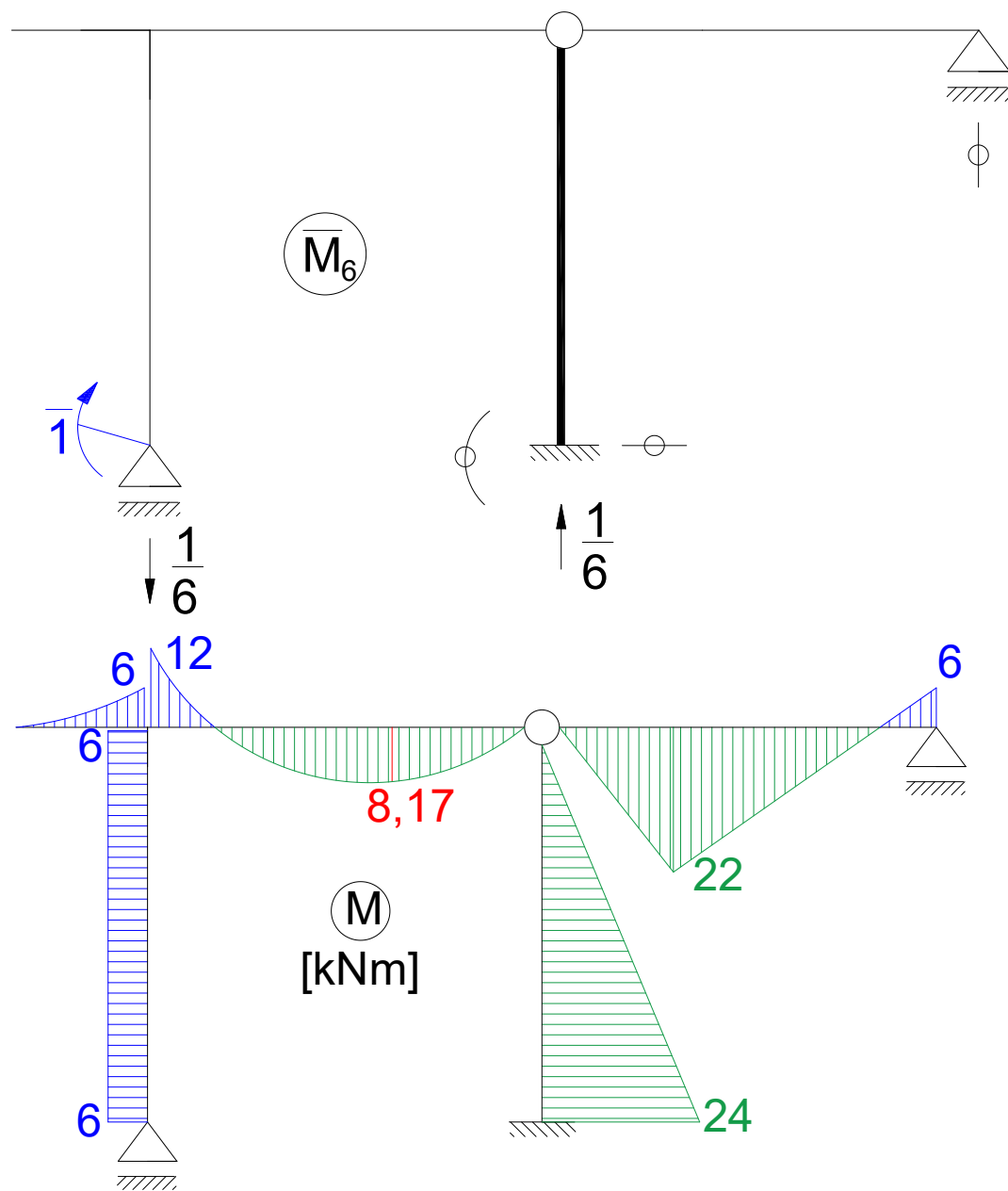


Obliczenia przemieszczeń z zasady prac wirtualnych:



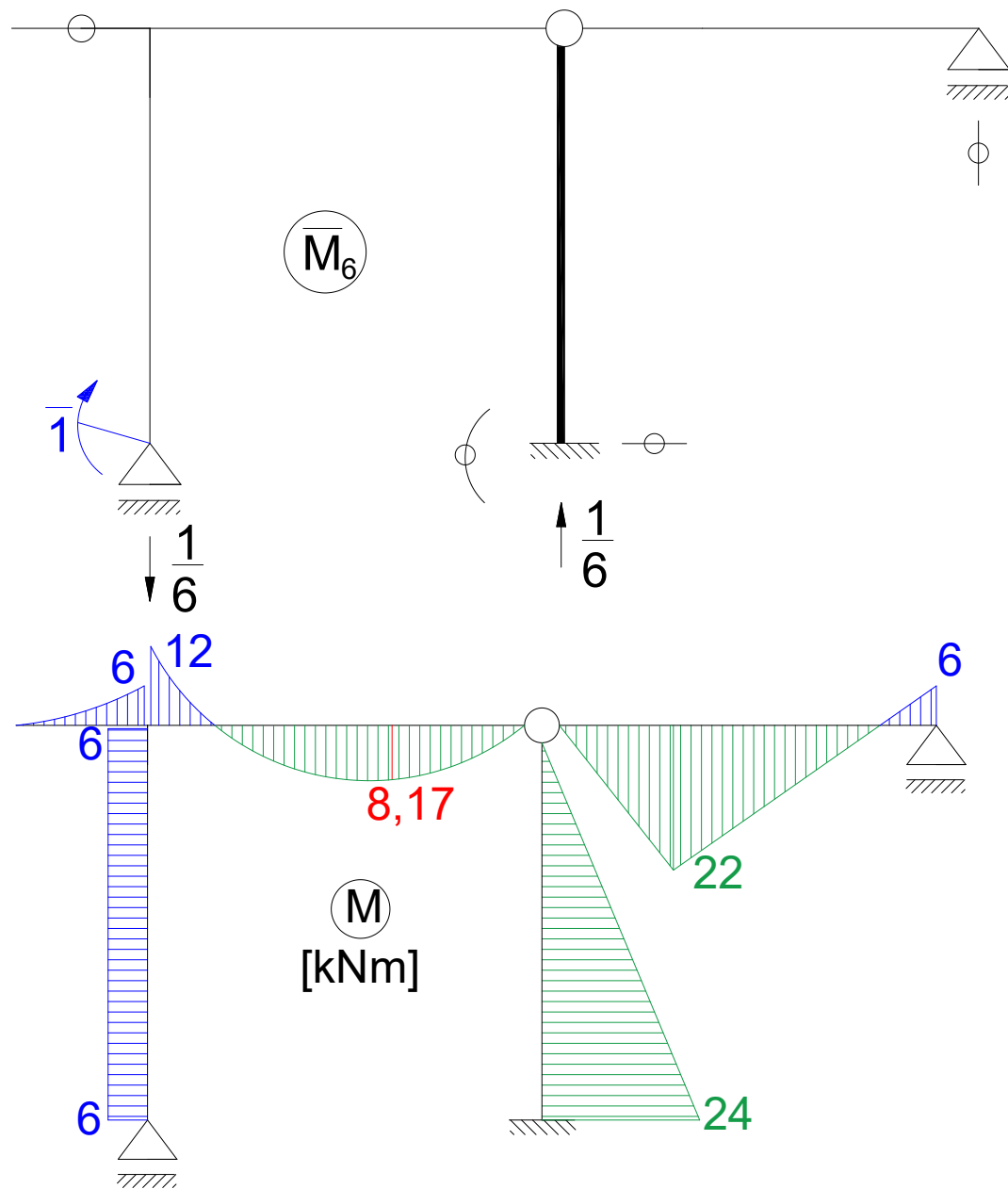
$$\varphi_A = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



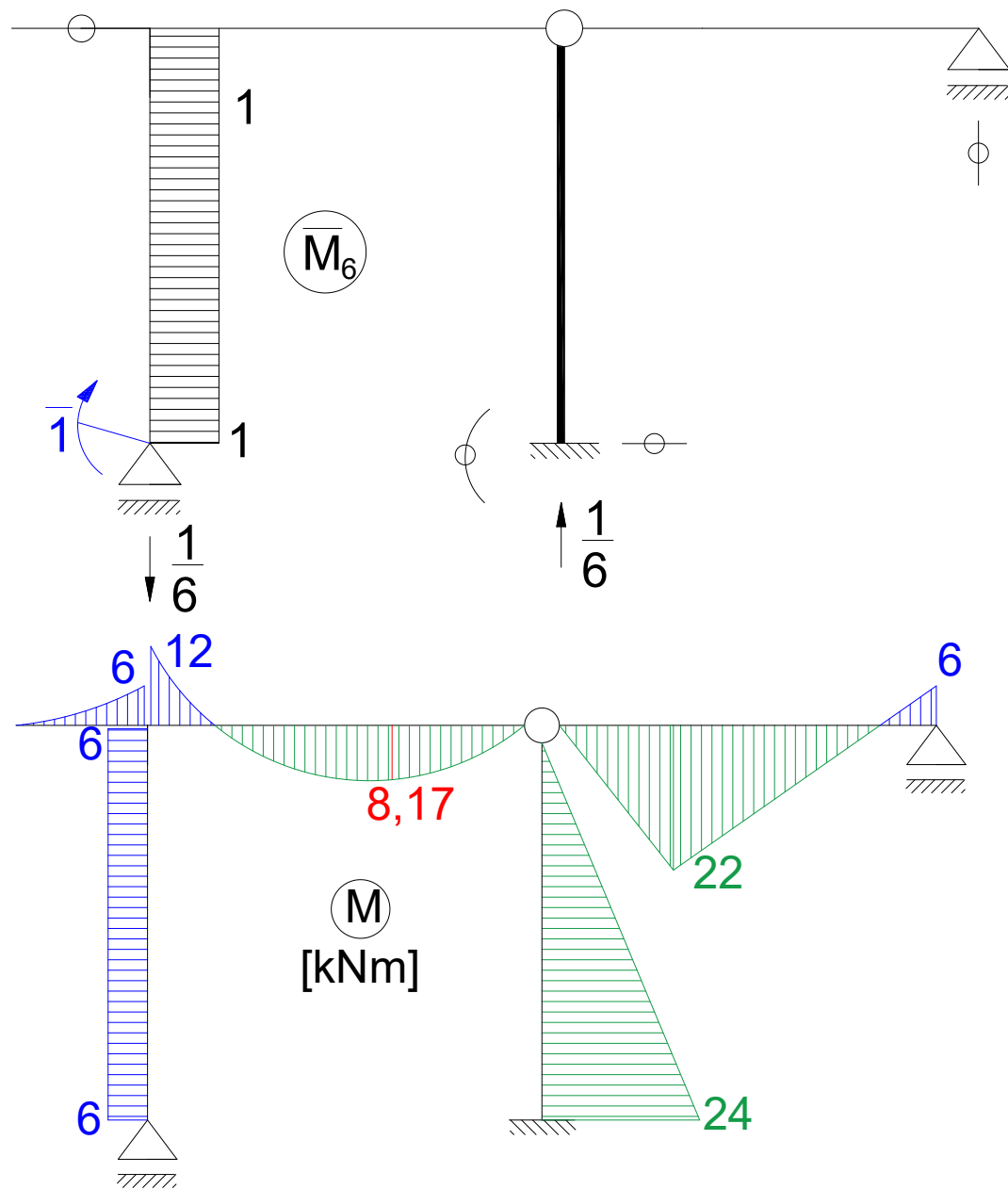
$$\varphi_A = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



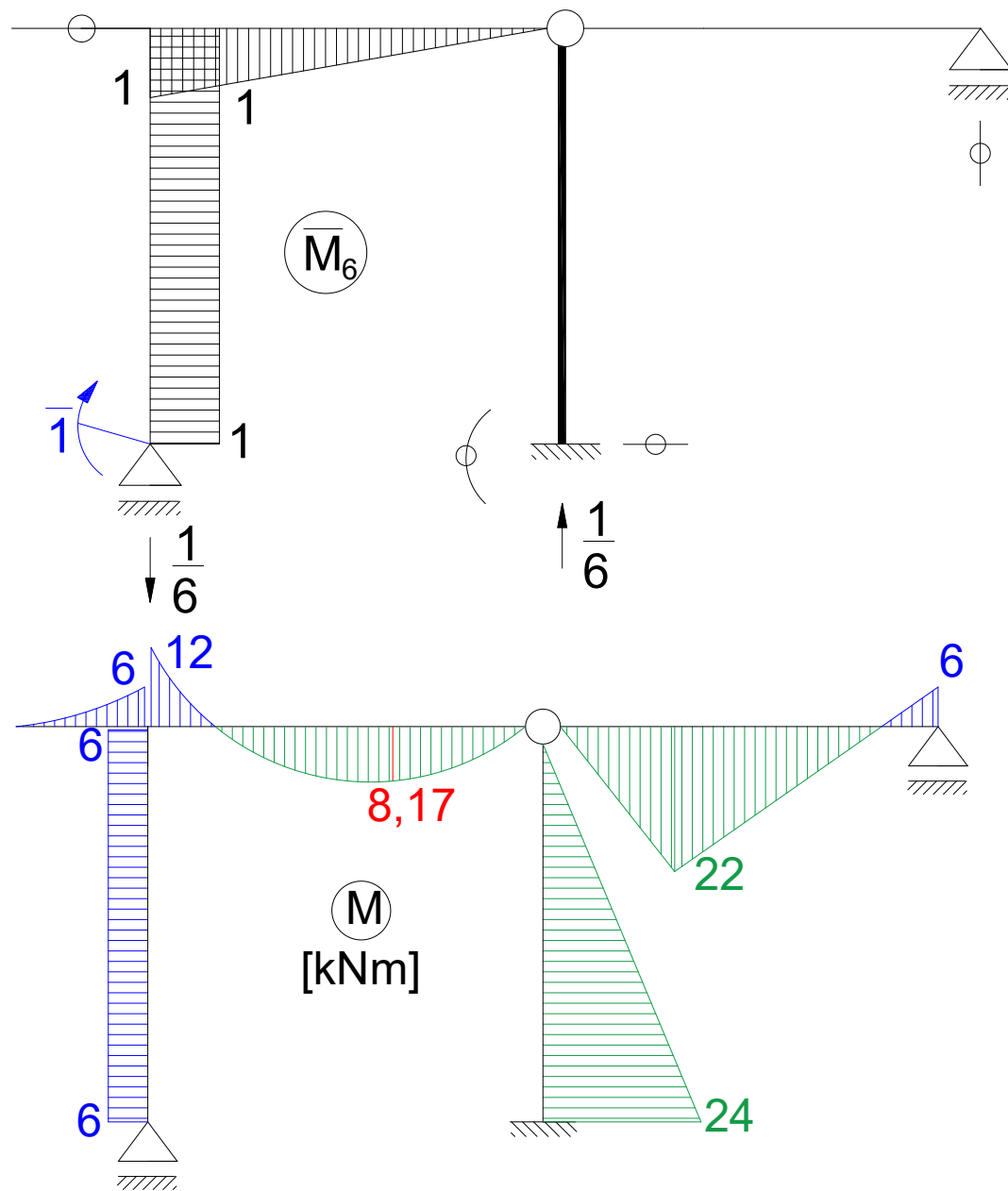
$$\varphi_A = ?$$

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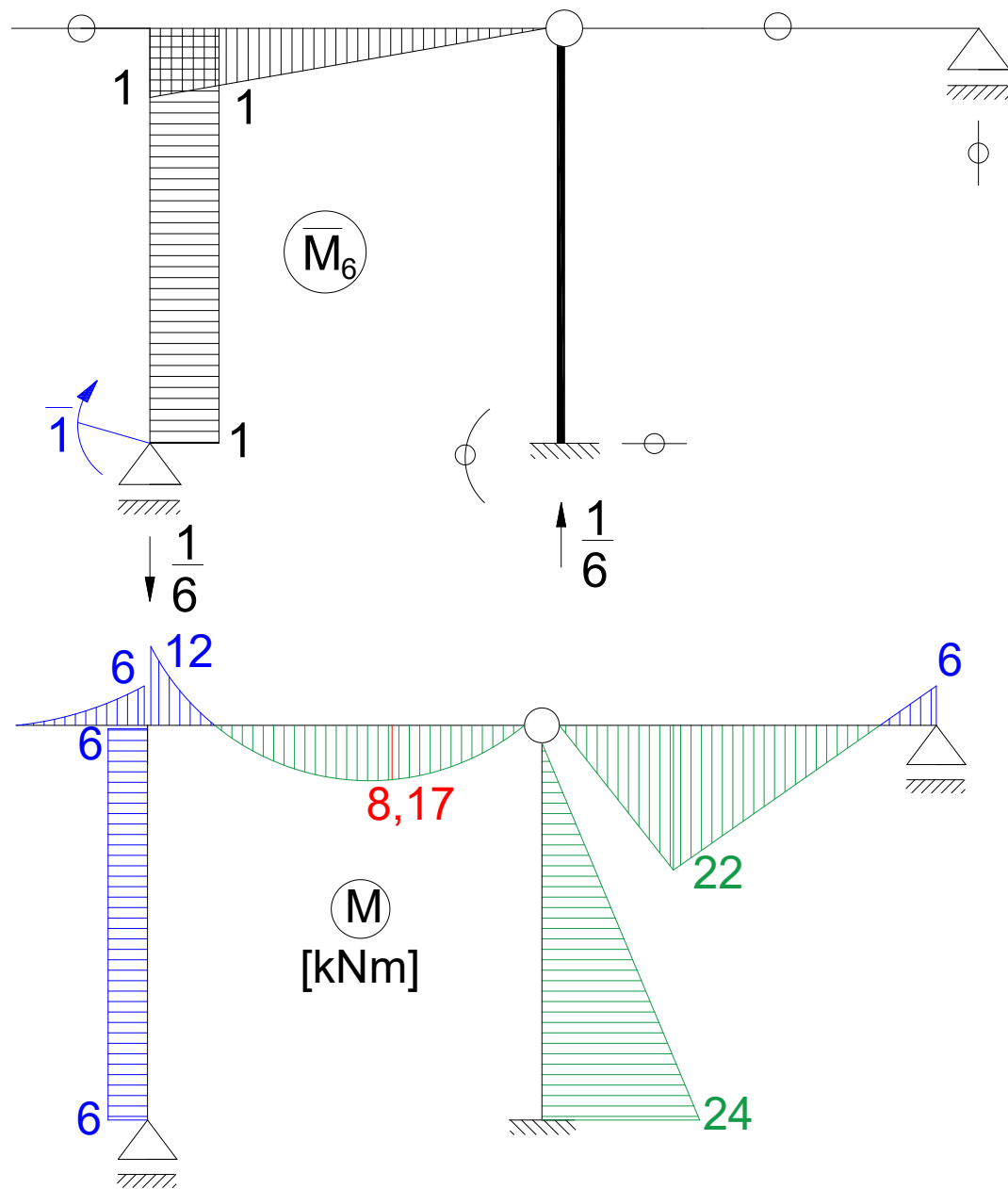
$$\varphi_A = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



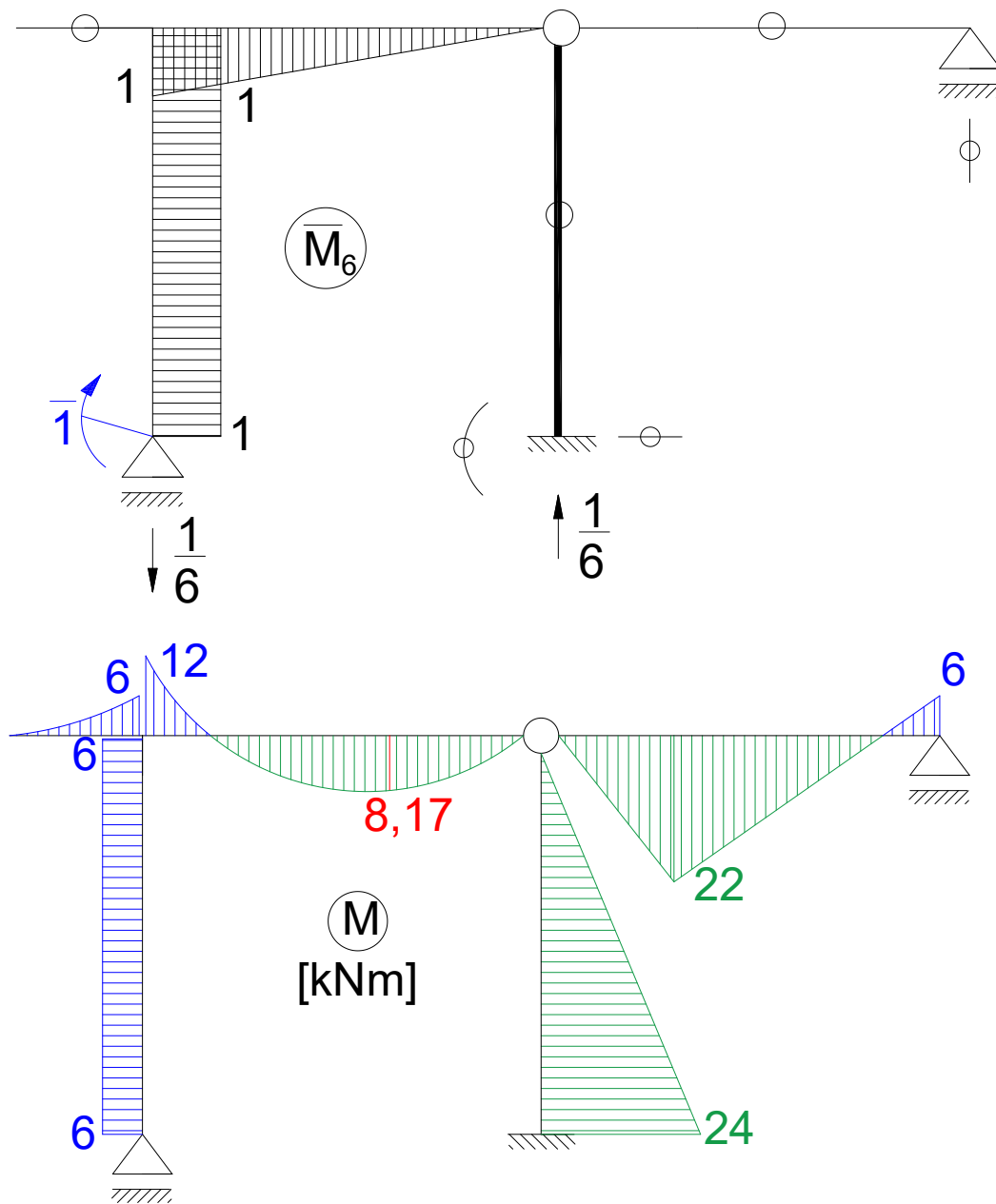
$$\varphi_A = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



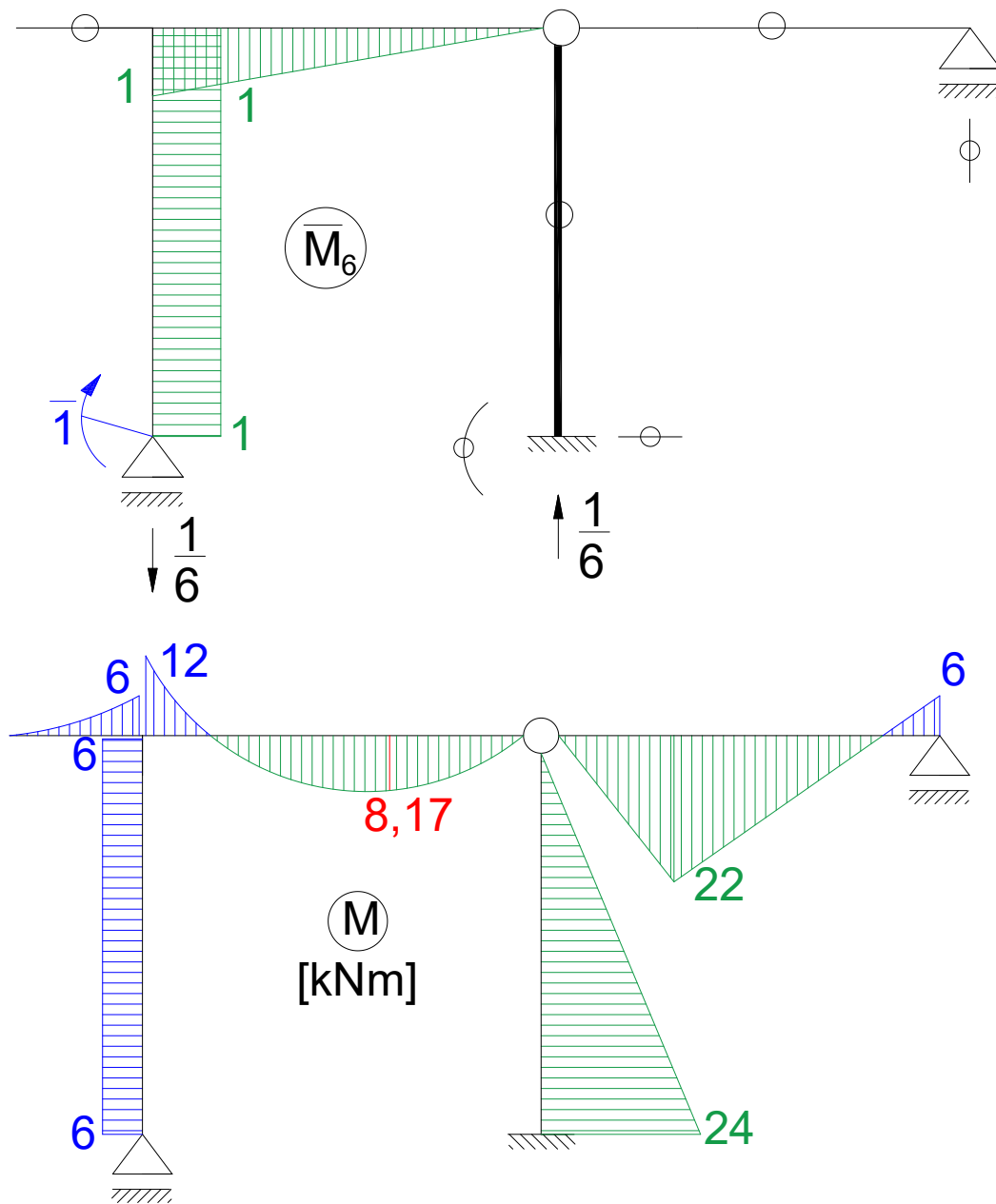
$$\varphi_A = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



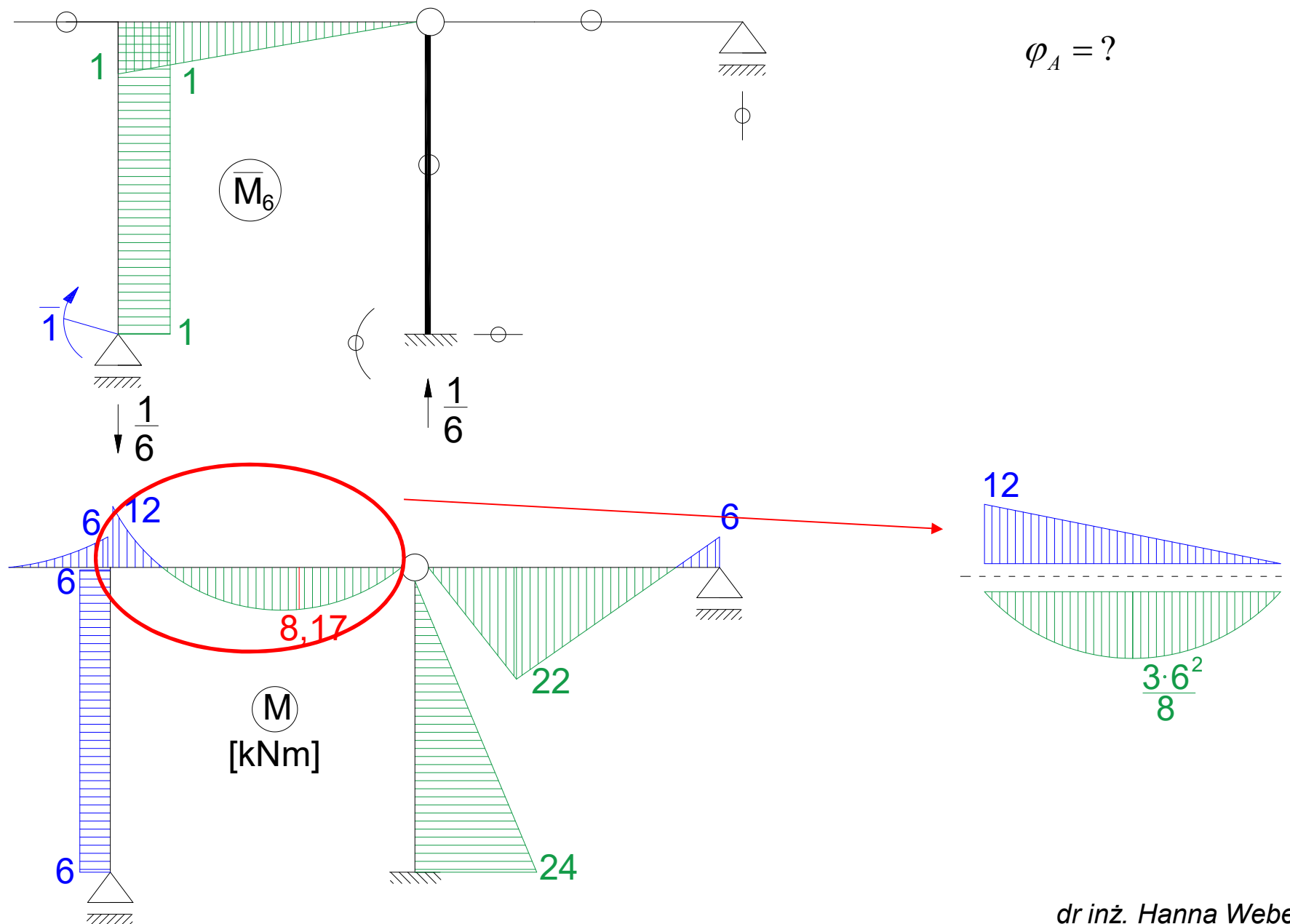
$$\varphi_A = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:

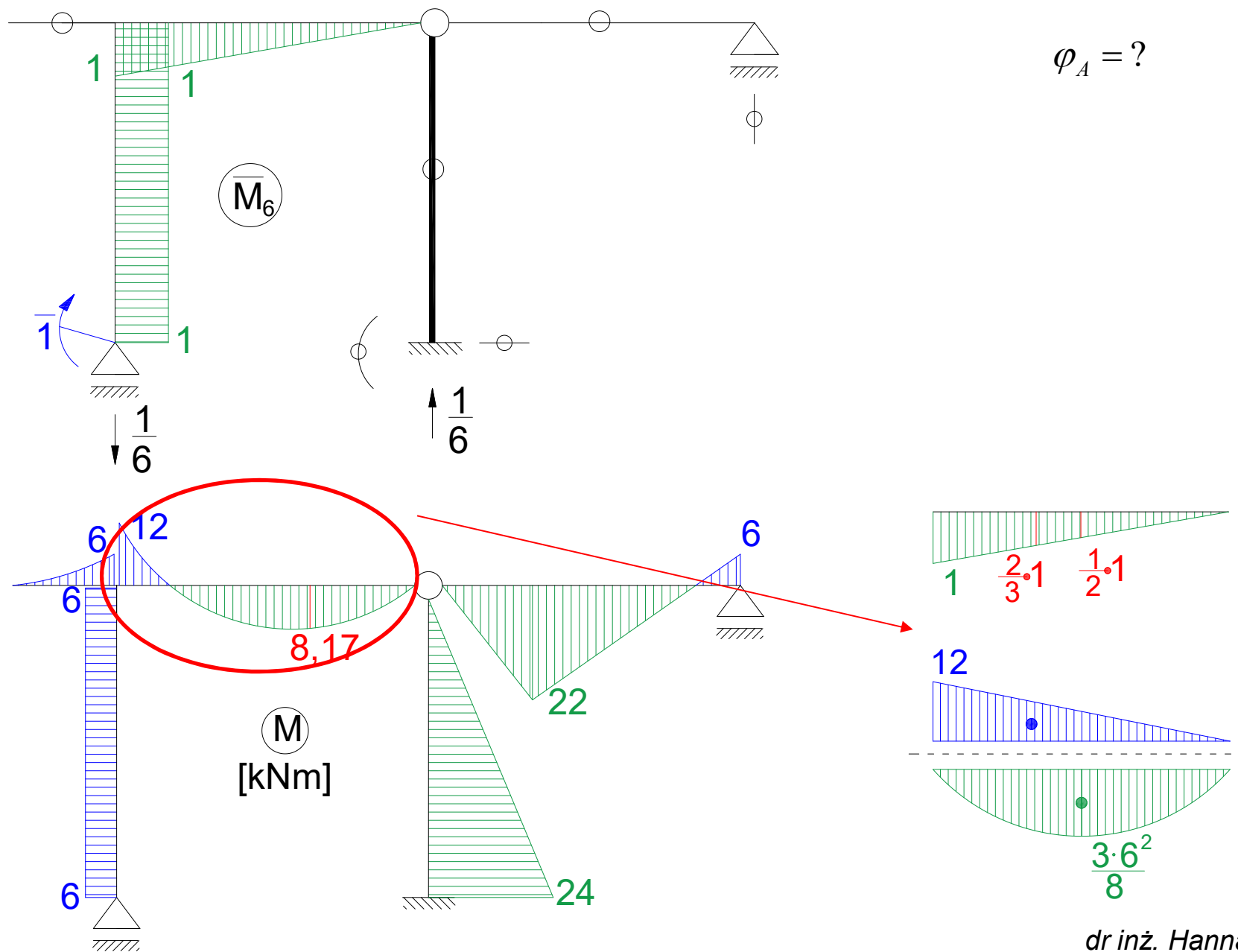


$$\varphi_A = ?$$

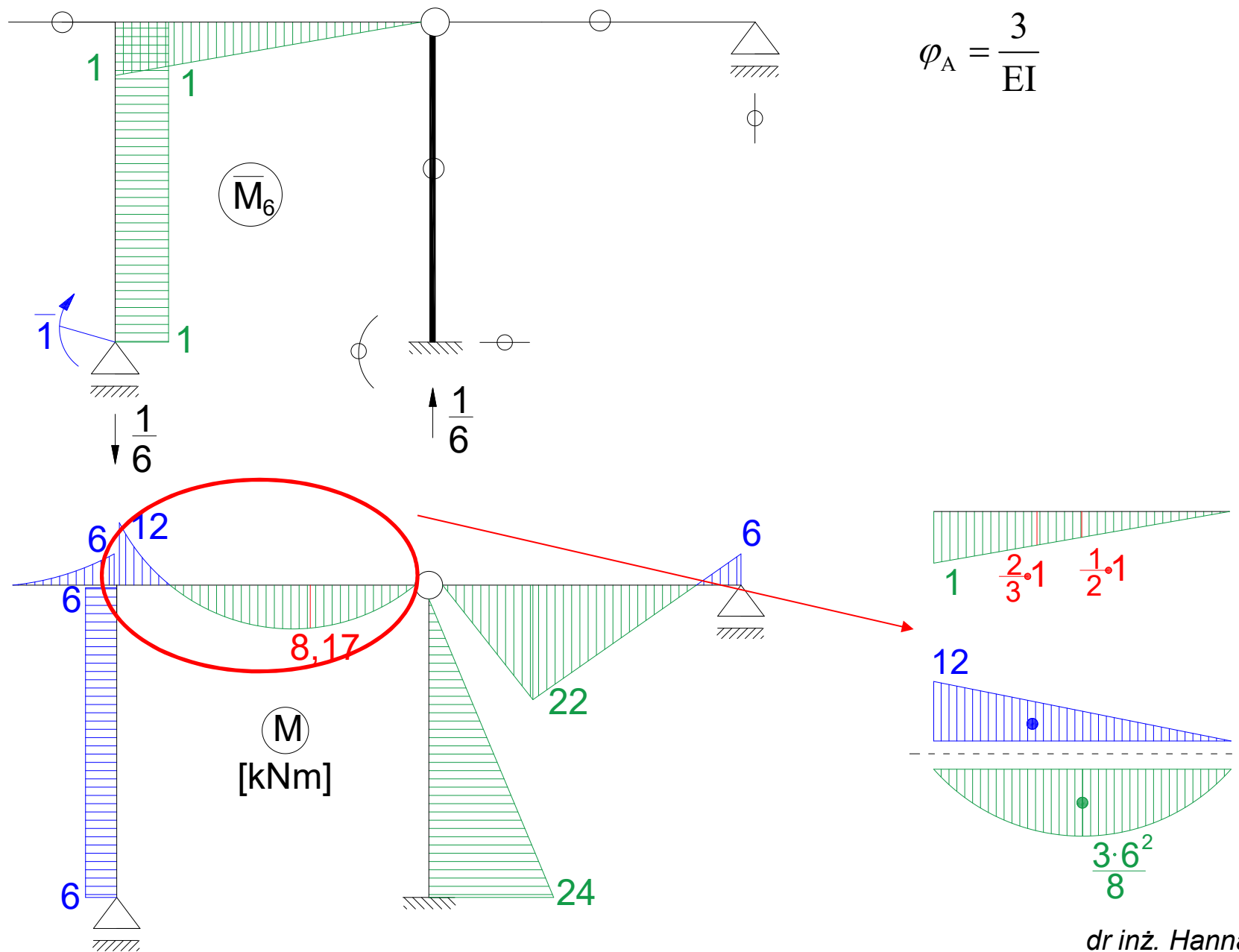
Obliczenia przemieszczeń z zasady prac wirtualnych:



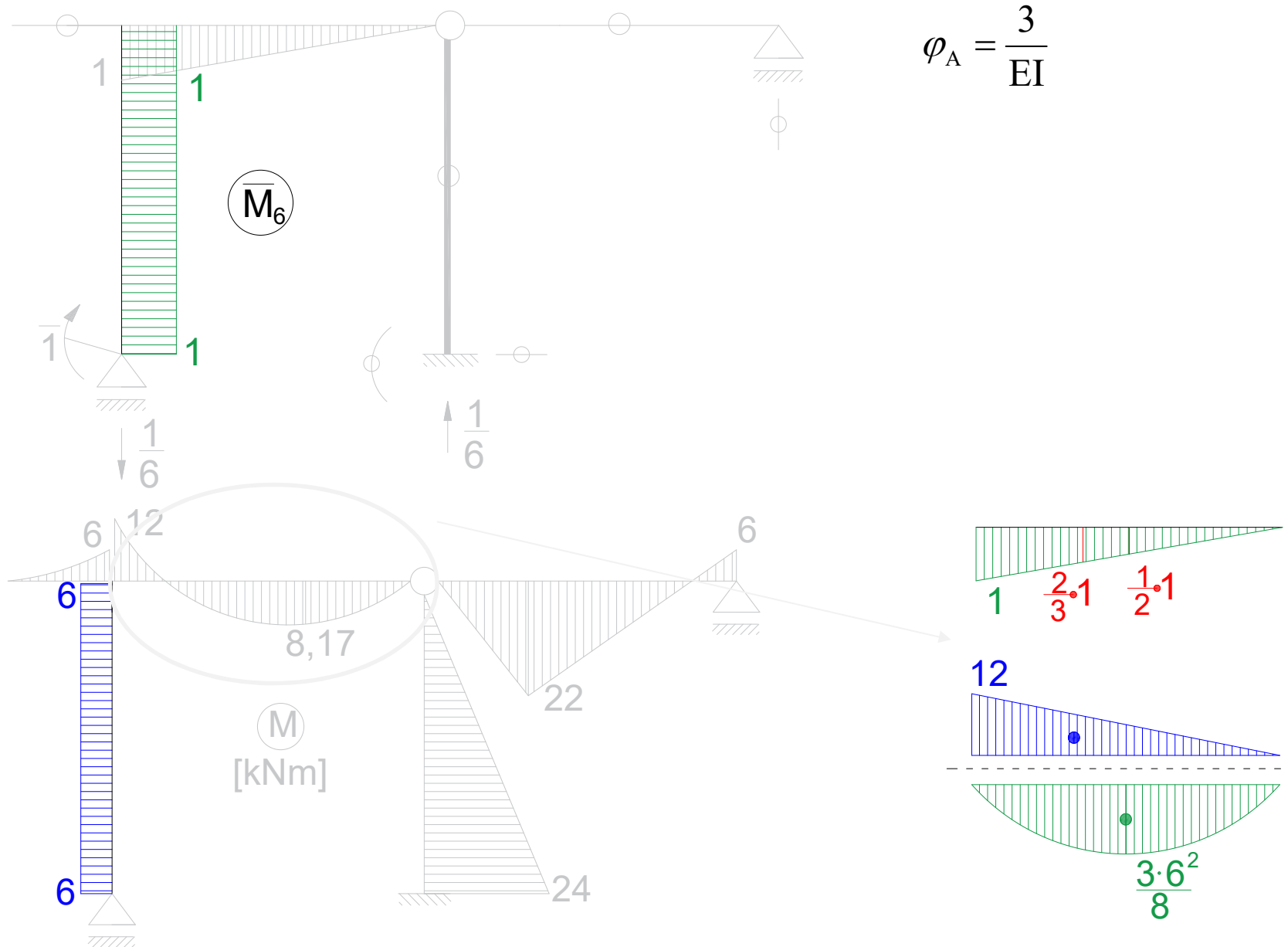
Obliczenia przemieszczeń z zasady prac wirtualnych:



Obliczenia przemieszczeń z zasady prac wirtualnych:

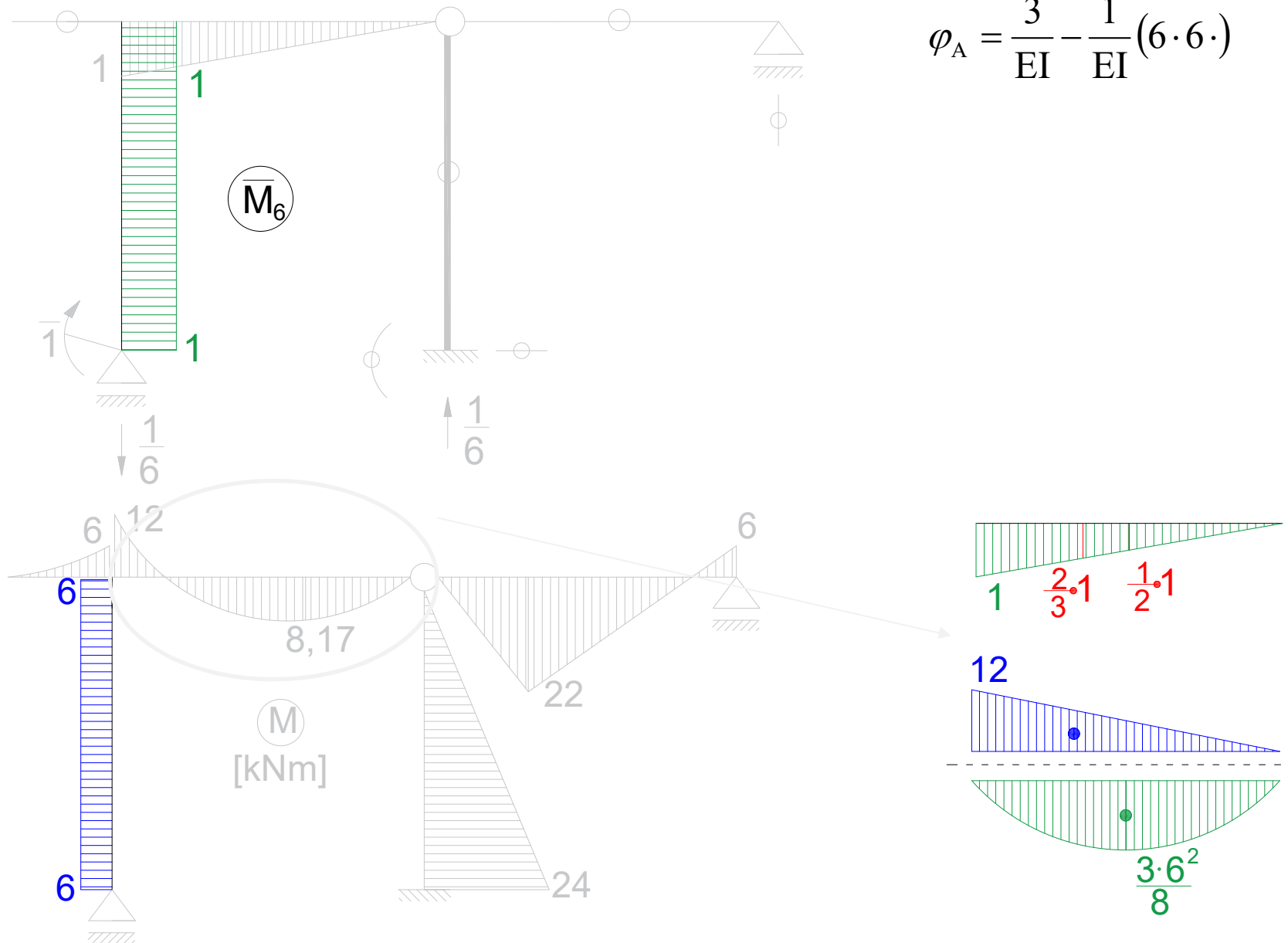


Obliczenia przemieszczeń z zasady prac wirtualnych:



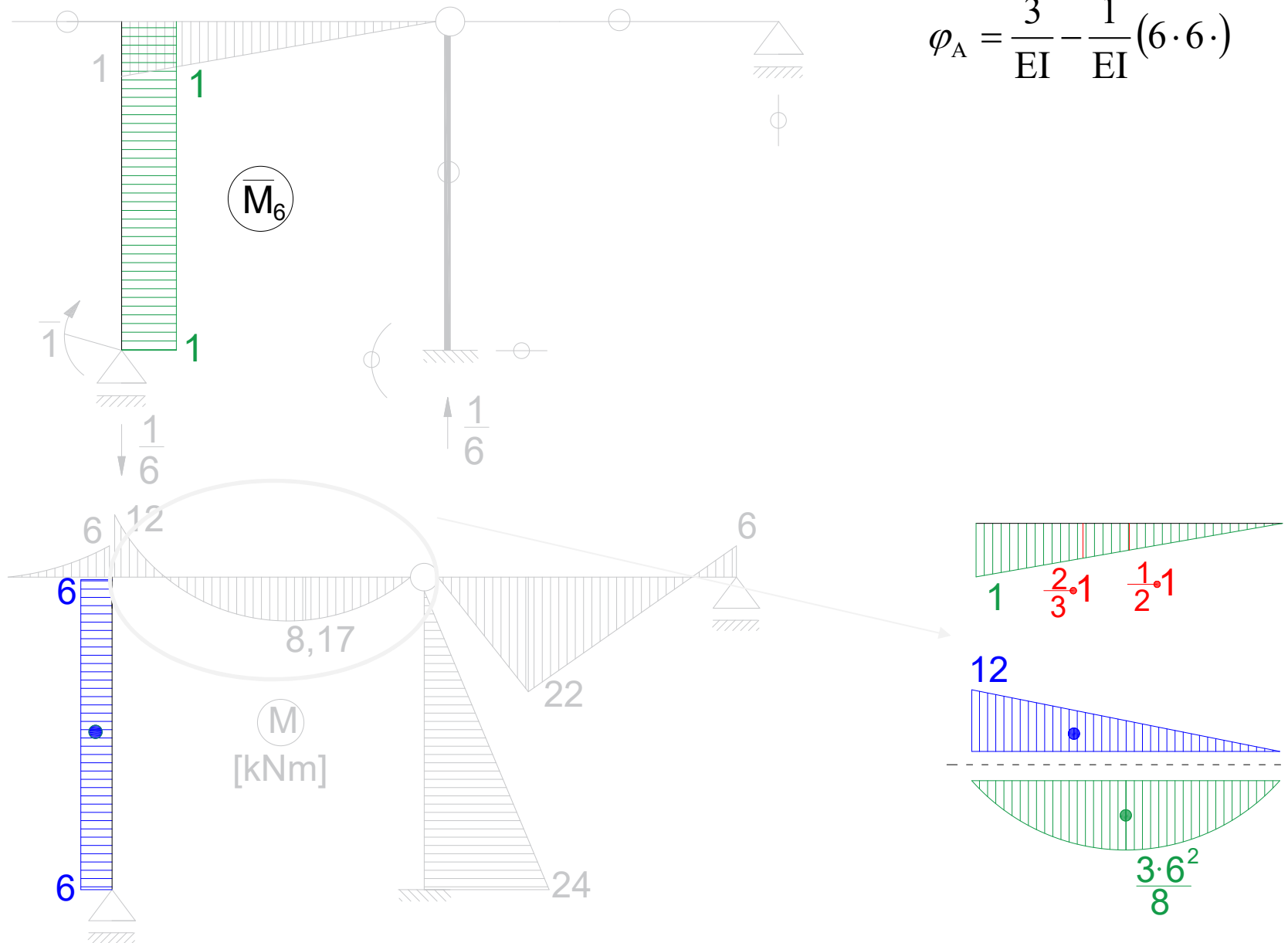
Obliczenia przemieszczeń z zasady prac wirtualnych:

$$\varphi_A = \frac{3}{EI} - \frac{1}{EI}(6 \cdot 6 \cdot)$$



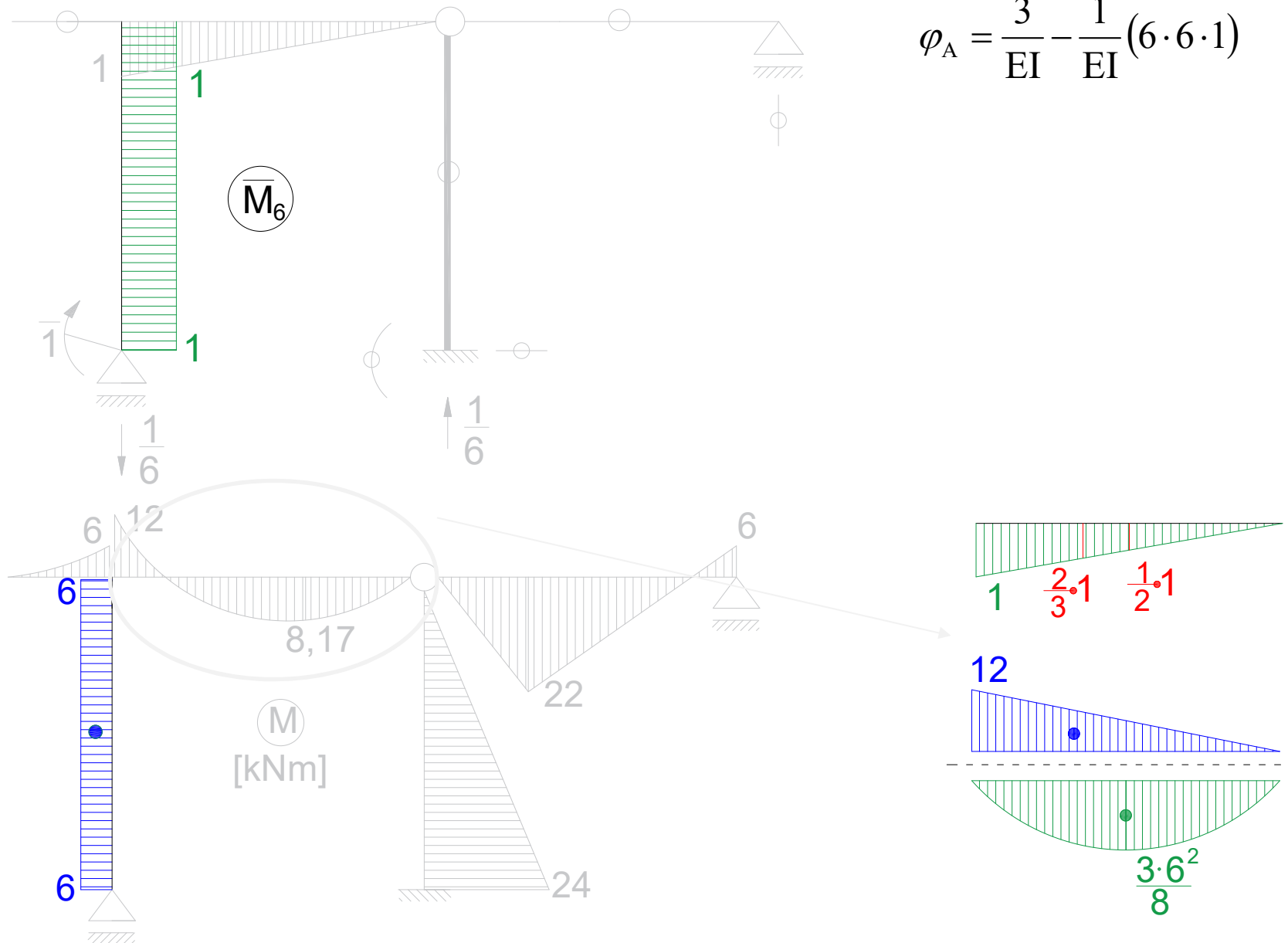
Obliczenia przemieszczeń z zasady prac wirtualnych:

$$\varphi_A = \frac{3}{EI} - \frac{1}{EI}(6 \cdot 6 \cdot)$$

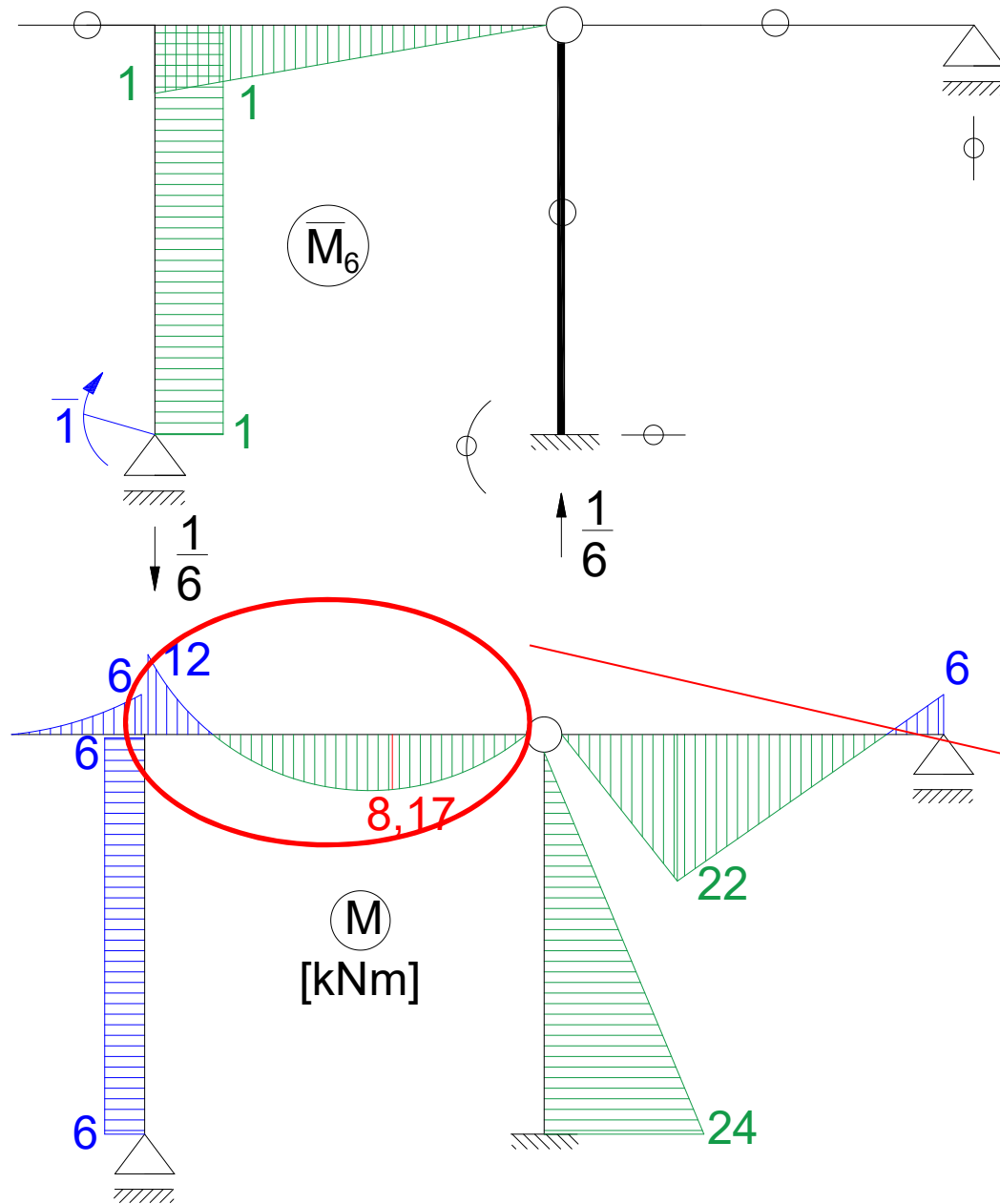


Obliczenia przemieszczeń z zasady prac wirtualnych:

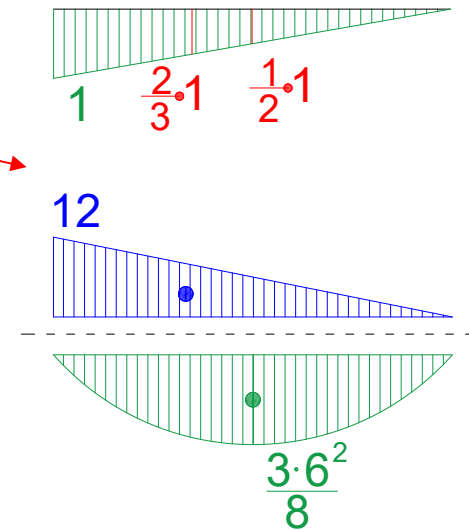
$$\varphi_A = \frac{3}{EI} - \frac{1}{EI}(6 \cdot 6 \cdot 1)$$



Obliczenia przemieszczeń z zasady prac wirtualnych:

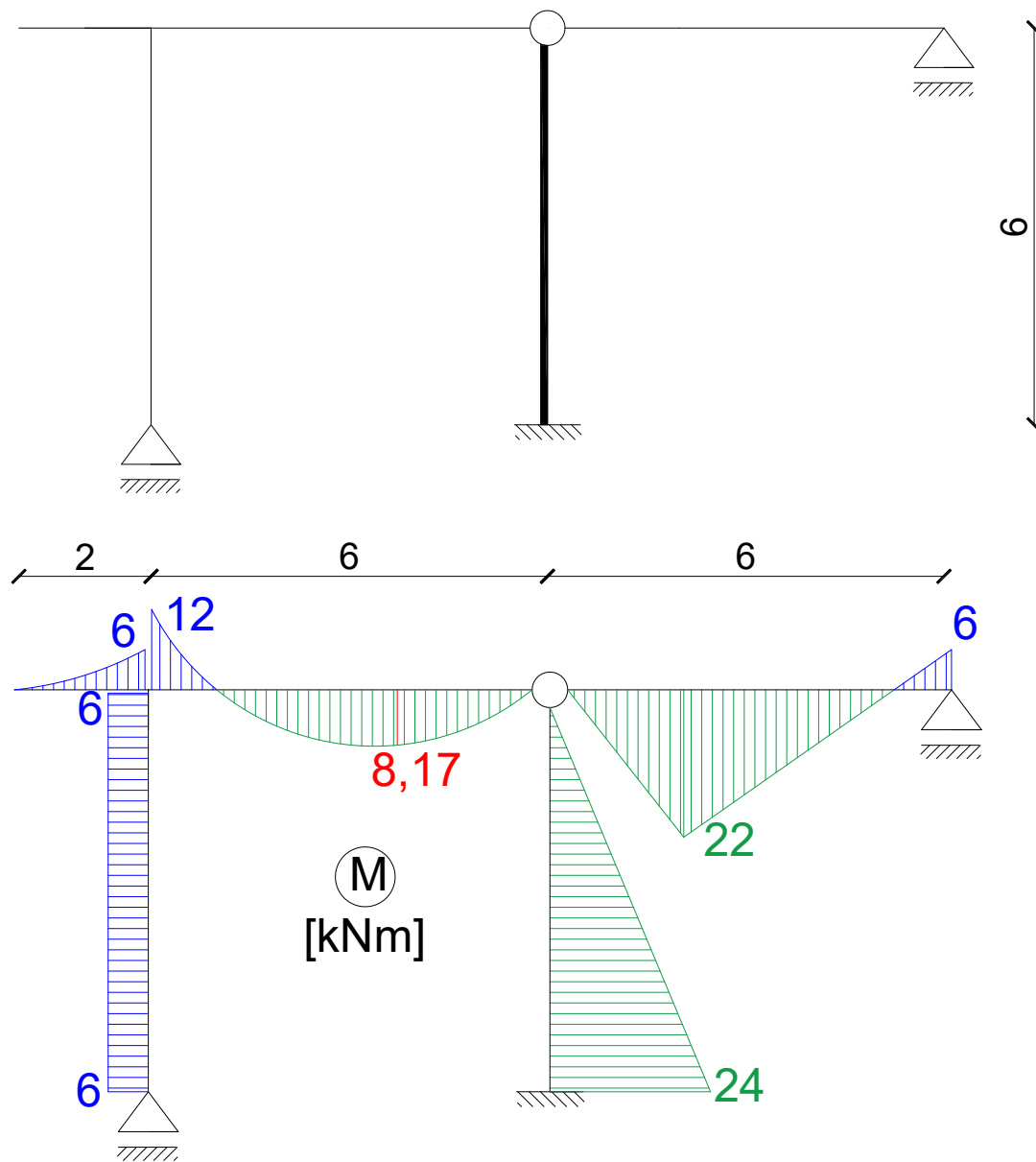


$$\varphi_A = \frac{3}{EI} - \frac{1}{EI} (6 \cdot 6 \cdot 1) = -\frac{33}{EI}$$

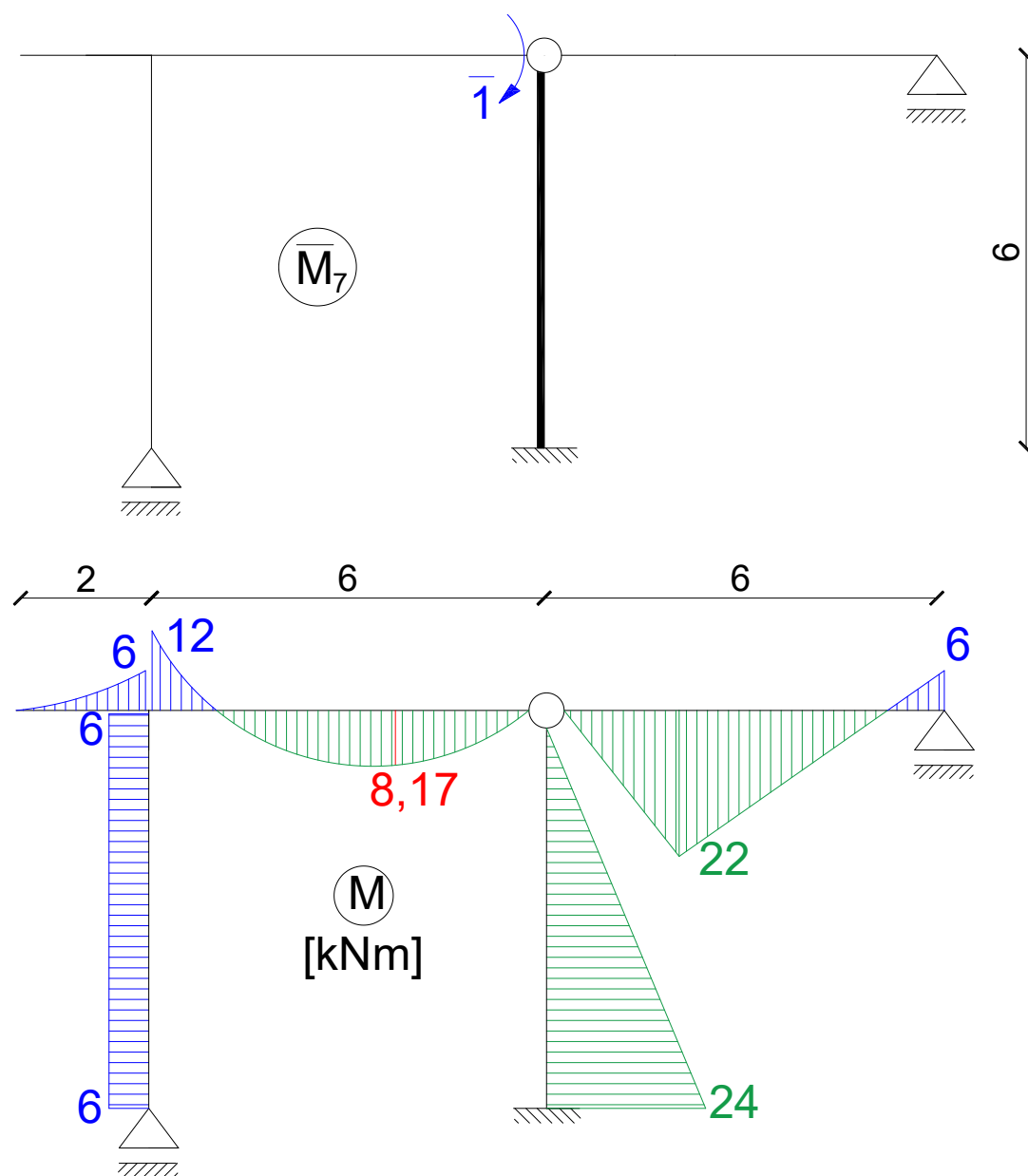


Obliczenia przemieszczeń z zasady prac wirtualnych:

$$\varphi_C^L = ?$$

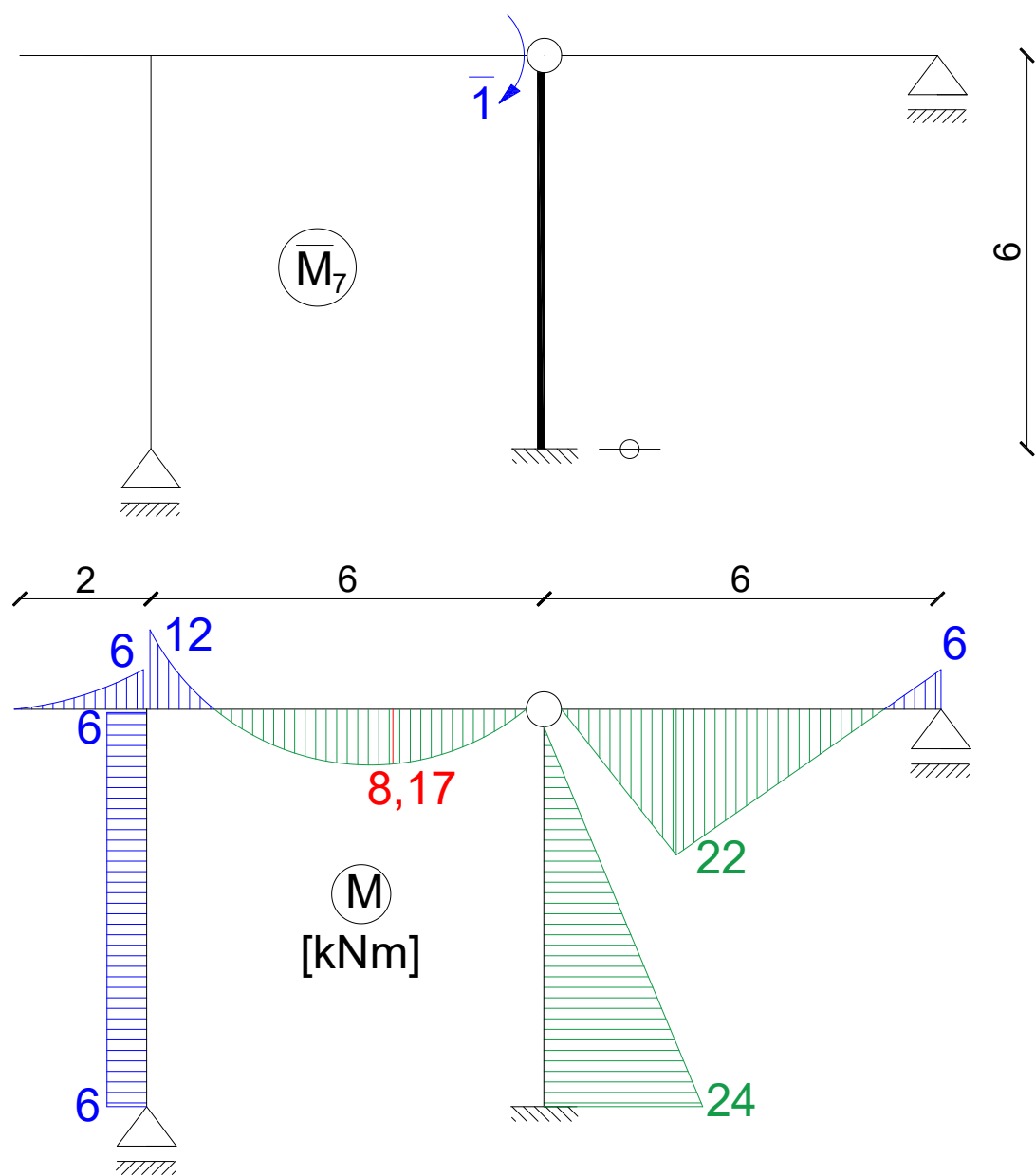


Obliczenia przemieszczeń z zasady prac wirtualnych:



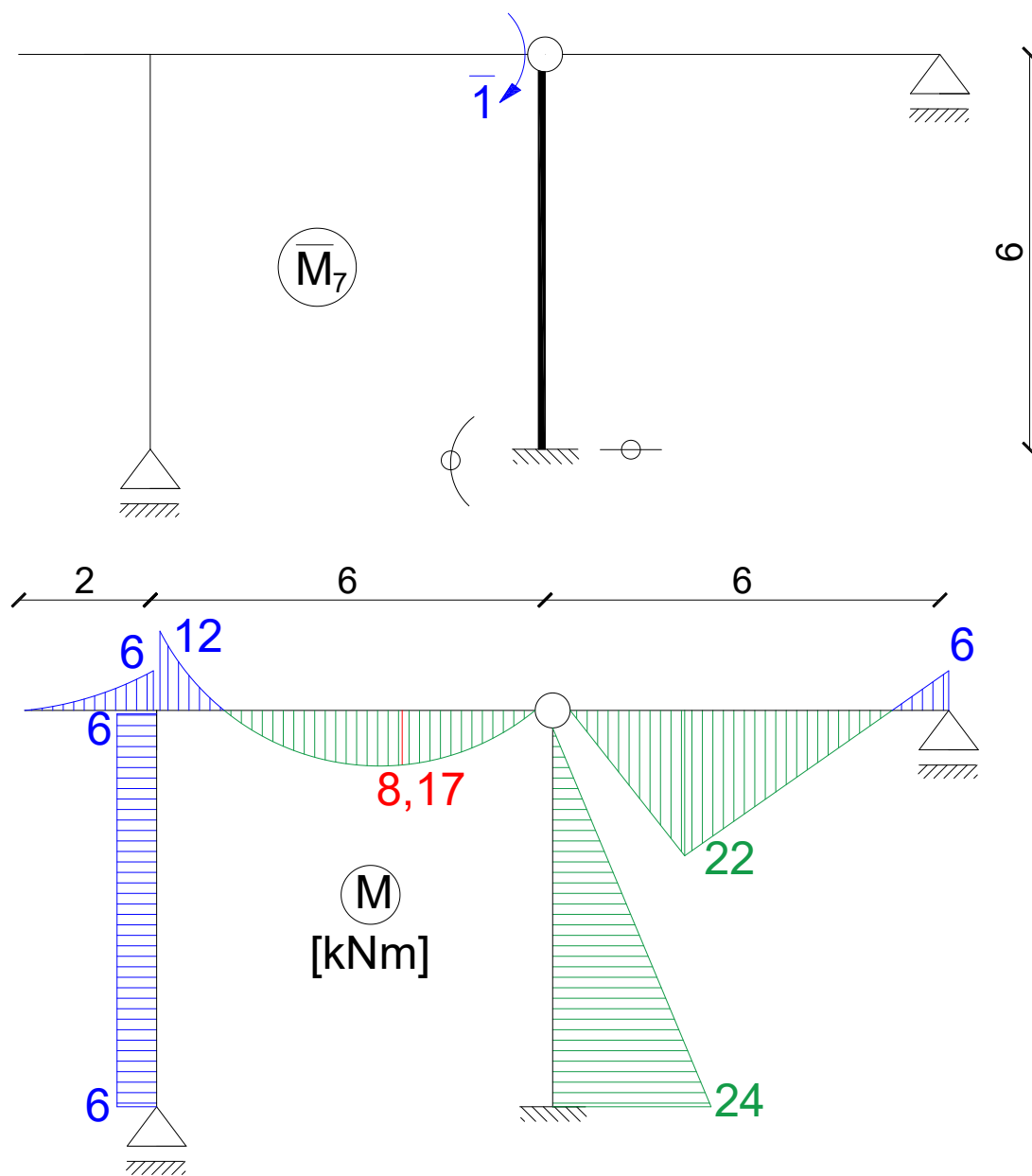
$$\varphi_C^L = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



$$\varphi_C^L = ?$$

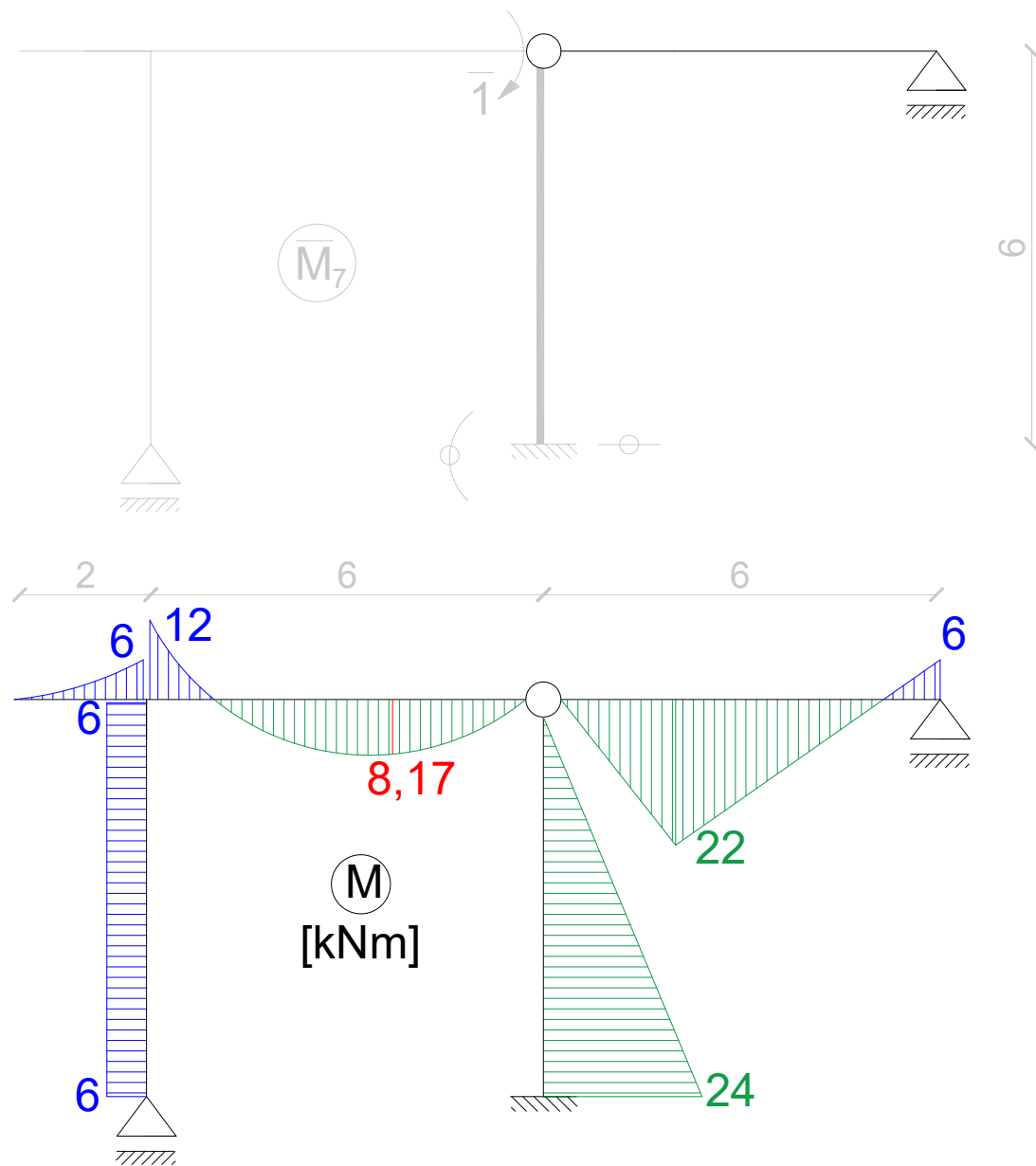
Obliczenia przemieszczeń z zasady prac wirtualnych:



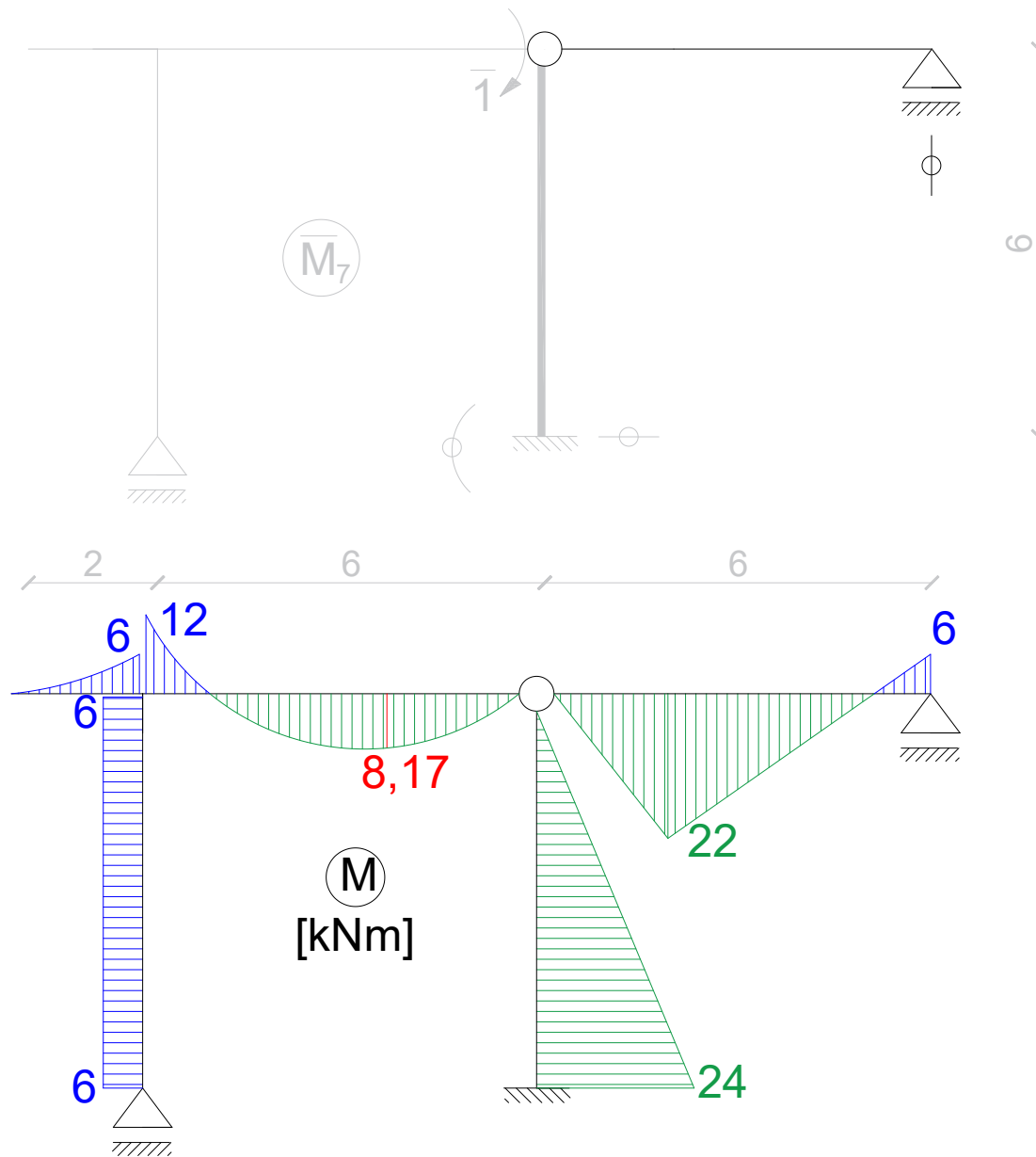
$$\varphi_C^L = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:

$$\varphi_C^L = ?$$

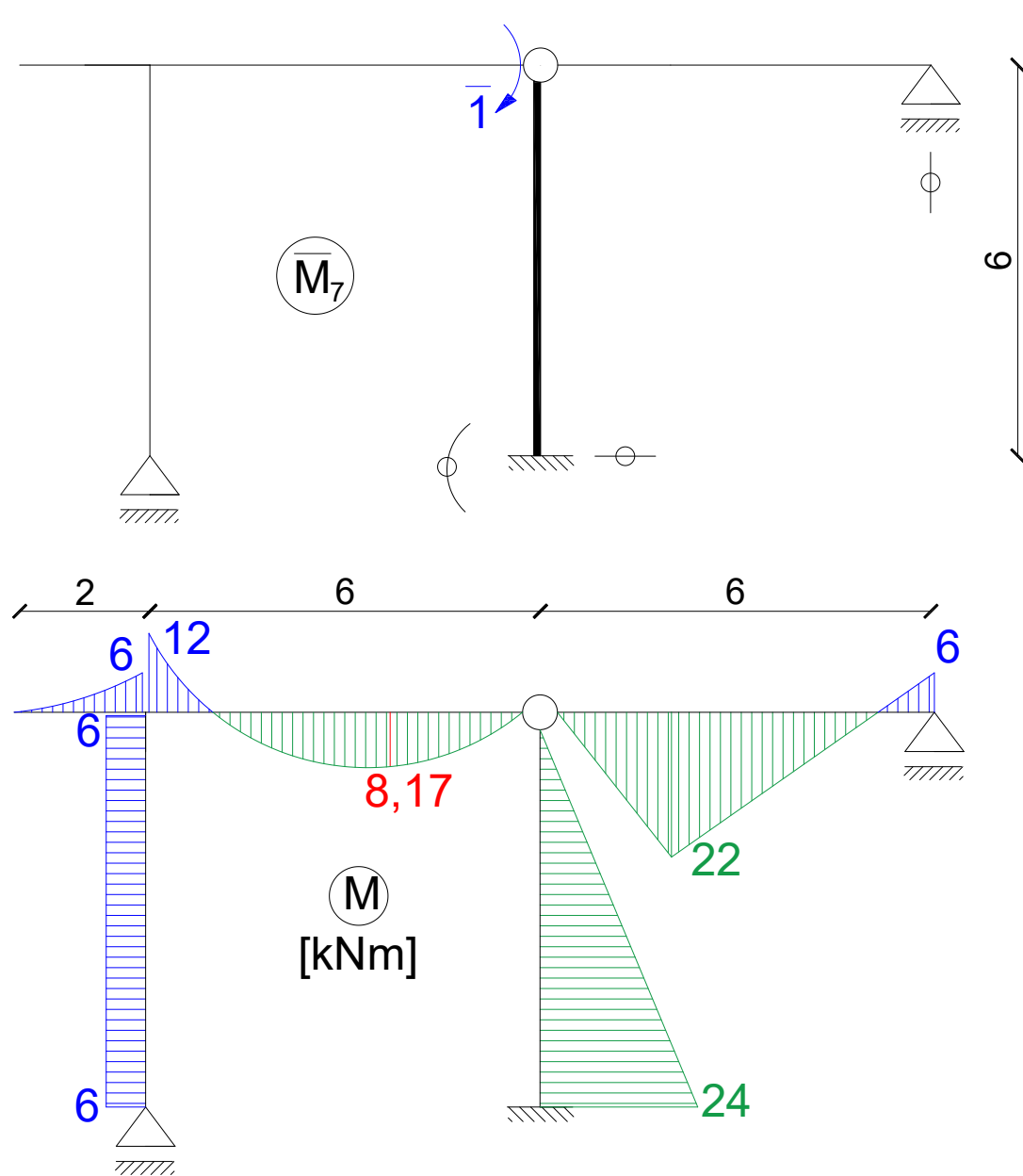


Obliczenia przemieszczeń z zasady prac wirtualnych:



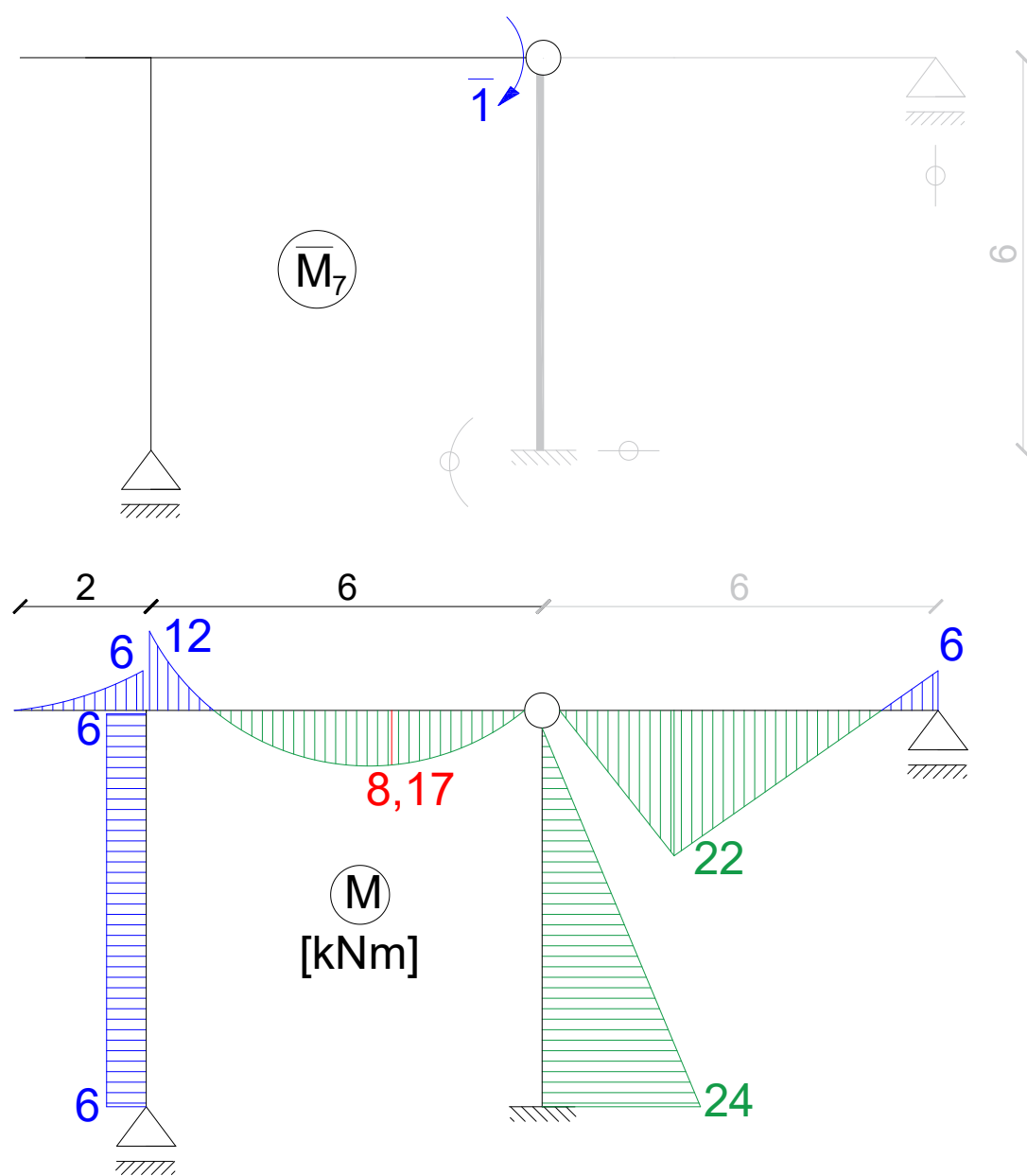
$$\phi_C^L = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



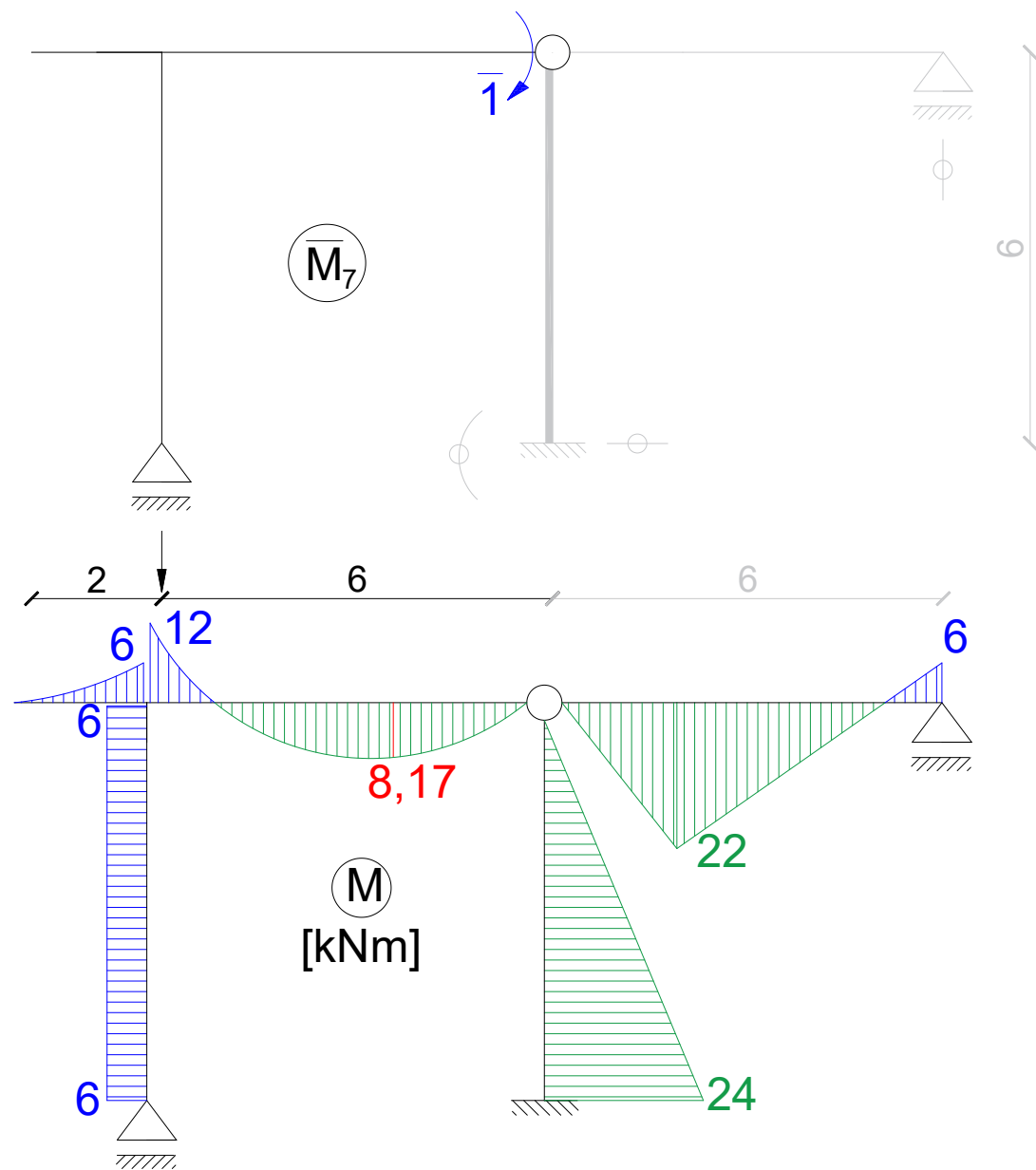
$$\varphi_C^L = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



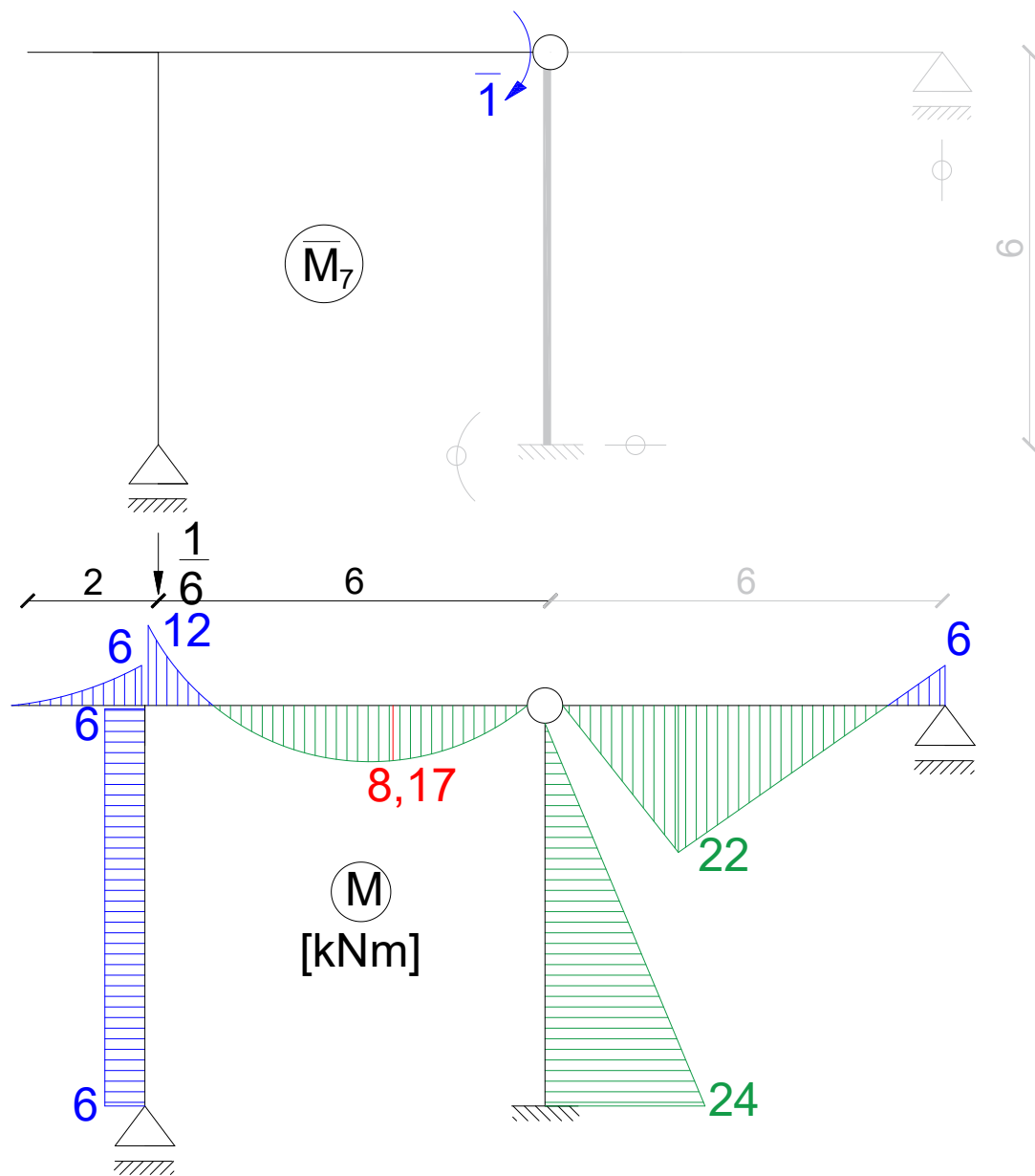
$$\varphi_C^L = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



$$\varphi_C^L = ?$$

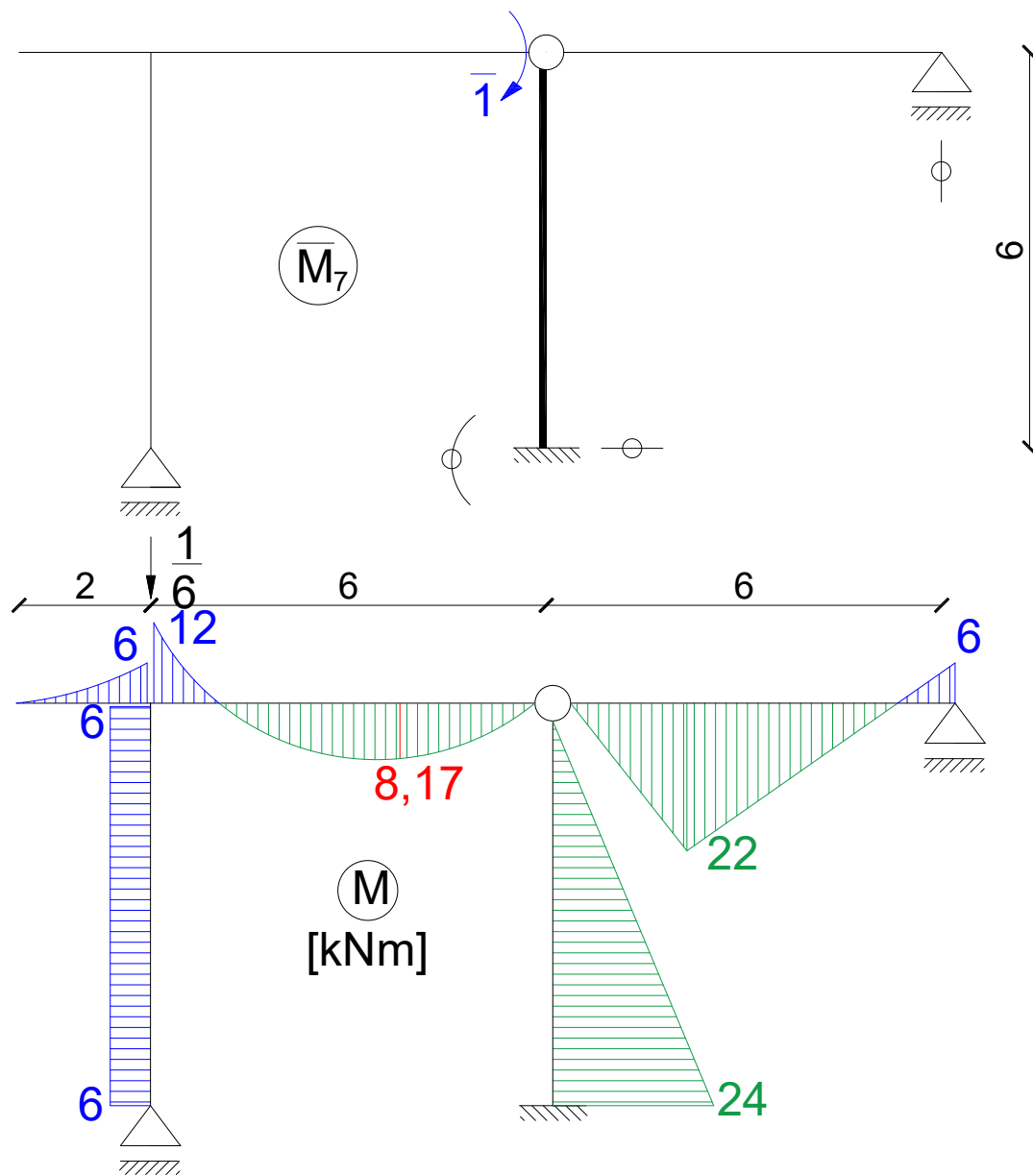
Obliczenia przemieszczeń z zasady prac wirtualnych:



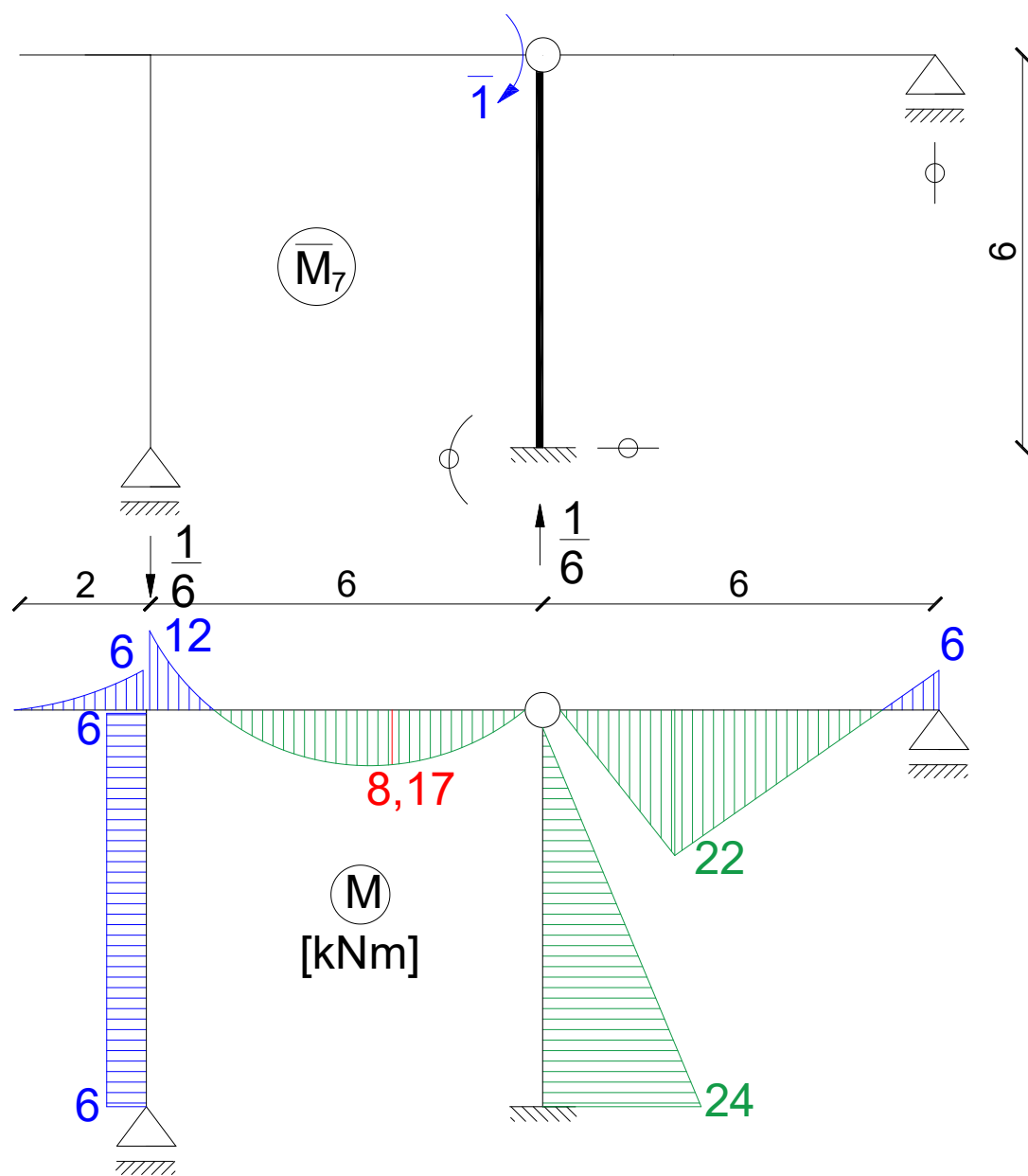
$$\varphi_C^L = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:

$$\varphi_C^L = ?$$

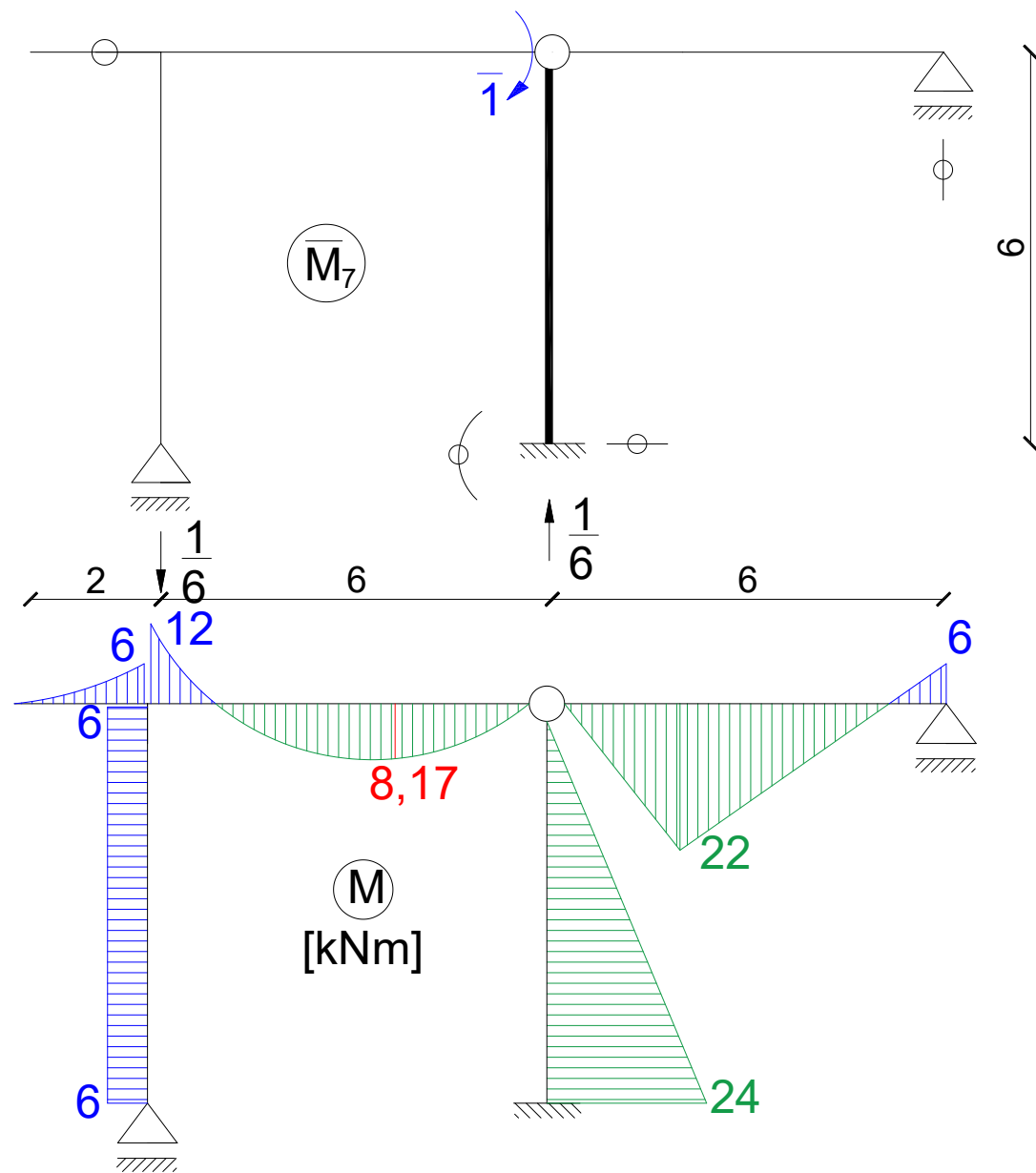


Obliczenia przemieszczeń z zasady prac wirtualnych:



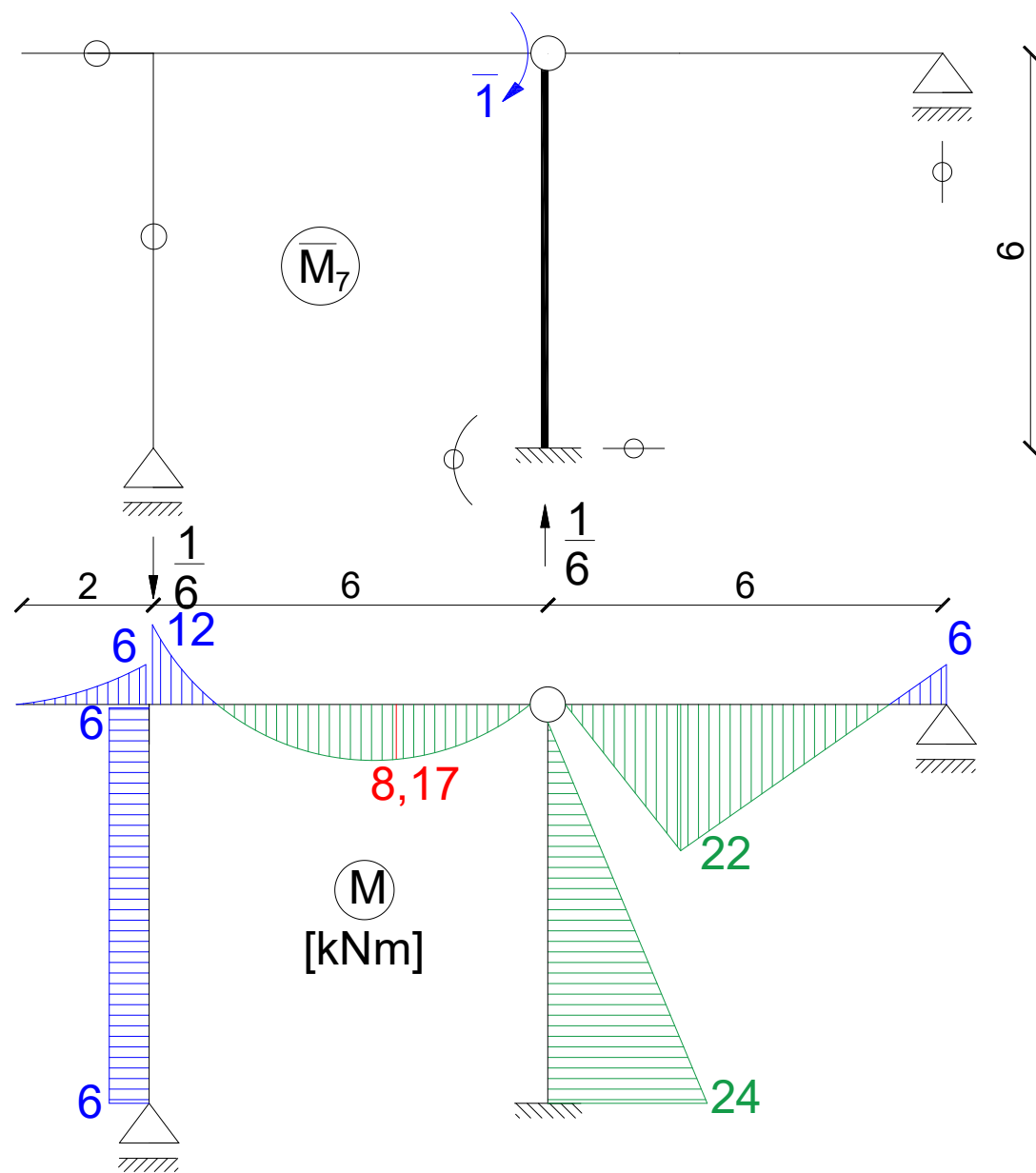
$$\varphi_C^L = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



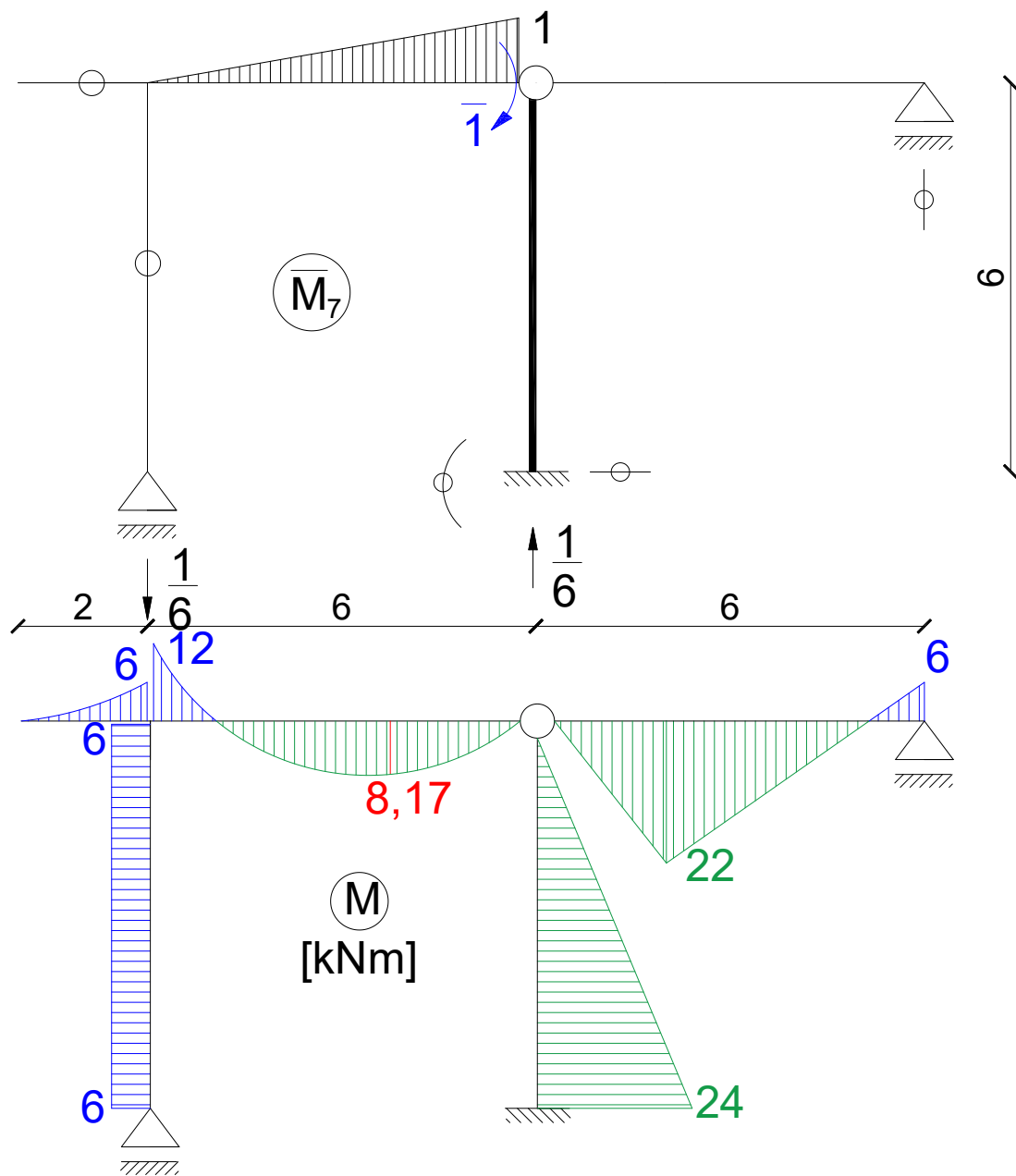
$$\varphi_C^L = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



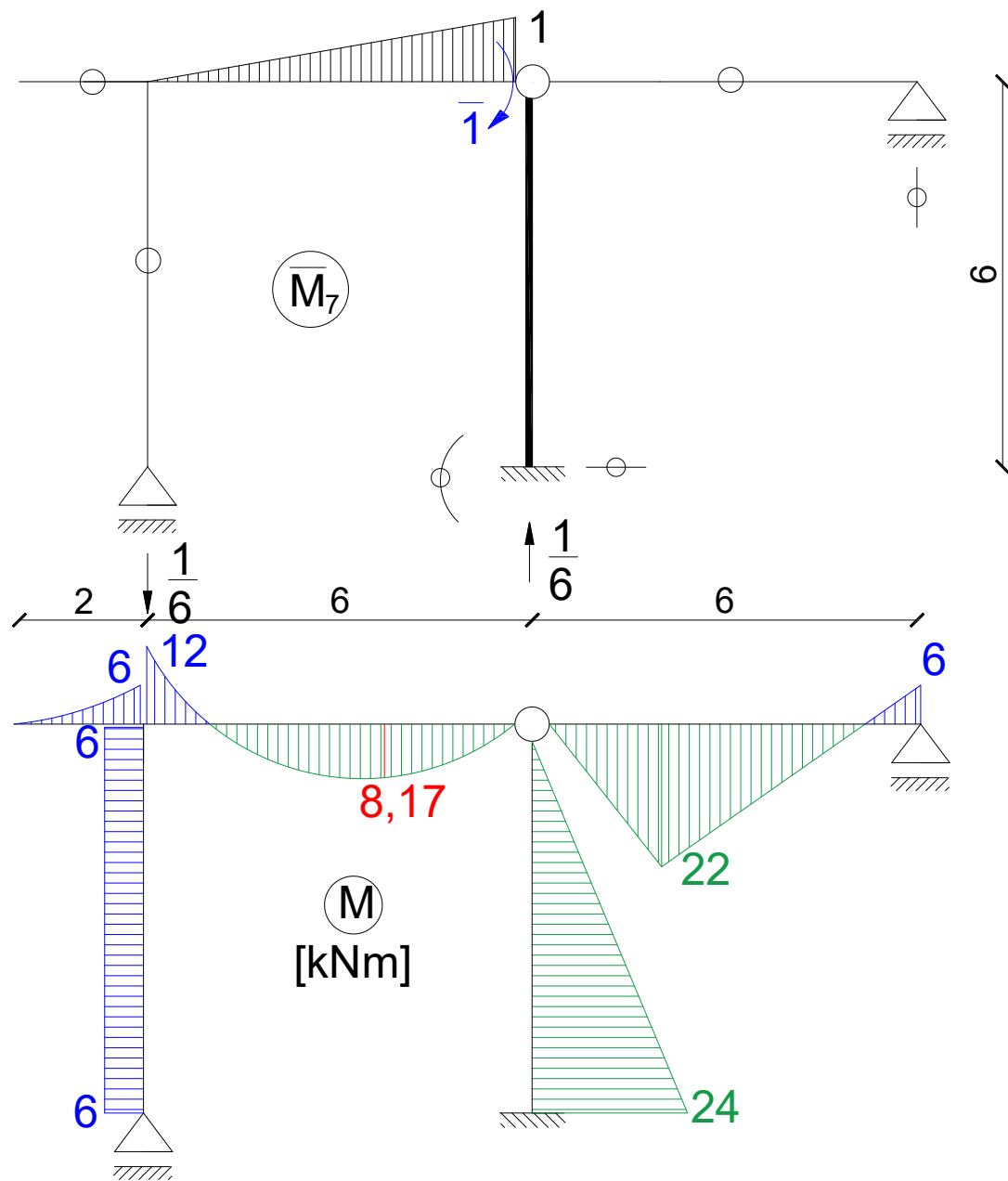
$$\varphi_C^L = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



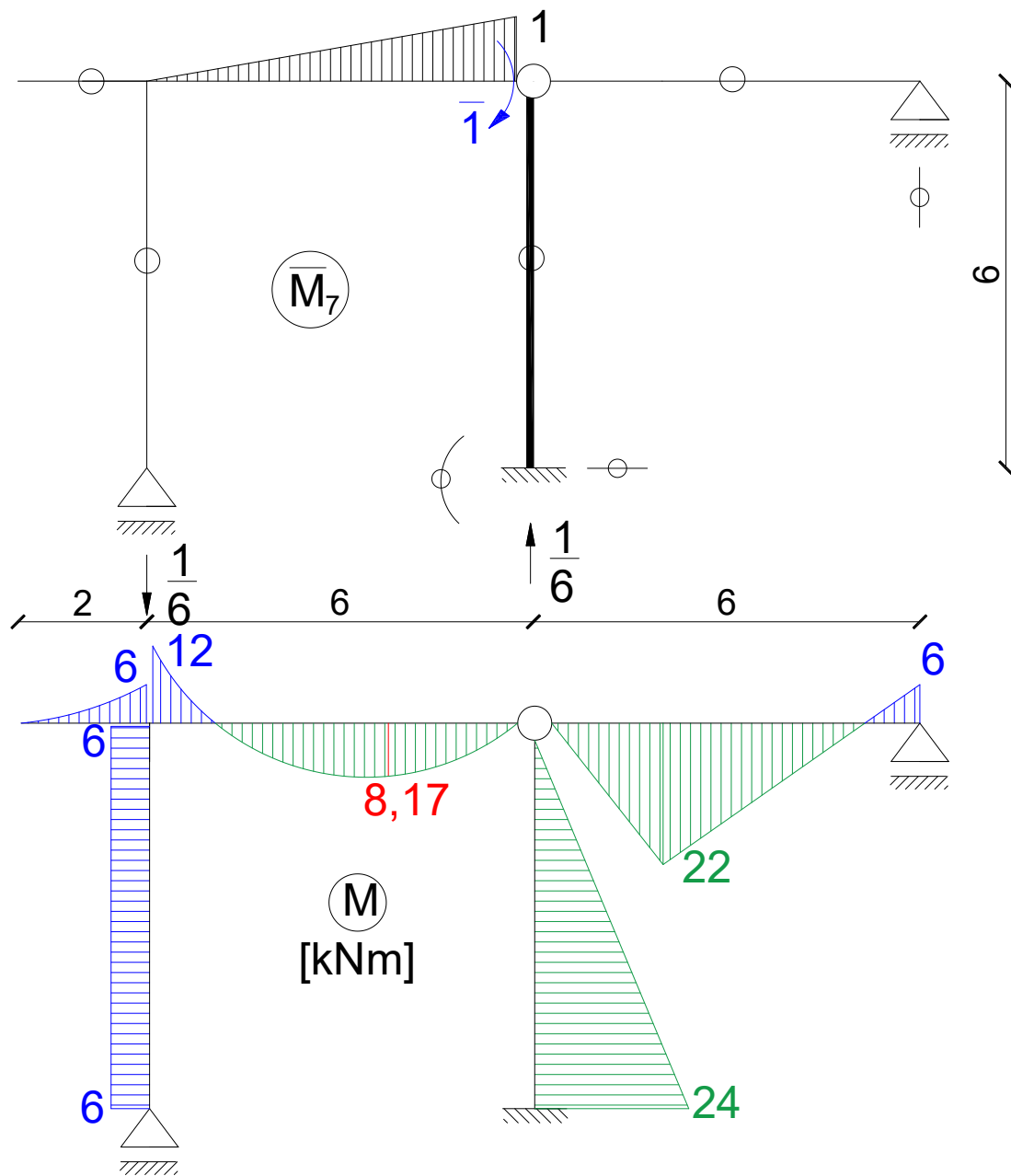
$$\varphi_C^L = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



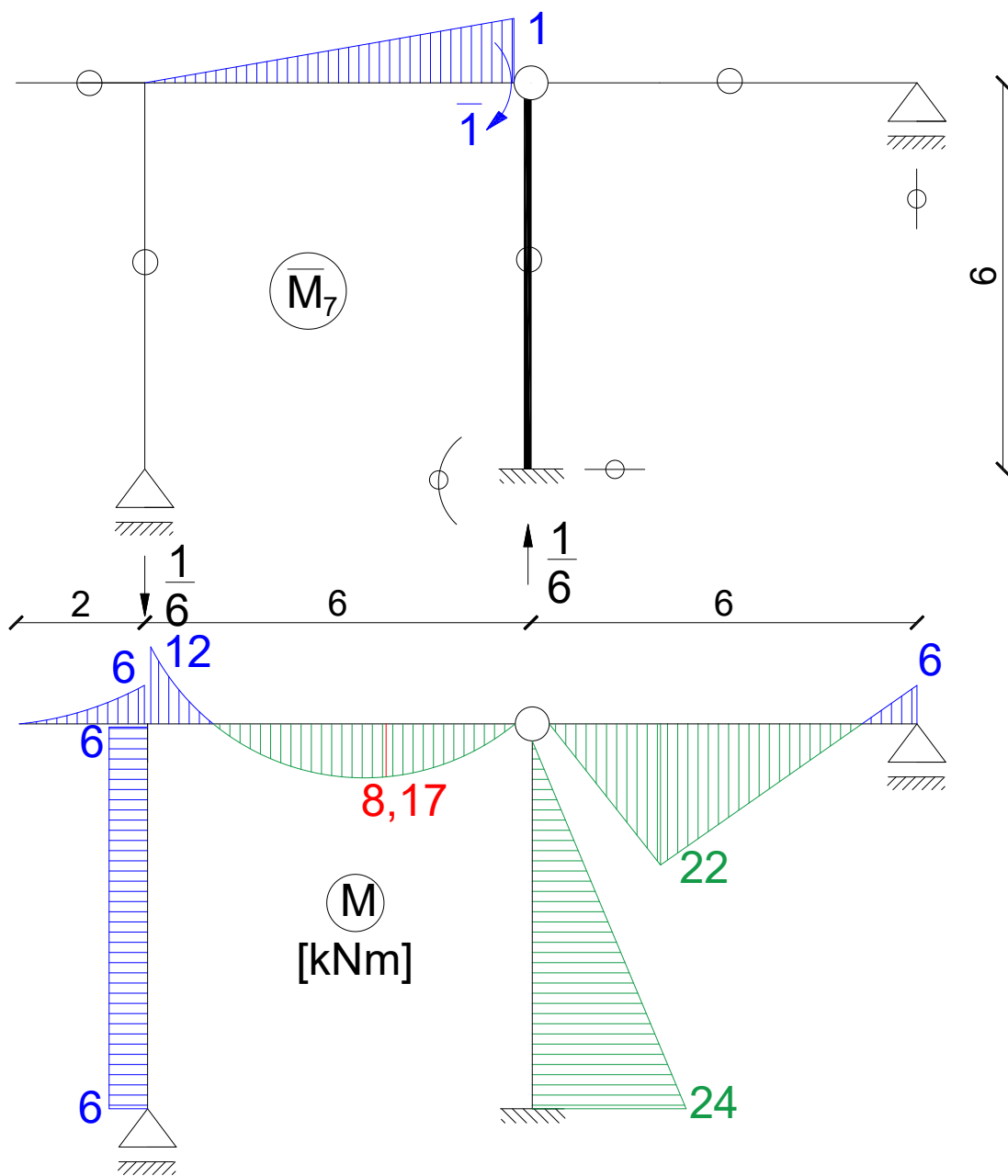
$$\varphi_C^L = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



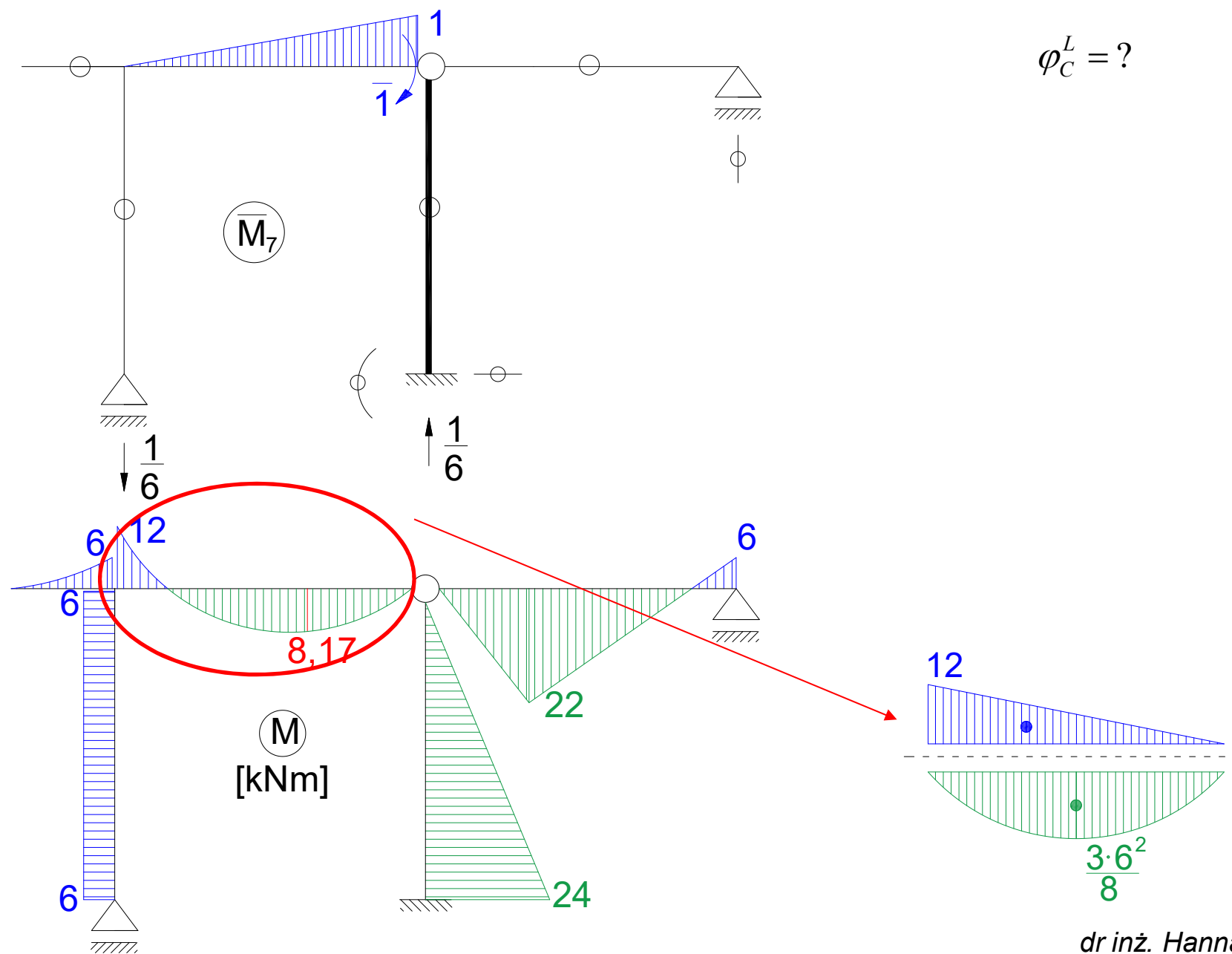
$$\varphi_C^L = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:

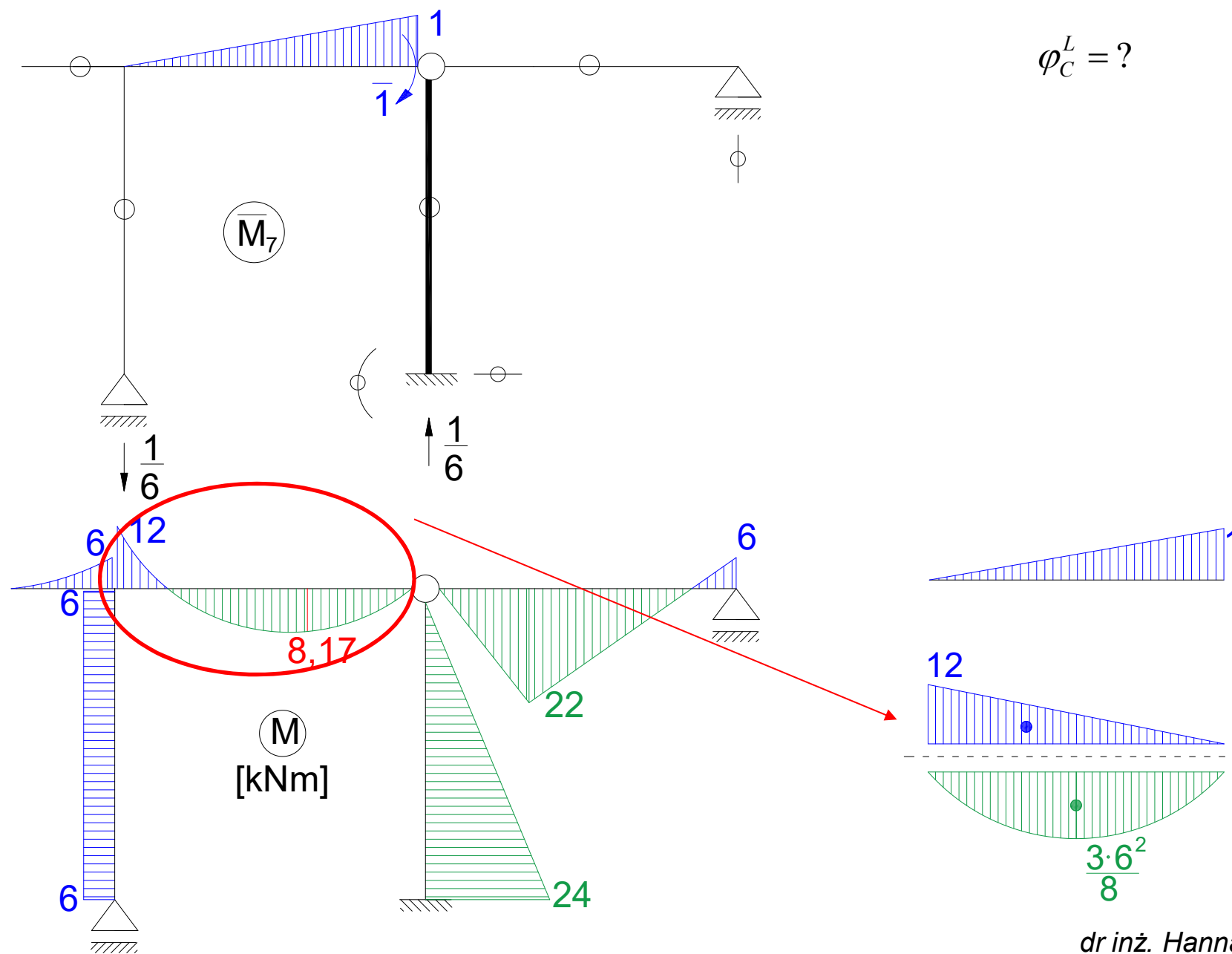


$$\varphi_C^L = ?$$

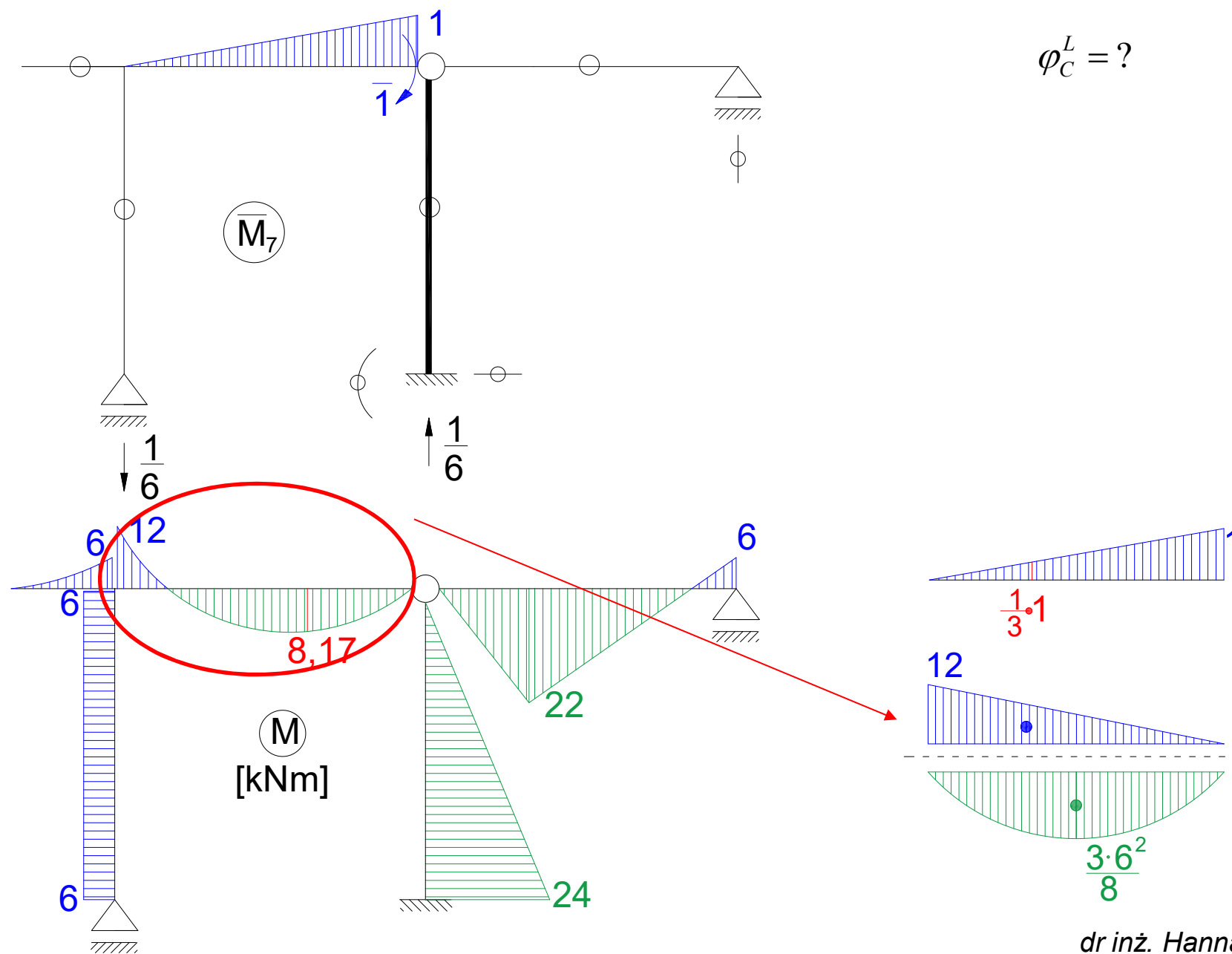
Obliczenia przemieszczeń z zasady prac wirtualnych:



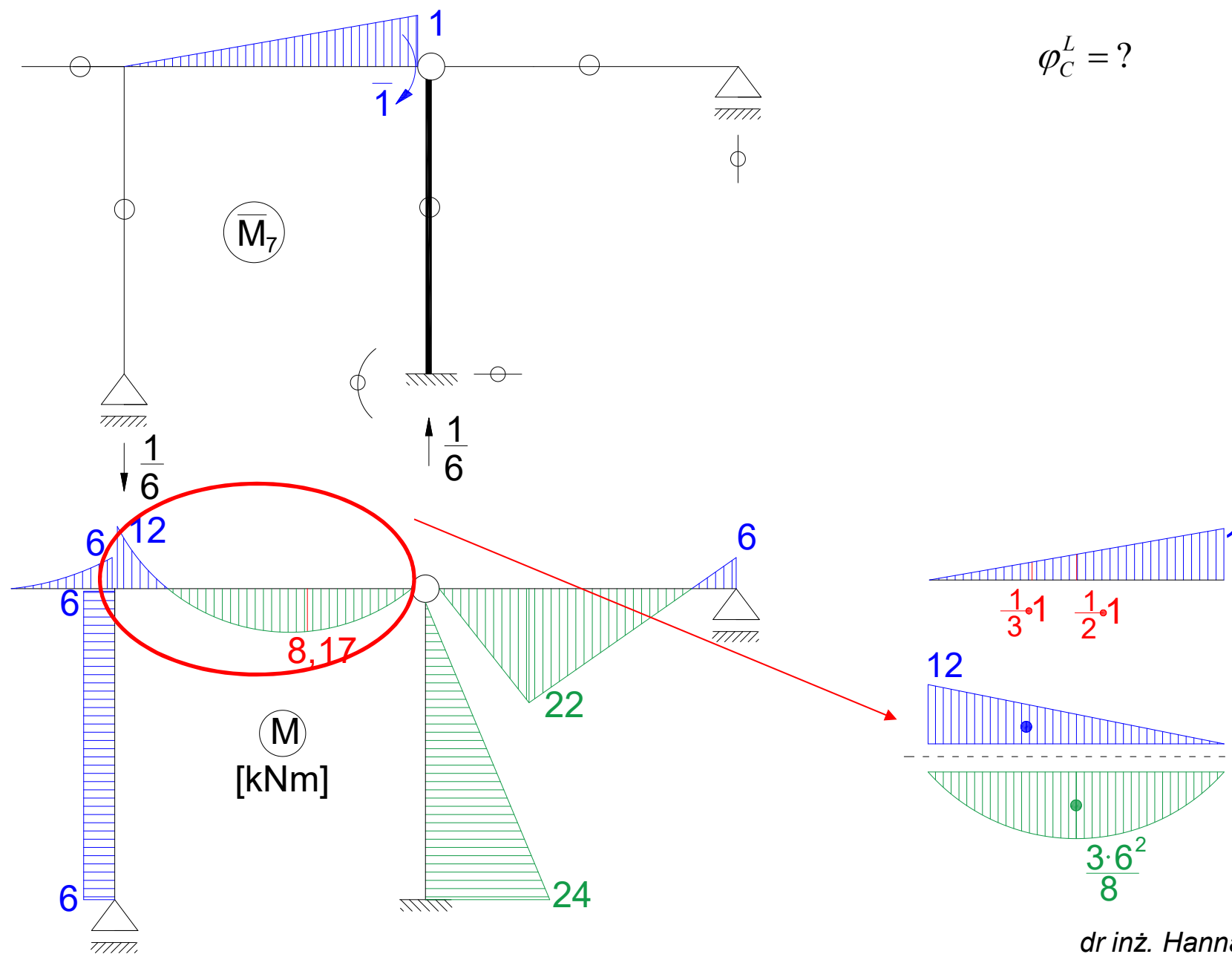
Obliczenia przemieszczeń z zasady prac wirtualnych:



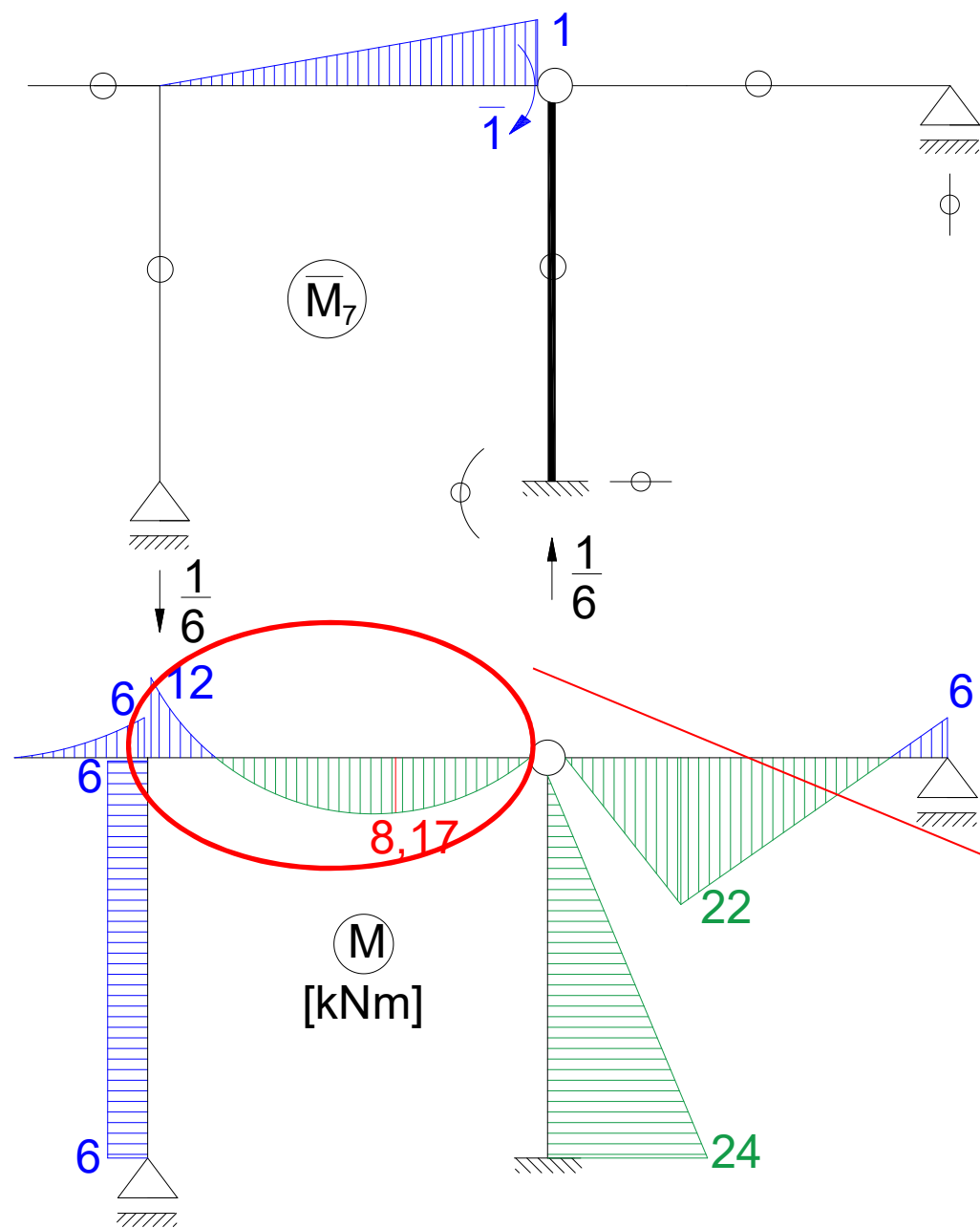
Obliczenia przemieszczeń z zasady prac wirtualnych:



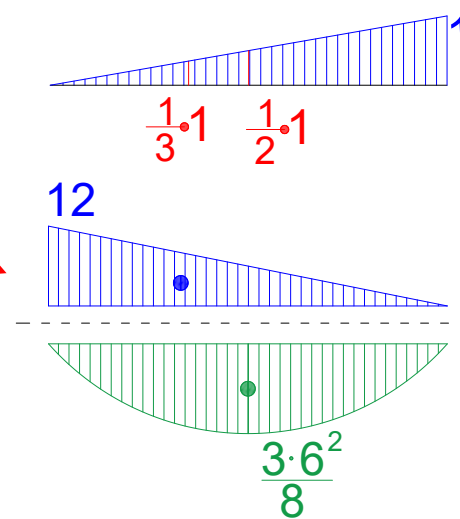
Obliczenia przemieszczeń z zasady prac wirtualnych:



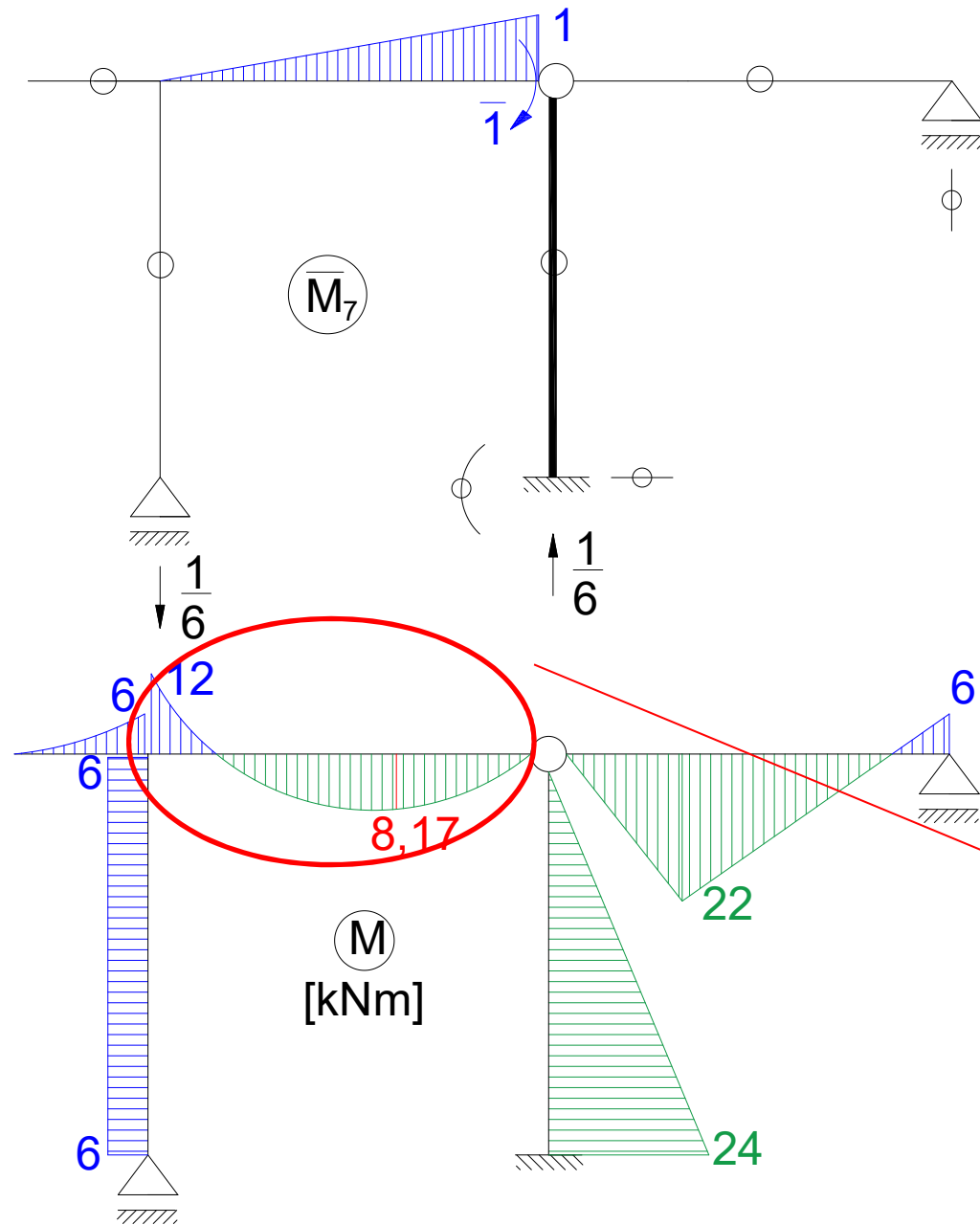
Obliczenia przemieszczeń z zasady prac wirtualnych:



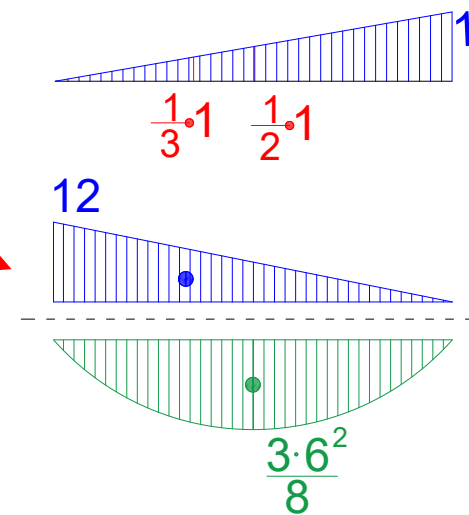
$$\varphi_C^L = \frac{1}{EI} \left(\frac{1}{2} \cdot 12 \cdot 6 \cdot \frac{1}{3} \cdot 1 \right)$$



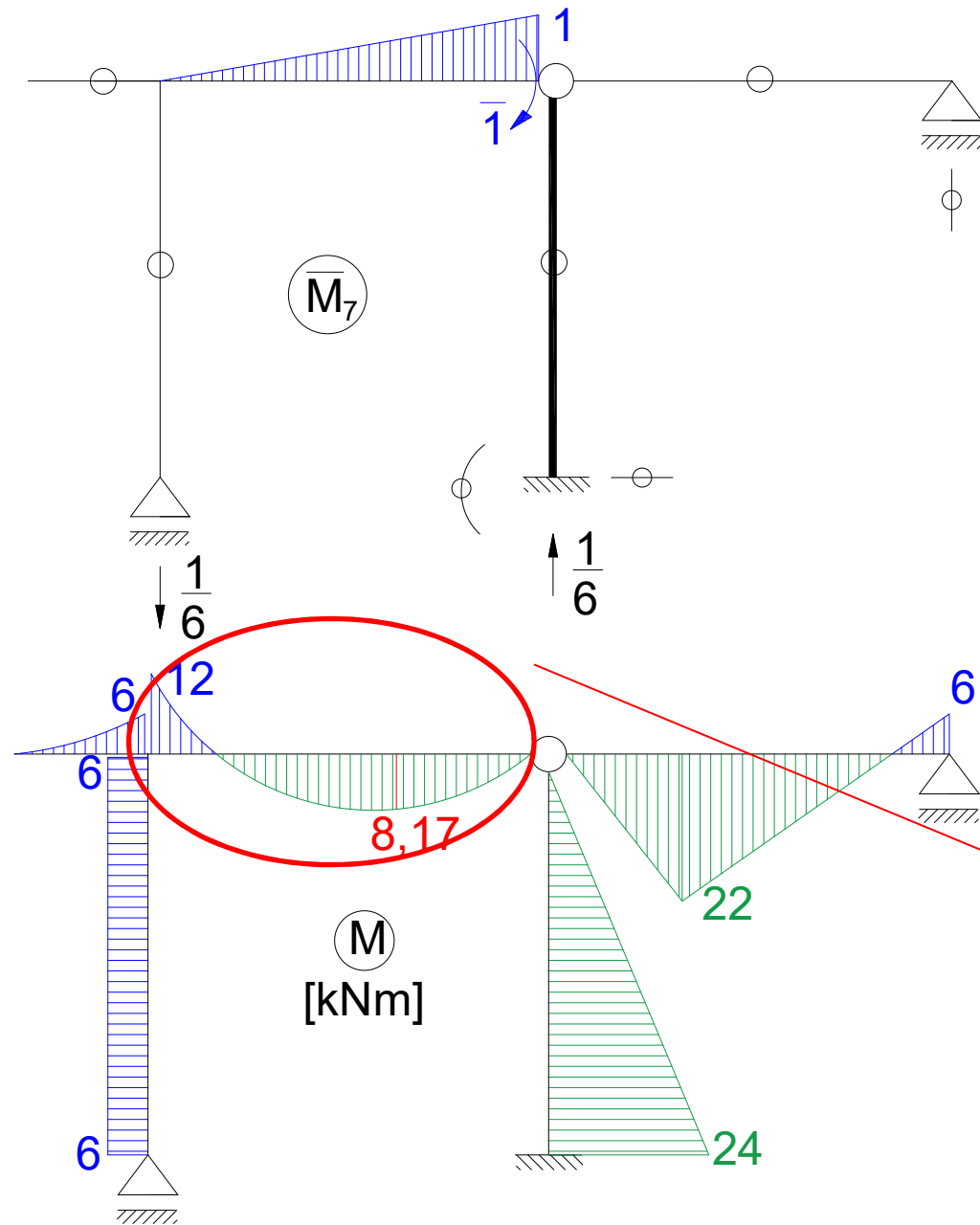
Obliczenia przemieszczeń z zasady prac wirtualnych:



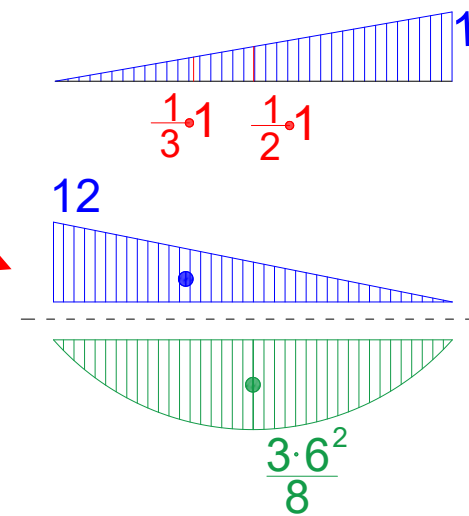
$$\varphi_C^L = \frac{1}{EI} \left(\frac{1}{2} \cdot 12 \cdot 6 \cdot \frac{1}{3} \cdot 1 \right) - \frac{1}{EI} \left(\frac{2}{3} \cdot \frac{3 \cdot 6^2}{8} \cdot 6 \cdot \frac{1}{2} \cdot 1 \right)$$



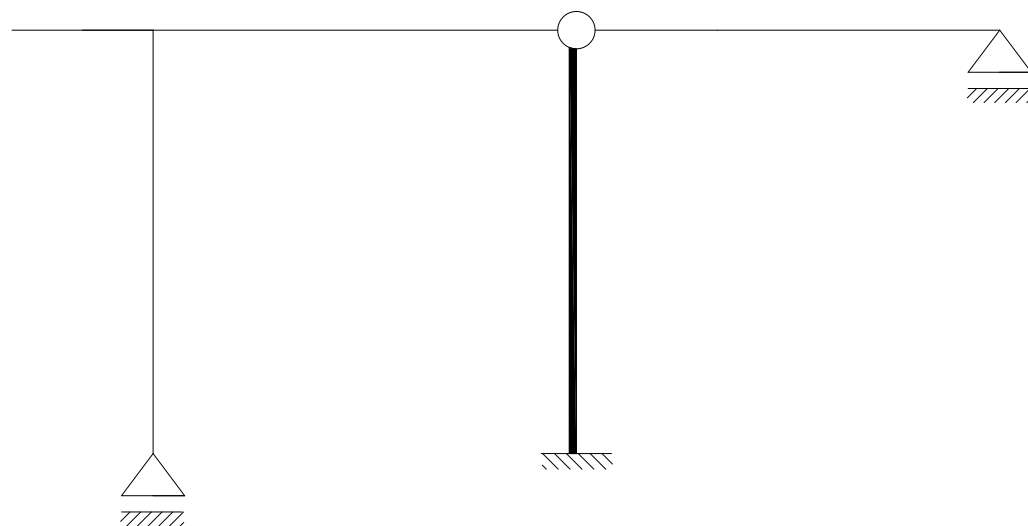
Obliczenia przemieszczeń z zasady prac wirtualnych:



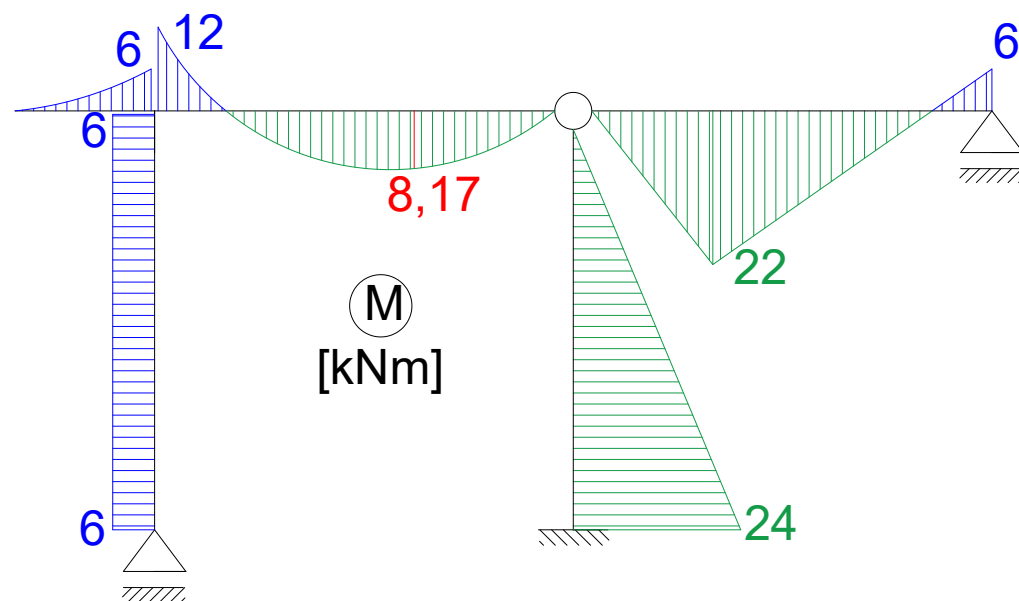
$$\begin{aligned}\varphi_C^L &= \frac{1}{EI} \left(\frac{1}{2} \cdot 12 \cdot 6 \cdot \frac{1}{3} \cdot 1 \right) \\ &\quad - \frac{1}{EI} \left(\frac{2}{3} \cdot \frac{3 \cdot 6^2}{8} \cdot 6 \cdot \frac{1}{2} \cdot 1 \right) \\ &= -\frac{15}{EI}\end{aligned}$$



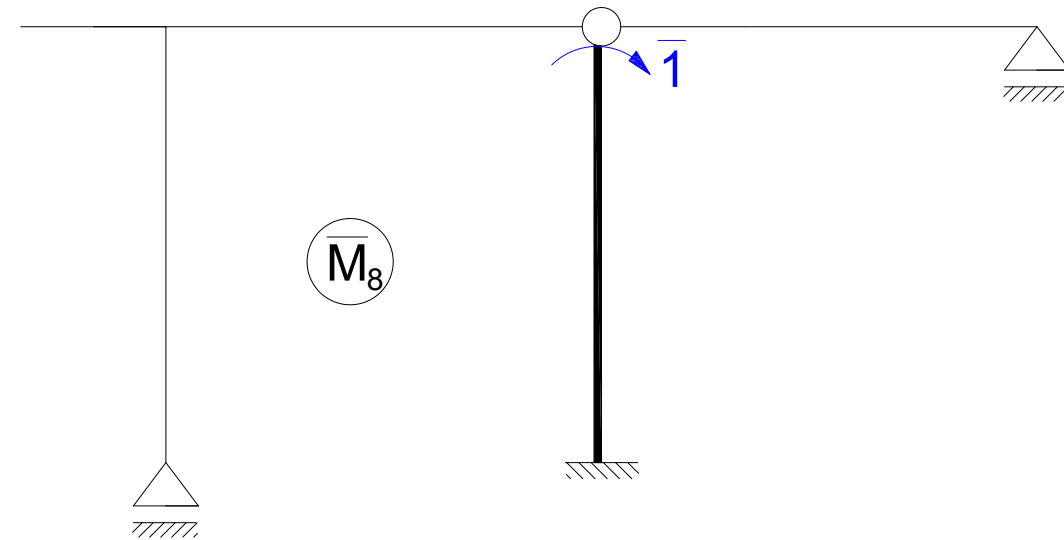
Obliczenia przemieszczeń z zasady prac wirtualnych:



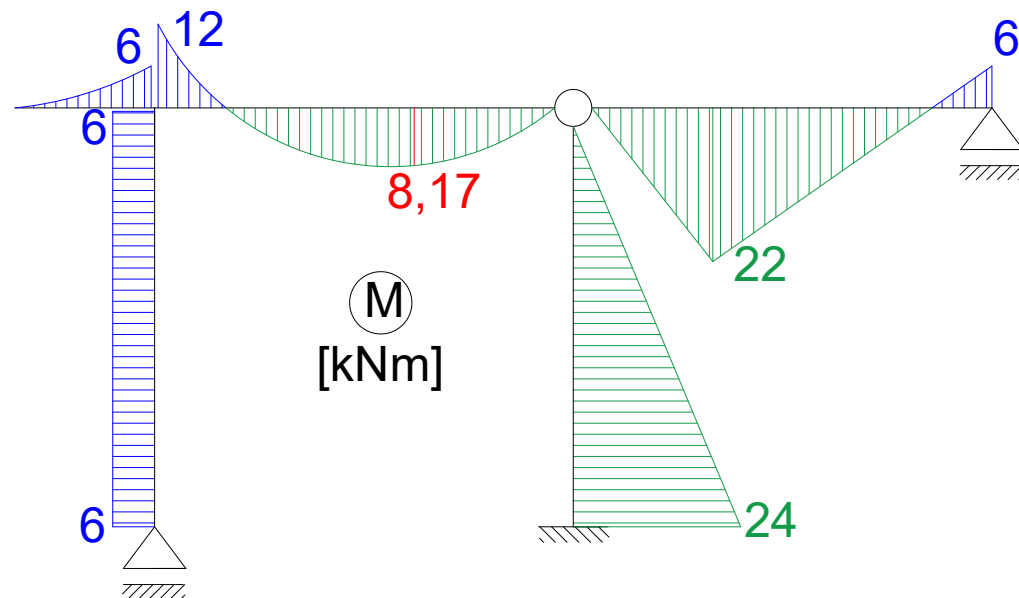
$$\varphi_C^d = ?$$



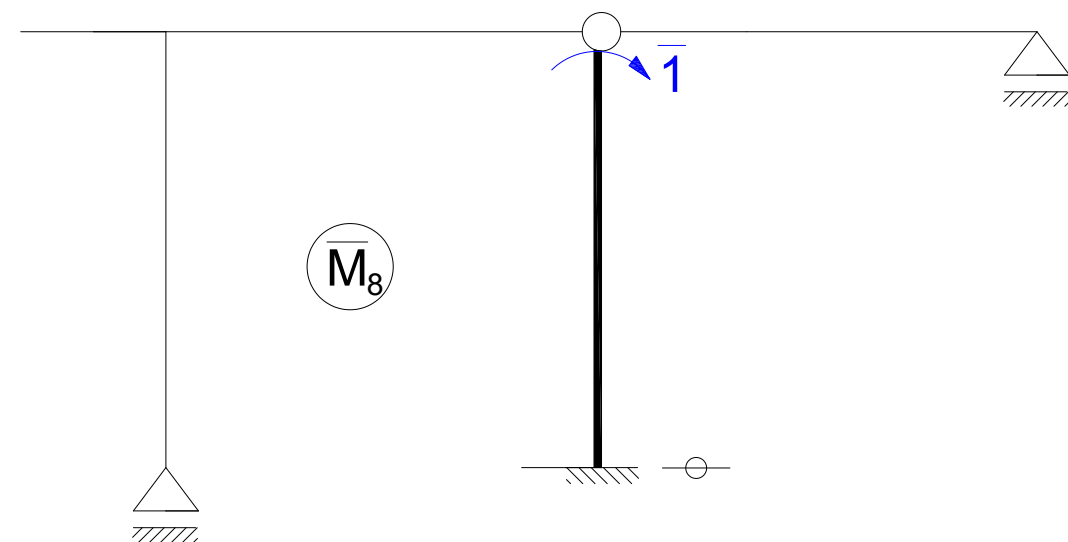
Obliczenia przemieszczeń z zasady prac wirtualnych:



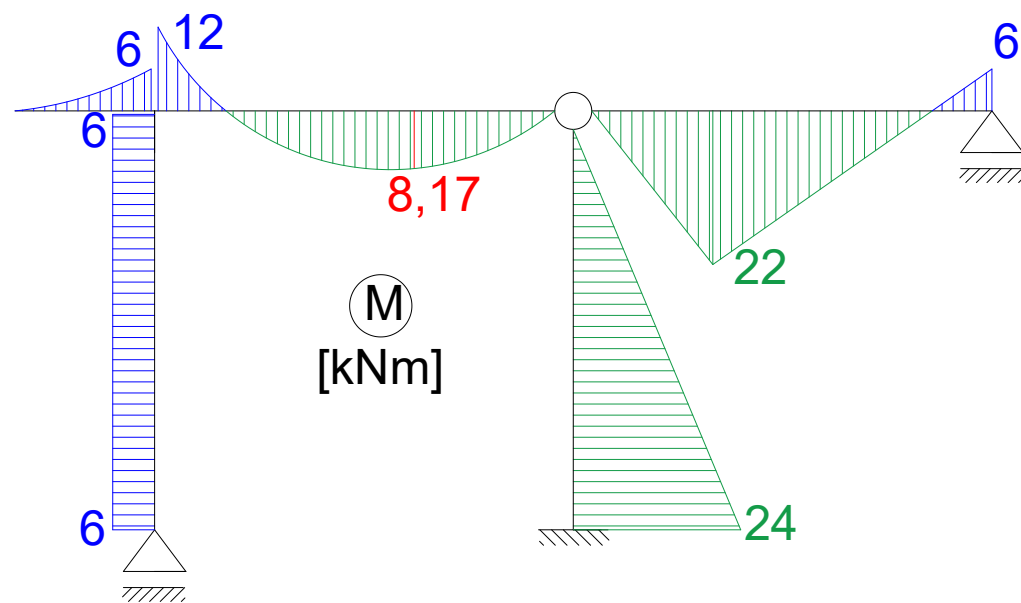
$$\varphi_C^d = ?$$



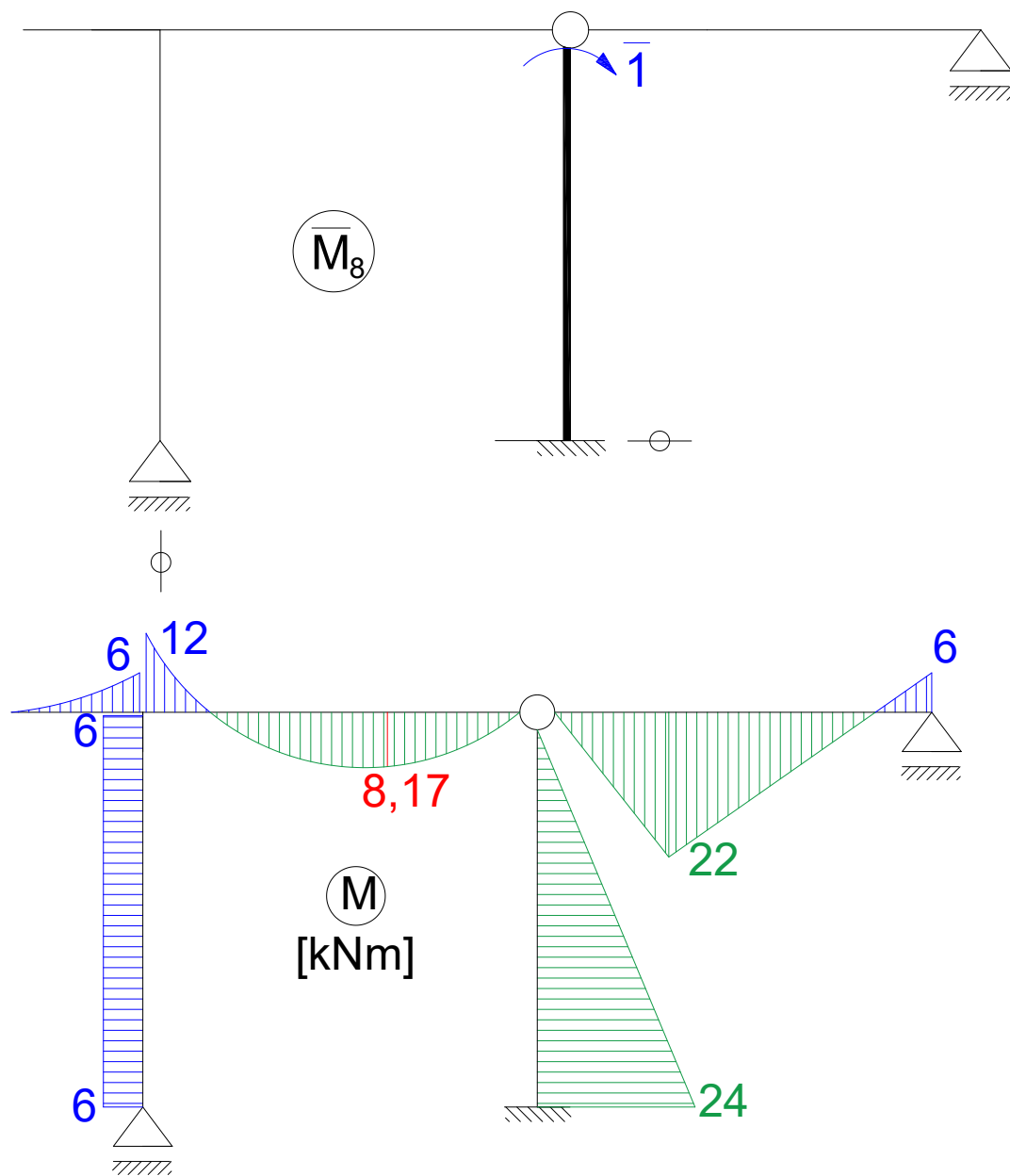
Obliczenia przemieszczeń z zasady prac wirtualnych:



$$\varphi_C^d = ?$$

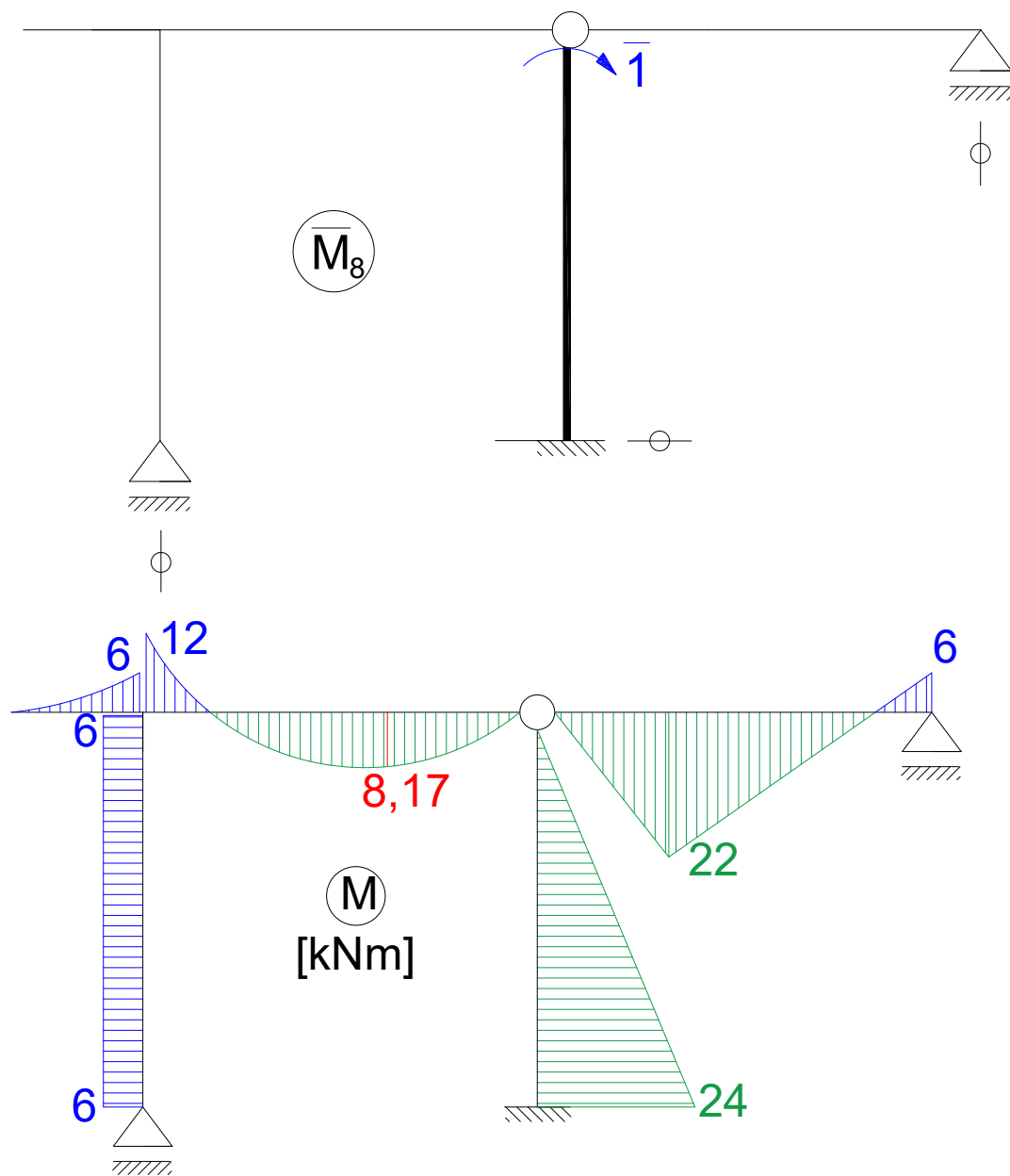


Obliczenia przemieszczeń z zasady prac wirtualnych:



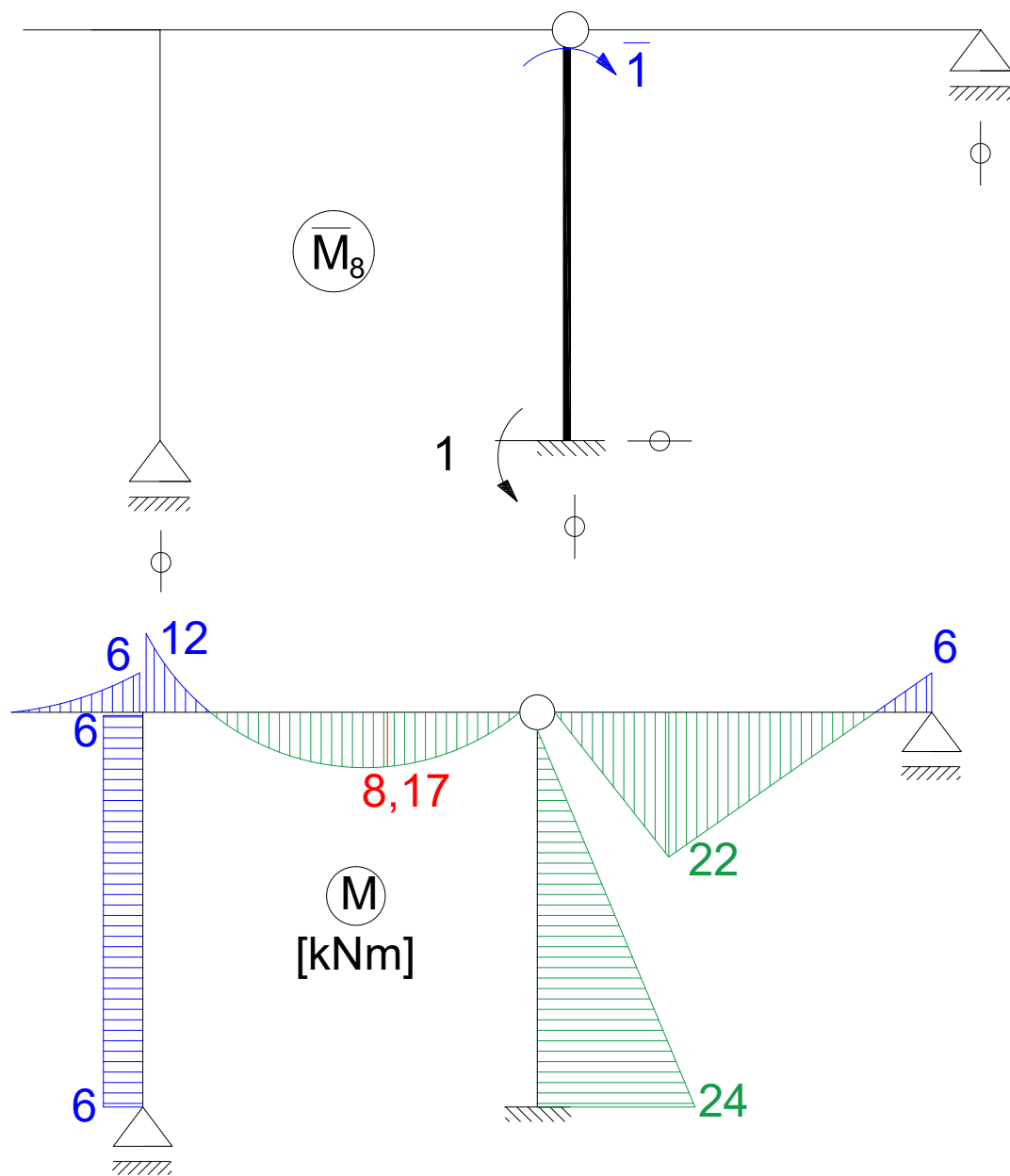
$$\varphi_C^d = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



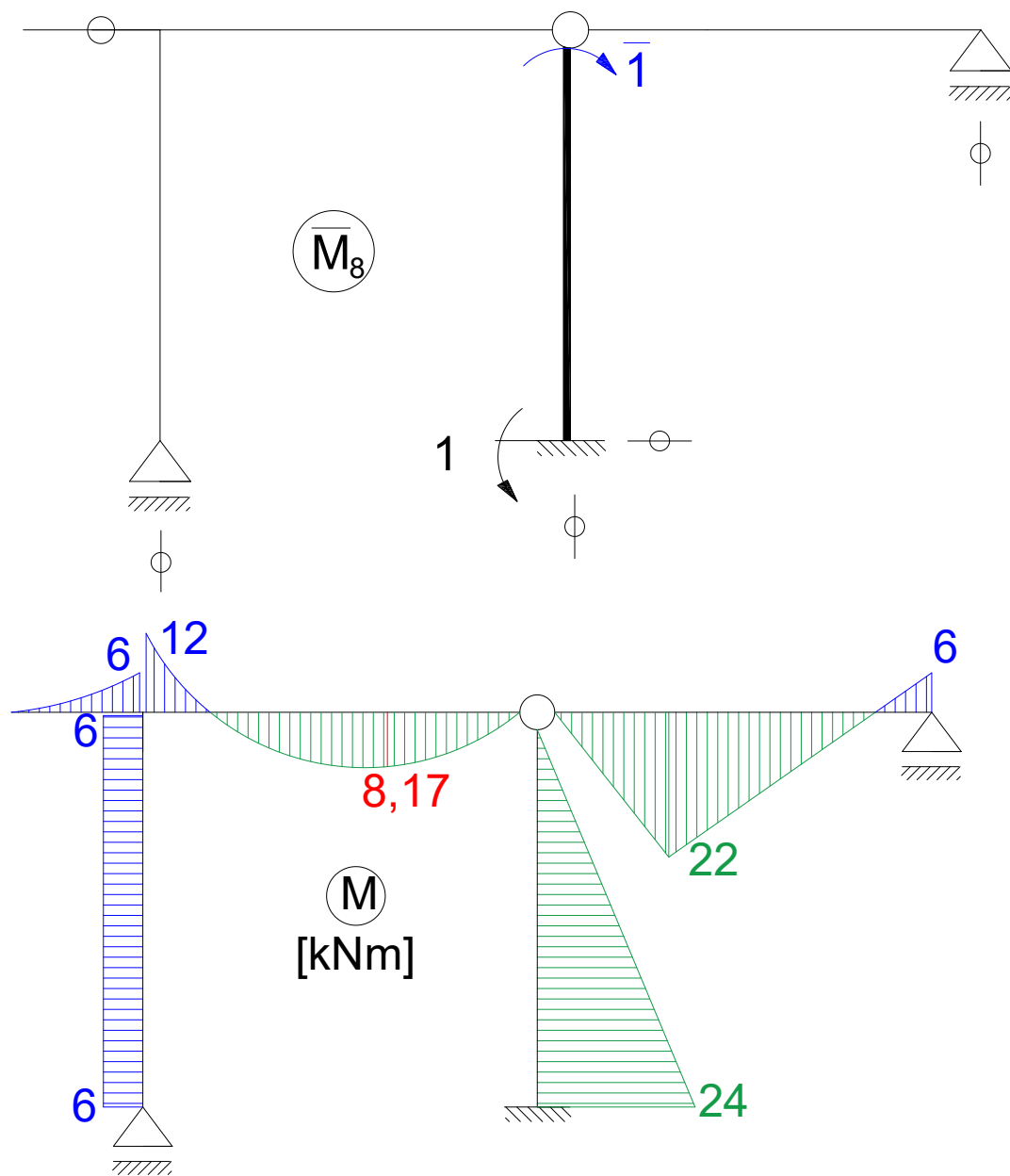
$$\varphi_C^d = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



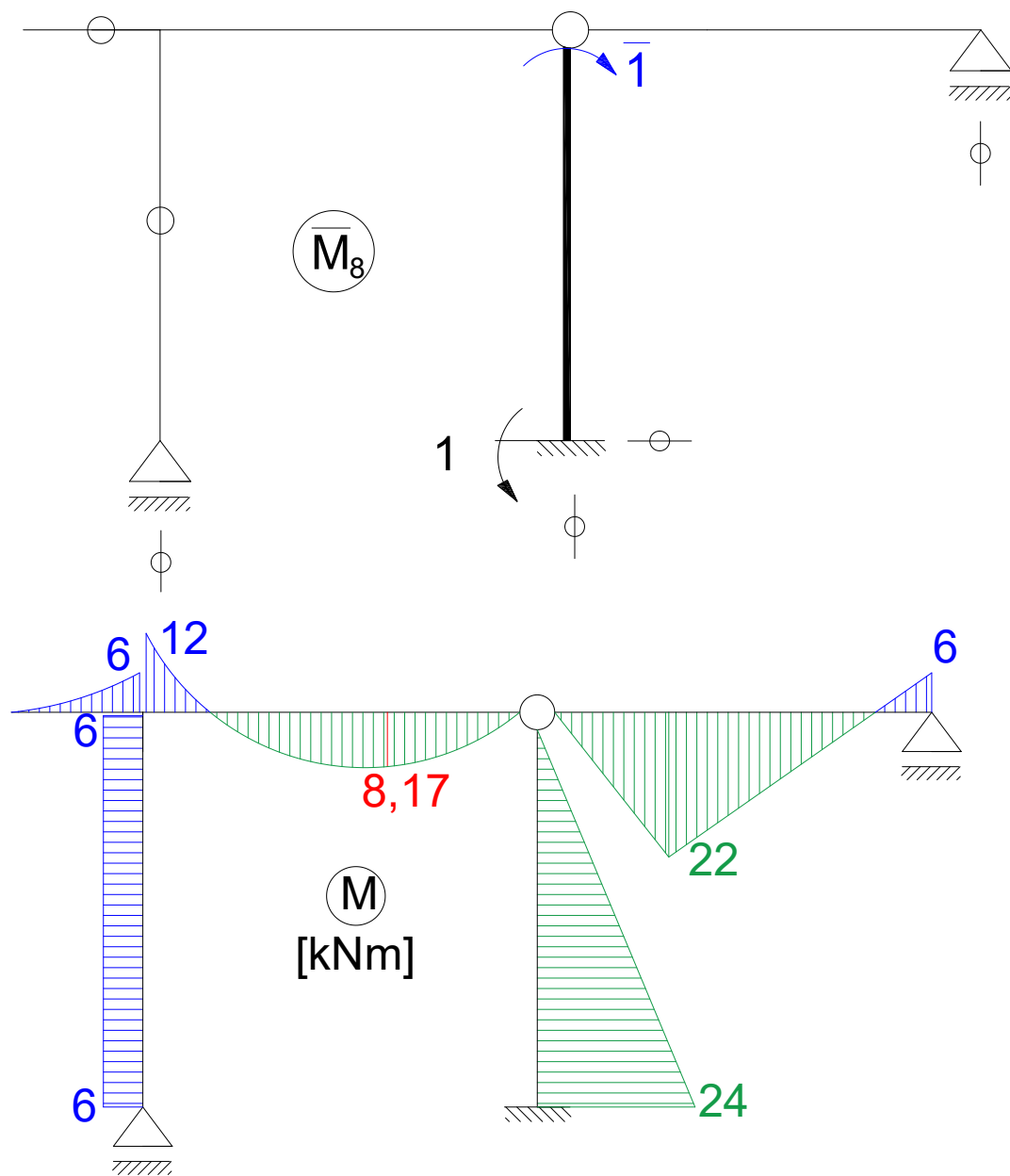
$$\varphi_C^d = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



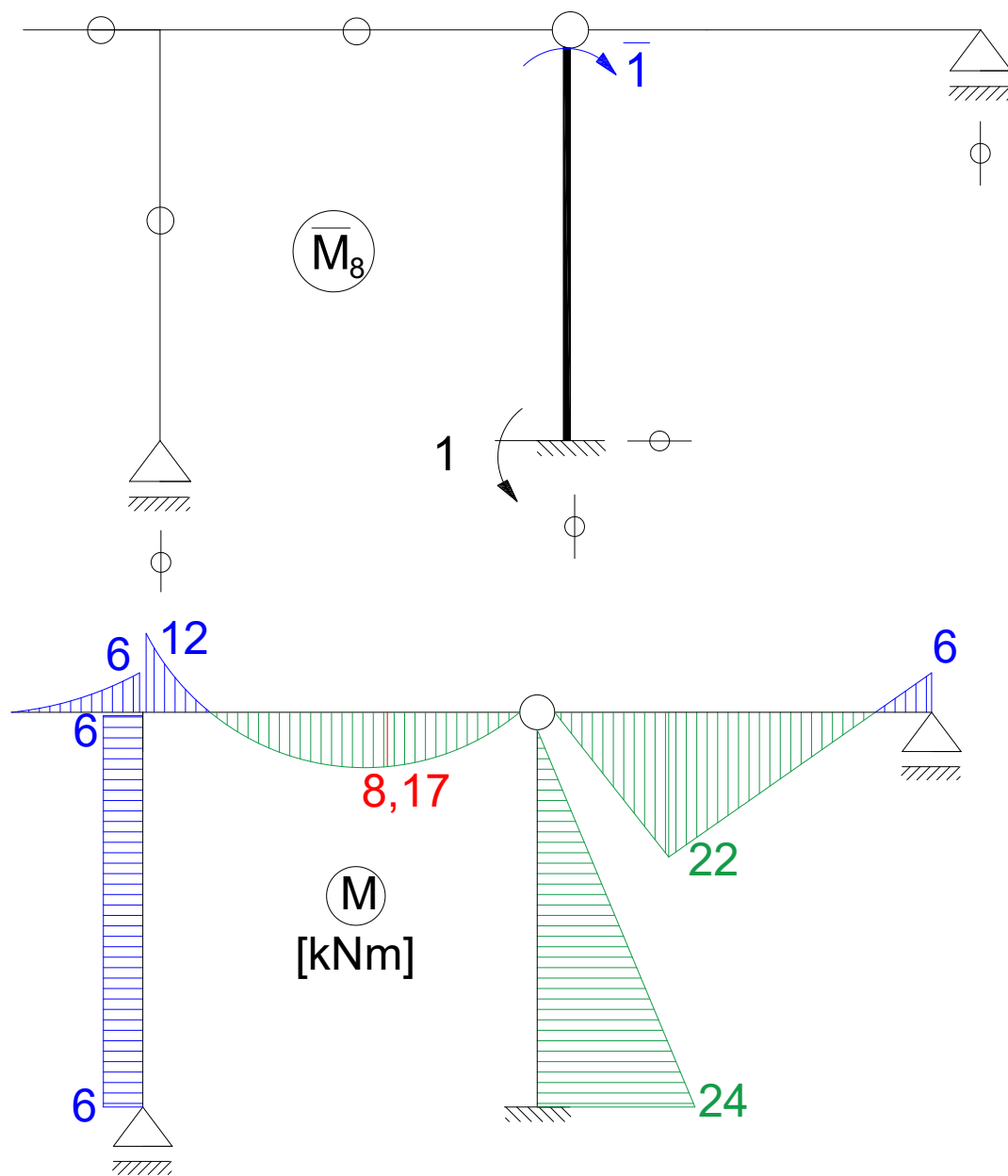
$$\varphi_C^d = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



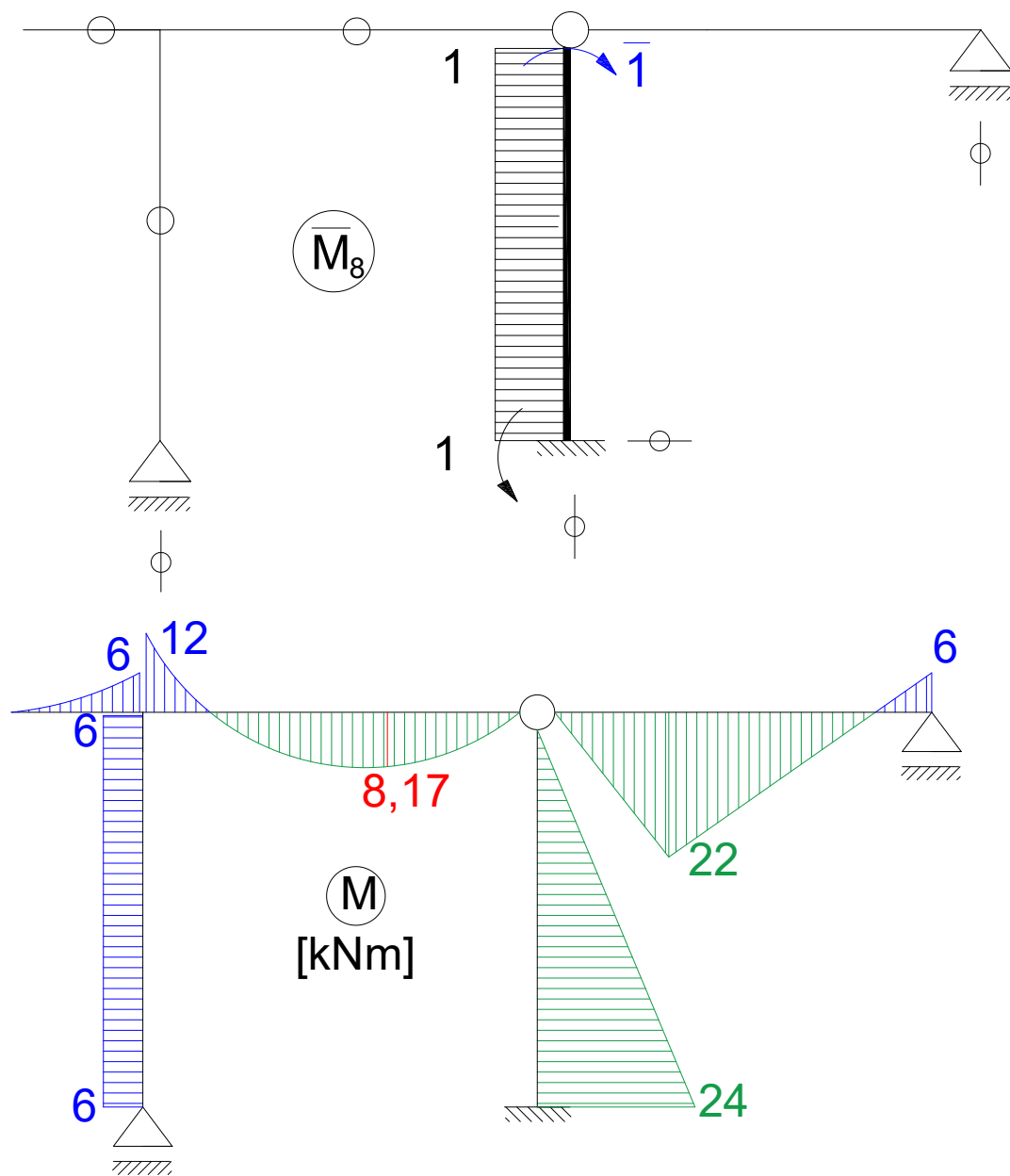
$$\varphi_C^d = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



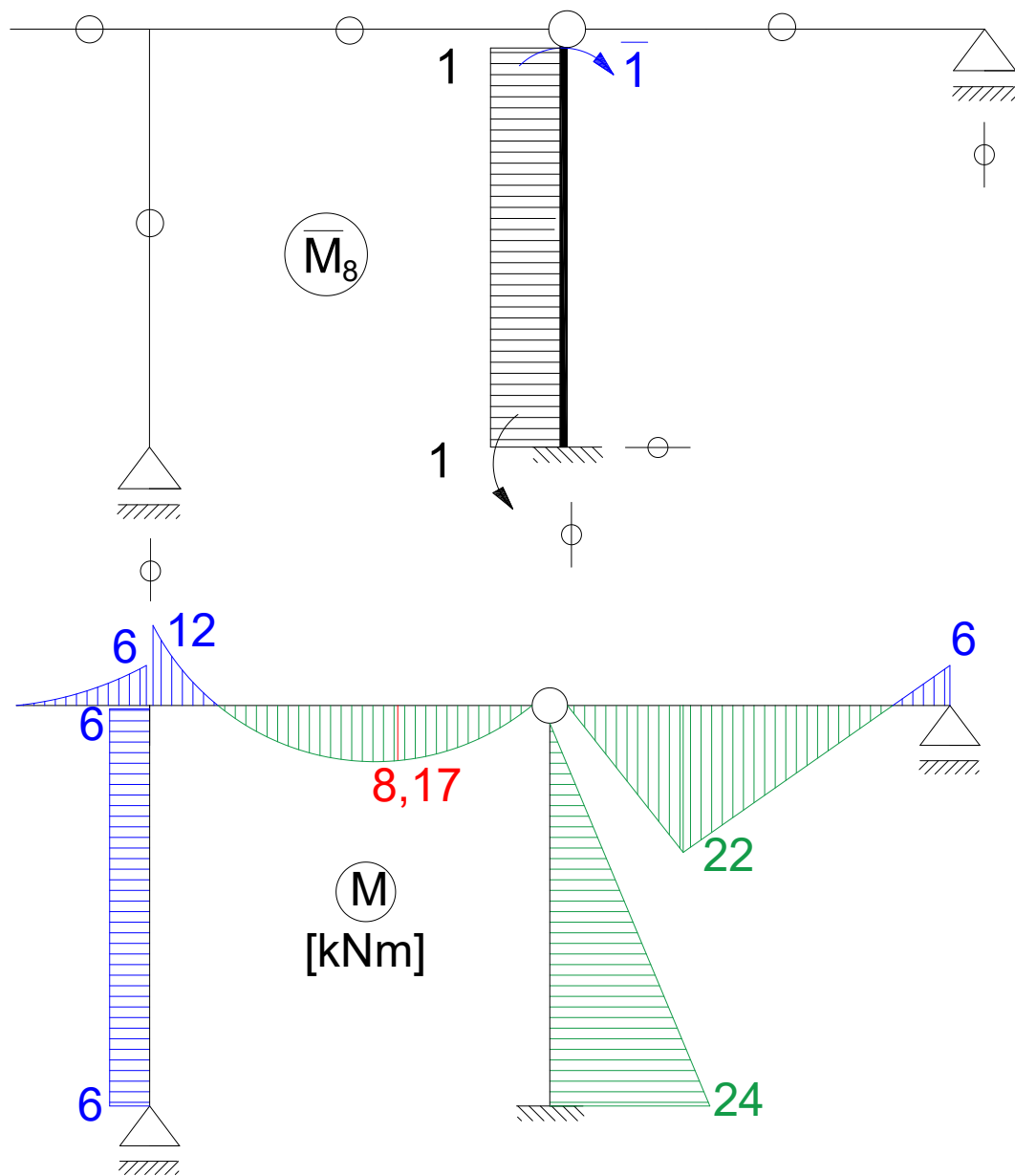
$$\varphi_C^d = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



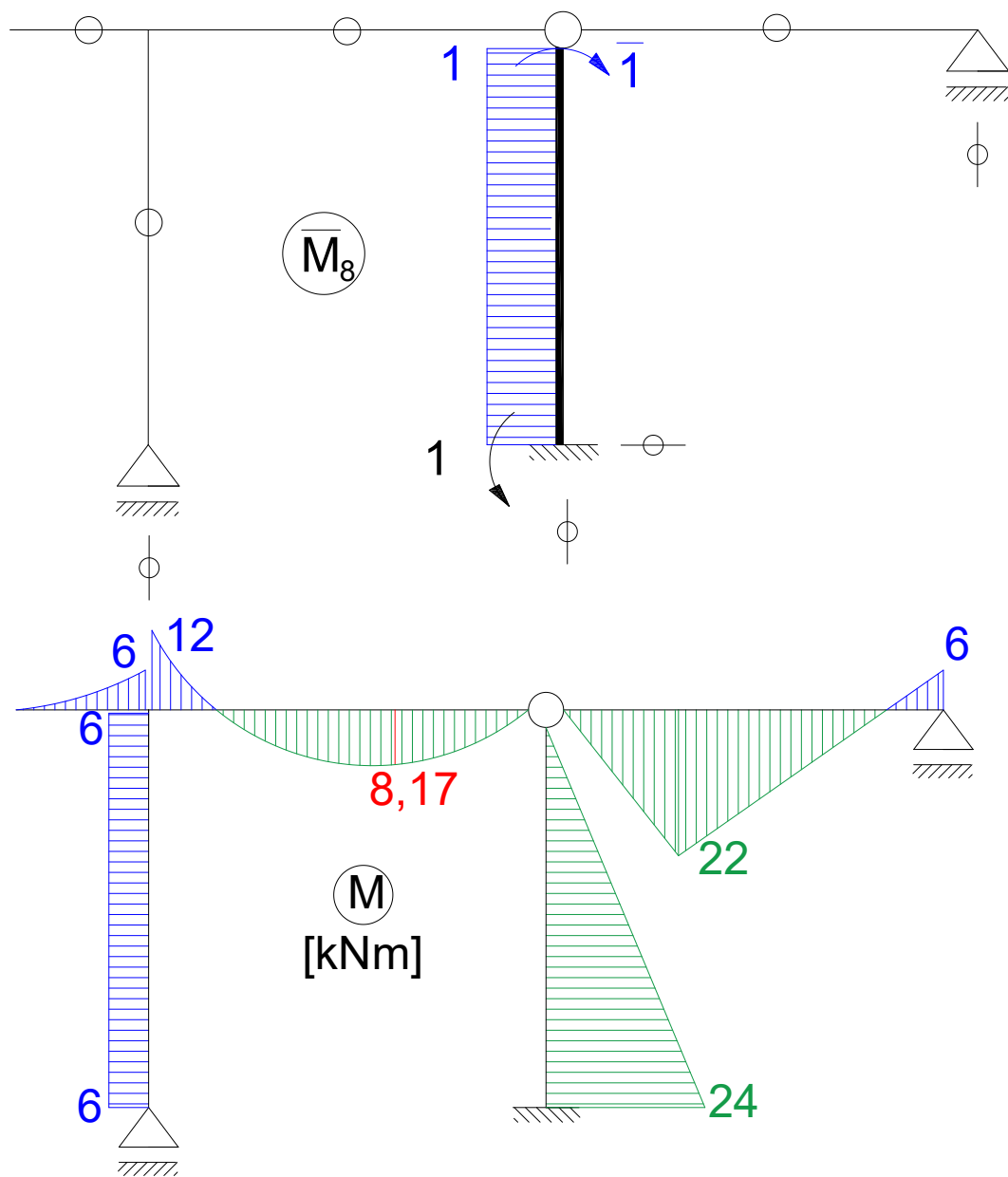
$$\varphi_C^d = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



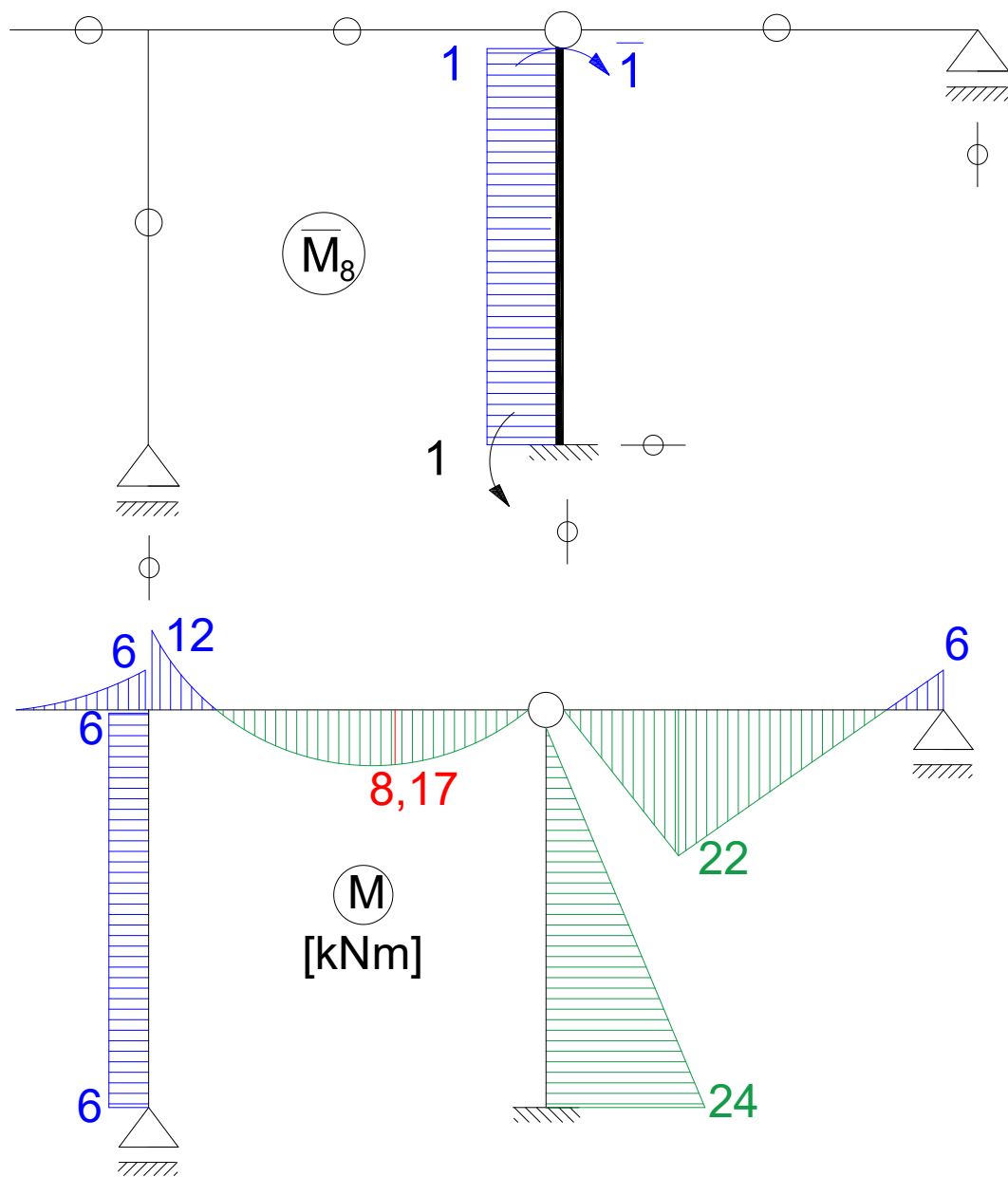
$$\varphi_C^d = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:

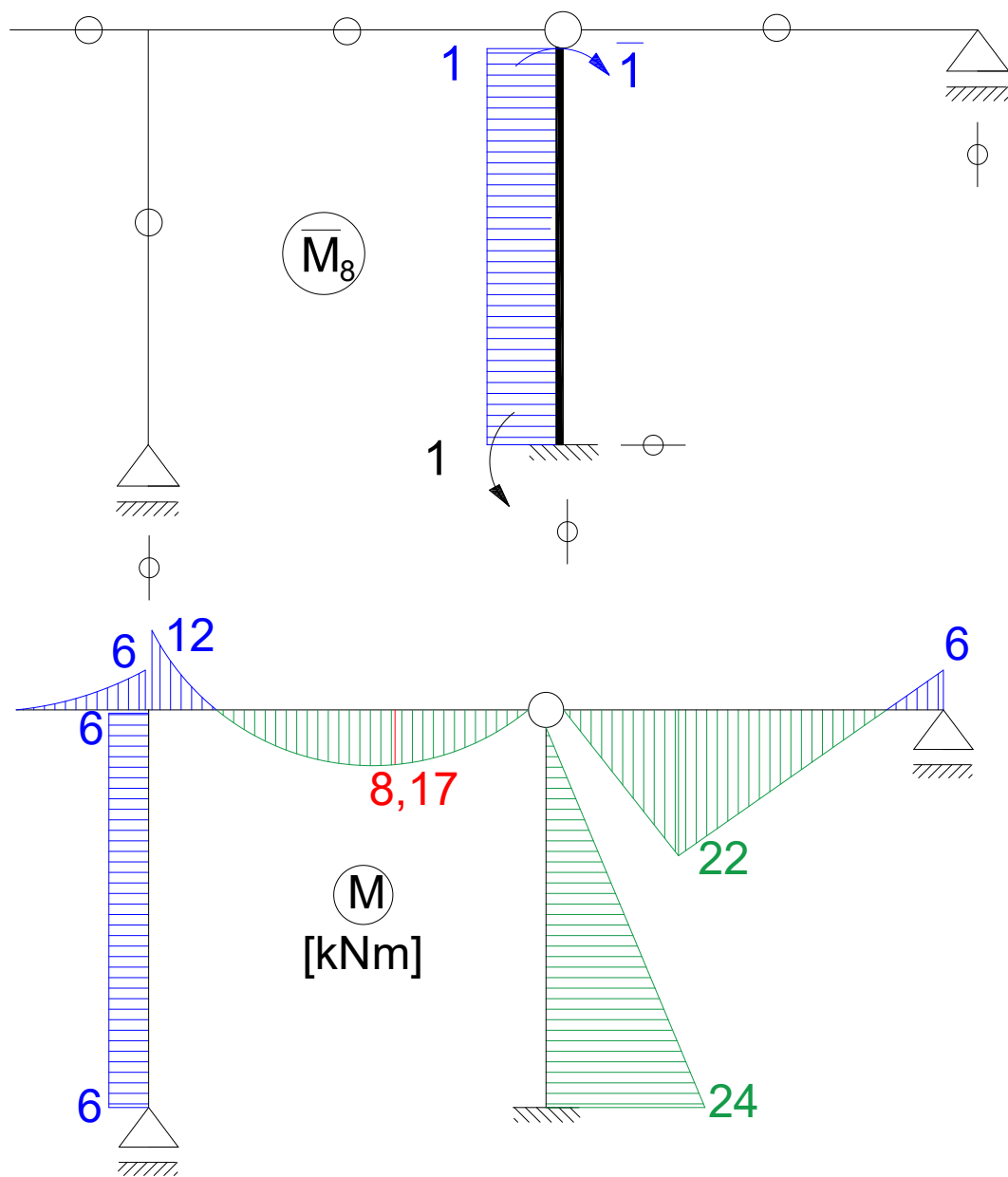


$$\varphi_C^d = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:

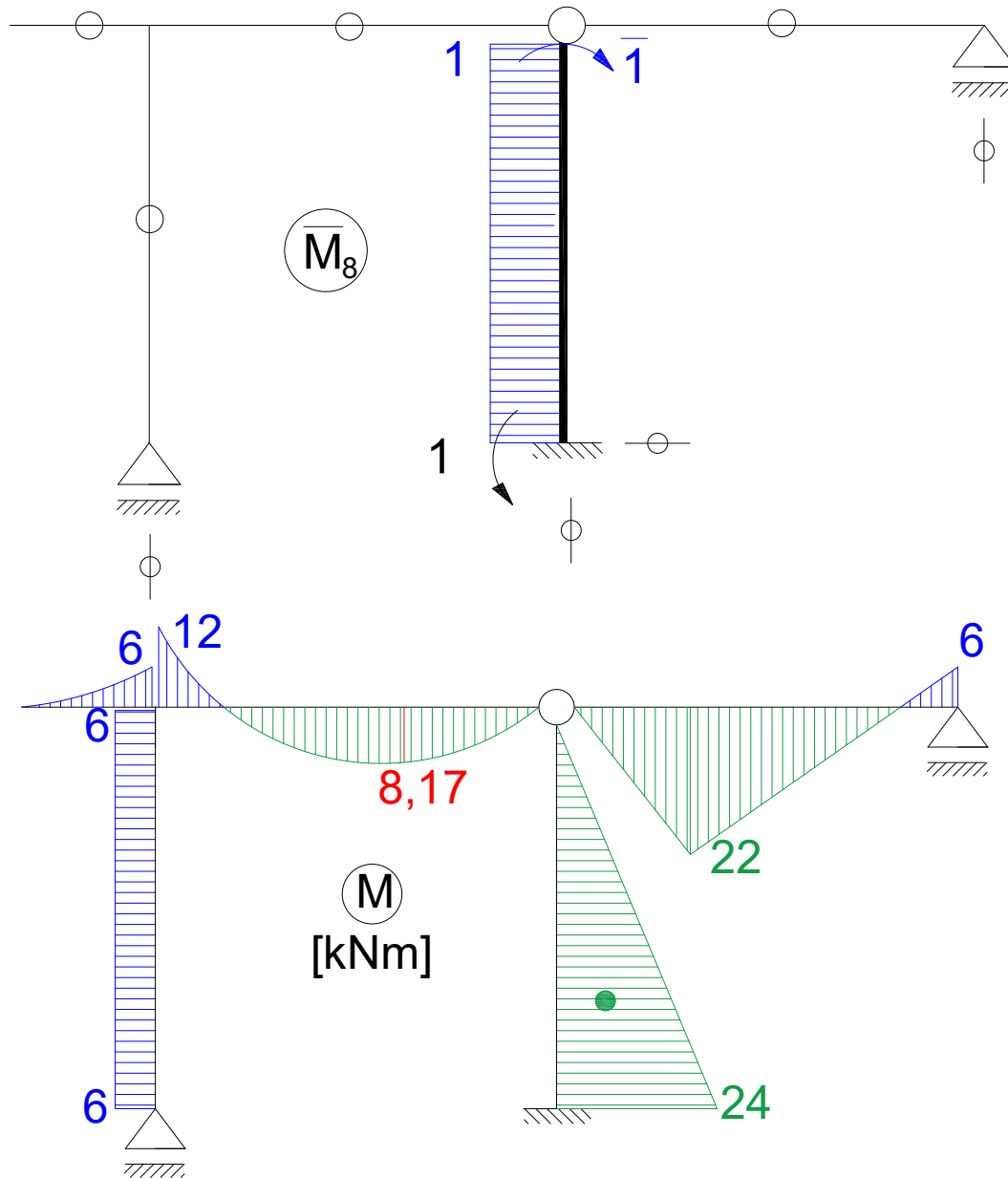


Obliczenia przemieszczeń z zasady prac wirtualnych:



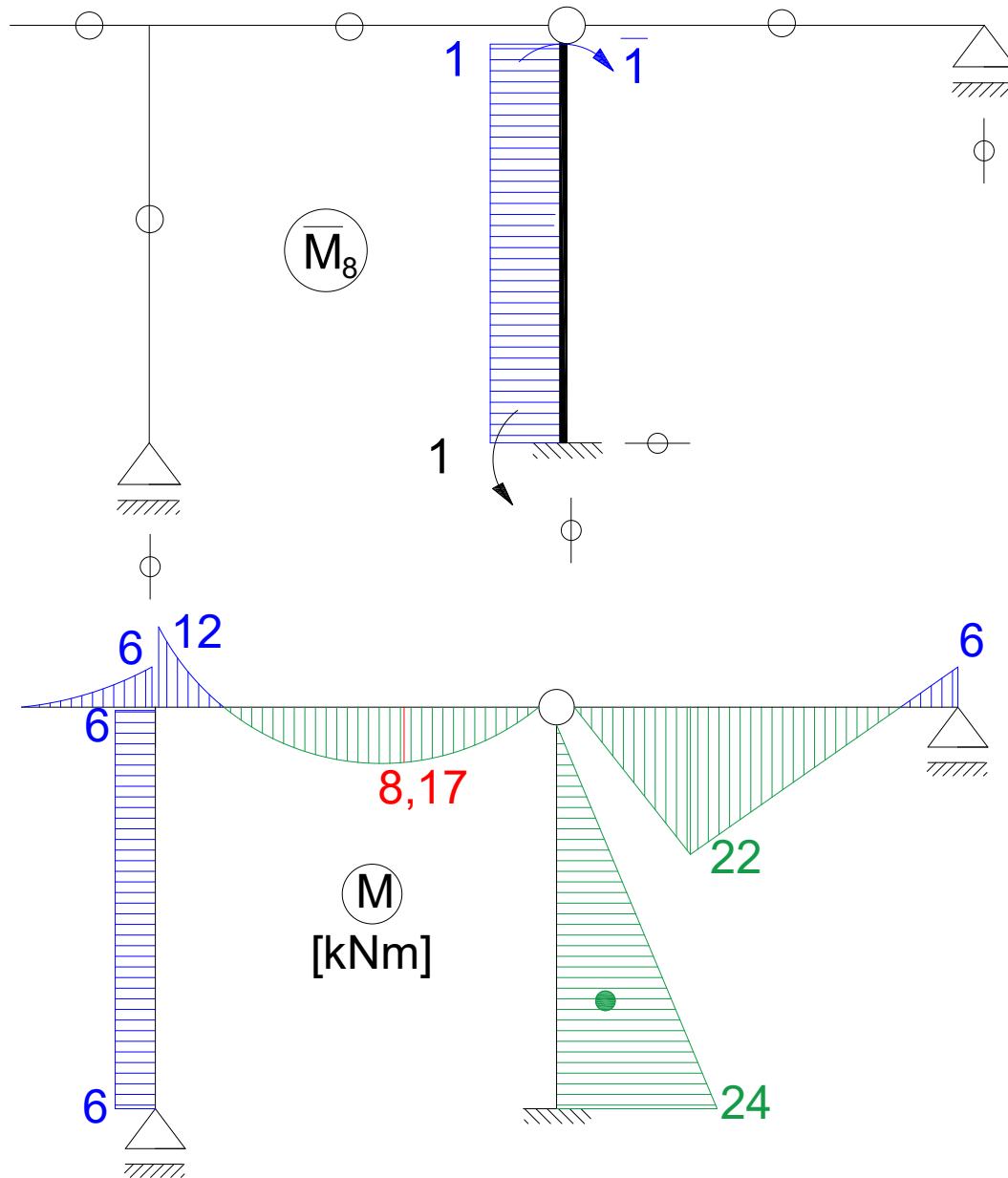
$$\varphi_C^d = -\frac{1}{2EI} \left(\frac{1}{2} \cdot 24 \cdot 6 \cdot \right)$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



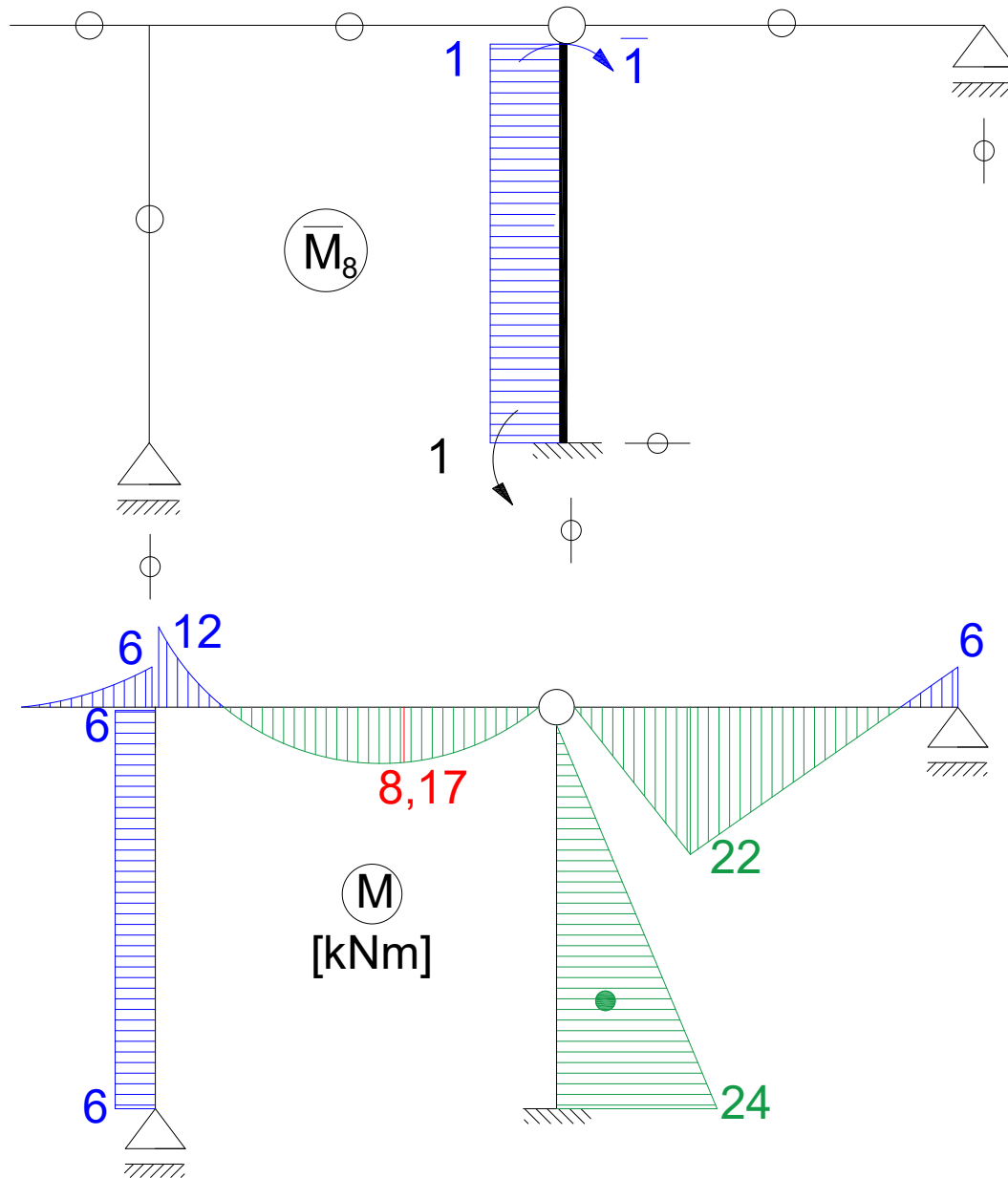
$$\phi_C^d = -\frac{1}{2EI} \left(\frac{1}{2} \cdot 24 \cdot 6 \cdot \right)$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



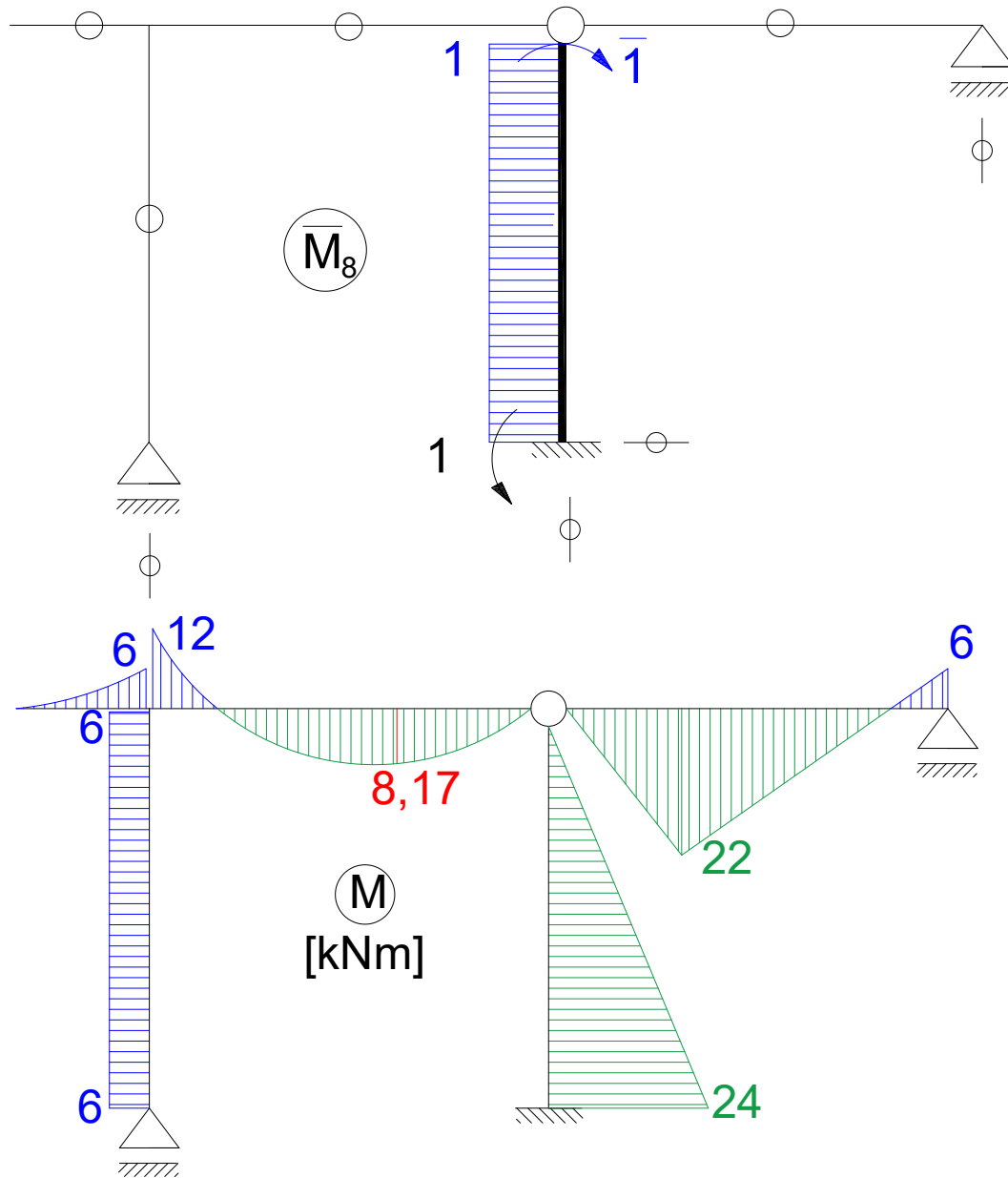
$$\varphi_C^d = -\frac{1}{2EI} \left(\frac{1}{2} \cdot 24 \cdot 6 \cdot 1 \right)$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



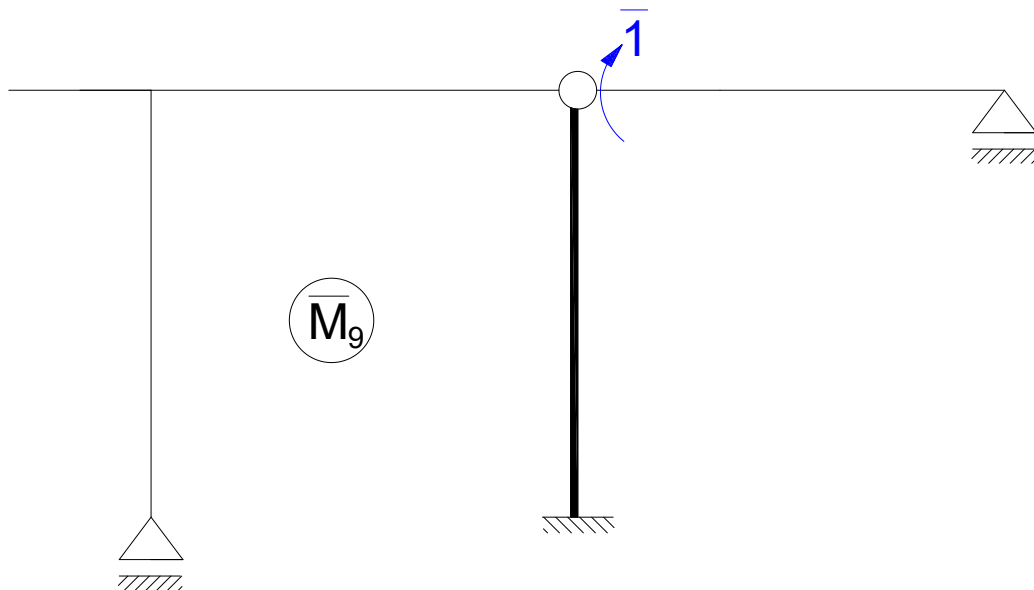
$$\varphi_C^d = -\frac{1}{2EI} \left(\frac{1}{2} \cdot 24 \cdot 6 \cdot 1 \right) = -\frac{36}{EI}$$

Obliczenia przemieszczeń z zasady prac wirtualnych:

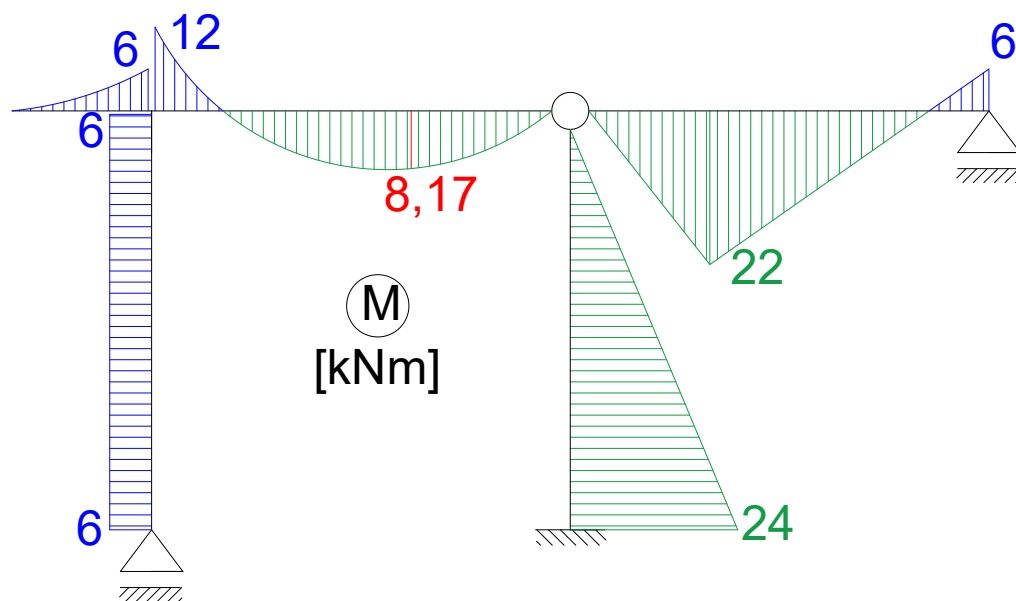


$$\varphi_C^d = -\frac{1}{2EI} \left(\frac{1}{2} \cdot 24 \cdot 6 \cdot 1 \right) = -\frac{36}{EI}$$

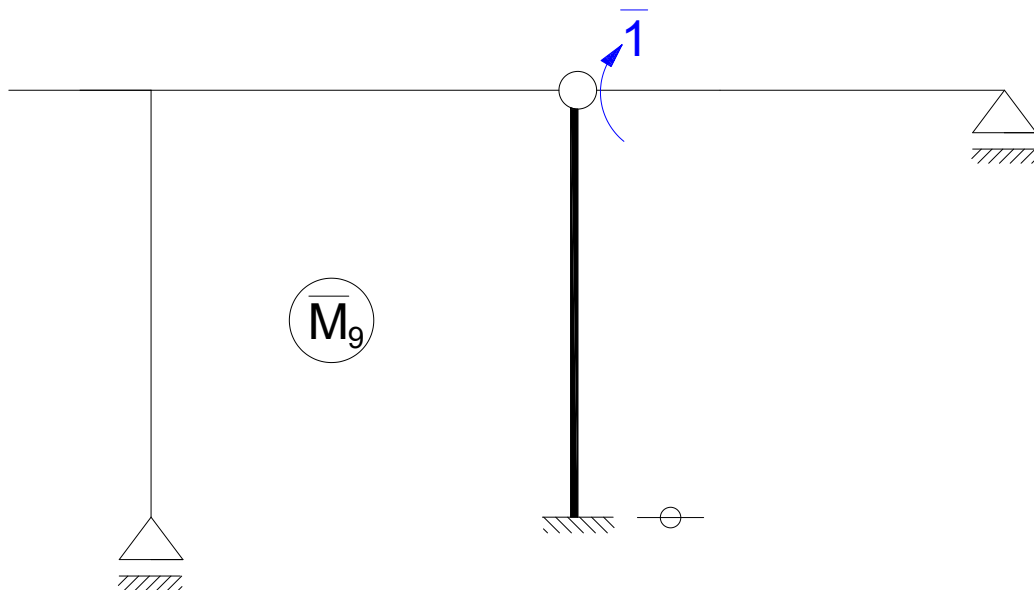
Obliczenia przemieszczeń z zasady prac wirtualnych:



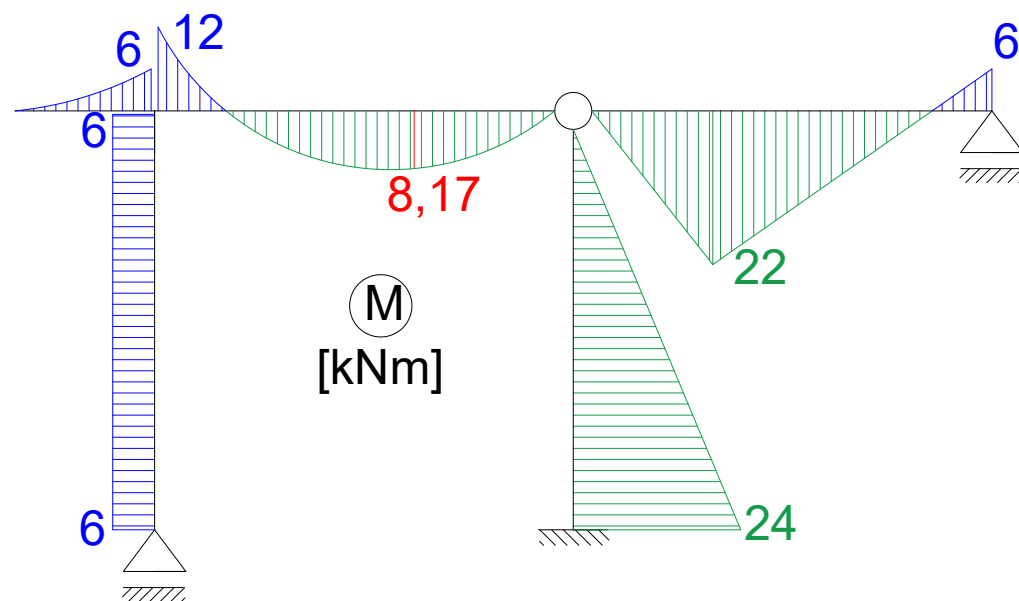
$$\varphi_C^P = ?$$



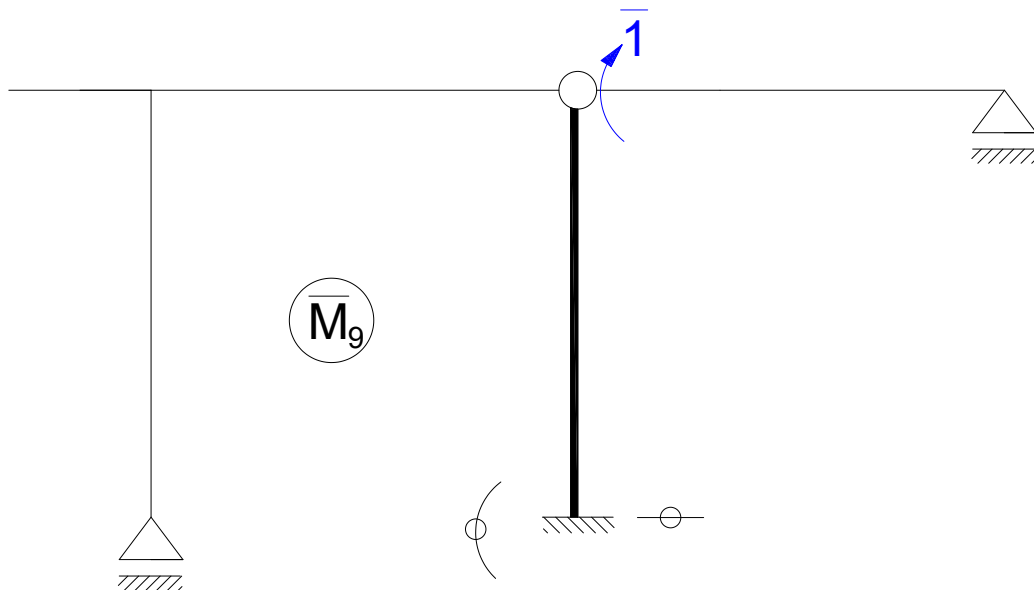
Obliczenia przemieszczeń z zasady prac wirtualnych:



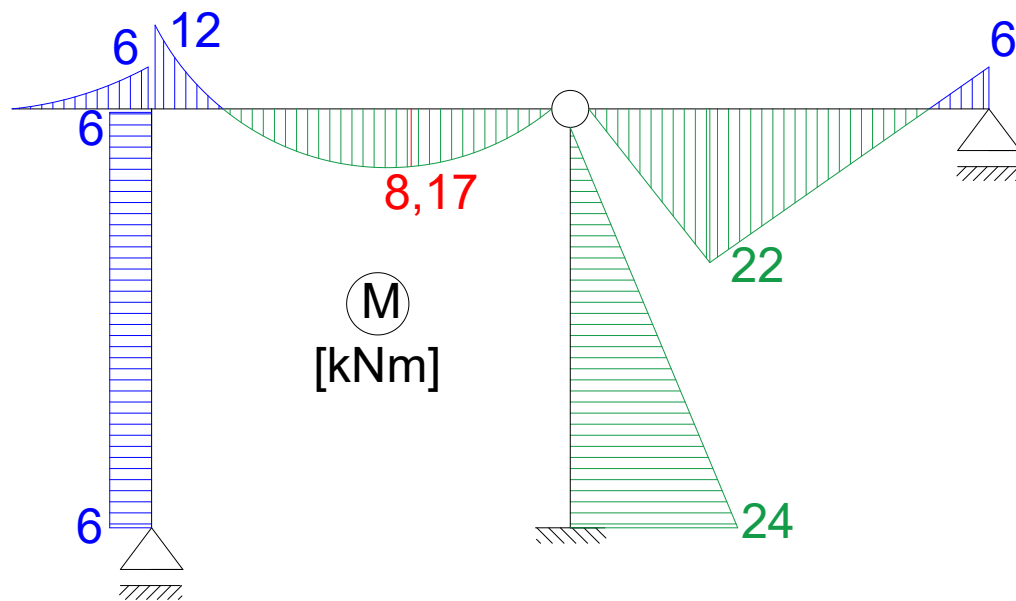
$$\varphi_C^P = ?$$



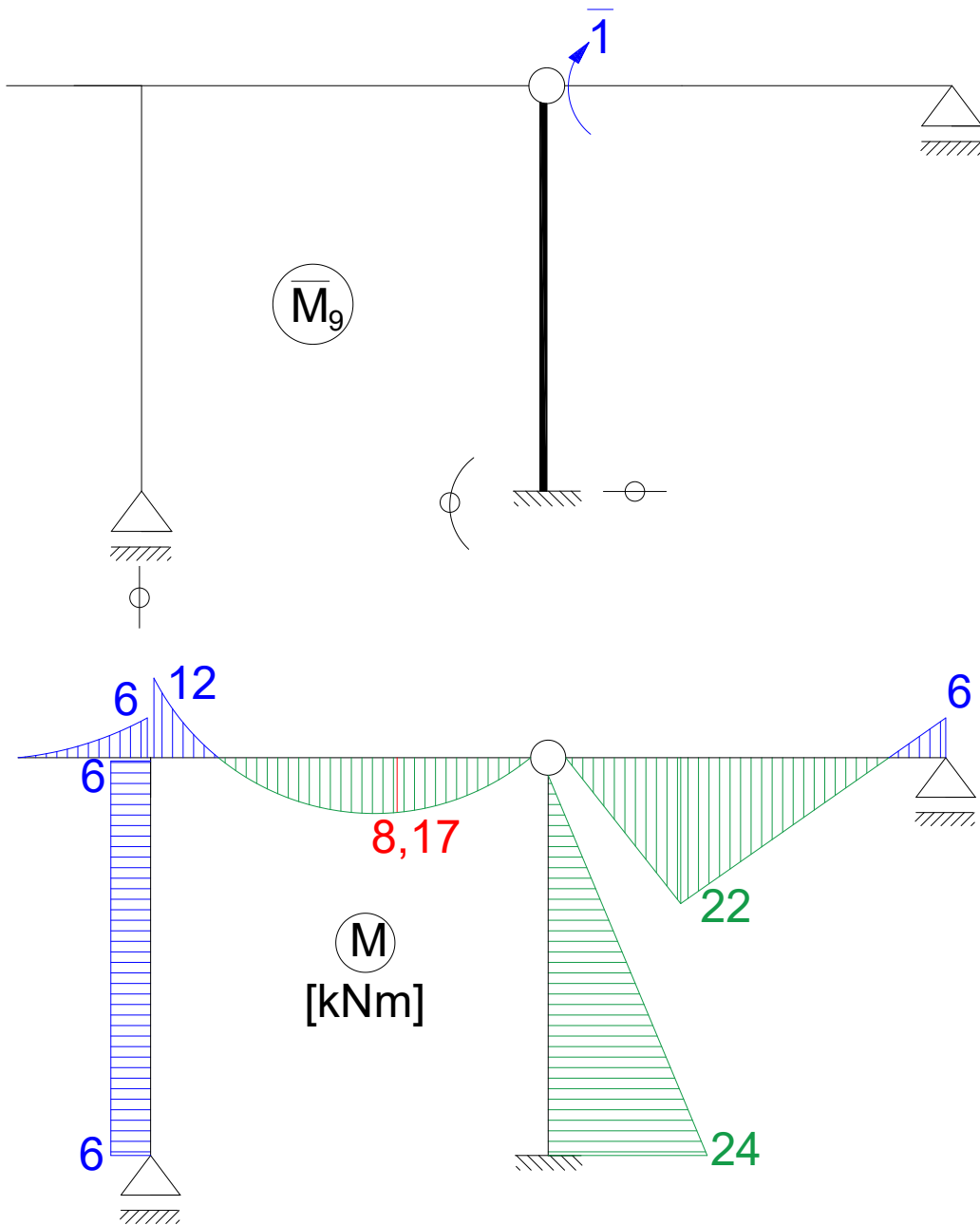
Obliczenia przemieszczeń z zasady prac wirtualnych:



$$\varphi_C^P = ?$$

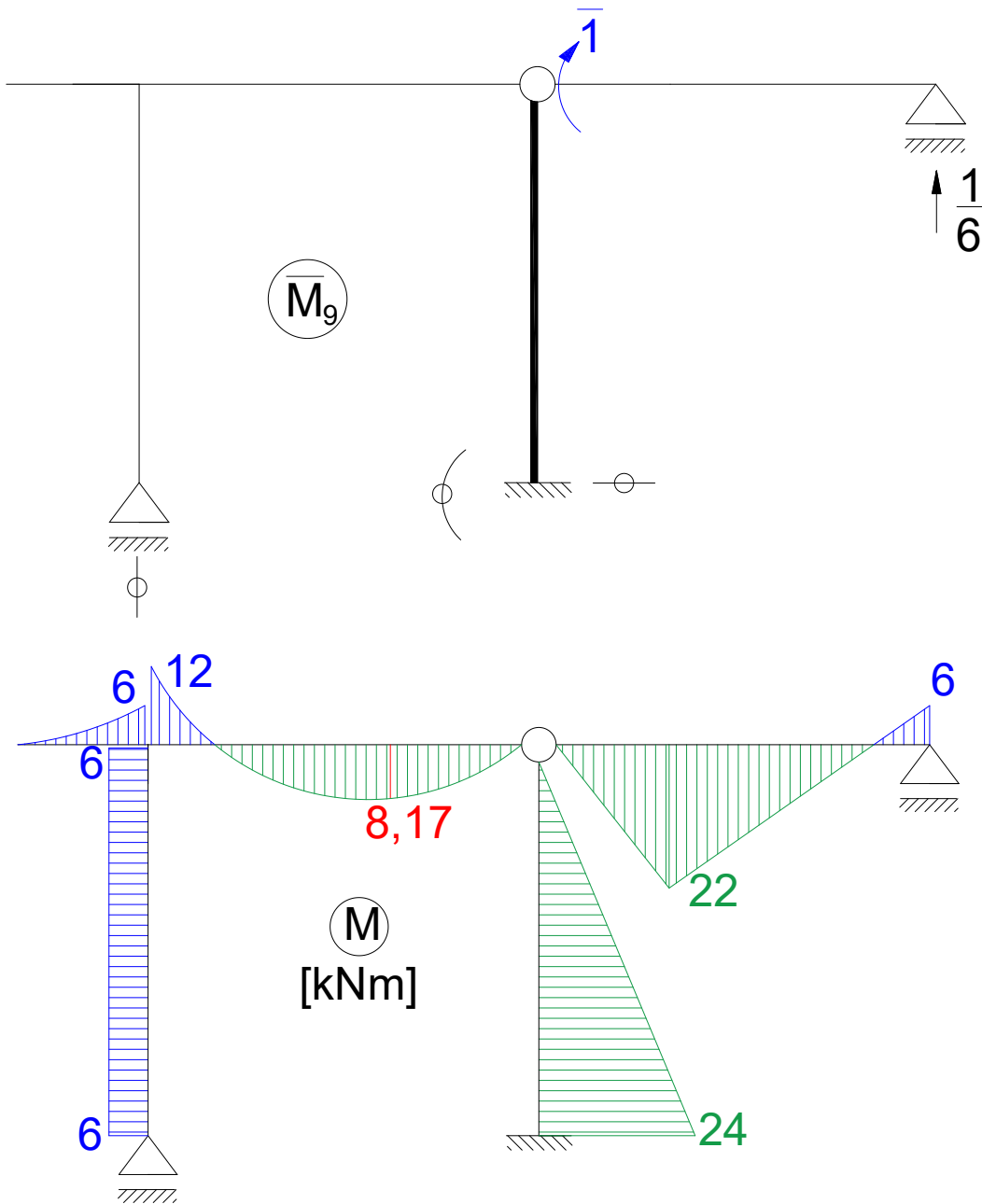


Obliczenia przemieszczeń z zasady prac wirtualnych:



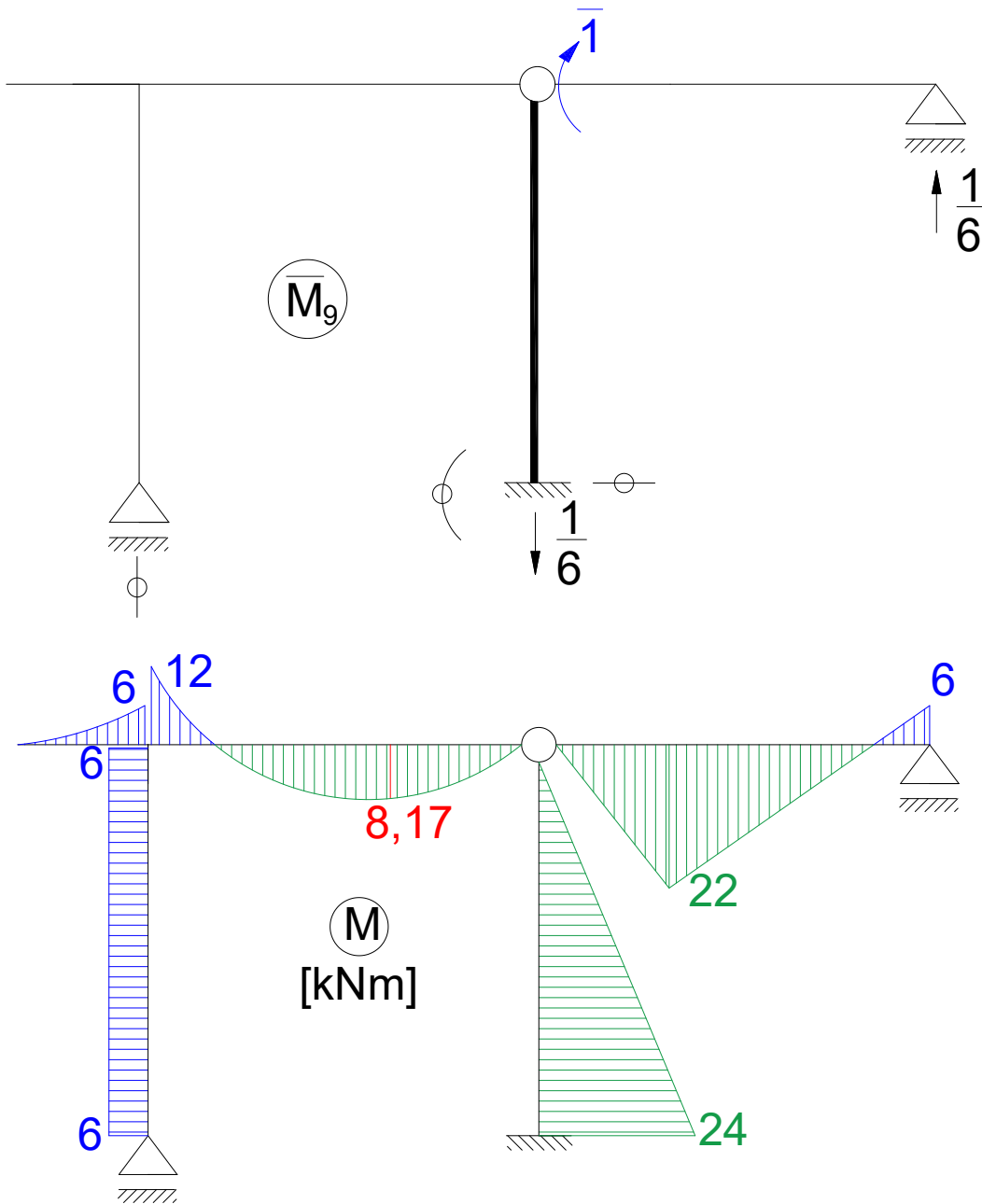
$$\phi_C^P = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



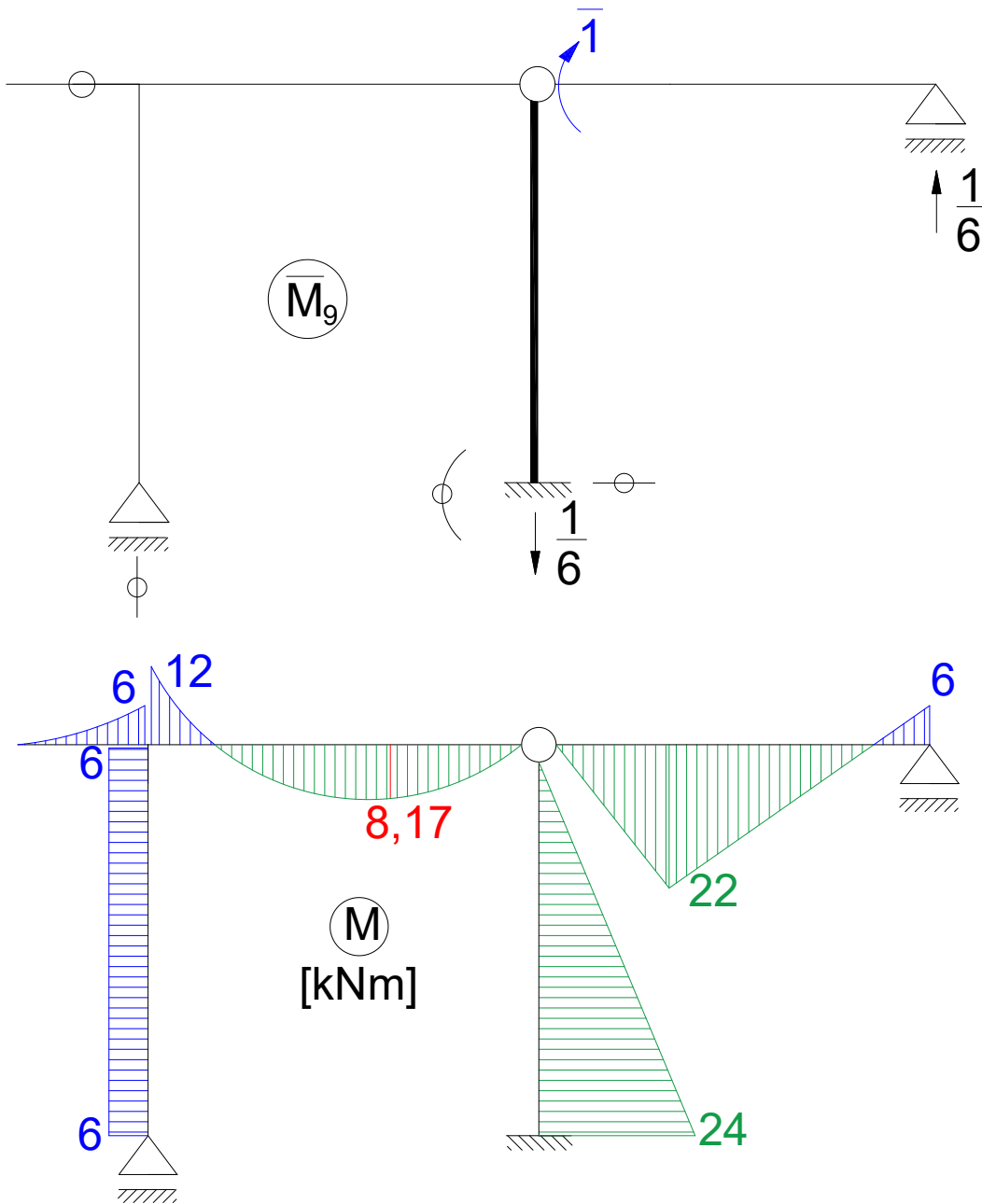
$$\phi_C^P = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



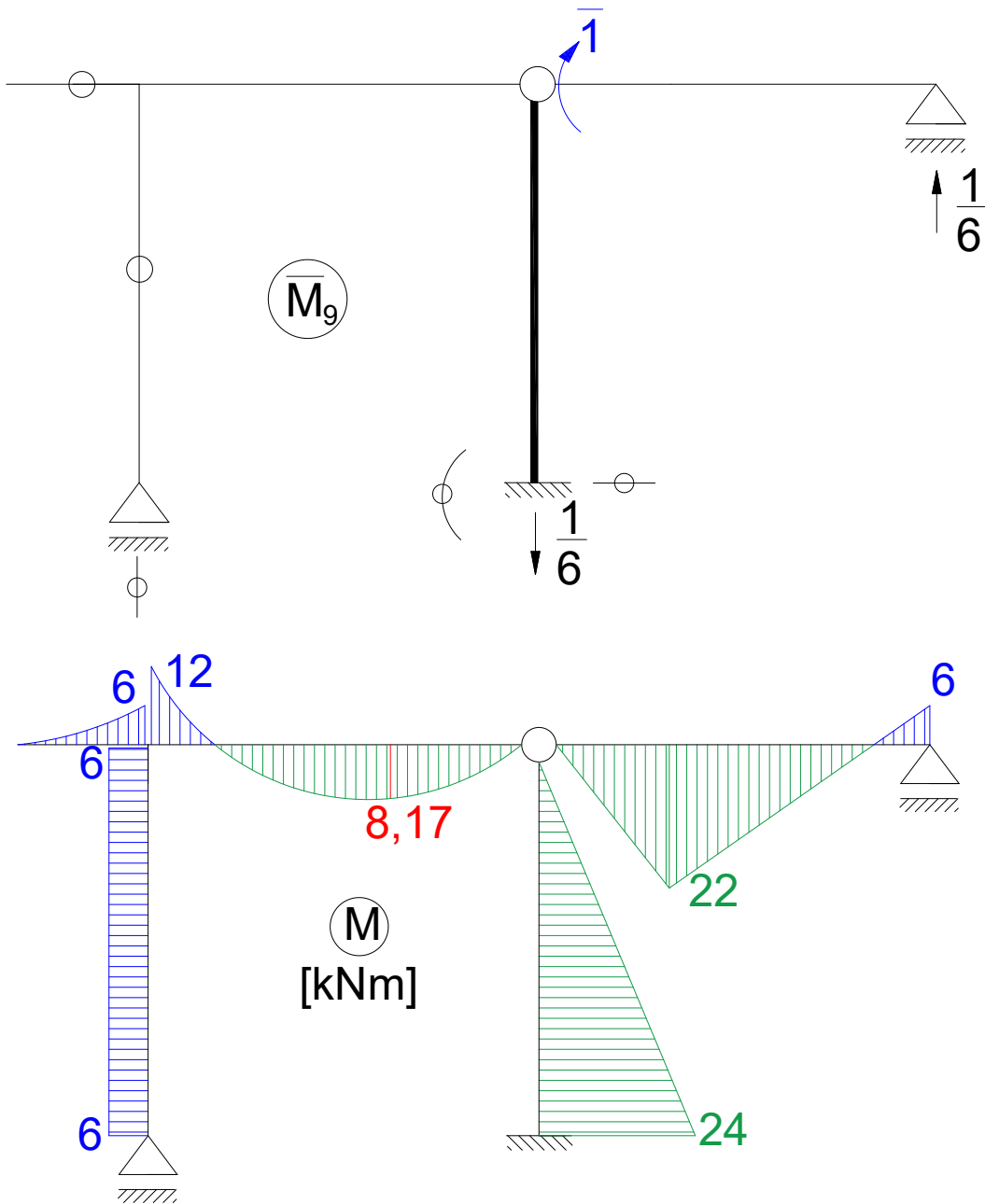
$$\phi_C^P = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



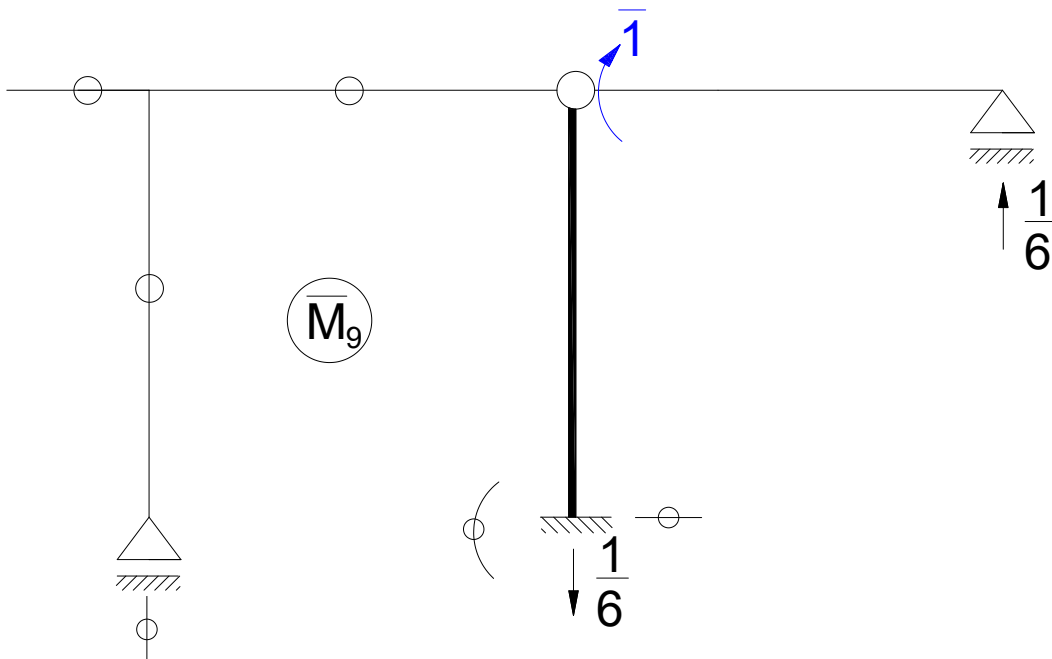
$$\phi_C^P = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:

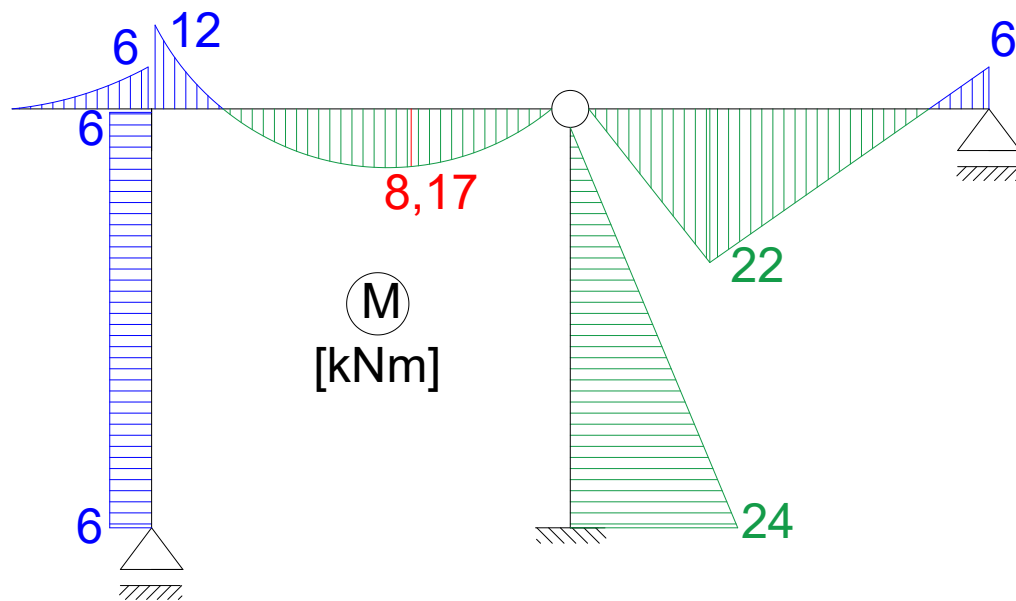


$$\phi_C^P = ?$$

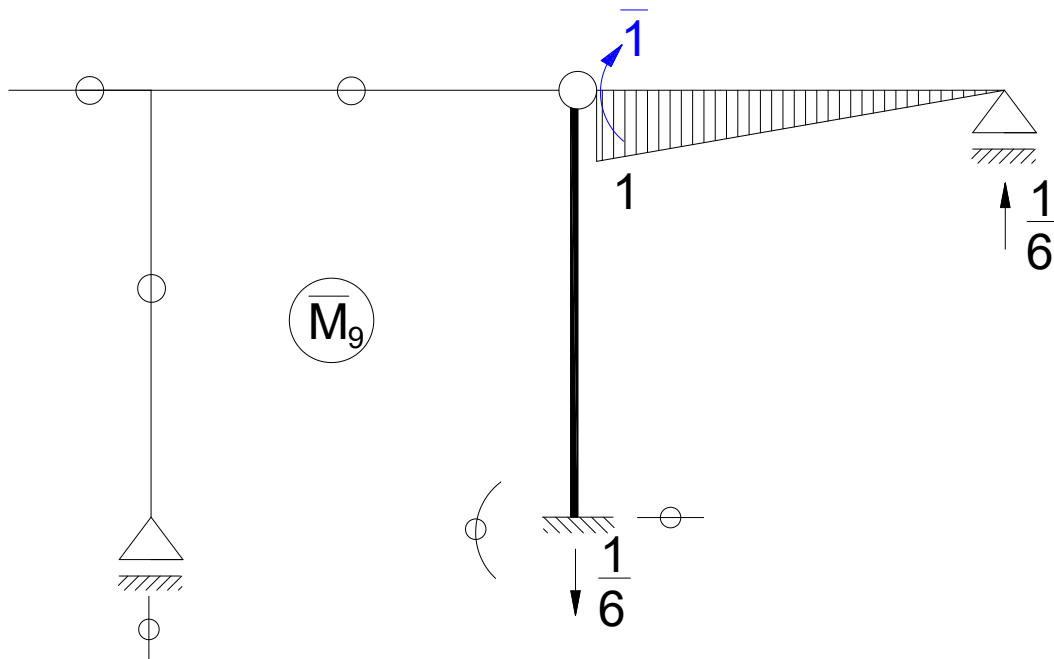
Obliczenia przemieszczeń z zasady prac wirtualnych:



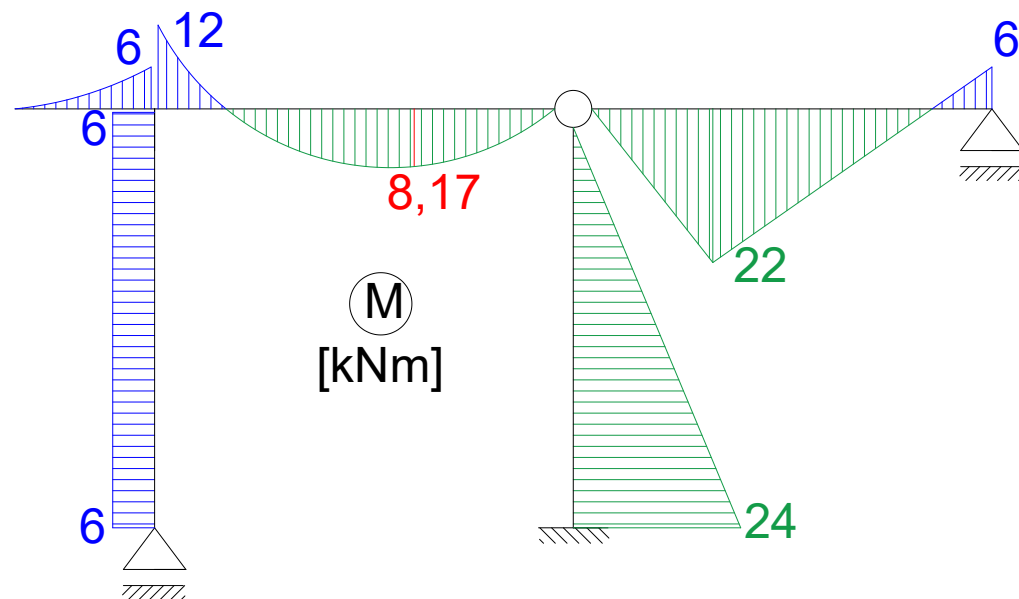
$$\phi_C^P = ?$$



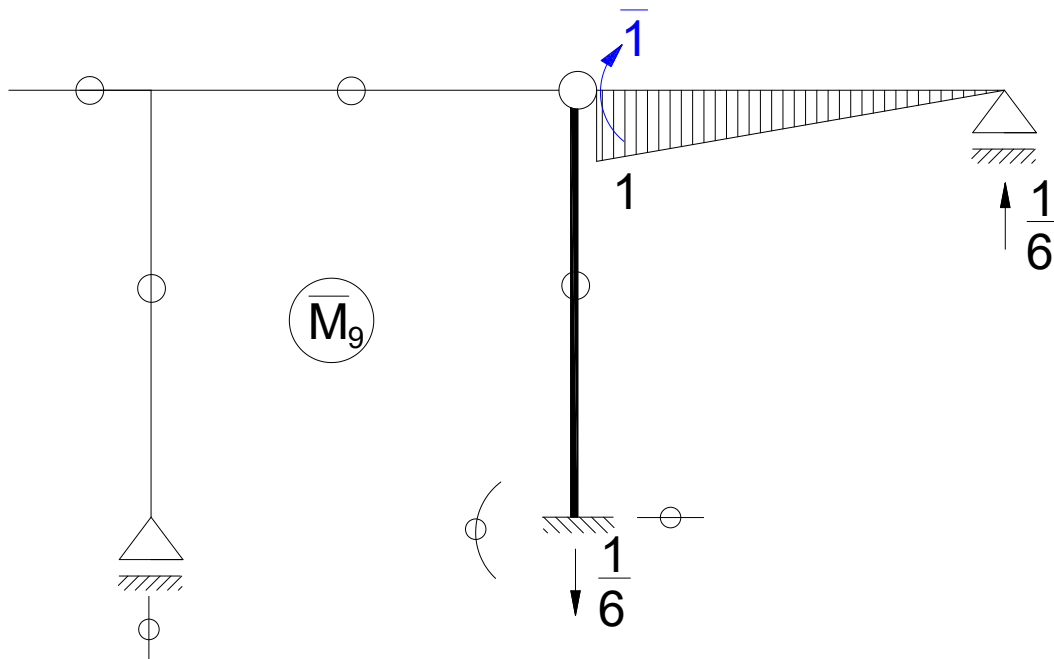
Obliczenia przemieszczeń z zasady prac wirtualnych:



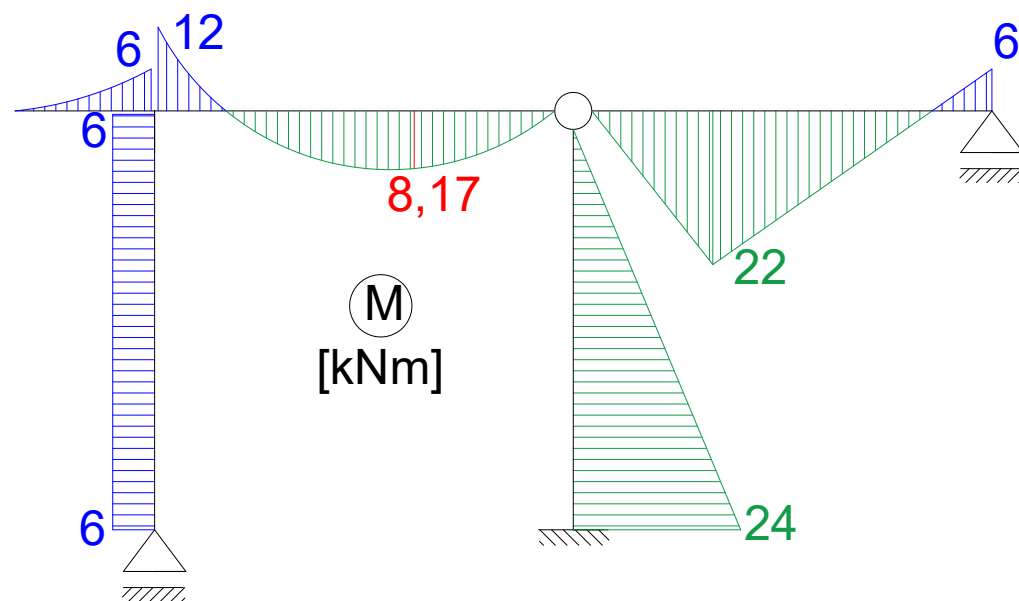
$$\phi_C^P = ?$$



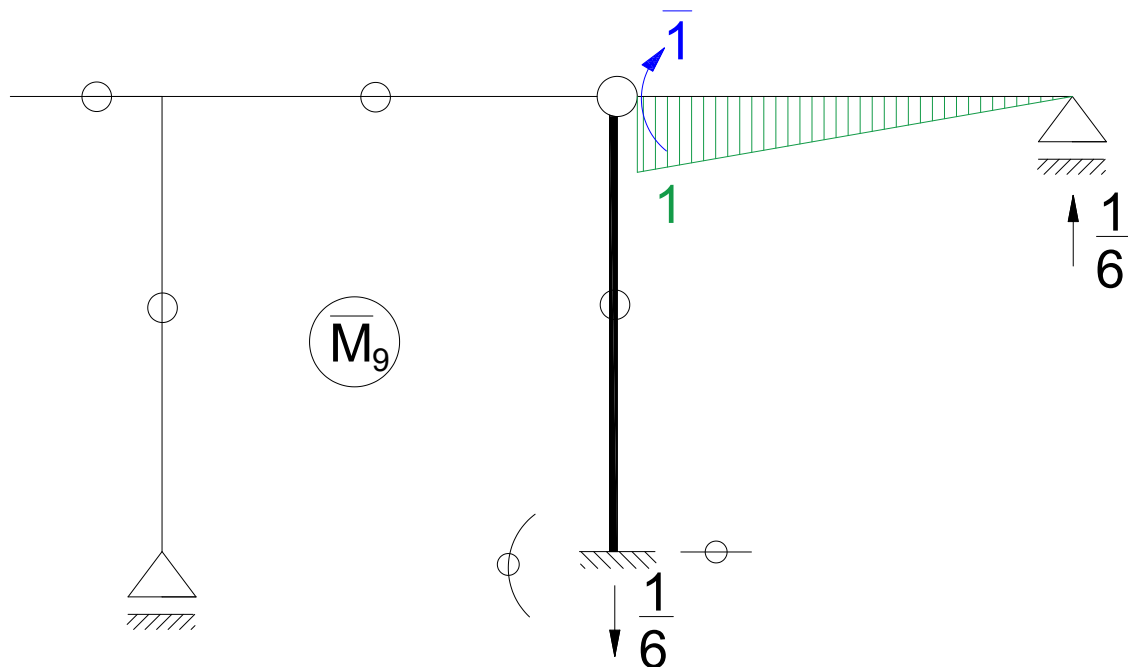
Obliczenia przemieszczeń z zasady prac wirtualnych:



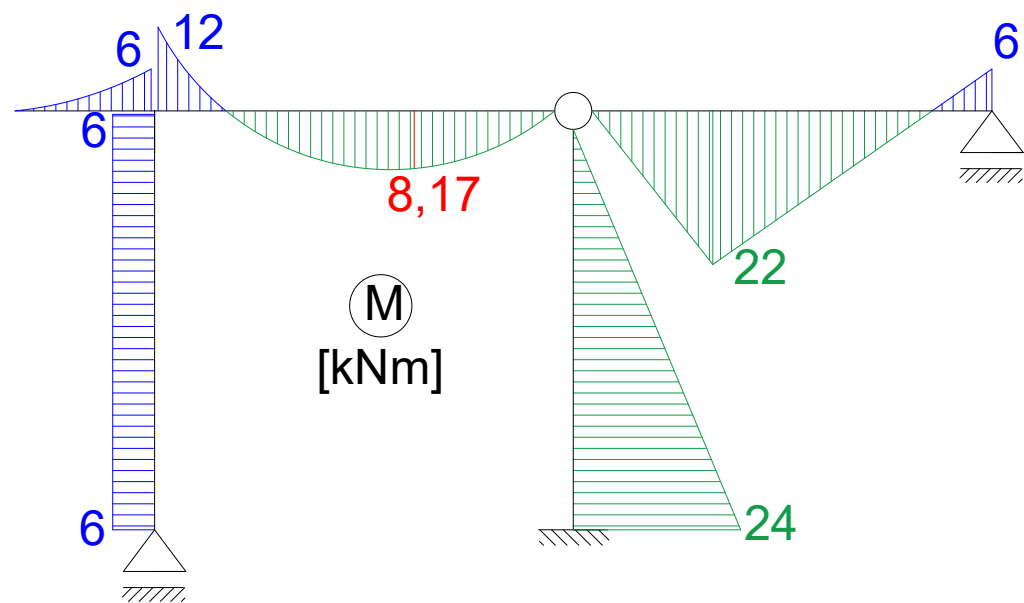
$$\phi_C^P = ?$$



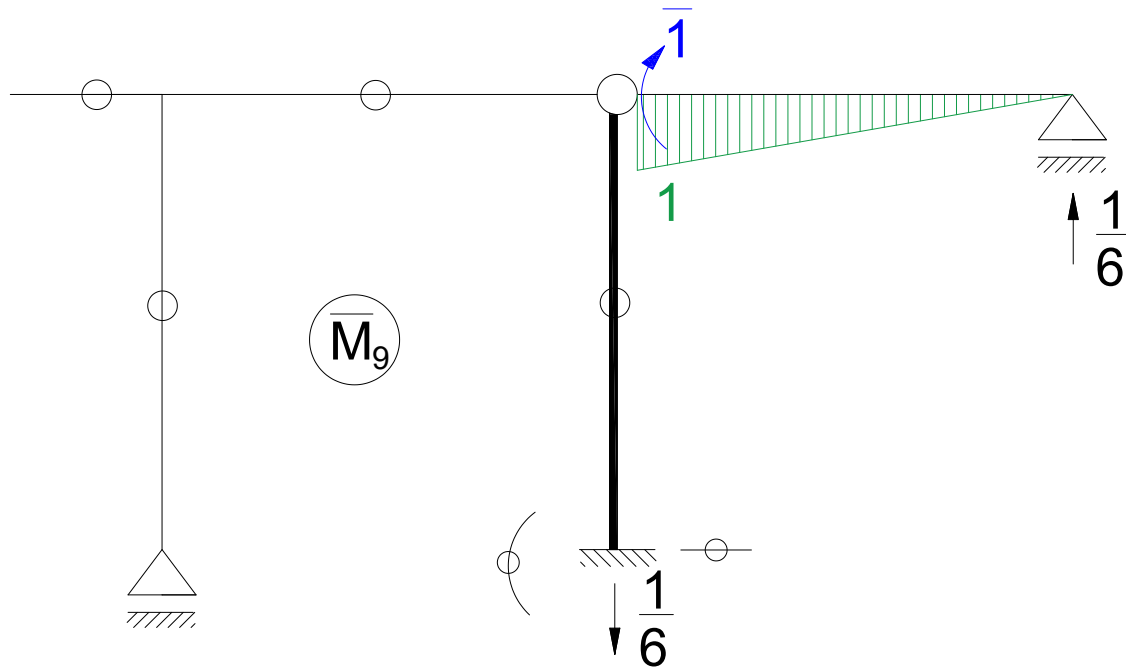
Obliczenia przemieszczeń z zasady prac wirtualnych:



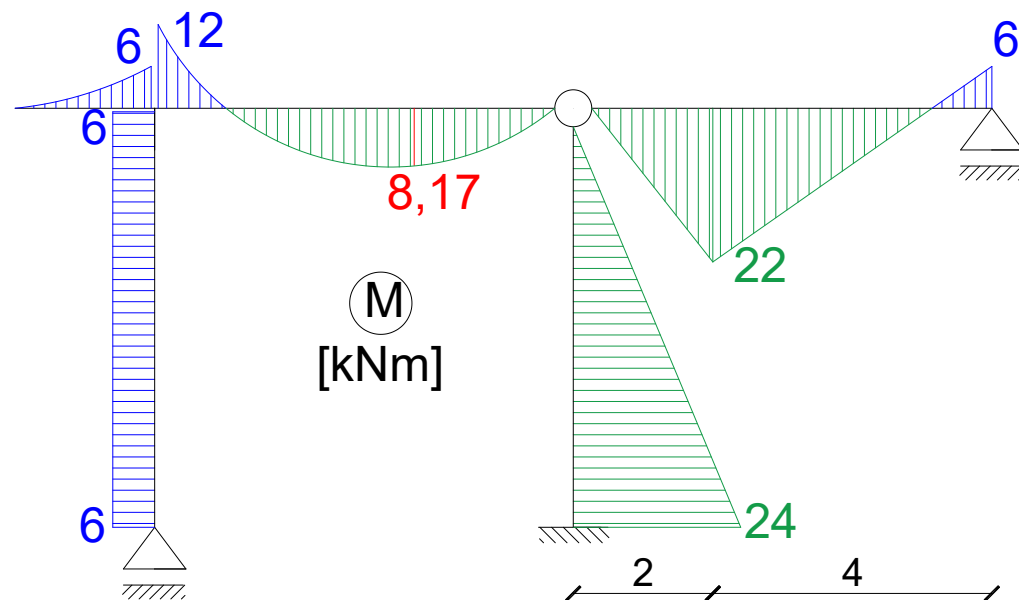
$$\varphi_C^P = ?$$



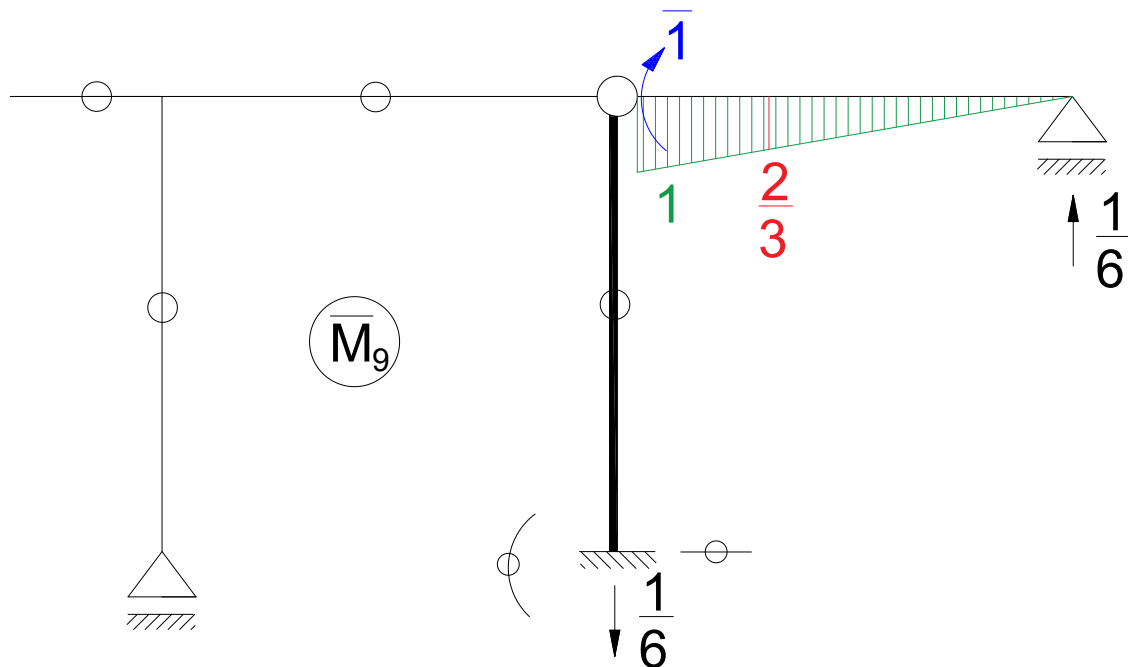
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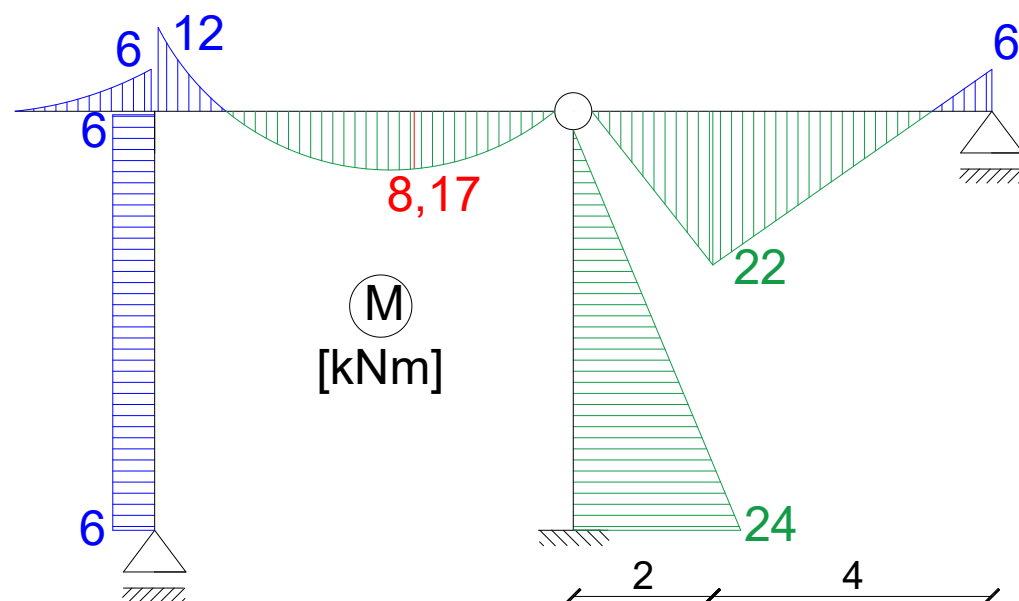
$$\phi_C^P = ?$$



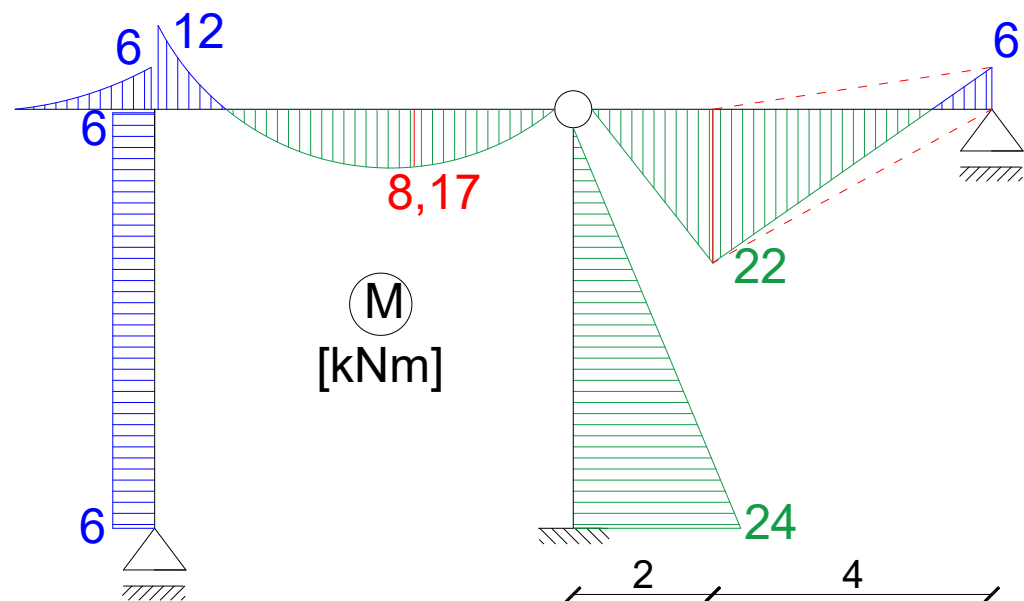
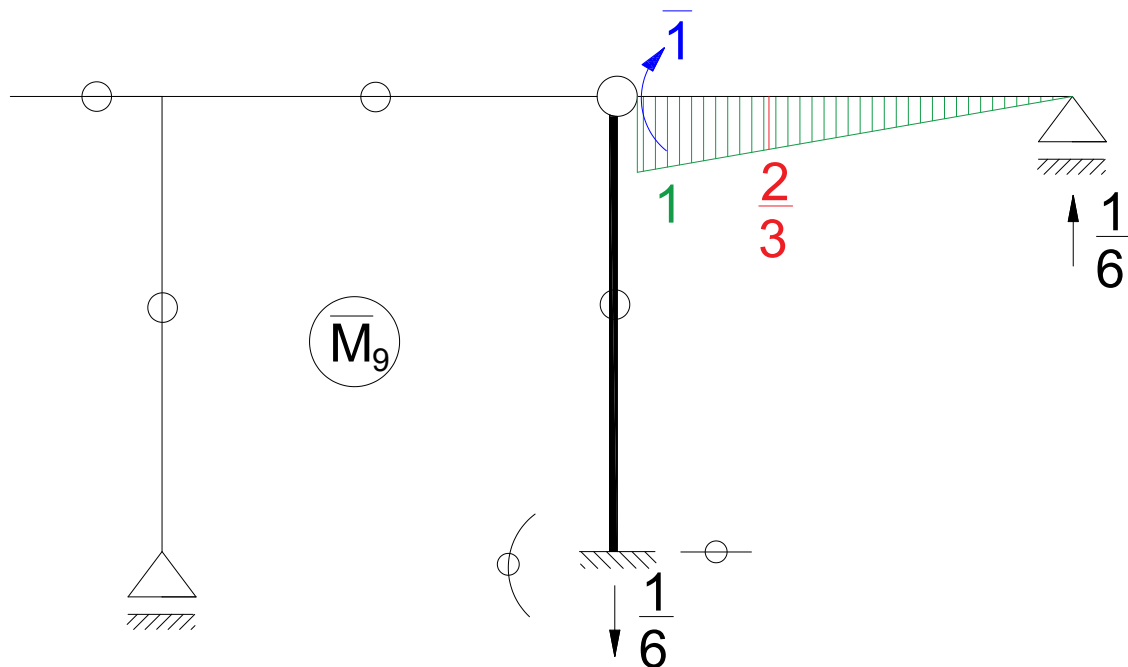
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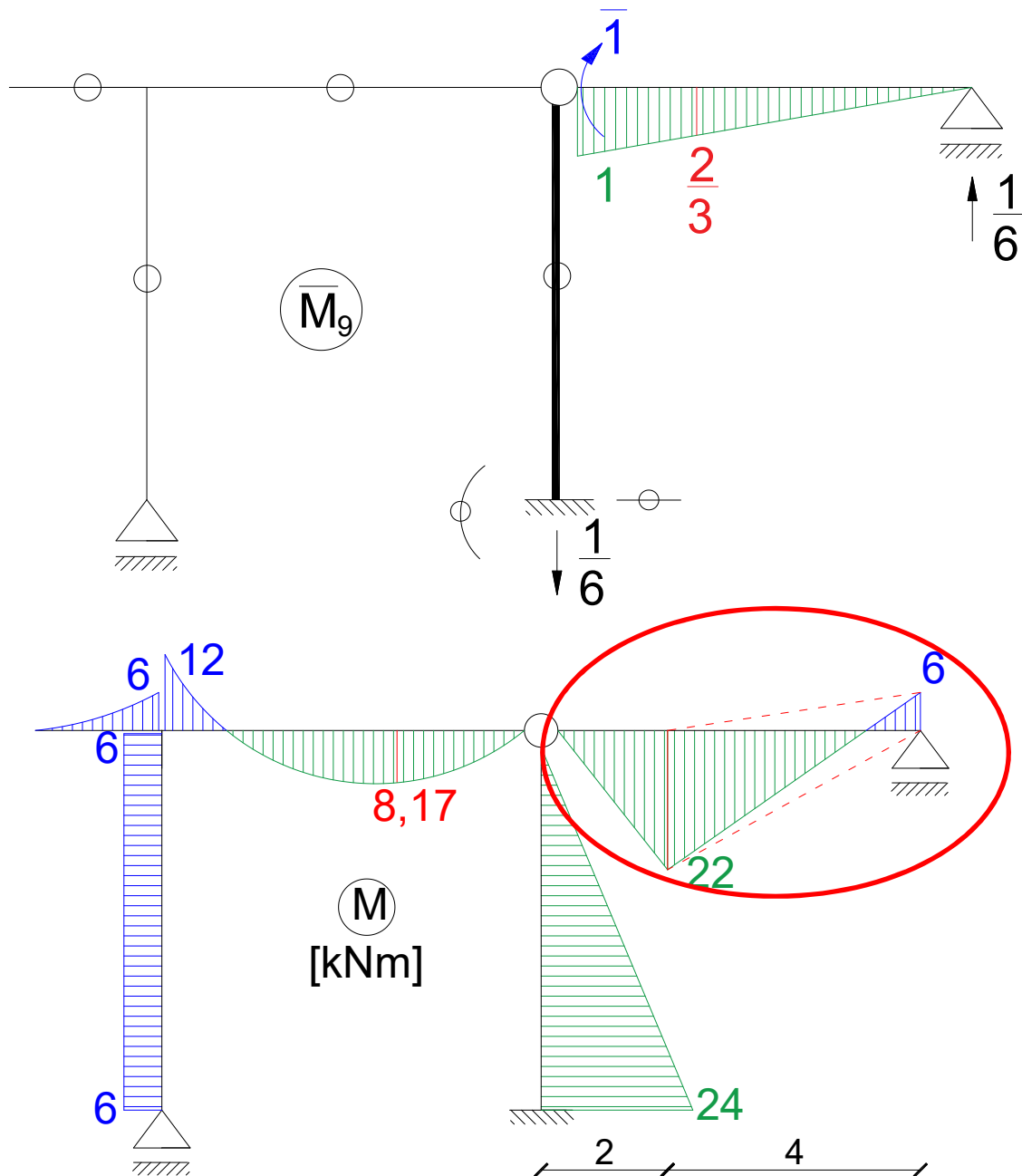
$$\phi_C^P = ?$$



Obliczenia przemieszczeń z zasady prac wirtualnych:

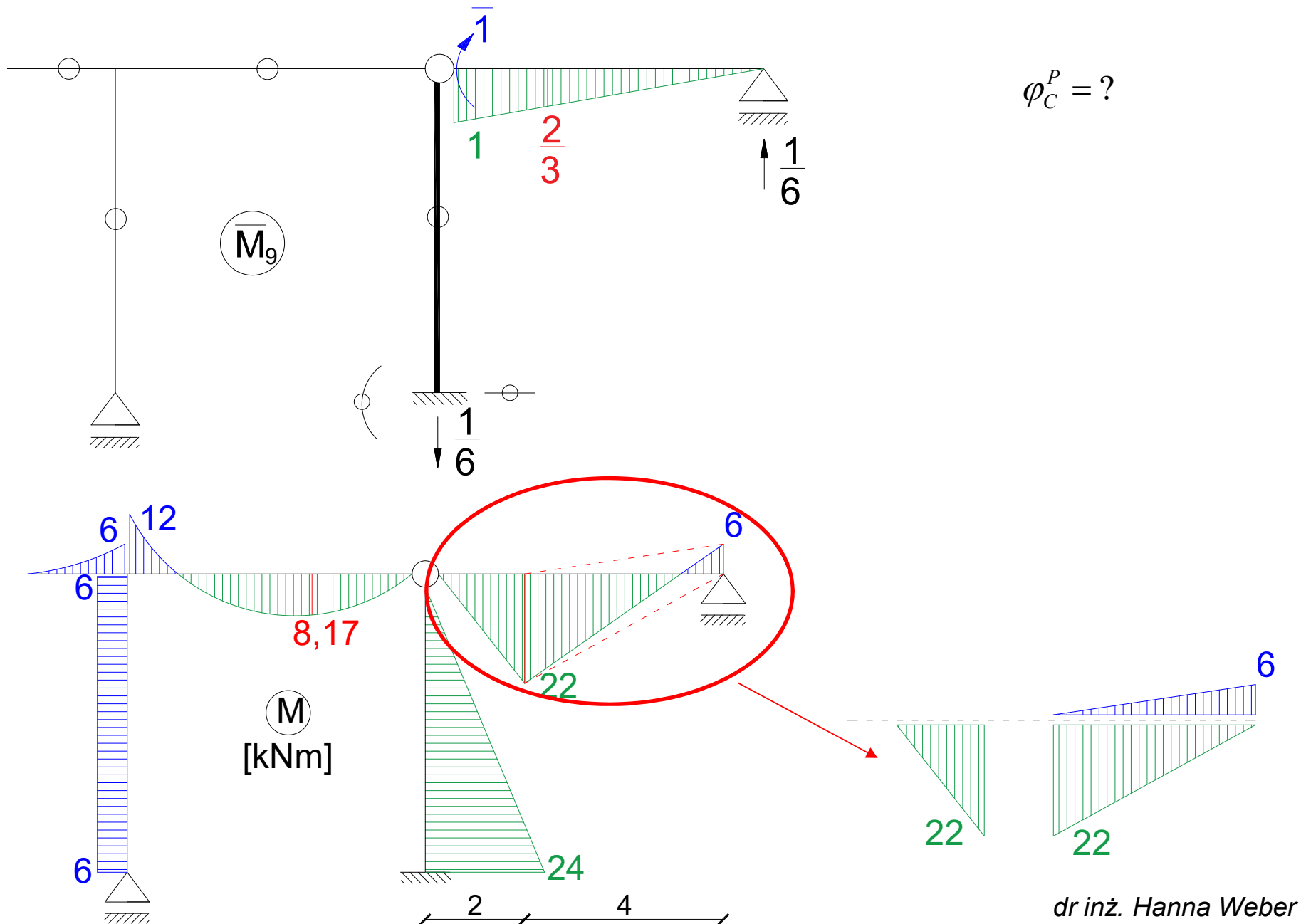


Obliczenia przemieszczeń z zasady prac wirtualnych:

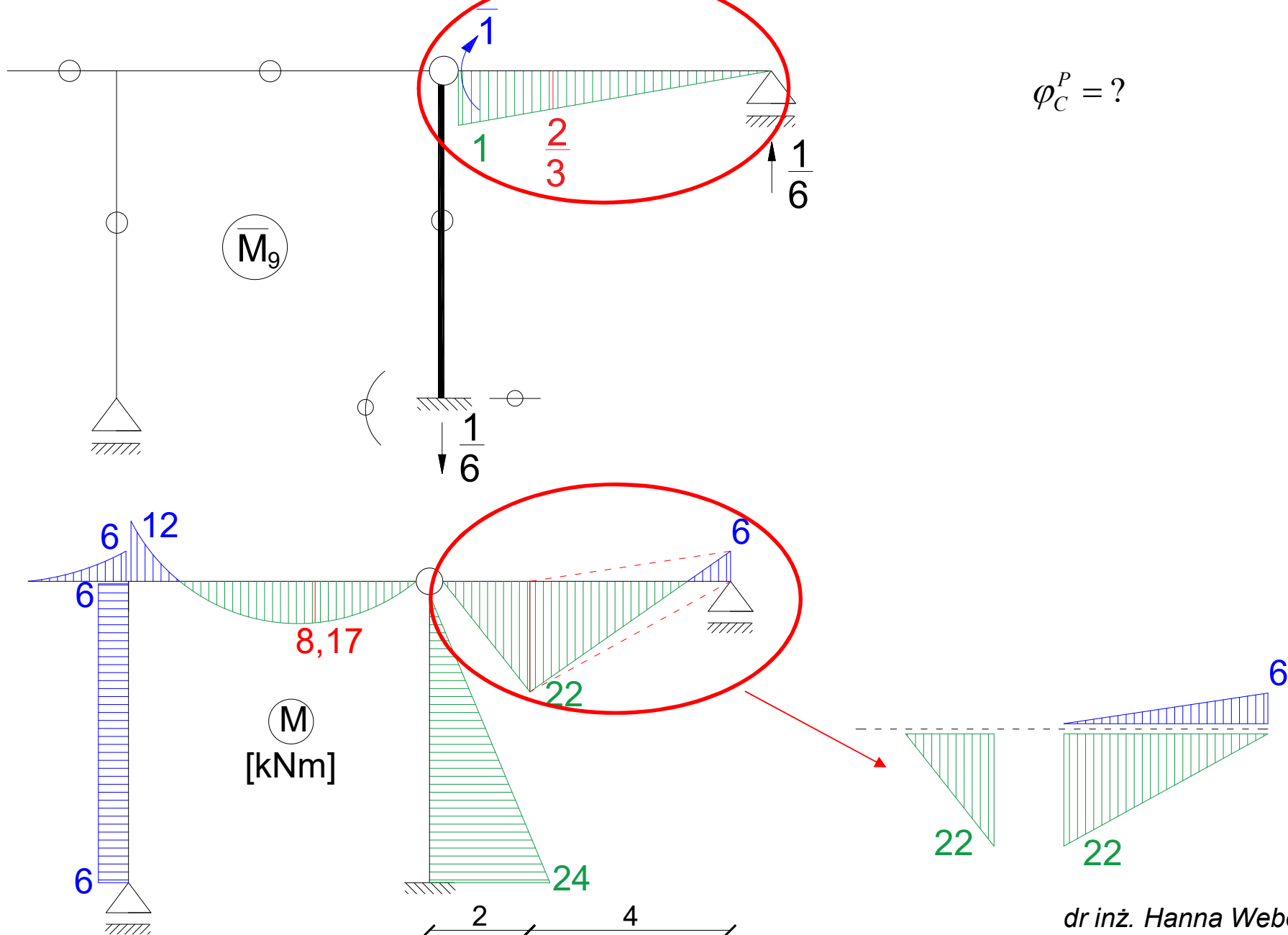


$$\phi_C^P = ?$$

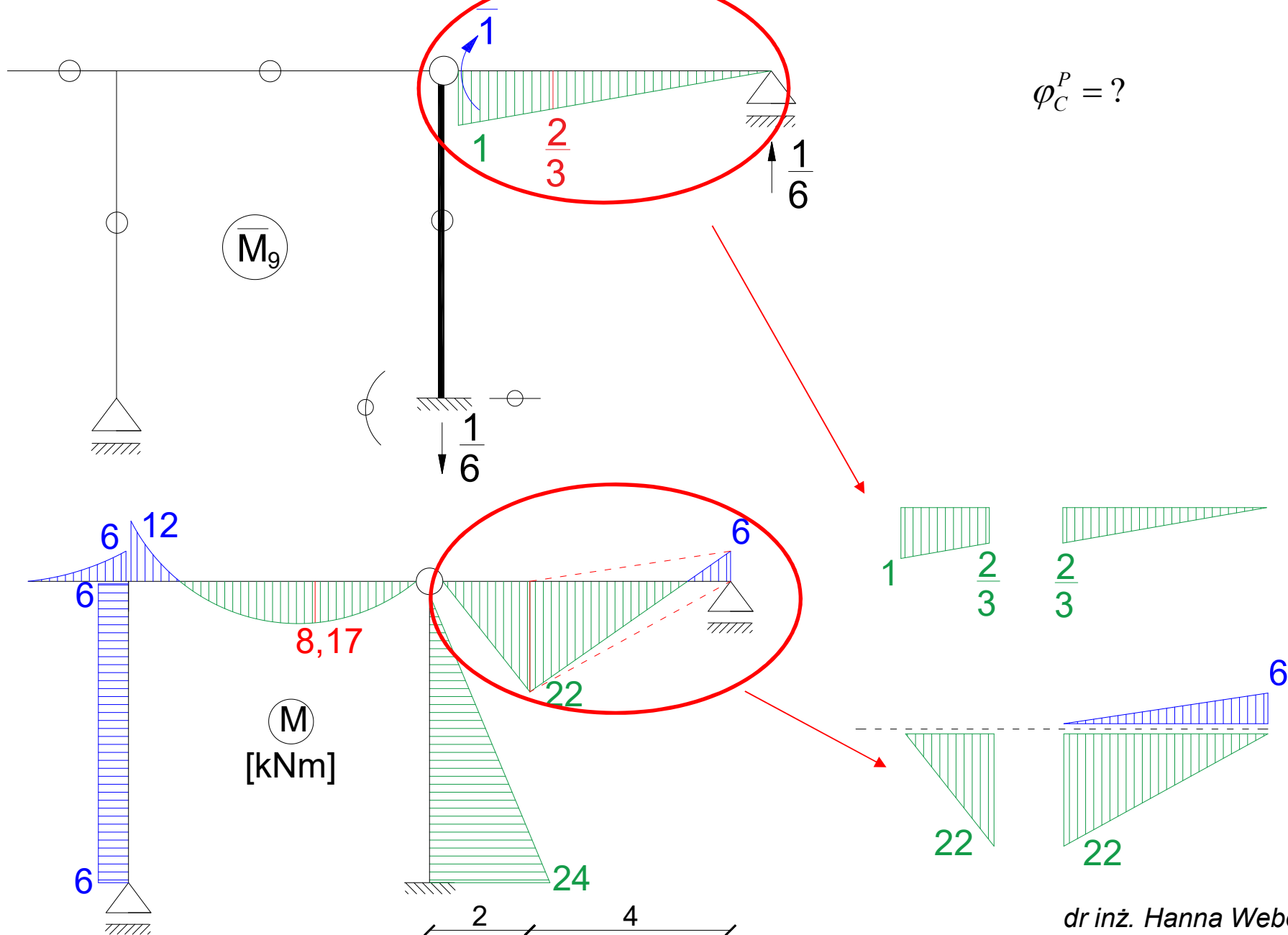
Obliczenia przemieszczeń z zasady prac wirtualnych:



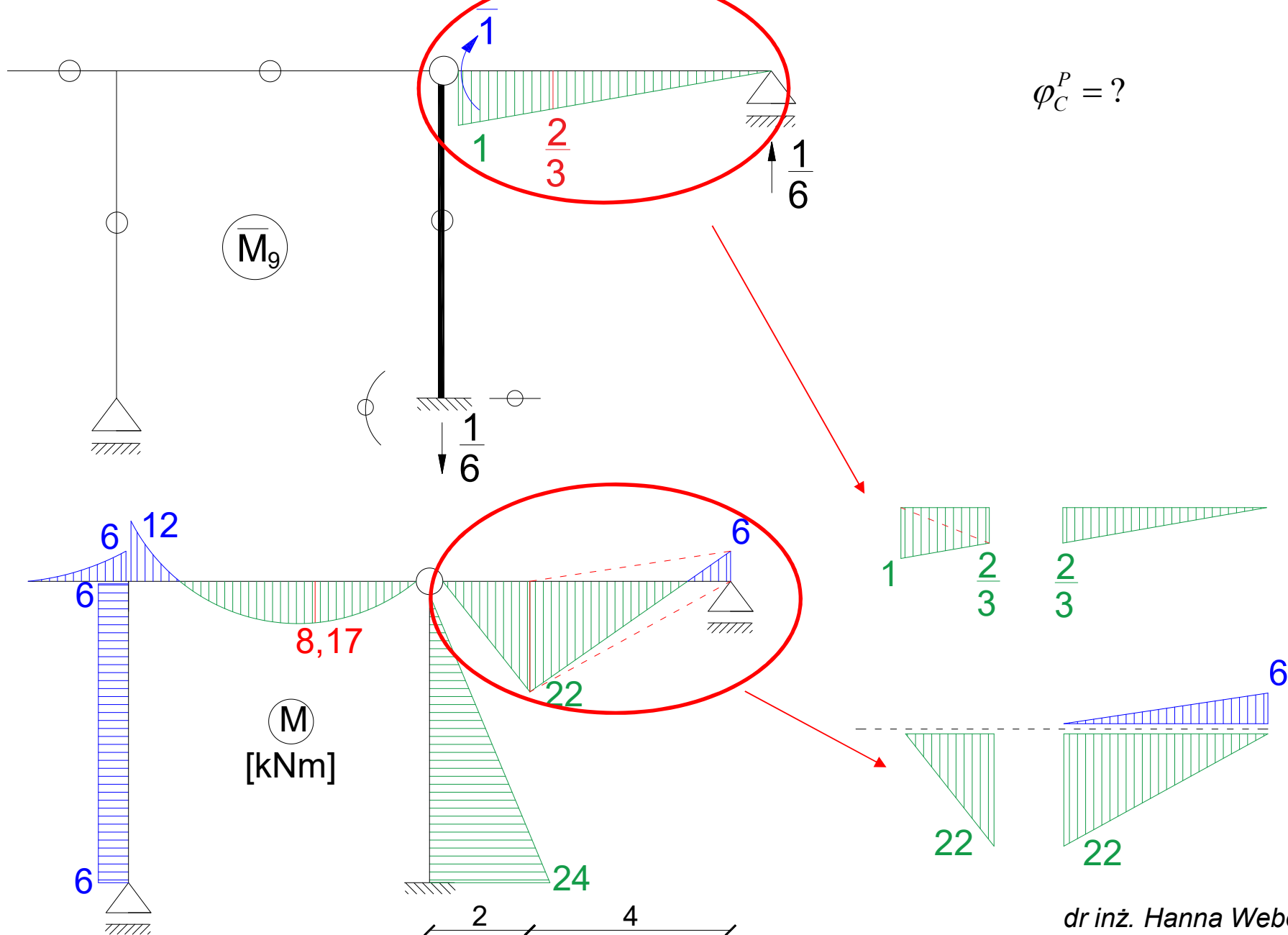
Obliczenia przemieszczeń z zasady prac wirtualnych:



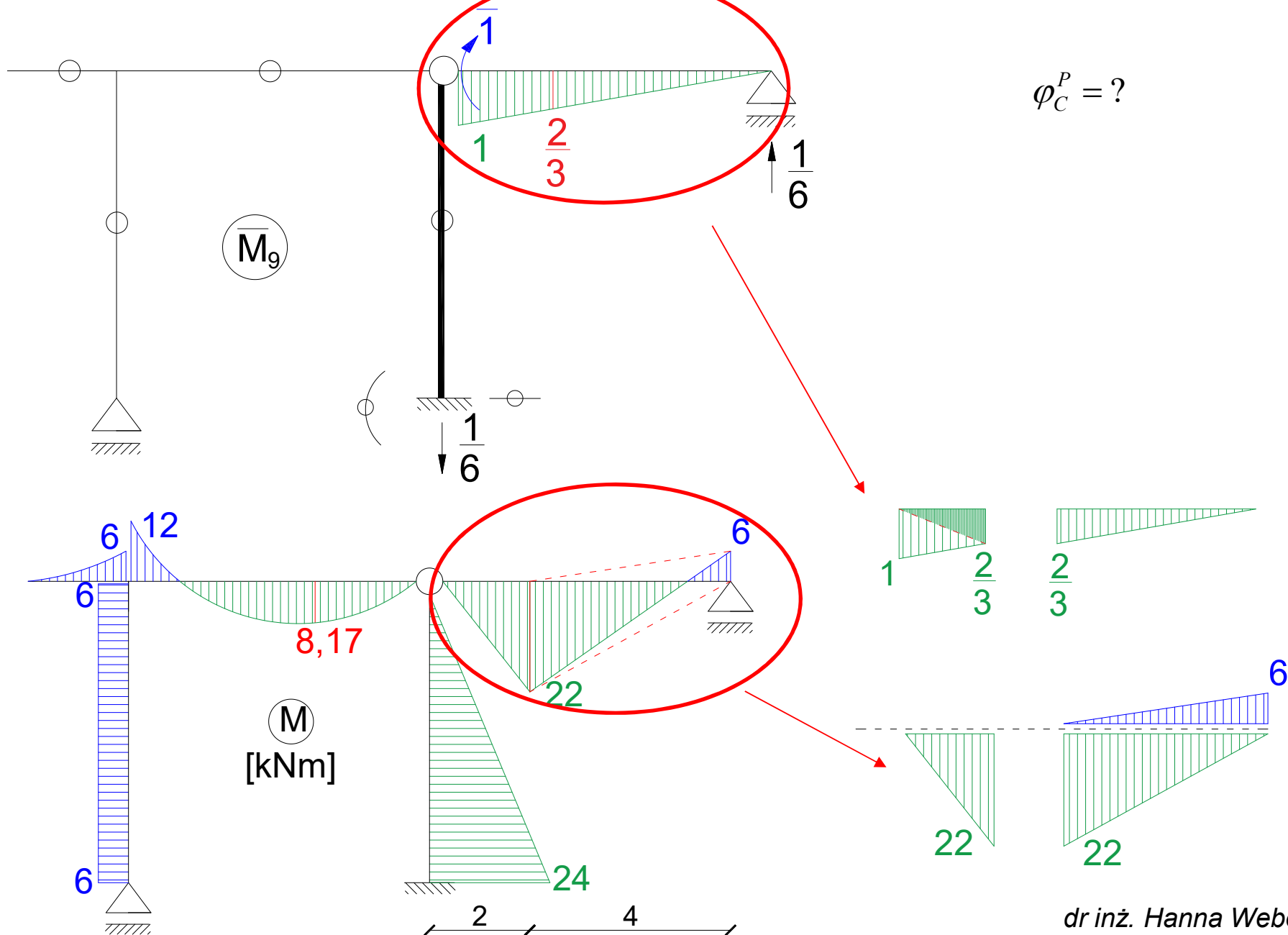
Obliczenia przemieszczeń z zasady prac wirtualnych:



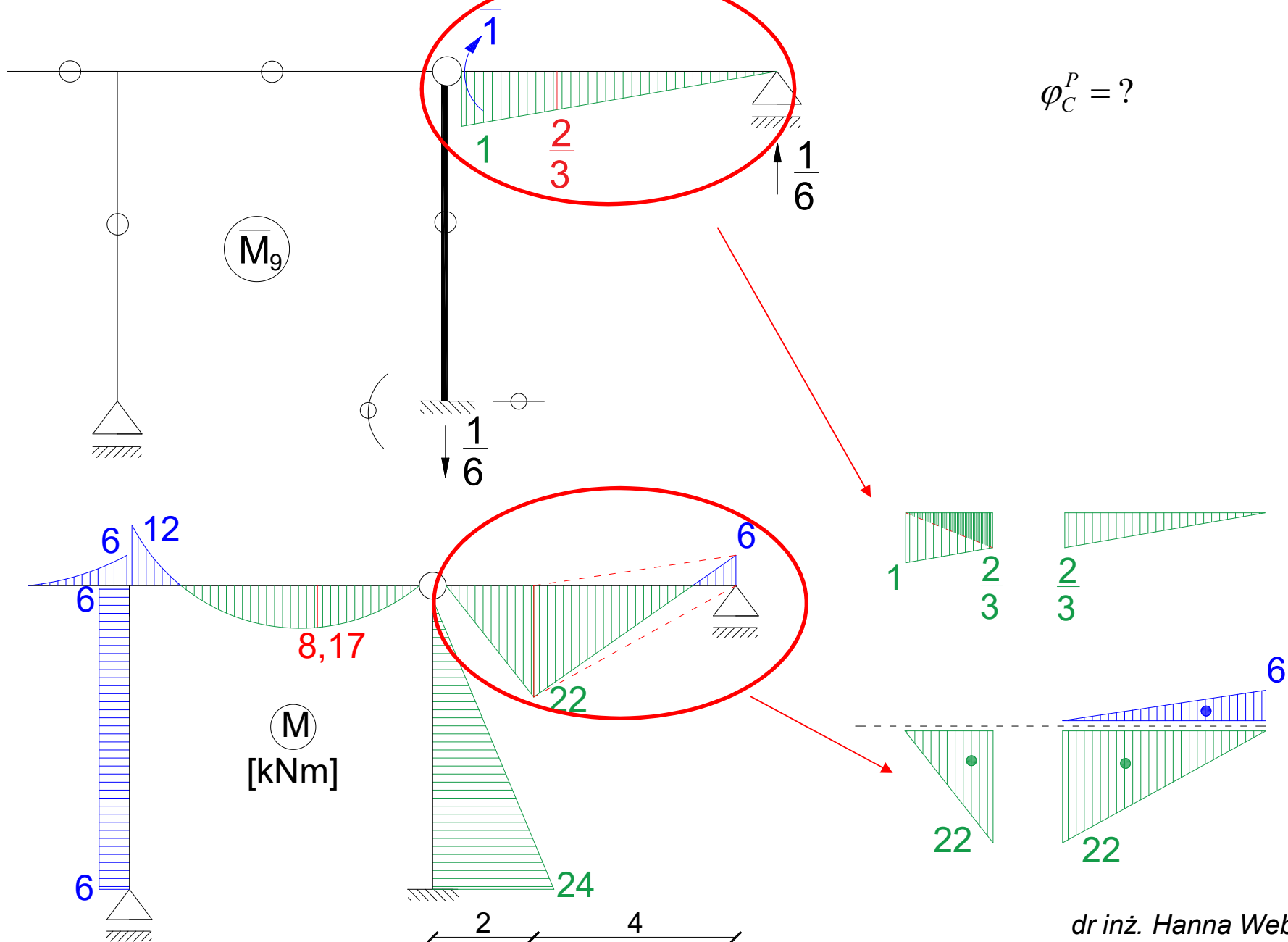
Obliczenia przemieszczeń z zasady prac wirtualnych:



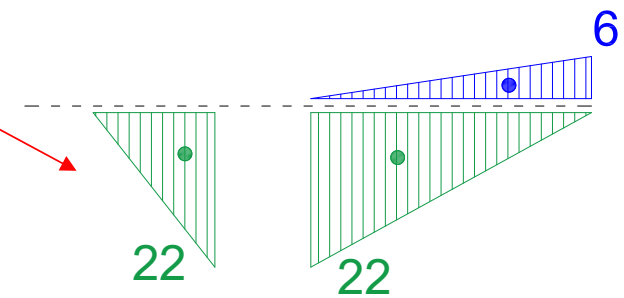
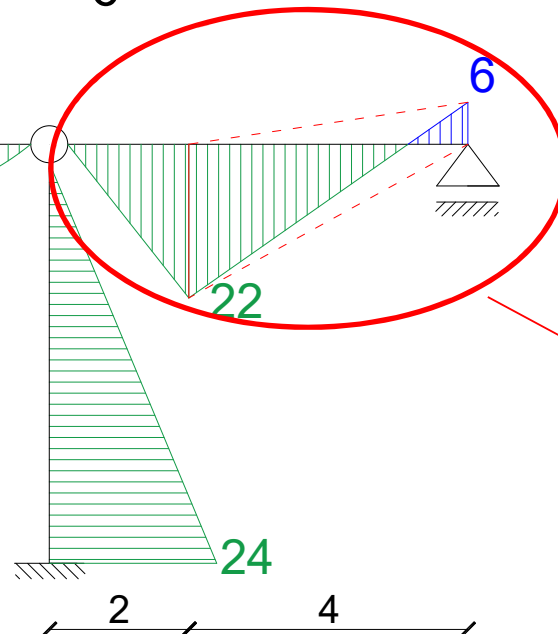
Obliczenia przemieszczeń z zasady prac wirtualnych:



Obliczenia przemieszczeń z zasady prac wirtualnych:

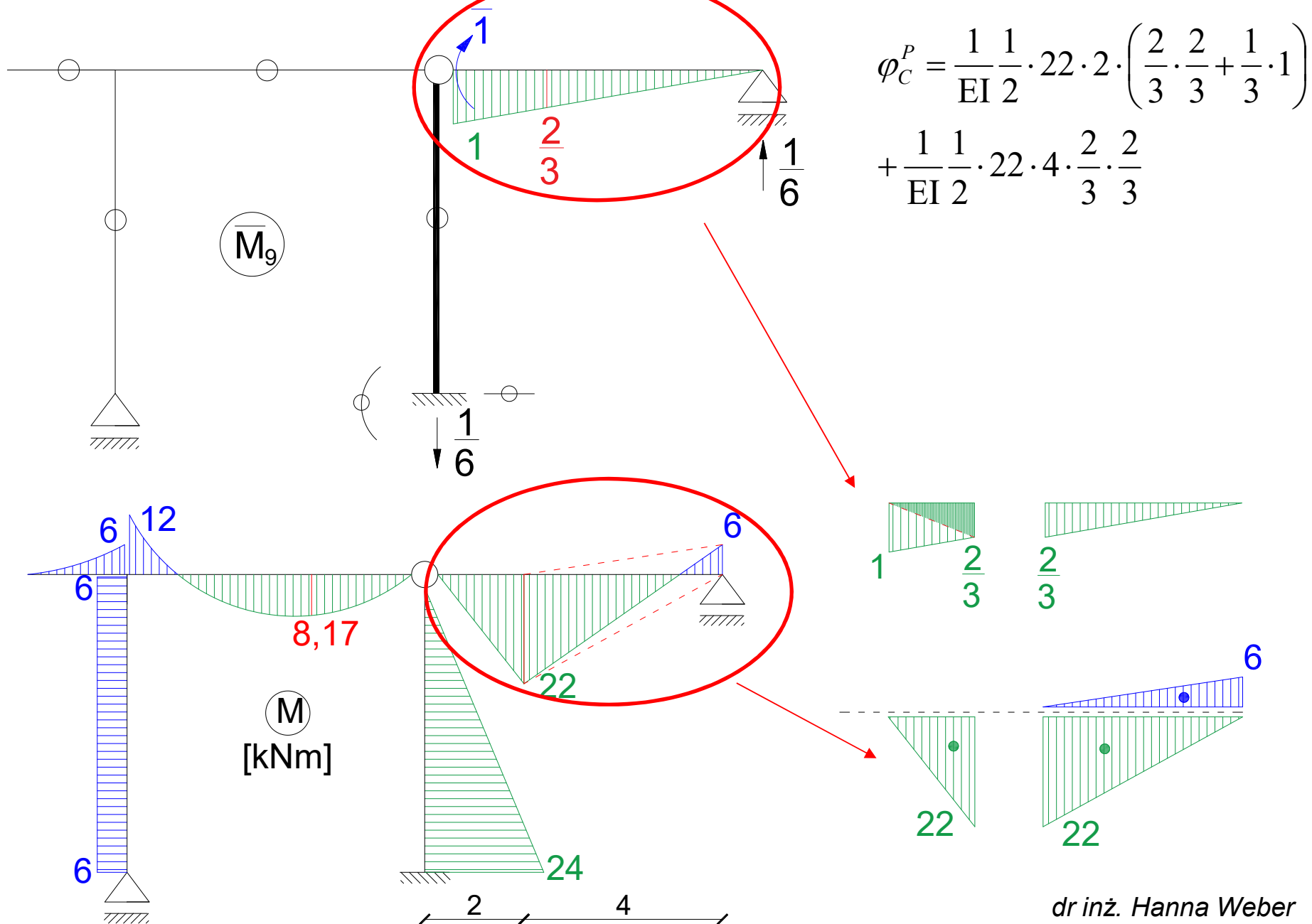


A diagram of a horizontal beam with three supports. The left support is a pin support. The middle support is a roller support. The right support is a roller support. A triangular load is applied to the beam, starting at zero at the middle support and increasing linearly to a peak at the right support. The load is represented by a green shaded area with vertical lines. A red circle highlights the triangular load area. A blue arrow labeled '1' points to the peak of the load. A green arrow labeled '1' points to the base of the load. A red arrow labeled '2' points to the peak of the load. A red arrow labeled '3' points to the base of the load. A black arrow labeled '1/6' points to the right support.

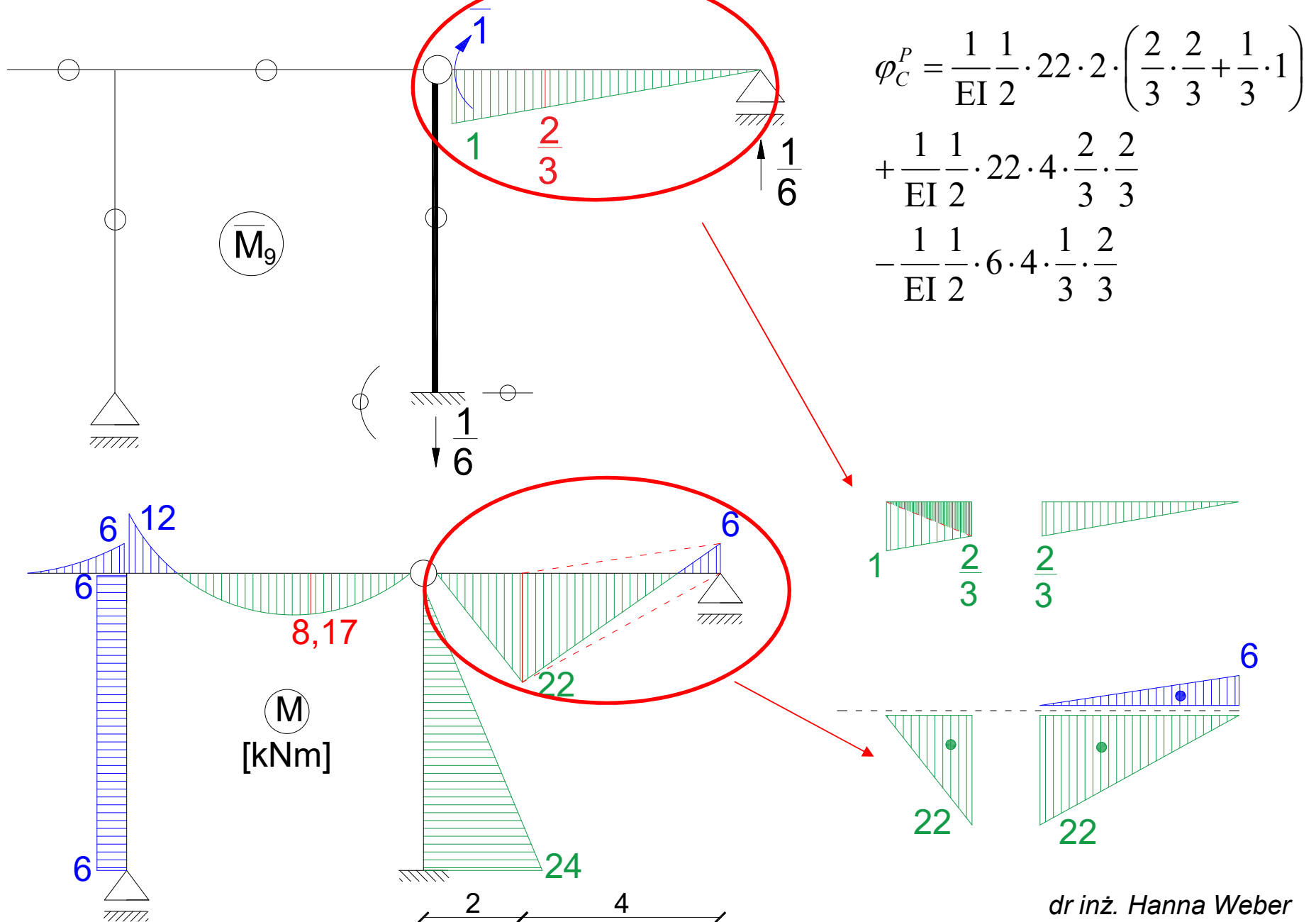


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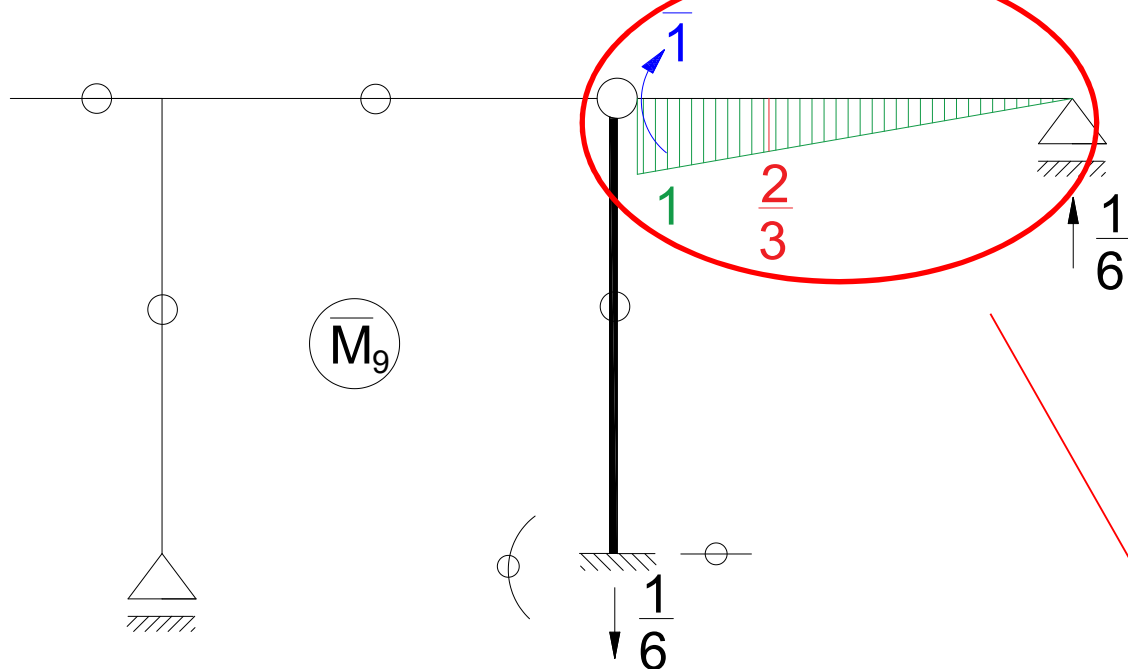
Obliczenia przemieszczeń z zasady prac wirtualnych:



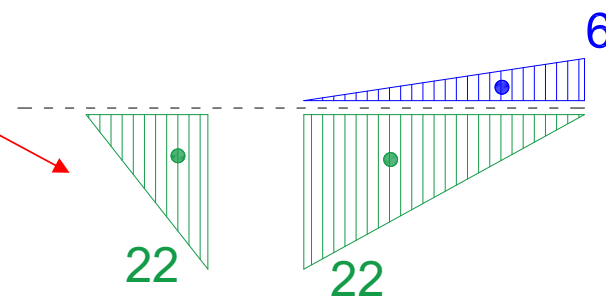
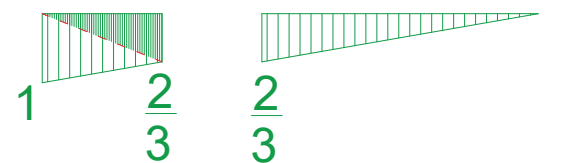
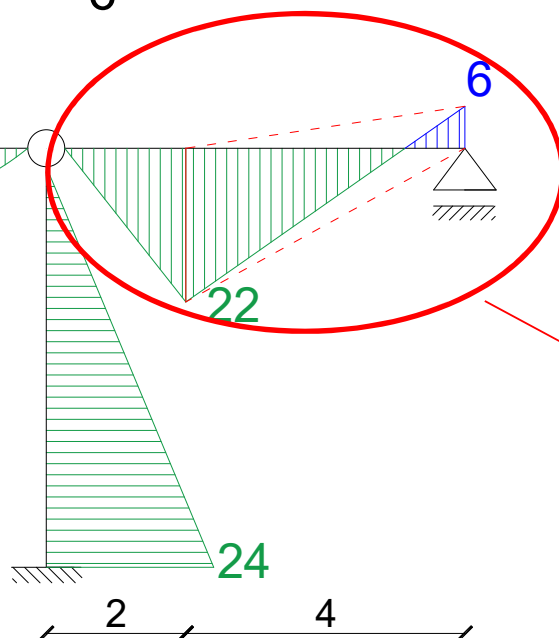
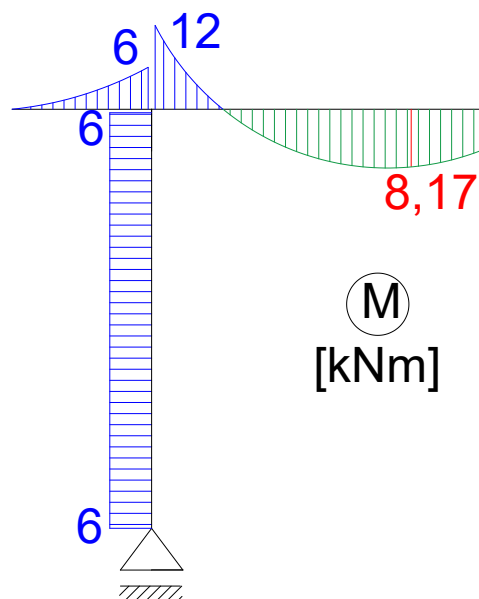
Obliczenia przemieszczeń z zasady prac wirtualnych:



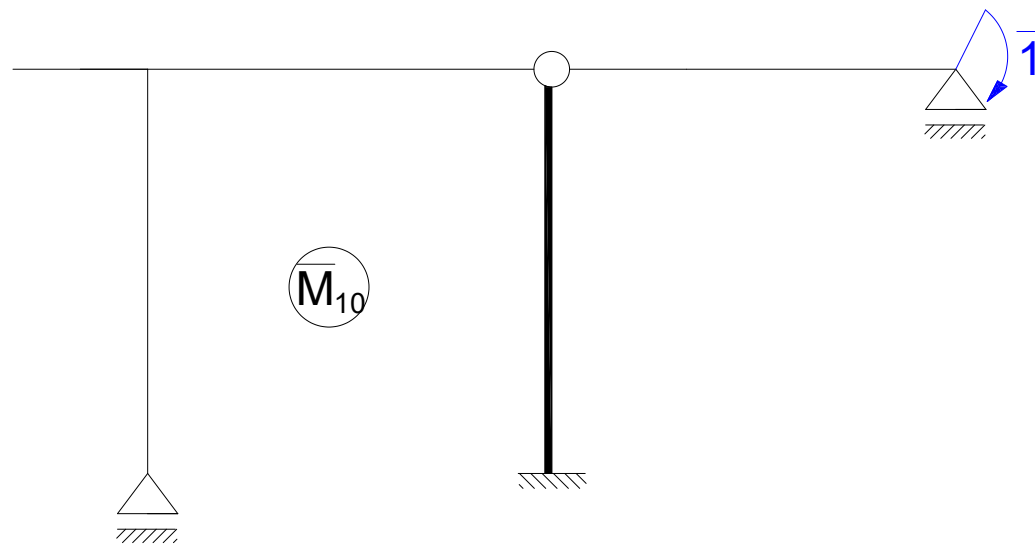
Obliczenia przemieszczeń z zasady prac wirtualnych:



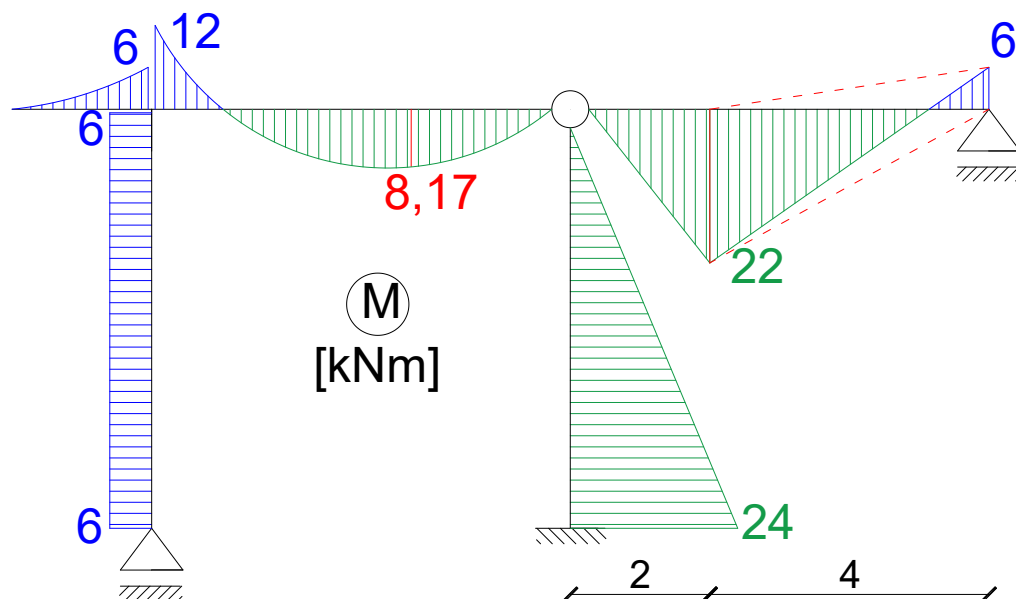
$$\begin{aligned}\varphi_C^P &= \frac{1}{EI} \frac{1}{2} \cdot 22 \cdot 2 \cdot \left(\frac{2}{3} \cdot \frac{2}{3} + \frac{1}{3} \cdot 1 \right) \\ &+ \frac{1}{EI} \frac{1}{2} \cdot 22 \cdot 4 \cdot \frac{2}{3} \cdot \frac{2}{3} \\ &- \frac{1}{EI} \frac{1}{2} \cdot 6 \cdot 4 \cdot \frac{1}{3} \cdot \frac{2}{3} \\ &= \frac{34}{EI}\end{aligned}$$



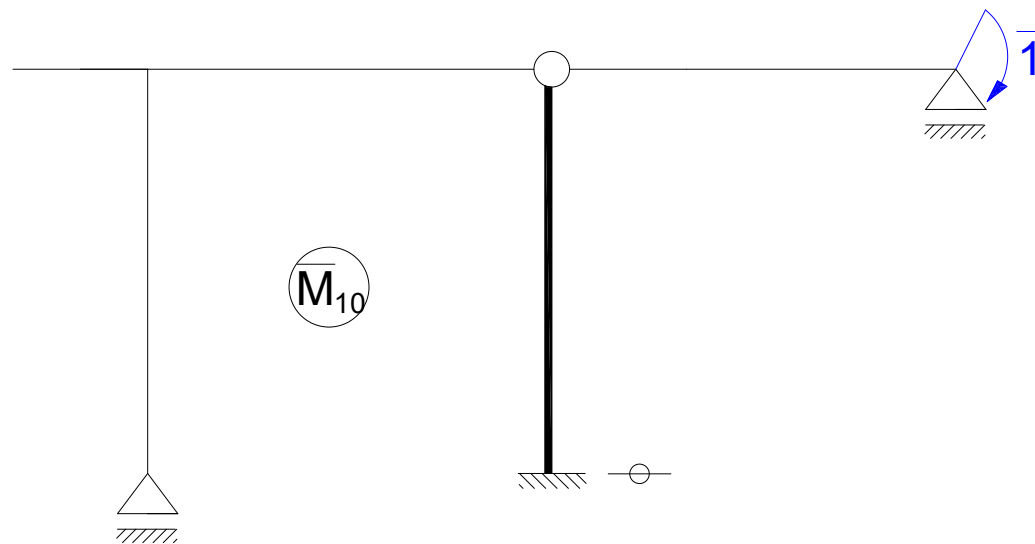
Obliczenia przemieszczeń z zasady prac wirtualnych:



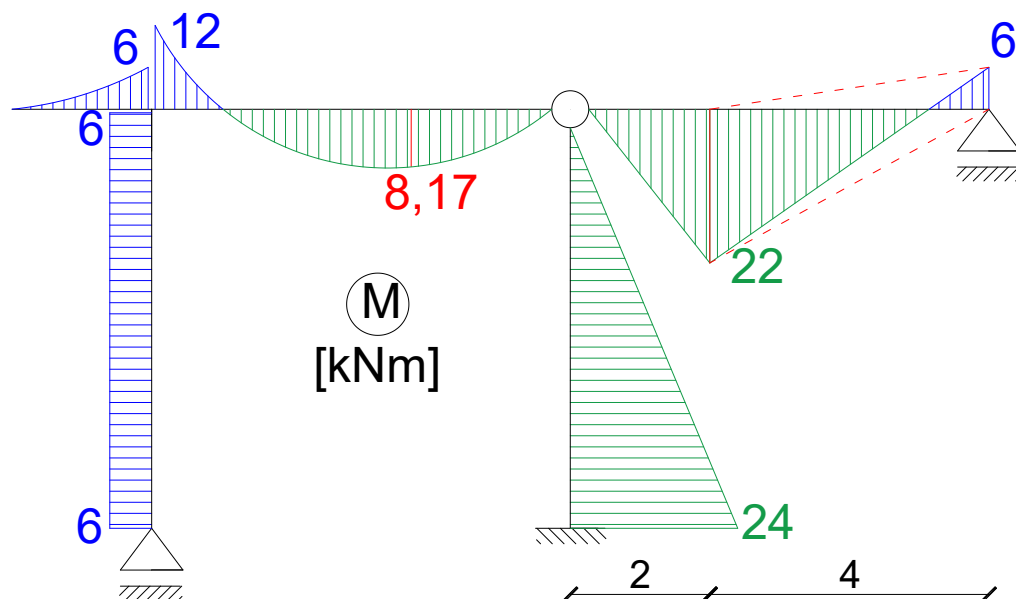
$$\varphi_D = ?$$



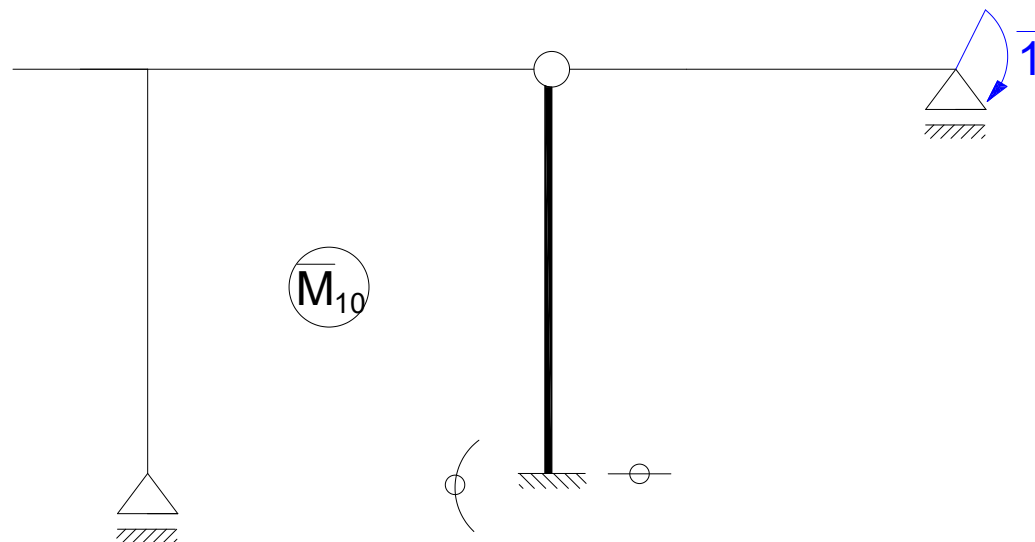
Obliczenia przemieszczeń z zasady prac wirtualnych:



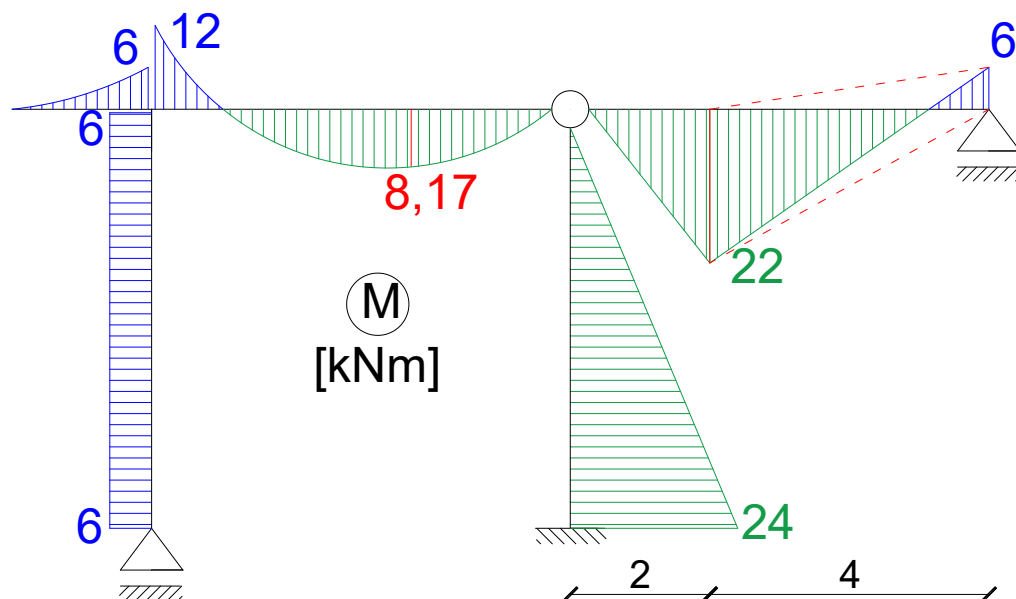
$$\varphi_D = ?$$



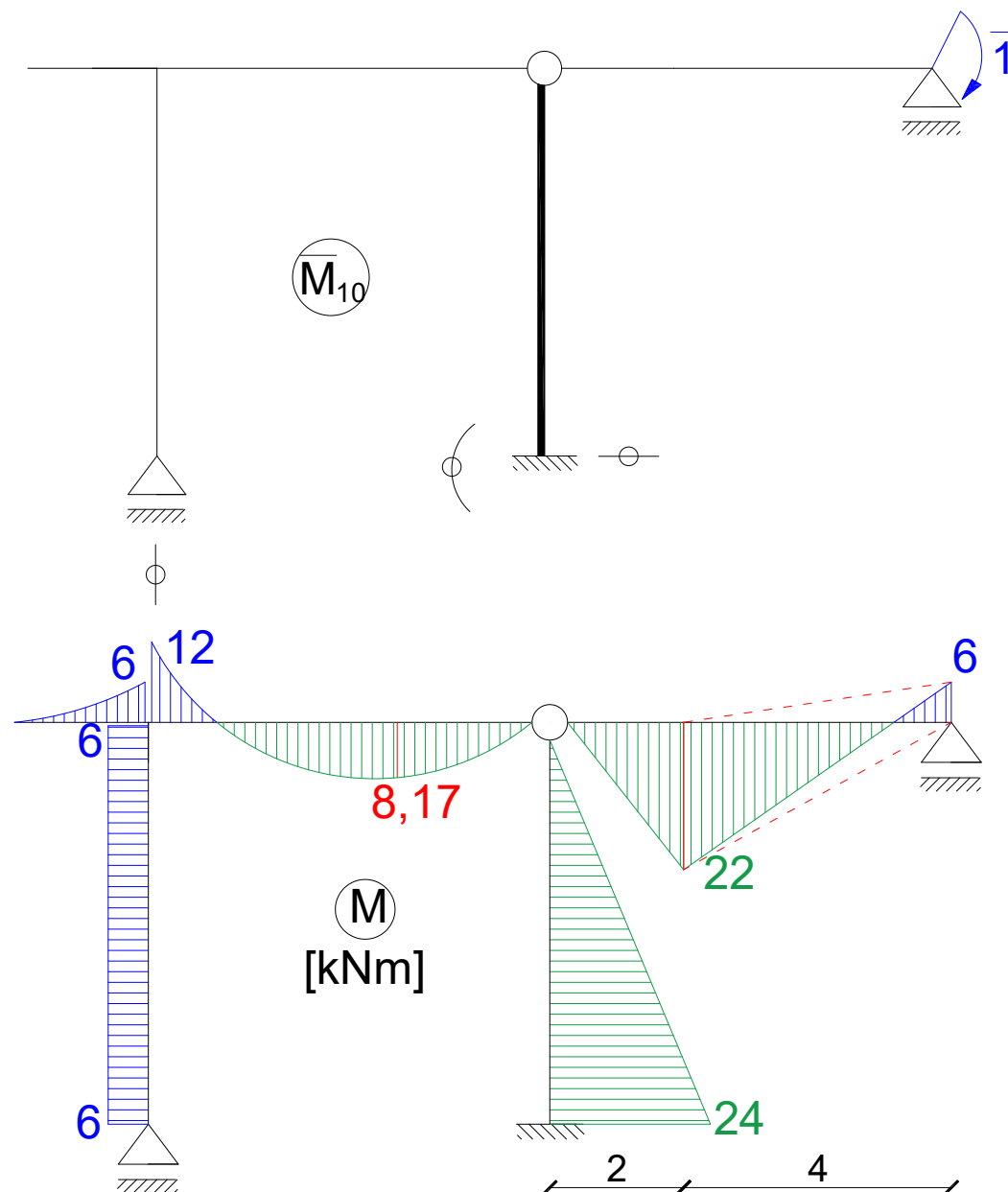
Obliczenia przemieszczeń z zasady prac wirtualnych:



$$\varphi_D = ?$$

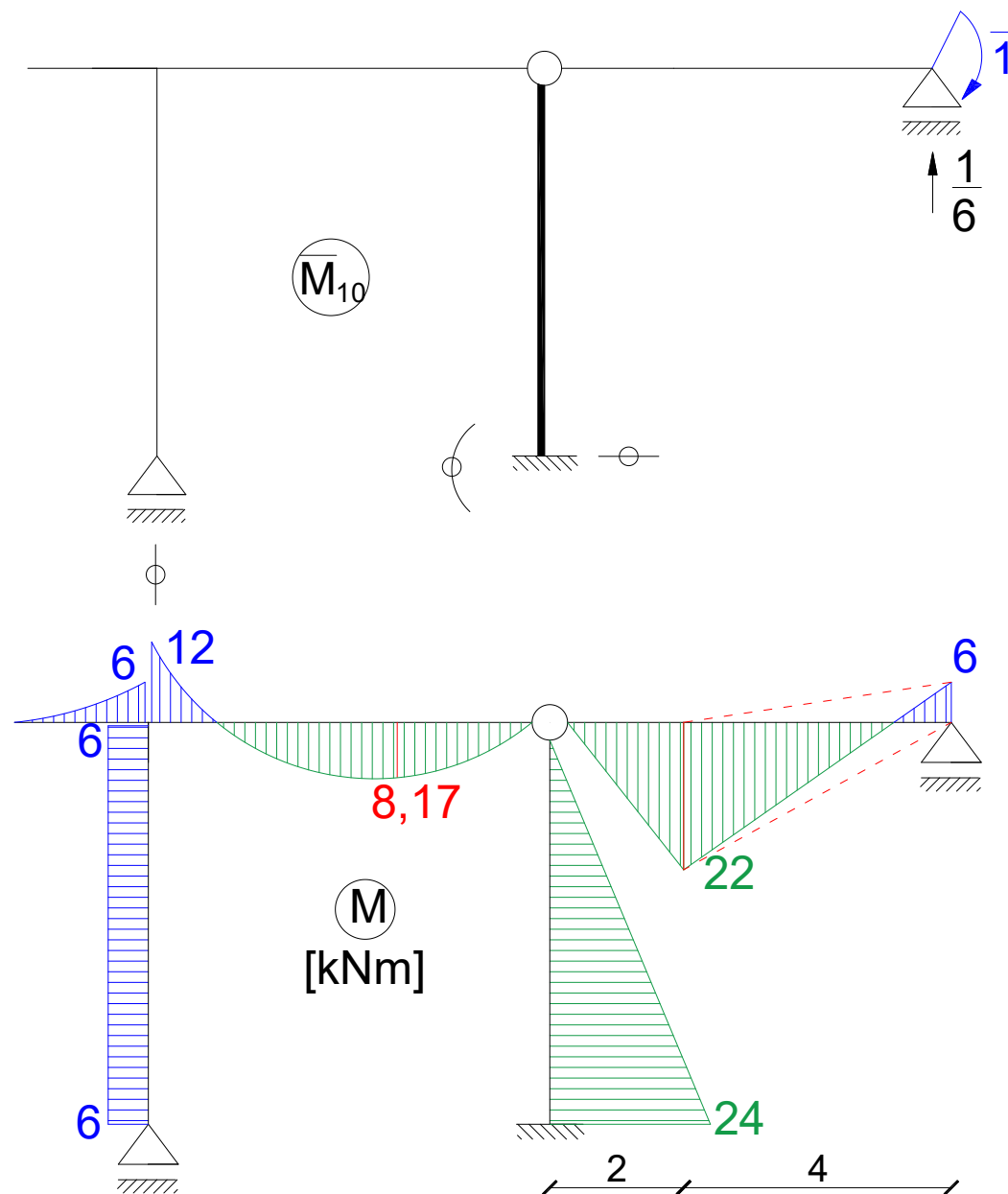


Obliczenia przemieszczeń z zasady prac wirtualnych:



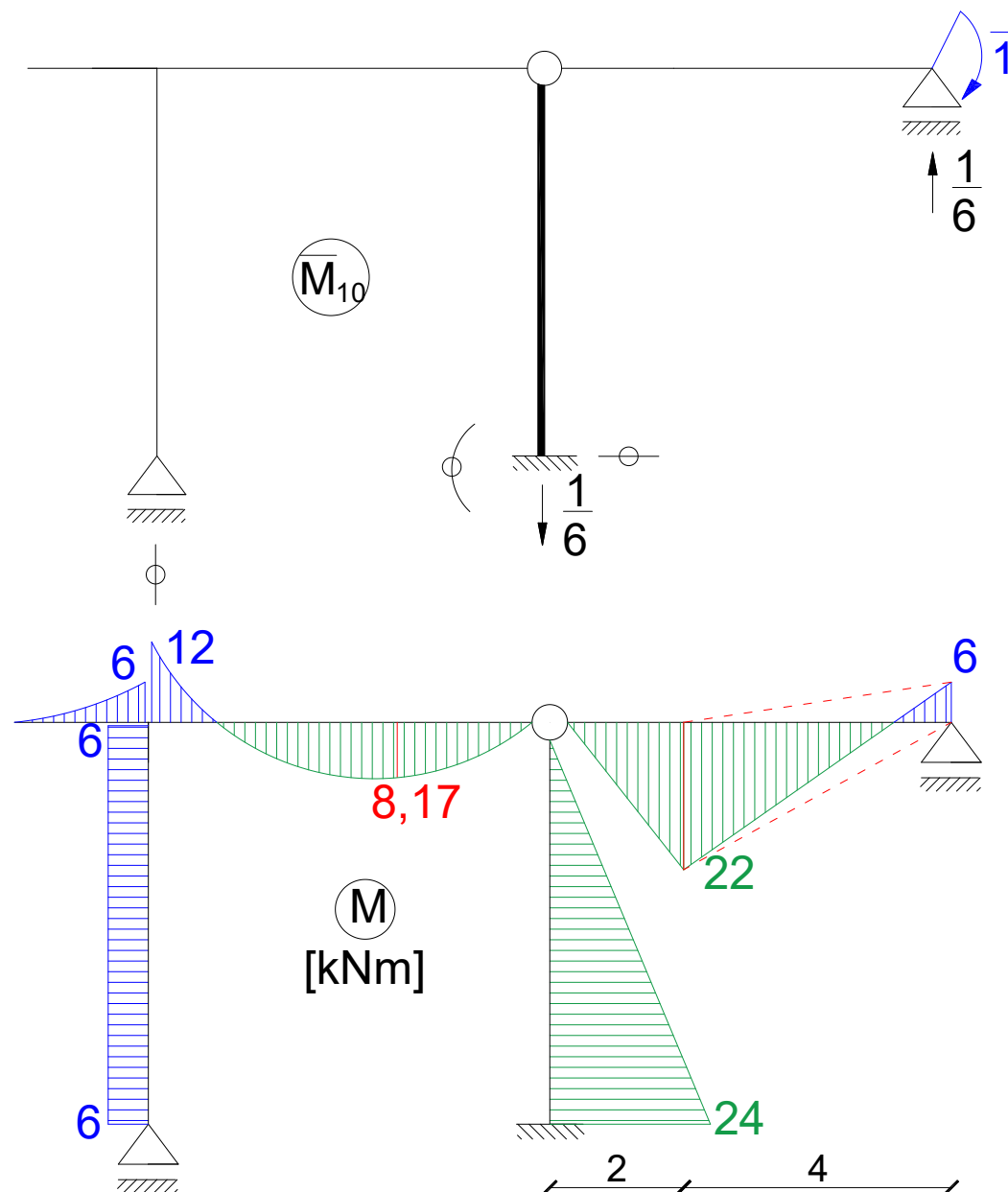
$$\varphi_D = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



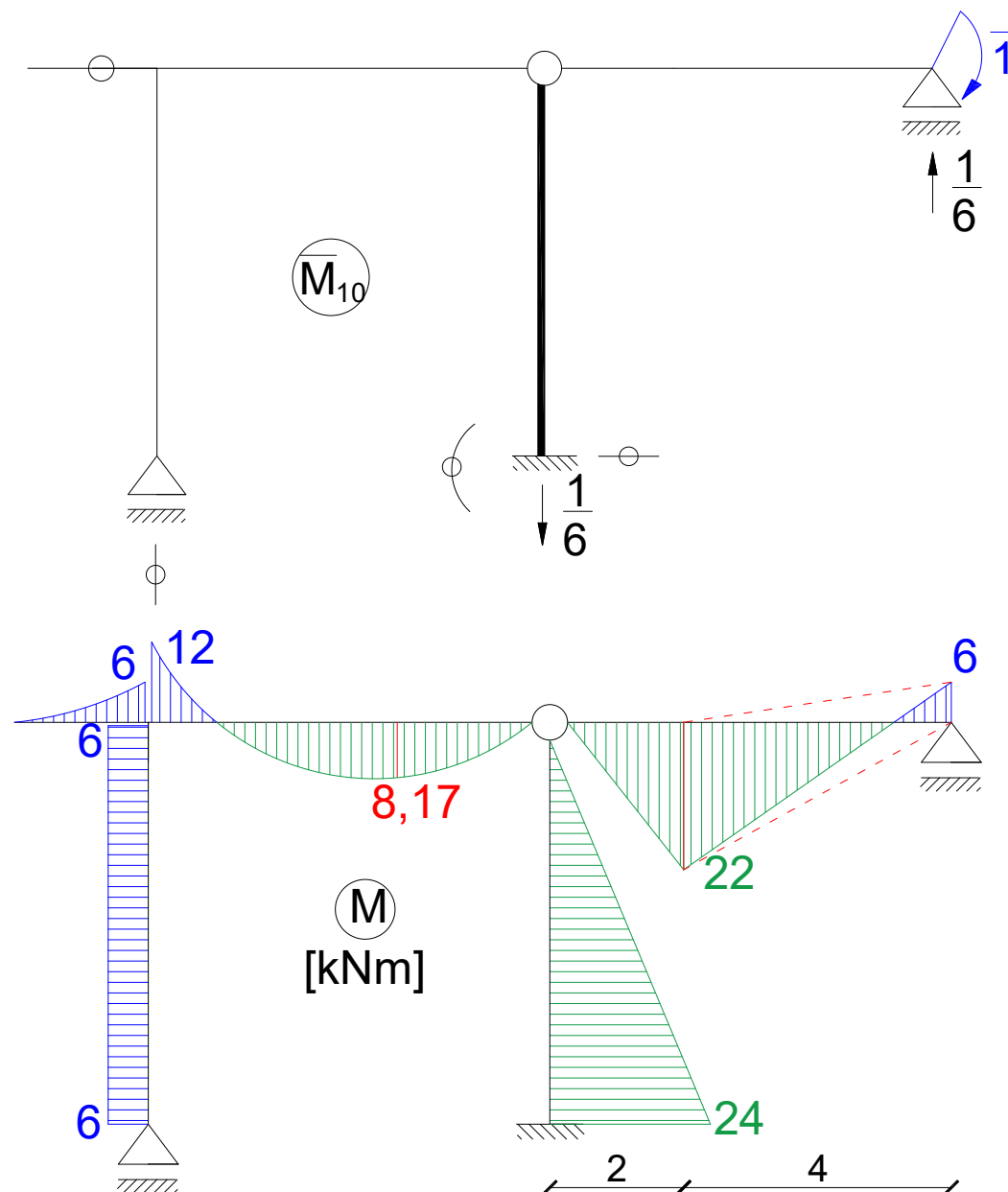
$$\varphi_D = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



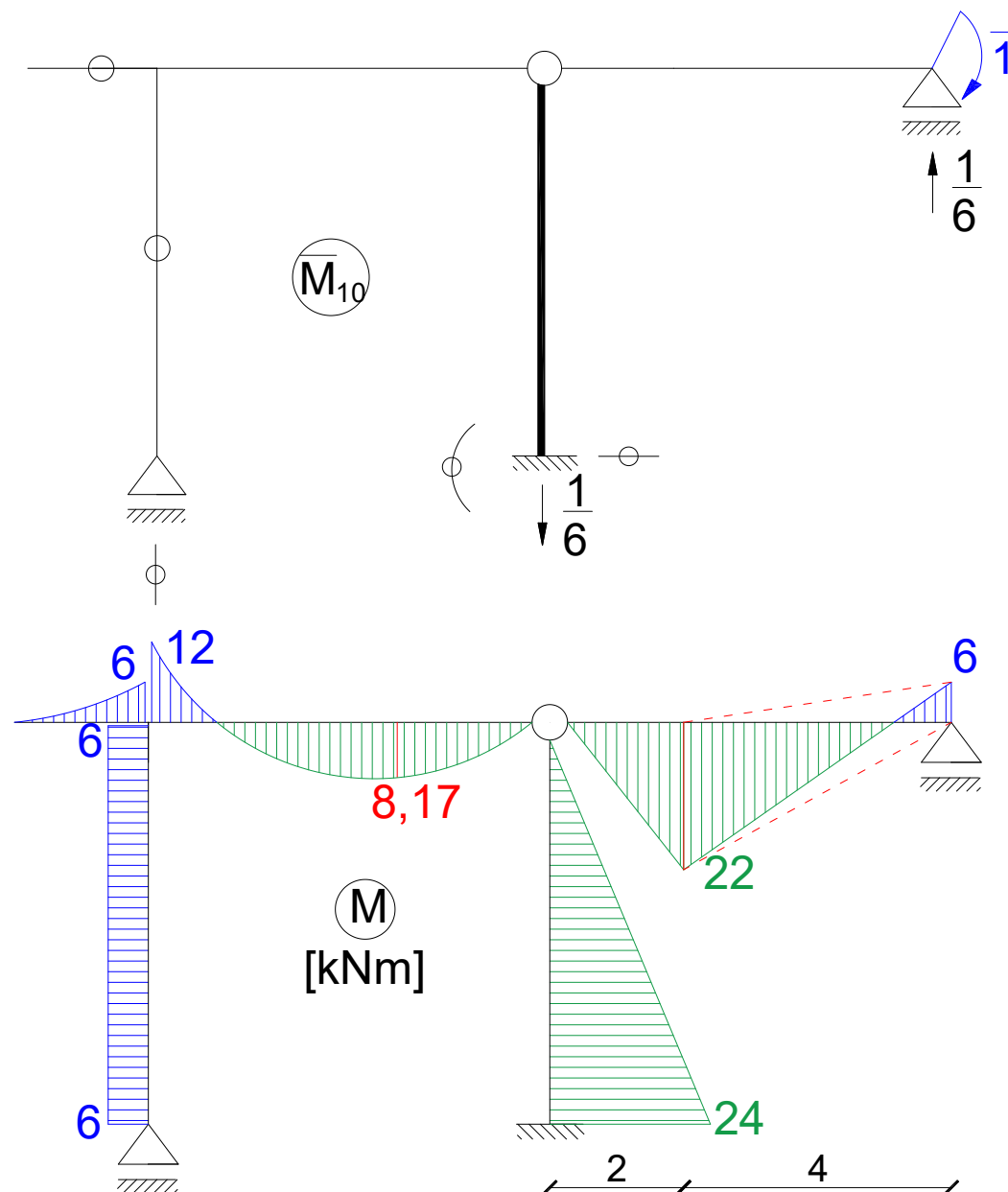
$$\varphi_D = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



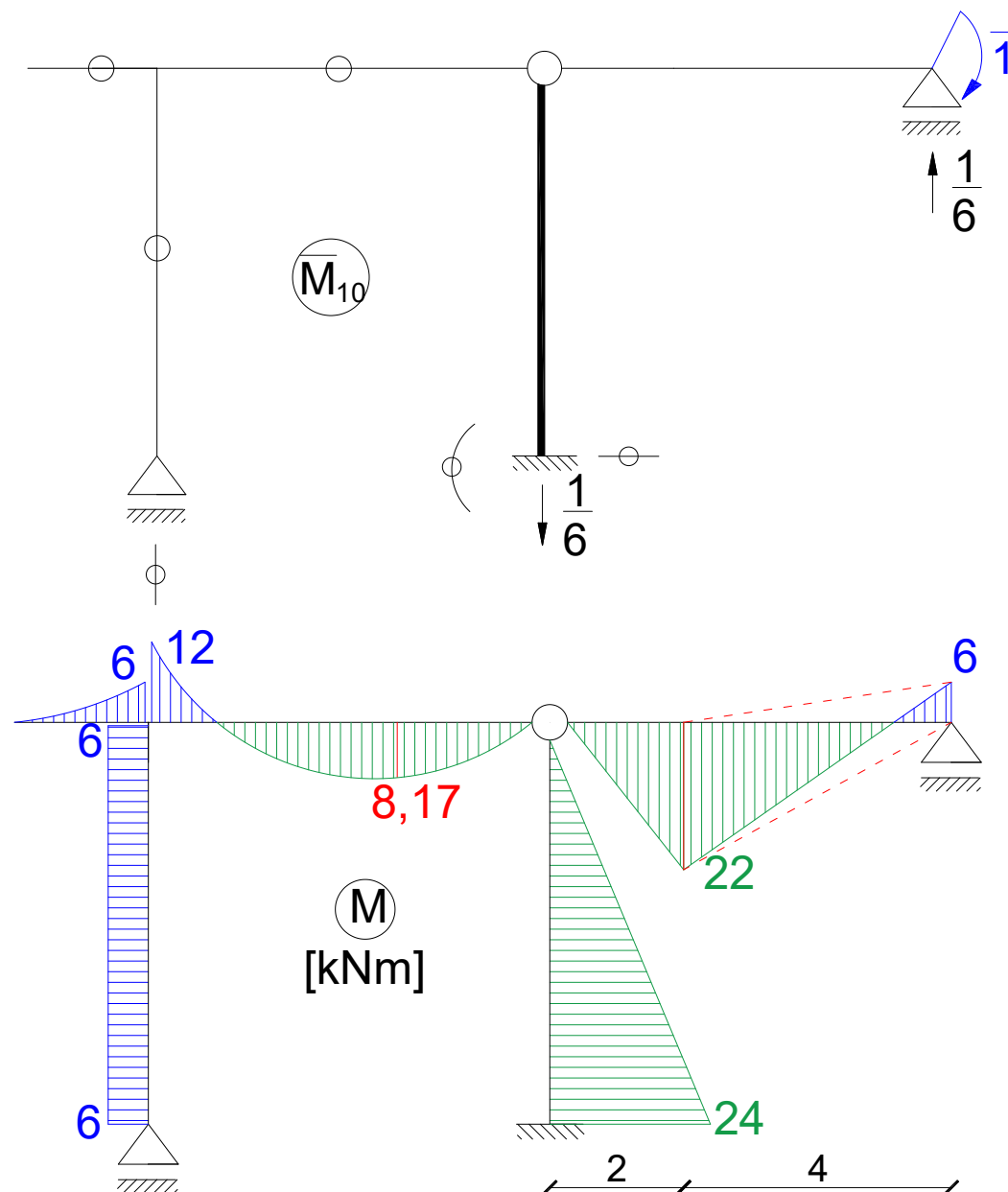
$$\varphi_D = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



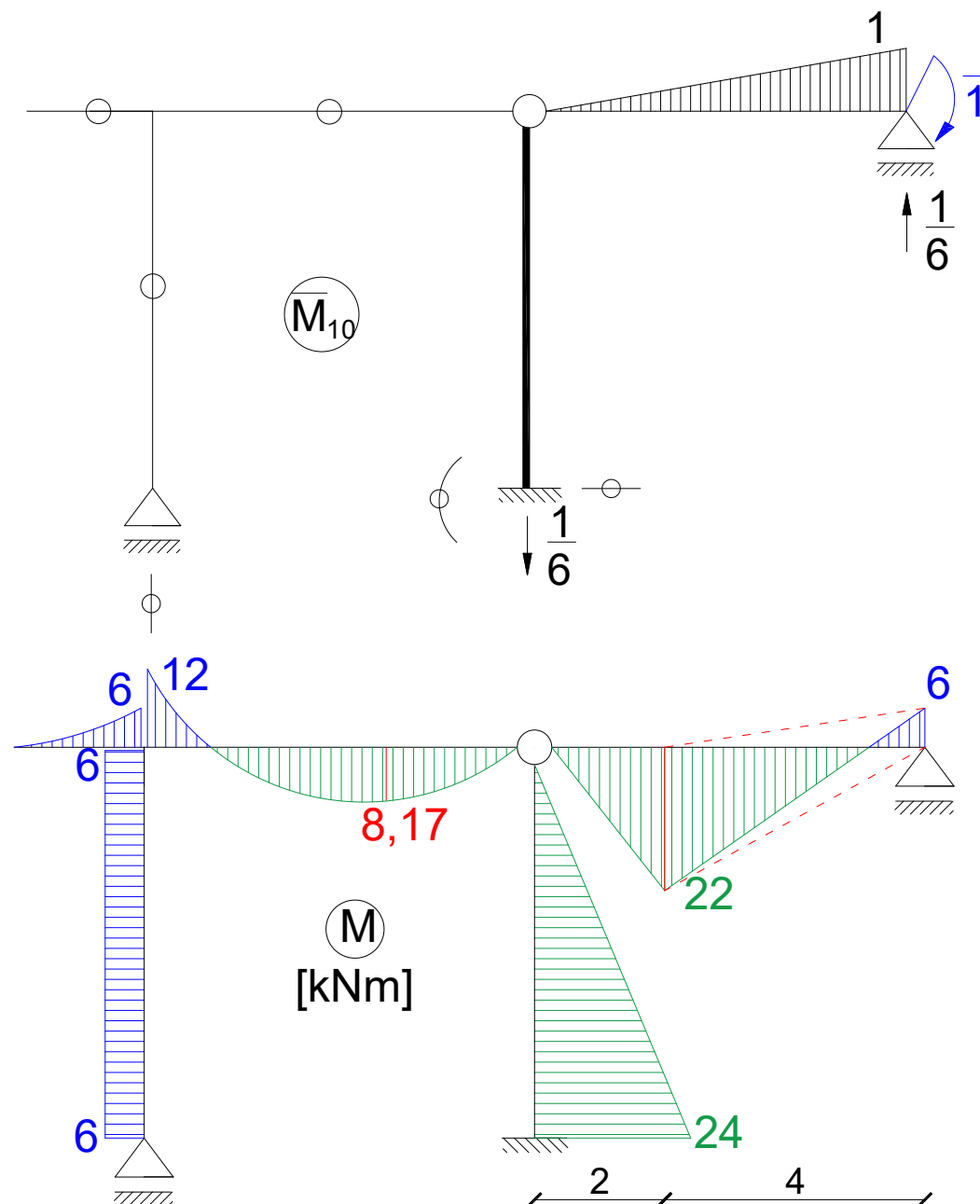
$$\varphi_D = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



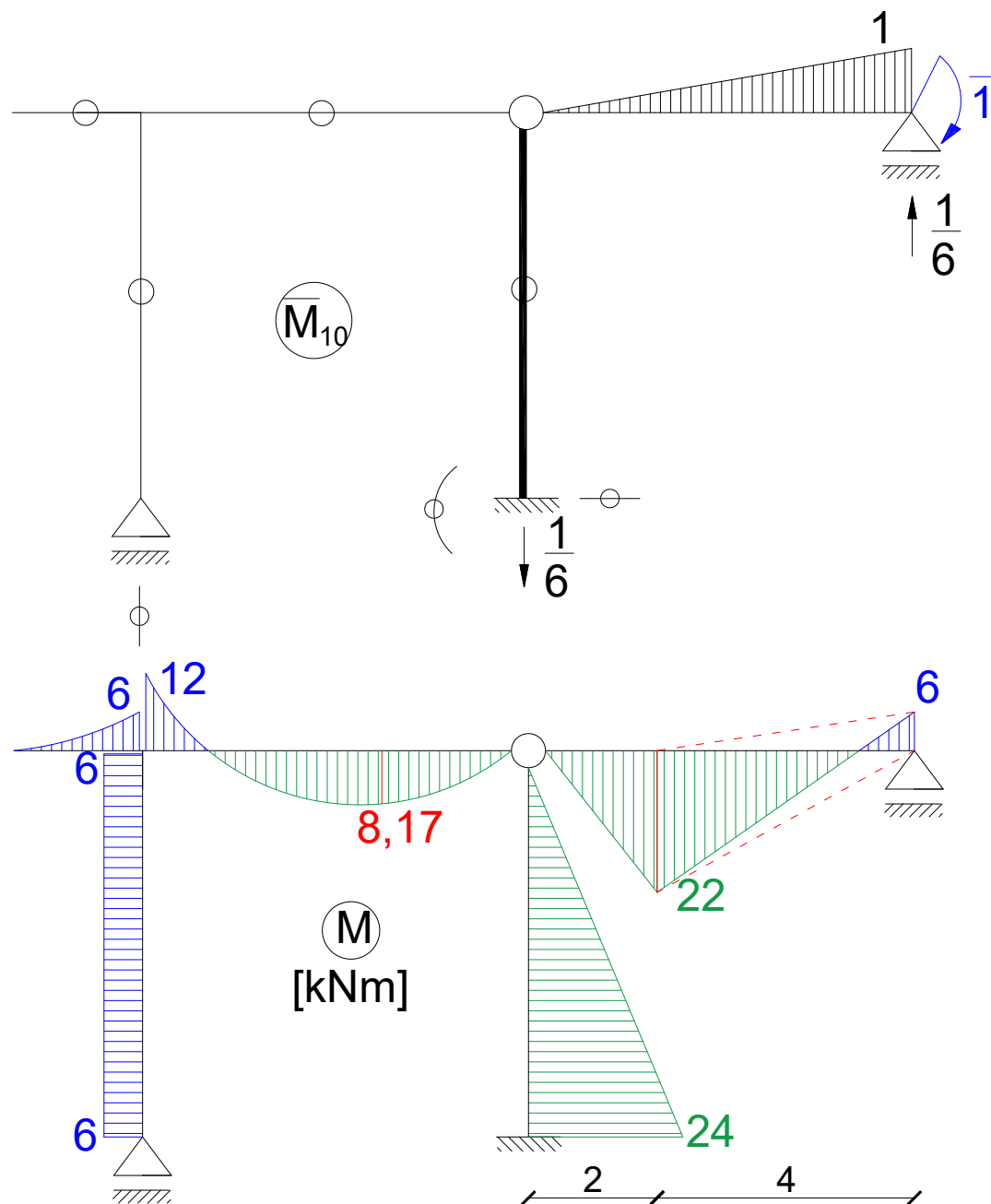
$$\varphi_D = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



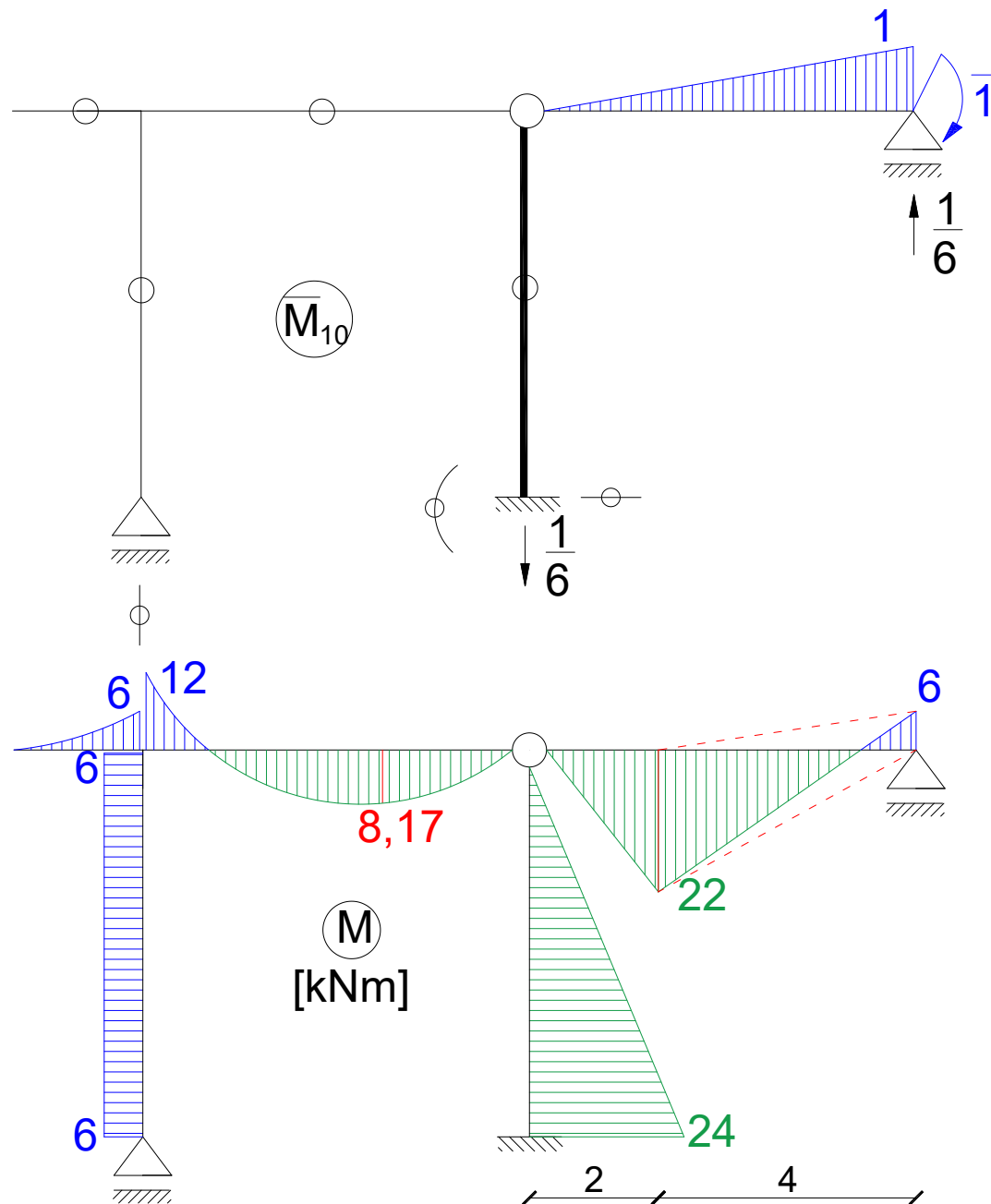
$$\varphi_D = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



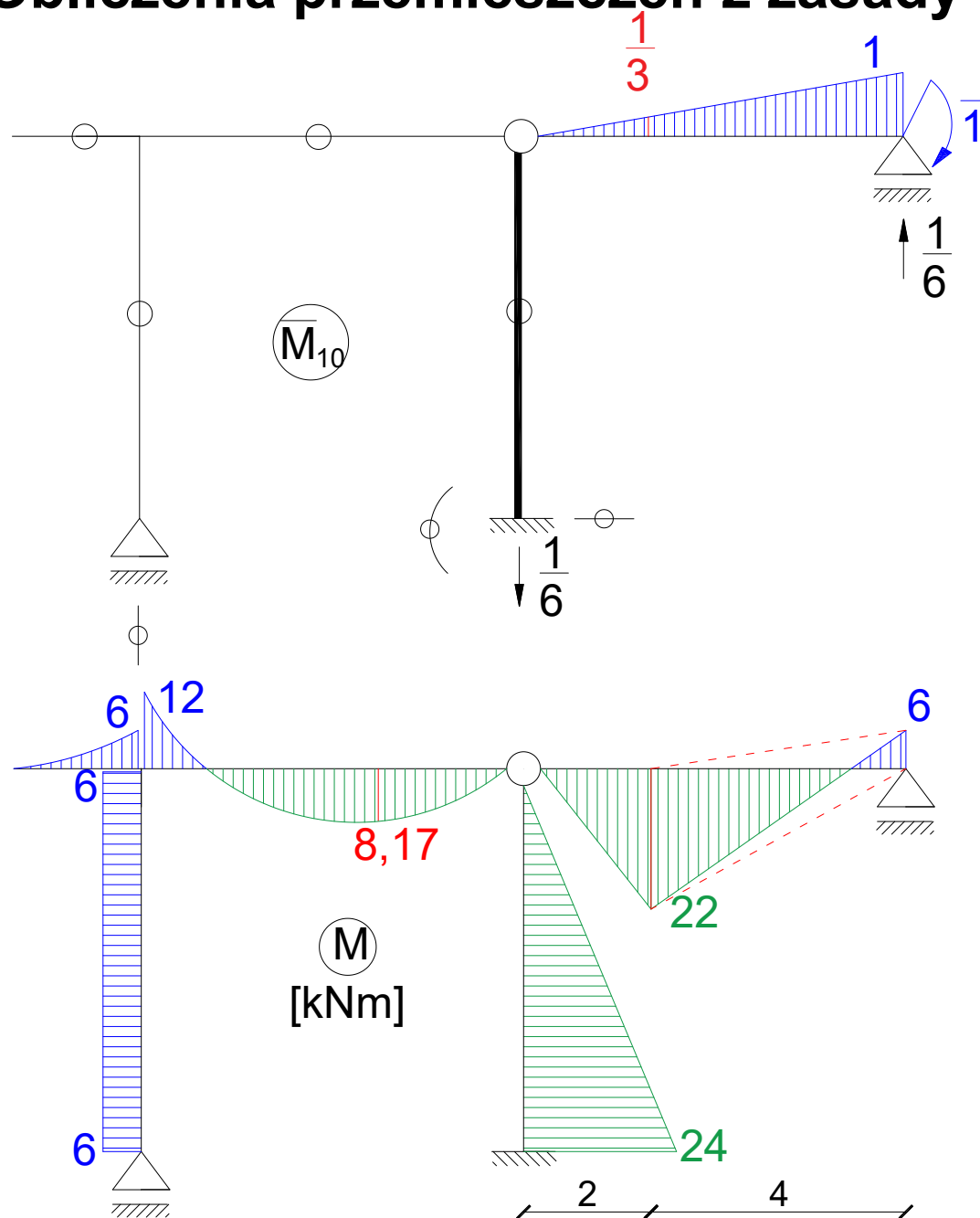
$$\varphi_D = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:



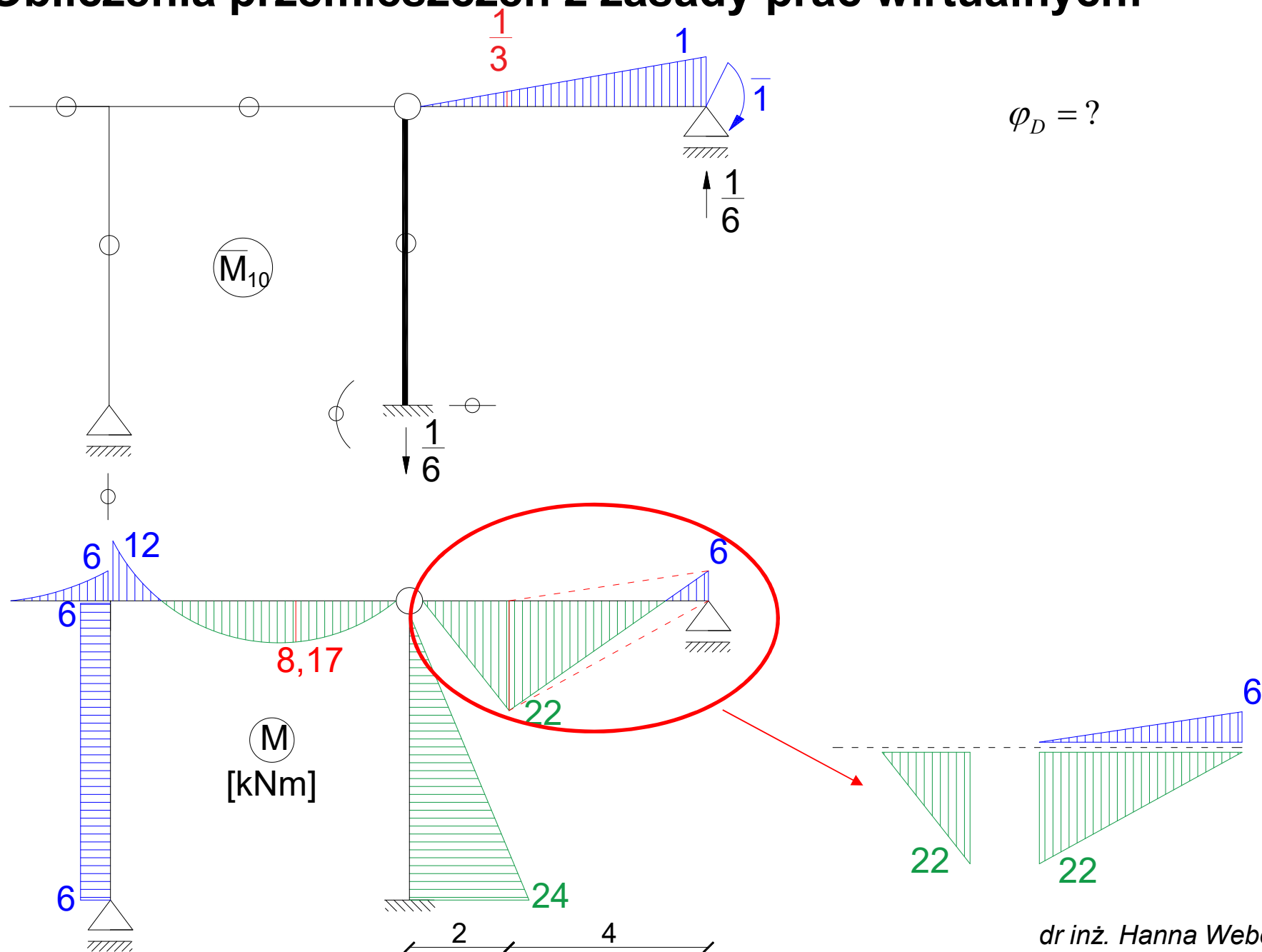
$$\varphi_D = ?$$

Obliczenia przemieszczeń z zasady prac wirtualnych:

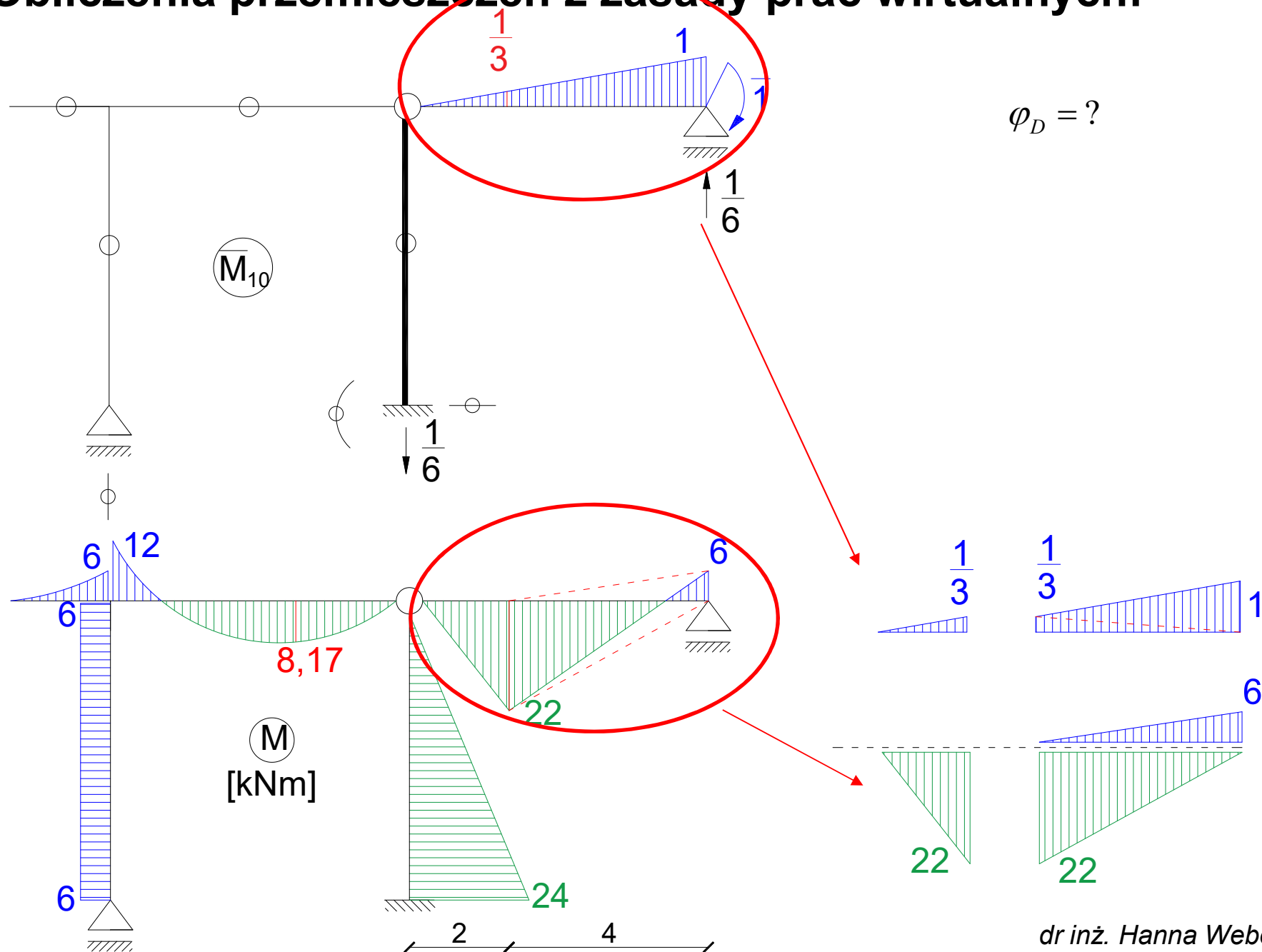


$$\varphi_D = ?$$

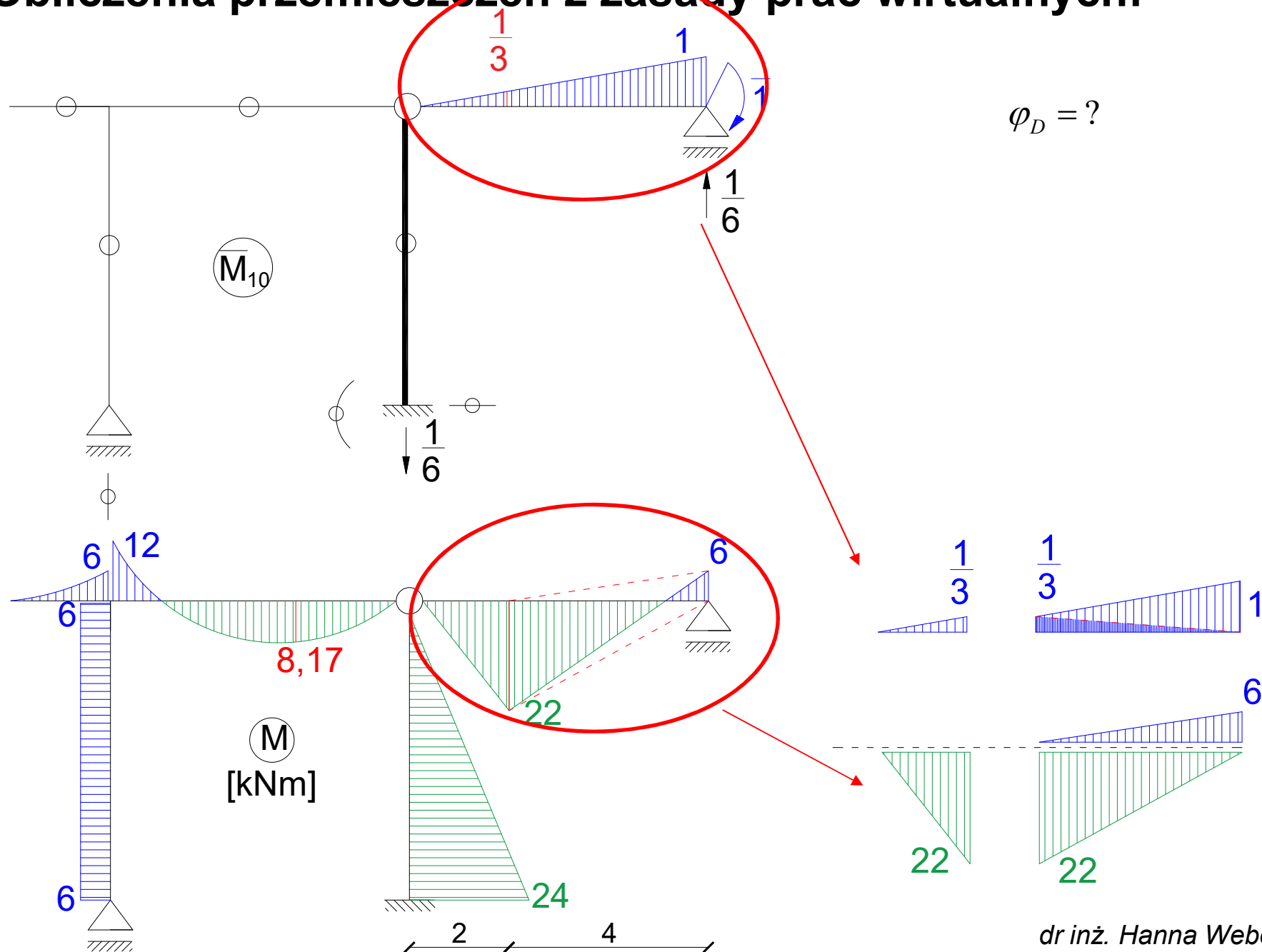
Obliczenia przemieszczeń z zasady prac wirtualnych:



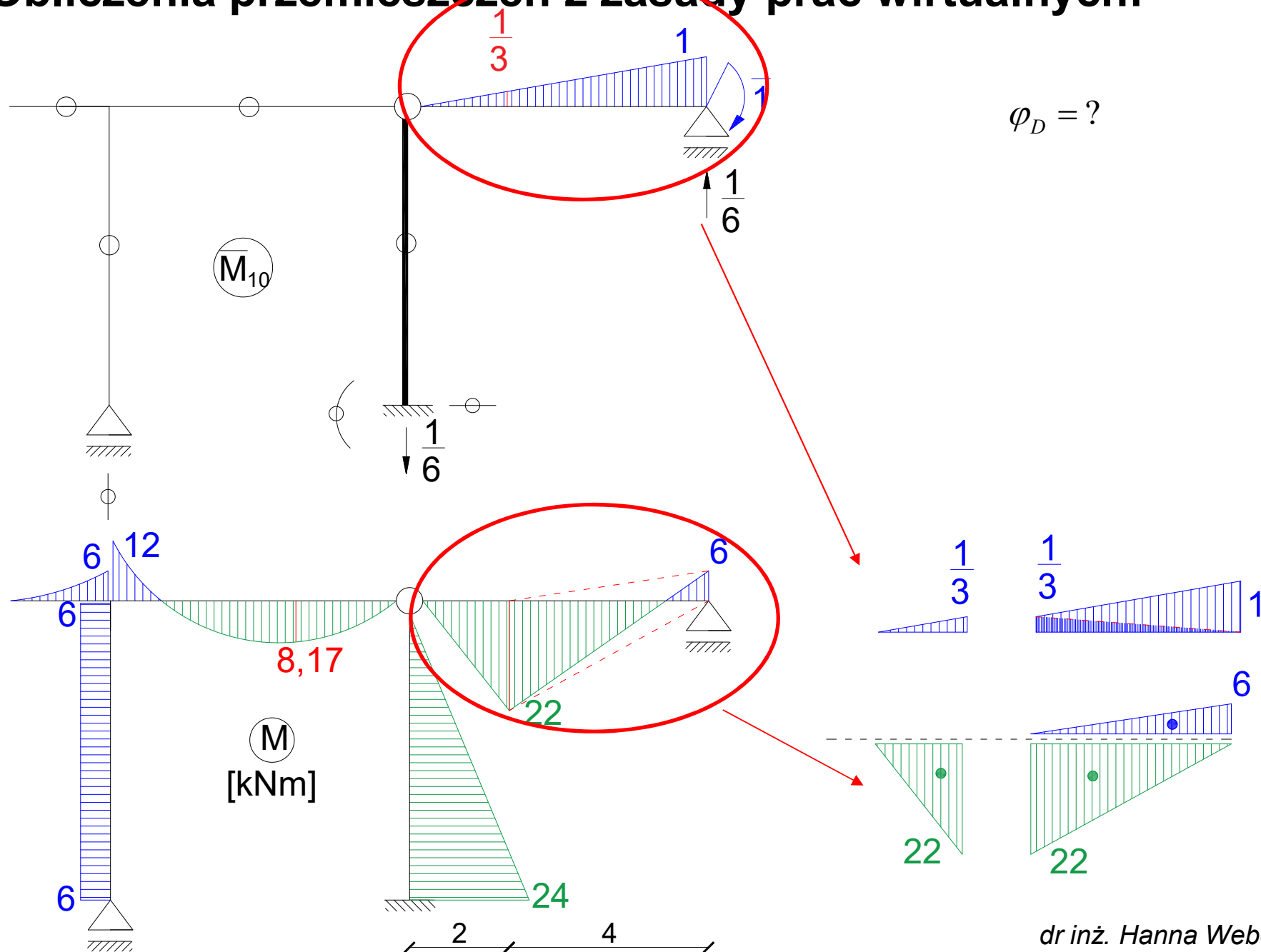
Obliczenia przemieszczeń z zasady prac wirtualnych:



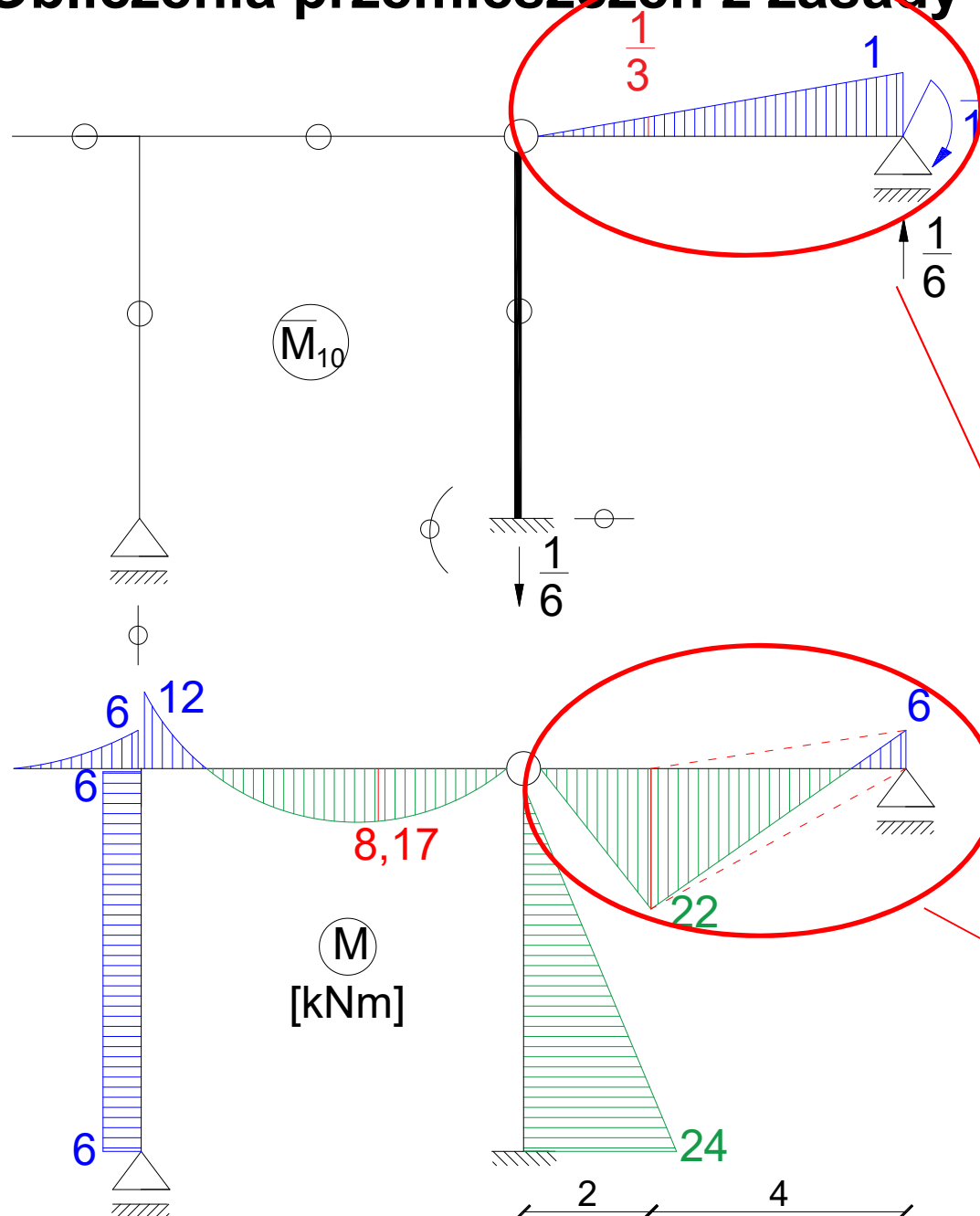
Obliczenia przemieszczeń z zasady prac wirtualnych:



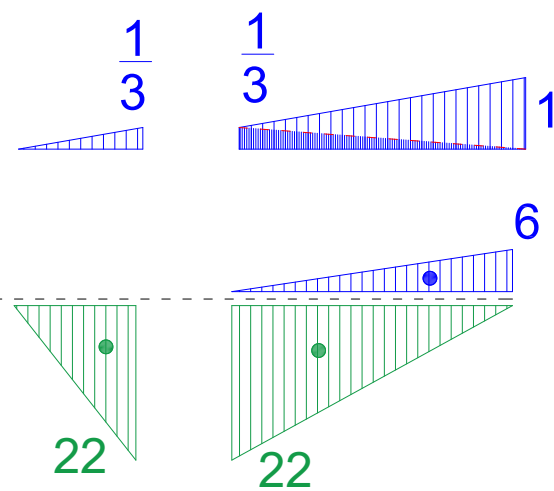
Obliczenia przemieszczeń z zasady prac wirtualnych:



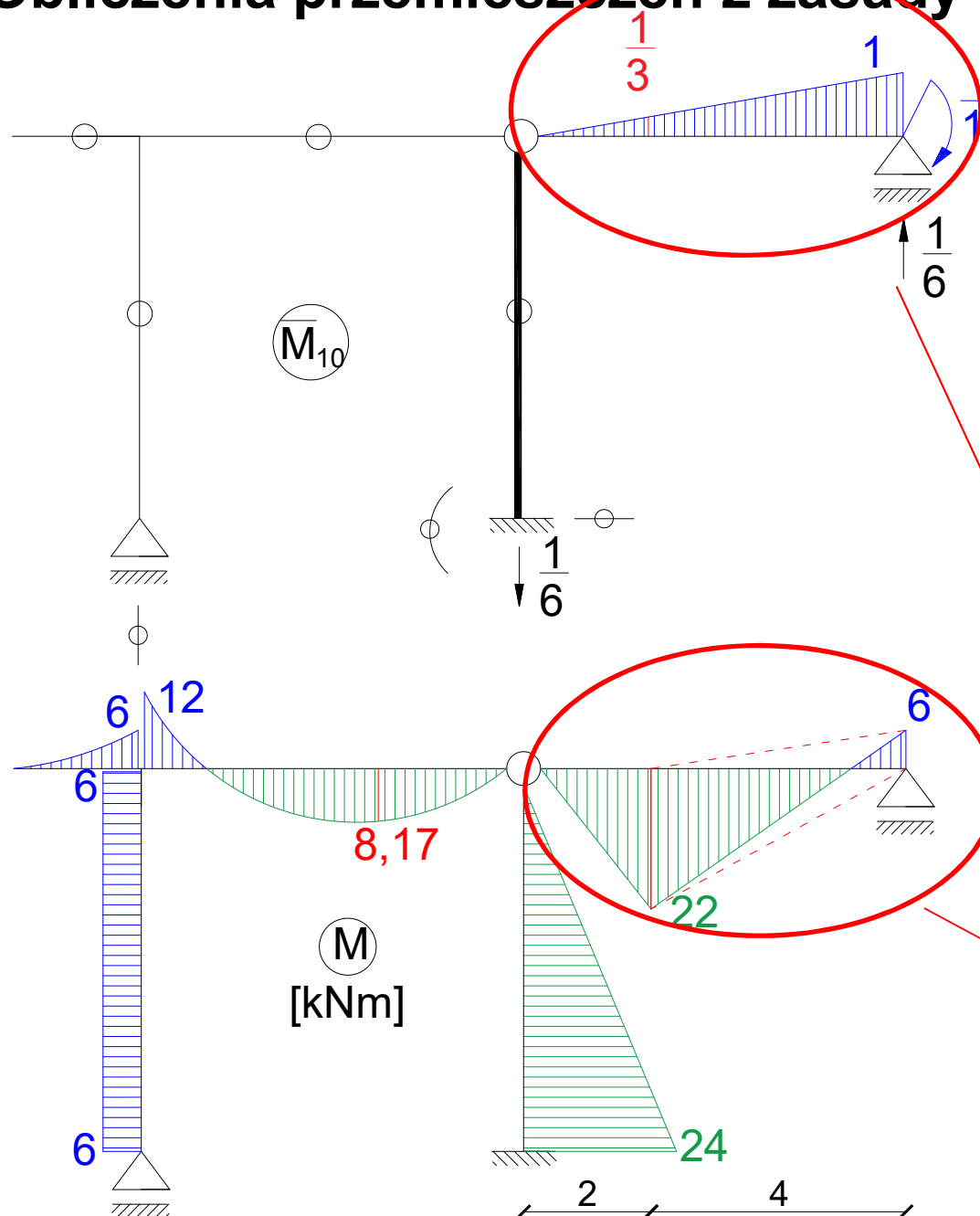
Obliczenia przemieszczeń z zasady prac wirtualnych:



$$\varphi_D = -\frac{1}{EI} \frac{1}{2} \cdot 22 \cdot 2 \cdot \frac{2}{3} \cdot \frac{1}{3}$$

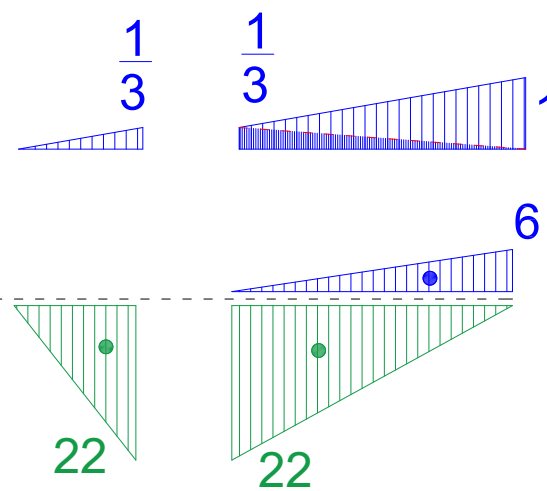


Obliczenia przemieszczeń z zasady prac wirtualnych:

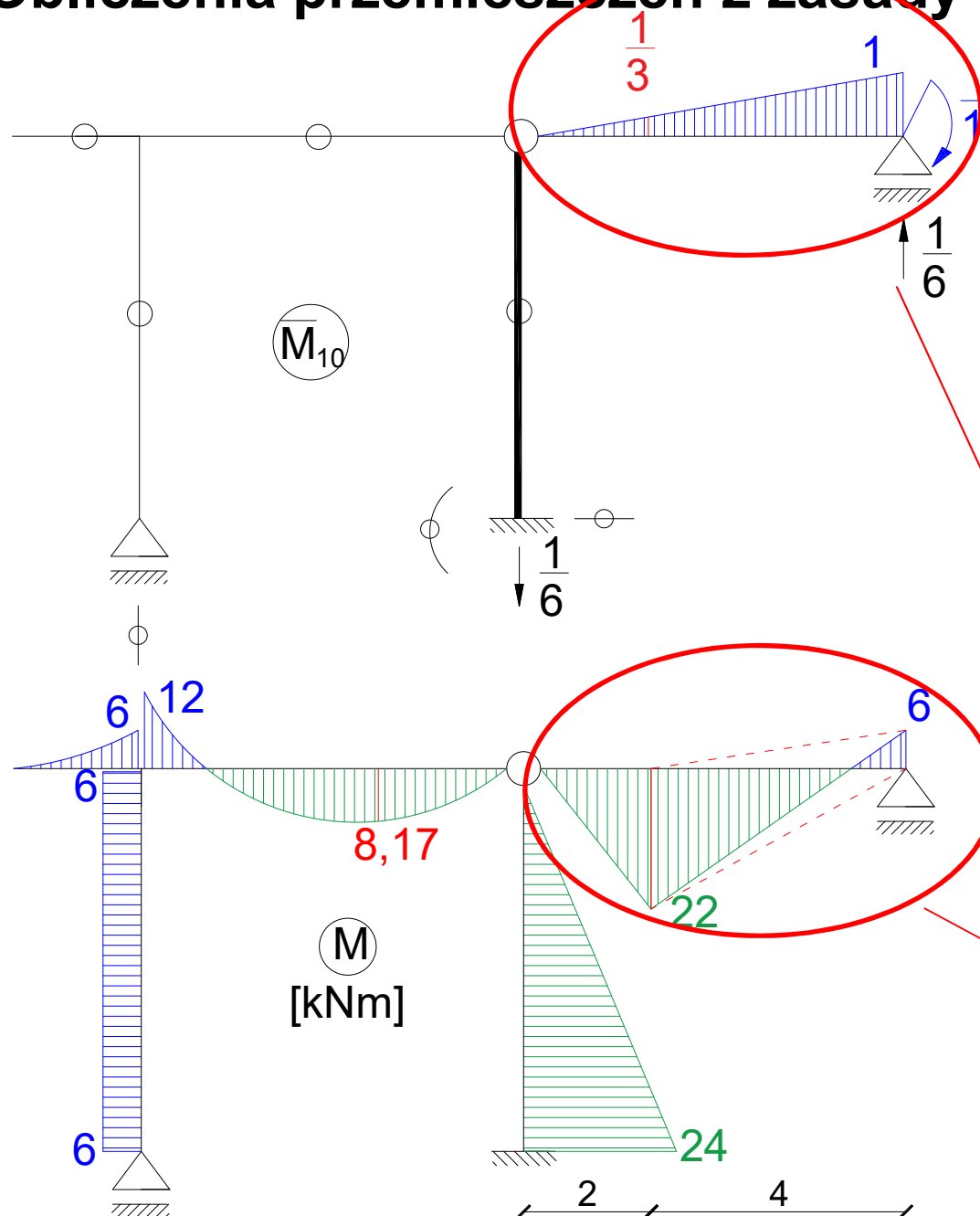


$$\varphi_D = -\frac{1}{EI} \frac{1}{2} \cdot 22 \cdot 2 \cdot \frac{2}{3} \cdot \frac{1}{3}$$

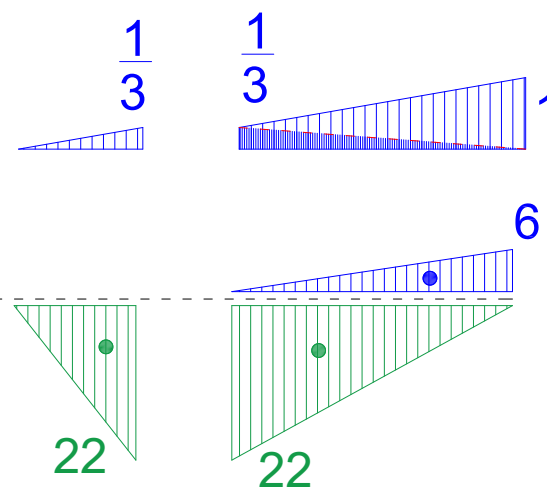
$$- \frac{1}{EI} \frac{1}{2} \cdot 22 \cdot 4 \cdot \left(\frac{2}{3} \cdot \frac{1}{3} + \frac{1}{3} \cdot 1 \right)$$



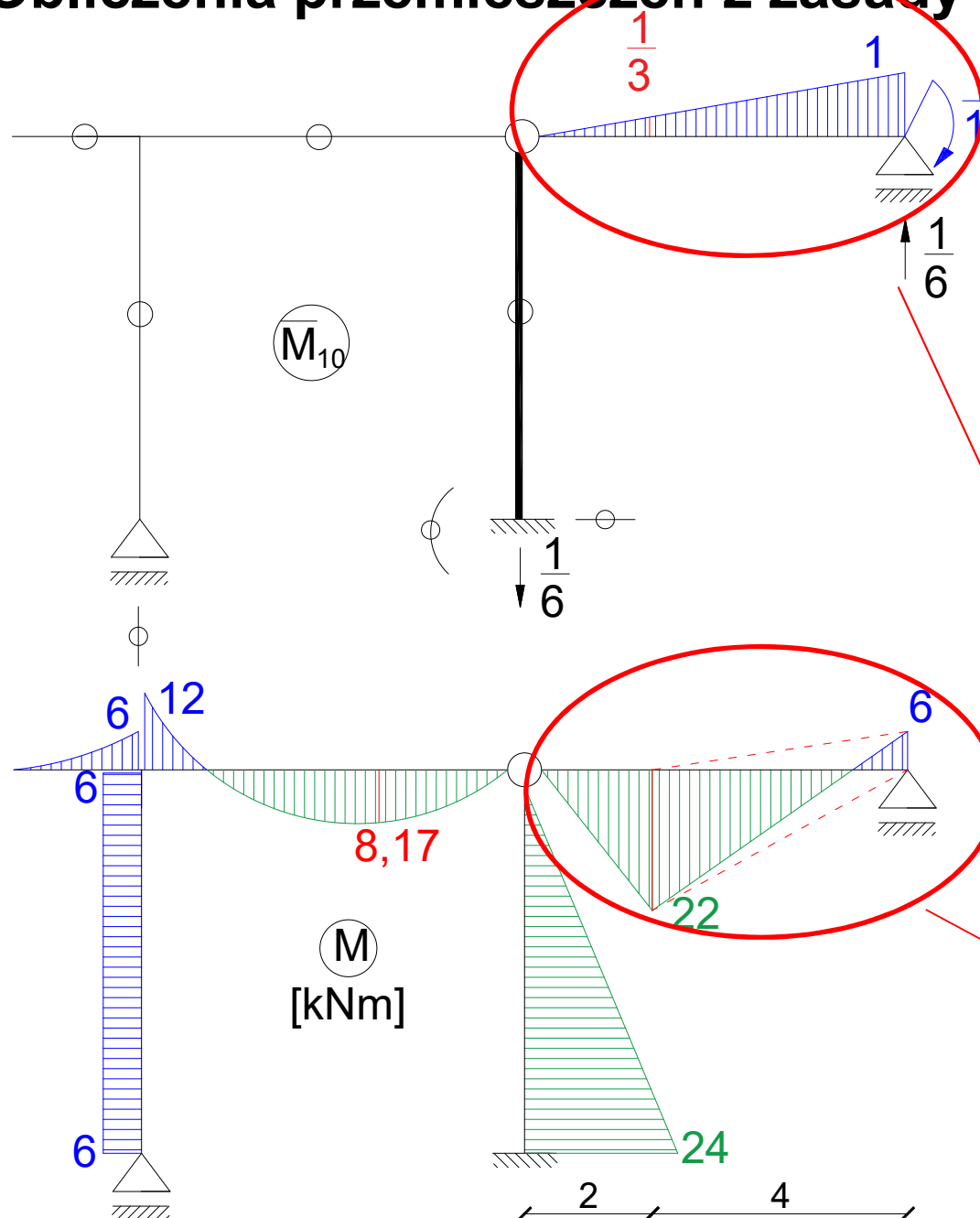
Obliczenia przemieszczeń z zasady prac wirtualnych:



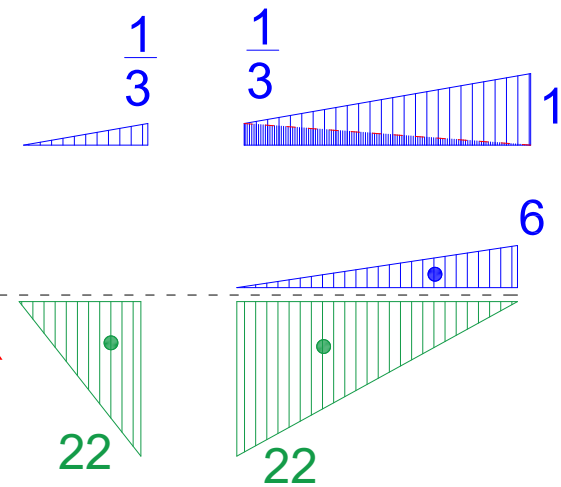
$$\begin{aligned} \varphi_D = & -\frac{1}{EI} \frac{1}{2} \cdot 22 \cdot 2 \cdot \frac{2}{3} \cdot \frac{1}{3} \\ & -\frac{1}{EI} \frac{1}{2} \cdot 22 \cdot 4 \cdot \left(\frac{2}{3} \cdot \frac{1}{3} + \frac{1}{3} \cdot 1 \right) \\ & +\frac{1}{EI} \frac{1}{2} \cdot 6 \cdot 4 \cdot \left(\frac{1}{3} \cdot \frac{1}{3} + \frac{2}{3} \cdot 1 \right) \end{aligned}$$



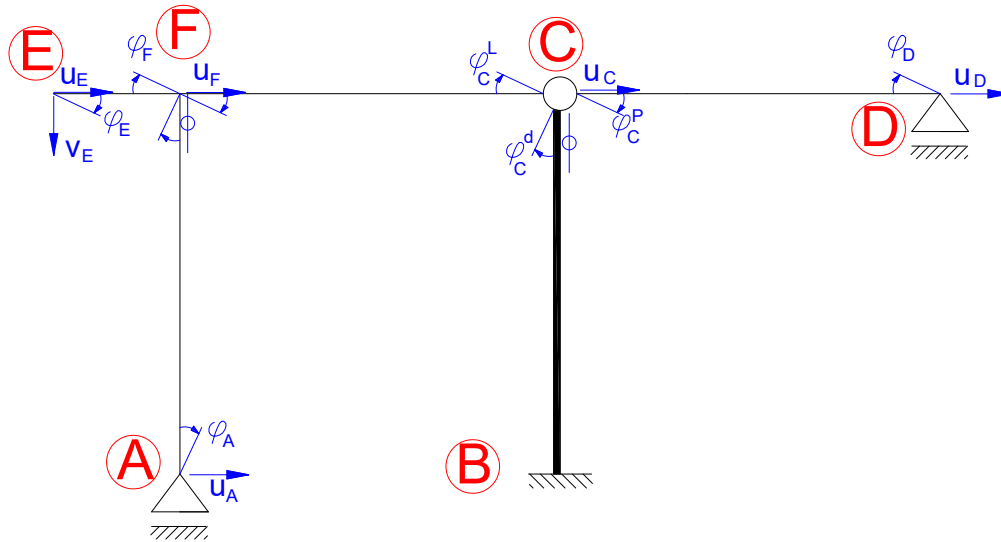
Obliczenia przemieszczeń z zasady prac wirtualnych:



$$\begin{aligned}\varphi_D &= -\frac{1}{EI} \frac{1}{2} \cdot 22 \cdot 2 \cdot \frac{2}{3} \cdot \frac{1}{3} \\ &\quad - \frac{1}{EI} \frac{1}{2} \cdot 22 \cdot 4 \cdot \left(\frac{2}{3} \cdot \frac{1}{3} + \frac{1}{3} \cdot 1 \right) \\ &\quad + \frac{1}{EI} \frac{1}{2} \cdot 6 \cdot 4 \cdot \left(\frac{1}{3} \cdot \frac{1}{3} + \frac{2}{3} \cdot 1 \right) \\ &= -\frac{20}{EI}\end{aligned}$$



Odształcona postać ramy:



Założenie $1/EI=a \rightarrow$

$$u_C = u_D = u_E = u_F = -\frac{144}{EI}$$

$$u_A = -\frac{54}{EI}$$

$$v_E = \frac{0}{EI}$$

$$\varphi_A = -\frac{33}{EI}$$

$$\varphi_E = -\frac{1}{EI}$$

$$\varphi_F = \frac{3}{EI}$$

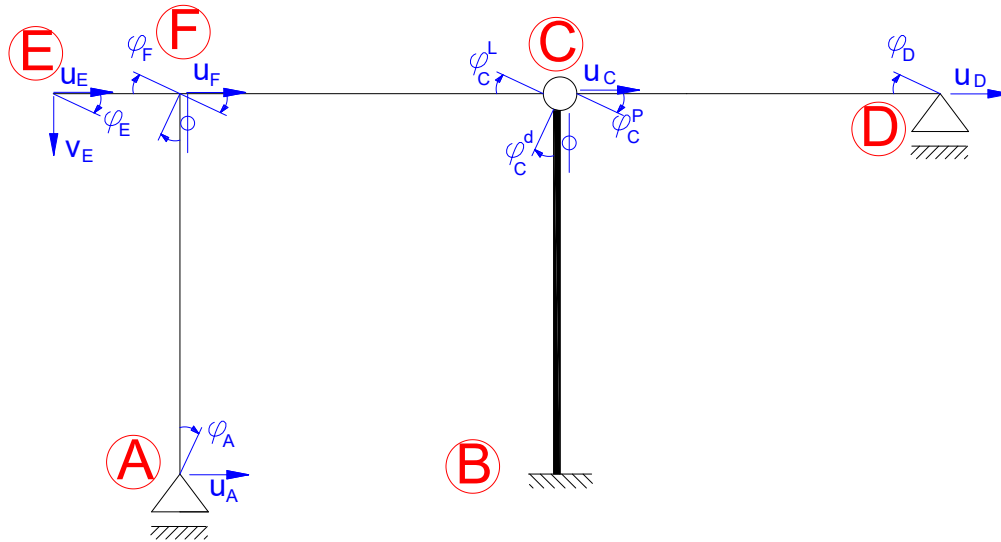
$$\varphi_C^L = -\frac{15}{EI}$$

$$\varphi_C^P = \frac{34}{EI}$$

$$\varphi_C^d = -\frac{36}{EI}$$

$$\varphi_D = -\frac{20}{EI}$$

Odształcona postać ramy:



Założenie $1/EI=a \rightarrow$

$$u_C = u_D = u_E = u_F = -\frac{144}{EI} = -144a$$

$$u_A = -\frac{54}{EI} = -54a$$

$$v_E = \frac{0}{EI} = 0$$

$$\varphi_A = -\frac{33}{EI} = -33a$$

$$\varphi_E = -\frac{1}{EI} = -a$$

$$\varphi_F = \frac{3}{EI} = 3a$$

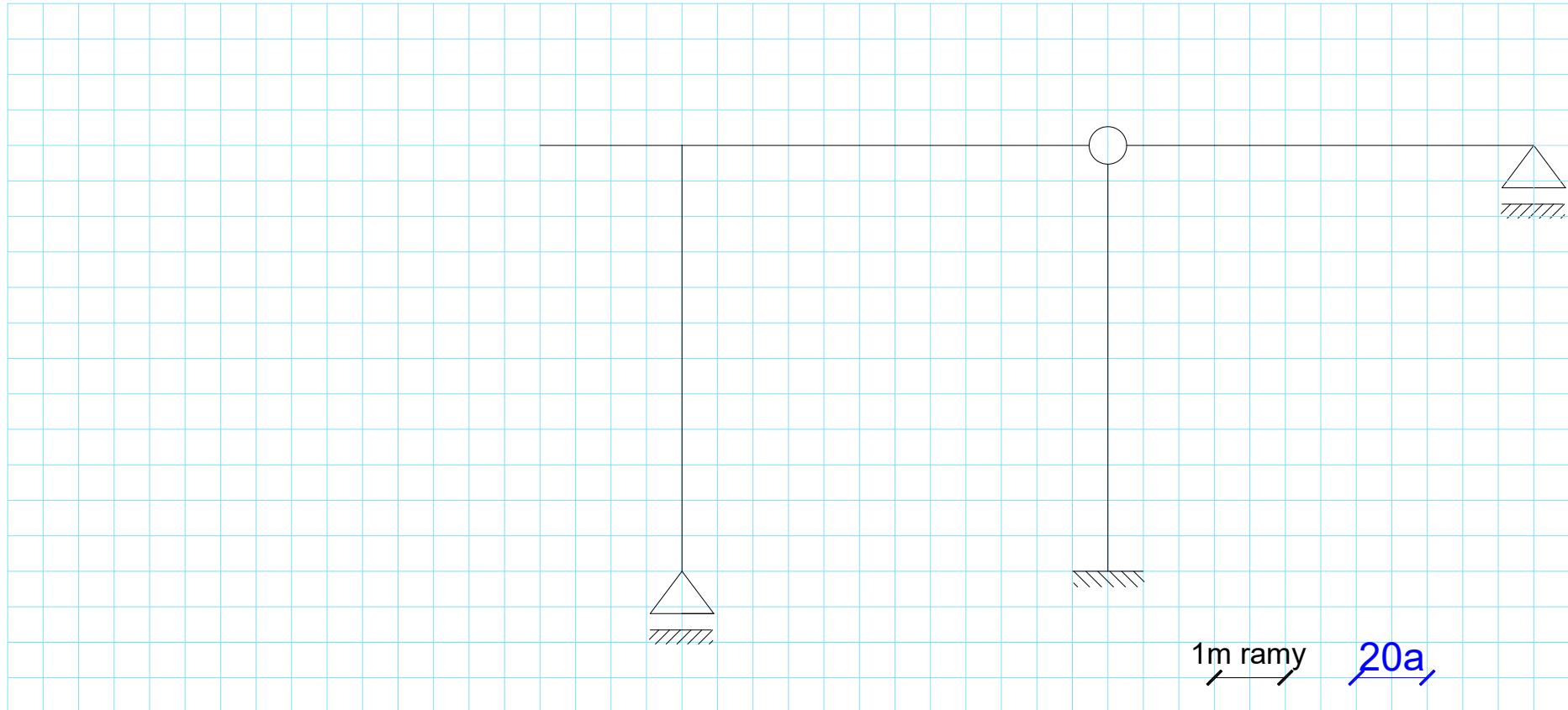
$$\varphi_C^L = -\frac{15}{EI} = -15a$$

$$\varphi_C^P = \frac{34}{EI} = 34a$$

$$\varphi_C^d = -\frac{36}{EI} = -36a$$

$$\varphi_D = -\frac{20}{EI} = -20a$$

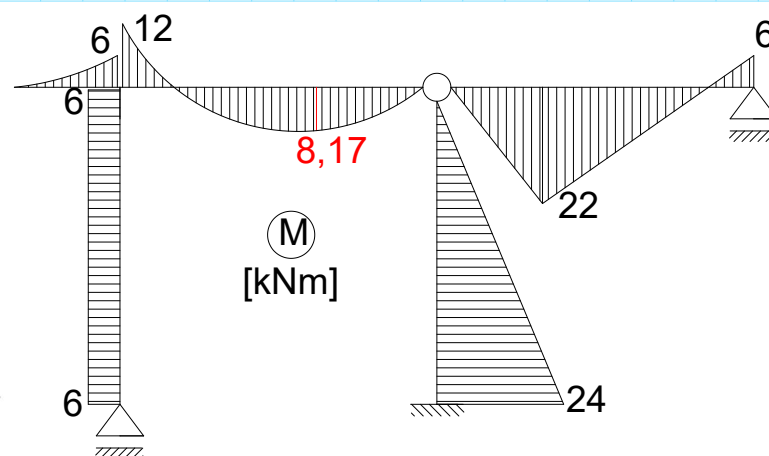
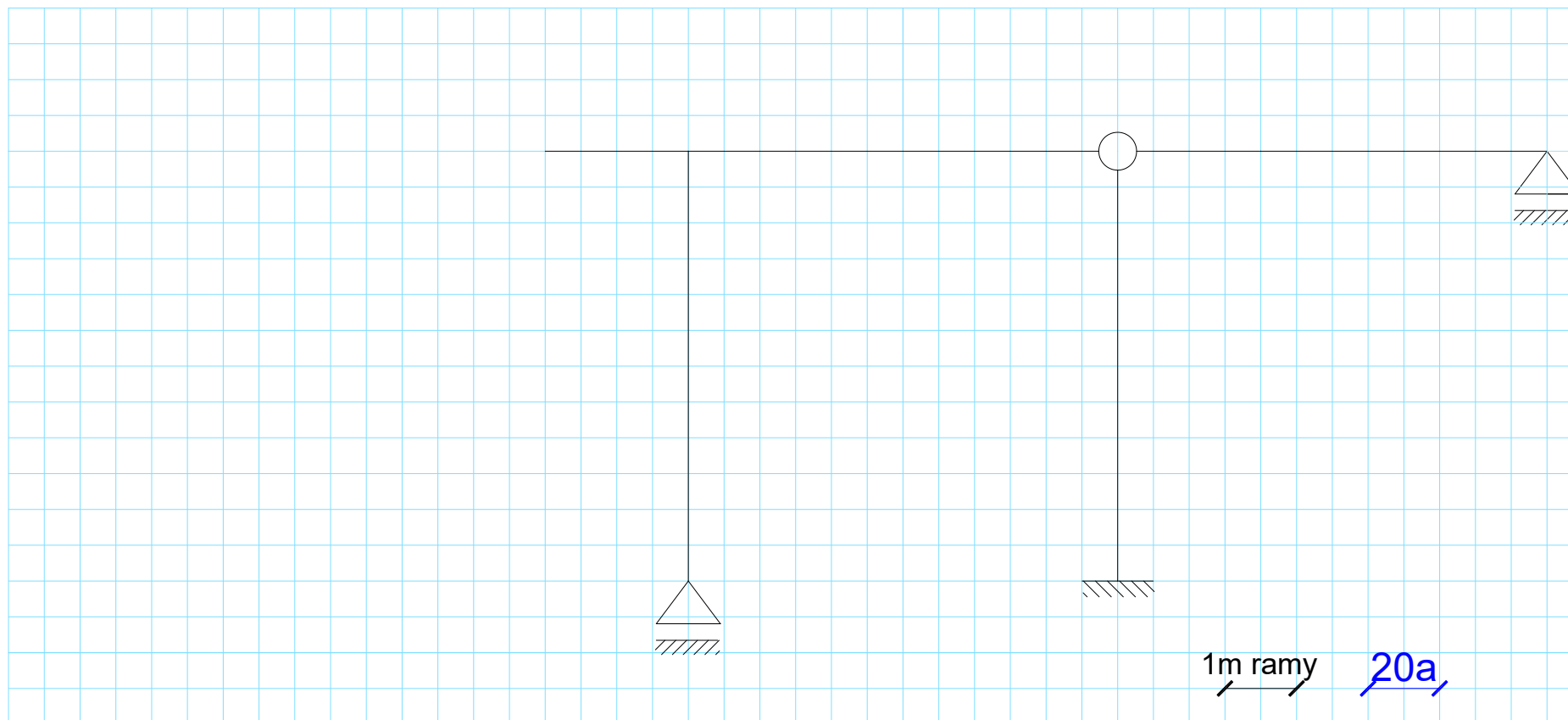
Odkształcona postać ramy:



$$u_C = -144a \quad u_A = -54a \quad v_E = 0$$

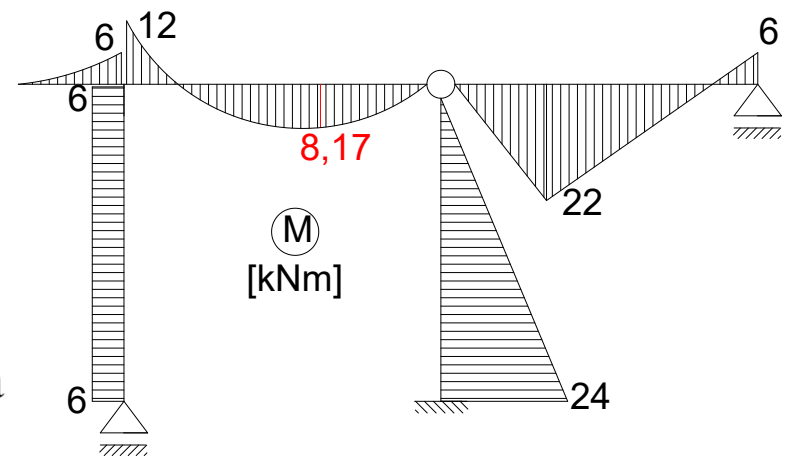
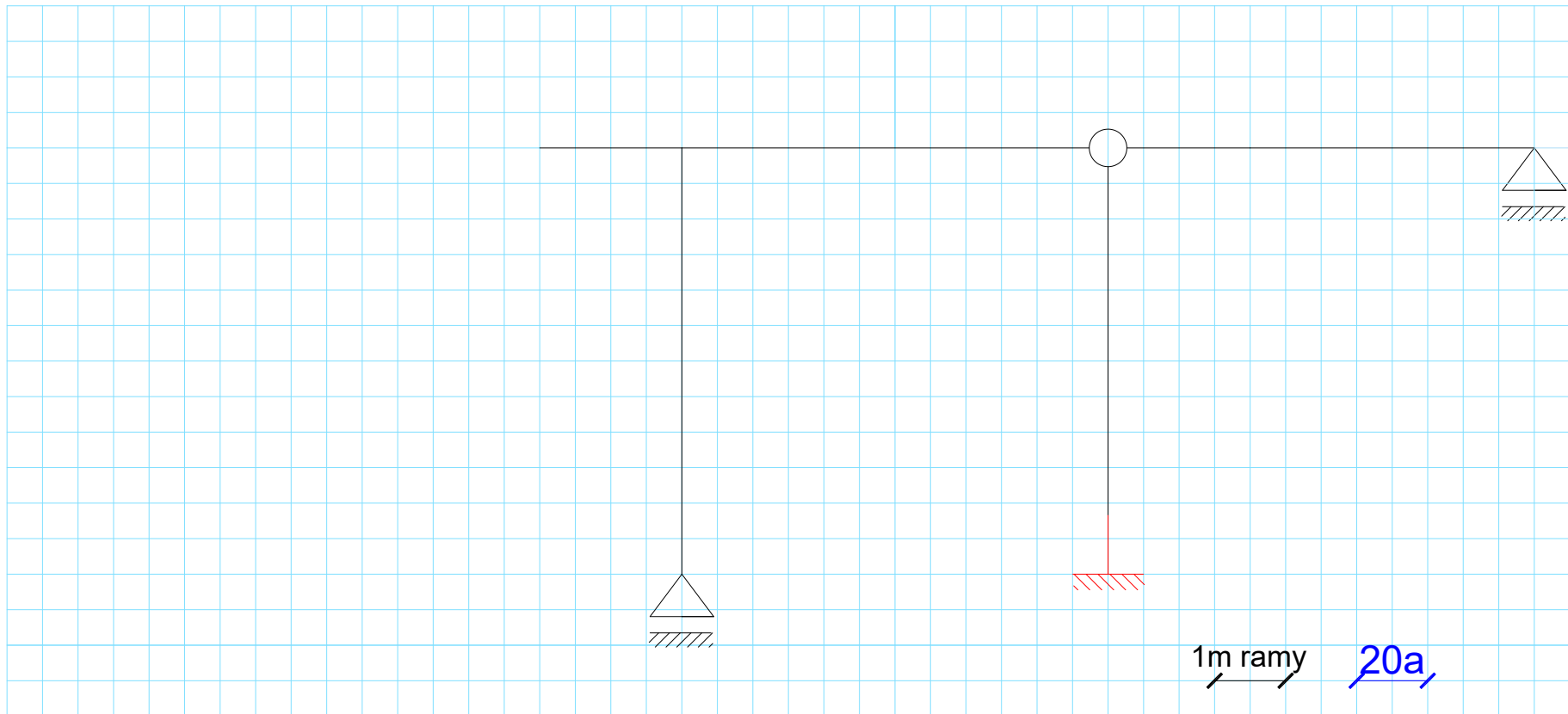
$$\varphi_A = -33a \quad \varphi_E = -a \quad \varphi_F = 3a \quad \varphi_C^L = -15a$$

$$\varphi_C^P = 34a \quad \varphi_C^d = -36a \quad \varphi_D = -20a$$



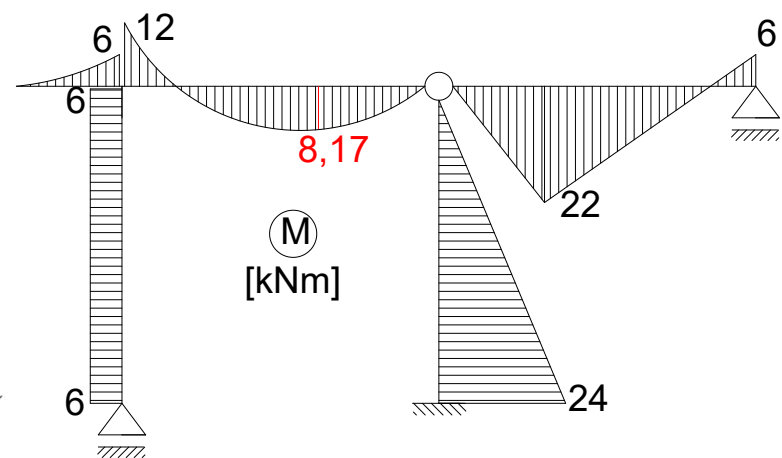
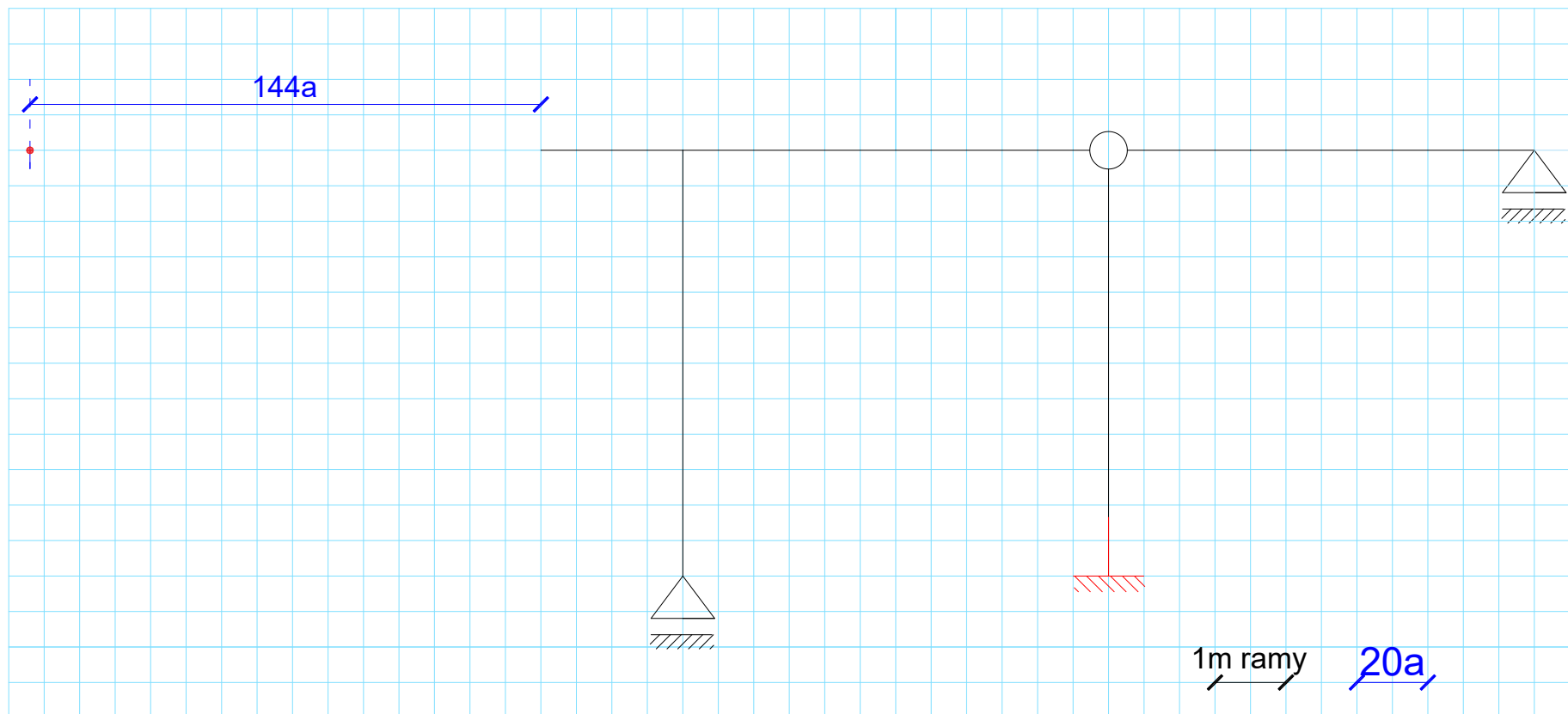
$$\begin{aligned}
 u_C &= -144a & u_A &= -54a & v_E &= 0 \\
 \varphi_A &= -33a & \varphi_E &= -a & \varphi_F &= 3a & \varphi_C^L &= -15a \\
 \varphi_C^P &= 34a & \varphi_C^d &= -36a & \varphi_D &= -20a
 \end{aligned}$$

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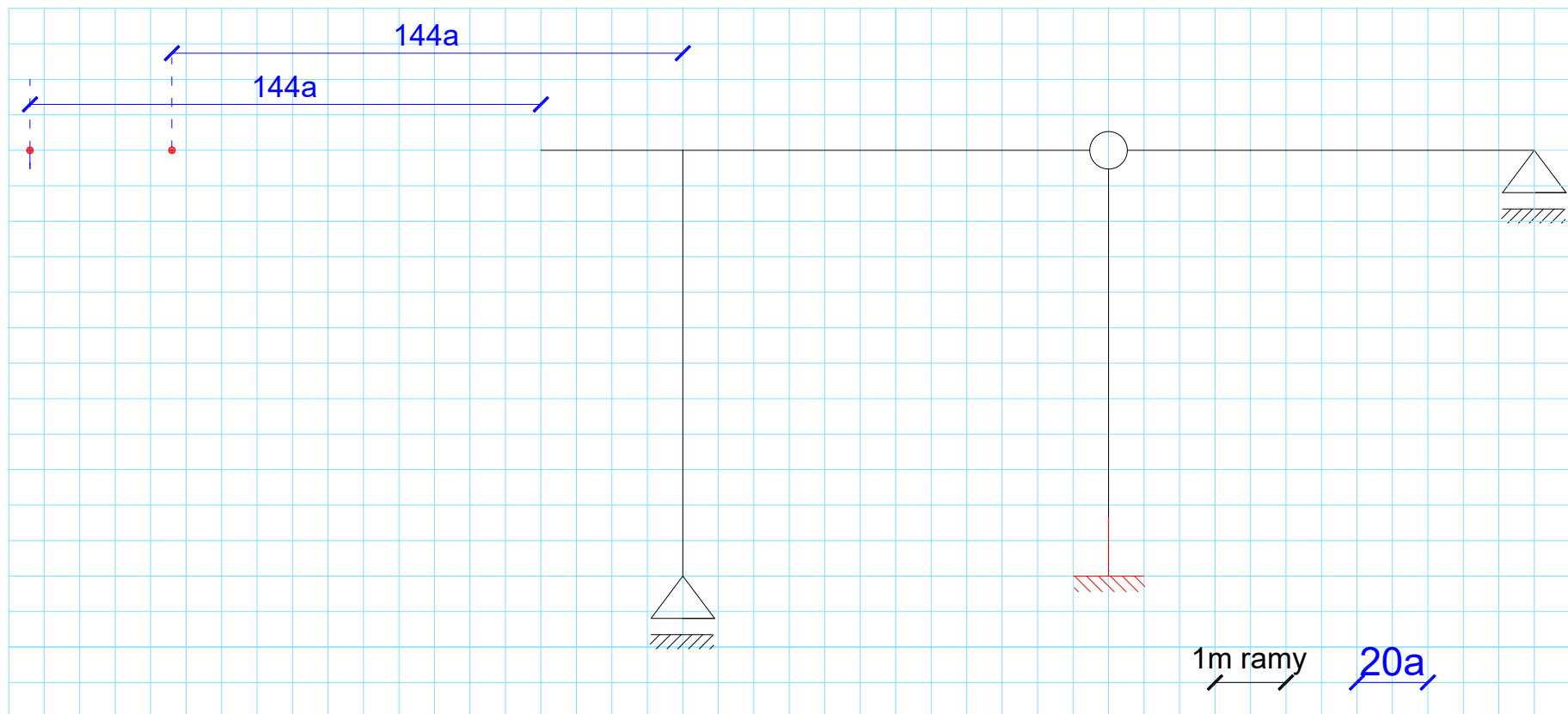
$$\begin{aligned}
 u_C &= -144a & u_A &= -54a & v_E &= 0 \\
 \varphi_A &= -33a & \varphi_E &= -a & \varphi_F &= 3a & \varphi_C^L &= -15a \\
 \varphi_C^P &= 34a & \varphi_C^d &= -36a & \varphi_D &= -20a
 \end{aligned}$$

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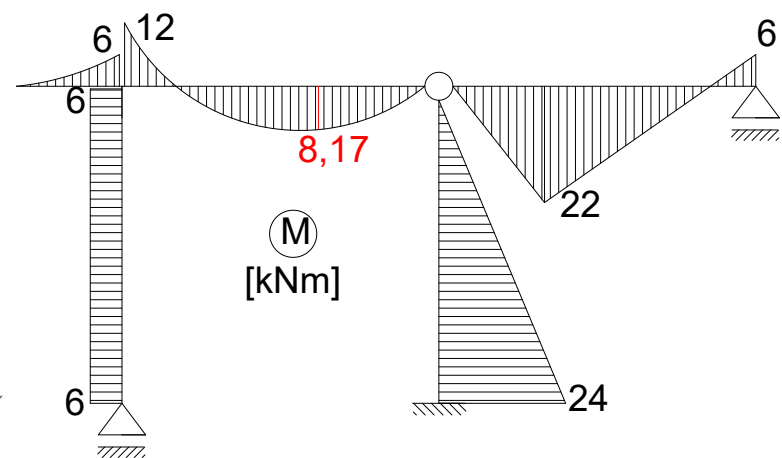


$$\begin{aligned}
 u_C &= -144a & u_A &= -54a & v_E &= 0 \\
 \varphi_A &= -33a & \varphi_E &= -a & \varphi_F &= 3a & \varphi_C^L &= -15a \\
 \varphi_C^P &= 34a & \varphi_C^d &= -36a & \varphi_D &= -20a
 \end{aligned}$$

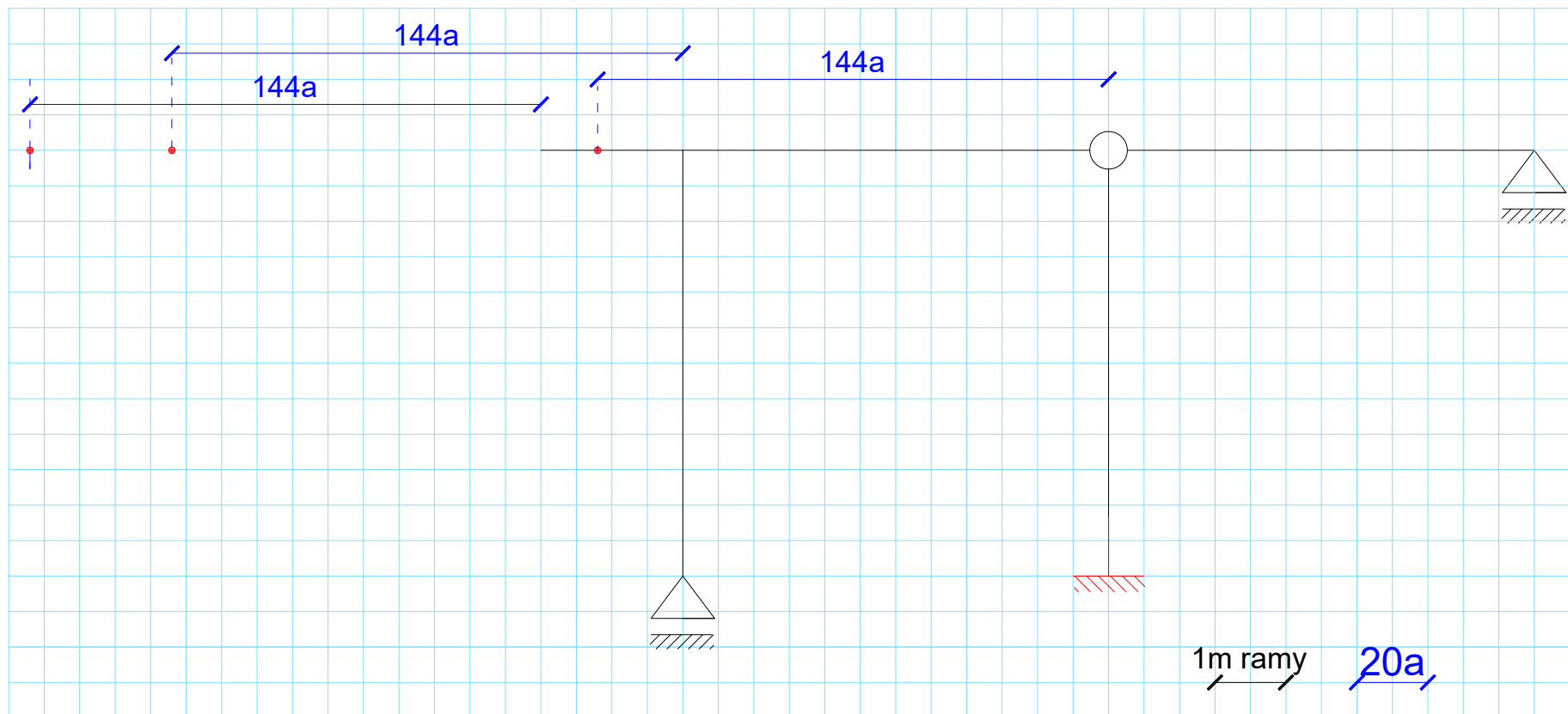
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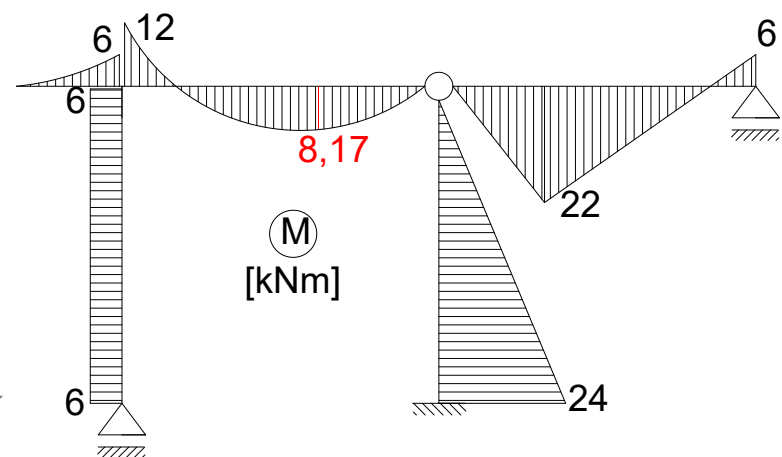
$$\begin{aligned}
 u_C &= -144a & u_A &= -54a & v_E &= 0 \\
 \varphi_A &= -33a & \varphi_E &= -a & \varphi_F &= 3a & \varphi_C^L &= -15a \\
 \varphi_C^P &= 34a & \varphi_C^d &= -36a & \varphi_D &= -20a
 \end{aligned}$$



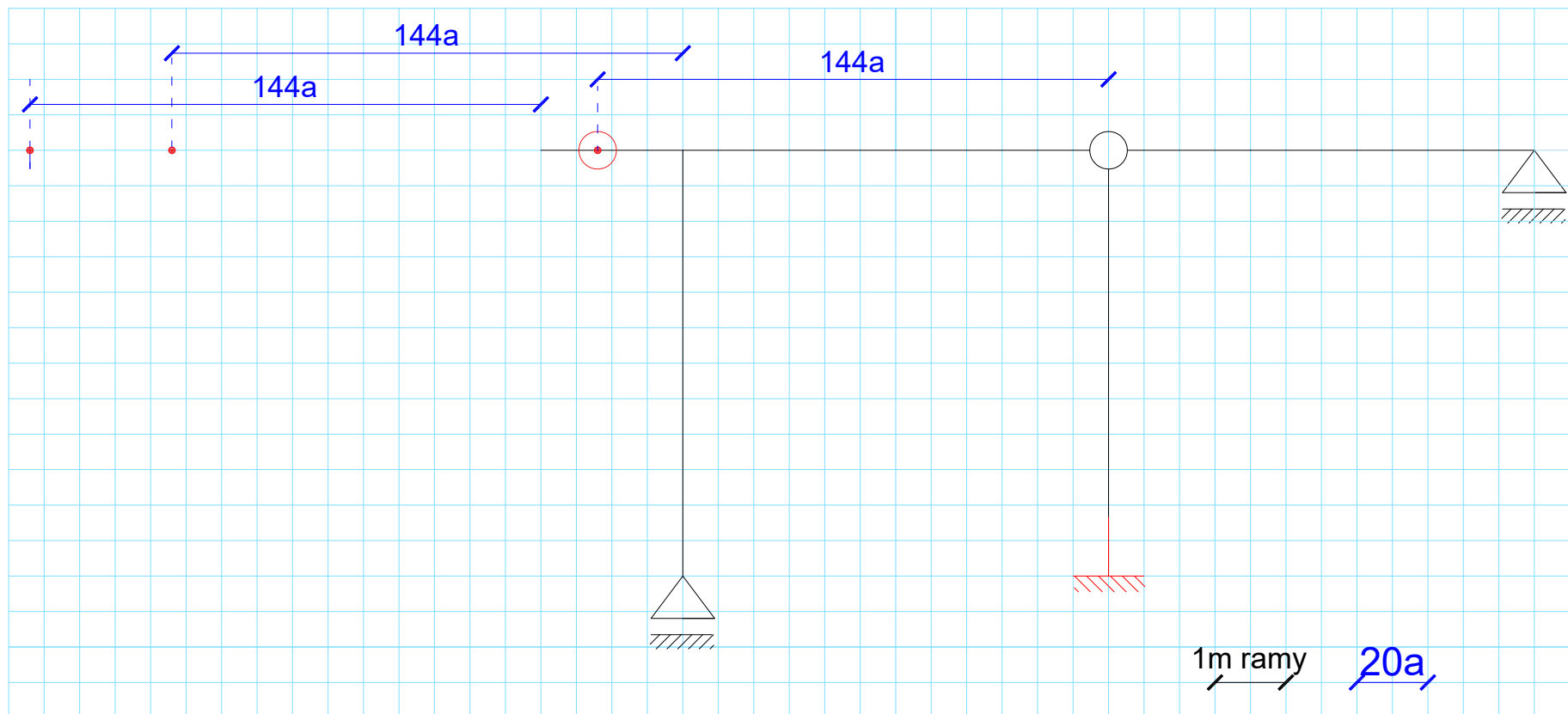
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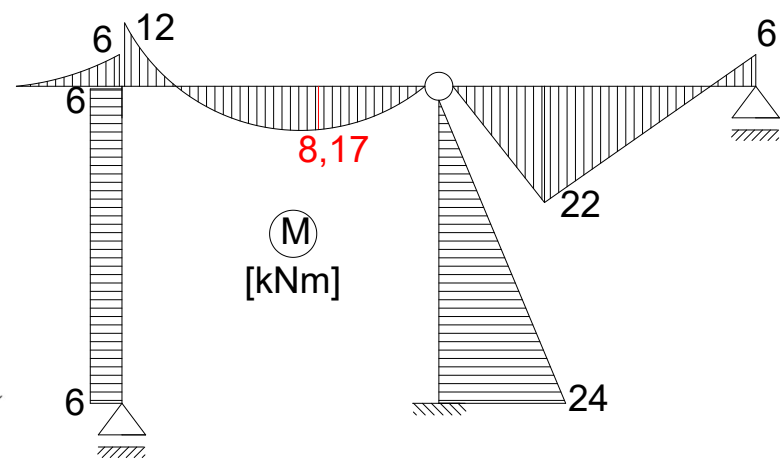
$$\begin{aligned}
 u_C &= -144a & u_A &= -54a & v_E &= 0 \\
 \varphi_A &= -33a & \varphi_E &= -a & \varphi_F &= 3a & \varphi_C^L &= -15a \\
 \varphi_C^P &= 34a & \varphi_C^d &= -36a & \varphi_D &= -20a
 \end{aligned}$$



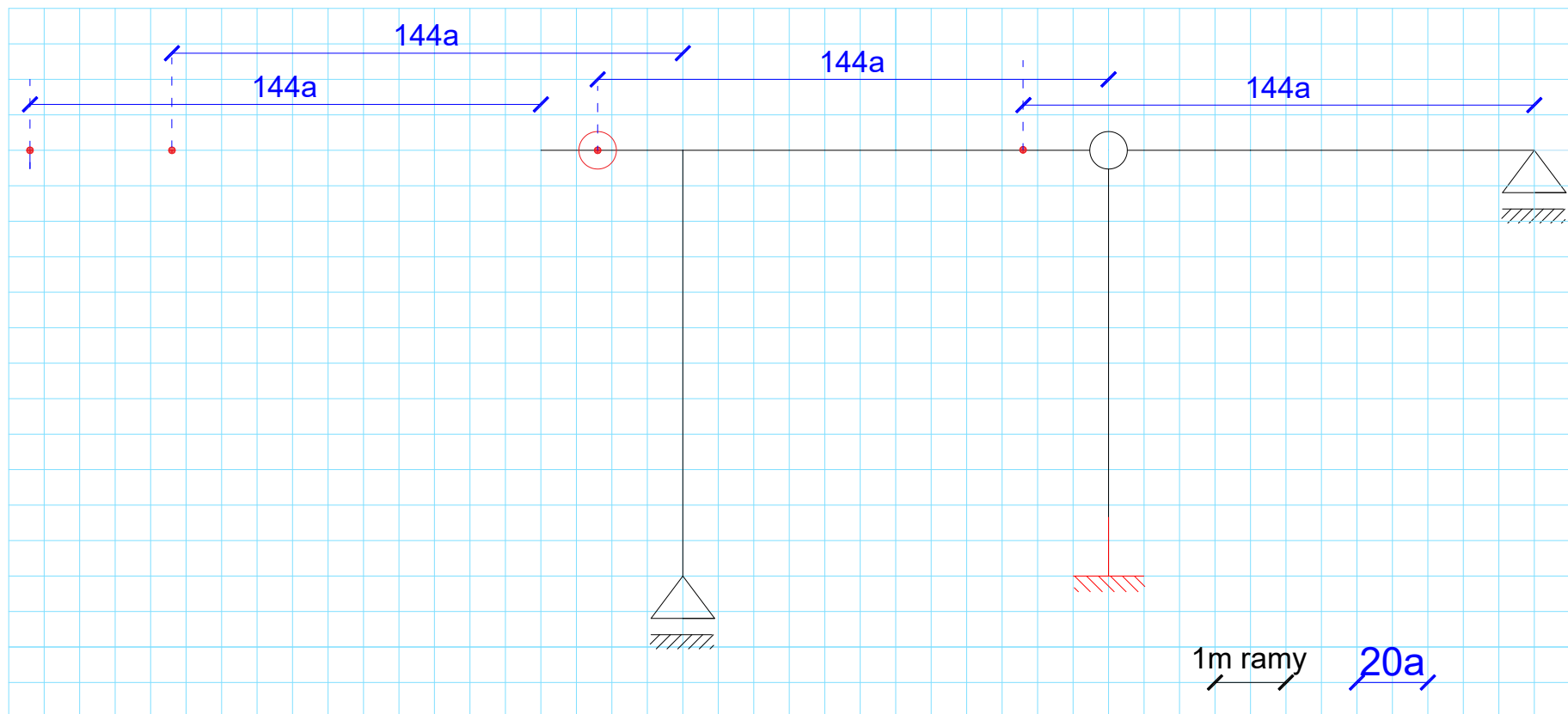
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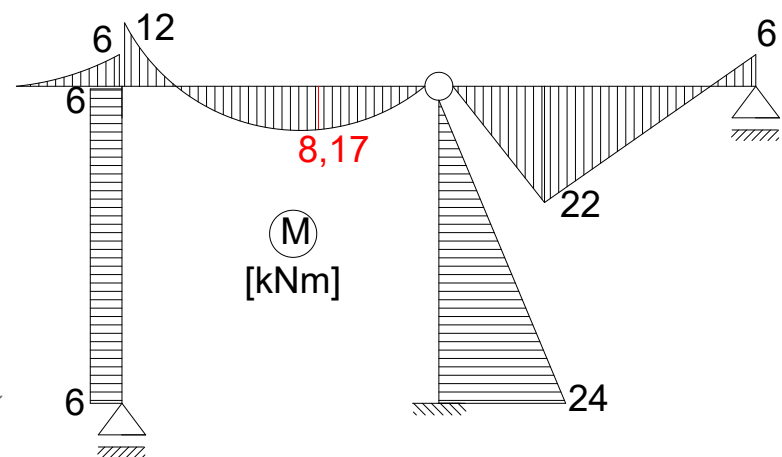
$$\begin{aligned}
 u_C &= -144a & u_A &= -54a & v_E &= 0 \\
 \varphi_A &= -33a & \varphi_E &= -a & \varphi_F &= 3a & \varphi_C^L &= -15a \\
 \varphi_C^P &= 34a & \varphi_C^d &= -36a & \varphi_D &= -20a
 \end{aligned}$$



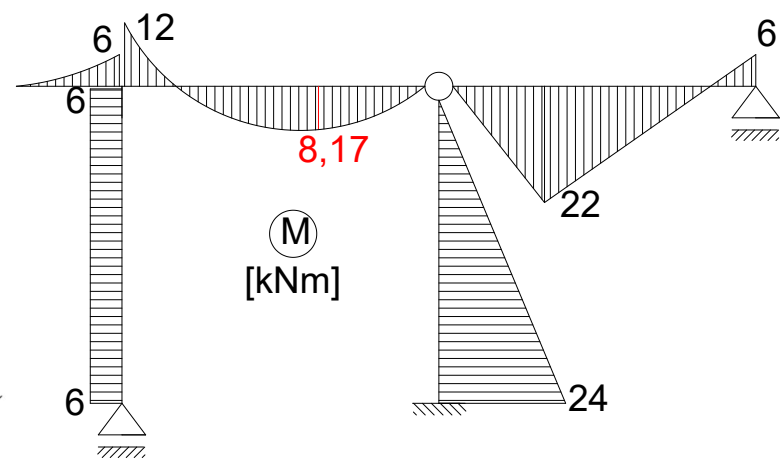
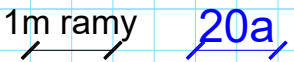
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$$\begin{aligned}
 u_C &= -144a & u_A &= -54a & v_E &= 0 \\
 \varphi_A &= -33a & \varphi_E &= -a & \varphi_F &= 3a & \varphi_C^L &= -15a \\
 \varphi_C^P &= 34a & \varphi_C^d &= -36a & \varphi_D &= -20a
 \end{aligned}$$

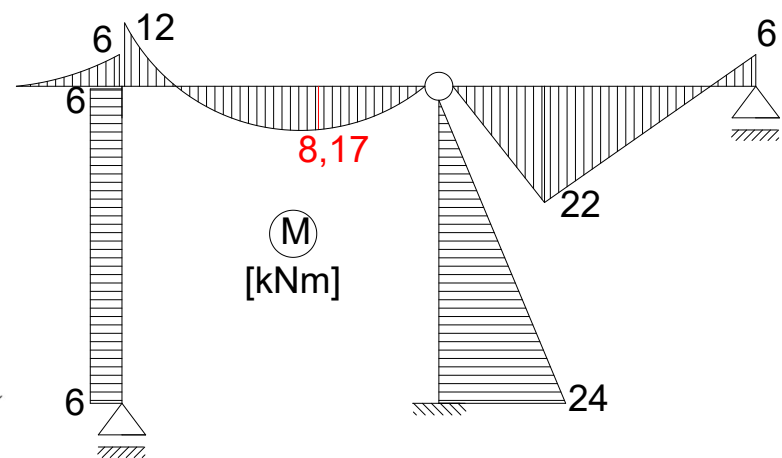
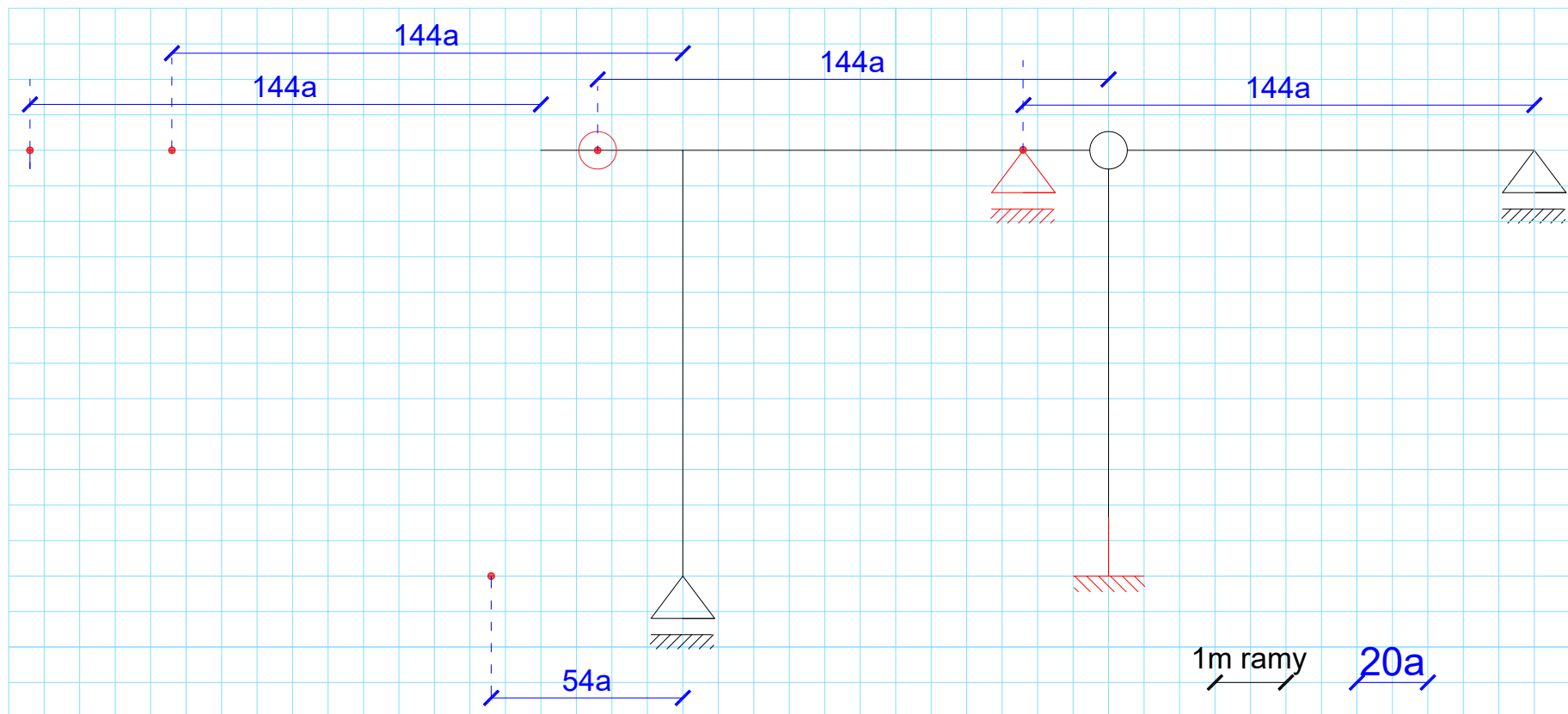


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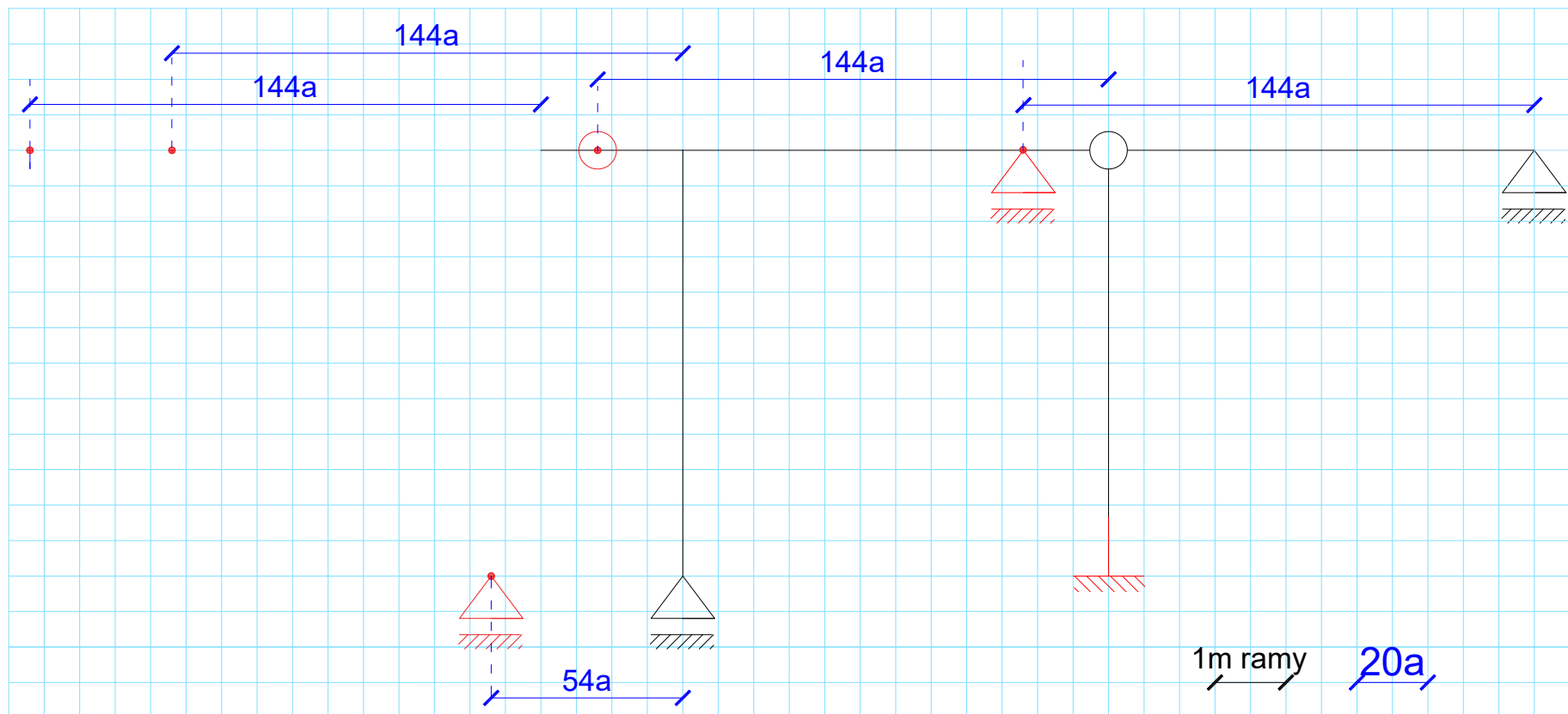
$$\begin{array}{lll} u_C = -144a & u_A = -54a & v_E = 0 \\ \varphi_A = -33a & \varphi_E = -a & \varphi_F = 3a \quad \varphi_C^L = -15a \\ \varphi_C^P = 34a & \varphi_C^d = -36a & \varphi_D = -20a \end{array}$$

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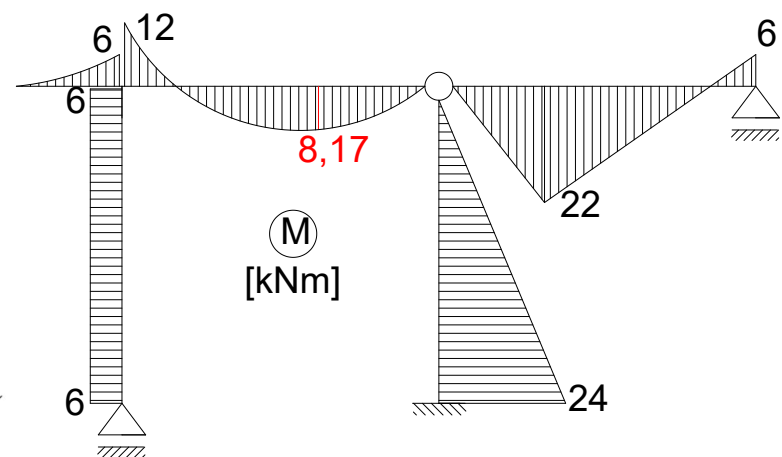


$$\begin{aligned}
 u_C &= -144a & u_A &= -54a & v_E &= 0 \\
 \varphi_A &= -33a & \varphi_E &= -a & \varphi_F &= 3a & \varphi_C^L &= -15a \\
 \varphi_C^P &= 34a & \varphi_C^d &= -36a & \varphi_D &= -20a
 \end{aligned}$$

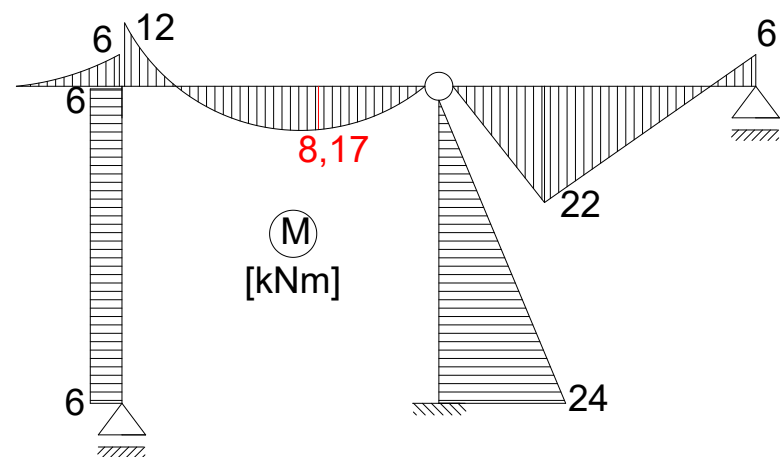
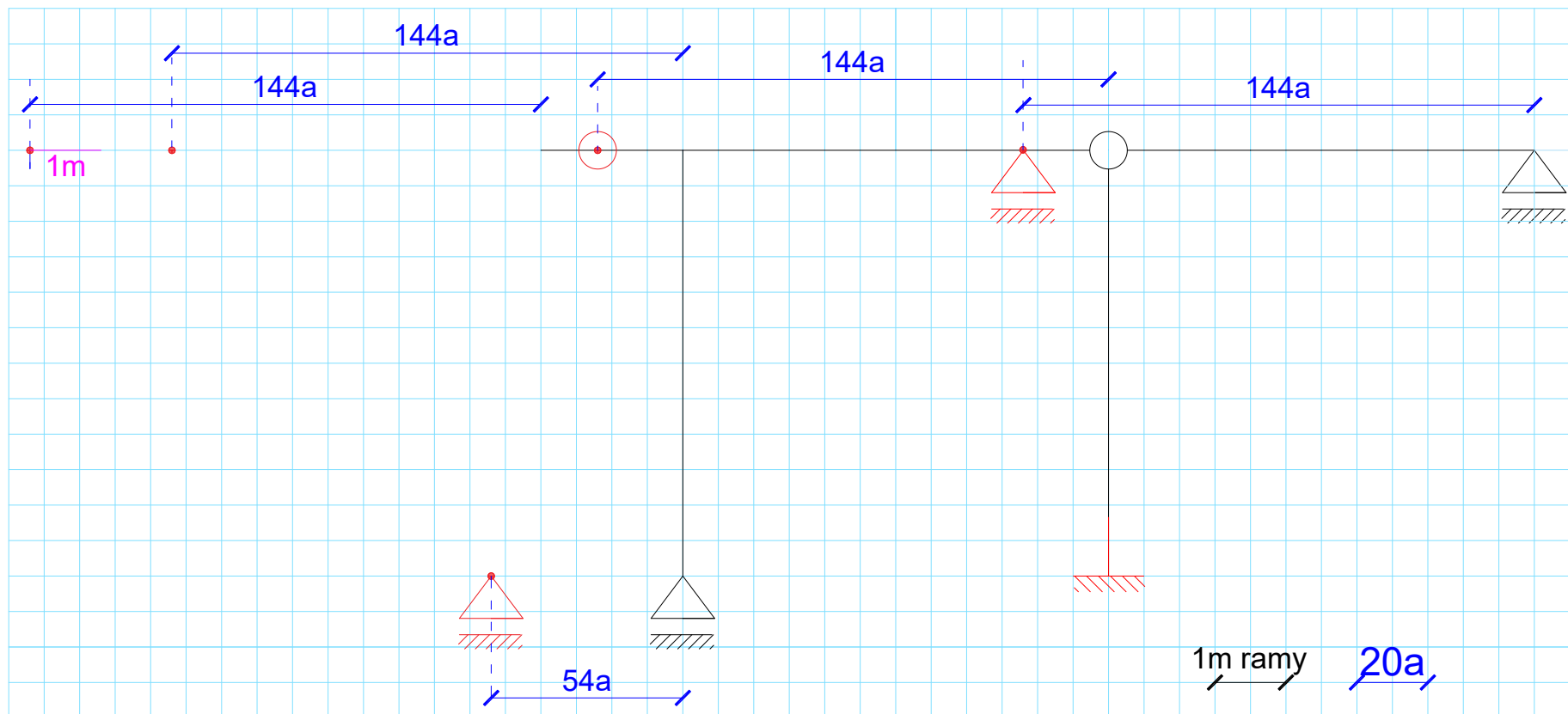
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$$\begin{aligned}
 u_C &= -144a & u_A &= -54a & v_E &= 0 \\
 \varphi_A &= -33a & \varphi_E &= -a & \varphi_F &= 3a & \varphi_C^L &= -15a \\
 \varphi_C^P &= 34a & \varphi_C^d &= -36a & \varphi_D &= -20a
 \end{aligned}$$

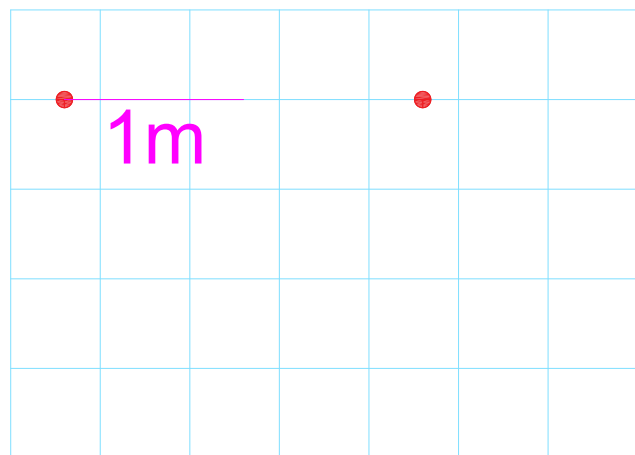
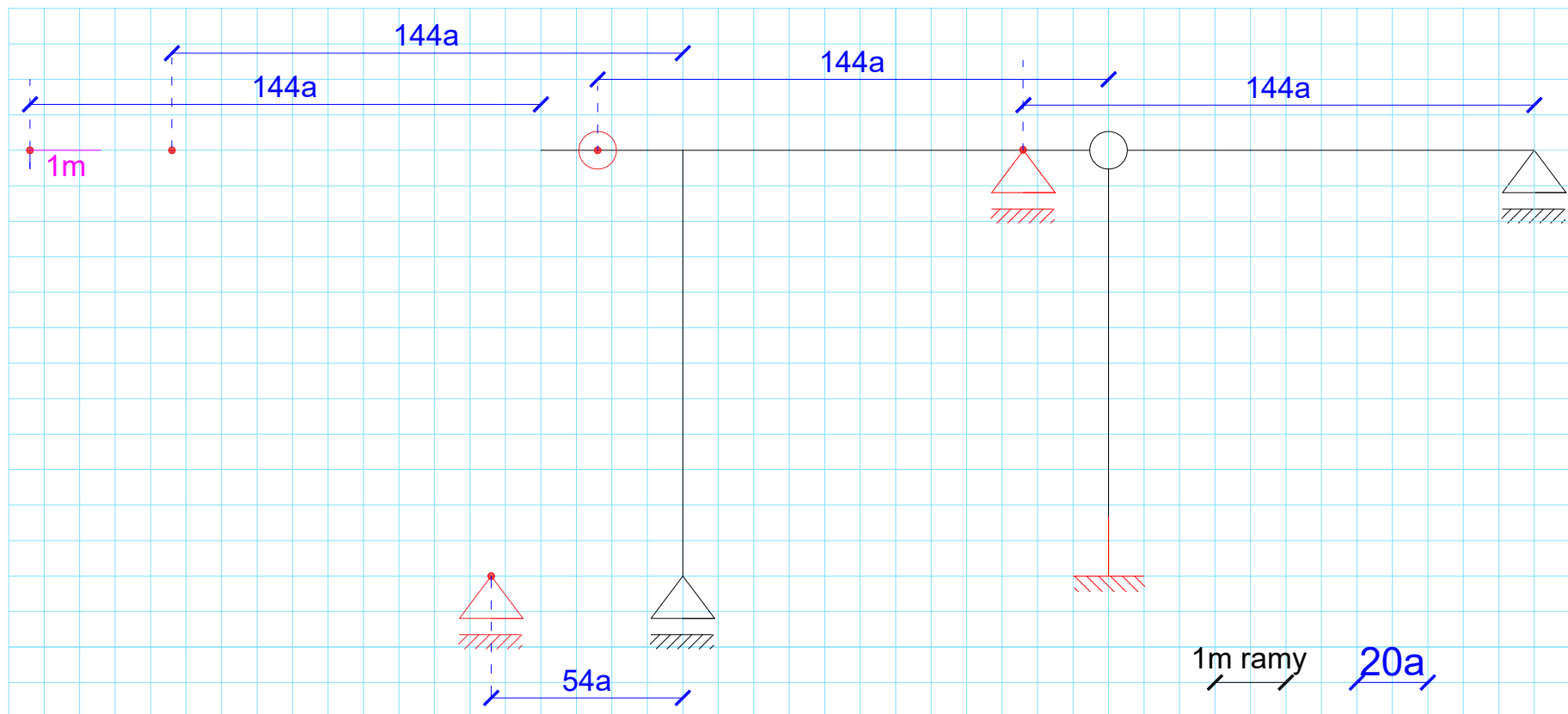


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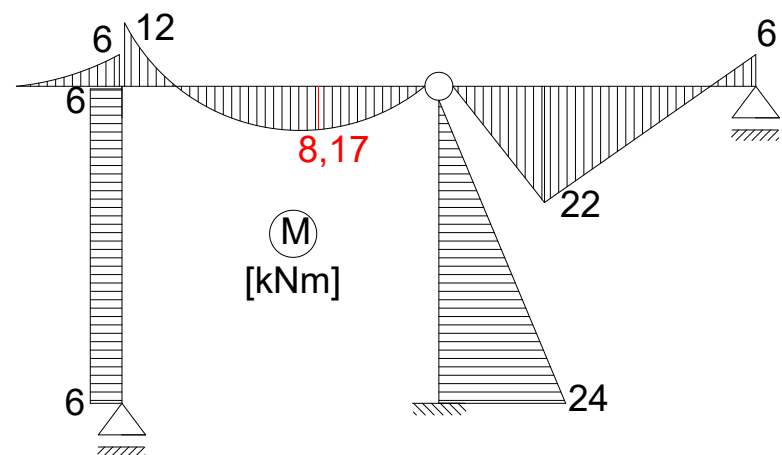
$$\varphi_E = -a \quad \varphi_F = 3a$$

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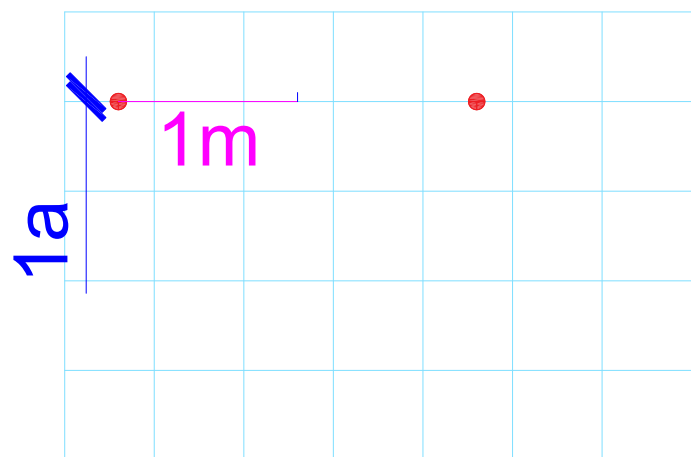
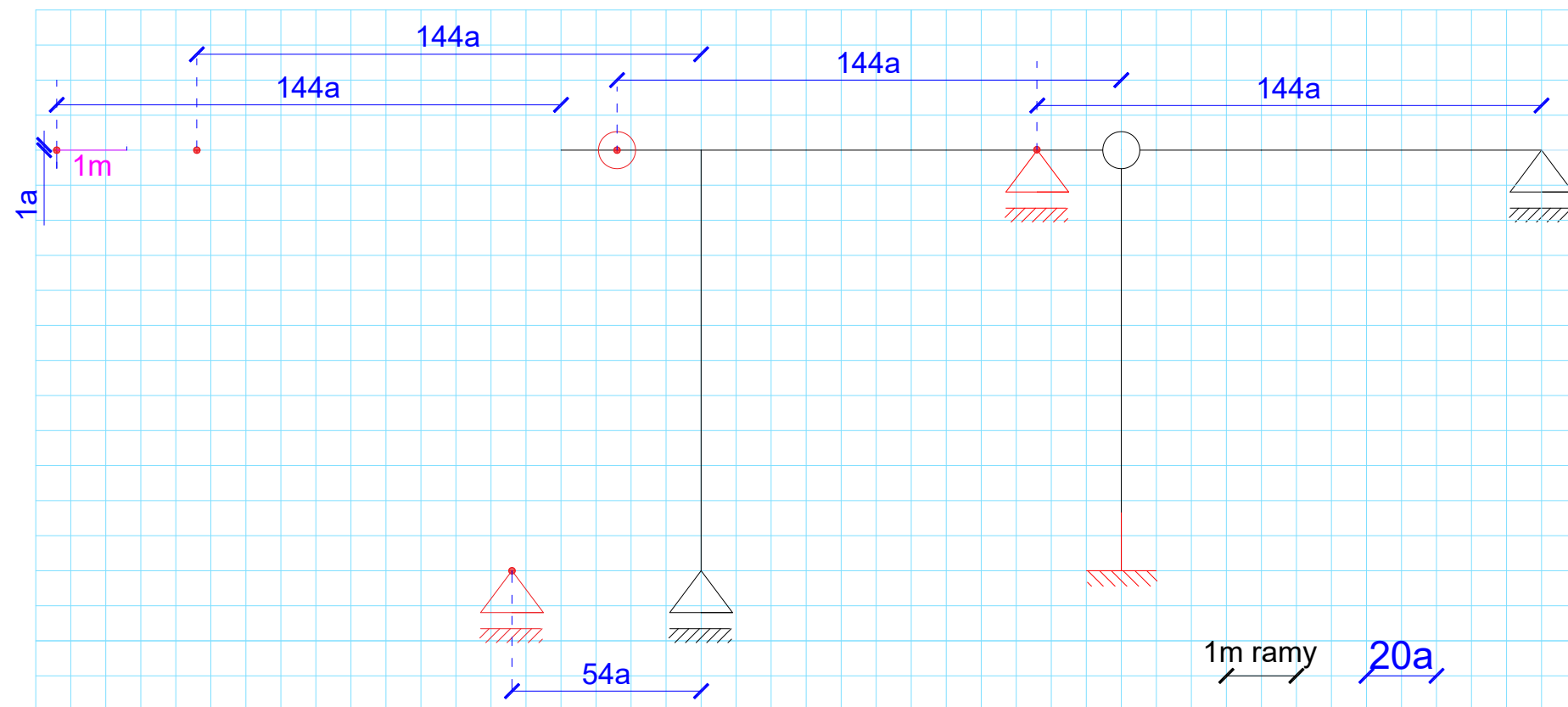


$$\varphi_E = -a$$

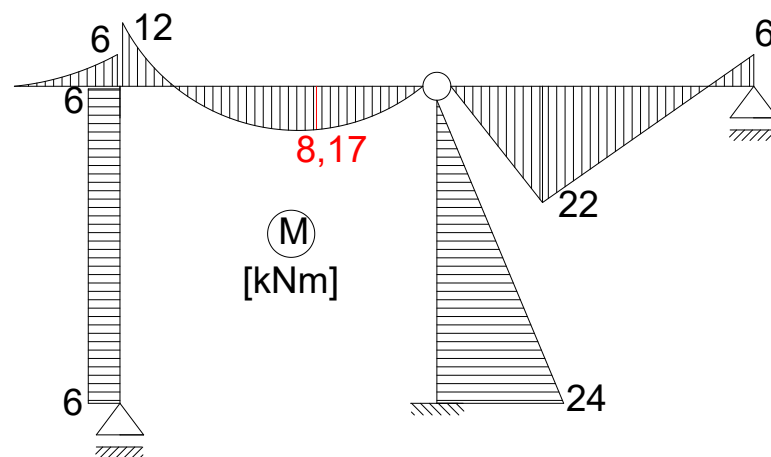
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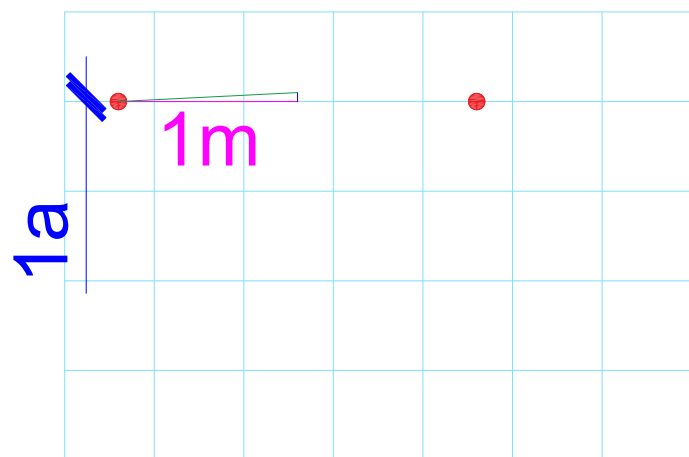
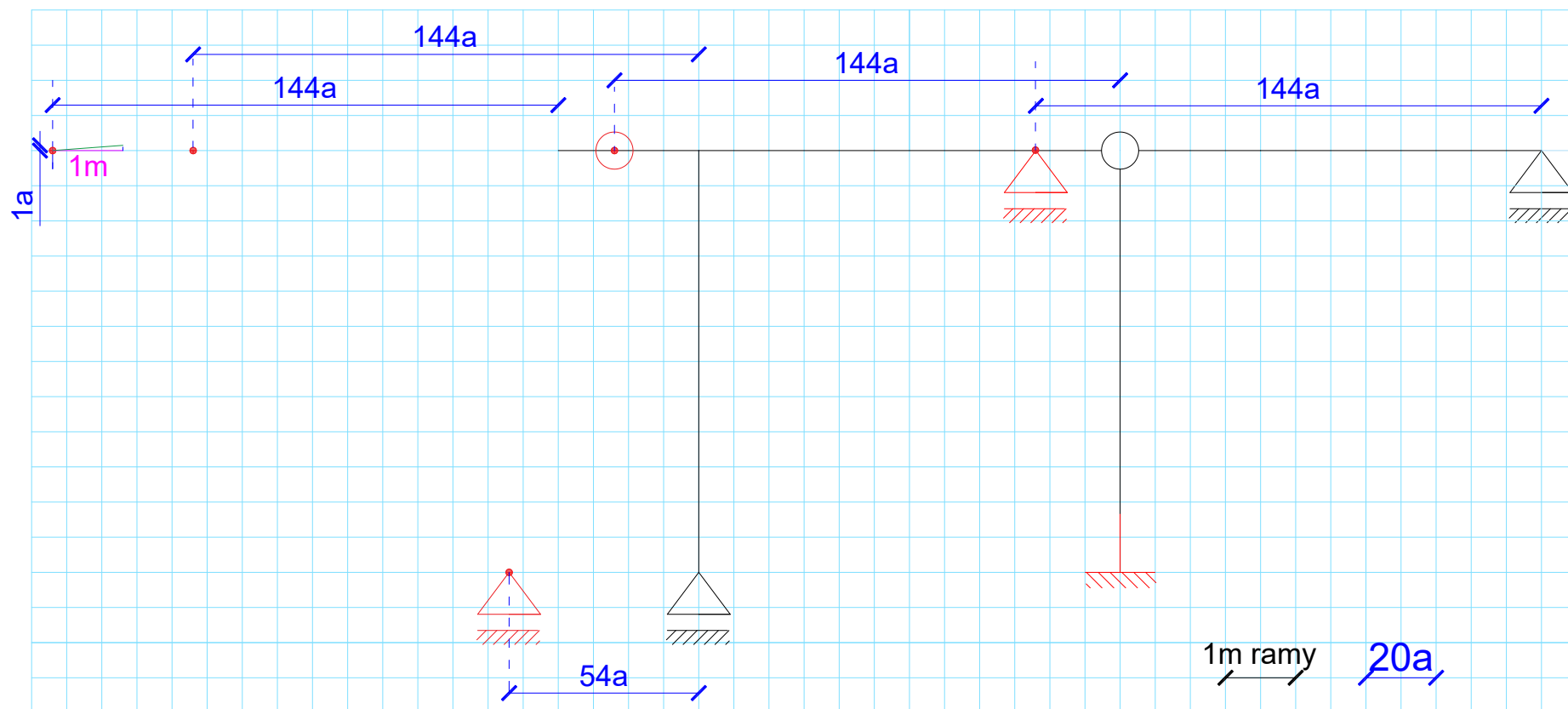
dr inż. Hanna Weber



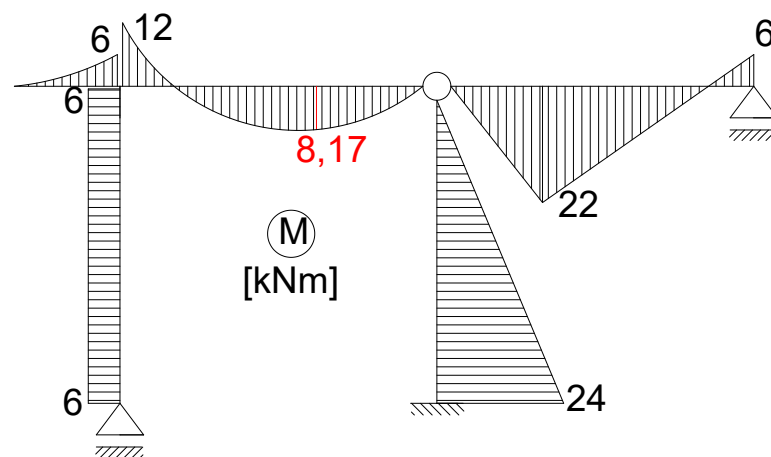
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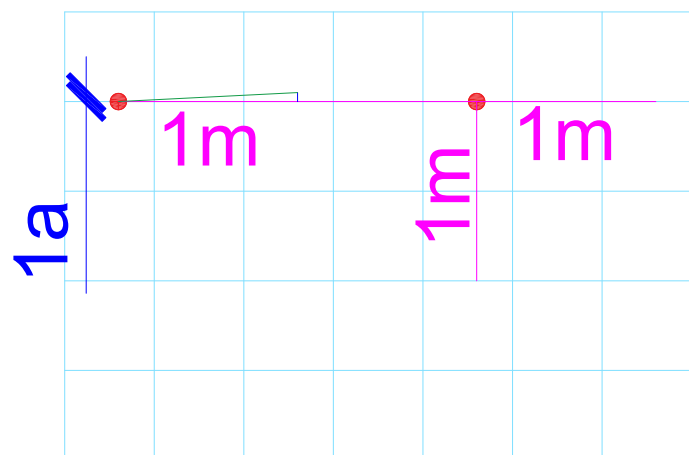
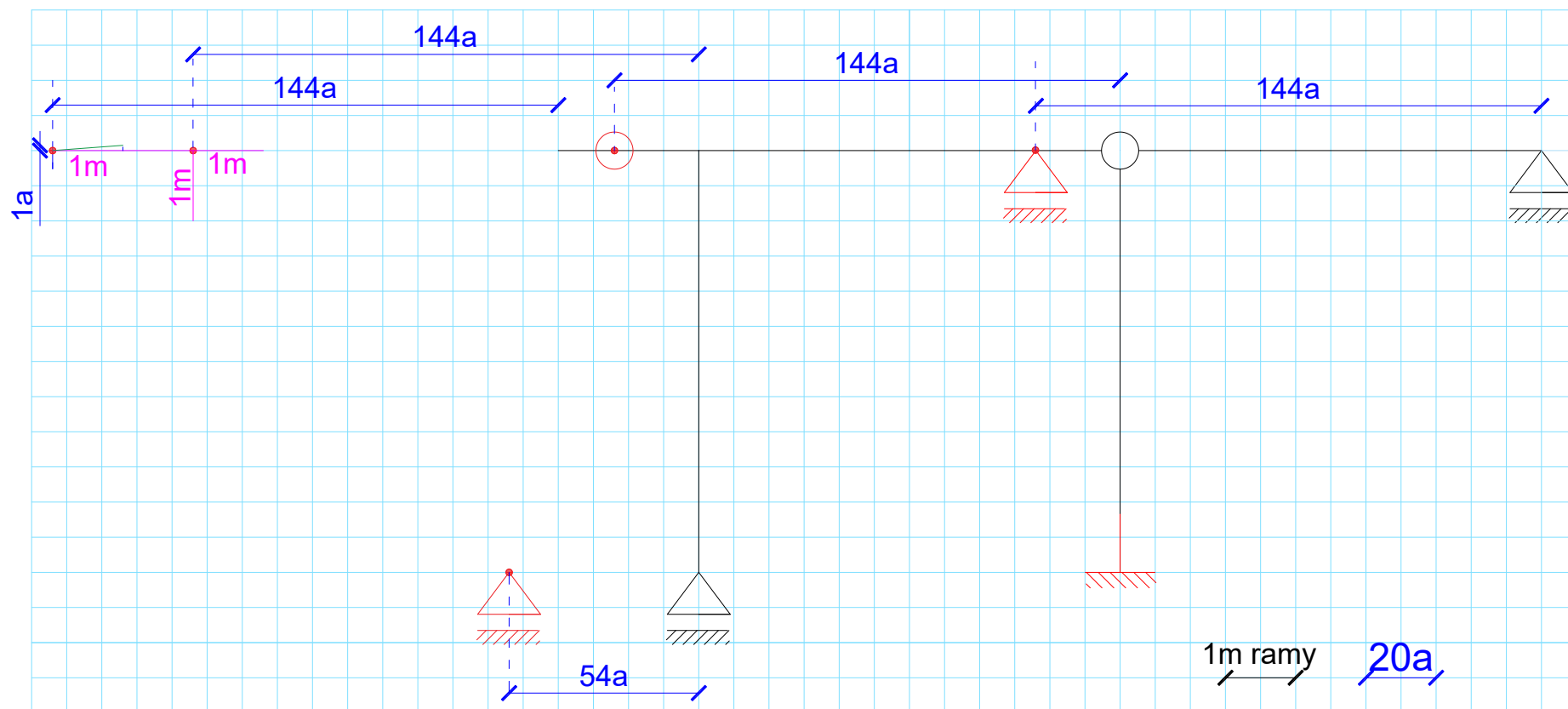
dr inż. Hanna Weber



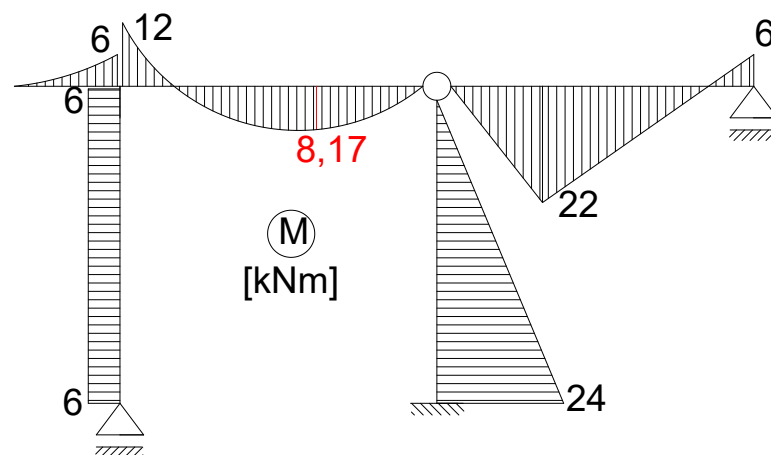
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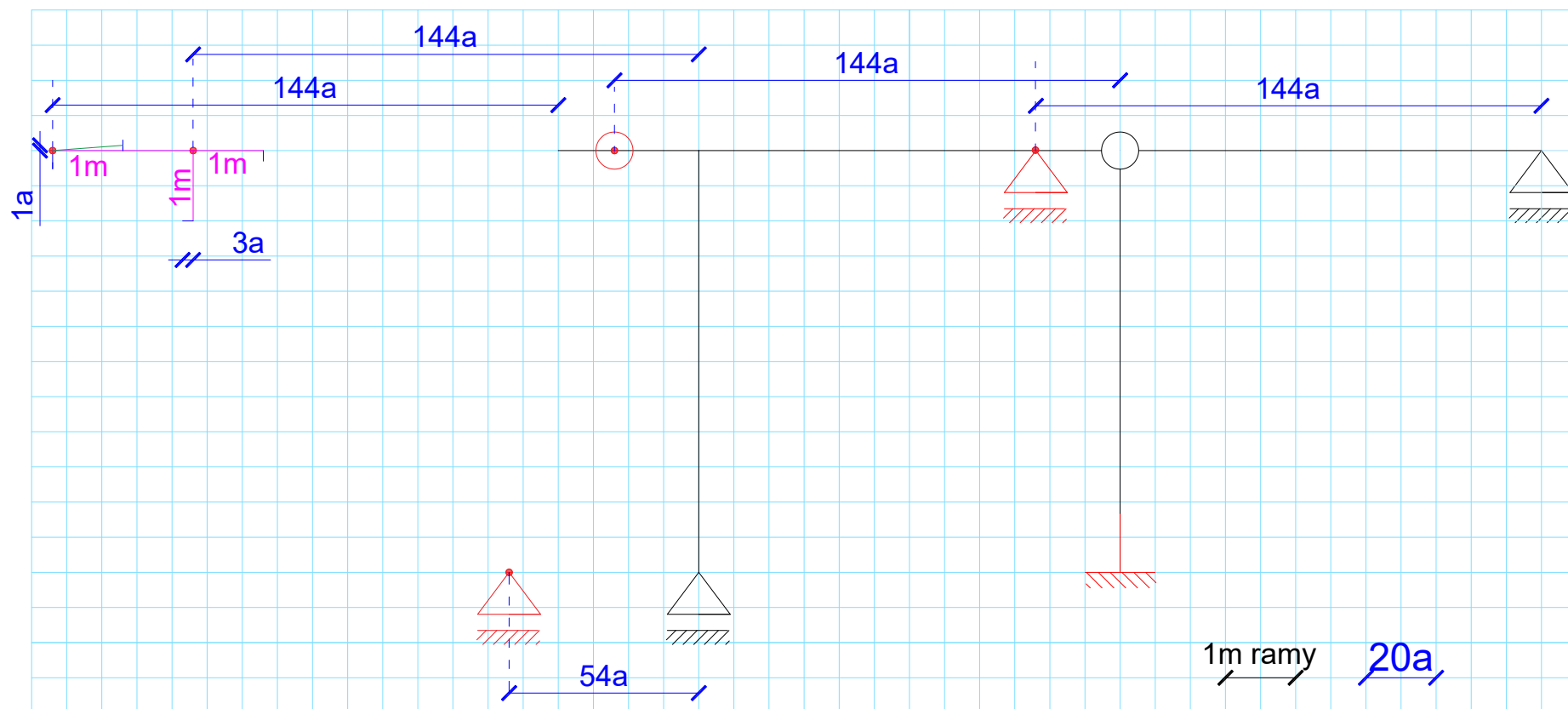


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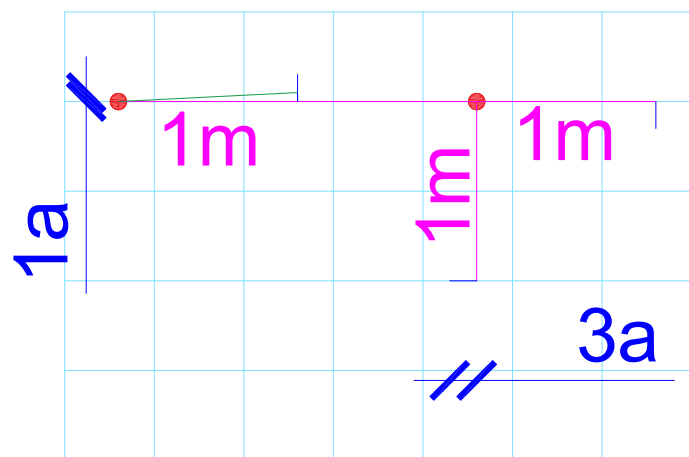


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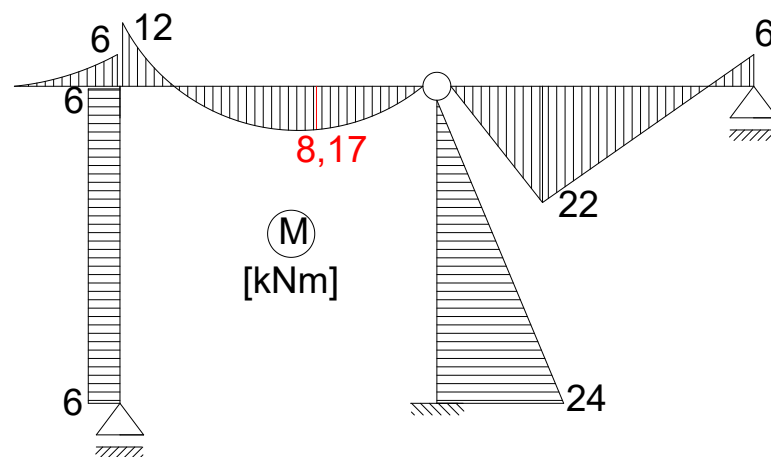




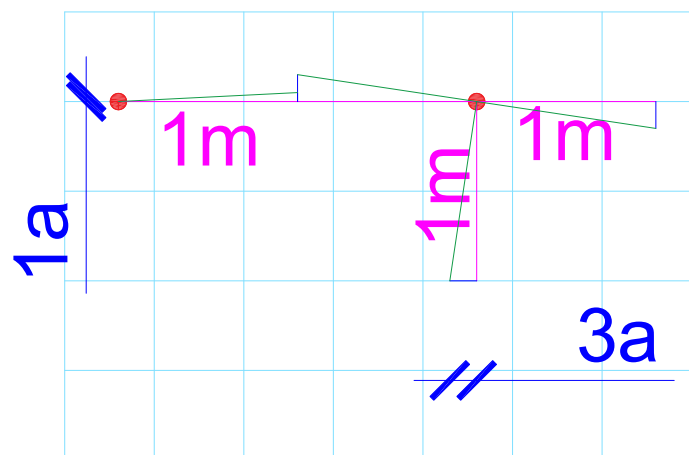
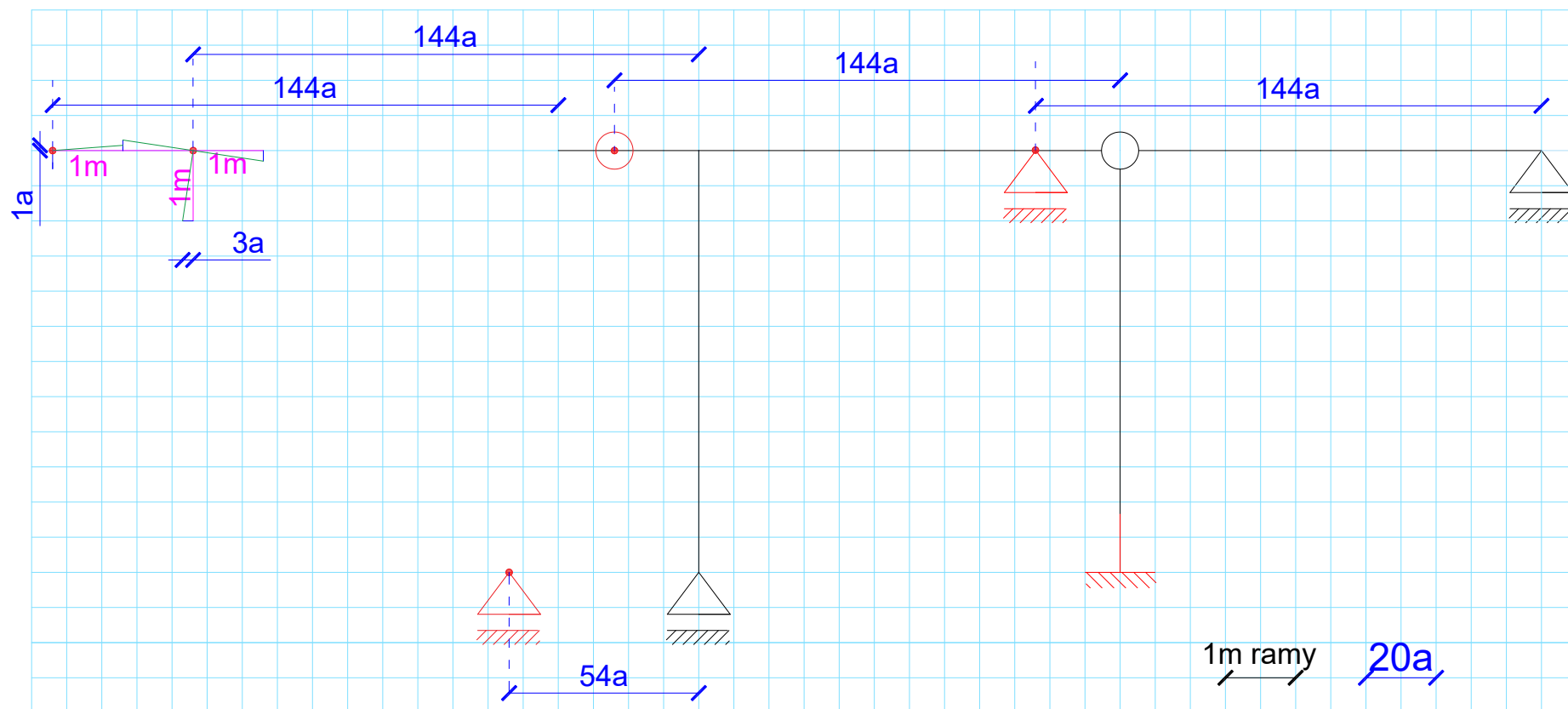
$1m$ ramy $20a$



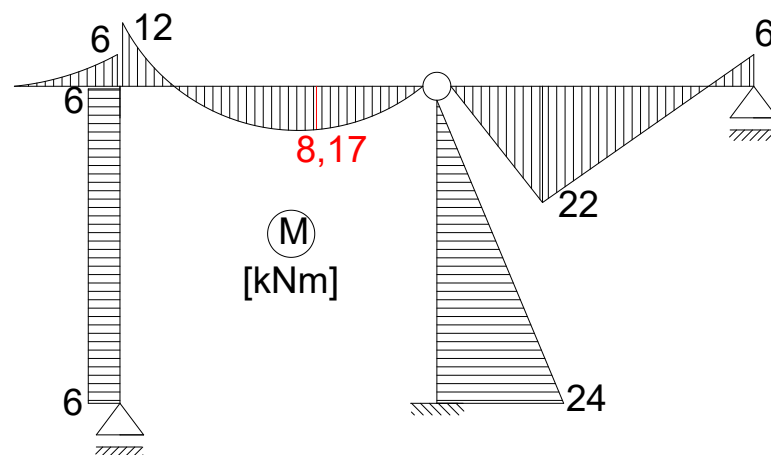
$$\varphi_E = -a \quad \varphi_F = 3a$$



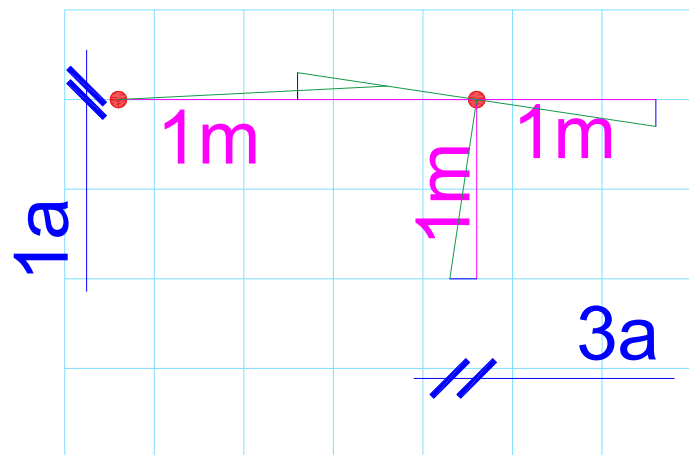
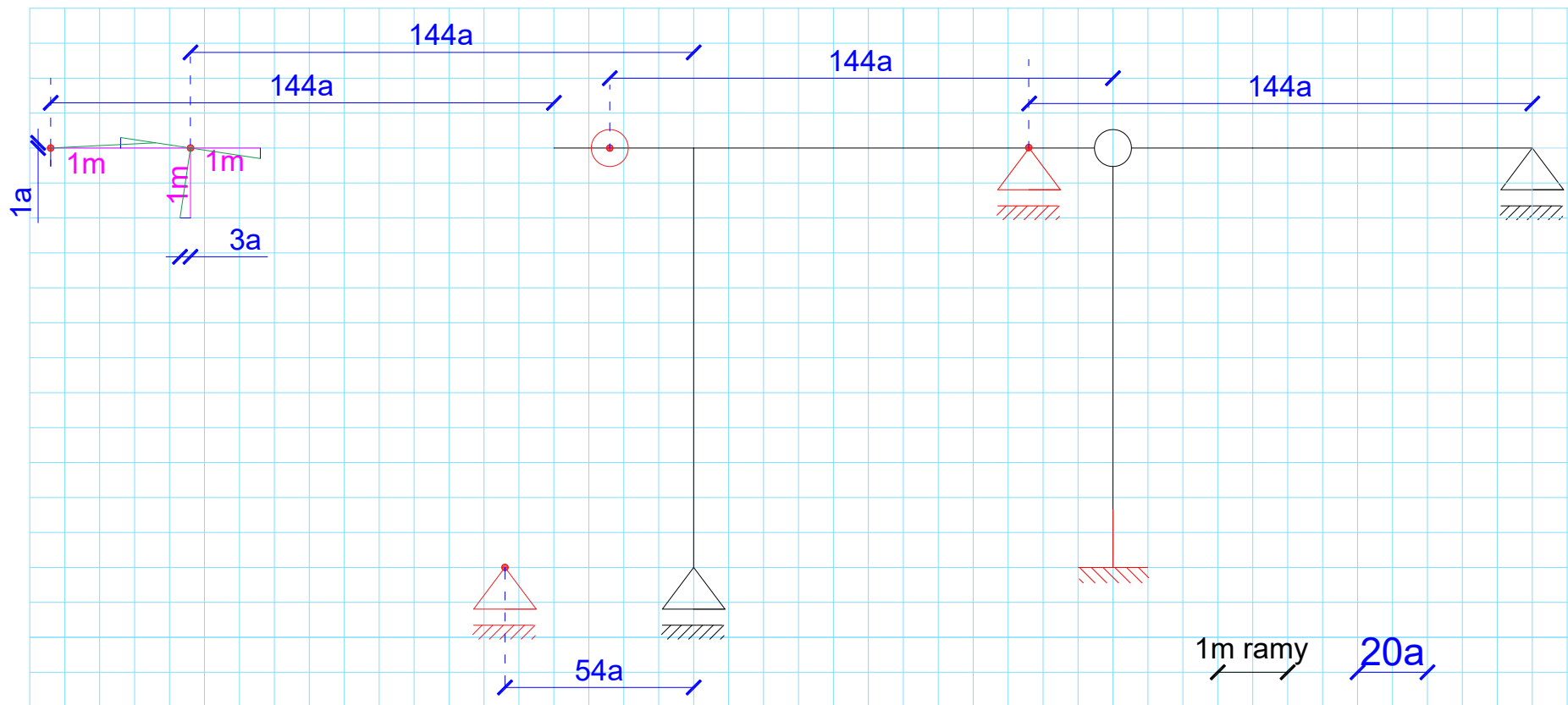
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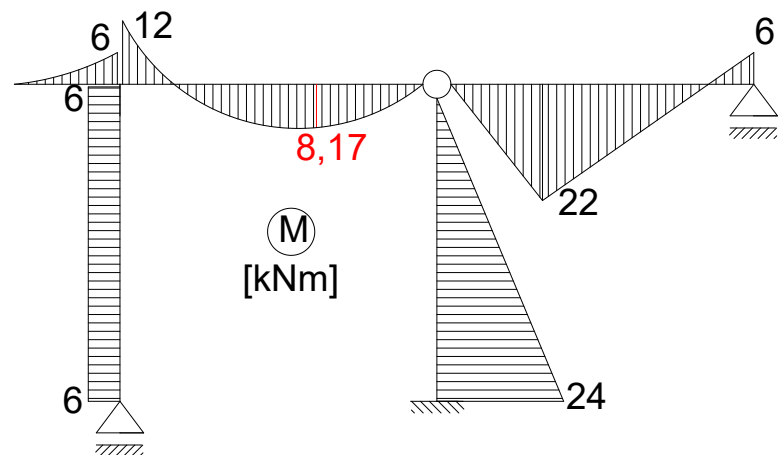
$$\varphi_E = -a \quad \varphi_F = 3a$$



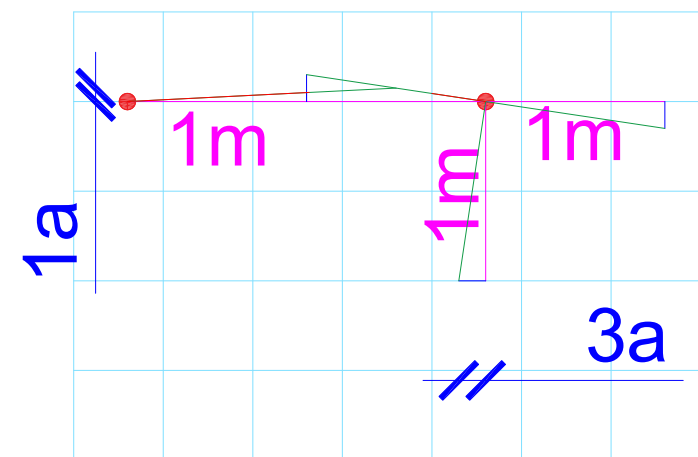
dr inż. Hanna Weber



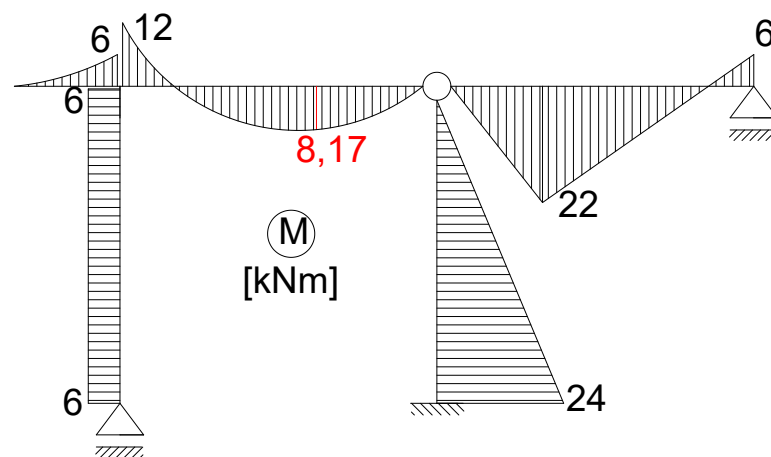
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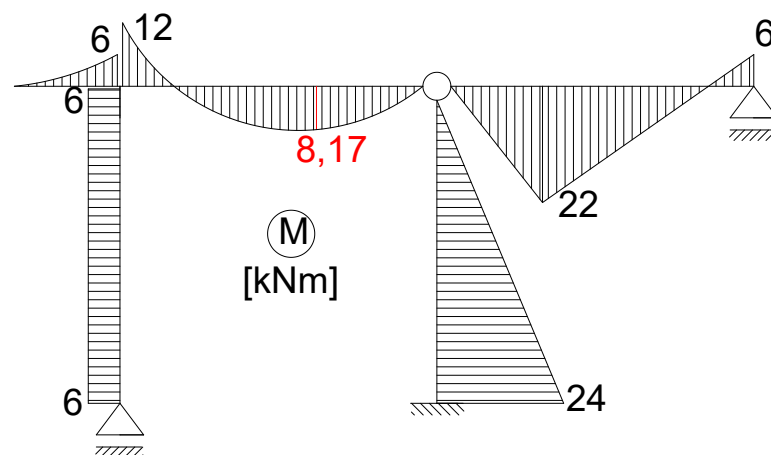
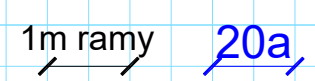
dr inž. Hanna Weber



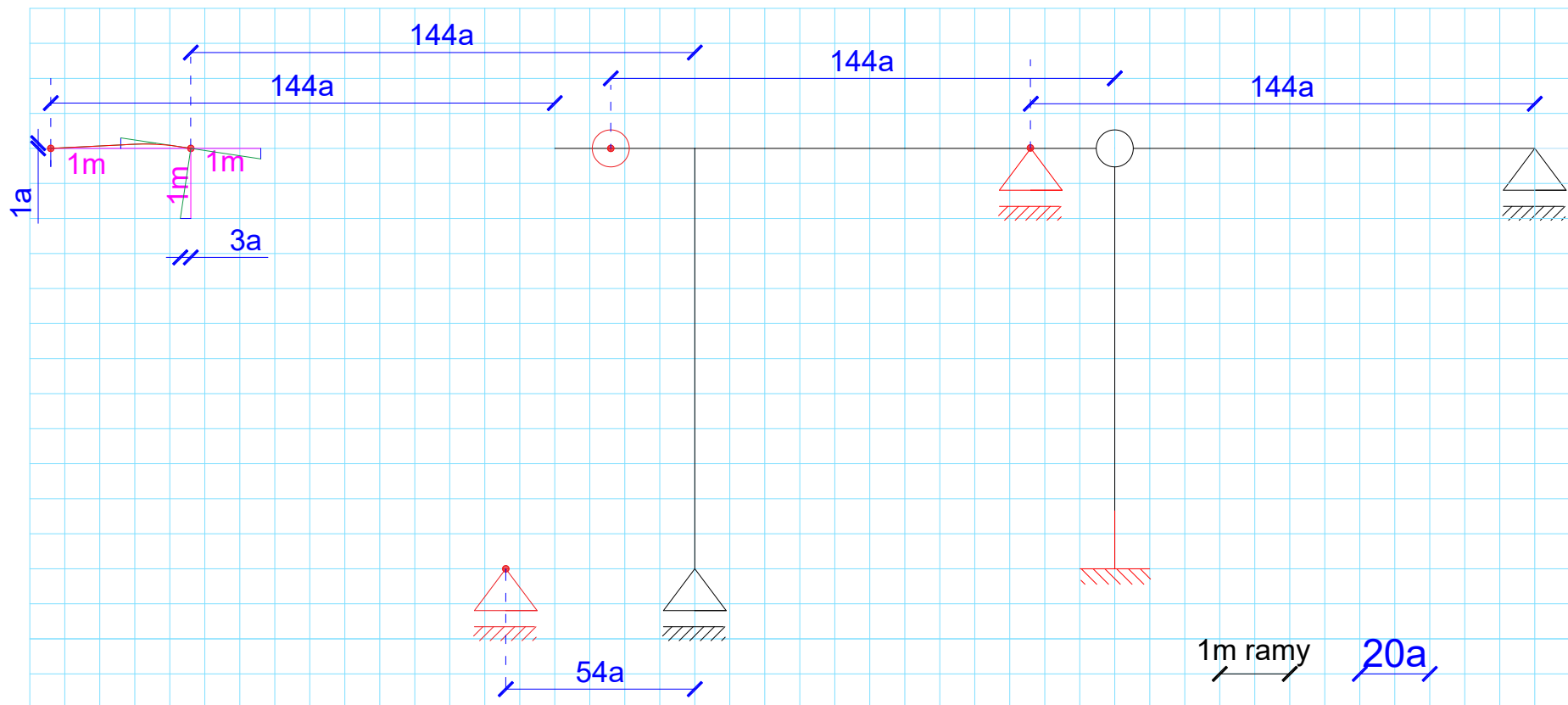
$$\varphi_E = -a \qquad \varphi_F = 3a$$



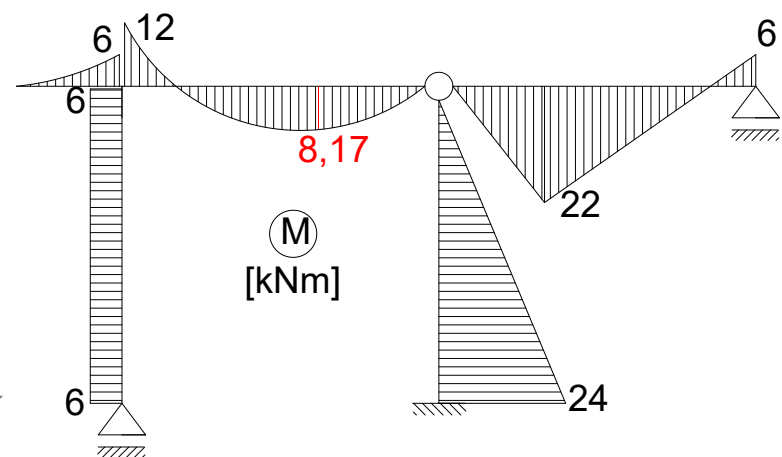
dr inż. Hanna Weber



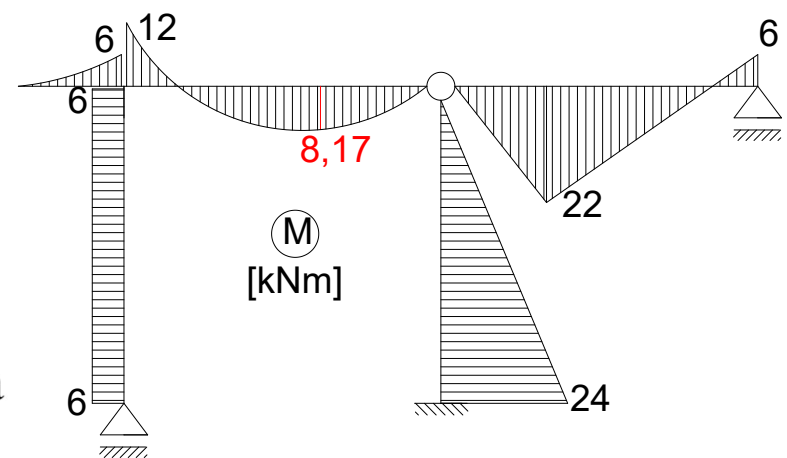
dr inż. Hanna Weber



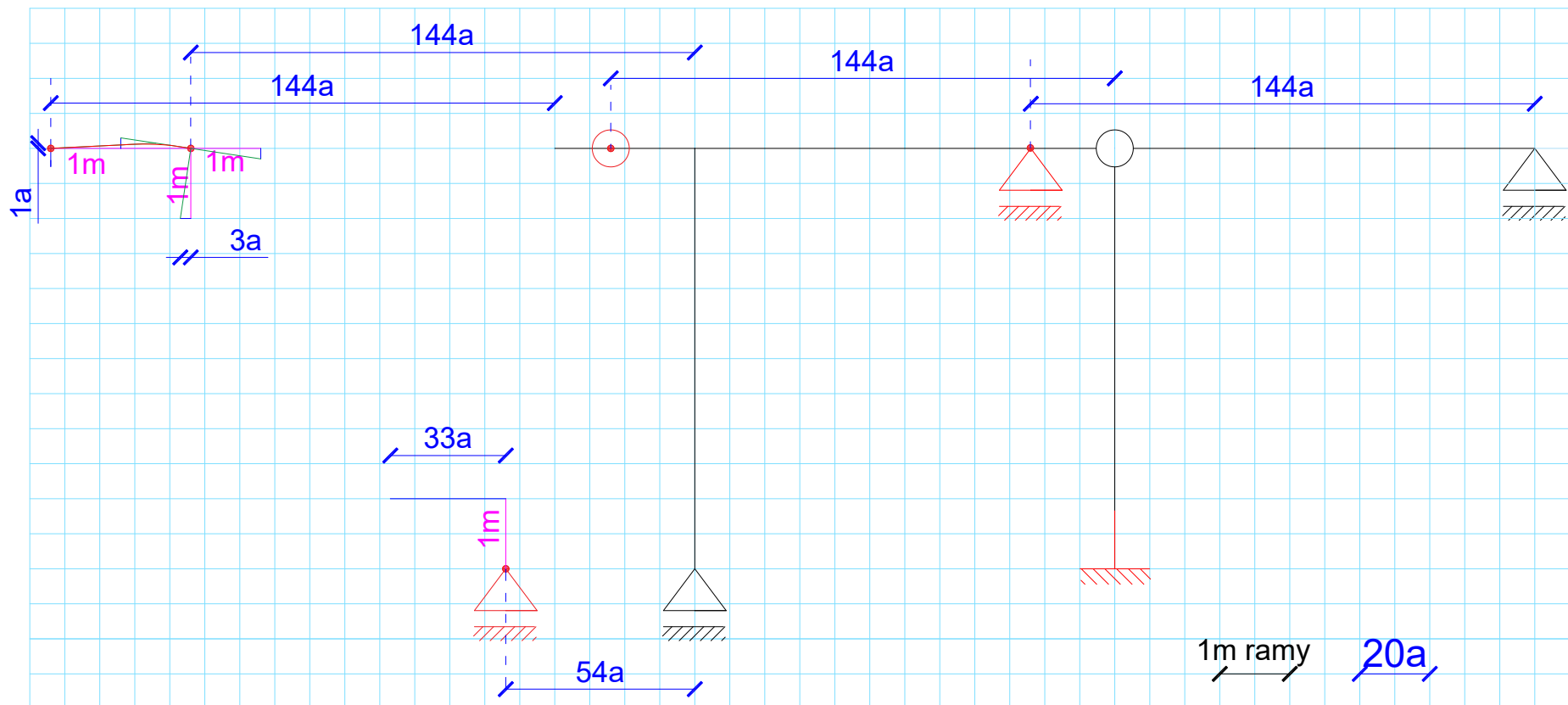
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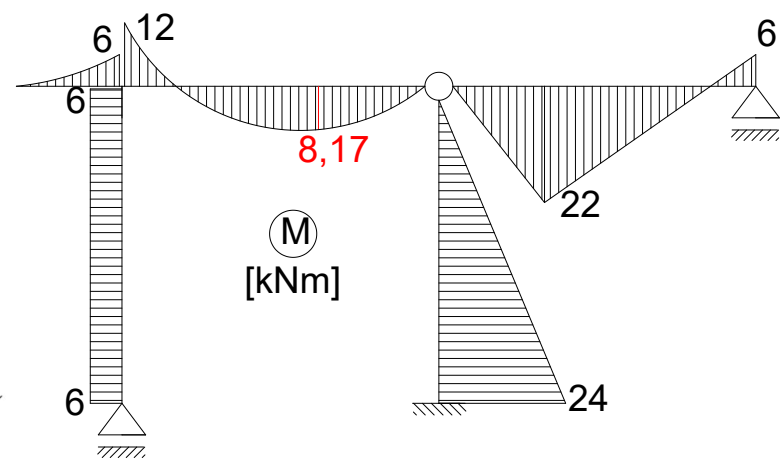
dr inż. Hanna Weber



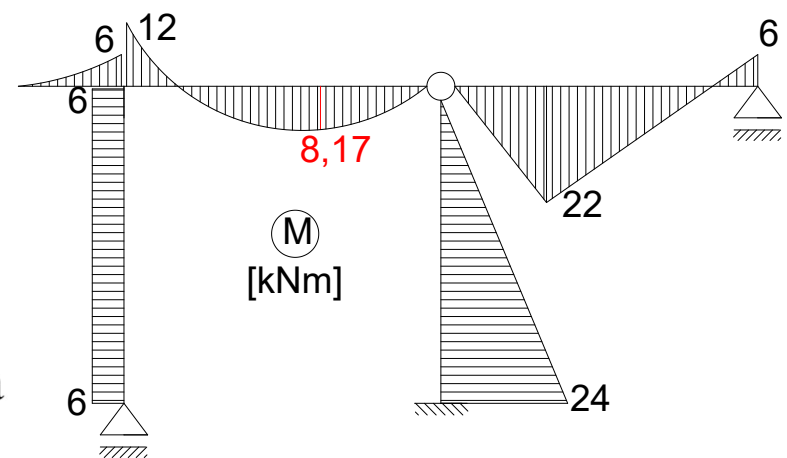
dr inż. Hanna Weber



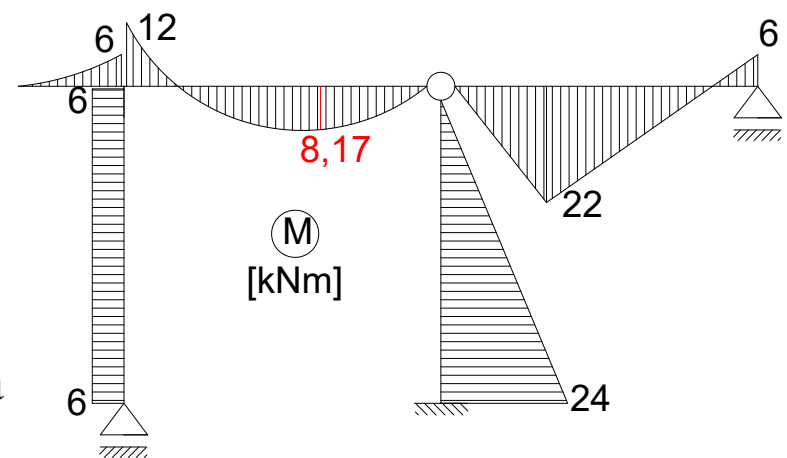
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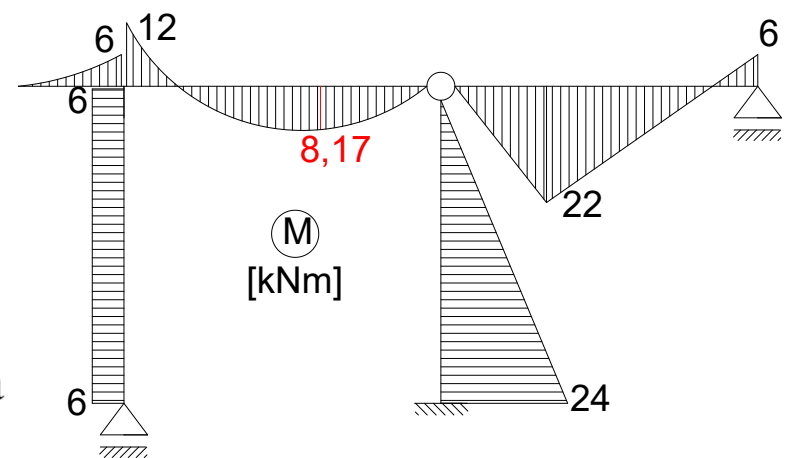
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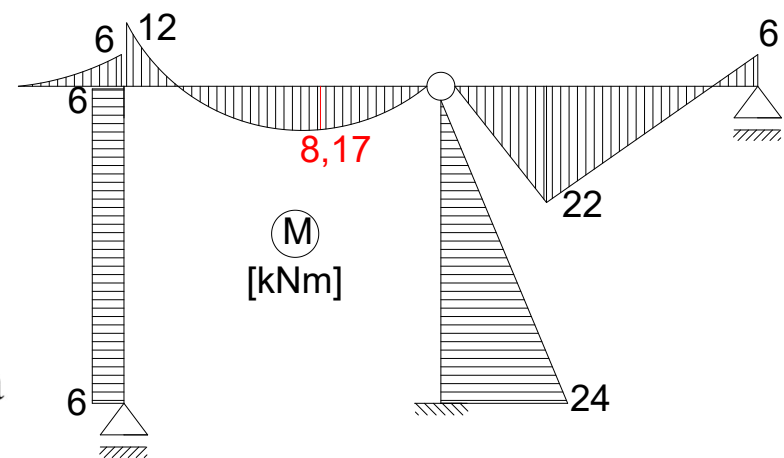
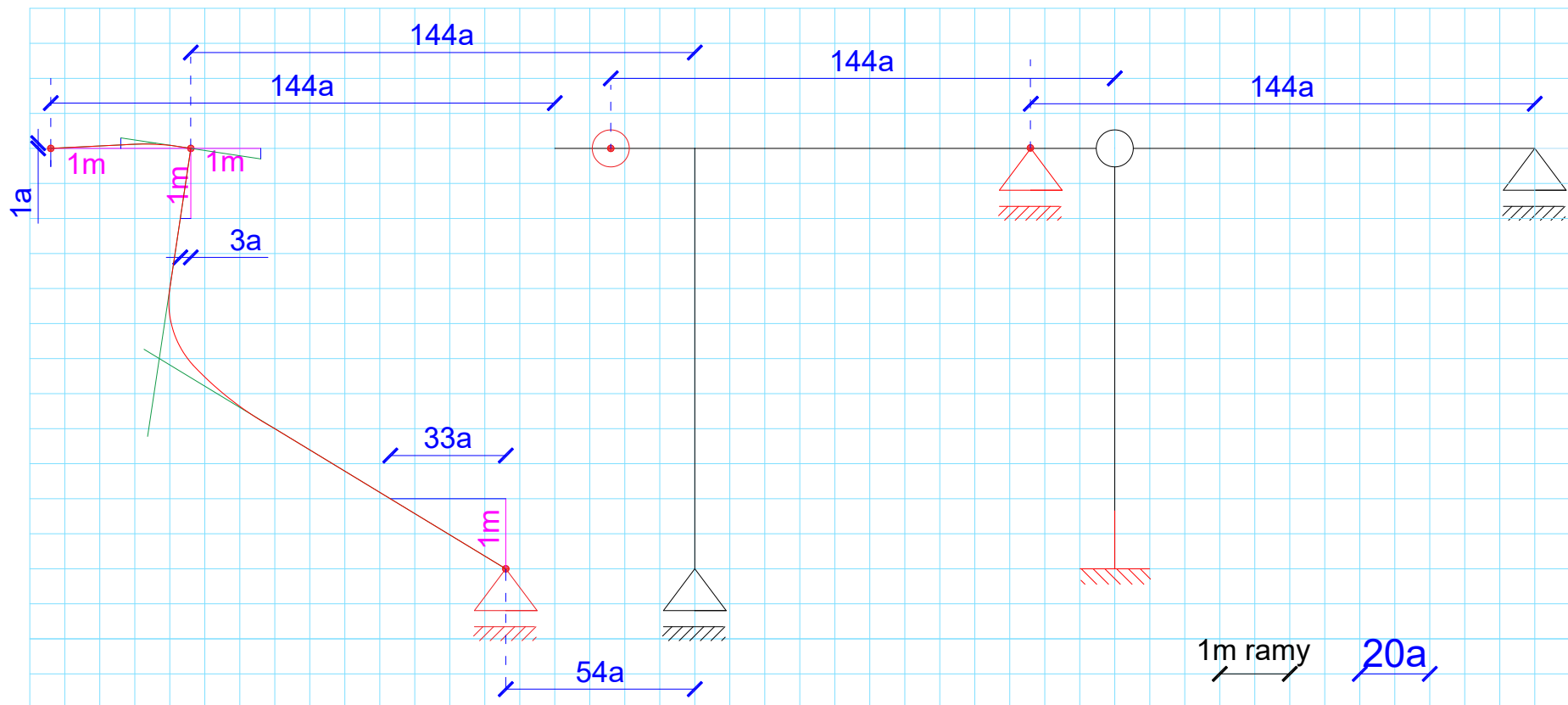
dr inż. Hanna Weber



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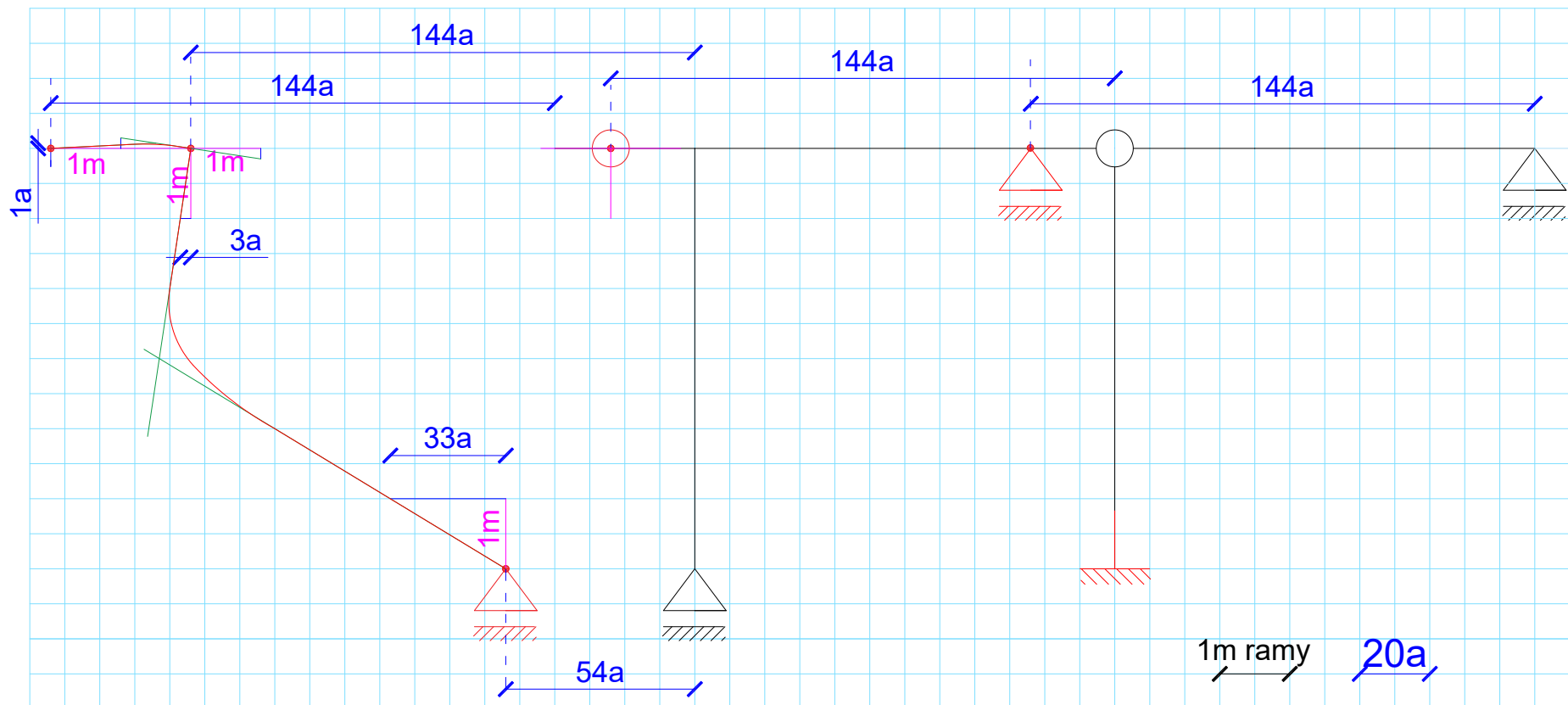


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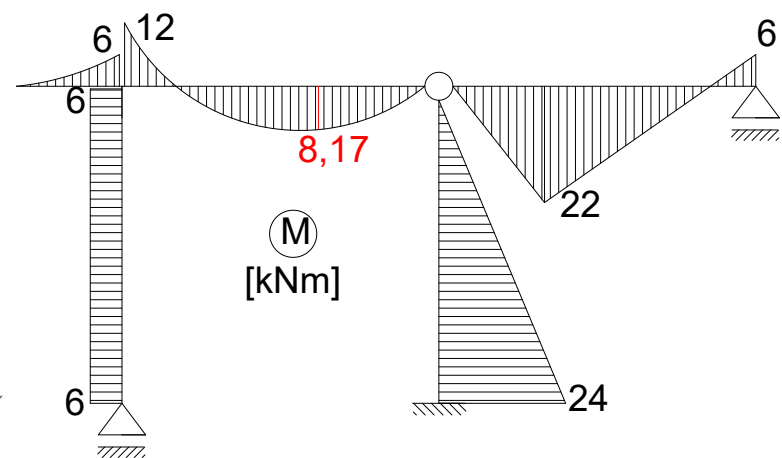


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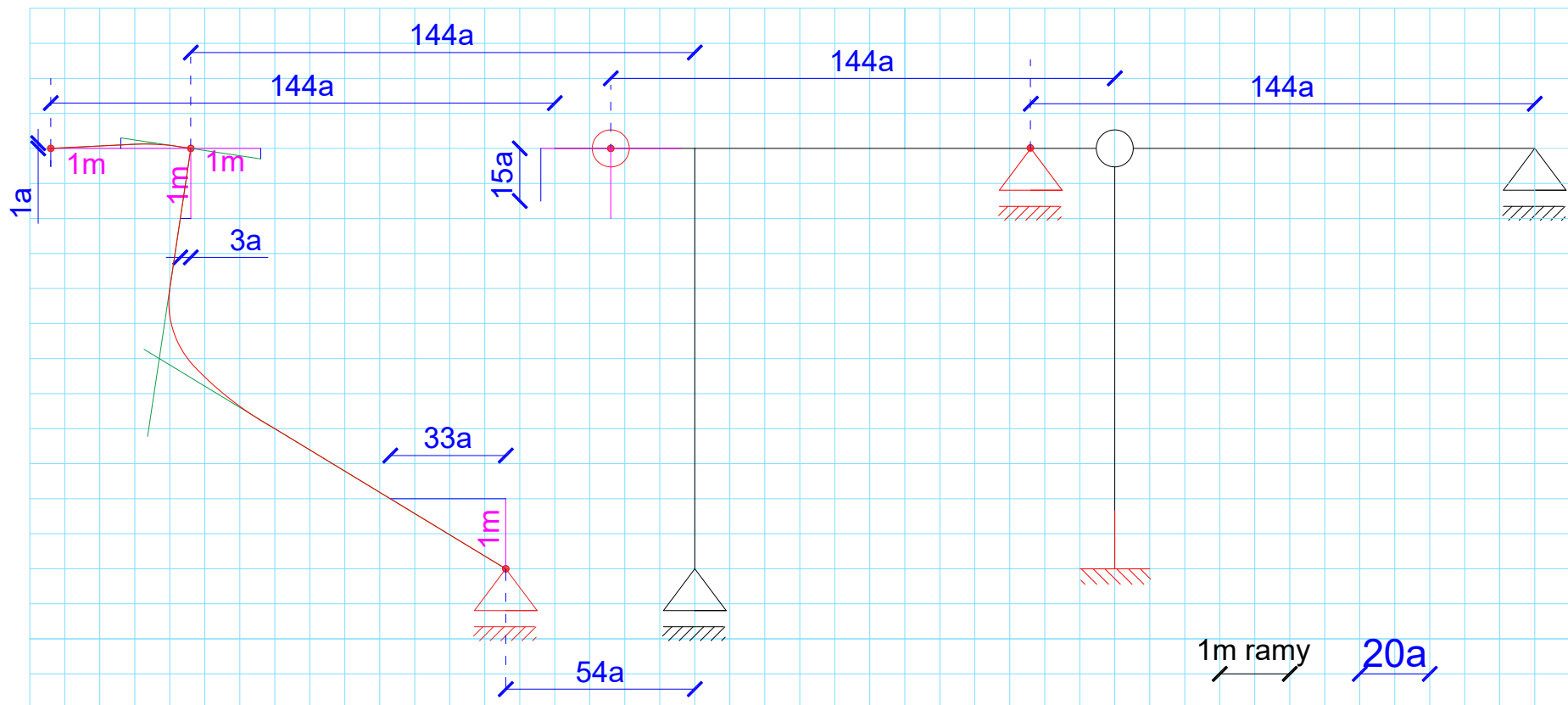
dr inż. Hanna Weber



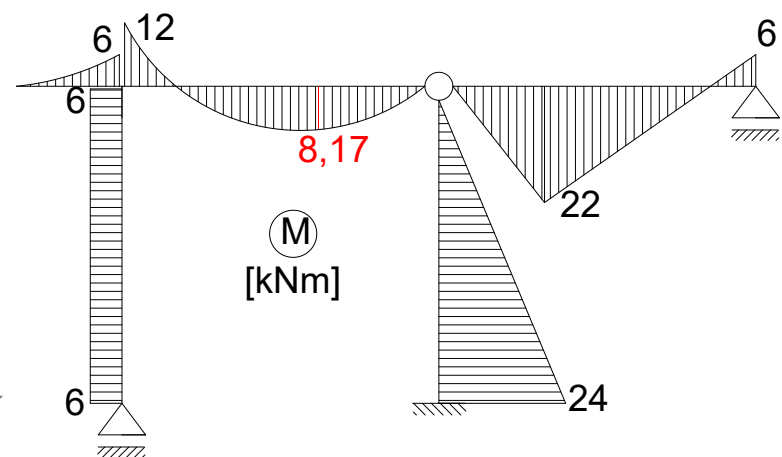
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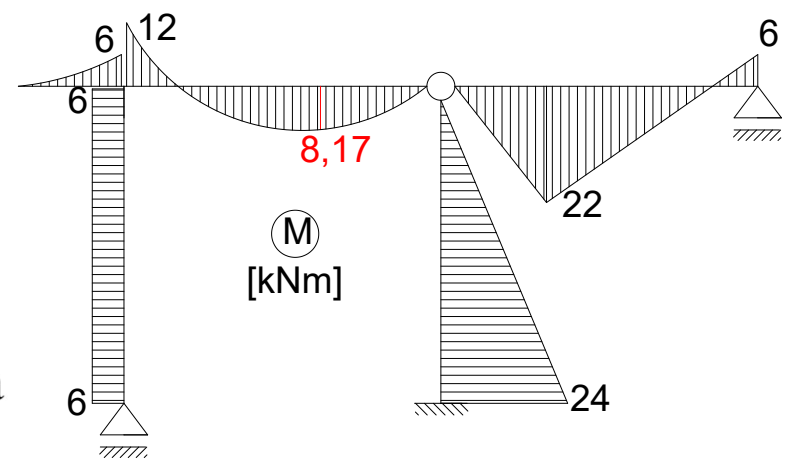
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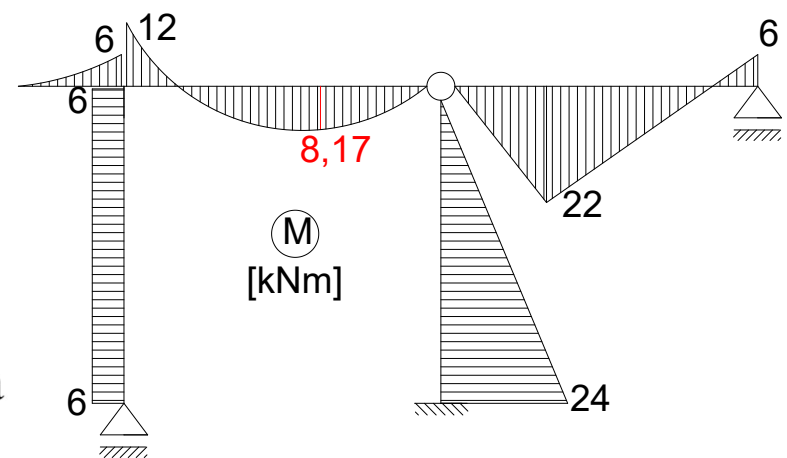
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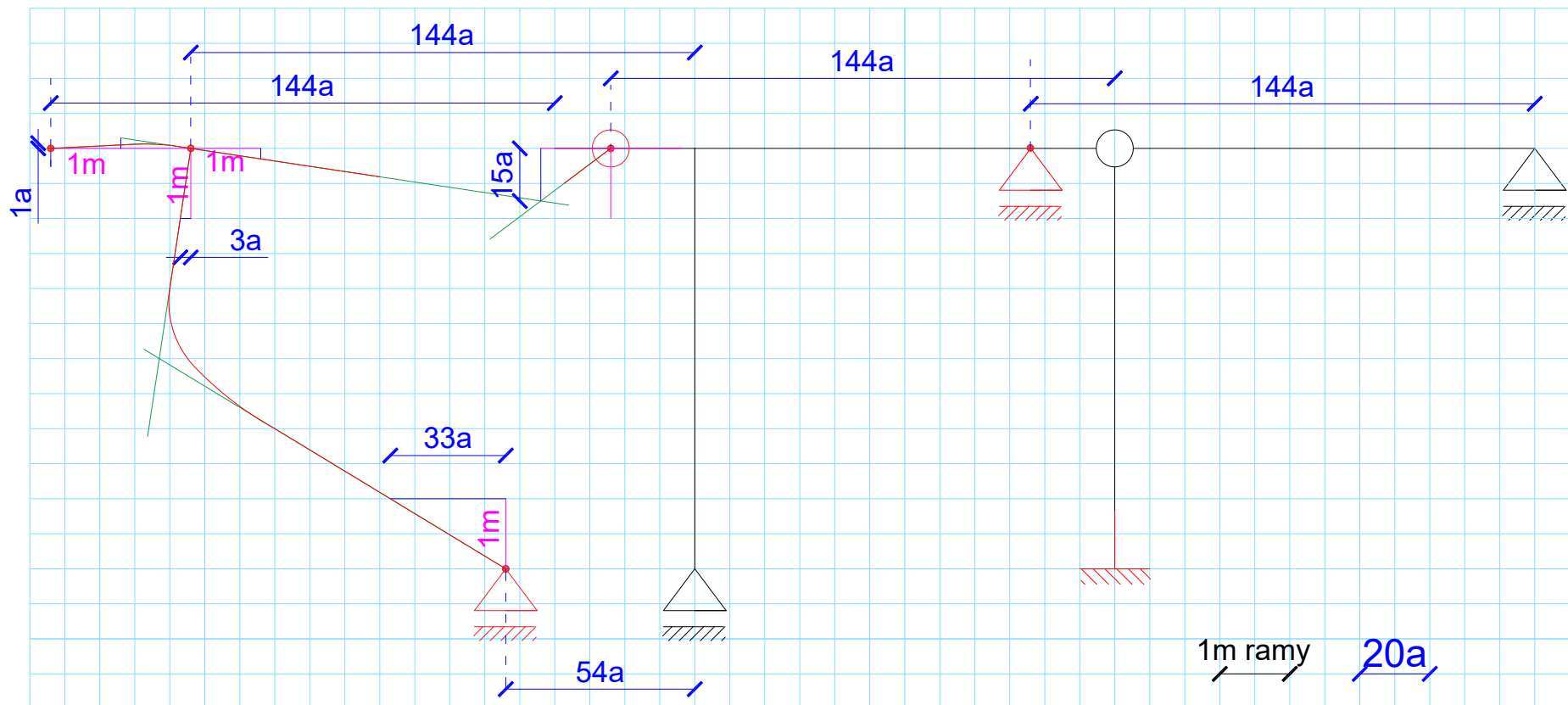
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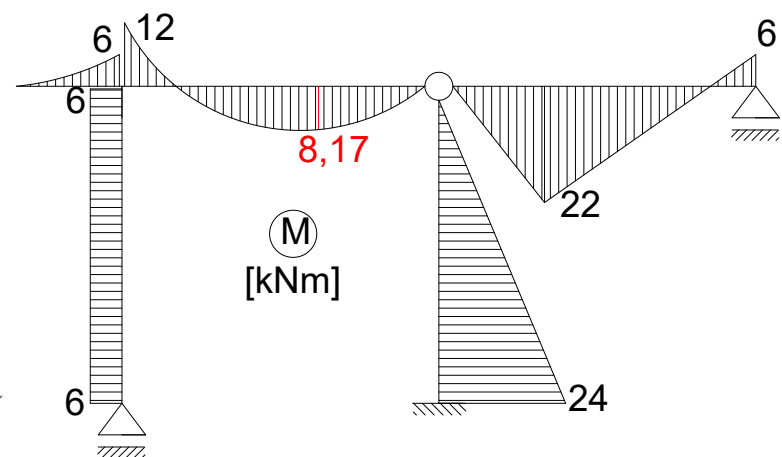
dr inż. Hanna Weber



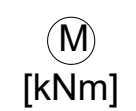
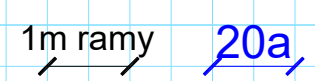
dr inż. Hanna Weber



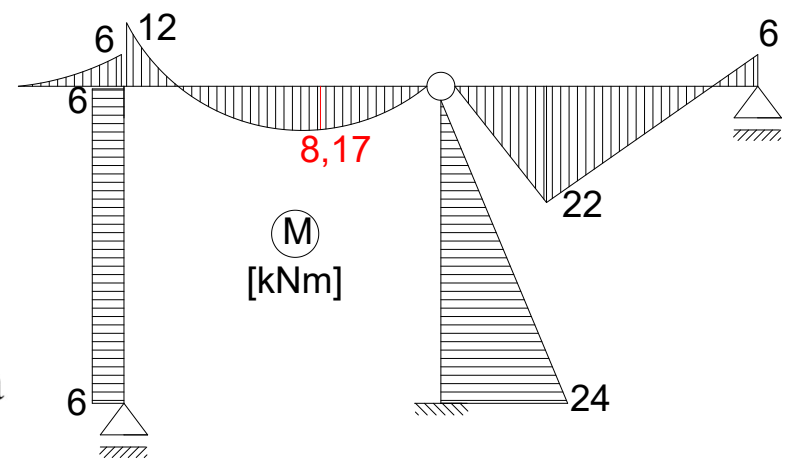
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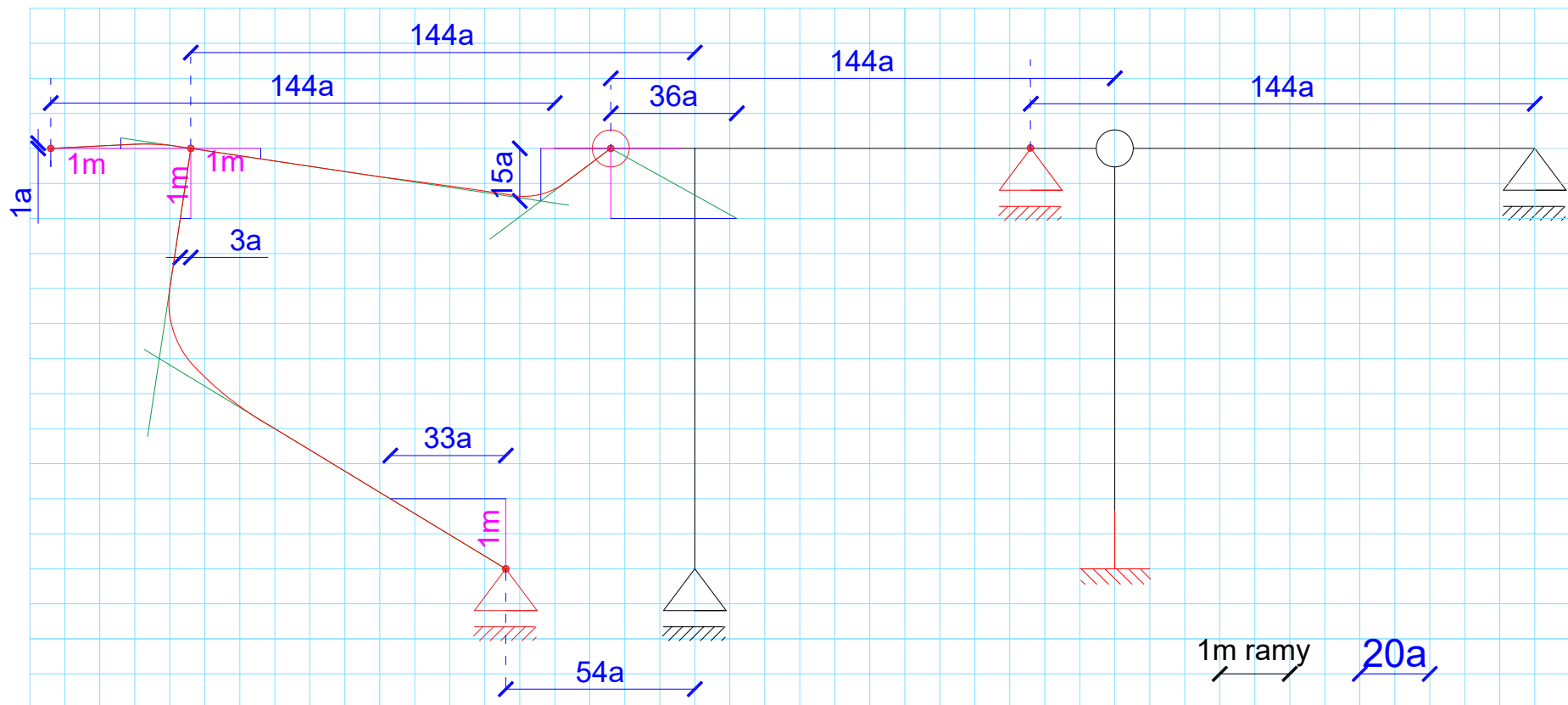
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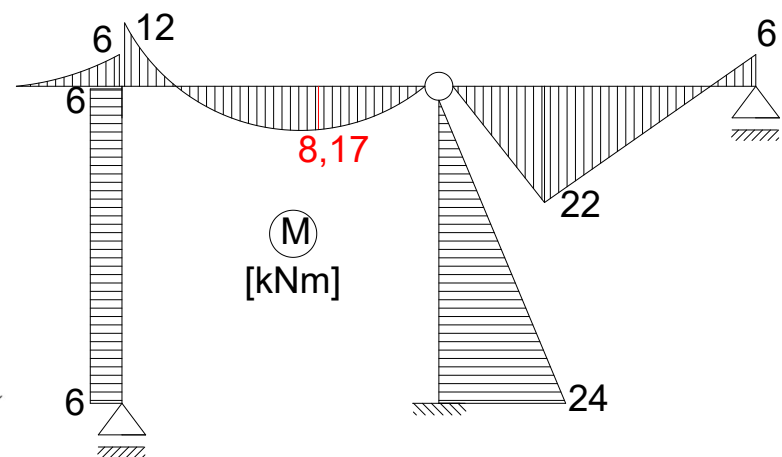
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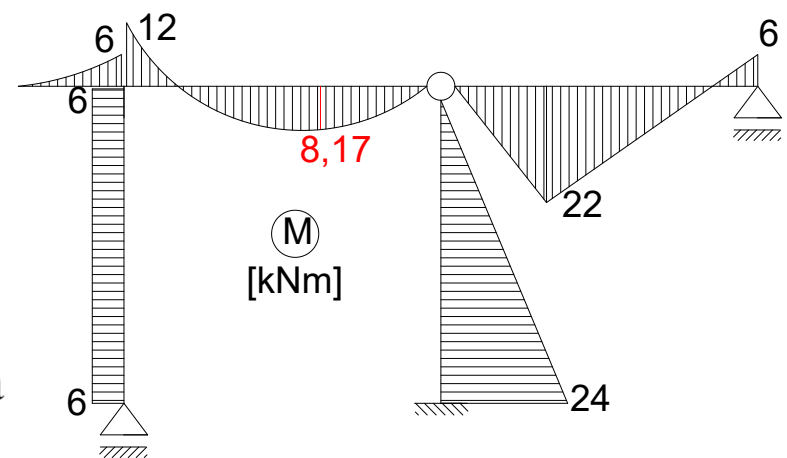
dr inż. Hanna Weber



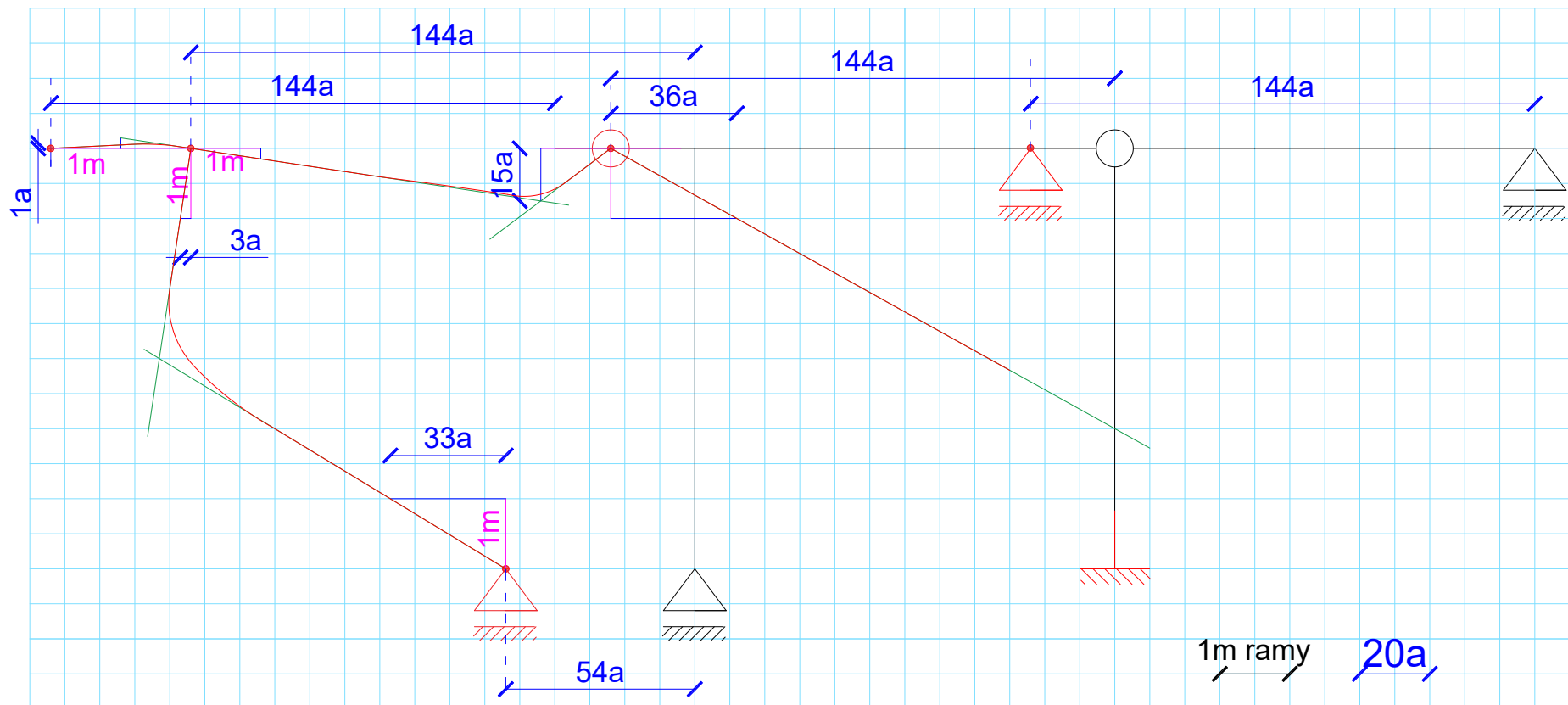
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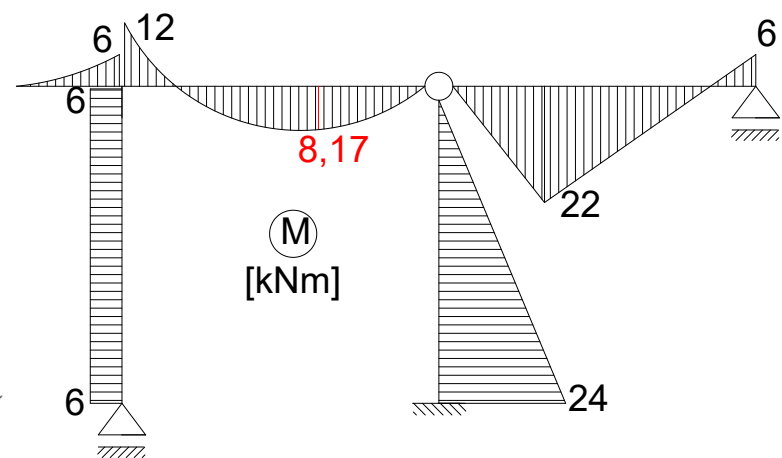
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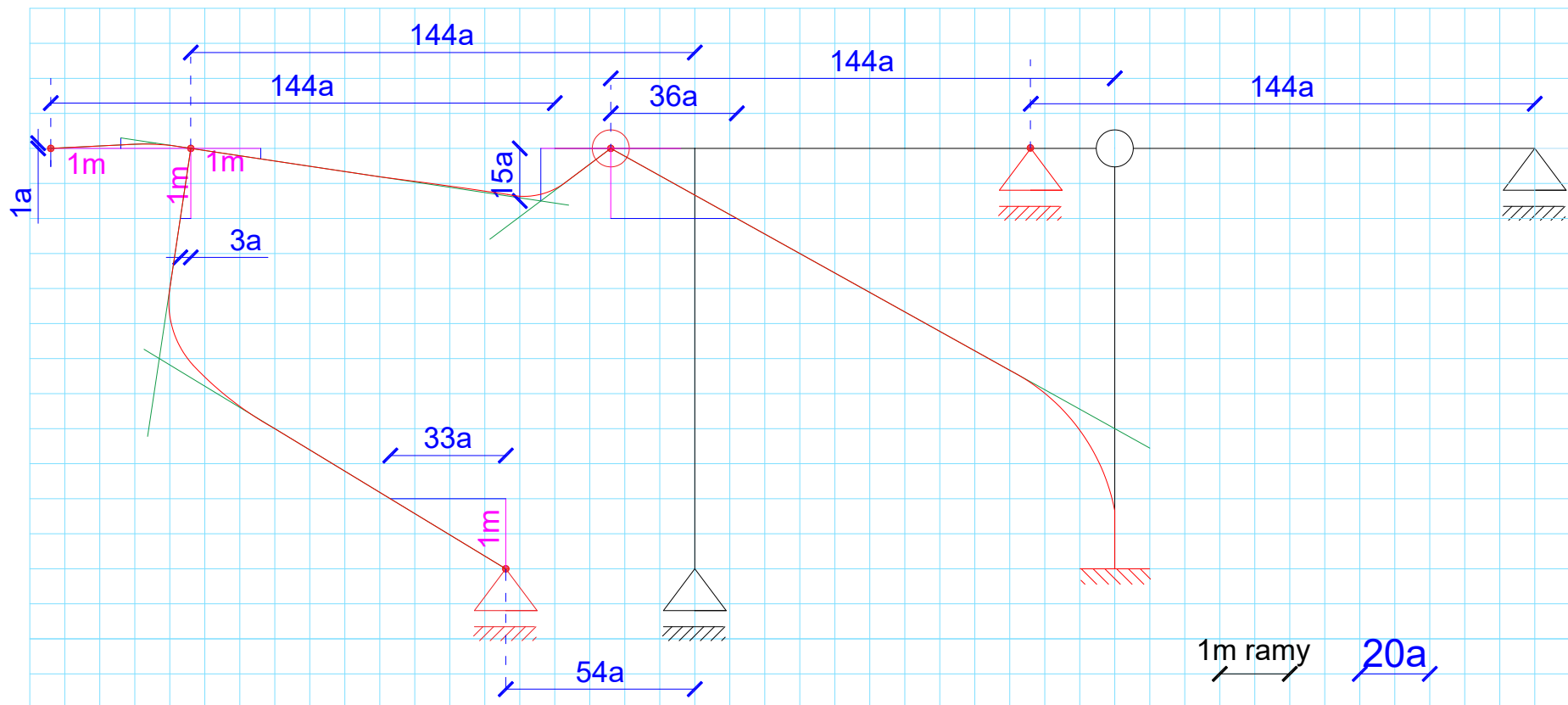
dr inż. Hanna Weber



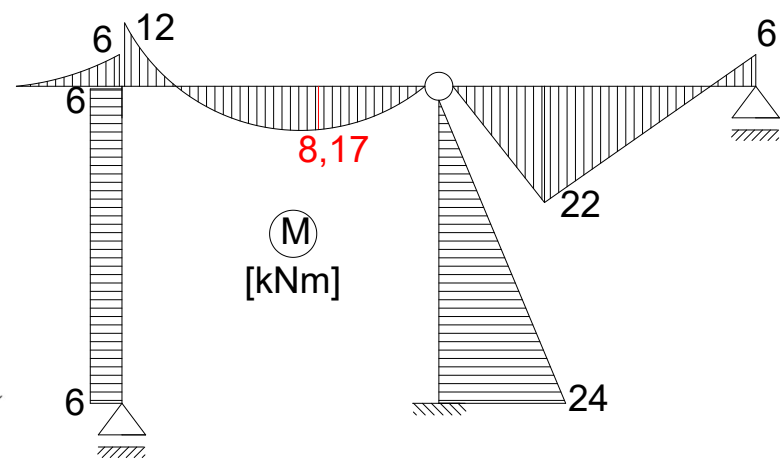
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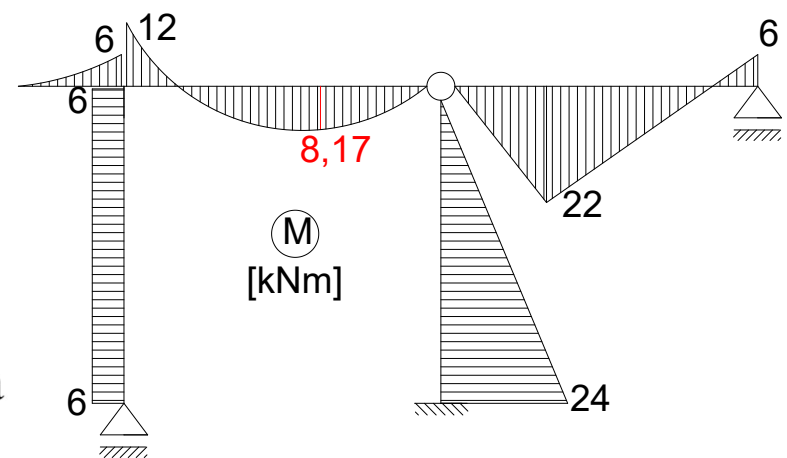
dr inž. Hanna Weber



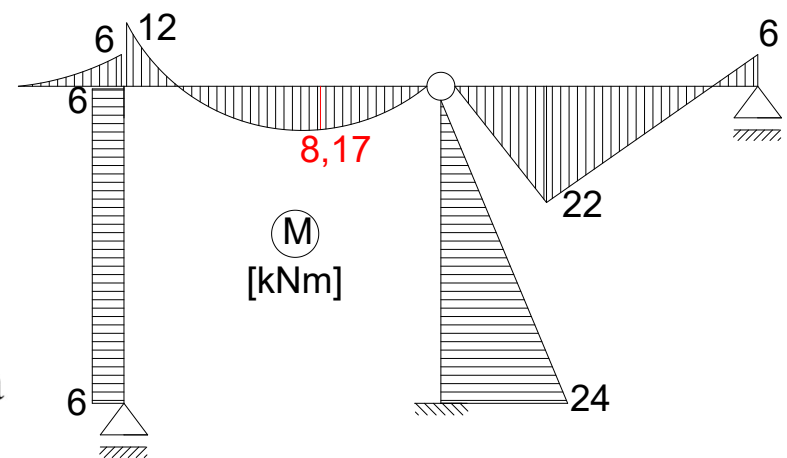
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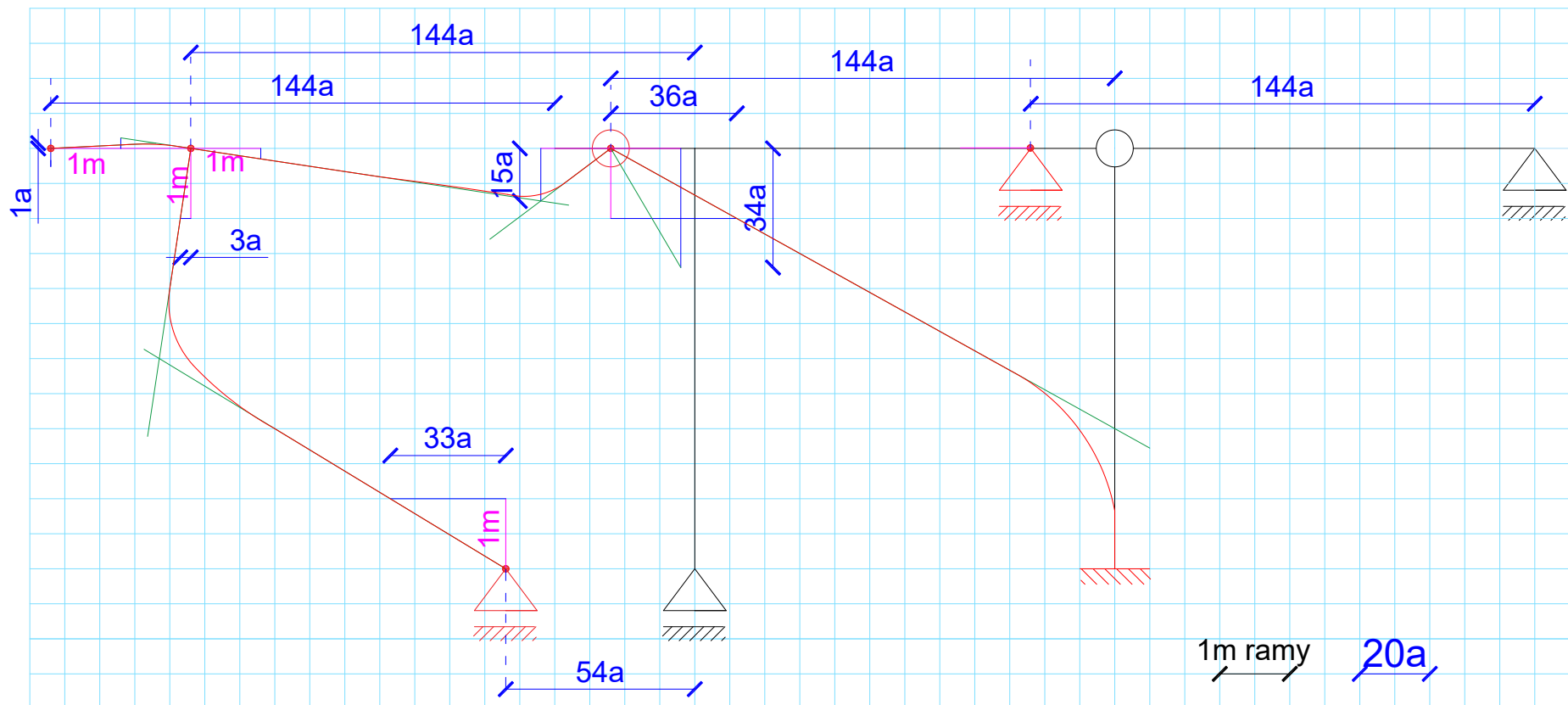
dr inż. Hanna Weber



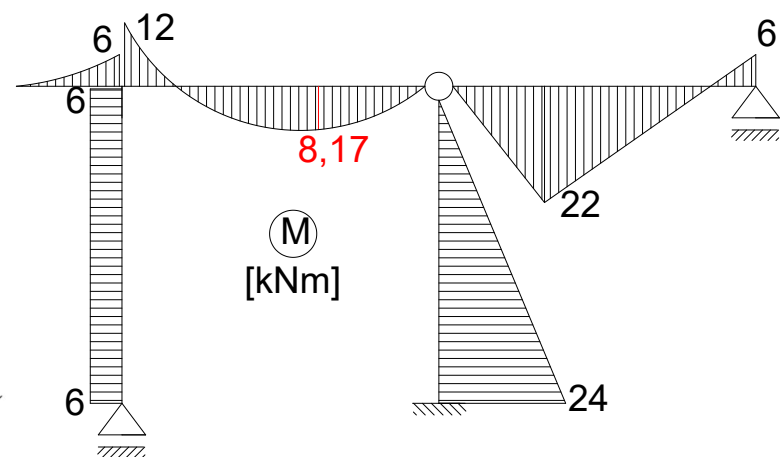
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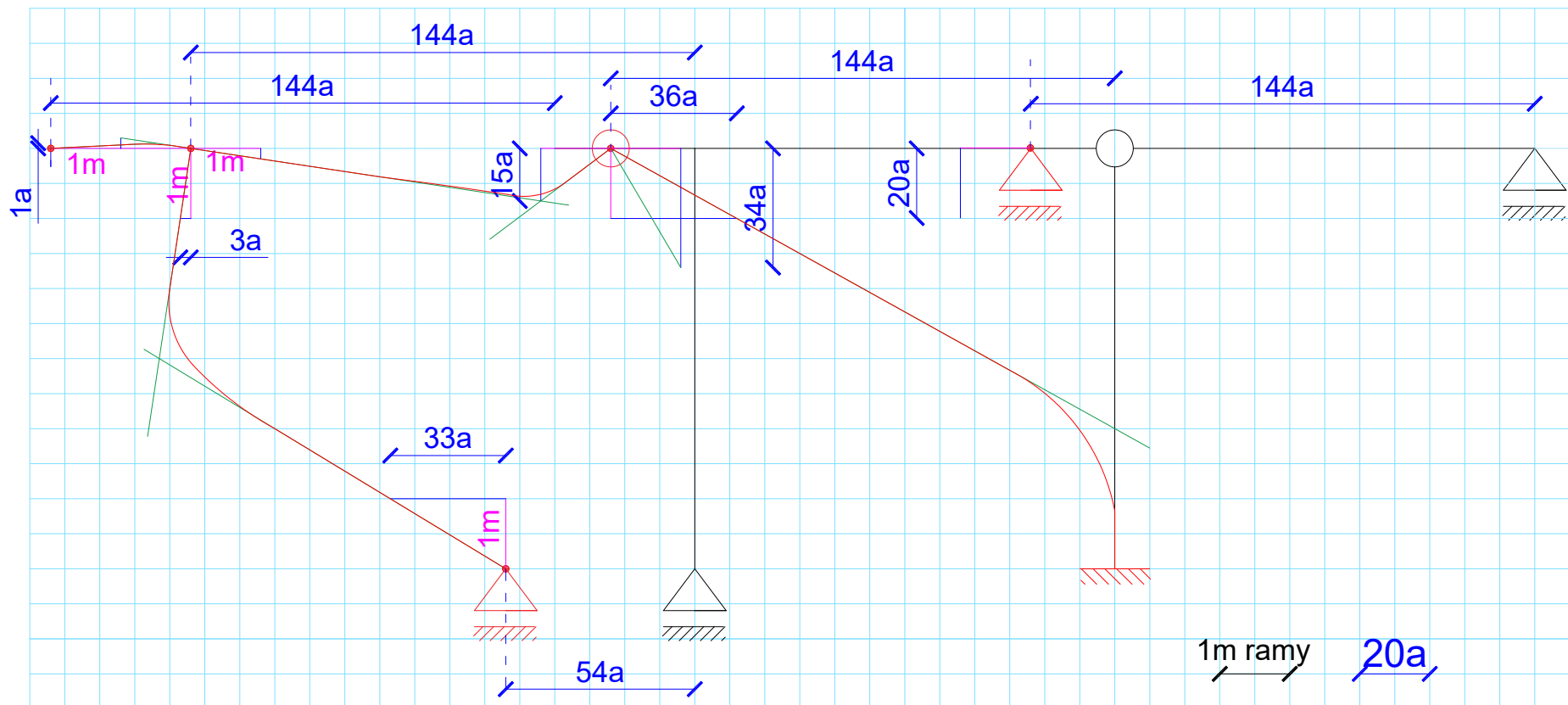
dr inż. Hanna Weber



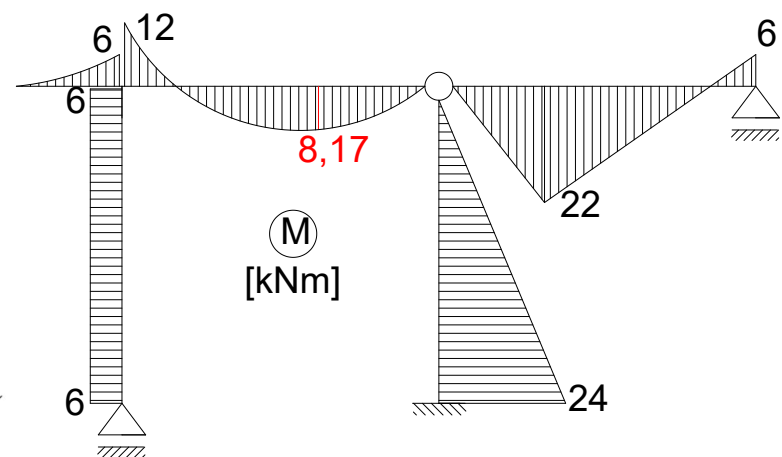
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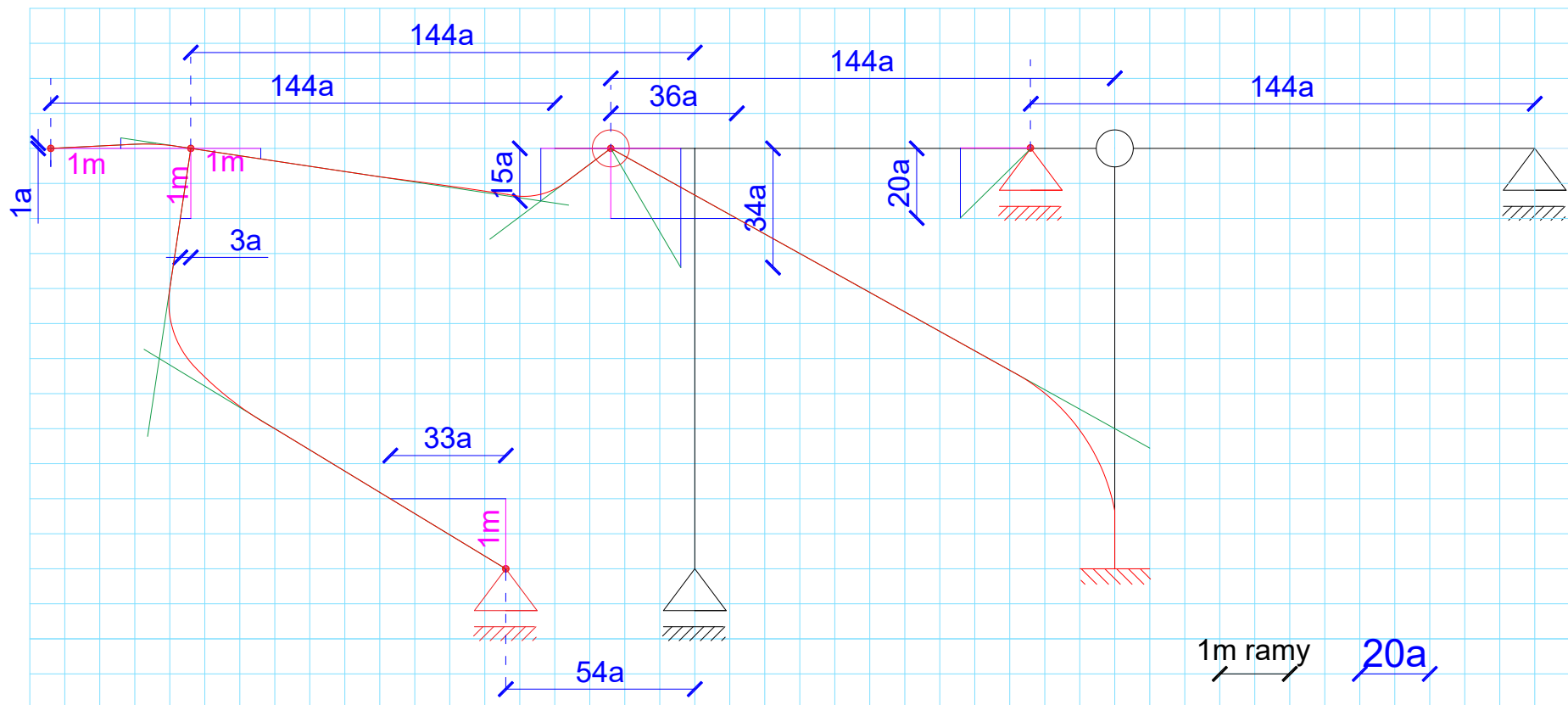
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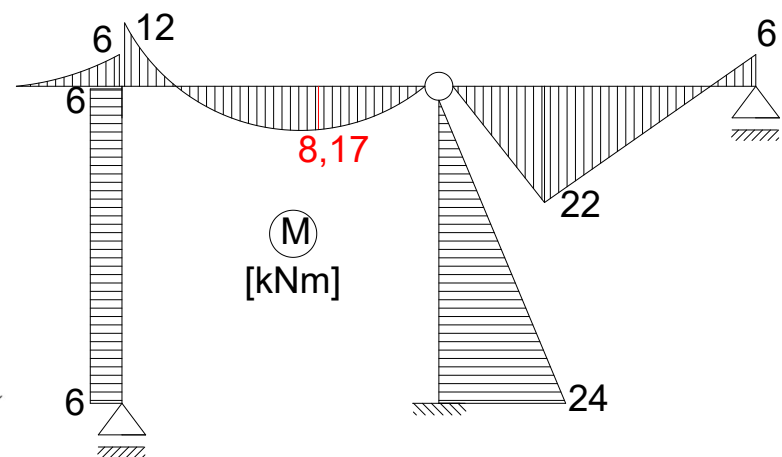
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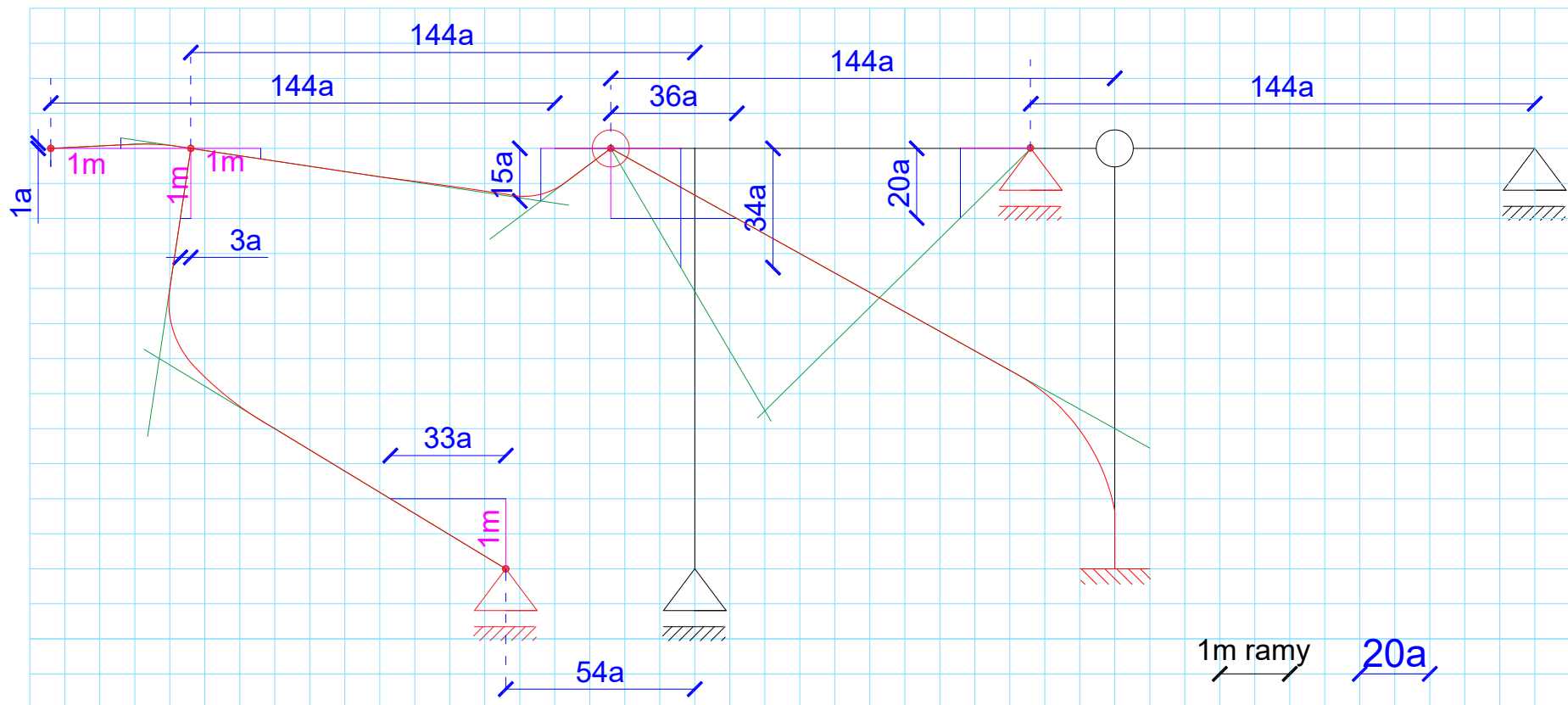
dr inż. Hanna Weber



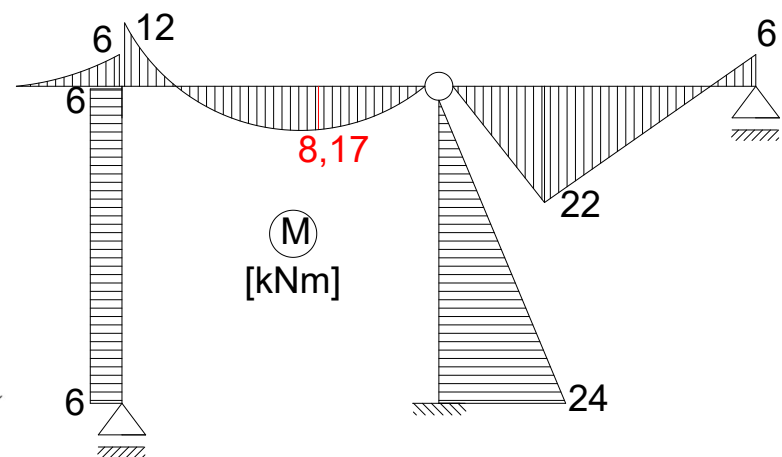
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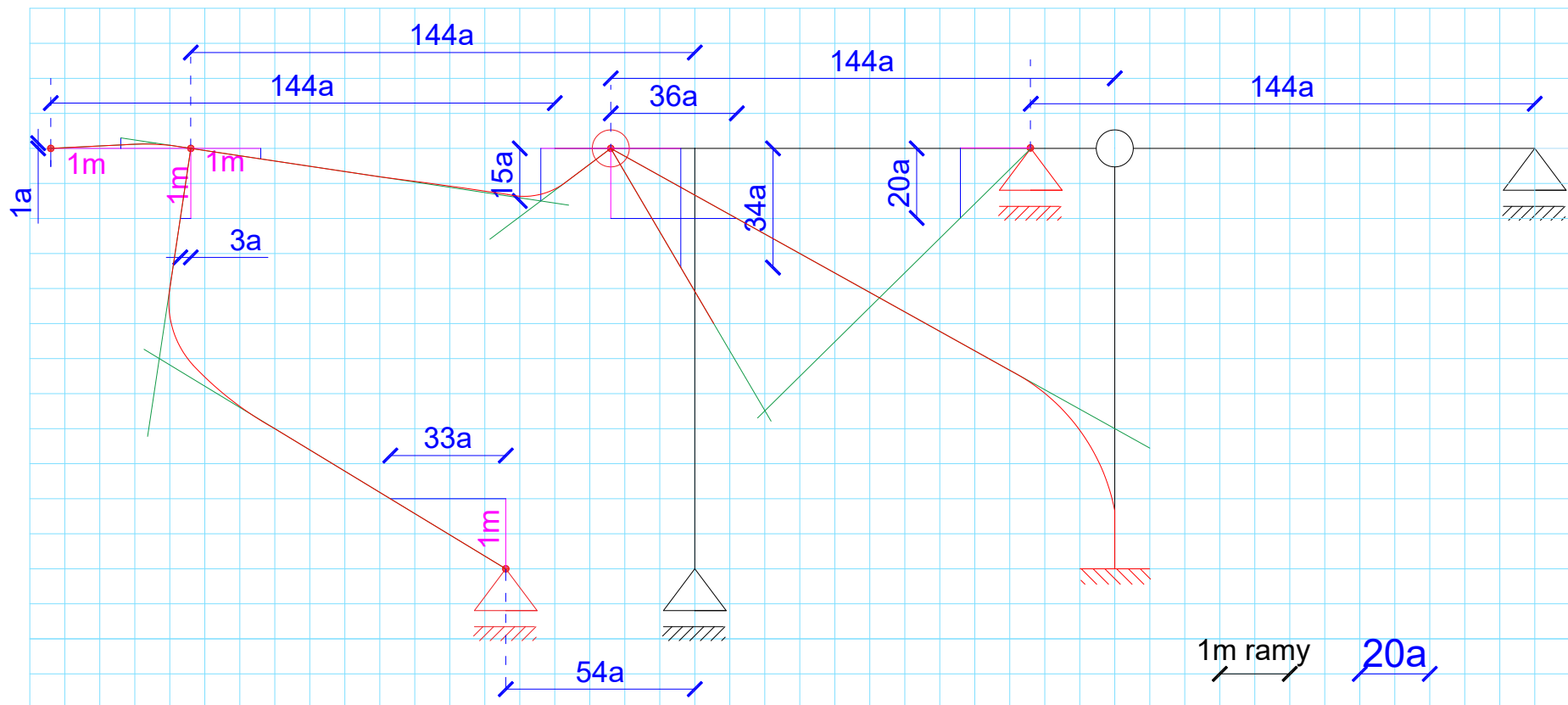
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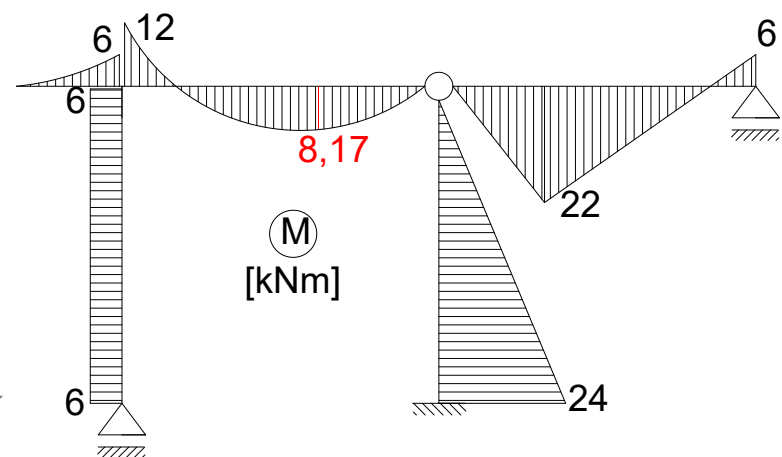
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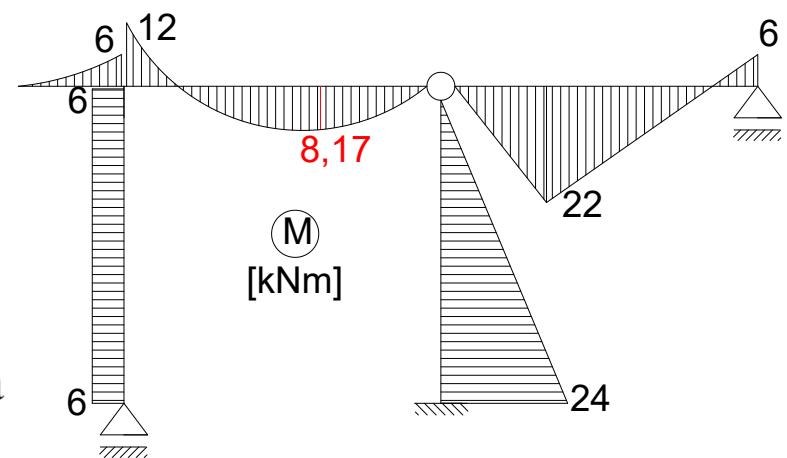
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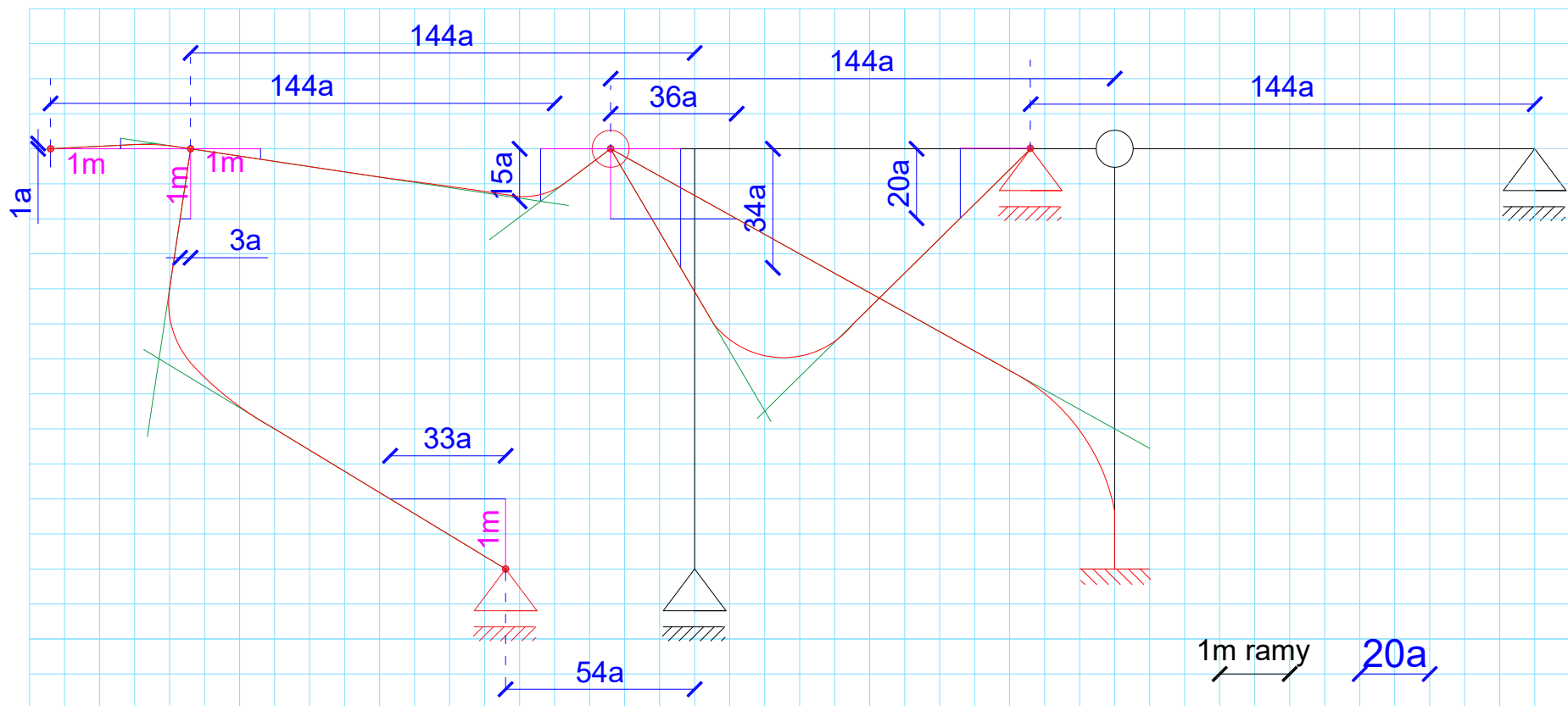
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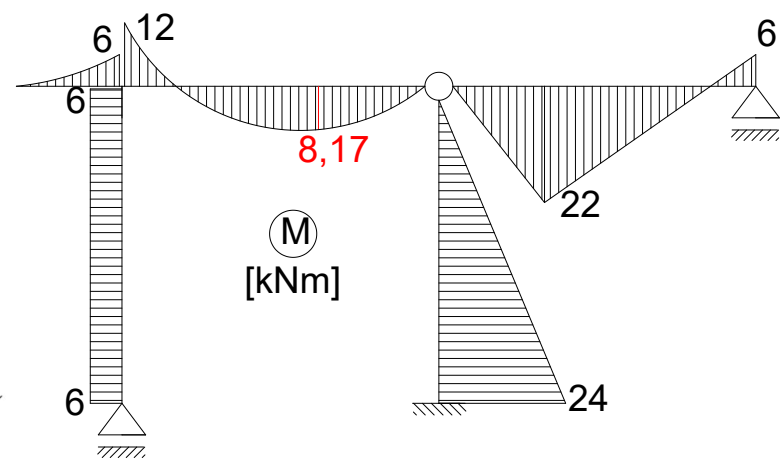
dr inż. Hanna Weber



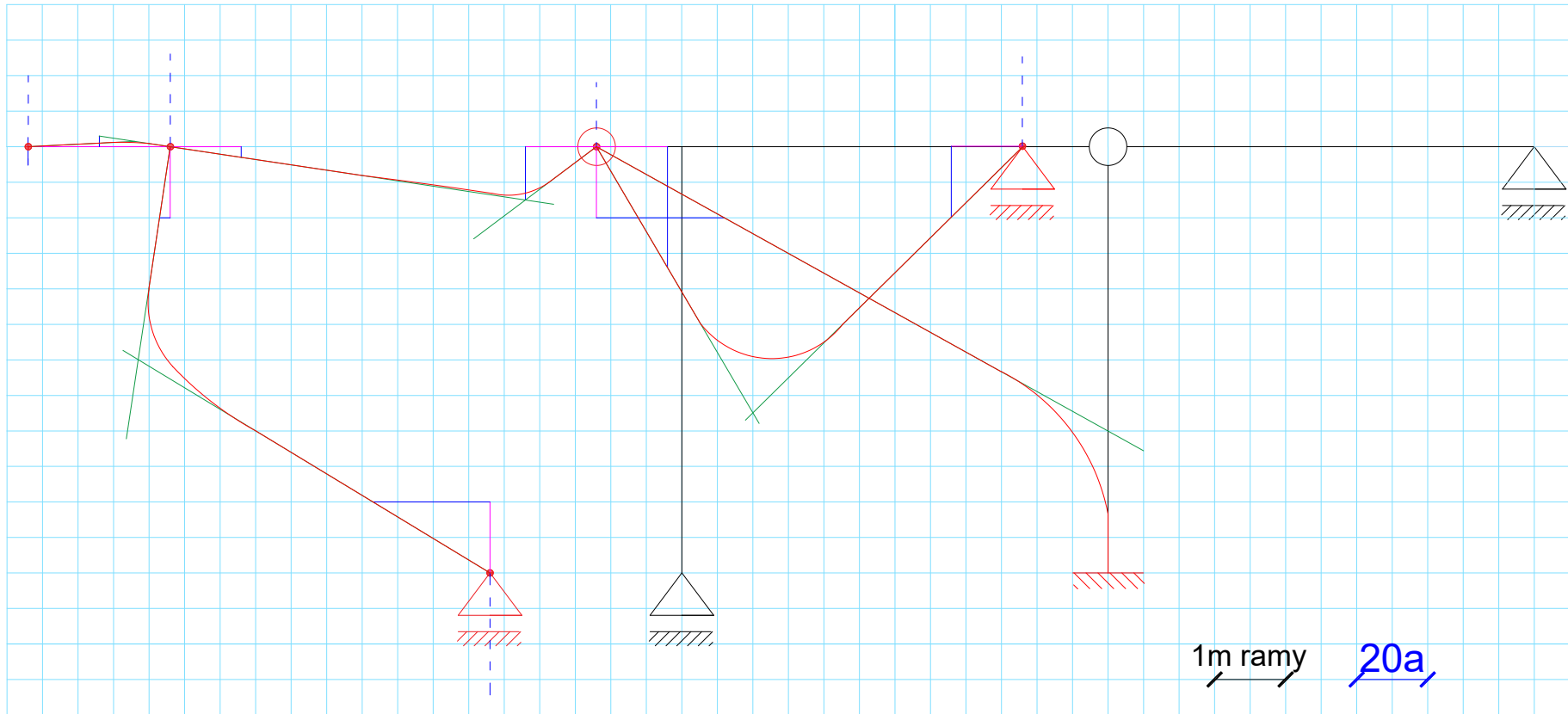
dr inż. Hanna Weber



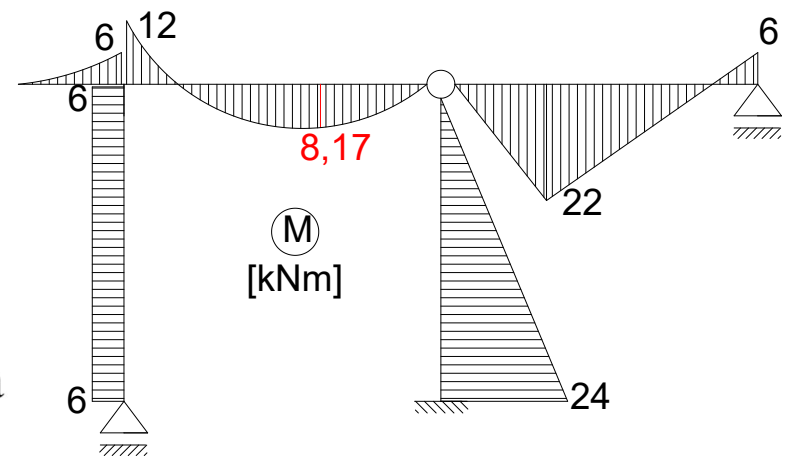
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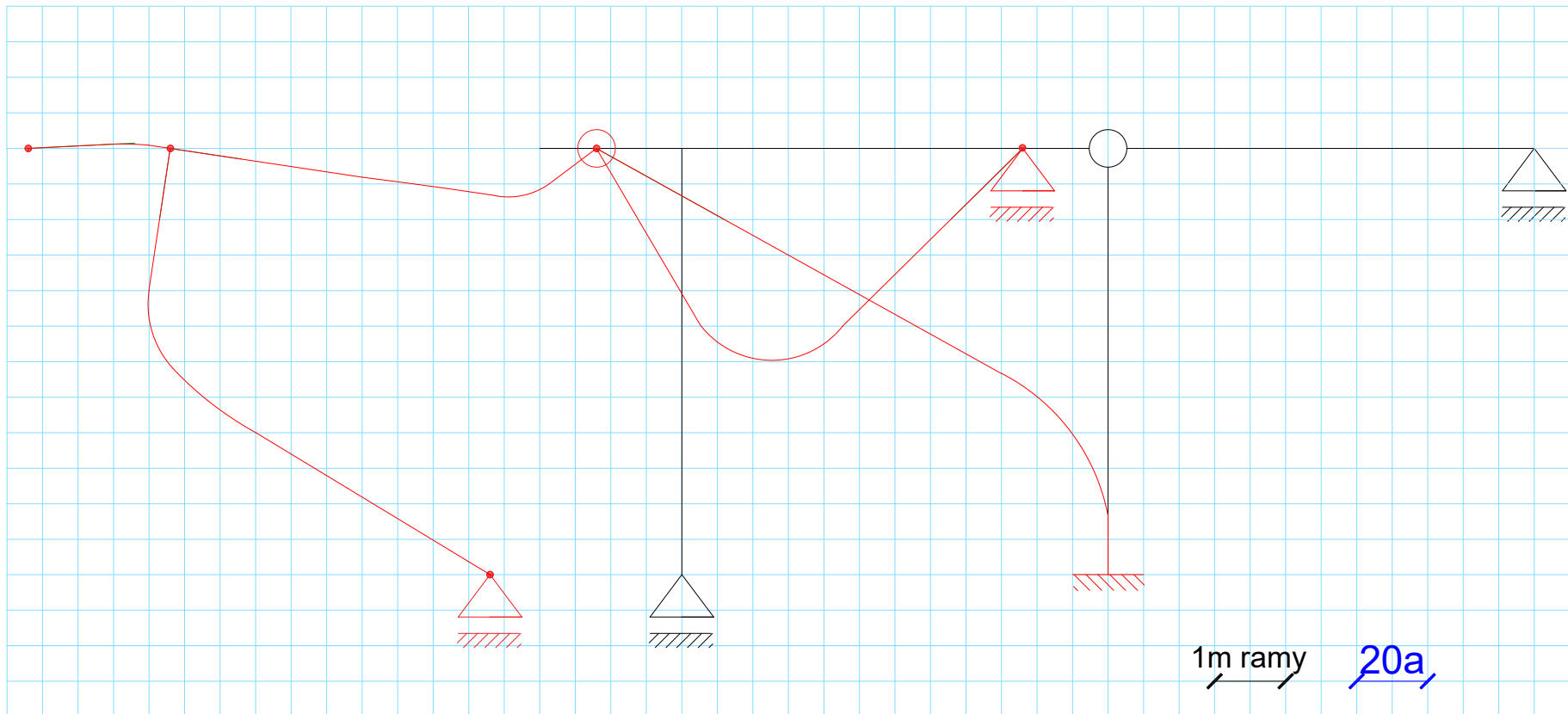
dr inż. Hanna Weber



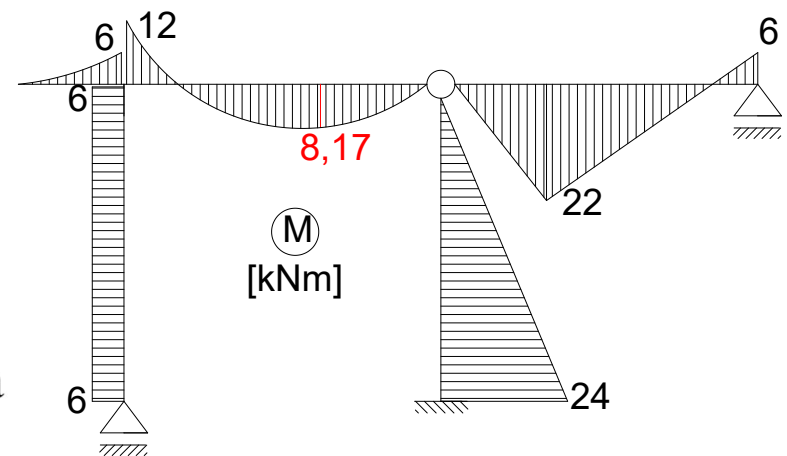
$$\begin{aligned}
 u_C &= -144a & u_A &= -54a & v_E &= 0 \\
 \varphi_A &= -33a & \varphi_E &= -a & \varphi_F &= 3a & \varphi_C^L &= -15a \\
 \varphi_C^P &= 34a & \varphi_C^d &= -36a & \varphi_D &= -20a
 \end{aligned}$$



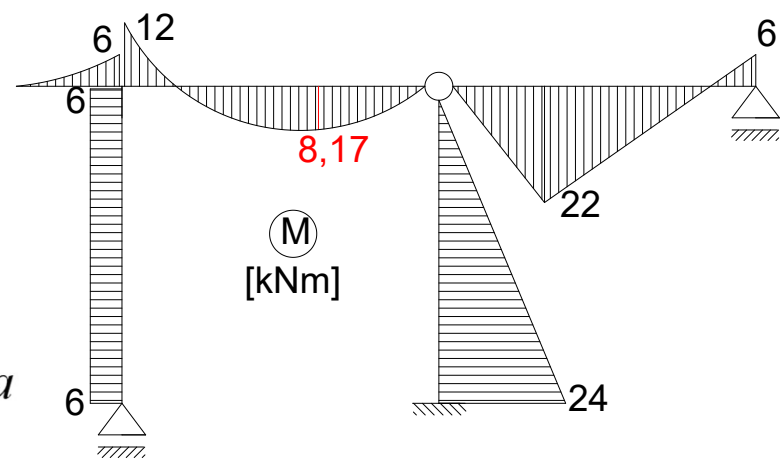
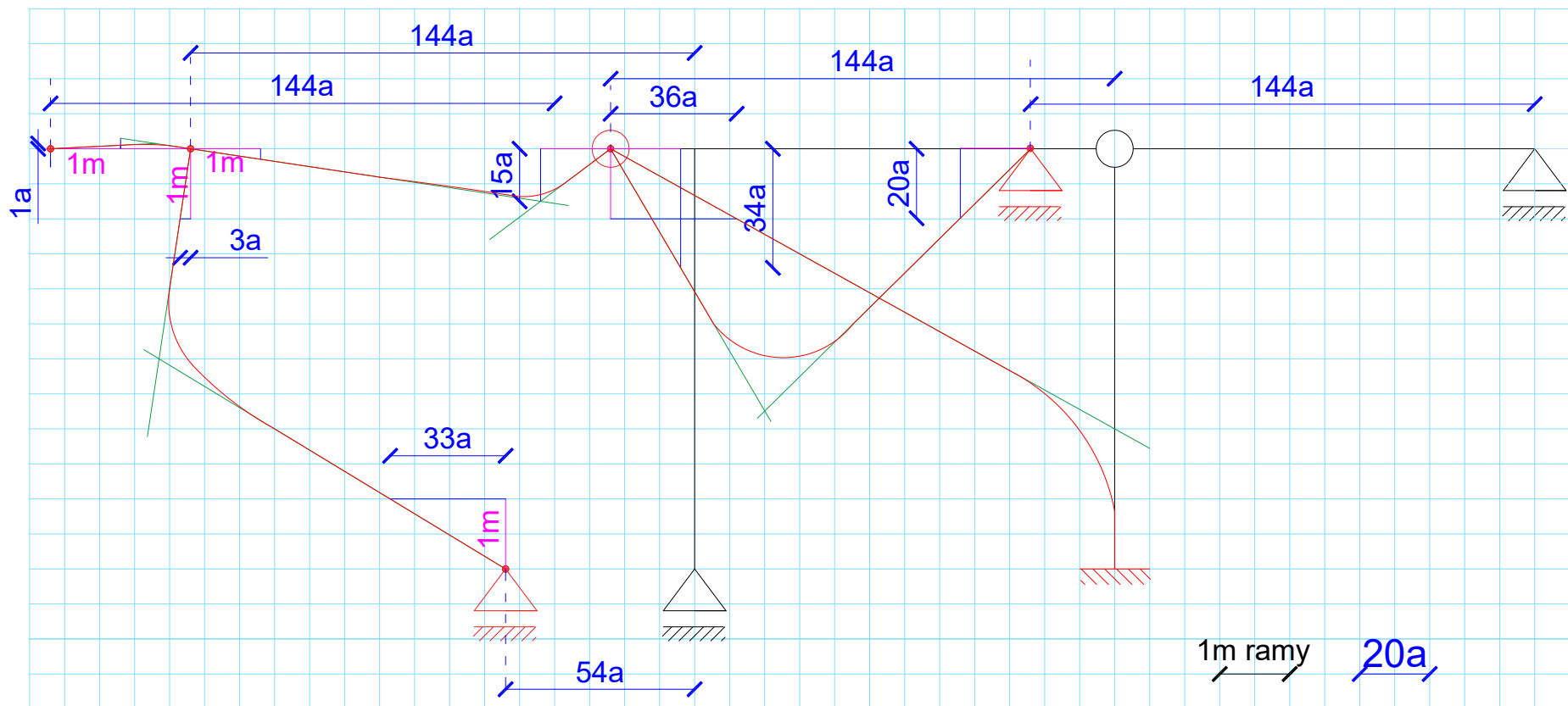
dr inż. Hanna Weber



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dr inż. Hanna Weber

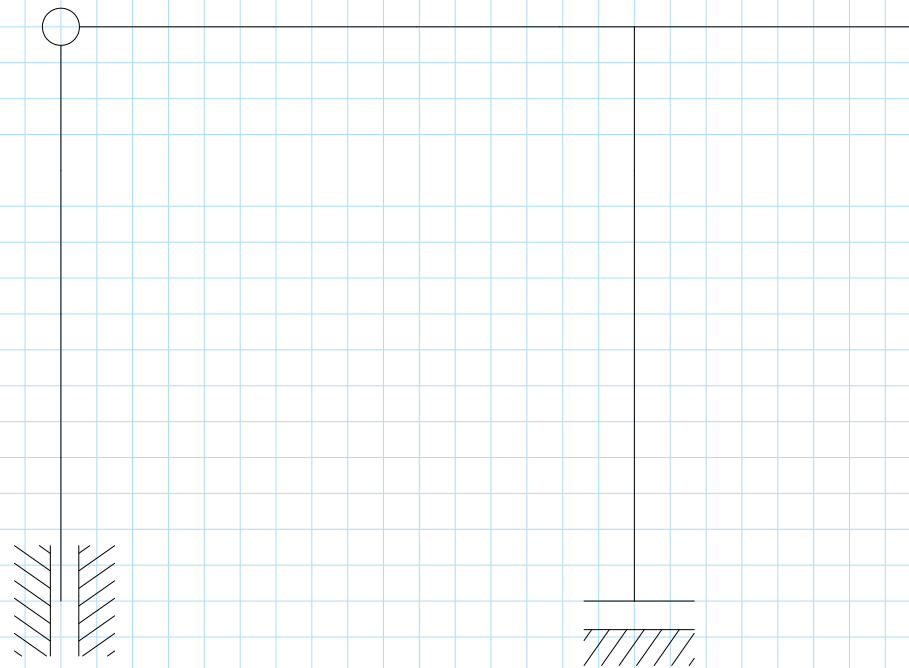


$$u_C = -144a \quad u_A = -54a \quad v_E = 0$$

$$\varphi_A = -33a \quad \varphi_E = -a \quad \varphi_F = 3a \quad \varphi_C^L = -15a$$

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dr inż. Hanna Weber



100a
1m ramy

$$v_A = v_C = 480a$$

$$u_C = u_D = u_E = -304a$$

$$u_B = -352a$$

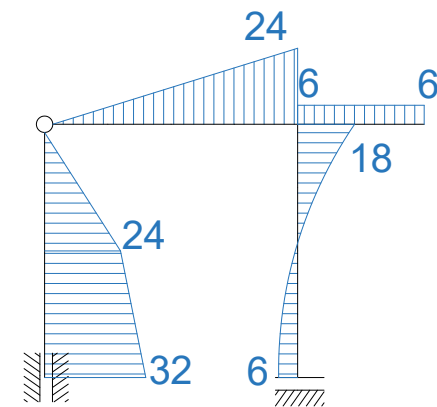
$$v_E = -12a$$

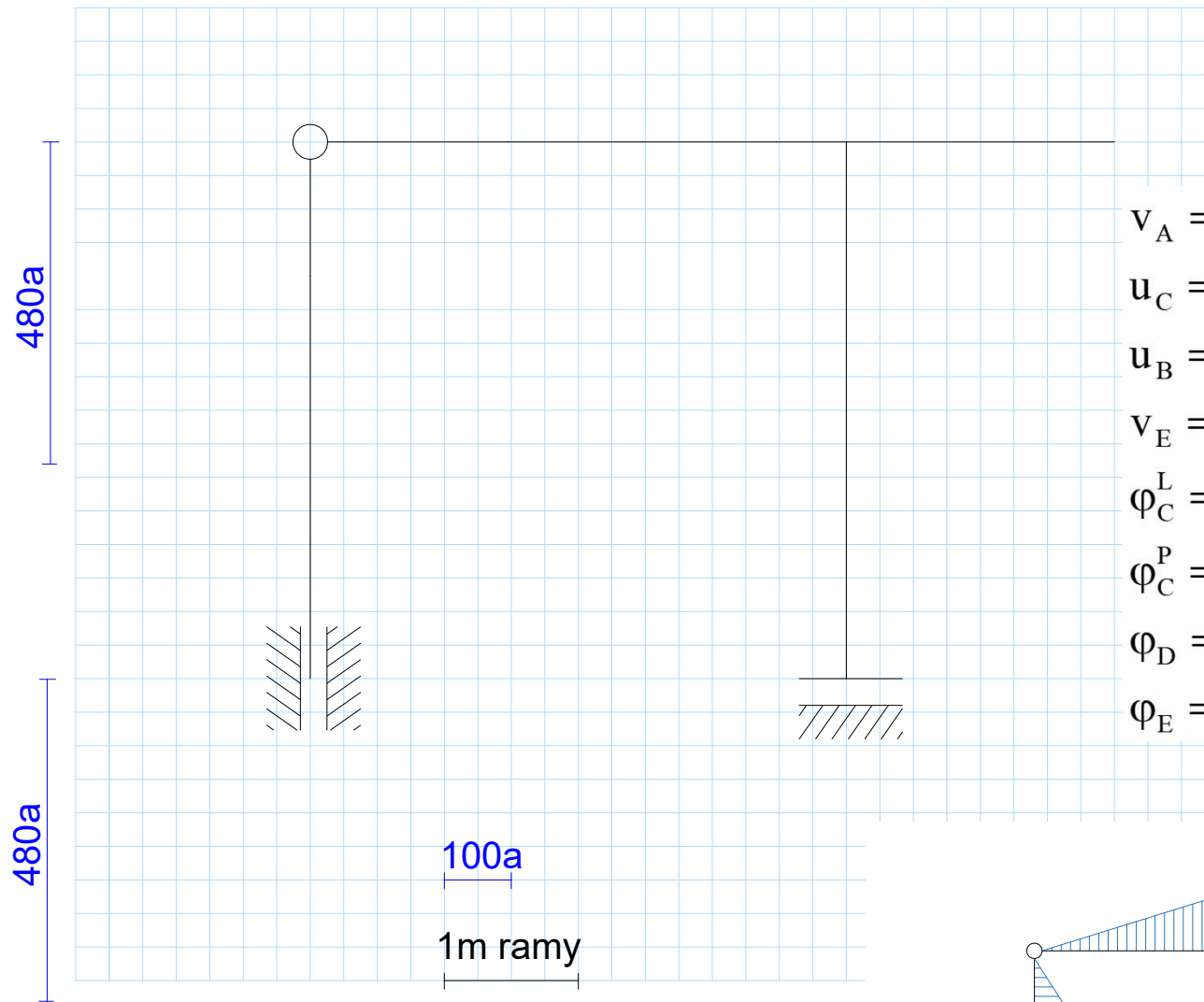
$$\phi_C^L = -120a$$

$$\phi_C^P = -168a$$

$$\phi_D = -24a$$

$$\phi_E = 12a$$





$$v_A = v_C = 480a$$

$$u_C = u_D = u_E = -304a$$

$$u_B = -352a$$

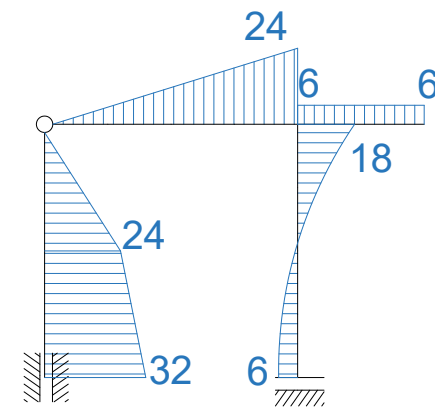
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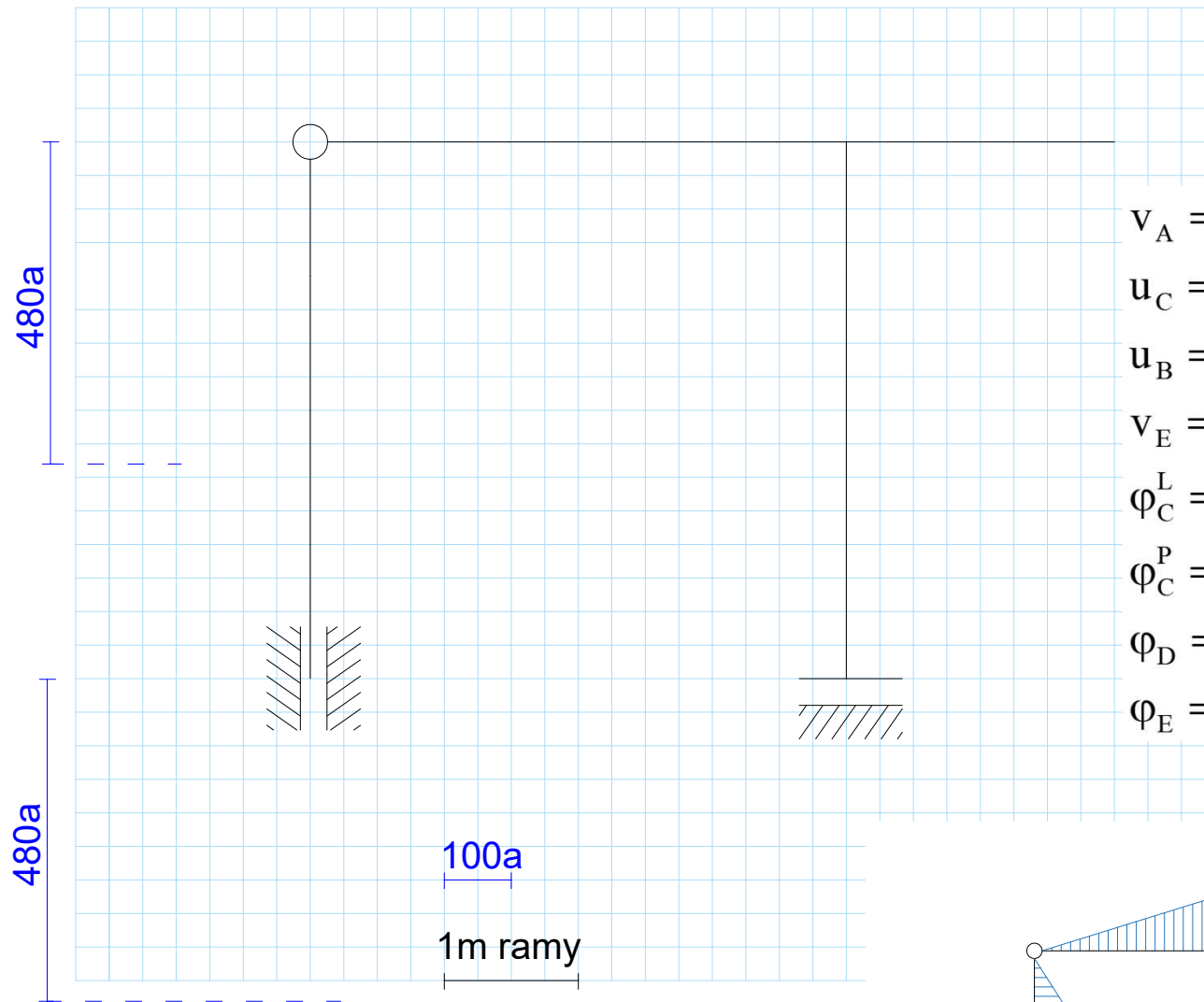
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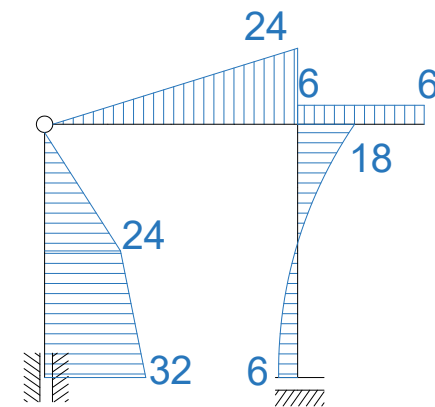
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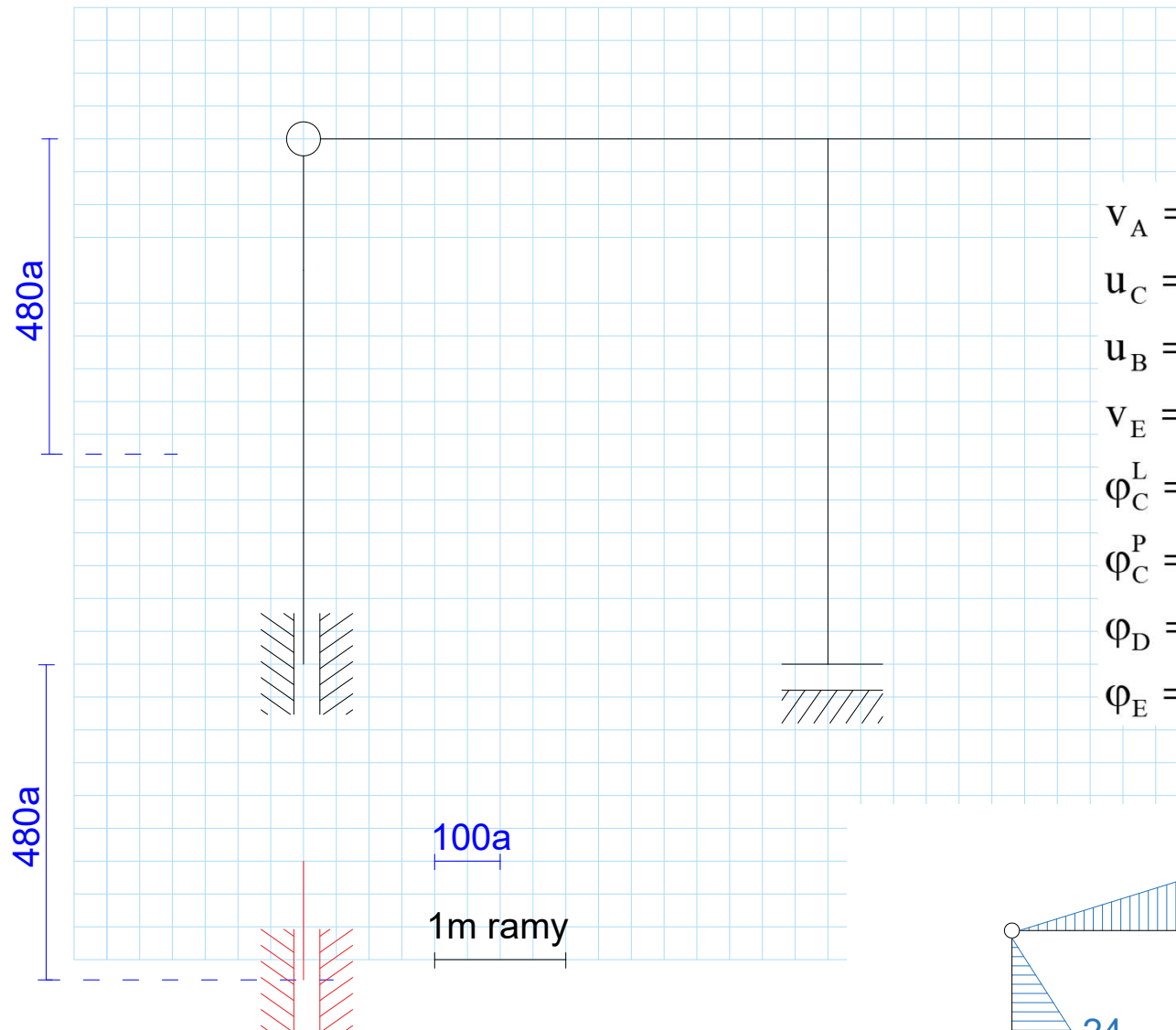
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$$v_A = v_C = 480a$$

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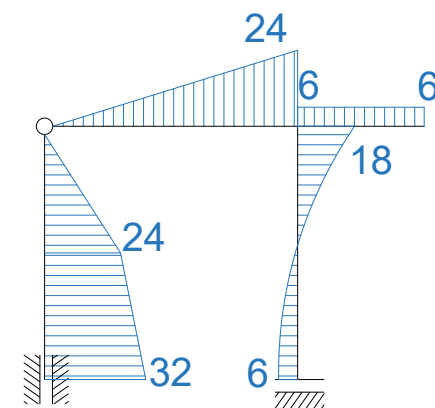
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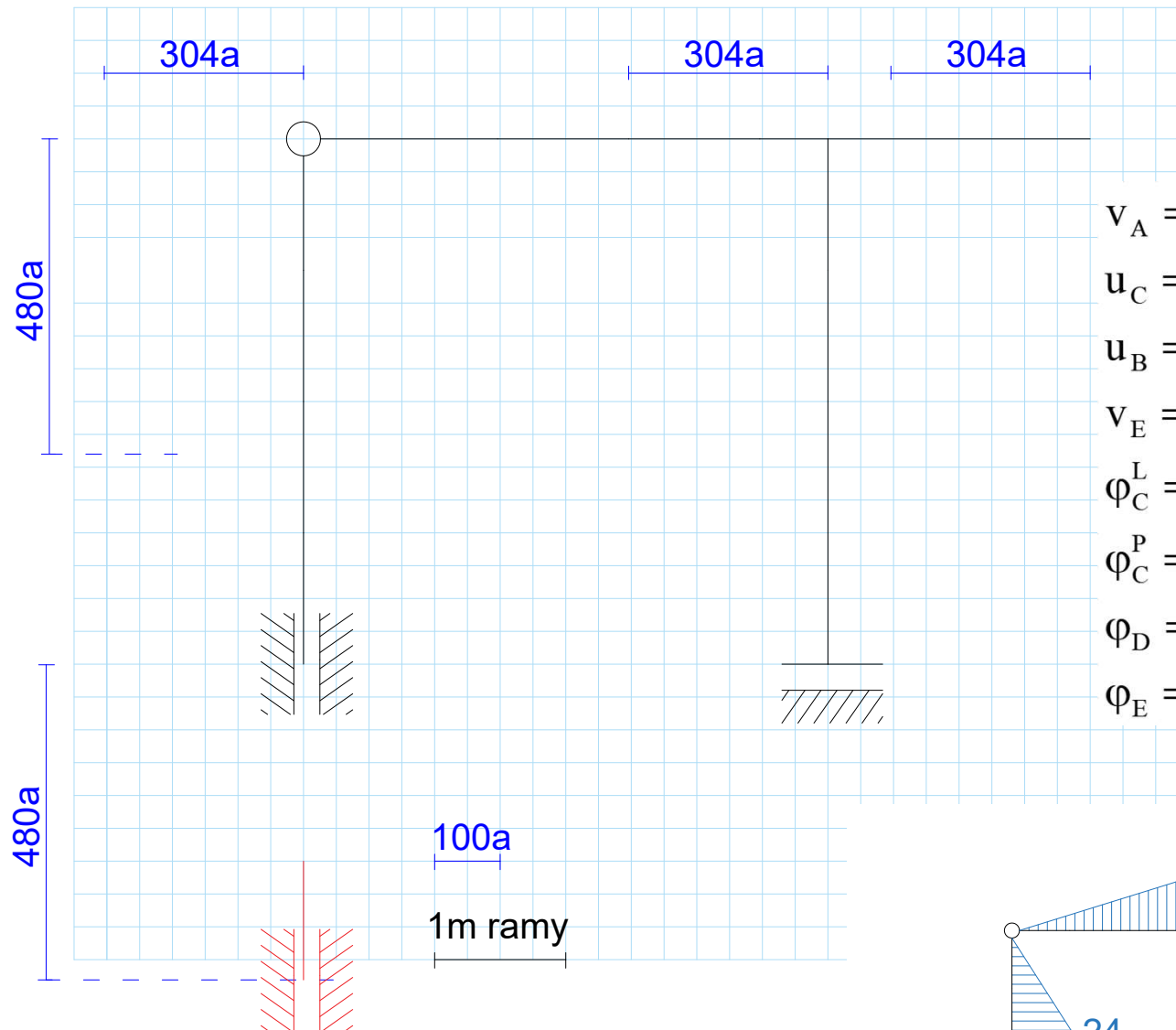
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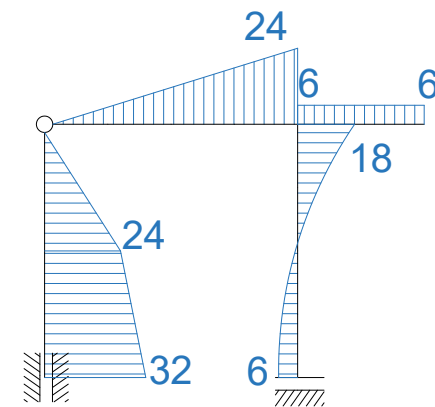
$$v_E = -12a$$

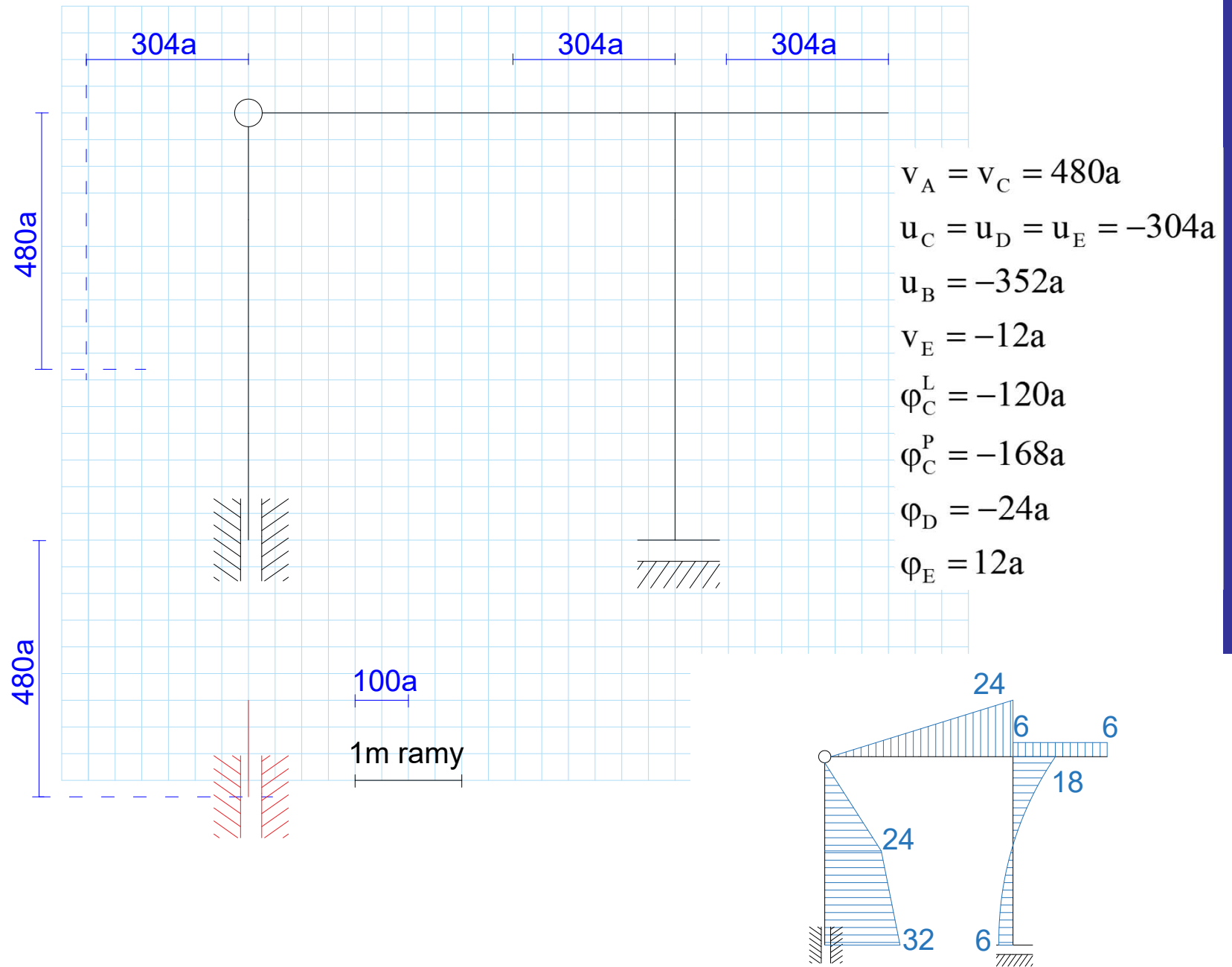
$$\phi_C^L = -120a$$

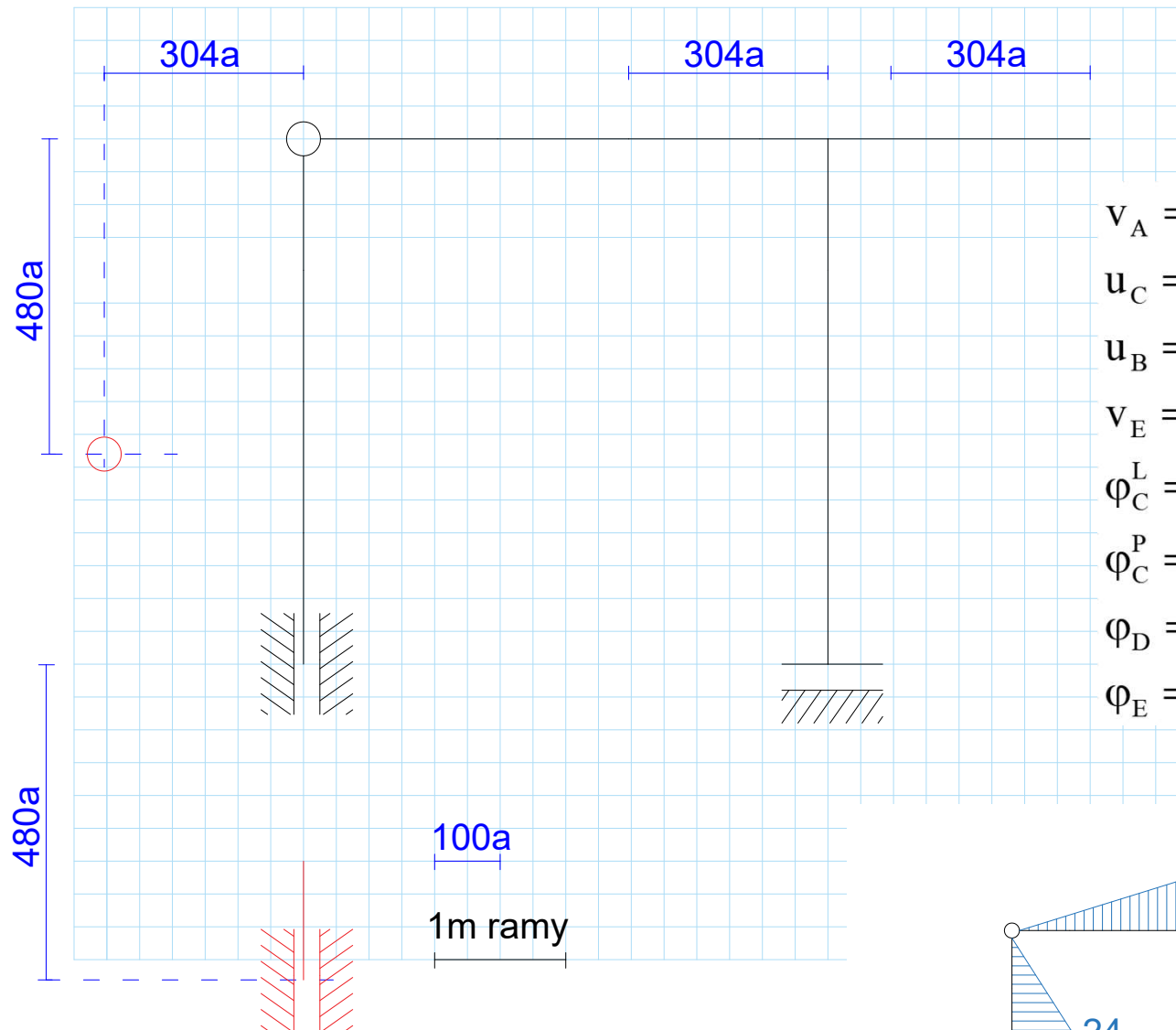
$$\phi_C^P = -168a$$

$$\phi_D = -24a$$

$$\phi_E = 12a$$







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$$u_B = -352a$$

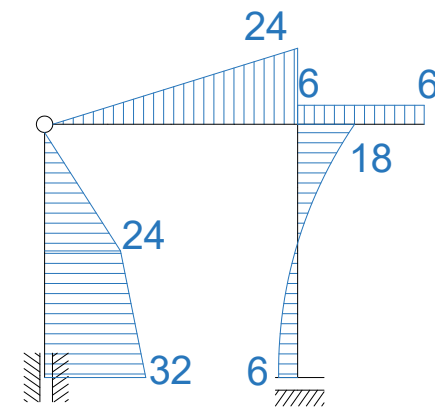
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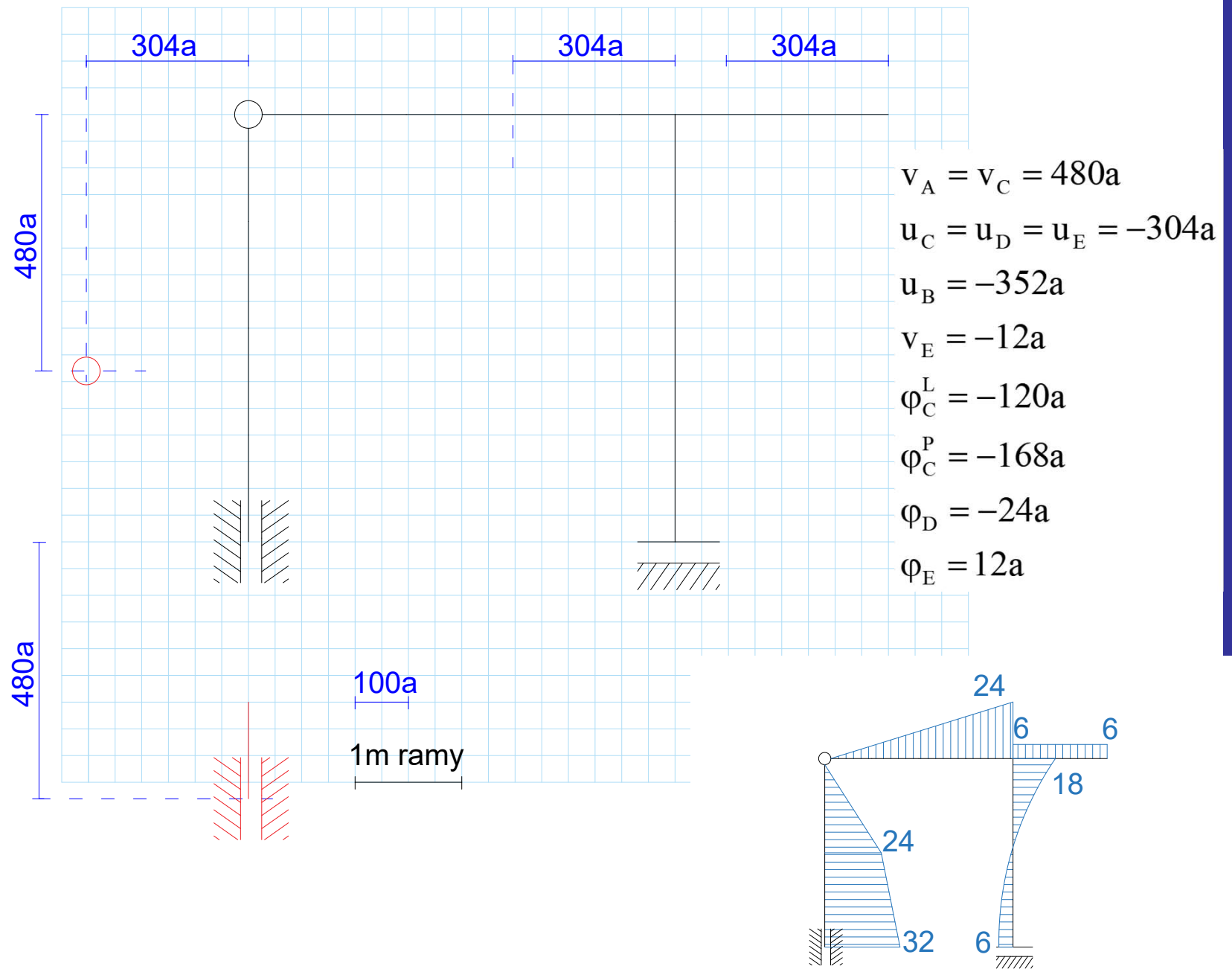
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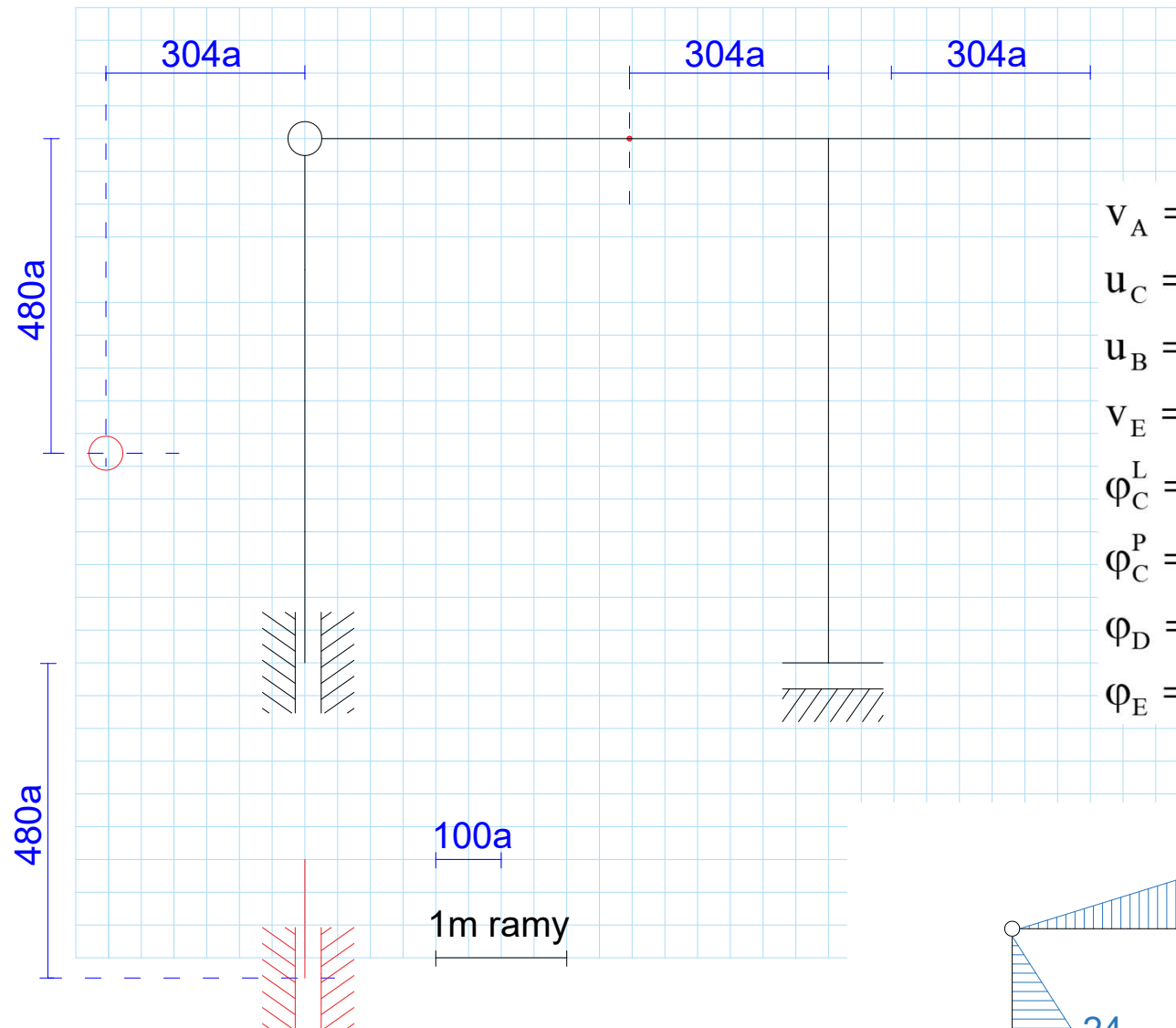
$$\phi_C^P = -168a$$

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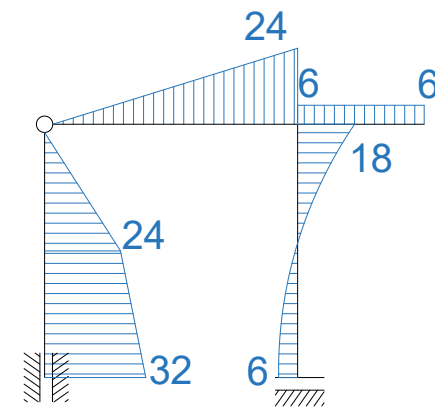
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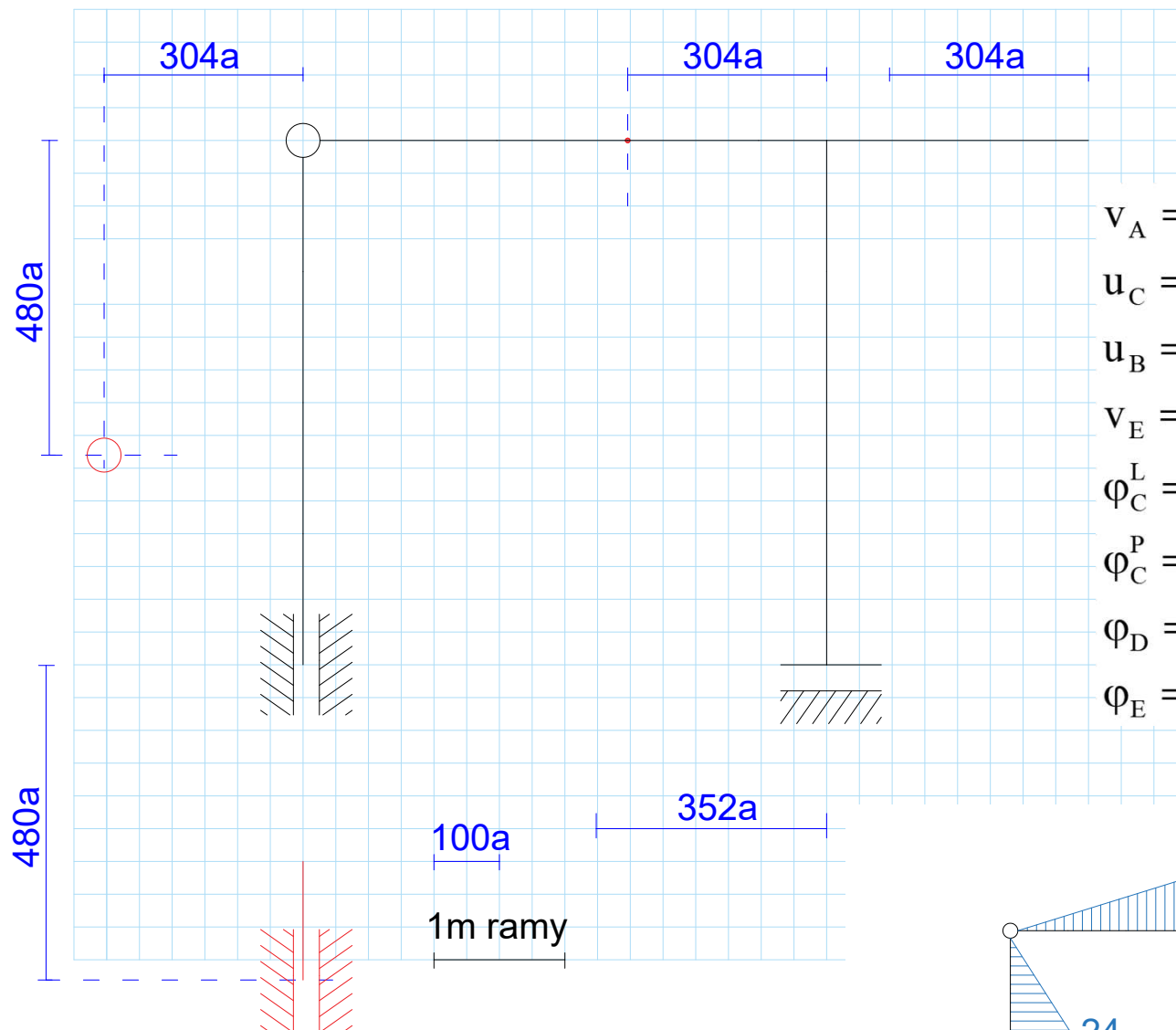
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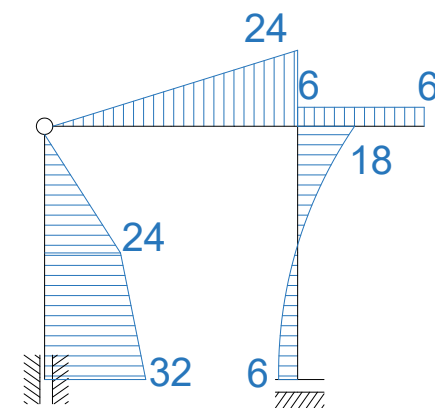
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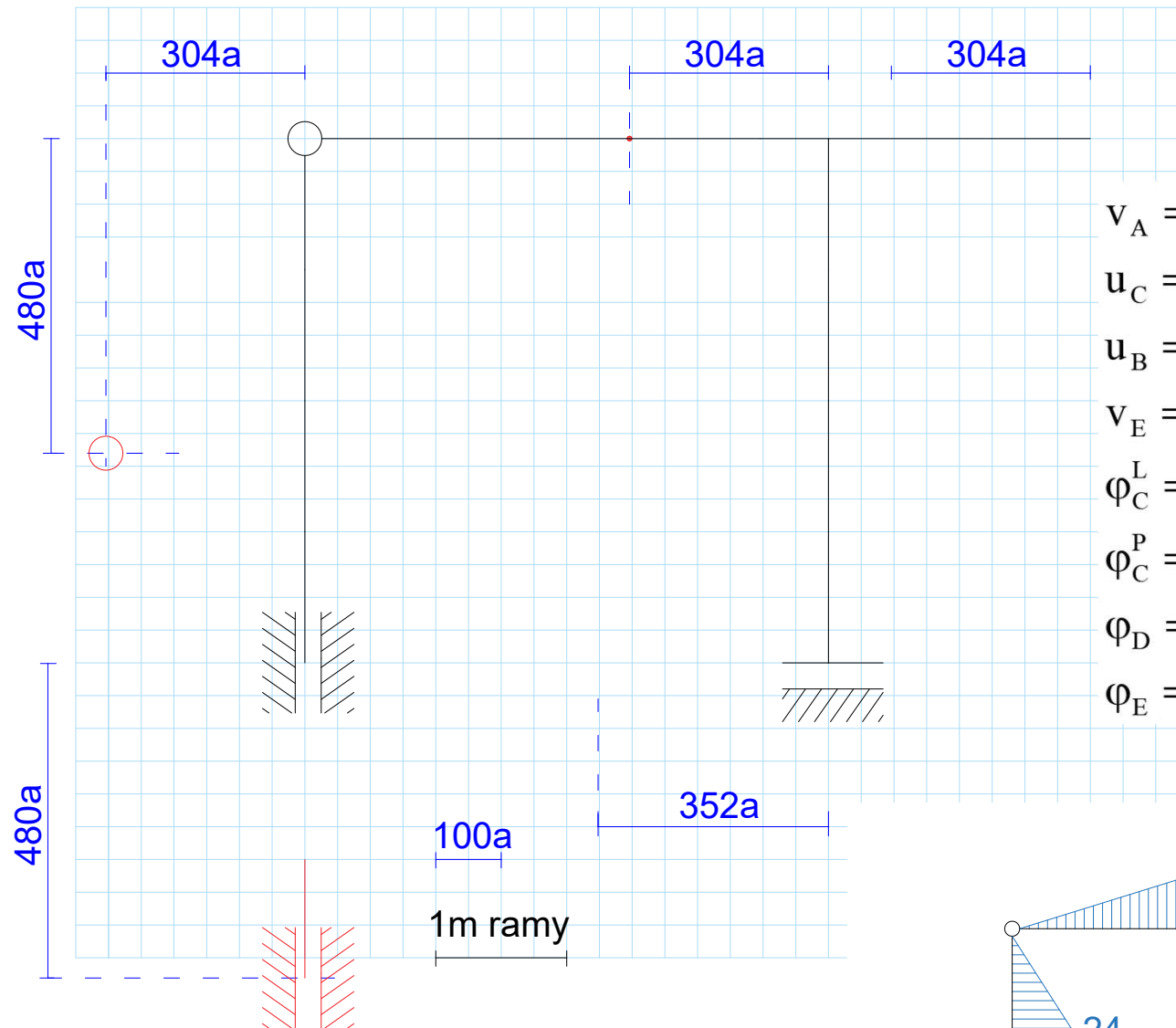
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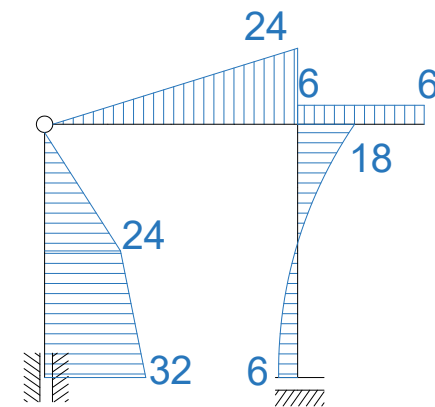
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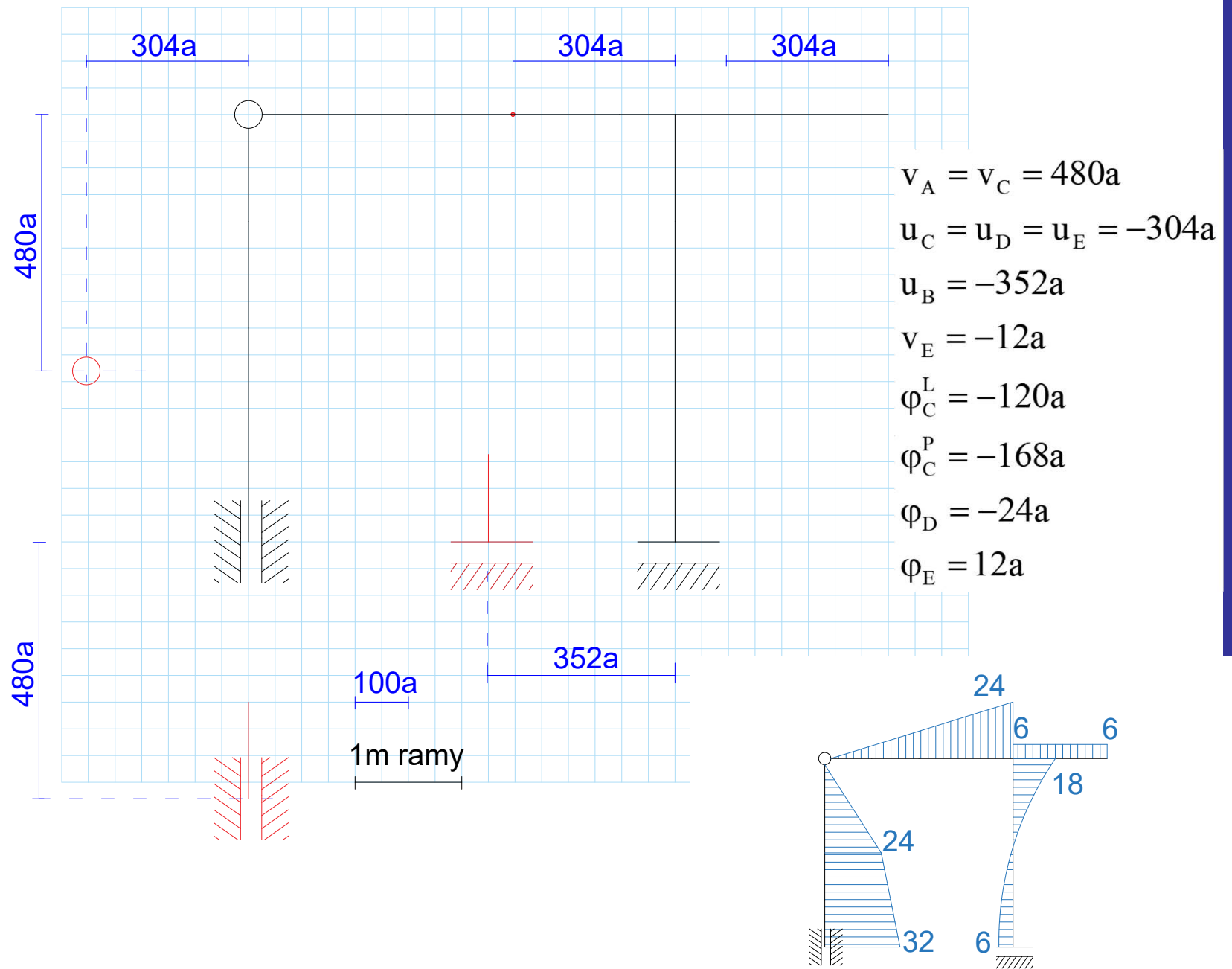
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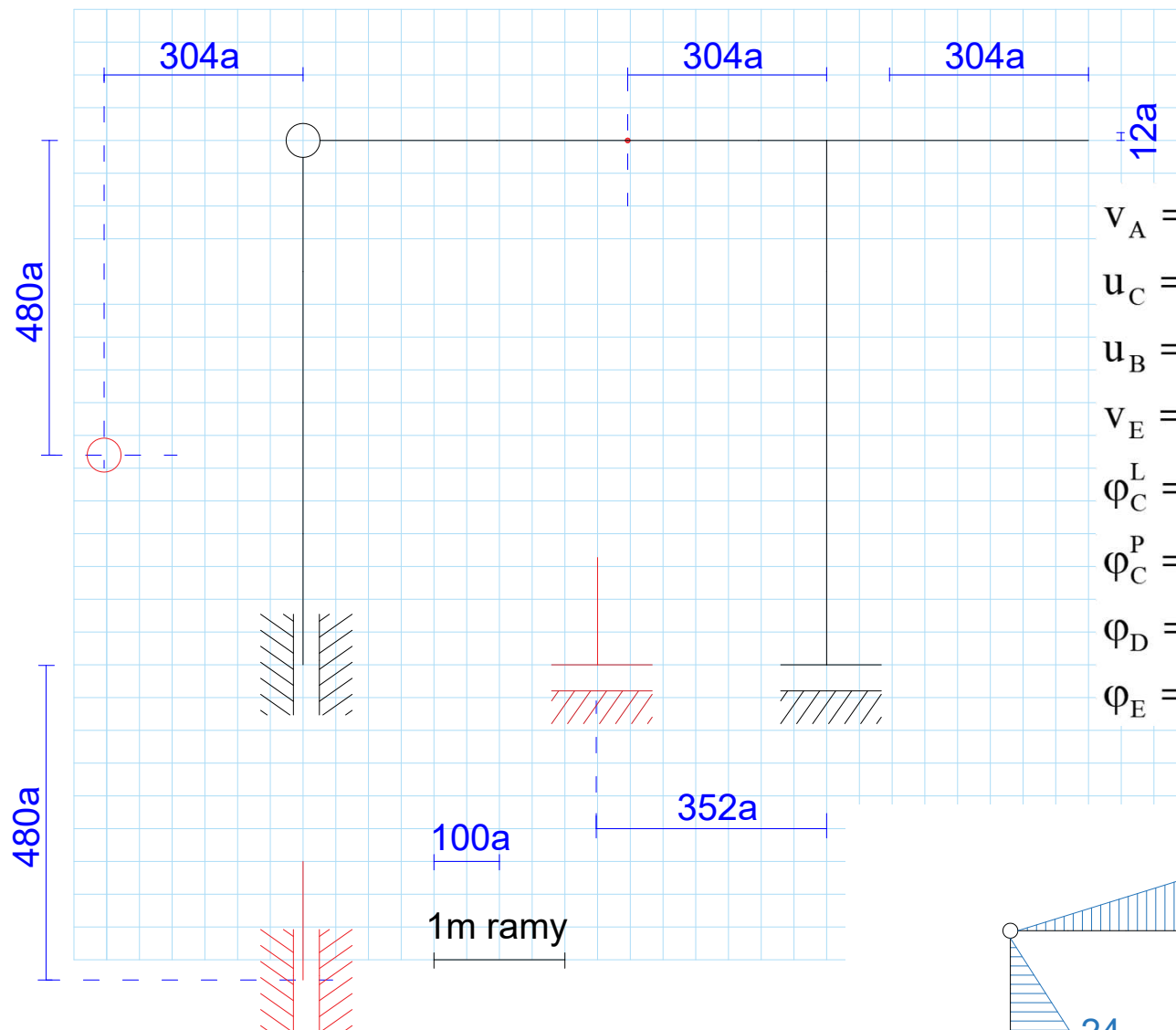
$$\phi_C^P = -168a$$

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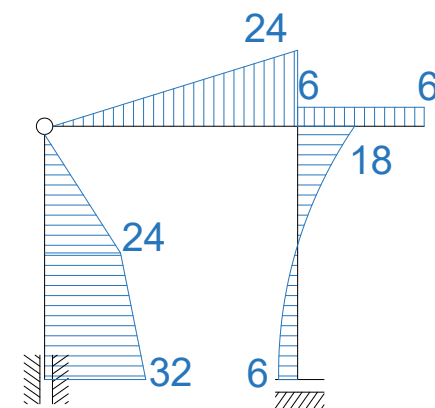
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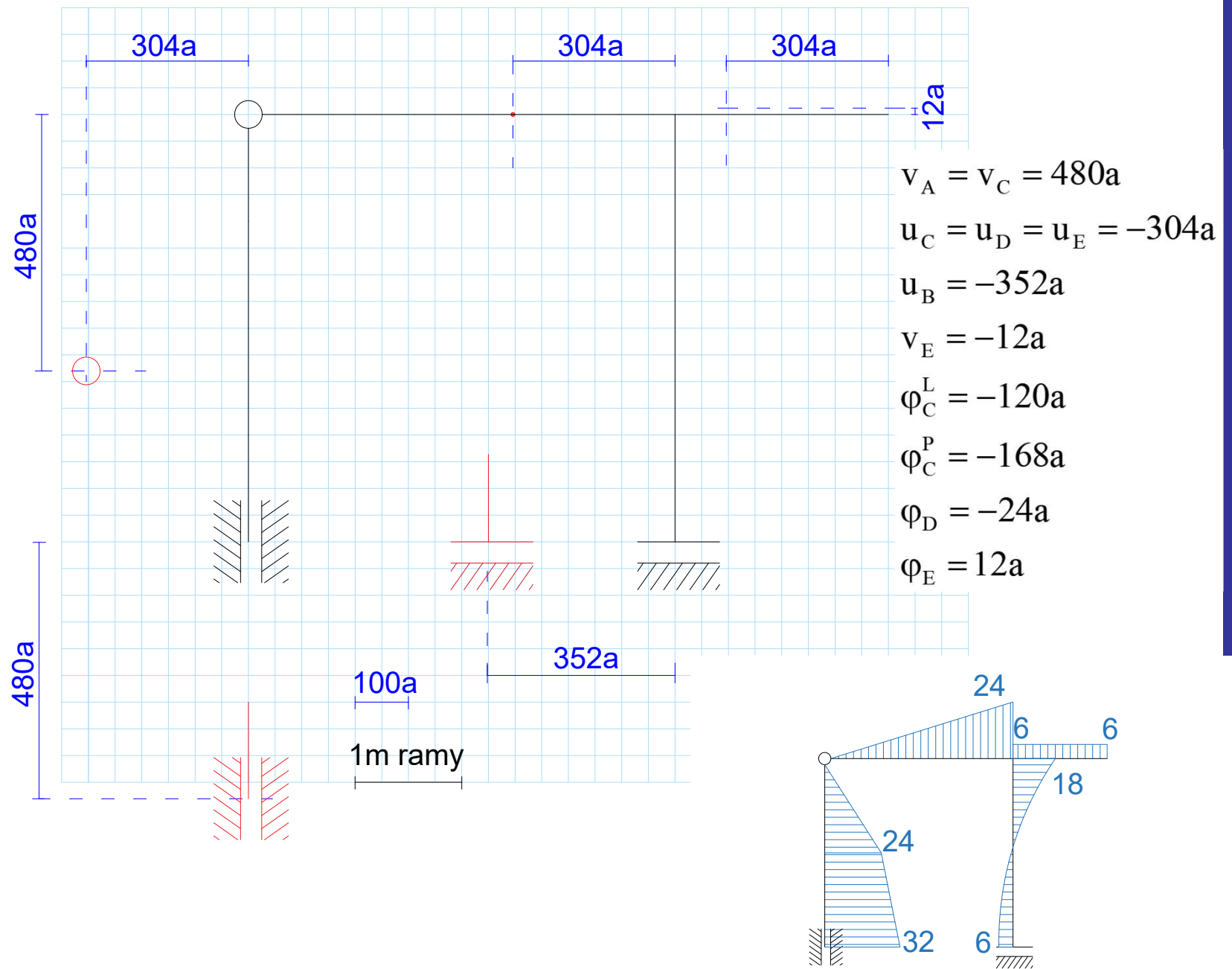
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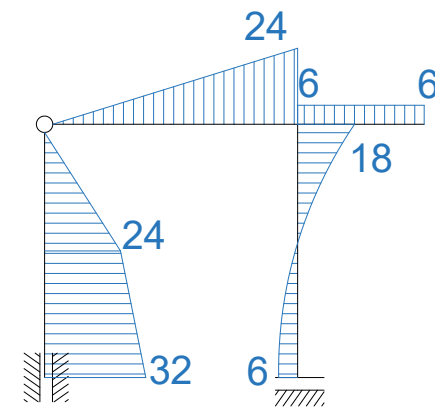
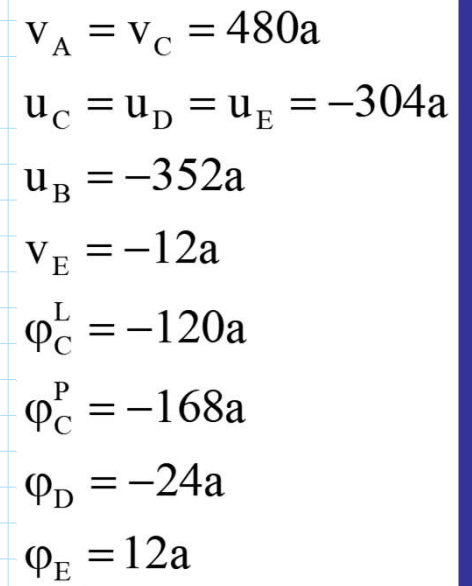
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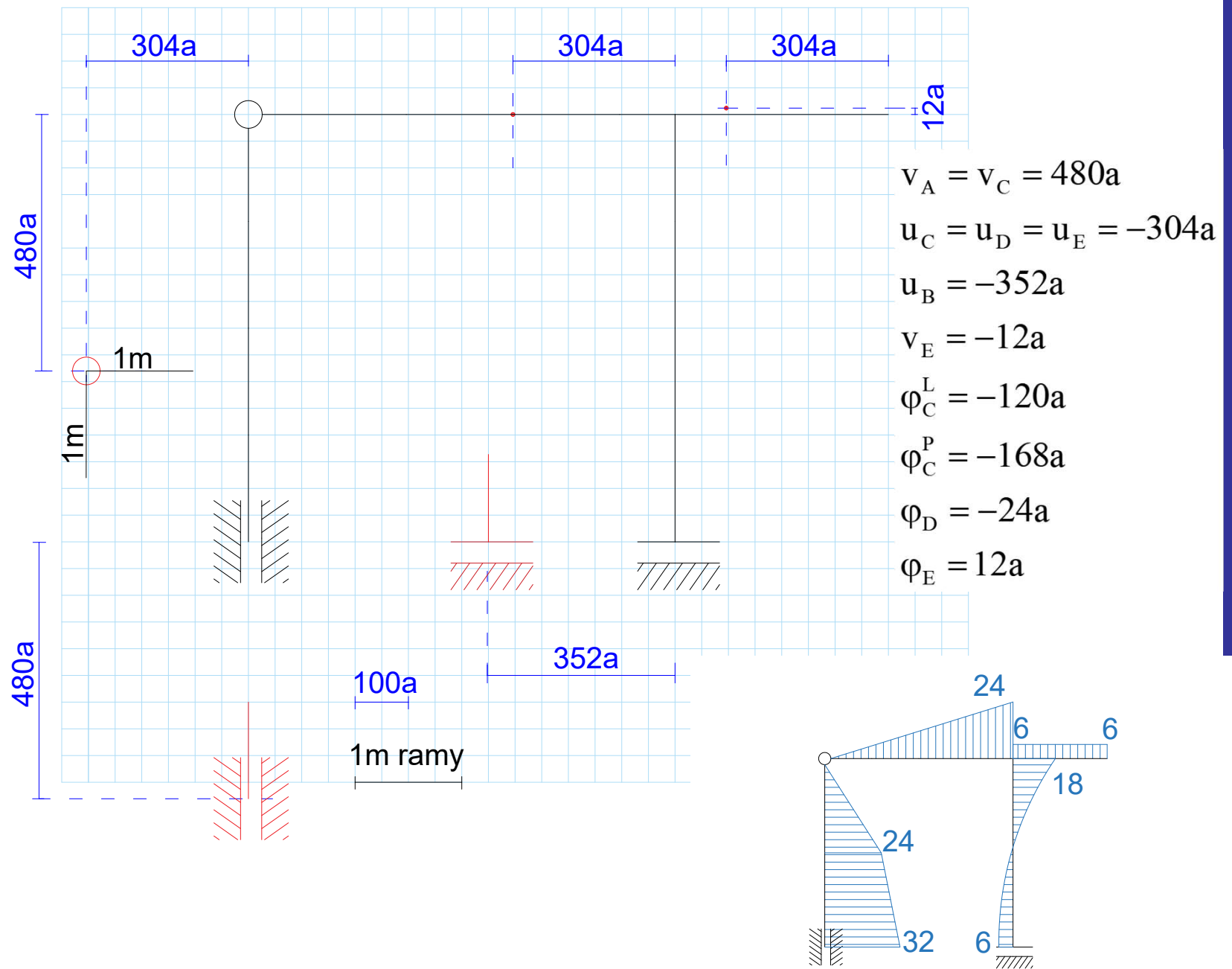
$$\phi_D = -24a$$

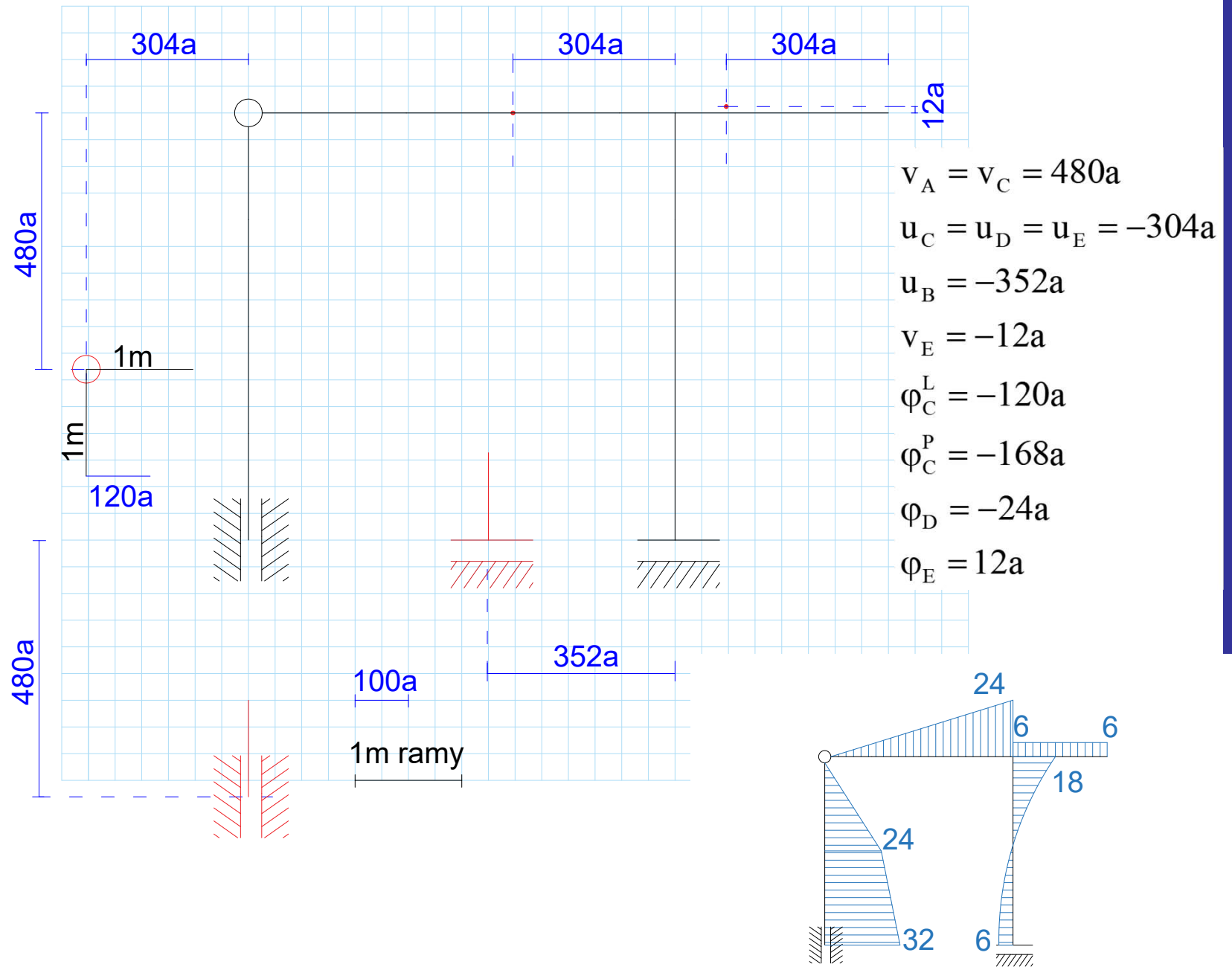
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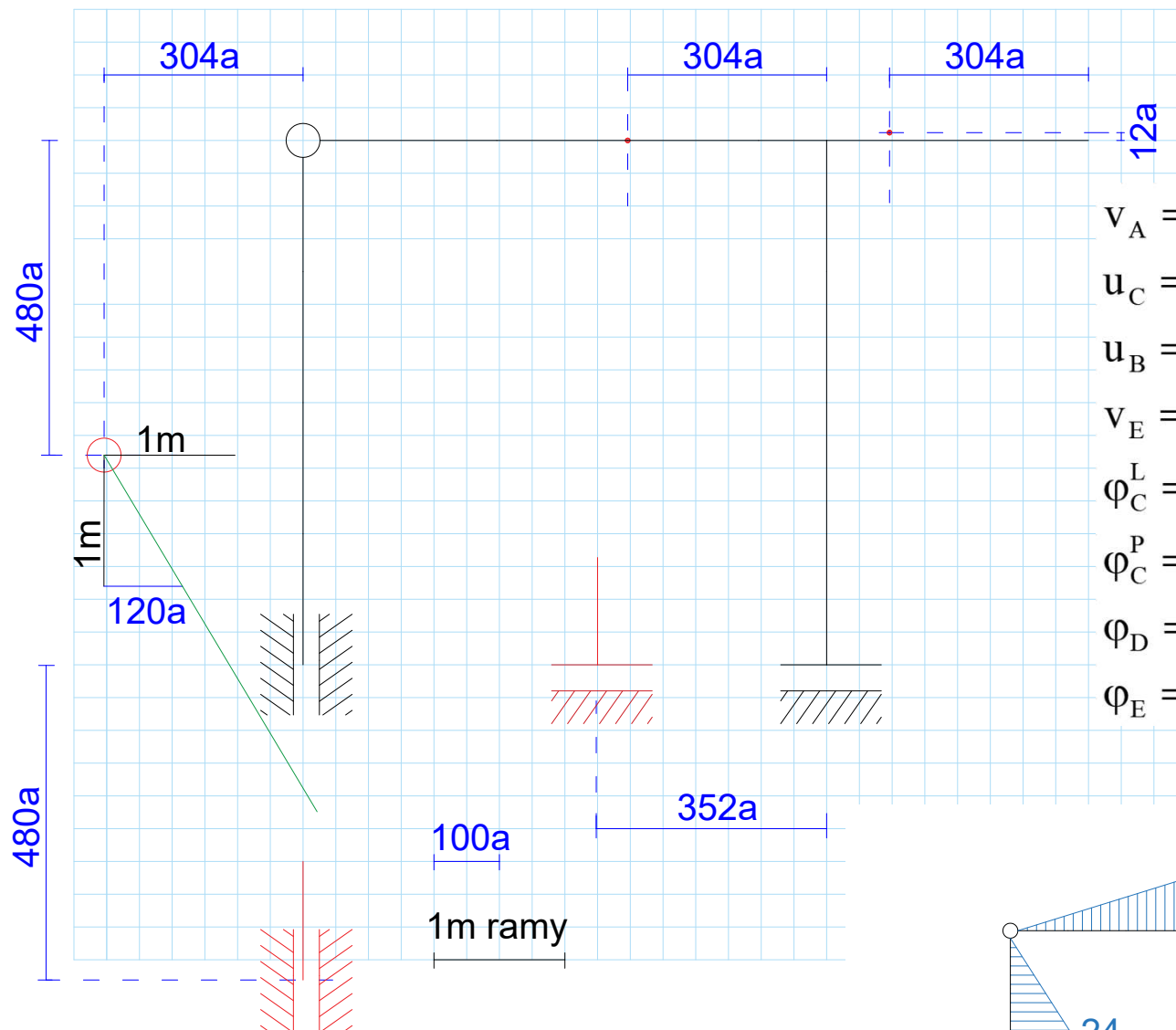












$$v_A = v_C = 480a$$

$$u_C = u_D = u_E = -304a$$

$$u_B = -352a$$

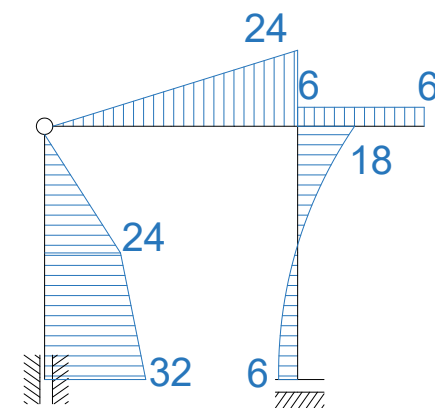
$$v_E = -12a$$

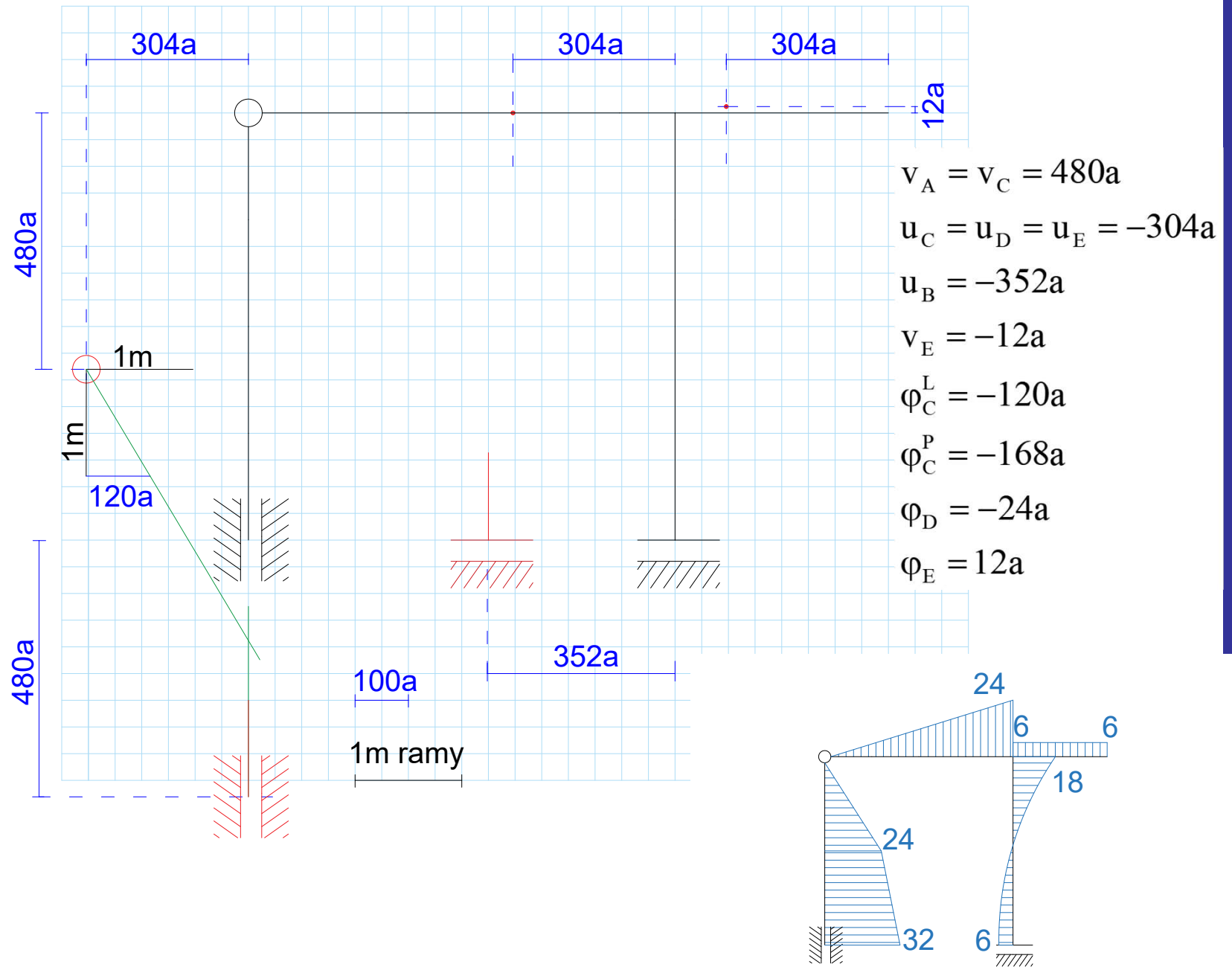
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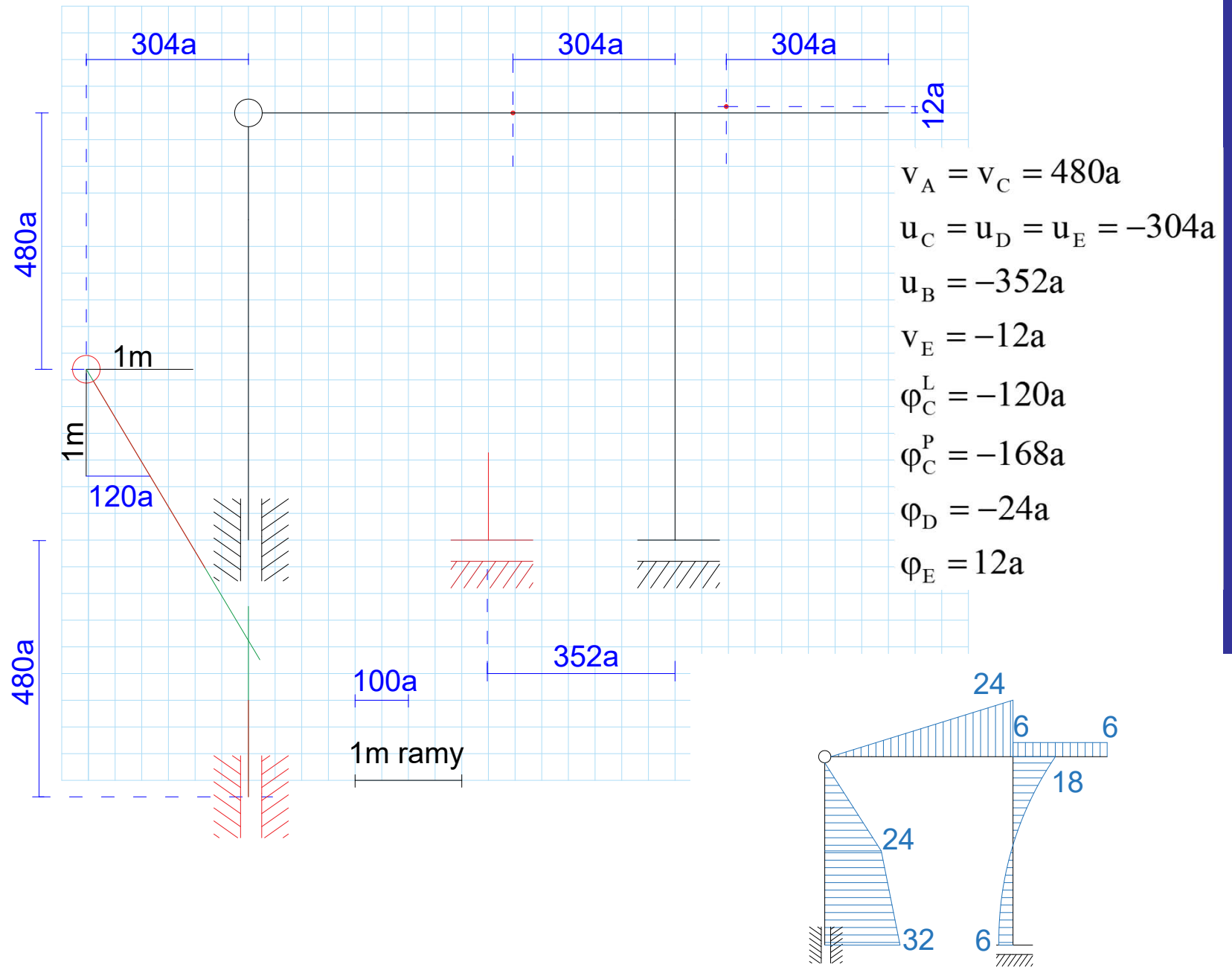
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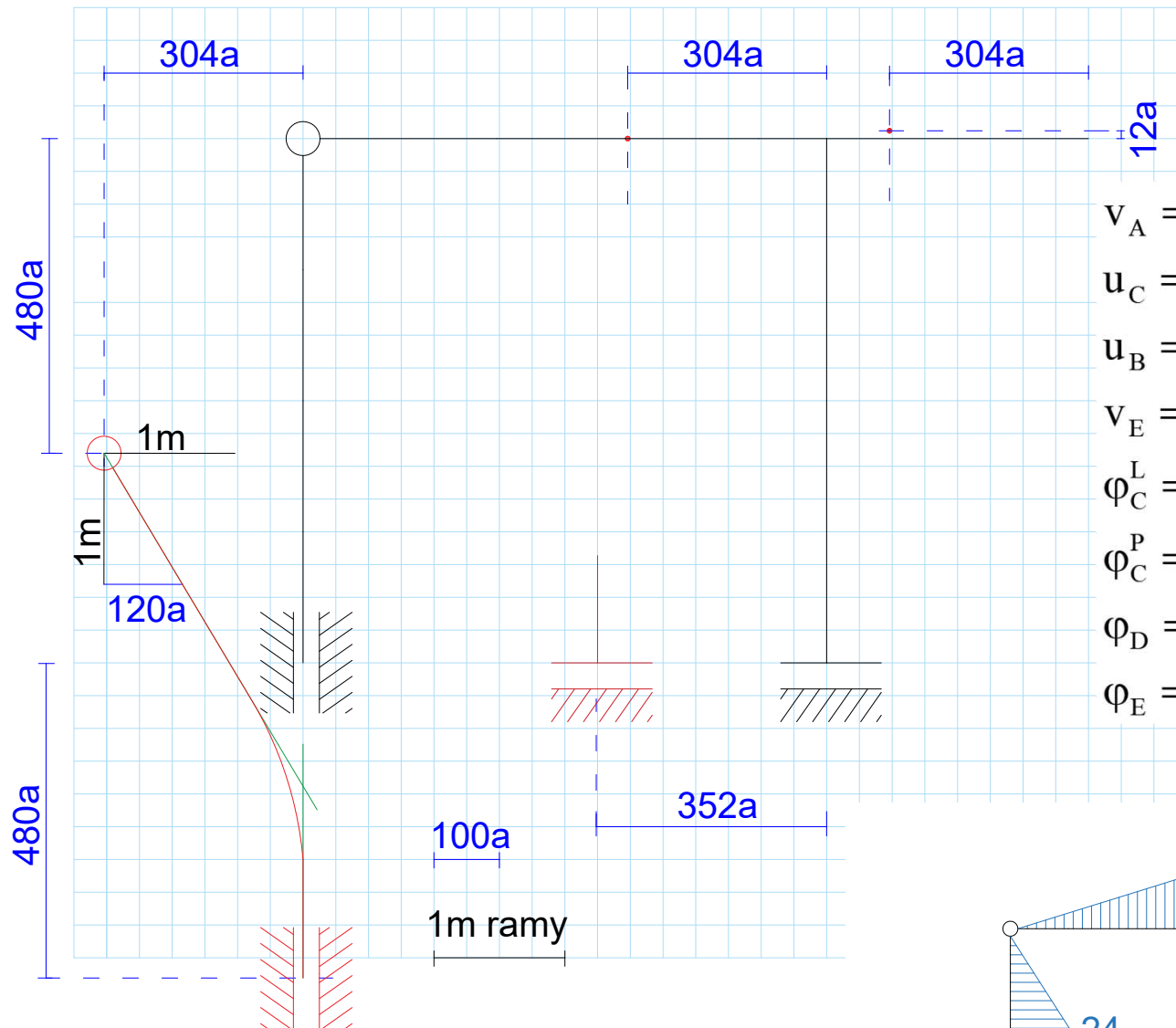
$$\phi_D = -24a$$

$$\phi_E = 12a$$









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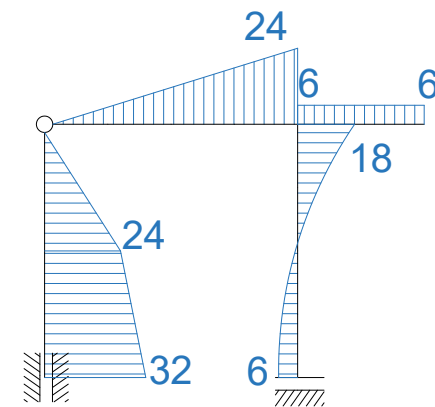
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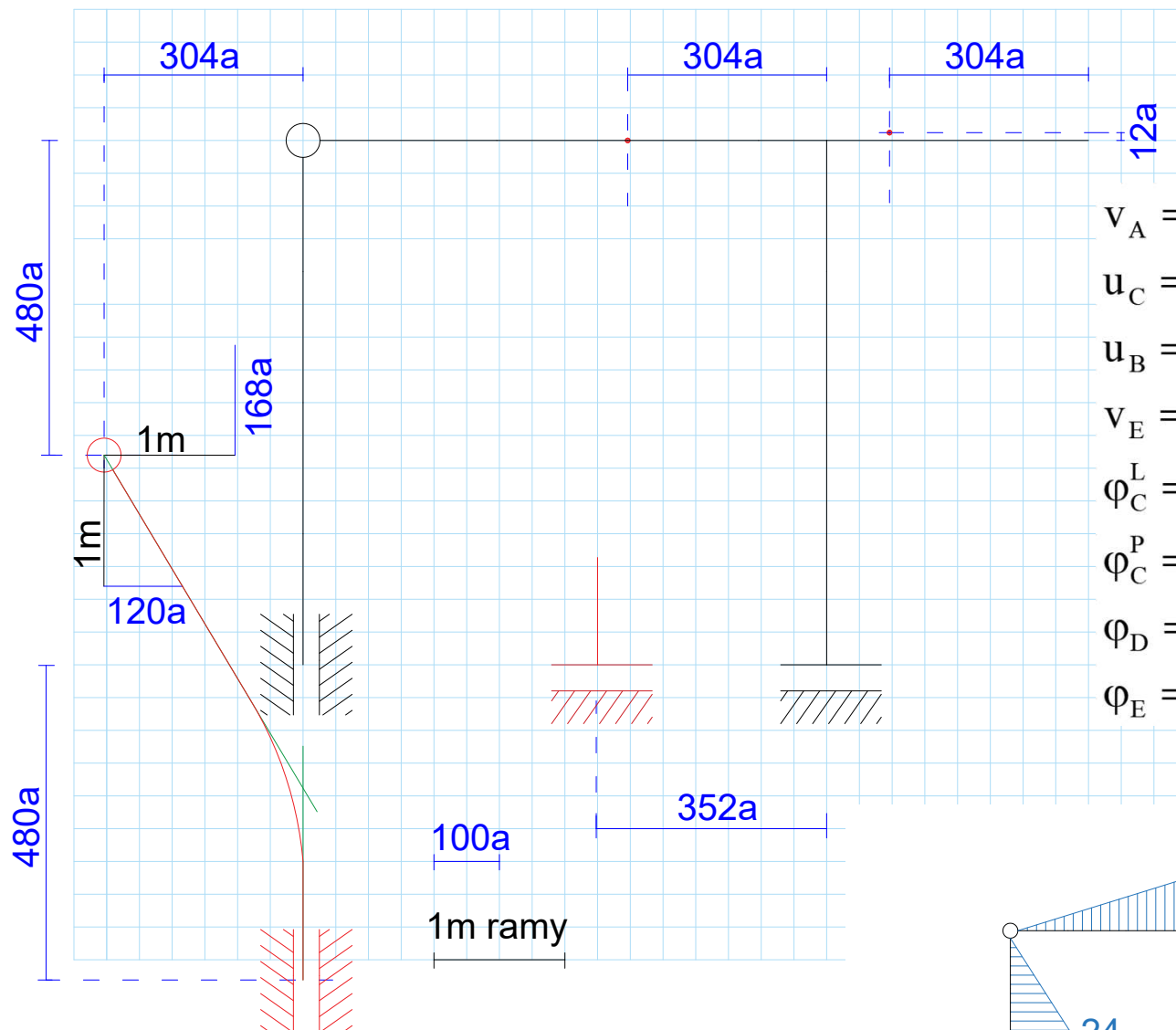
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$$\phi_E = 12a$$





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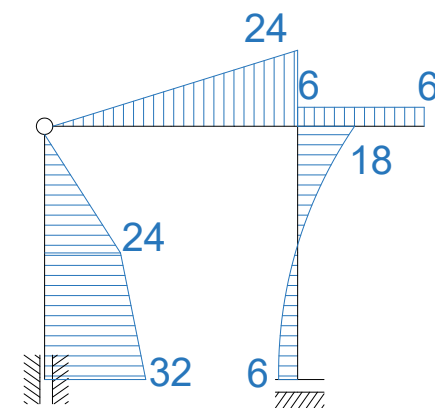
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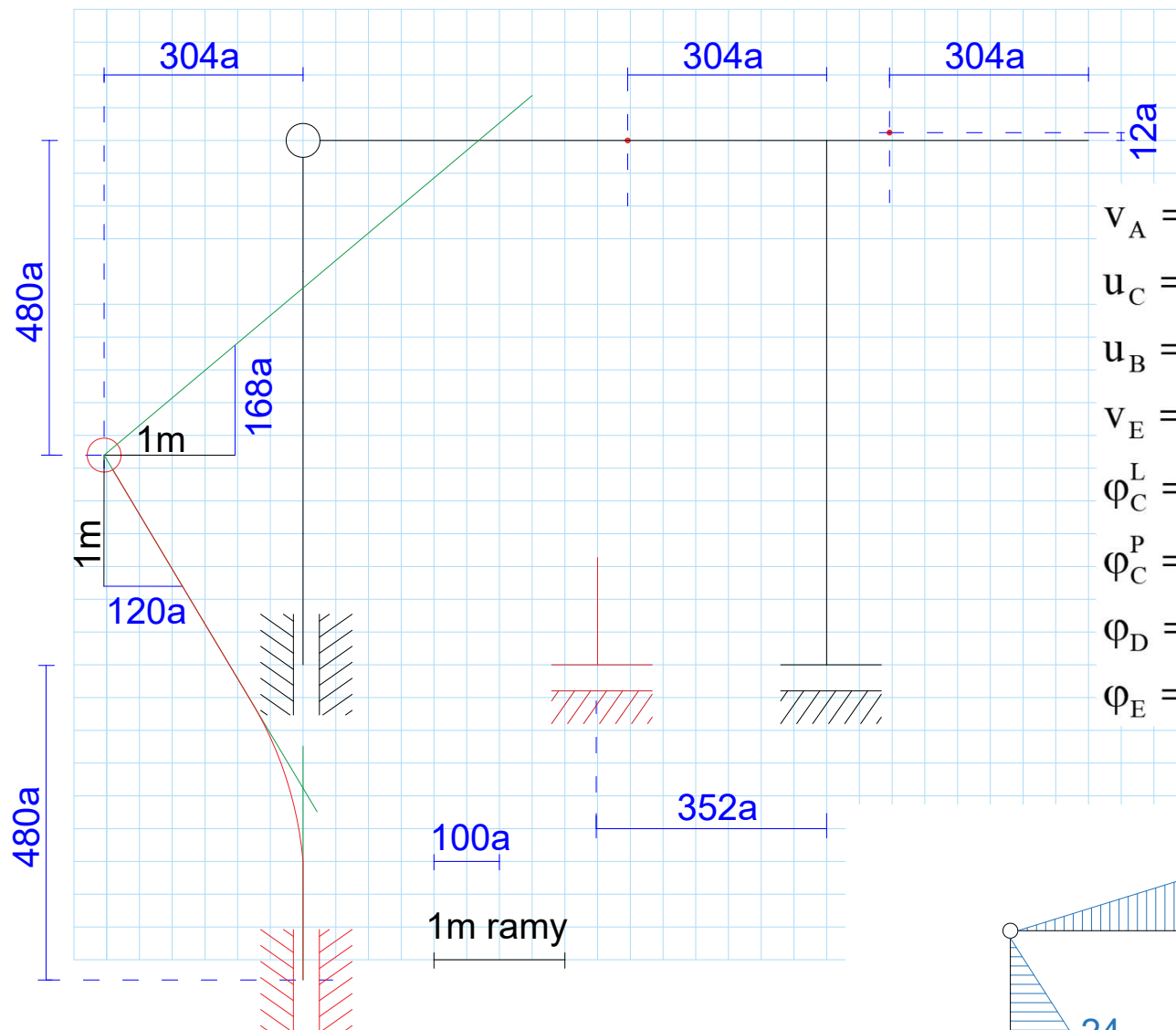
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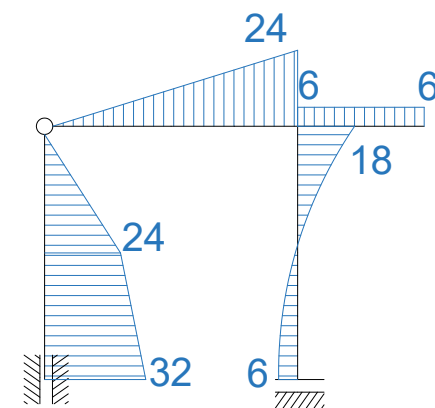
$$v_E = -12a$$

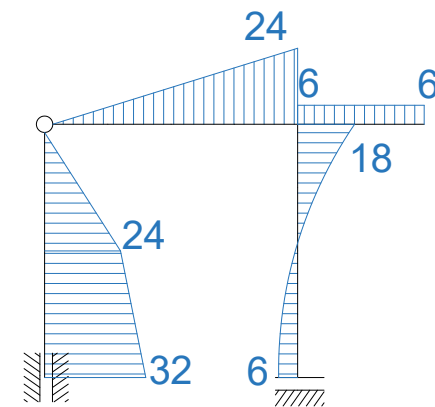
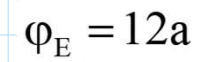
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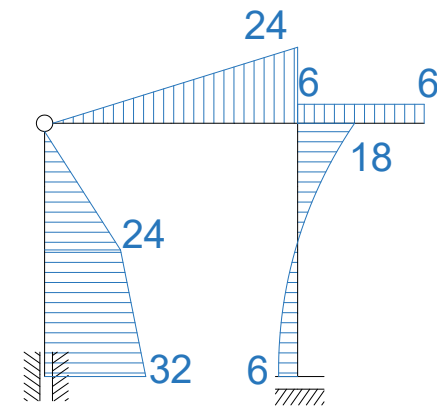
$$\phi_C^P = -168a$$

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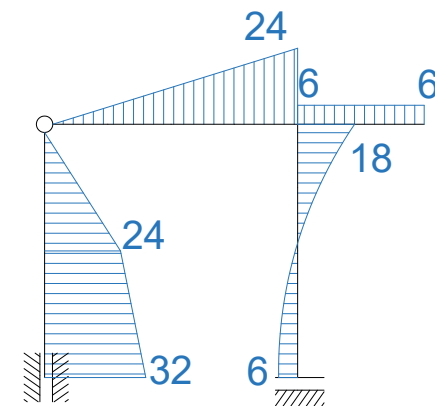
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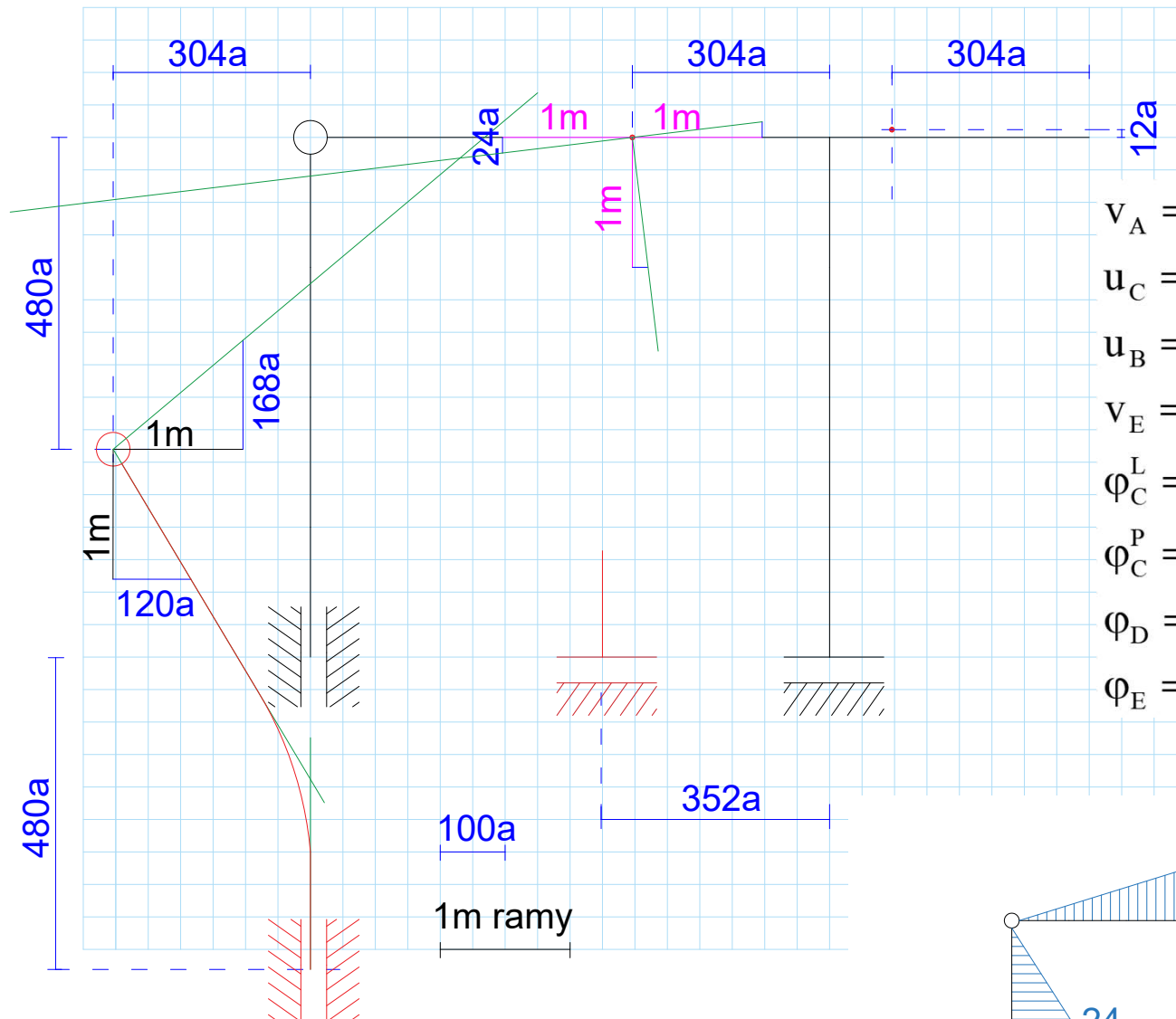




$$\varphi_E = 12a$$



$$\varphi_E = 12a$$



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$$u_B = -352a$$

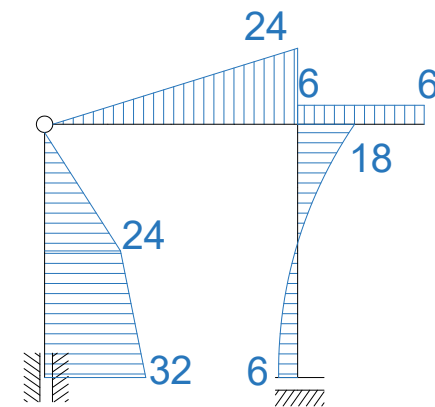
$$v_E = -12a$$

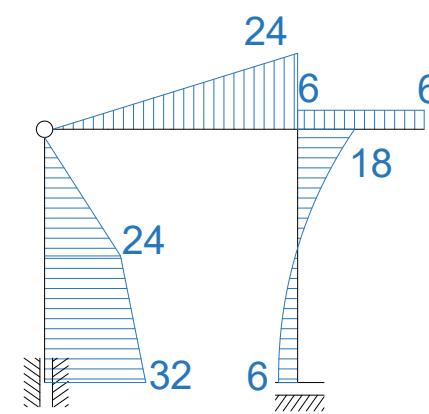
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$$\phi_C^P = -168a$$

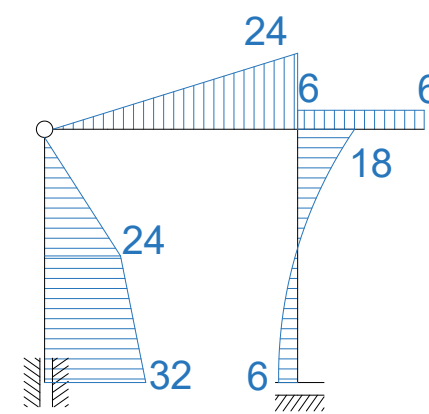
$$\phi_D = -24a$$

$$\phi_E = 12a$$

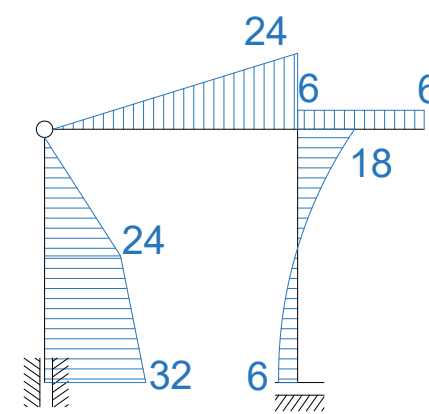




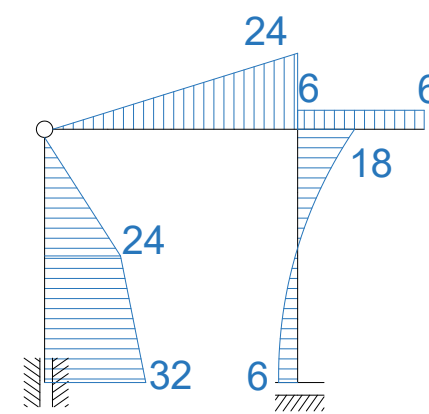
$$\varphi_E = 12a$$



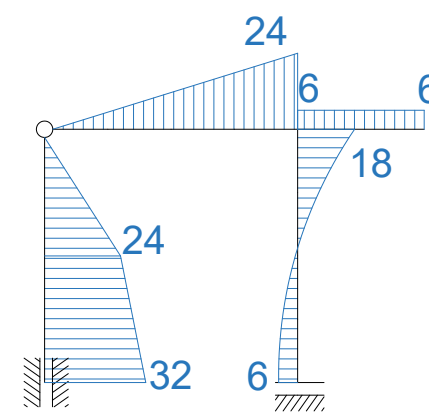
$$\varphi_E = 12a$$



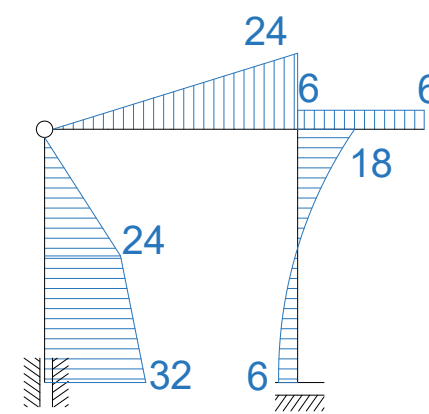
$$\varphi_E = 12a$$



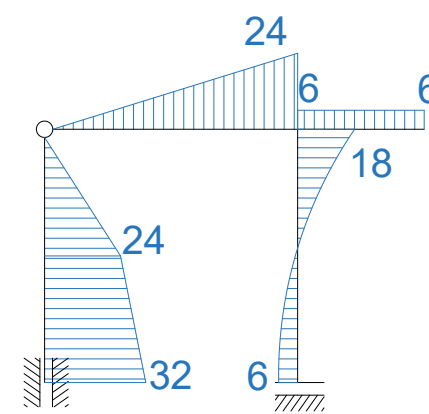
$$\varphi_E = 12a$$



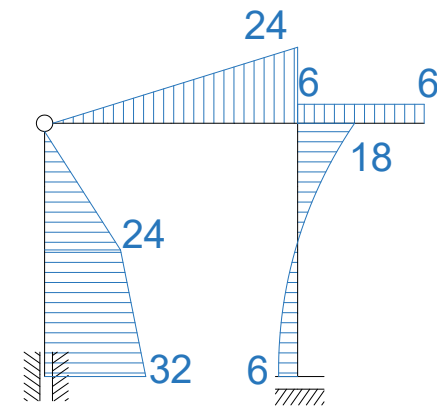
$$\varphi_E = 12a$$



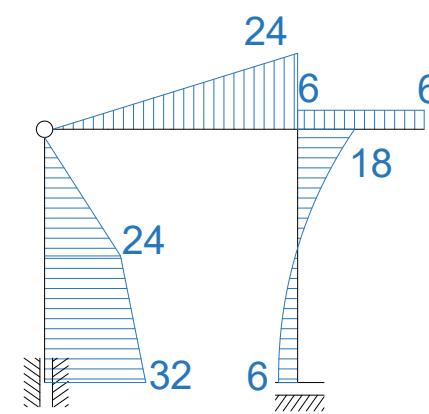
$$\varphi_E = 12a$$



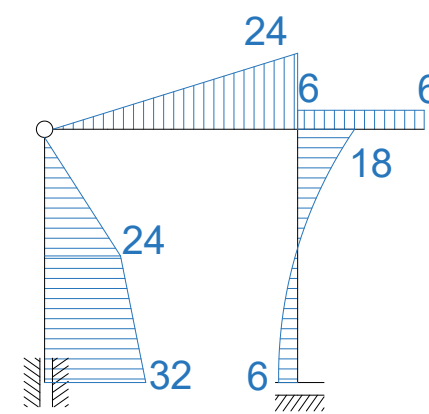
$$\varphi_E = 12a$$



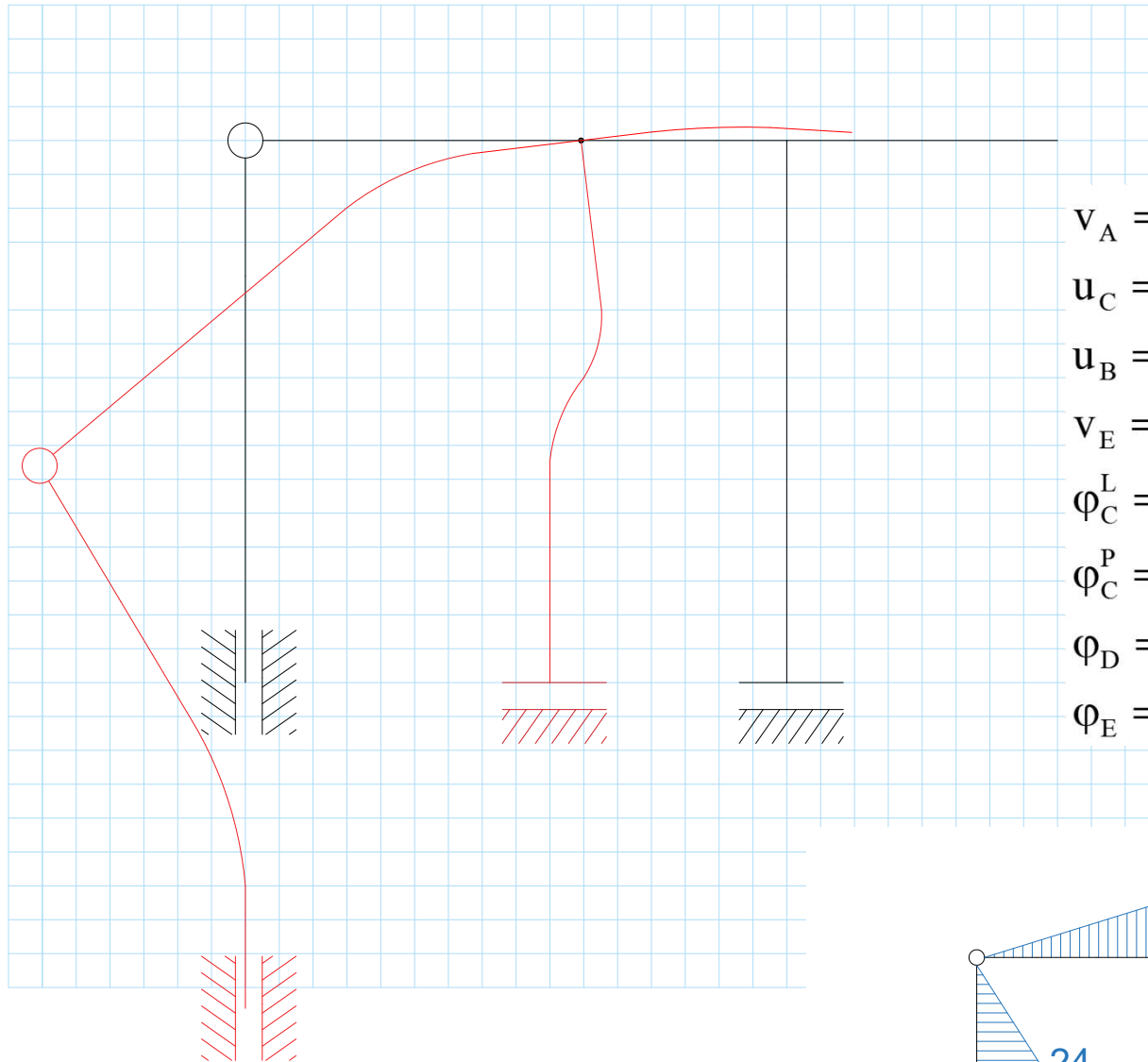
$$\varphi_E = 12a$$



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