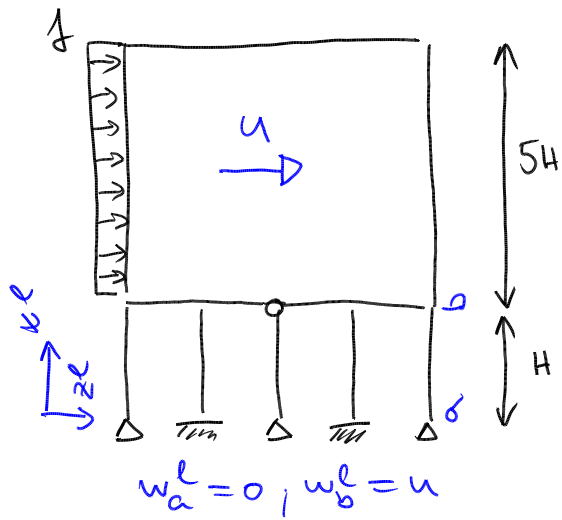


→ Pomocí přírůstkové metody vypočítat $f^{(1)}$ a f^{\max}

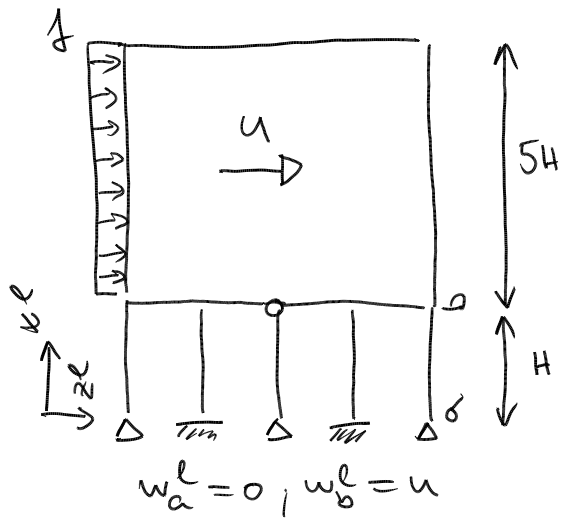


→ Pomocí přírůstkové metody vypočítat $f^{(1)}$ a f^{\max}

$$M_{ba,w} = k \left[\varphi_a + 2\varphi_b + \frac{3(w_b^l - w_a^l)}{L} \right]$$

$$\downarrow \frac{2EI}{L}$$

$$M_{ba,w} = \frac{3k}{2} \left[\varphi_b + \frac{w_b^l - w_a^l}{L} \right]$$



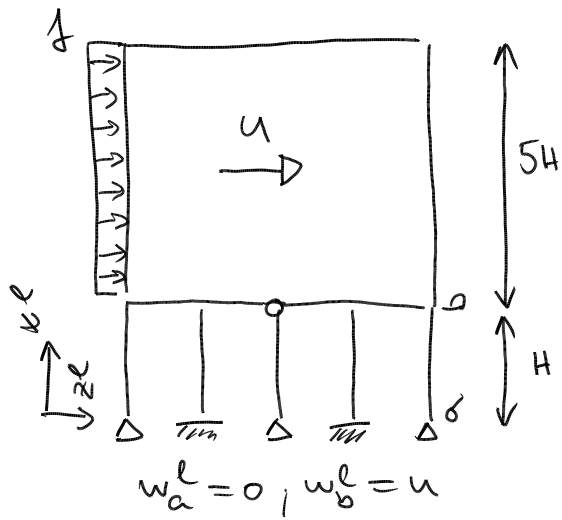
→ Pomocí přírůstkové metody vypočítat $f^{(1)}$ a f^{\max}

$$M_{ba,w} = k \left[\varphi_a + 2\varphi_b + \frac{3(w_b^l - w_a^l)}{L} \right] \dots = \frac{6EI}{H^2} u$$

$$\left. \begin{array}{l} \rightarrow \\ \uparrow \end{array} \right\} \frac{2EI}{L}$$

↳ dvojnásobný moment při stejném posunu

$$M_{ba,wk} = \frac{3k}{2} \left[\varphi_b + \frac{w_b^l - w_a^l}{L} \right] \dots = \frac{3EI}{H^2} u$$

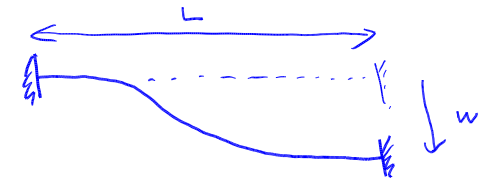


→ Pomocí přírůstkové metody vypočítat $f^{(1)}$ a f^{\max}

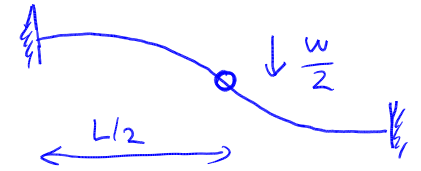
$$M_{ba,w} = k \left[\varphi_a + 2\varphi_b + \frac{3(w_b^l - w_a^l)}{L} \right] \dots = \frac{6EI}{H^2} u$$

$$\left\{ \begin{array}{l} \frac{2EI}{L} \\ \uparrow \end{array} \right.$$

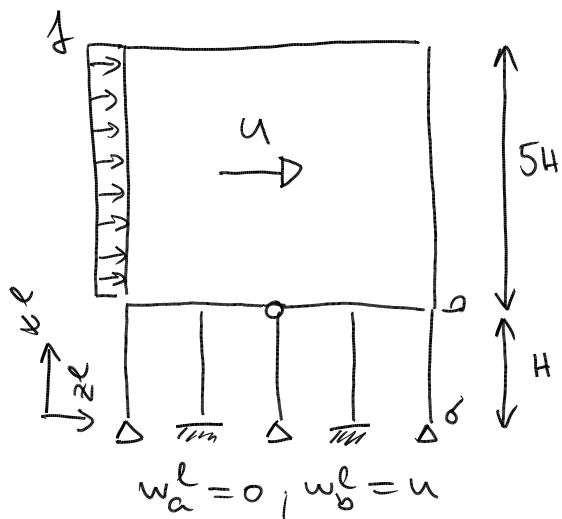
$$M_{ba,uk} = \frac{3k}{2} \left[\varphi_b + \frac{w_b^l - w_a^l}{L} \right] \dots = \frac{3EI}{H^2} u$$



↳ dvojnásobný moment při stejném posunu



$$M_{uk} = \frac{3EI}{\left(\frac{L}{2}\right)^2} \frac{w}{2} = \frac{4 \cdot 3 \cdot EI \cdot w}{2L^2} = \frac{6EI \cdot w}{L^2}$$

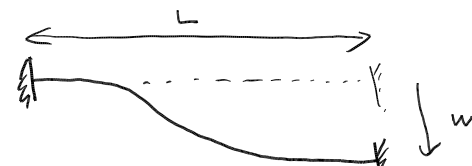


→ Pomocí přírůstkové metody vypočítat $f^{(1)}$ a f^{\max}

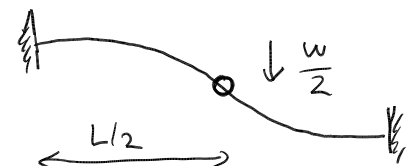
$$M_{ba,w} = k \left[\varphi_a + 2\varphi_b + \frac{3(w_b^l - w_a^l)}{L} \right] \dots = \frac{6EI}{H^2} u$$

$$\left\{ \begin{array}{l} \frac{2EI}{L} \\ \uparrow \end{array} \right.$$

$$M_{ba,ku} = \frac{3k}{2} \left[\varphi_b + \frac{w_b^l - w_a^l}{L} \right] \dots = \frac{3EI}{H^2} u$$



↳ dvojnásobný moment při stejném posunu

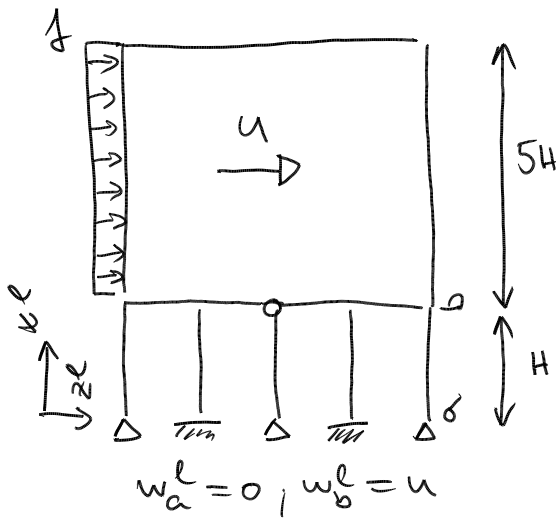


$$M_{wk} = \frac{3EI}{(L/2)^2} \frac{w}{2} = \frac{4 \cdot 3 \cdot EI \cdot w}{2L^2} = \frac{6EI}{L^2} w$$

→ ŘEŠENÍ: pátou podmínku rovnováhy $2[Z_{ba,w} + Z_{ba,ku}] = 5H \cdot f$

$$Z_{ba,w} = \frac{3 \frac{2EI}{L}}{L} \left[\varphi_a + \varphi_b + \frac{2(w_b^l - w_a^l)}{L} \right] = \frac{12EI}{L^3} w_b = \frac{12EI}{H^3} u$$

$$Z_{ba,ku} = \frac{3 \frac{2EI}{L}}{2L} \left[\varphi_b + \frac{w_b^l - w_a^l}{L} \right] = \frac{3EI}{L^3} w_b^l = \frac{3EI}{H^3} u$$

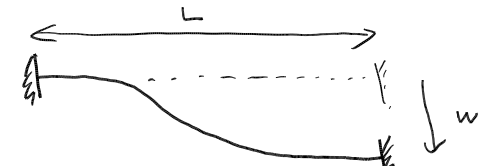


→ Pomocí přírůstkové metody vypočítat $f^{(1)}$ a f^{\max}

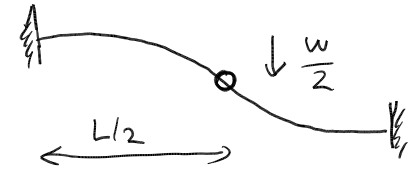
$$M_{ba,w} = k \left[\varphi_a + 2\varphi_b + \frac{3(w_b^l - w_a^l)}{L} \right] \dots = \frac{6EI}{H^2} u$$

$$\left\{ \begin{array}{l} \frac{2EI}{L} \\ \uparrow \end{array} \right.$$

$$M_{ba,k} = \frac{3k}{2} \left[\varphi_b + \frac{w_b^l - w_a^l}{L} \right] \dots = \frac{3EI}{H^2} u$$



↳ dvojnásobný moment při stejném posunu



$$M_{wk} = \frac{3EI}{(\frac{L}{2})^2} \frac{W}{2} = \frac{4 \cdot 3 \cdot EI \cdot W}{2L^2} = \frac{6EI}{L^2} W$$

→ ŘEŠENÍ: pátou podmínku rovnováhy $2[Z_{ba,w} + Z_{ba,kv}] = 5H \cdot f$

$$Z_{ba,w} = \frac{3 \frac{2EI}{L}}{L} \left[\varphi_a + \varphi_b + \frac{2(w_b^l - w_a^l)}{L} \right] = \frac{12EI}{L^3} w_b = \frac{12EI}{H^3} u$$

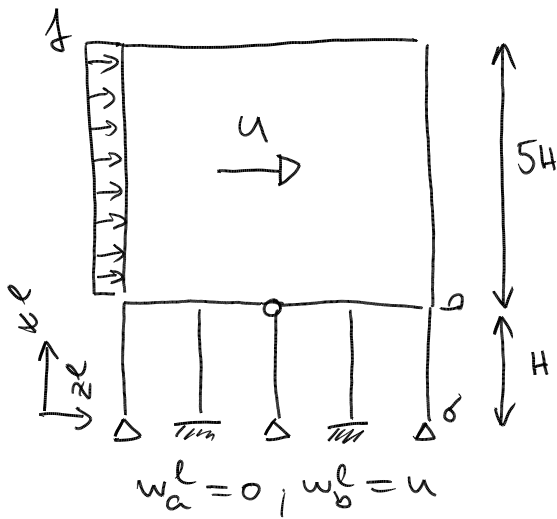
$$Z_{ba,kv} = \frac{3 \frac{2EI}{L}}{2L} \left[\varphi_b + \frac{w_b^l - w_a^l}{L} \right] = \frac{3EI}{L^3} w_b^l = \frac{3EI}{H^3} u$$

$$\left. \begin{array}{l} \\ \\ \end{array} \right\} 2 \left[(12+3) \frac{EI}{H^3} u \right] = 5H f$$

$$\frac{30EI}{H^3} u = 5H f \rightarrow u = \frac{fH^4}{6EI}$$

$$M_{uv} > M_{kv} \rightarrow \frac{6EI}{H^2} \cdot \frac{fH^4}{6EI} = M_0$$

$$\rightarrow \underline{\underline{f^{(1)} = \frac{M_0}{H^2}}}$$

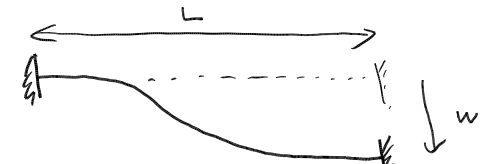


→ Pomocí přírůstkové metody vypočítat $f^{(1)}$ a f^{max}

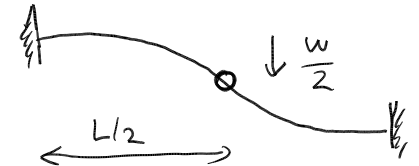
$$M_{ba,w} = k \left[\varphi_a + 2\varphi_b + \frac{3(w_b^l - w_a^l)}{L} \right] \dots = \frac{6EI}{H^2} u$$

$$\left\{ \begin{array}{l} \frac{2EI}{L} \\ \uparrow \end{array} \right.$$

$$M_{ba,kv} = \frac{3k}{2} \left[\varphi_b + \frac{w_b^l - w_a^l}{L} \right] \dots = \frac{3EI}{H^2} u$$



↳ dvojnásobný moment při stejném posunu



$$M_{kv} = \frac{3EI}{(L/2)^2} \cdot \frac{W}{2} = \frac{4 \cdot 3 \cdot EI \cdot W}{2L^2} = \frac{6EI}{L^2} W$$

→ ŘEŠENÍ: pětice podmínek rovnováhy $2 [Z_{ba,w} + Z_{ba,kv}] = 5H \cdot f$

$$Z_{ba,w} = \frac{3 \frac{2EI}{L}}{L} \left[\varphi_a + \varphi_b + \frac{2(w_b^l - w_a^l)}{L} \right] = \frac{12EI}{L^3} w_b = \frac{12EI}{H^3} u$$

$$Z_{ba,kv} = \frac{3 \frac{2EI}{L}}{2L} \left[\varphi_b + \frac{w_b^l - w_a^l}{L} \right] = \frac{3EI}{L^3} w_b^l = \frac{3EI}{H^3} u$$

$$\left. \begin{array}{l} \\ \\ \end{array} \right\} 2 \left[(12+3) \frac{EI}{H^3} u \right] = 5H f$$

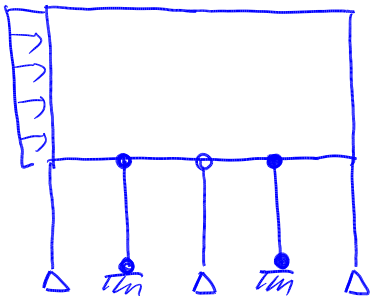
$$\frac{30EI}{H^3} u = 5H f \rightarrow u = \frac{fH^4}{6EI}$$

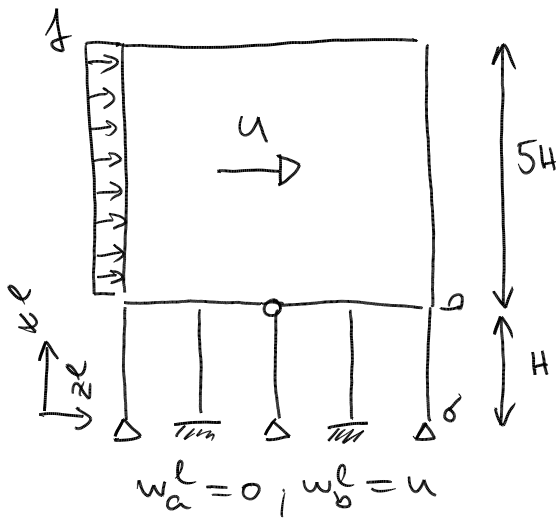
$$M_{wv} > M_{kv} \rightarrow \frac{6EI}{H^2} \cdot \frac{fH^4}{6EI} = M_0$$

$$\rightarrow \underline{\underline{f^{(1)} = \frac{M_0}{H^2}}}$$

→ ÚPRAVA STATICKÉHO SCHEMATU

$f^{(2)}$

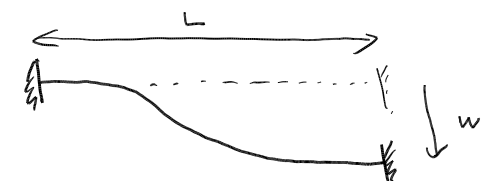




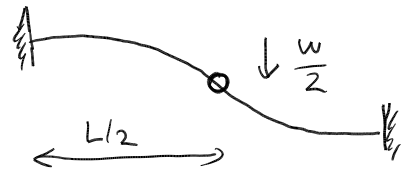
→ Pomocí přírůstkové metody vypočítat $f^{(1)}$ a f^{max}

$$M_{ba,w} = k \left[\varphi_a + 2\varphi_b + \frac{3(w_b^l - w_a^l)}{L} \right] \dots = \frac{6EI}{H^2} u$$

$$M_{ba,k} = \frac{3k}{2} \left[\varphi_b + \frac{w_b^l - w_a^l}{L} \right] \dots = \frac{3EI}{H^2} u$$



↳ dvojnásobný moment při stejném posunu



$$M_{wk} = \frac{3EI}{(L/2)^2} \cdot \frac{W}{2} = \frac{4 \cdot 3 \cdot EI \cdot W}{2L^2} = \frac{6EI \cdot W}{L^2}$$

→ ŘEŠENÍ: pátové podmínky rovnováhy $2[Z_{ba,w} + Z_{ba,k}] = 5H \cdot f$

$$Z_{ba,w} = \frac{3 \frac{2EI}{L}}{L} \left[\varphi_a + \varphi_b + \frac{2(w_b^l - w_a^l)}{L} \right] = \frac{12EI}{L^3} w_b = \frac{12EI}{H^3} u$$

$$Z_{ba,k} = \frac{3 \frac{2EI}{L}}{2L} \left[\varphi_b + \frac{w_b^l - w_a^l}{L} \right] = \frac{3EI}{L^3} w_b = \frac{3EI}{H^3} u$$

$$2 \left[(12+3) \frac{EI}{H^3} u \right] = 5H f$$

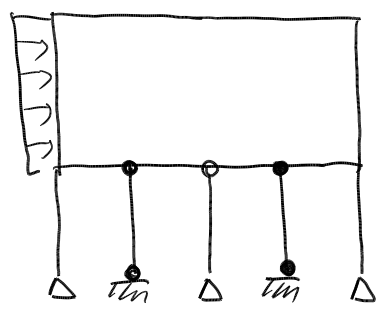
$$\frac{30EI}{H^3} u = 5H f \rightarrow u = \frac{f H^4}{6EI}$$

$$M_{wv} > M_{kv} \rightarrow \frac{6EI}{H^2} \cdot \frac{f H^4}{6EI} = M_0$$

$$\rightarrow \underline{\underline{f^{(1)} = \frac{M_0}{H^2}}}$$

→ ÚPRAVA STATICKÉHO SCHEMATU

$\Delta f^{(2)}$

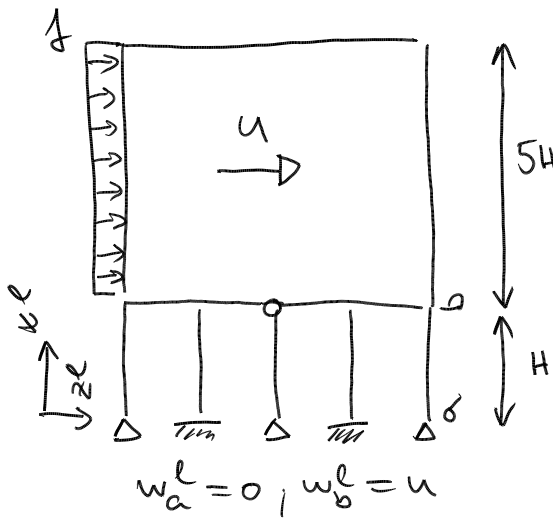


→ pátové podmínky rovnováhy: $2 Z_{ba,k} = 5H \Delta f^{(2)}$

$$6 \frac{EI}{H^3} u = 5H \Delta f^{(2)} \rightarrow u = \frac{5}{6} \frac{H^4}{EI} \Delta f^{(2)}$$

$$\Delta M_{kv} = M_0 - \frac{M_0}{2} = \frac{M_0}{2} = \frac{3EI}{H^2} u = \frac{3EI}{H^2} \cdot \frac{5}{6} \frac{H^4}{EI} \Delta f^{(2)}$$

(substitue $f^{(1)}$)

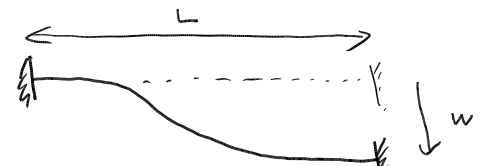


→ Pomocí přírůstkové metody vypočítat $f^{(1)}$ a f^{max}

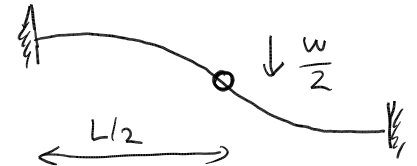
$$M_{ba,w} = k \left[\varphi_a + 2\varphi_b + \frac{3(w_b^l - w_a^l)}{L} \right] \dots = \frac{6EI}{H^2} u$$

$$\left\{ \begin{array}{l} \frac{2EI}{L} \\ \uparrow \end{array} \right.$$

$$M_{ba,k} = \frac{3k}{2} \left[\varphi_b + \frac{w_b^l - w_a^l}{L} \right] \dots = \frac{3EI}{H^2} u$$



↳ dvojnásobný moment při stejném posunu



$$M_{wk} = \frac{3EI}{(L/2)^2} \cdot \frac{W}{2} = \frac{4 \cdot 3 \cdot EI \cdot W}{2L^2} = \frac{6EI \cdot W}{L^2}$$

→ ŘEŠENÍ: pátové podmínky rovnováhy $2[Z_{ba,w} + Z_{ba,k}] = 5H \cdot f$

$$Z_{ba,w} = \frac{3 \frac{2EI}{L}}{L} \left[\varphi_a + \varphi_b + \frac{2(w_b^l - w_a^l)}{L} \right] = \frac{12EI w_b}{L^3} = \frac{12EI}{H^3} u$$

$$Z_{ba,k} = \frac{3 \frac{2EI}{L}}{2L} \left[\varphi_b + \frac{w_b^l - w_a^l}{L} \right] = \frac{3EI w_b^l}{L^3} = \frac{3EI}{H^3} u$$

$$\left. \begin{array}{l} \\ \\ \end{array} \right\} 2 \left[(12+3) \frac{EI}{H^3} u \right] = 5H f$$

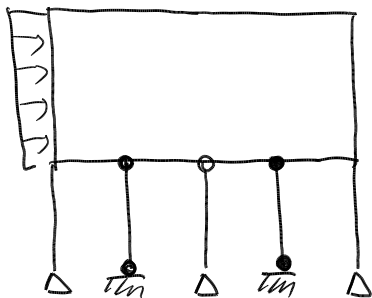
$$\frac{30EI}{H^3} u = 5H f \rightarrow u = \frac{f H^4}{6EI}$$

$$M_{wv} > M_{kv} \rightarrow \frac{6EI}{H^2} \cdot \frac{f H^4}{6EI} = M_0$$

$$\rightarrow \underline{\underline{f^{(1)} = \frac{M_0}{H^2}}}$$

→ ÚPRAVA STATICKÉHO SCHEMATU

$\Delta f^{(2)}$



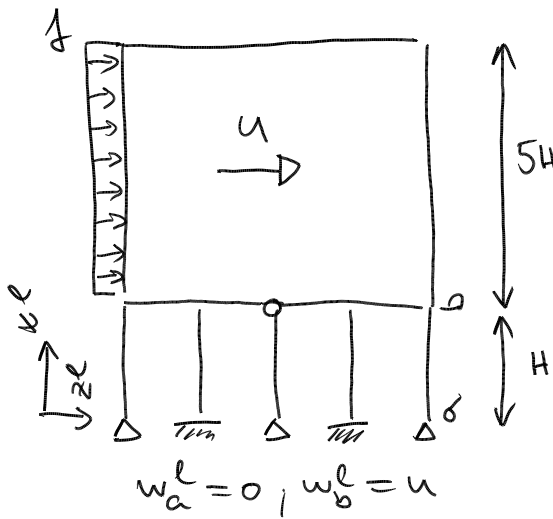
→ pátové podmínky rovnováhy: $2 Z_{ba,k} = 5H \Delta f^{(2)}$

$$6 \frac{EI}{H^3} u = 5H \Delta f^{(2)} \rightarrow u = \frac{5}{6} \frac{H^4}{EI} \Delta f^{(2)}$$

$$\Delta M_{kv} = M_0 - \frac{M_0}{2} = \frac{M_0}{2} = \frac{3EI}{H^2} u = \frac{3EI}{H^2} \cdot \frac{5}{6} \frac{H^4}{EI} \Delta f^{(2)}$$

(účinok od $f^{(1)}$)

$$\rightarrow \Delta f^{(2)} = \frac{M_0}{5H^2}$$

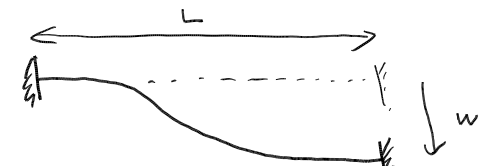


→ Pomocí přírůstkové metody vypočítat $f^{(1)}$ a f^{max}

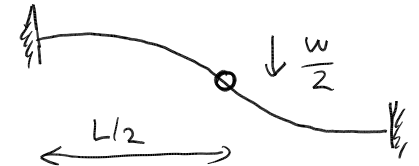
$$M_{ba,w} = k \left[\varphi_a + 2\varphi_b + \frac{3(w_b^l - w_a^l)}{L} \right] \dots = \frac{6EI}{H^2} u$$

$$\left\{ \begin{array}{l} \frac{2EI}{L} \\ \uparrow \end{array} \right.$$

$$M_{ba,k} = \frac{3k}{2} \left[\varphi_b + \frac{w_b^l - w_a^l}{L} \right] \dots = \frac{3EI}{H^2} u$$



↳ dvojnásobný moment při stejném posunu



$$M_{wk} = \frac{3EI}{(\frac{L}{2})^2} \cdot \frac{W}{2} = \frac{4 \cdot 3 \cdot EI \cdot W}{2L^2} = \frac{6EI \cdot W}{L^2}$$

→ ŘEŠENÍ: pátové podmínky rovnováhy $2 [Z_{ba,w} + Z_{ba,k}] = 5H \cdot f$

$$Z_{ba,w} = \frac{3 \frac{2EI}{L}}{L} \left[\varphi_a + \varphi_b + \frac{2(w_b^l - w_a^l)}{L} \right] = \frac{12EI}{L^3} w_b = \frac{12EI}{H^3} u$$

$$Z_{ba,k} = \frac{3 \frac{2EI}{L}}{2L} \left[\varphi_b + \frac{w_b^l - w_a^l}{L} \right] = \frac{3EI}{L^3} w_b^l = \frac{3EI}{H^3} u$$

$$\left. \begin{array}{l} \\ \\ \end{array} \right\} 2 \left[(12+3) \frac{EI}{H^3} u \right] = 5H f$$

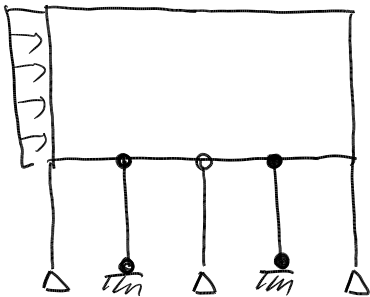
$$\frac{30EI}{H^3} u = 5H f \rightarrow u = \frac{fH^4}{6EI}$$

$$M_{wv} > M_{kv} \rightarrow \frac{6EI}{H^2} \cdot \frac{fH^4}{6EI} = M_0$$

$$\rightarrow \underline{\underline{f^{(1)} = \frac{M_0}{H^2}}}$$

→ ÚPRAVA STATICKÉHO SCHEMATU

$\Delta f^{(2)}$



→ pátové podmínky rovnováhy: $2 Z_{ba,k} = 5H \Delta f^{(2)}$

$$6 \frac{EI}{H^3} u = 5H \Delta f^{(2)} \rightarrow u = \frac{5}{6} \frac{H^4}{EI} \Delta f^{(2)}$$

$$\Delta M_{kv} = M_0 - \frac{M_0}{2} = \frac{M_0}{2} = \frac{3EI}{H^2} u = \frac{3EI}{H^2} \cdot \frac{5}{6} \frac{H^4}{EI} \Delta f^{(2)}$$

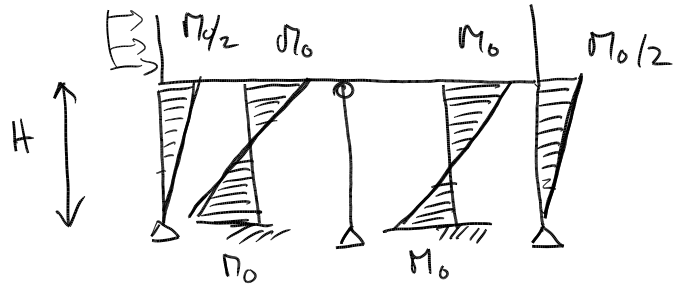
(súčinok od $f^{(1)}$)

$$\rightarrow \Delta f^{(2)} = \frac{M_0}{5H^2}$$

$$\rightarrow \underline{\underline{f^{(2)} = f^{(1)} + \Delta f^{(2)} = \frac{M_0}{H^2} + \frac{M_0}{5H^2} = \frac{6}{5} \frac{M_0}{H^2}}}$$

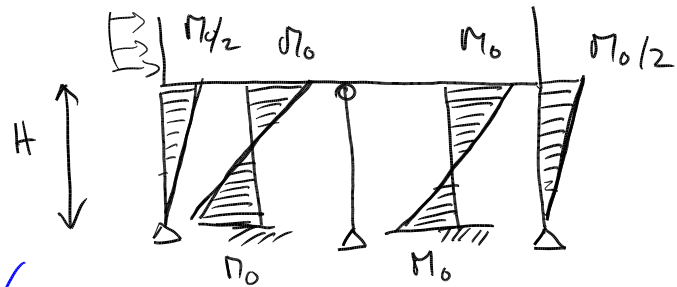
→ ulepšeny postup výpočtu

Rozložení M při vzniku 1. plast. kloubu

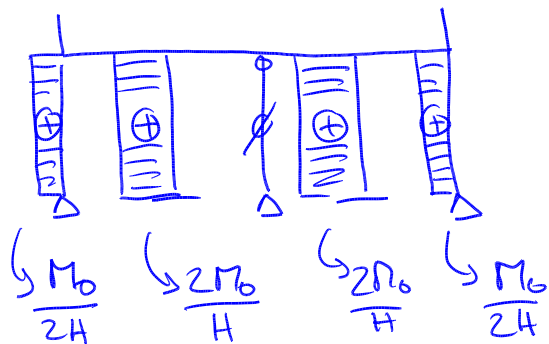


→ ulepšeny postup výpočtu

Rozložení M při vzniku 1. plast. kloubu

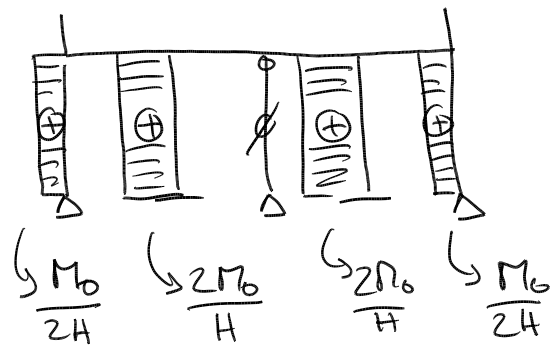
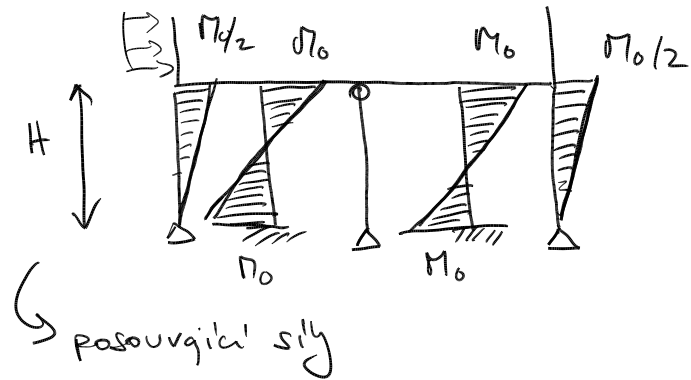


→ posouvající síly



→ ulepšeny postup výpočtu

Rozložení M při vzniku 1. plast. kloubu

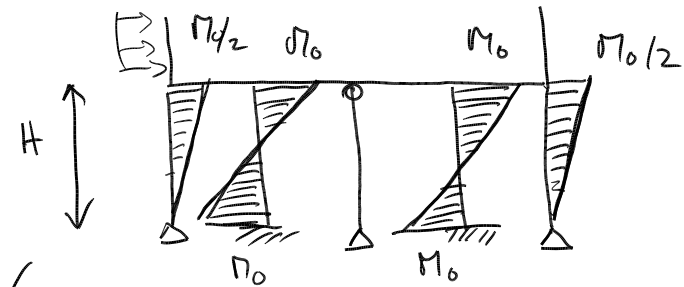


$$\sum = 2 \left[\frac{M_0}{24} + \frac{2M_0}{H} \right] = 5H \cdot f^{(1)}$$

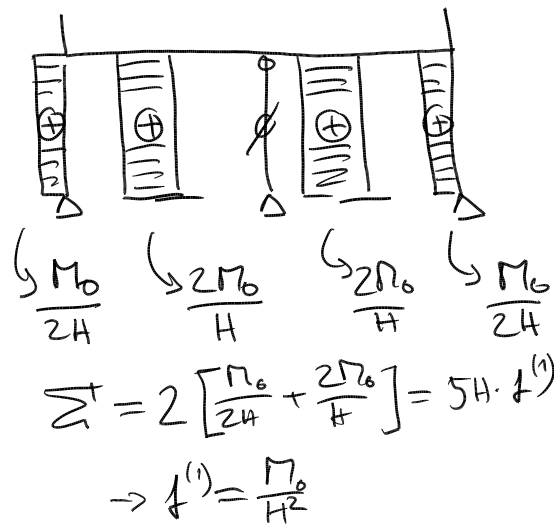
$$\rightarrow f^{(1)} = \frac{M_0}{4H^2}$$

→ ulepšeny postup výpočtu

Rozložení M při vzniku 1. plast. kloubu

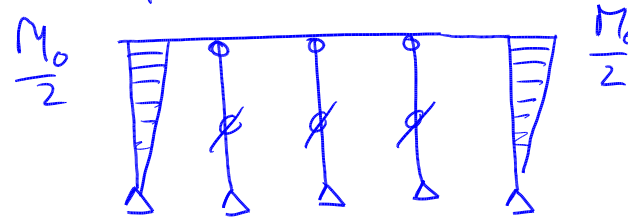


→ posouvající síly



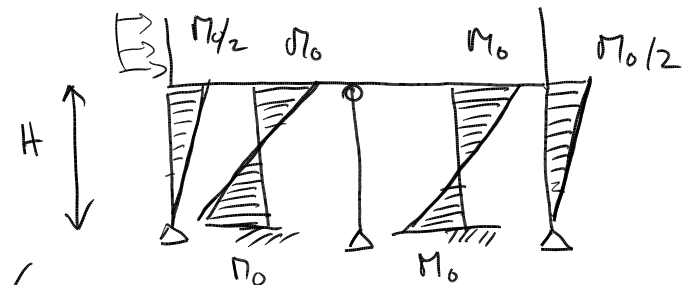
Výpočet max. únosnosti

průběh $\Delta M^{(2)}$

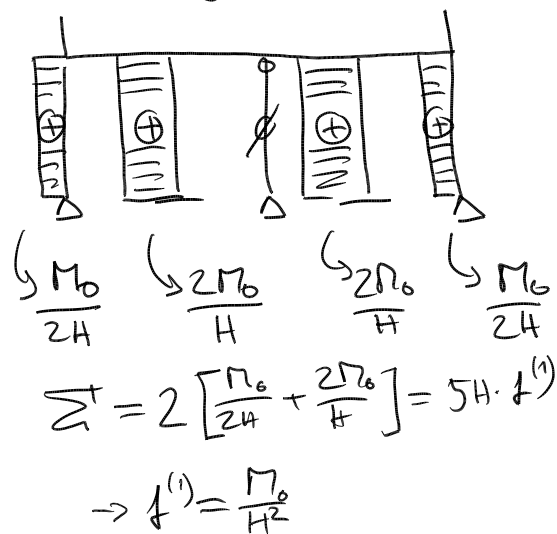


→ ulepšeny postup výpočtu

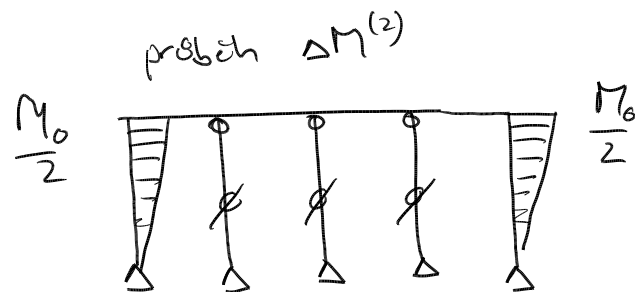
Rozložení M při vzniku 1. plast. kloubu



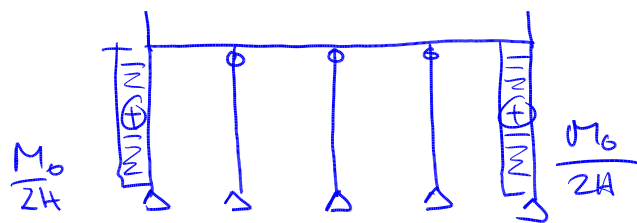
→ posouvající síly



Výpočet max. únosnosti



→ problém $\Delta V^{(2)}$



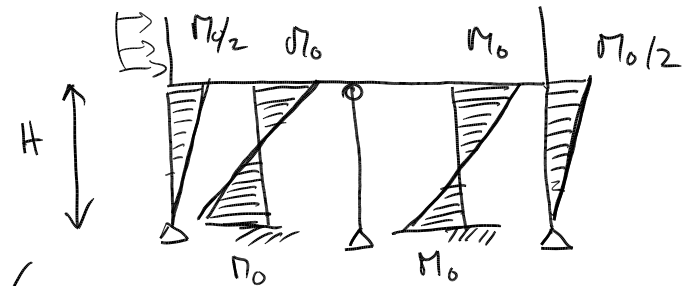
$$\sum \frac{2M_0}{2H} = 5H \Delta f^{(2)}$$

$$\rightarrow \Delta f^{(2)} = \frac{M_0}{5H^2}$$

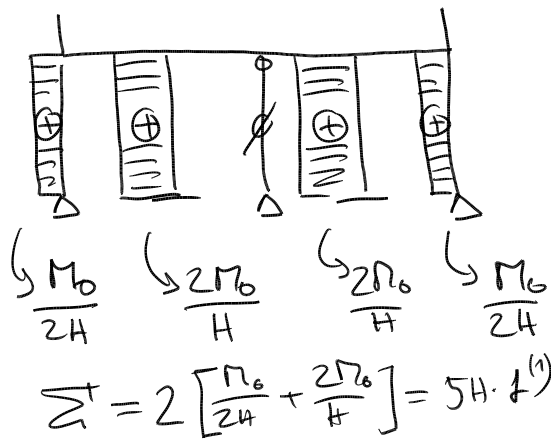
$$\rightarrow \underline{\underline{f^{(2)} = \frac{6}{5} \frac{M_0}{H^2}}}$$

→ ulepšeny postup výpočtu

Rozložení M při vzniku 1. plast. kloubu



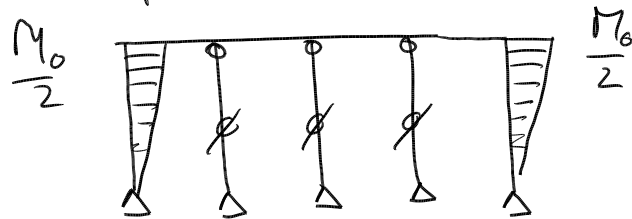
→ posouvající síly



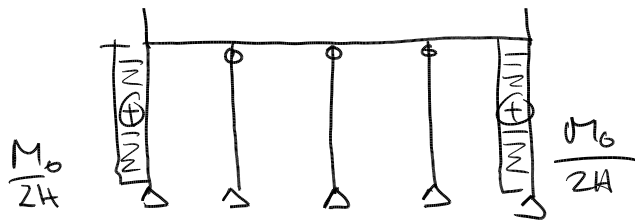
$$\rightarrow f^{(1)} = \frac{M_0}{H^2}$$

Výpočet max. únosnosti

průběh $\Delta M^{(2)}$



→ průběh $\Delta V^{(2)}$

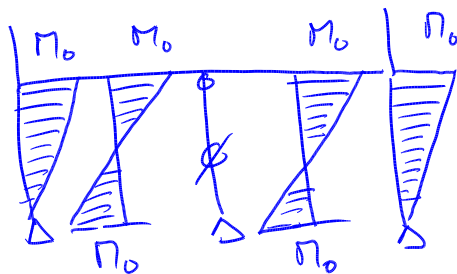


$$\sum 2 \frac{M_0}{2H} = 5H \Delta f^{(2)}$$

$$\rightarrow \Delta f^{(2)} = \frac{M_0}{5H^2}$$

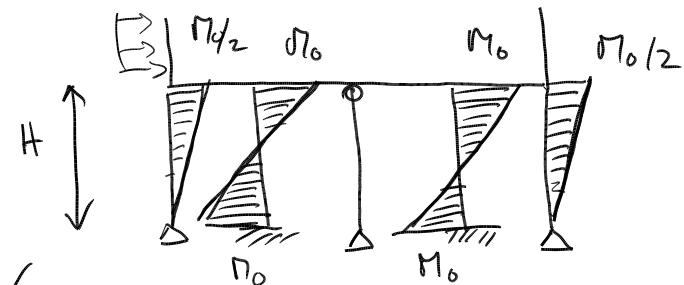
$$\rightarrow \underline{\underline{f^{(2)} = \frac{6}{5} \frac{M_0}{H^2}}}$$

→ finální průběh $M^{(2)}$

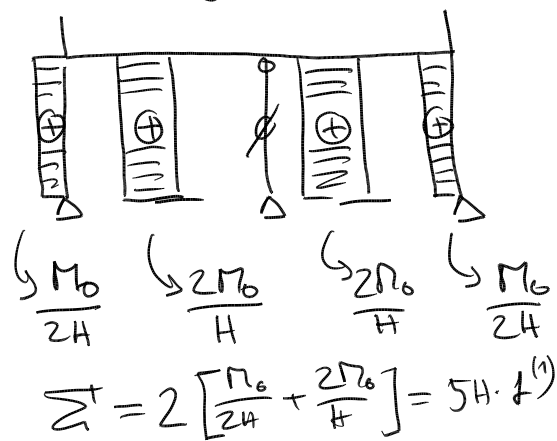


→ ulepšeny postup výpočtu

Rozložení M při vzniku 1. plast. kloubu



→ posouvající síly

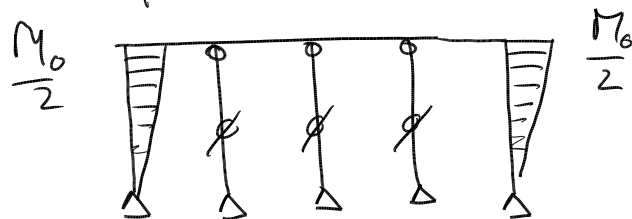


$$\sum = 2 \left[\frac{M_0}{2H} + \frac{2M_0}{H} \right] = 5H \cdot f^{(1)}$$

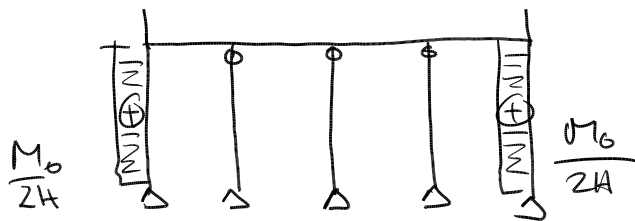
$$\rightarrow f^{(1)} = \frac{M_0}{H^2}$$

Výpočet max. únosnosti

průběh $\Delta M^{(2)}$



→ průběh $\Delta V^{(2)}$

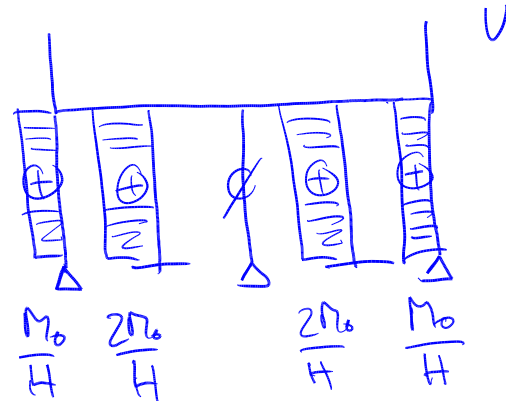
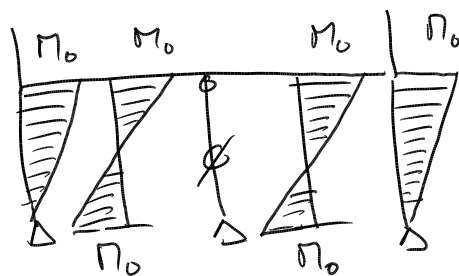


$$\sum \frac{2M_0}{2H} = 5H \Delta f^{(2)}$$

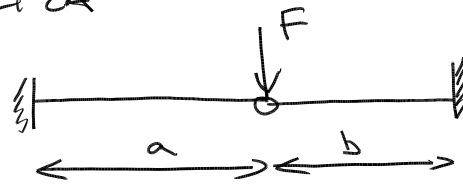
$$\rightarrow \Delta f^{(2)} = \frac{M_0}{5H^2}$$

$$\rightarrow \underline{\underline{f^{(2)} = \frac{6}{5} \frac{M_0}{H^2}}}$$

→ finální průběh $M^{(2)}$

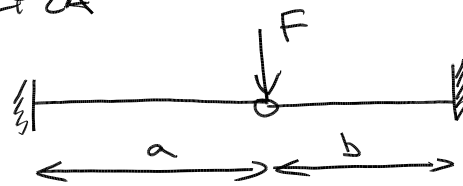


MEZNI PLASTICKA ANALYZA



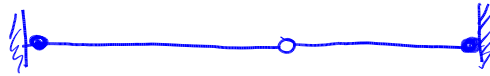
mezni plasticky moment M_0

MEZNI PLASTICKA ANALYZA

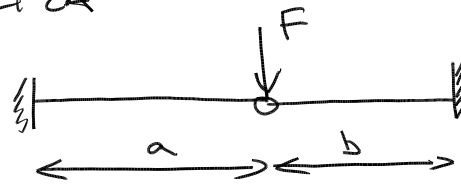


mezni plasticky moment M_0

PRPE - opakovani

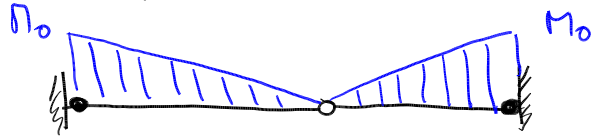


MEZNI PLASTICKA ANALYZA

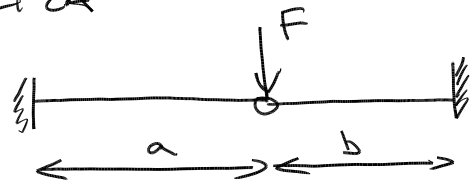


mezni plasticky moment M_0

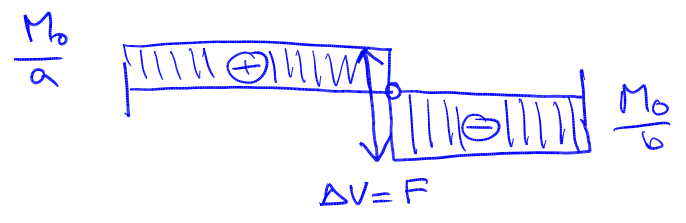
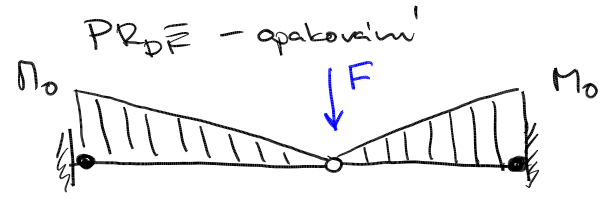
PRDF - opakovani



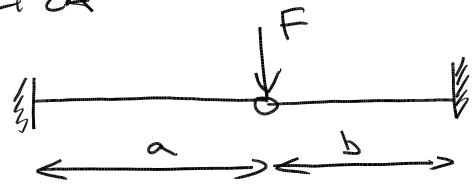
MEZNI PLASTICKA ANALYZA



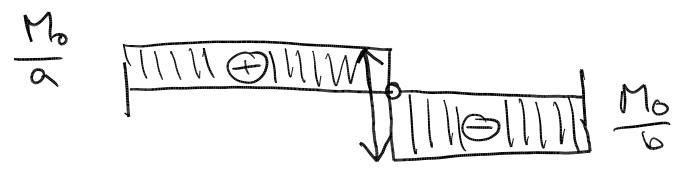
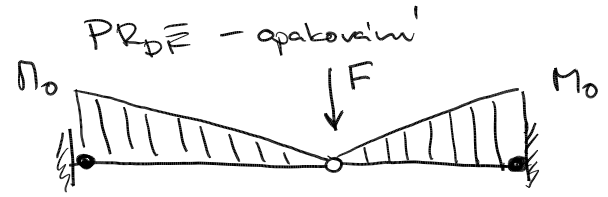
mezni plasticky moment M_0



MEZNI PLASTICKA ANALYZA



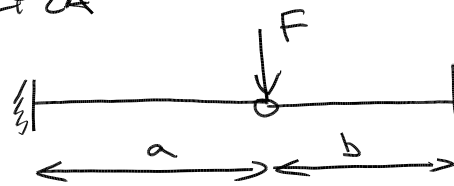
mezni plasticky moment M_0



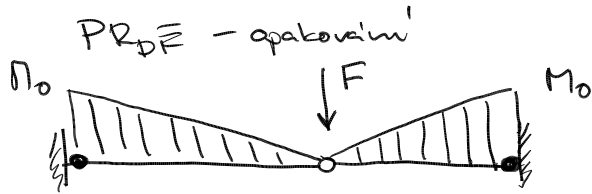
$$\Delta V = F$$

$$\Delta V = \frac{M_0}{a} + \frac{M_0}{b}$$

MEZNI PLASTICKA ANALYZA



mezní plastický moment M_0

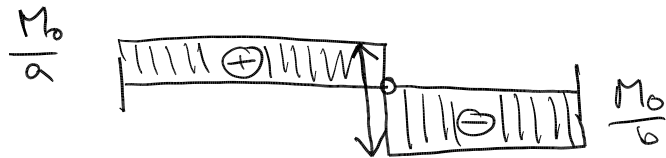


PRPM - kinematická metoda

kinematický přípustný mechanismus

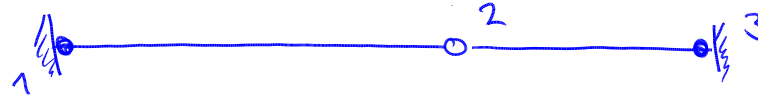
→ rychlosti posunu a deformace splňují geometrické vztahy

→ vnější síly poskytují kladný výkon

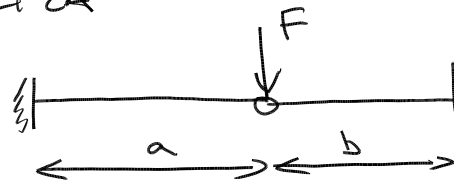


$$\Delta V = F$$

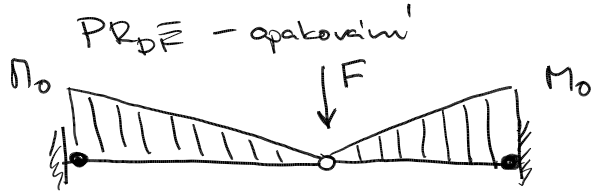
$$\Delta V = \frac{M_0}{a} + \frac{M_0}{b}$$



MEZNI PASTICKA ANALYZA



mezni plasticky moment M_0

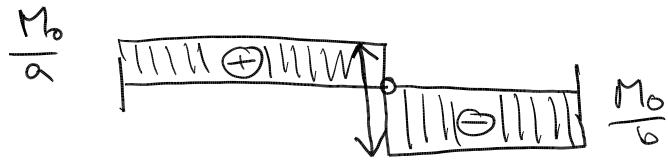


PRPM - kinematicka metoda

kinematicky pri'pustny mechanismus

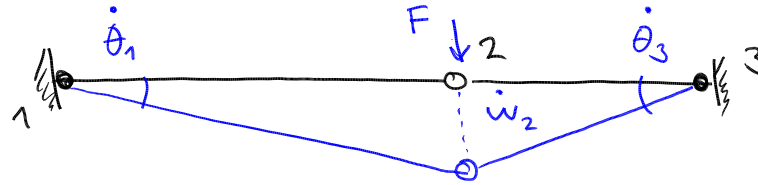
→ gabolsti paruni a deformacei splyni' geometricki ra

→ vnjsi sily podavaju' kladny' vykon

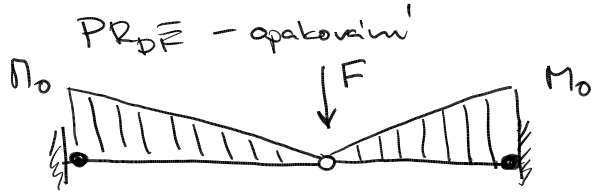


$$\Delta V = F$$

$$\Delta V = \frac{M_0}{a} + \frac{M_0}{b}$$



MEZNI PLASTICKA ANALYZA

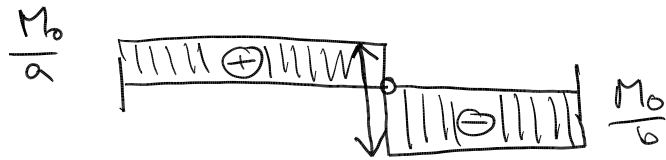


PRPM - kinematicka metoda

kinematicky pri'pustny mechanismus

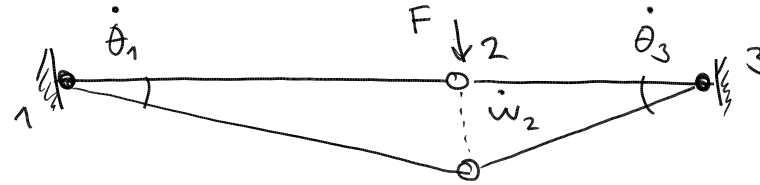
→ rovnoblasti posunu a deformacei spln'ujici geometricki vztahy

→ vn'jsi sily podavaji' kladny' vykon



$$\Delta V = F \cdot w_2$$

$$\Delta V = \frac{M_0}{a} \cdot \theta_1 + \frac{M_0}{b} \cdot \theta_3$$

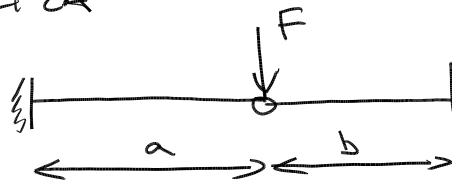


$$\text{Výkon vn'jsich sil} = \text{Dissipacni výkon}$$

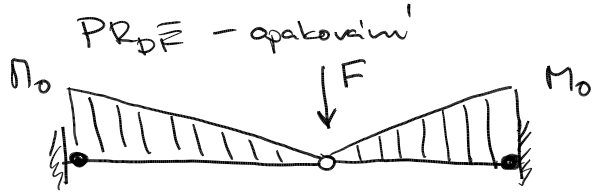
$$\sum F_i \dot{w}_i$$

$$= \sum M_0 \dot{\theta}_i$$

MEZNI PLASTICKA ANALYZA



mezní plastický moment M_0

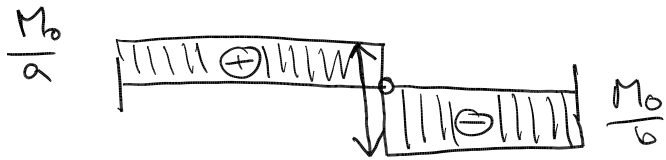


PRPM - kinematická metoda

kinematický přípustný mechanismus

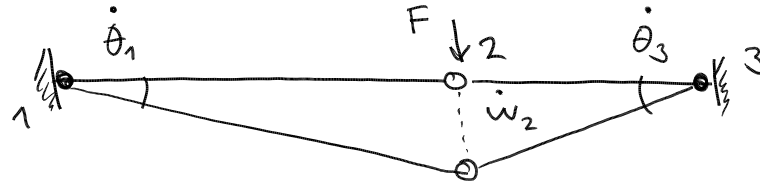
→ rovnost práce a deformací splývají geometrické ra

→ vnější síly podávají kladný výkon



$$\Delta V = F$$

$$\Delta V = \frac{M_0}{a} + \frac{M_0}{b}$$



Výkon vnějších sil

$$\sum F_i \dot{w}_i$$

$$F \cdot \dot{w}_2$$

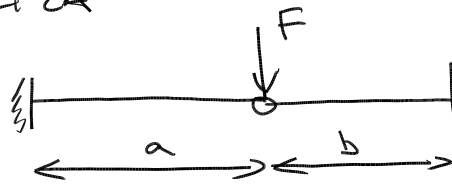
= Disipační výkon

$$= \sum M_0 \dot{\theta}_i$$

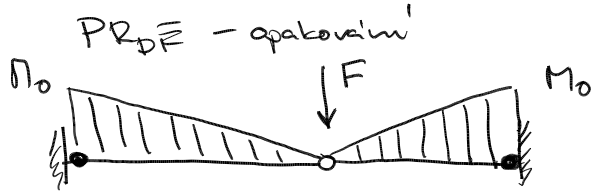
$$= M_0 \dot{\theta}_1 + M_0 \dot{\theta}_3$$

$$\hookrightarrow \frac{\dot{w}_2}{a} \quad \hookrightarrow \frac{\dot{w}_2}{b}$$

MEZNI PLASTICKA ANALYZA



mezní plastický moment M_0

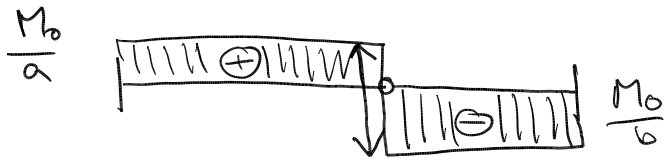


PRPM - kinematická metoda

kinematický přípustný mechanismus

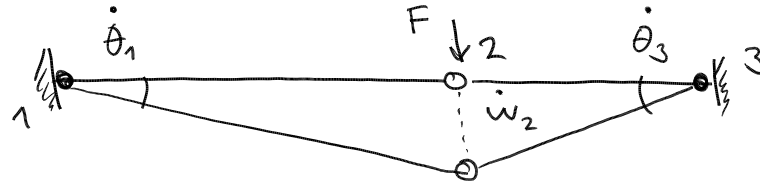
→ rychlosti posunu a deformací splývají geometrické vze

→ vnější síly podávají kladný výkon



$$\Delta V = F$$

$$\Delta V = \frac{M_0}{a} + \frac{M_0}{b}$$



Výkon vnějších sil

$$\sum F_i \dot{w}_i$$

$$F \cdot \dot{w}_2$$

$$F \cdot \dot{w}_2$$

= Disipační výkon

$$= \sum M_0 \dot{\theta}_i$$

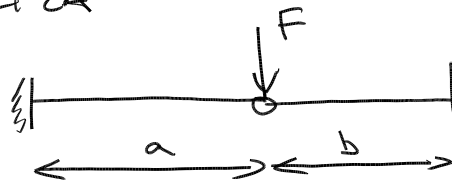
$$= M_0 \dot{\theta}_1 + M_0 \dot{\theta}_3$$

$$\hookrightarrow \frac{\dot{w}_2}{a}$$

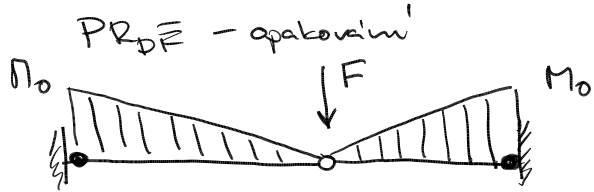
$$\frac{\dot{w}_2}{b}$$

$$= \left(\frac{M_0}{a} + \frac{M_0}{b} \right) \dot{w}_2$$

MEZNI PLASTICKA ANALYZA



mezní plastický moment M_0

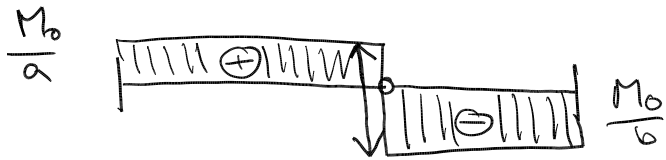


PRPM - kinematická metoda

kinematický přípustný mechanismus

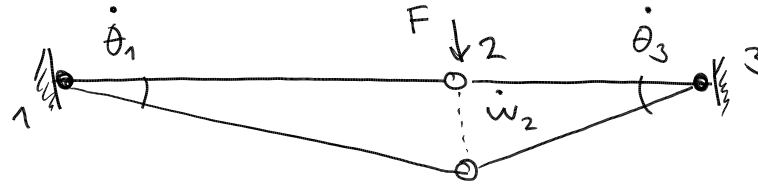
→ rovnost práce a deformací splnění geometrické rovnice

→ vnější síly podávají kladný výkon



$$\Delta V = F$$

$$\Delta V = \frac{M_0}{a} + \frac{M_0}{b}$$



Výkon vnějších sil

$$\sum F_i \dot{w}_i$$

$$F \cdot \dot{w}_2$$

$$F \cdot \dot{w}_2$$

= Disipační výkon

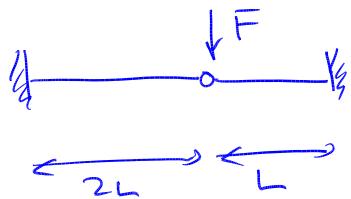
$$= \sum M_0 \dot{\theta}_i$$

$$= M_0 \dot{\theta}_1 + M_0 \dot{\theta}_3$$

$$\hookrightarrow \frac{\dot{w}_2}{a} + \frac{\dot{w}_2}{b}$$

$$= \left(\frac{M_0}{a} + \frac{M_0}{b} \right) \dot{w}_2$$

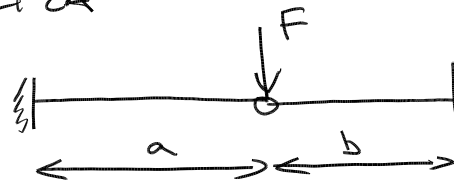
→ viz minulý týden



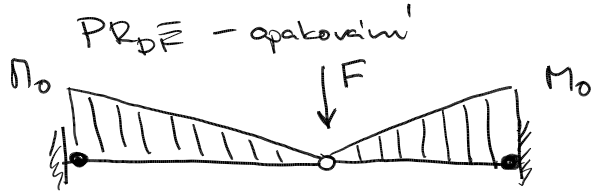
$F_{max} = 75 \text{ kN}$
přímá metoda

$$L = 2 \text{ m} \quad M_0 = 100 \text{ kNm}$$

MEZNI PLASTICKA ANALYZA



mezní plastický moment M_0

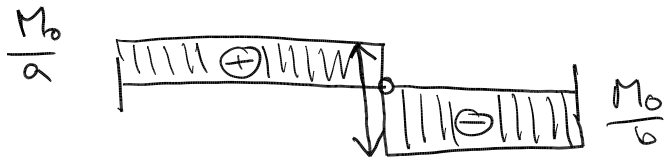


PRPM - kinematická metoda

kinematický přípustný mechanismus

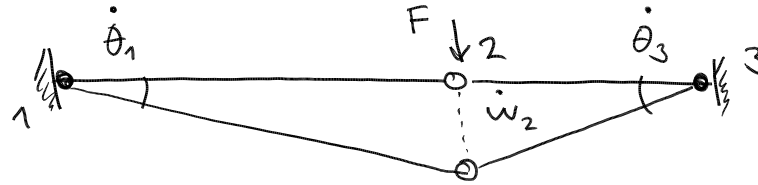
→ rychlosti posunu a deformací splývají geometrické ra

→ vnější síly podávají kladný výkon



$\Delta V = F$

$\Delta V = \frac{M_0}{a} + \frac{M_0}{b}$



Výkon vnějších sil

= Disipační výkon

$\sum F_i \dot{w}_i$

= $\sum M_0 \dot{\theta}_i$

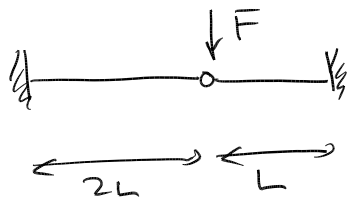
$F \cdot \dot{w}_2$

= $M_0 \dot{\theta}_1 + M_0 \dot{\theta}_3$

$F \cdot \dot{w}_2$

= $(\frac{M_0}{a} + \frac{M_0}{b}) \dot{w}_2$

→ viz minulý týden

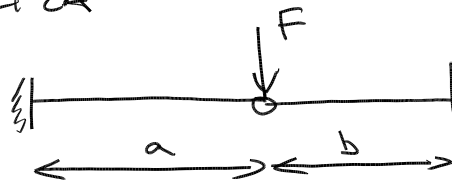


$F_{max} = 75 \text{ kN}$
přímá metoda

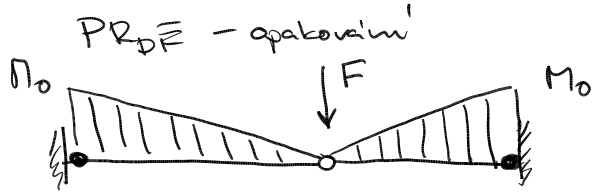
$F = 100 \left(\frac{1}{4} + \frac{1}{2} \right) = \underline{\underline{75 \text{ kN}}}$

$L = 2 \text{ m} \quad M_0 = 100 \text{ kNm}$

MEZNI PLASTICKA ANALYZA



mezní plastický moment M_0

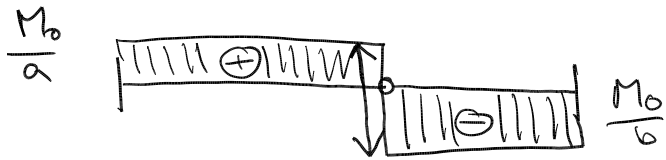


PRPM - kinematická metoda

kinematický přípustný mechanismus

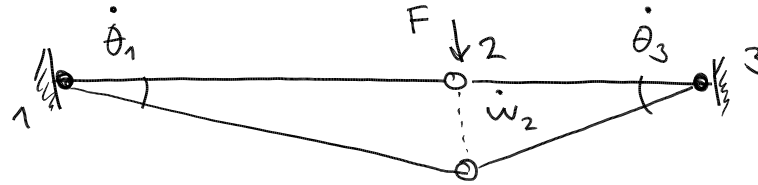
→ rychlosti posunu a deformací splývají geometrické vztahy

→ vnější síly podávají kladný výkon



$$\Delta V = F$$

$$\Delta V = \frac{M_0}{a} + \frac{M_0}{b}$$



Výkon vnějších sil

$$\sum F_i \dot{w}_i$$

$$F \cdot \dot{w}_2$$

$$F \cdot \dot{w}_2$$

= Disipační výkon

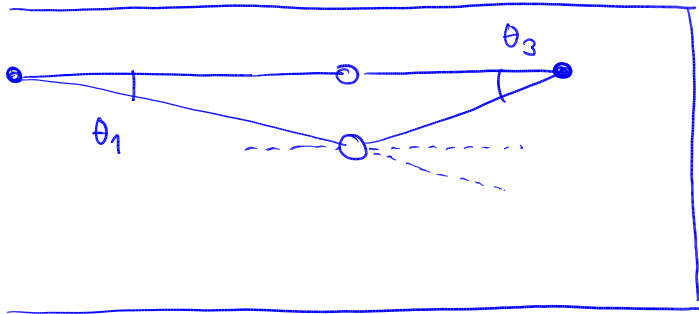
$$= \sum M_0 \dot{\theta}_i$$

$$= M_0 \dot{\theta}_1 + M_0 \dot{\theta}_3$$

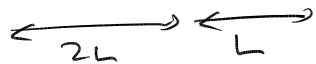
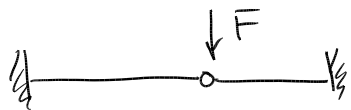
$$\hookrightarrow \frac{\dot{w}_2}{a}$$

$$\frac{\dot{w}_2}{b}$$

$$= \left(\frac{M_0}{a} + \frac{M_0}{b} \right) \dot{w}_2$$



→ viz minulý týden



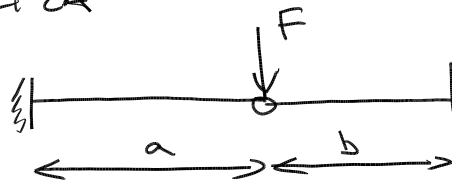
$$L = 2\text{m} \quad M_0 = 100 \text{ kNm}$$

$$F_{\text{max}} = 75 \text{ kN}$$

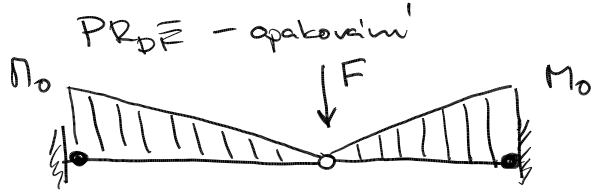
přímá metoda

$$F = 100 \left(\frac{1}{4} + \frac{1}{2} \right) = \underline{\underline{75 \text{ kN}}}$$

MEZNI PLASTICKA ANALYZA



mezní plastický moment M_0

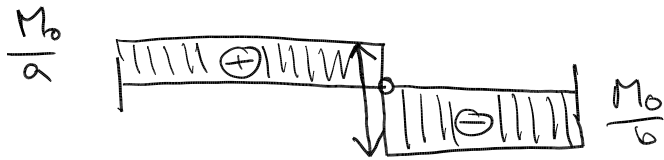


PRPM - kinematická metoda

kinematický přípustný mechanismus

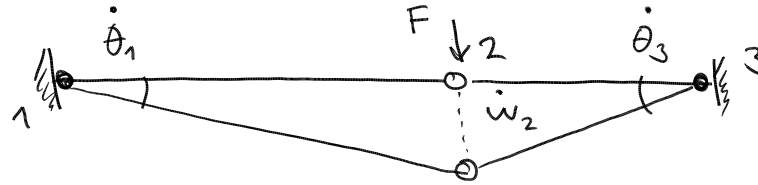
→ rychlosti posunu a deformací splývají geometrické vztahy

→ vnější síly podávají kladný výkon



$$\Delta V = F$$

$$\Delta V = \frac{M_0}{a} + \frac{M_0}{b}$$



Výkon vnějších sil

$$\sum F_i \dot{w}_i$$

$$F \cdot \dot{w}_2$$

$$F \cdot \dot{w}_2$$

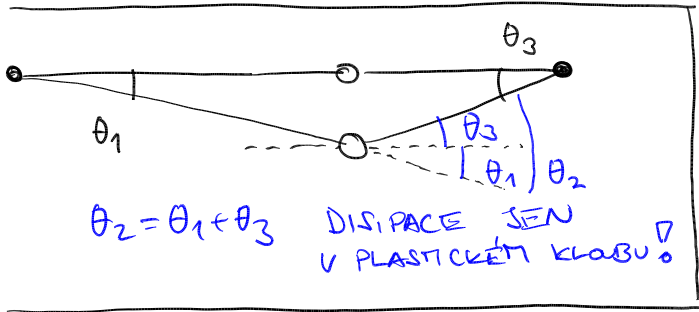
= Disipační výkon

$$= \sum M_0 \dot{\theta}_i$$

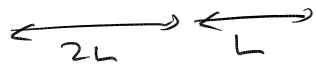
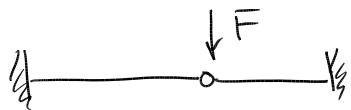
$$= M_0 \dot{\theta}_1 + M_0 \dot{\theta}_3$$

$$\hookrightarrow \frac{\dot{w}_2}{a} + \frac{\dot{w}_2}{b}$$

$$= \left(\frac{M_0}{a} + \frac{M_0}{b} \right) \dot{w}_2$$



→ viz minulý týden



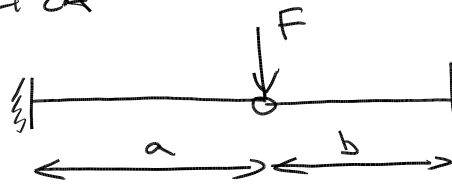
$$L = 2\text{m} \quad M_0 = 100 \text{ kNm}$$

$$F_{\text{max}} = 75 \text{ kN}$$

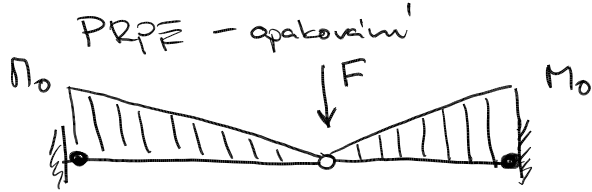
přímá metoda

$$F = 100 \left(\frac{1}{4} + \frac{1}{2} \right) = \underline{\underline{75 \text{ kN}}}$$

MEZNI PLASTICKA ANALYZA



mezni plasticky moment M_0

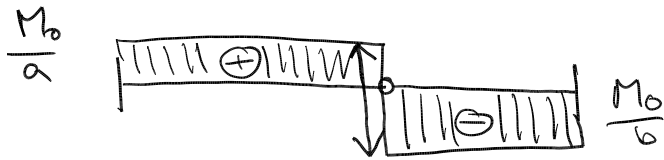


PRPM - kinematicka metoda

kinematicky pri'pustny mechanismus

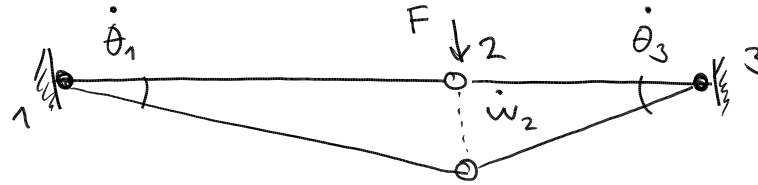
→ rychlosti posunu a deformaci splny' geometricki vztahy

→ vnjsi sily podavaju' kladny' vykon



$$\Delta V = F \cdot \delta$$

$$\Delta V = \frac{M_0}{a} \delta + \frac{M_0}{b} \delta$$



Vykon vnjsich sil

$$\sum F_i \dot{w}_i$$

$$F \cdot \dot{w}_2$$

$$F \cdot \dot{w}_2$$

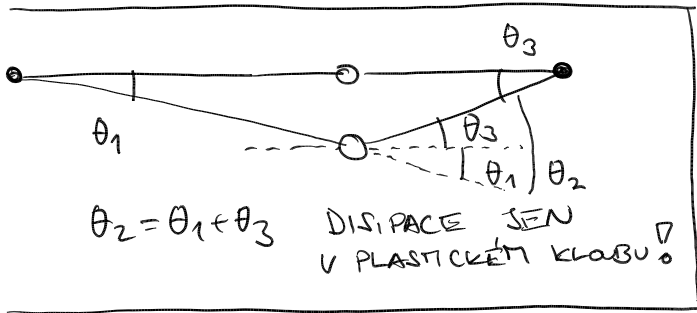
= Disipacni vykon

$$= \sum M_0 \dot{\theta}_i$$

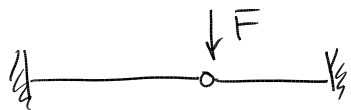
$$= M_0 \dot{\theta}_1 + M_0 \dot{\theta}_3$$

$$\hookrightarrow \dot{w}_2 \cdot \frac{1}{a} \quad \hookrightarrow \dot{w}_2 \cdot \frac{1}{b}$$

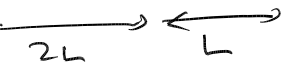
$$= \left(\frac{M_0}{a} + \frac{M_0}{b} \right) \dot{w}_2$$



→ viz minuly tyden



$F_{max} = 75 \text{ kN}$
pristkova metoda

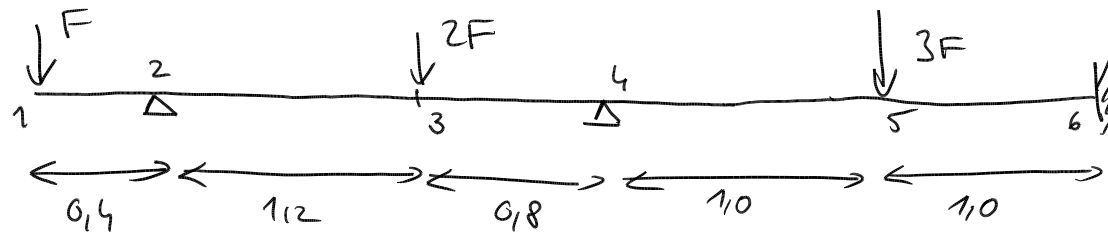


$L = 2 \text{ m}$ $M_0 = 100 \text{ kNm}$

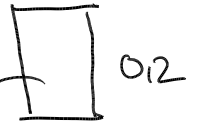
$$F = 100 \left(\frac{1}{4} + \frac{1}{2} \right) = \underline{\underline{75 \text{ kN}}}$$

S x SN konstrukce

→ kolaps pri S+1 plast. kloubech

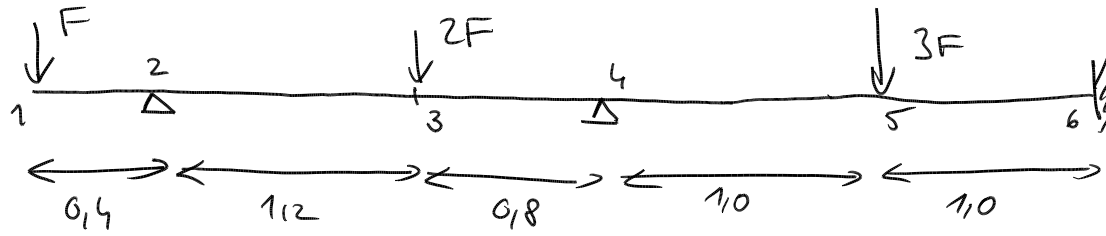



obdelnikový prvek



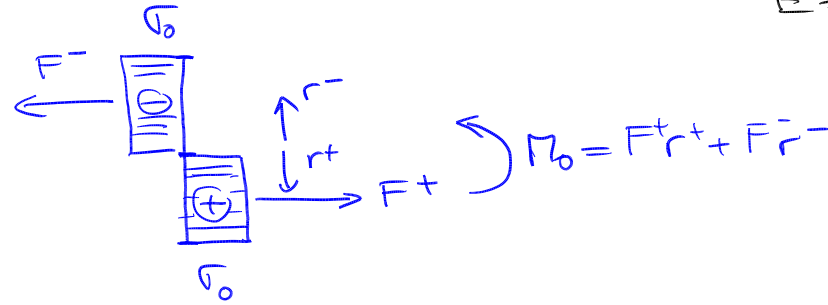
$$\sigma_0 = 100 \text{ MPa}$$

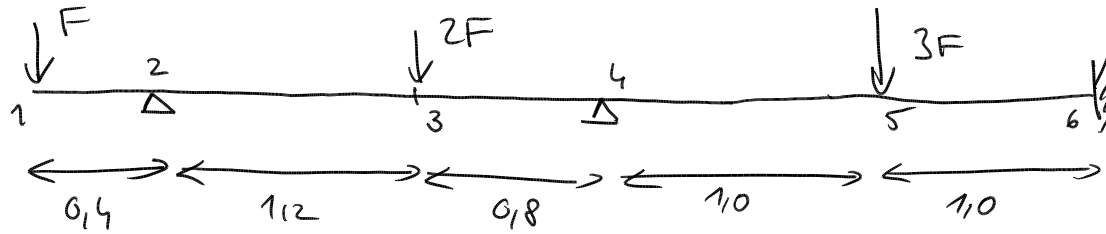
$$E = 10 \text{ GPa}$$




obdelnikovy prevez  $0,1$
 $\sigma_0 = 100 \text{ MPa}$
 $E = 10 \text{ GPa}$

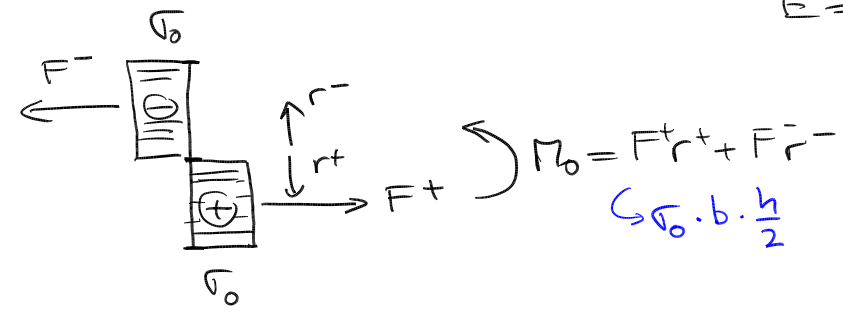
Vypočet mezního plastického momentu

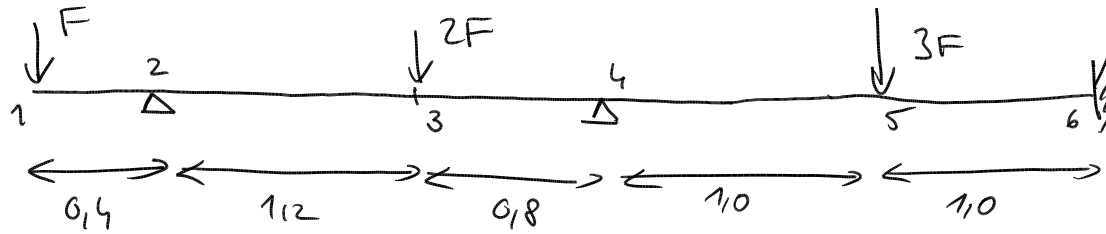




obdelnikovy prevez  $0,1$ $0,2$
 $\sigma_0 = 100 \text{ MPa}$
 $E = 10 \text{ GPa}$

Vypočet mezniho plastického momentu



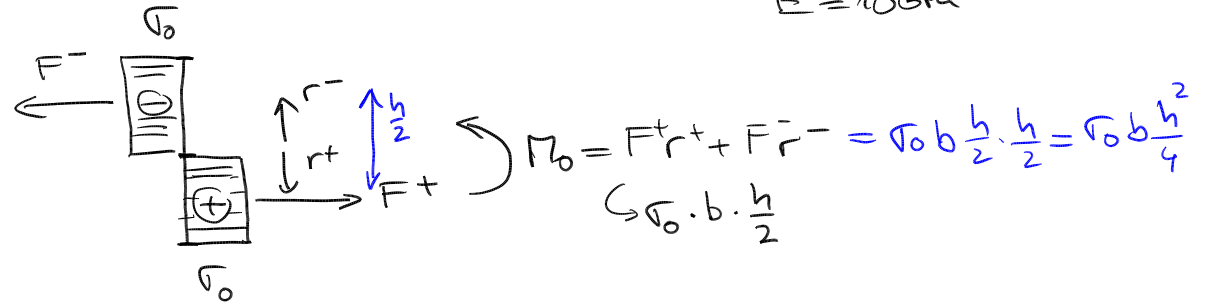


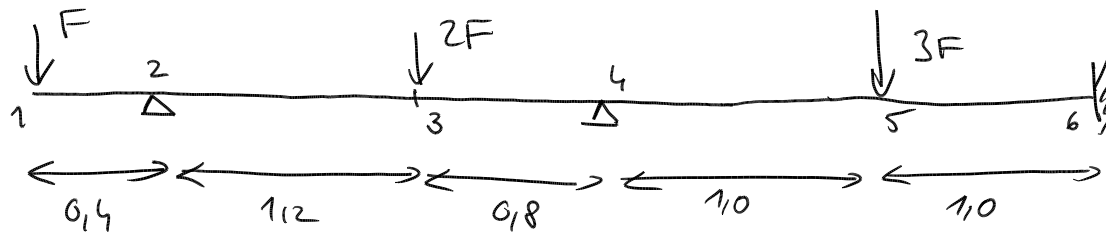
obdelnikový prerez

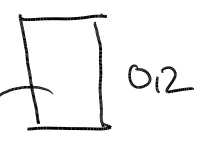
$\sigma_0 = 100 \text{ MPa}$

$E = 10 \text{ GPa}$

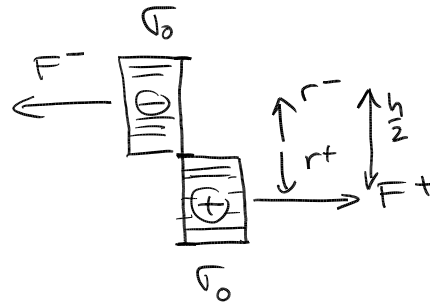
Vypočet mezního plastického momentu





obdelnikový prerez 
 $\sigma_0 = 100 \text{ MPa}$
 $E = 10 \text{ GPa}$

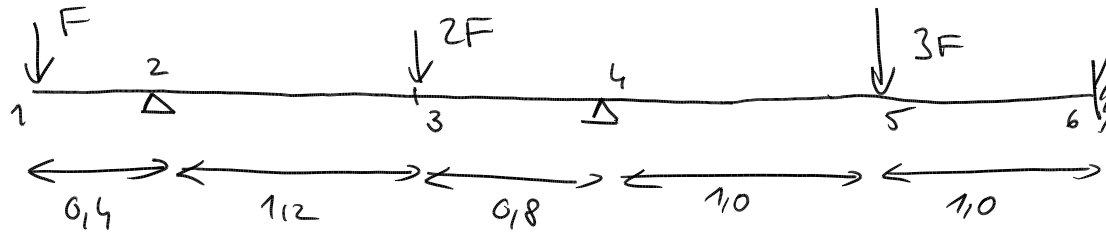
Vypočet mezního plastického momentu



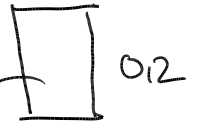
$$M_0 = F^+ r^+ + F^- r^- = \sigma_0 b \frac{h}{2} \cdot \frac{h}{2} = \sigma_0 b \frac{h^2}{4}$$

$$\hookrightarrow \sigma_0 \cdot b \cdot \frac{h}{2}$$

$$M_0 = 100 \cdot 0,1 \cdot \frac{0,2^2}{4} = 0,1 \text{ MNm} = \underline{\underline{100 \text{ kNm}}}$$



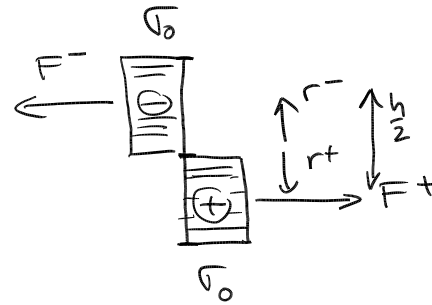
obdelnikový prerez



$$\sigma_0 = 100 \text{ MPa}$$

$$E = 10 \text{ GPa}$$

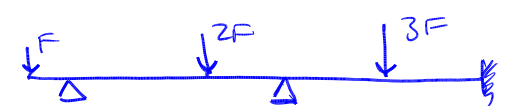
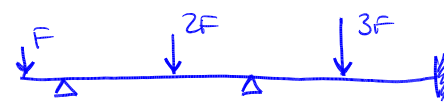
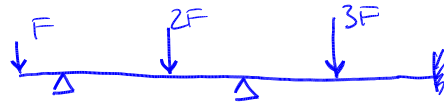
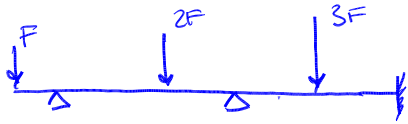
Vypočet mezního plastického momentu

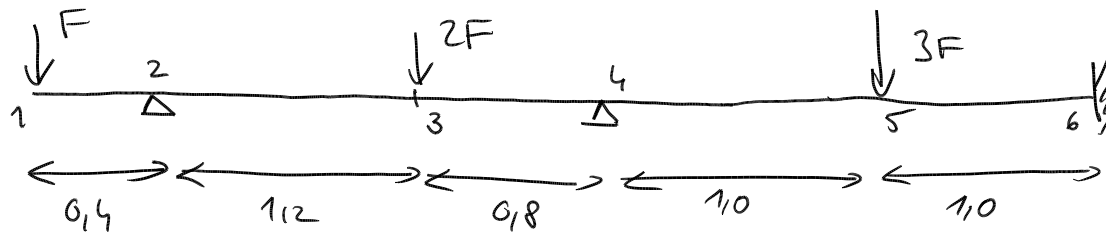


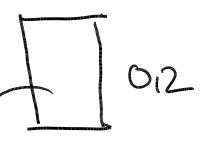
$$M_0 = F^+ r^+ + F^- r^- = \sigma_0 b \frac{h}{2} \cdot \frac{h}{2} = \sigma_0 b \frac{h^2}{4}$$

$$\hookrightarrow \sigma_0 \cdot b \cdot \frac{h}{2}$$

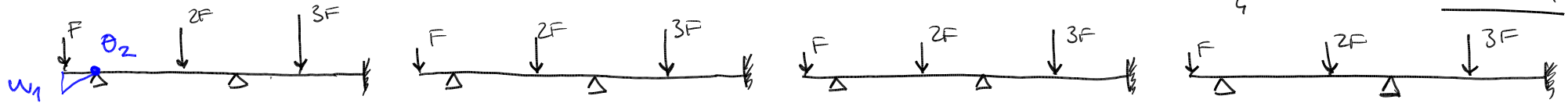
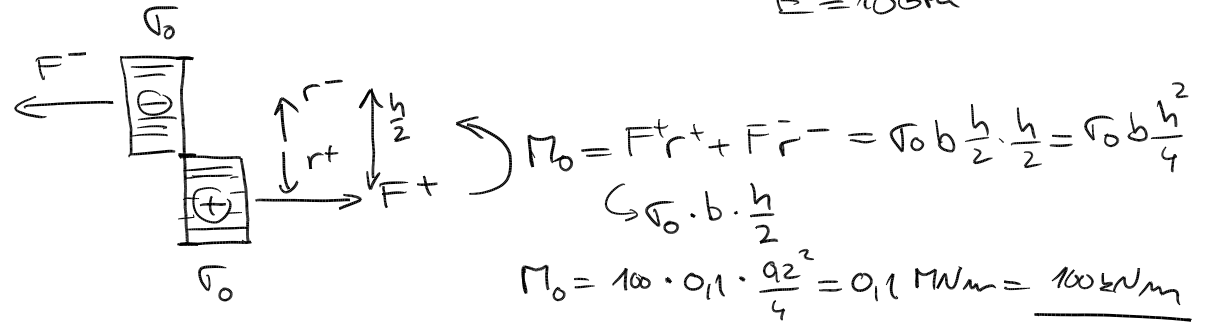
$$M_0 = 100 \cdot 0,1 \cdot \frac{0,2^2}{4} = 0,1 \text{ MNm} = \underline{\underline{100 \text{ kNm}}}$$





obdĺnikový prerez 
 $\sigma_0 = 100 \text{ MPa}$
 $E = 10 \text{ GPa}$

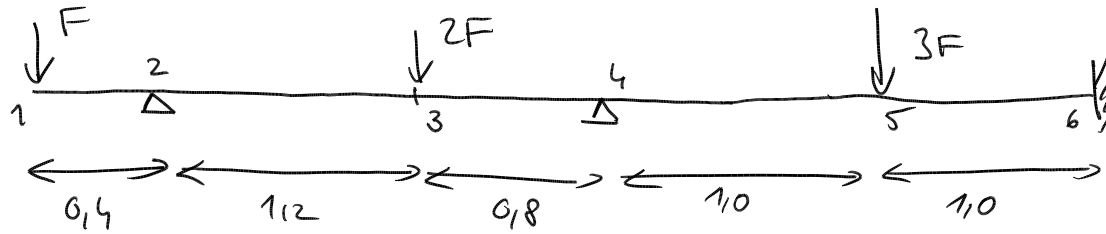
Vypočet mezního plastického momentu

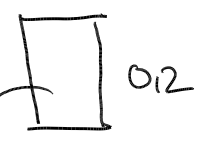


$$F_{ext} = F \cdot w_1$$

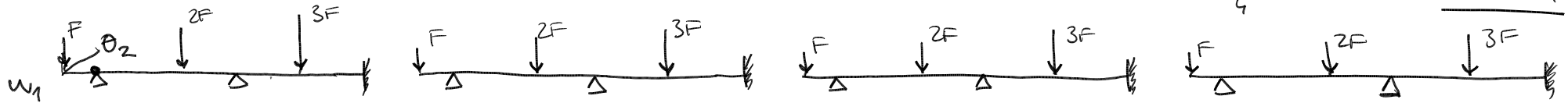
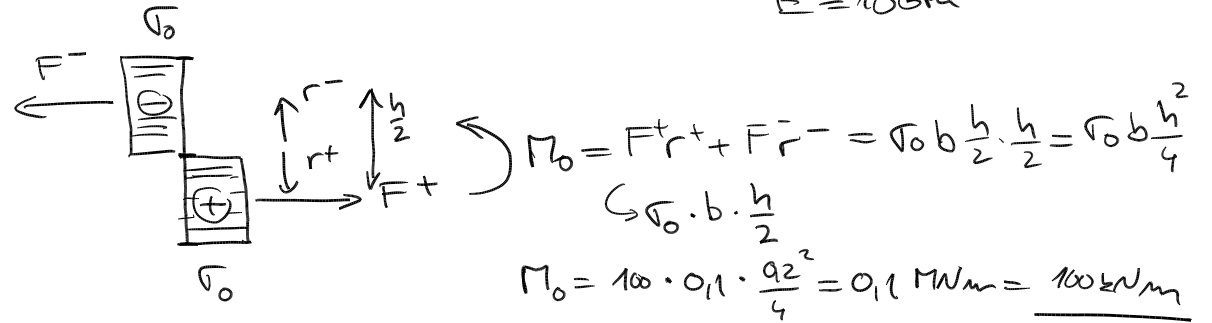
$$D_{int} = M_0 \cdot \dot{\theta}_2$$

$$\dot{\theta}_2 = \frac{\dot{w}_1}{0,4}$$



obdĺnikový prerez 
 $\sigma_0 = 100 \text{ MPa}$
 $E = 10 \text{ GPa}$

Vypočet mezního plastického momentu



$$F_{ext} = F \cdot w_1$$

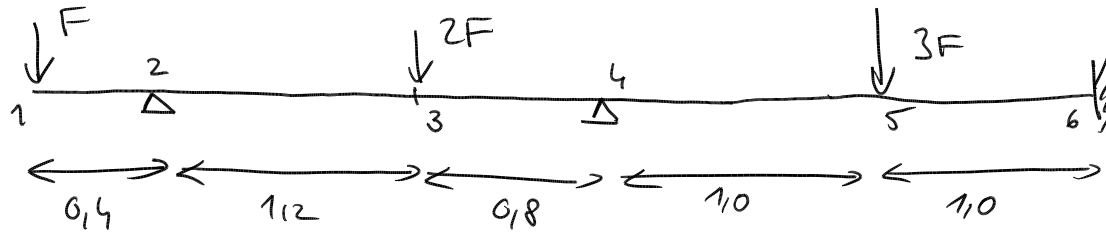
$$D_{int} = M_0 \cdot \dot{\theta}_2$$

$$\dot{\theta}_2 = \frac{\dot{w}_1}{0,4}$$

$$F_{ext} = D_{int}$$

$$F w_1 = M_0 \frac{\dot{w}_1}{0,4}$$

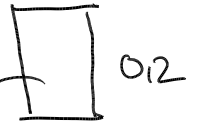
$$\rightarrow F = \frac{M_0}{0,4} = \frac{100}{0,4} = \underline{250 \text{ kN}}$$



obdelnikový prvek

$$\sigma_0 = 100 \text{ MPa}$$

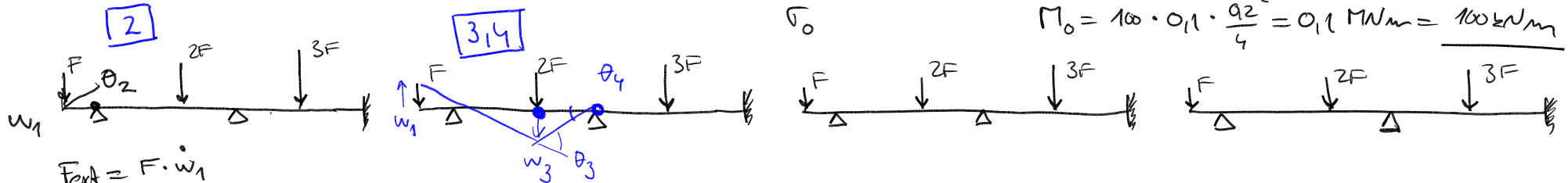
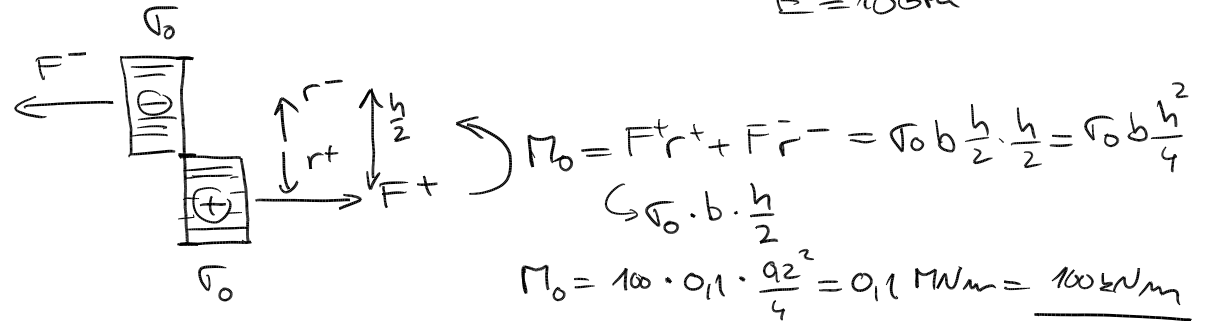
$$E = 10 \text{ GPa}$$



0,2

0,1

Vypočet mezního plastického momentu



$$F_{ext} = F \cdot \dot{w}_1$$

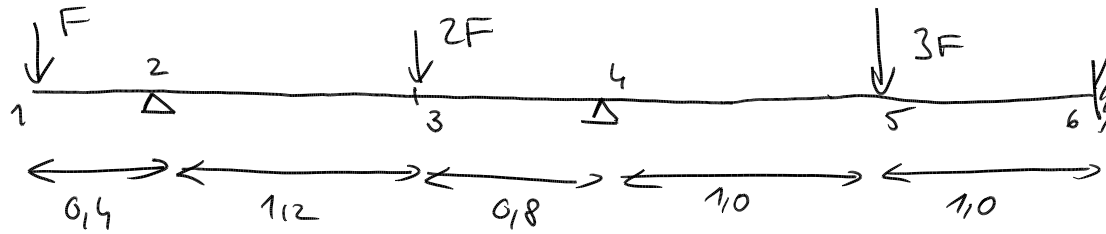
$$D_{int} = M_0 \cdot \dot{\theta}_2$$

$$\dot{\theta}_2 = \frac{\dot{w}_1}{0,4}$$

$$F_{ext} = D_{int}$$

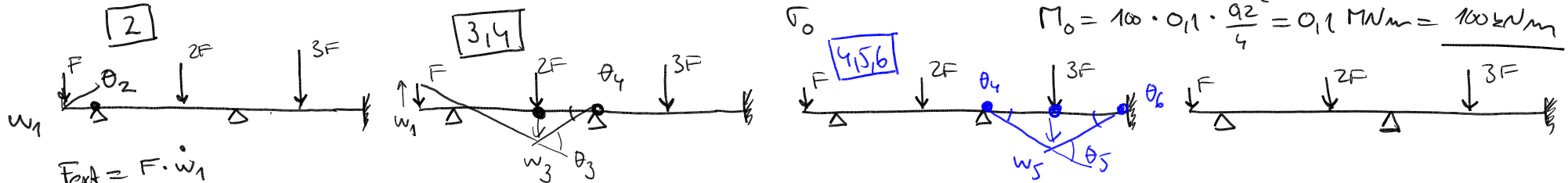
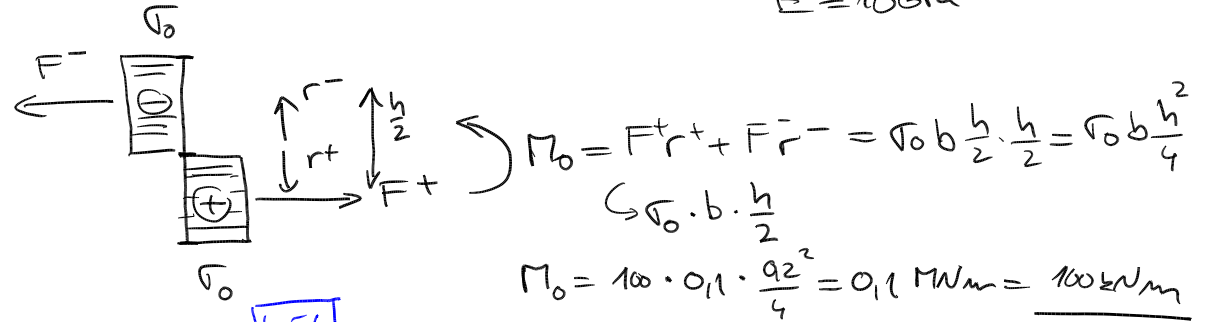
$$F \dot{w}_1 = M_0 \frac{\dot{w}_1}{0,4}$$

$$\rightarrow F = \frac{M_0}{0,4} = \frac{100}{0,4} = \underline{250 \text{ kN}}$$



obdelnikový prvek
 $\sigma_0 = 100 \text{ MPa}$
 $E = 10 \text{ GPa}$

Vypočet mezního plastického momentu



$$F_{ext} = F \cdot w_1$$

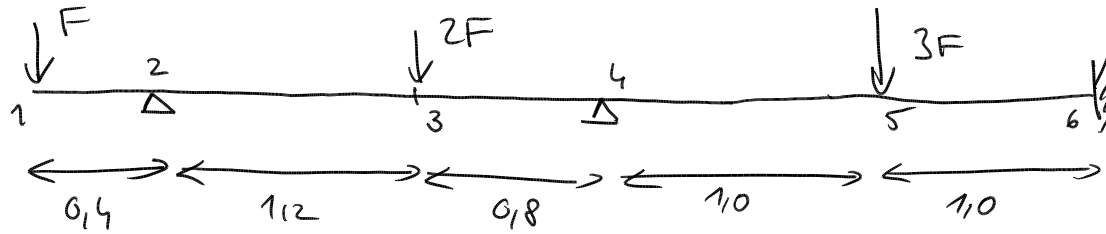
$$D_{int} = M_0 \cdot \dot{\theta}_2$$

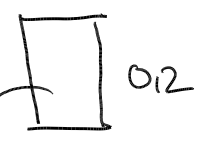
$$\dot{\theta}_2 = \frac{\dot{w}_1}{0,4}$$

$$F_{ext} = D_{int}$$

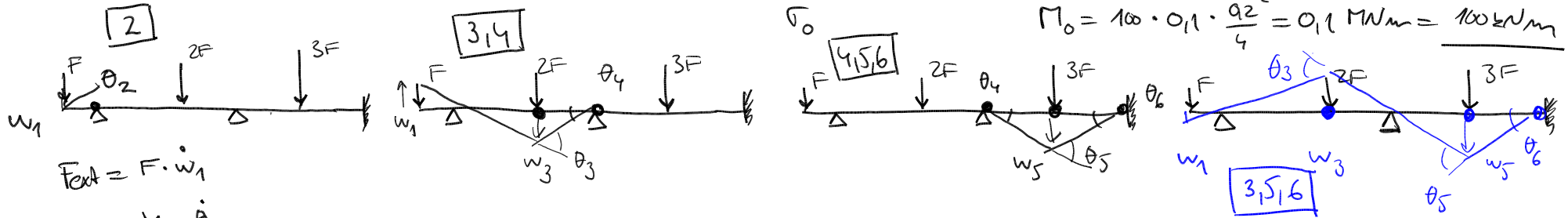
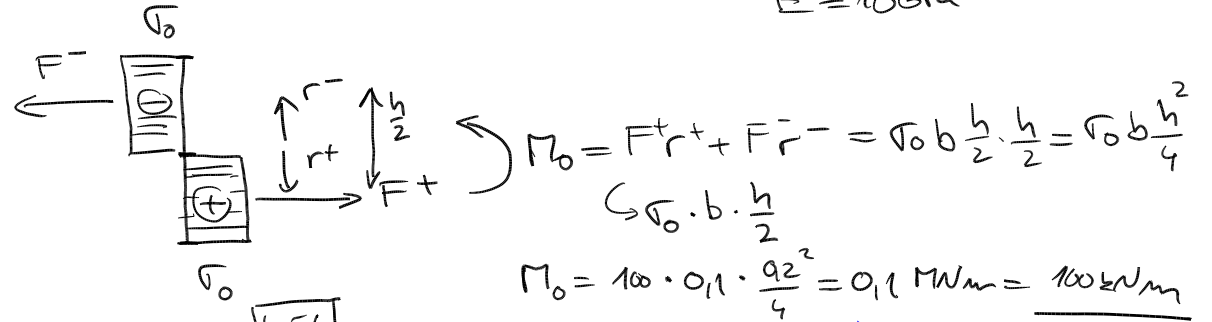
$$F \dot{w}_1 = M_0 \frac{\dot{w}_1}{0,4}$$

$$\rightarrow F = \frac{M_0}{0,4} = \frac{100}{0,4} = 250 \text{ kN}$$



obdelnikový prerez 
 $\sigma_0 = 100 \text{ MPa}$
 $E = 10 \text{ GPa}$

Výpočet mezního plastického momentu



$$F_{ext} = F \cdot \dot{w}_1$$

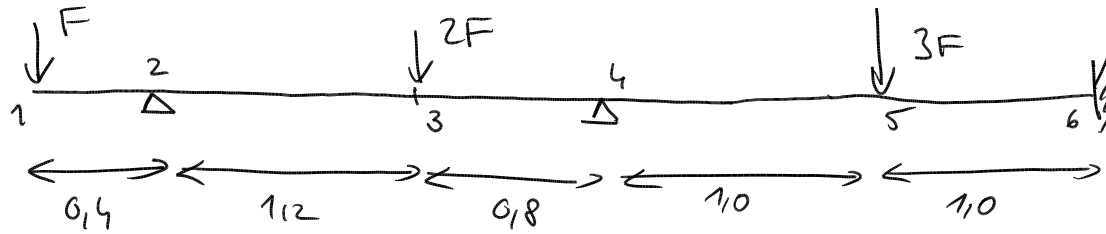
$$D_{int} = M_0 \cdot \dot{\theta}_2$$

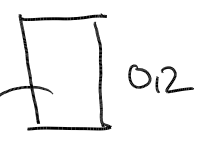
$$\dot{\theta}_2 = \frac{\dot{w}_1}{0,4}$$

$$F_{ext} = D_{int}$$

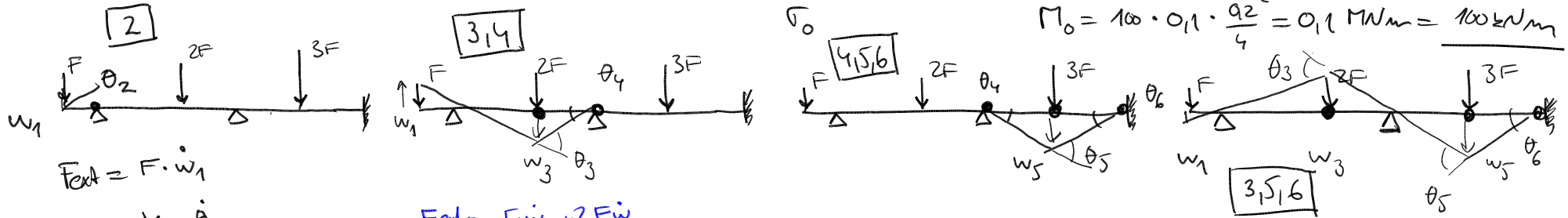
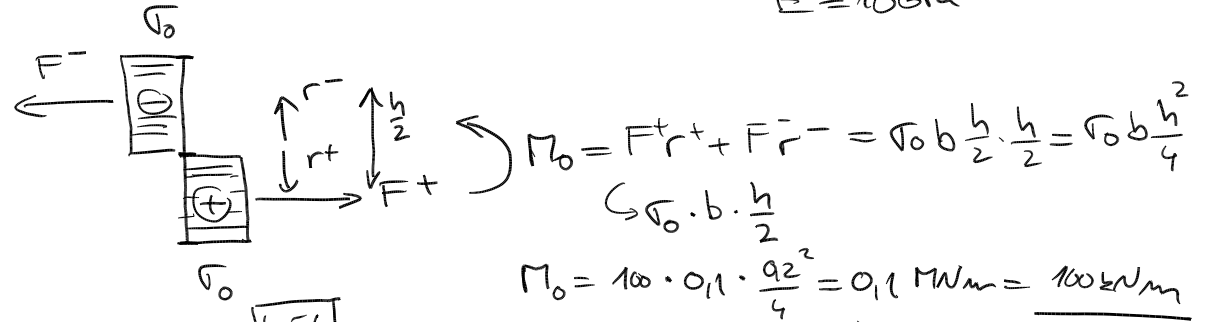
$$F \dot{w}_1 = M_0 \frac{\dot{w}_1}{0,4}$$

$$\rightarrow F = \frac{M_0}{0,4} = \frac{100}{0,4} = 250 \text{ kN}$$



obdelnikový prerez 
 $\sigma_0 = 100 \text{ MPa}$
 $E = 10 \text{ GPa}$

Výpočet mezního plastického momentu



$$F_{ext} = F \cdot \dot{w}_1$$

$$D_{int} = M_0 \cdot \dot{\theta}_2$$

$$\dot{\theta}_2 = \frac{\dot{w}_1}{0,4}$$

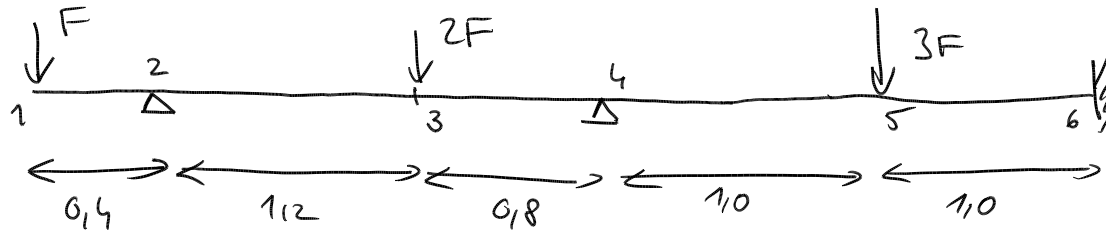
$$F_{ext} = D_{int}$$

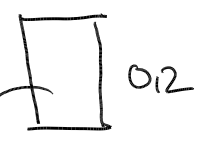
$$F \dot{w}_1 = M_0 \frac{\dot{w}_1}{0,4}$$

$$\rightarrow F = \frac{M_0}{0,4} = \frac{100}{0,4} = \underline{\underline{250 \text{ kN}}}$$

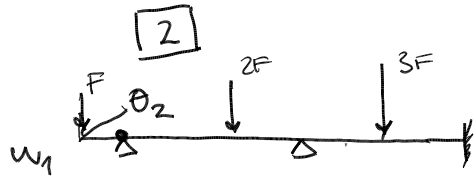
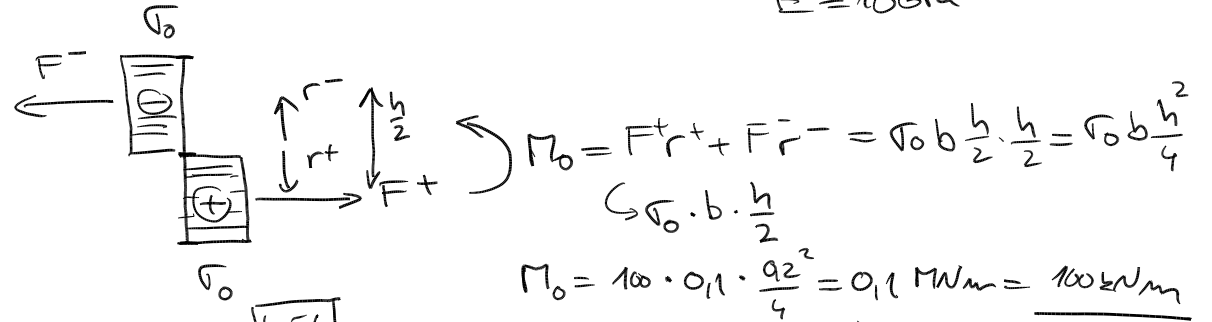
$$F_{ext} = -F \dot{w}_1 + 2F \dot{w}_3$$

$$D_{int} = M_0 (\dot{\theta}_3 + \dot{\theta}_4)$$



obdelnikový prerez 
 $\sigma_0 = 100 \text{ MPa}$
 $E = 10 \text{ GPa}$

Výpočet mezního plastického momentu



$$F_{ext} = F \cdot \dot{w}_1$$

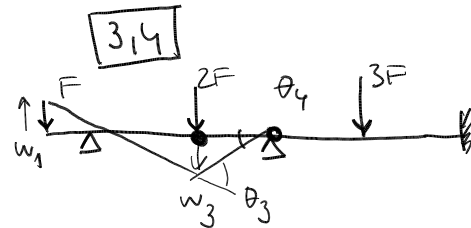
$$D_{int} = M_0 \cdot \dot{\theta}_2$$

$$\dot{\theta}_2 = \frac{\dot{w}_1}{0,4}$$

$$F_{ext} = D_{int}$$

$$F \dot{w}_1 = M_0 \frac{\dot{w}_1}{0,4}$$

$$\rightarrow F = \frac{M_0}{0,4} = \frac{100}{0,4} = 250 \text{ kN}$$

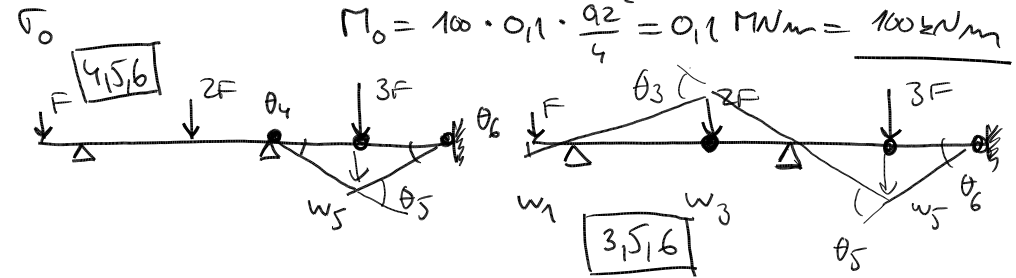


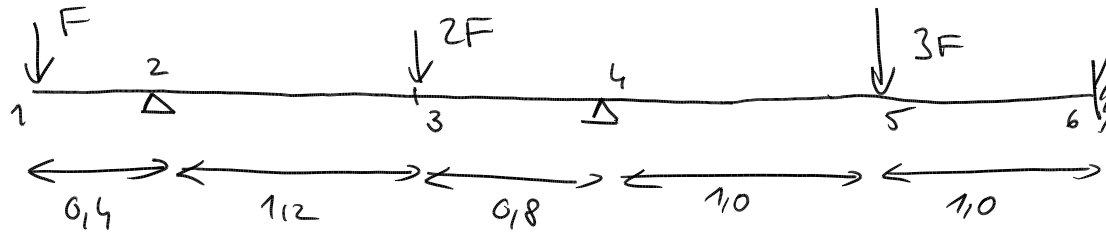
$$F_{ext} = -F \dot{w}_1 + 2F \dot{w}_3$$

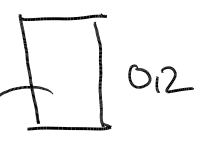
$$D_{int} = M_0 (\dot{\theta}_3 + \dot{\theta}_4)$$

$$\dot{w}_1 = \dot{\theta}_2 \cdot 0,4 \quad \dot{\theta}_4 = \frac{\dot{w}_3}{0,8}$$

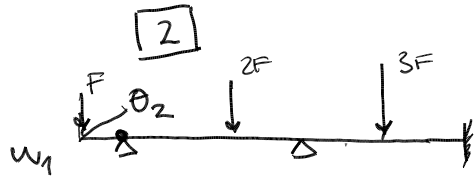
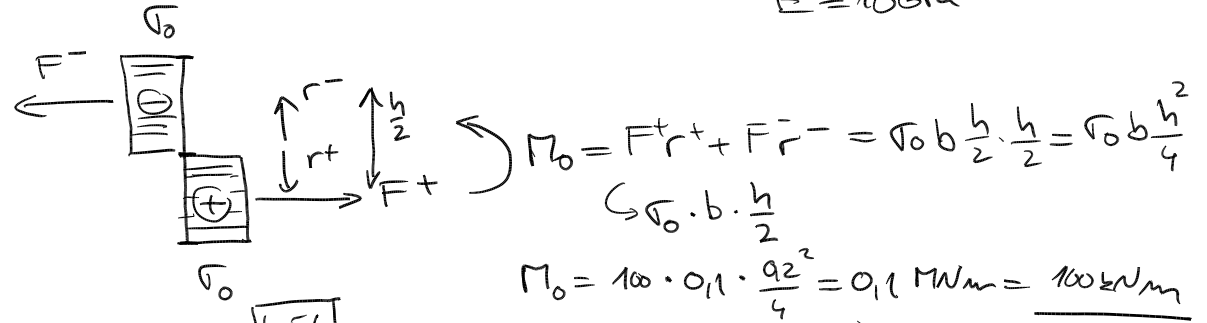
$$\dot{\theta}_3 = \dot{\theta}_2 + \dot{\theta}_4 = \dot{w}_3 \left(\frac{1}{1,2} + \frac{1}{0,8} \right)$$





obdelnikový prerez 
 $\sigma_0 = 100 \text{ MPa}$
 $E = 10 \text{ GPa}$

Výpočet mezního plastického momentu



$$F_{ext} = F \cdot \dot{w}_1$$

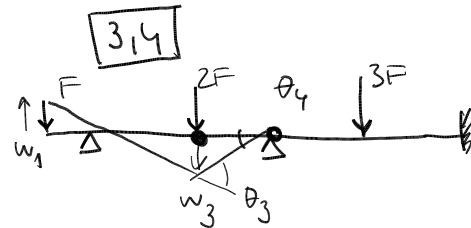
$$D_{int} = M_0 \cdot \dot{\theta}_2$$

$$\dot{\theta}_2 = \frac{\dot{w}_1}{0,4}$$

$$F_{ext} = D_{int}$$

$$F \dot{w}_1 = M_0 \frac{\dot{w}_1}{0,4}$$

$$\rightarrow F = \frac{M_0}{0,4} = \frac{100}{0,4} = 250 \text{ kN}$$



$$F_{ext} = -F \dot{w}_1 + 2F \dot{w}_3$$

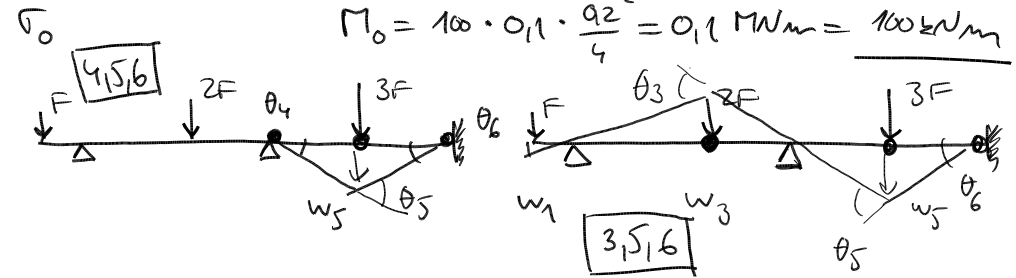
$$D_{int} = M_0 (\dot{\theta}_3 + \dot{\theta}_4)$$

$$\dot{w}_1 = \dot{\theta}_2 \cdot 0,4 \quad \dot{\theta}_4 = \frac{\dot{w}_3}{0,8}$$

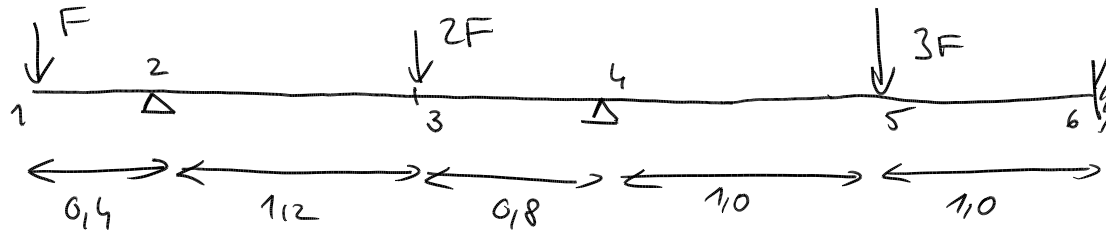
$$\hookrightarrow \frac{\dot{w}_3}{1,2}$$

$$\dot{\theta}_3 = \dot{\theta}_2 + \dot{\theta}_4 = \dot{w}_3 \left(\frac{1}{1,2} + \frac{1}{0,8} \right)$$

$$F_{ext} = -F \cdot \frac{\dot{w}_3 \cdot 0,4}{1,2} + 2F \cdot \dot{w}_3 = \dot{w}_3 \left(-\frac{1}{3} + 2 \right) \cdot F$$

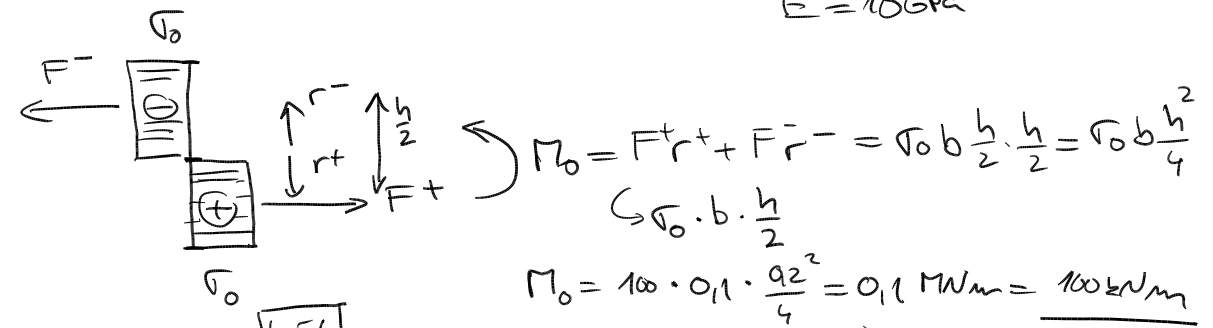


$$3,516$$

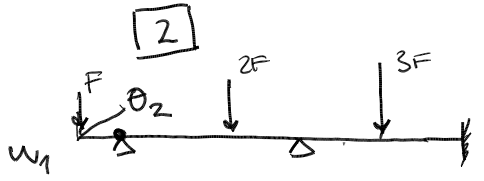


obdelnikový prvek
 $\sigma_0 = 100 \text{ MPa}$
 $E = 10 \text{ GPa}$

Výpočet mezního plastického momentu



$$M_0 = 100 \cdot 0.1 \cdot \frac{0.2^2}{4} = 0.1 \text{ MNm} = 100 \text{ kNm}$$



$$F_{ext} = F \cdot w_1$$

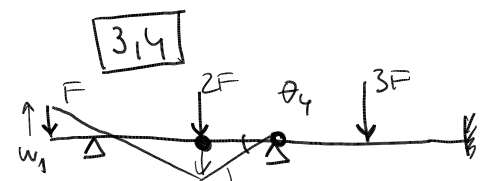
$$D_{int} = M_0 \cdot \dot{\theta}_2$$

$$\dot{\theta}_2 = \frac{\dot{w}_1}{0.4}$$

$$F_{ext} = D_{int}$$

$$F \dot{w}_1 = M_0 \frac{\dot{w}_1}{0.4}$$

$$\rightarrow F = \frac{M_0}{0.4} = \frac{100}{0.4} = 250 \text{ kN}$$



$$F_{ext} = -F \dot{w}_1 + 2F \dot{w}_3$$

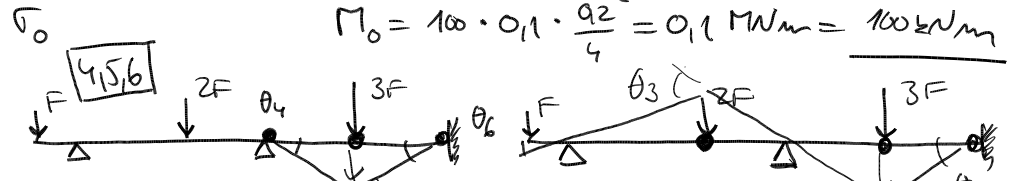
$$D_{int} = M_0 (\dot{\theta}_3 + \dot{\theta}_4)$$

$$\dot{w}_1 = \dot{\theta}_2 \cdot 0.4 \quad \dot{\theta}_4 = \frac{\dot{w}_3}{0.8}$$

$$\dot{\theta}_3 = \dot{\theta}_2 + \dot{\theta}_4 = \dot{w}_3 \left(\frac{1}{1.2} + \frac{1}{0.8} \right)$$

$$F_{ext} = -F \cdot \frac{\dot{w}_3 \cdot 0.4}{1.2} + 2F \cdot \dot{w}_3 = \dot{w}_3 \left(-\frac{1}{3} + 2 \right) \cdot F$$

$$D_{int} = M_0 \left[\left(\frac{1}{1.2} + \frac{1}{0.8} \right) \dot{w}_3 + \frac{\dot{w}_3}{0.8} \right]$$



$$F_{ext} = -F \dot{w}_1 + 2F \dot{w}_3 - 3F \dot{w}_5$$

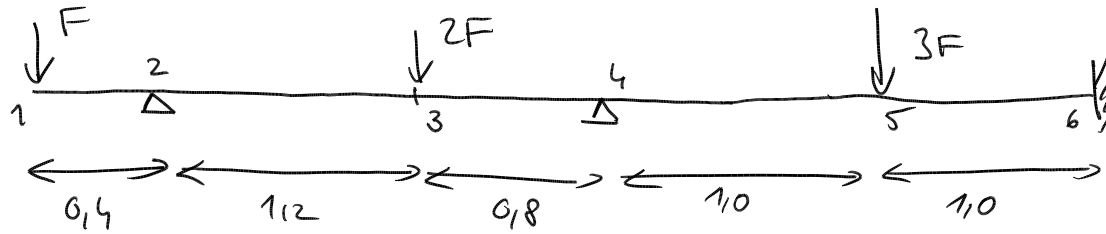
$$D_{int} = M_0 (\dot{\theta}_3 + \dot{\theta}_4 + \dot{\theta}_5)$$

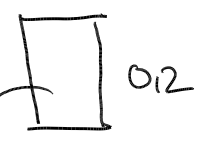
$$\dot{w}_1 = \dot{\theta}_2 \cdot 0.4 \quad \dot{\theta}_4 = \frac{\dot{w}_3}{0.8}$$

$$\dot{\theta}_3 = \dot{\theta}_2 + \dot{\theta}_4 = \dot{w}_3 \left(\frac{1}{1.2} + \frac{1}{0.8} \right)$$

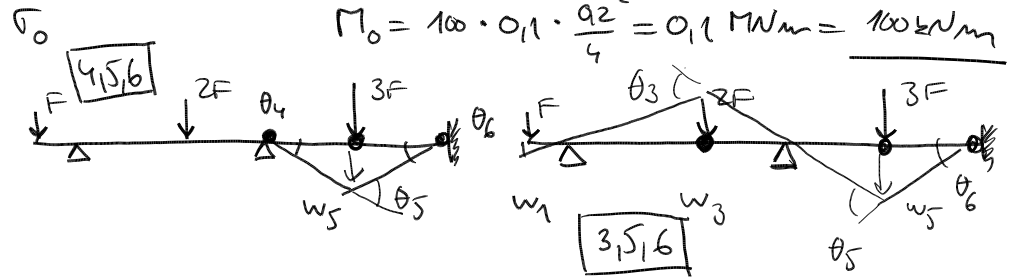
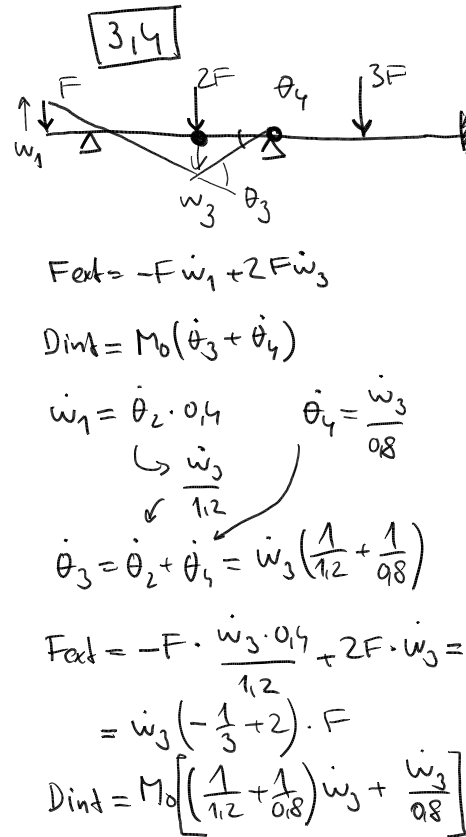
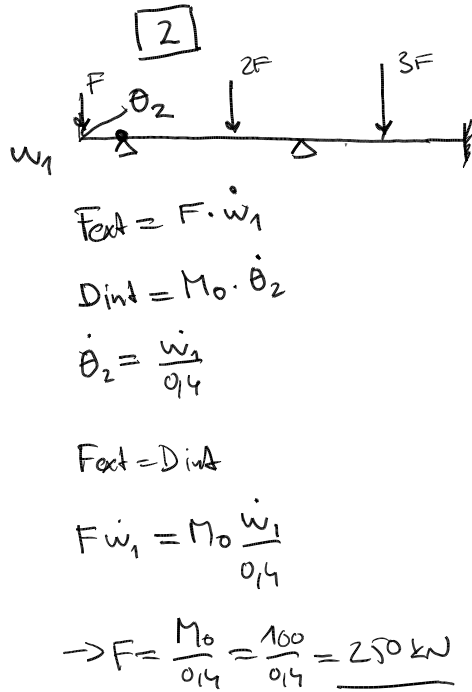
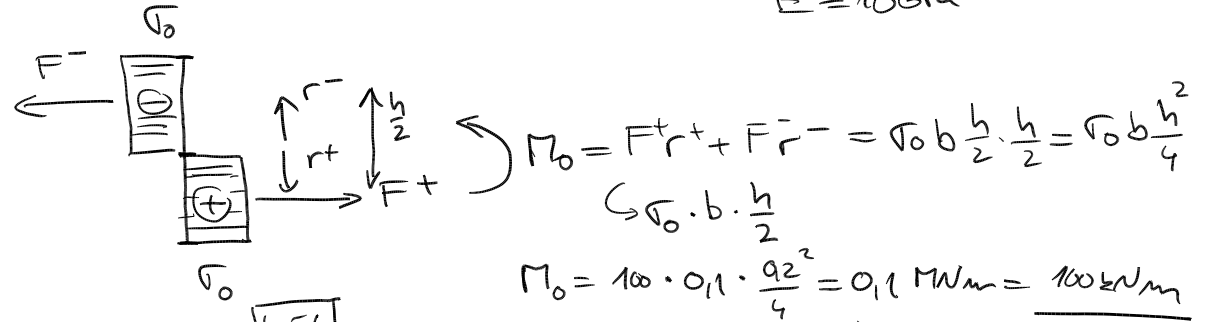
$$F_{ext} = -F \cdot \frac{\dot{w}_3 \cdot 0.4}{1.2} + 2F \cdot \dot{w}_3 - 3F \cdot \dot{w}_5 = \dot{w}_3 \left(-\frac{1}{3} + 2 - 3 \right) \cdot F$$

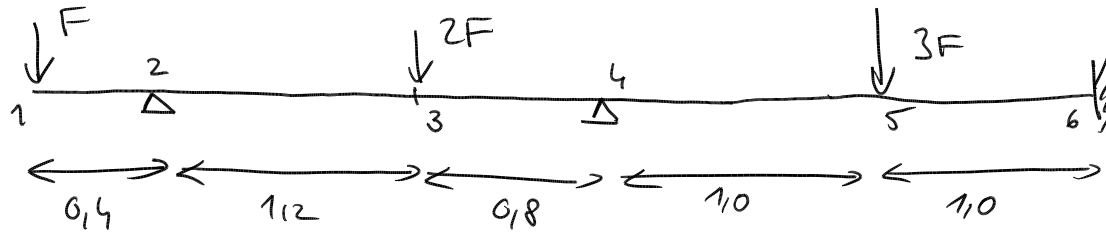
$$D_{int} = M_0 \left[\left(\frac{1}{1.2} + \frac{1}{0.8} \right) \dot{w}_3 + \frac{\dot{w}_3}{0.8} \right]$$



obdelnikový prerez 
 $\sigma_0 = 100 \text{ MPa}$
 $E = 10 \text{ GPa}$

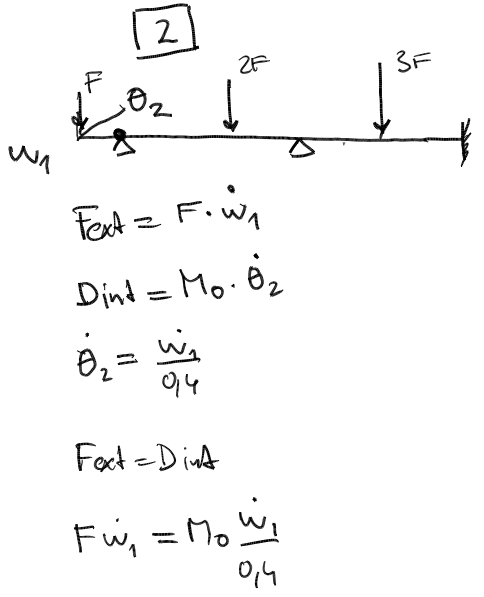
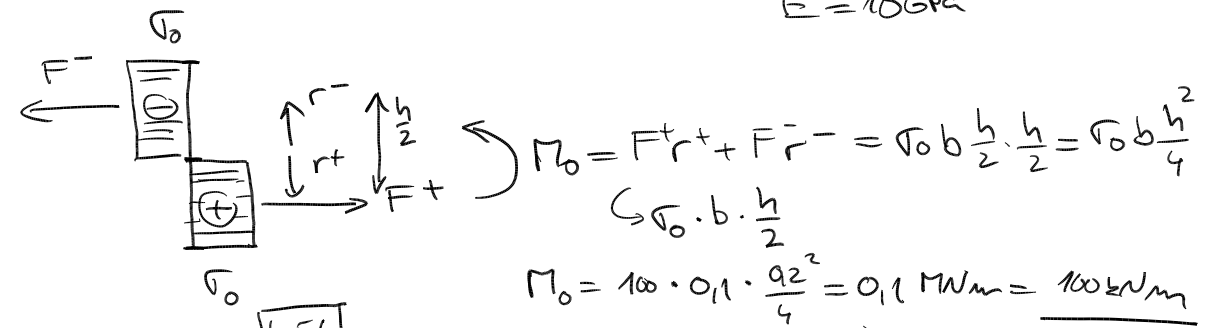
Výpočet mezního plastického momentu



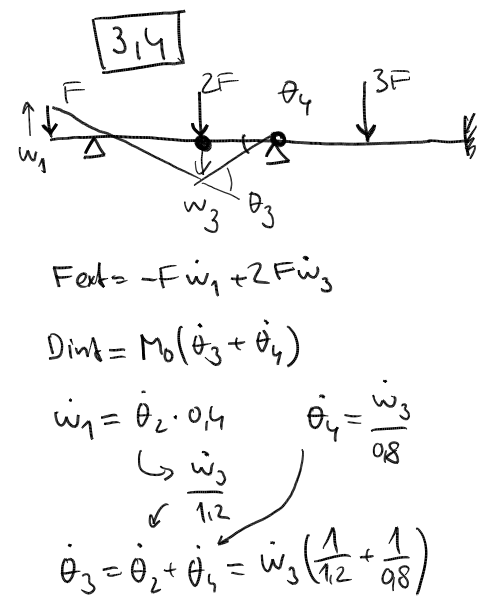


obdelnikový prvek
 $\sigma_0 = 100 \text{ MPa}$
 $E = 10 \text{ GPa}$

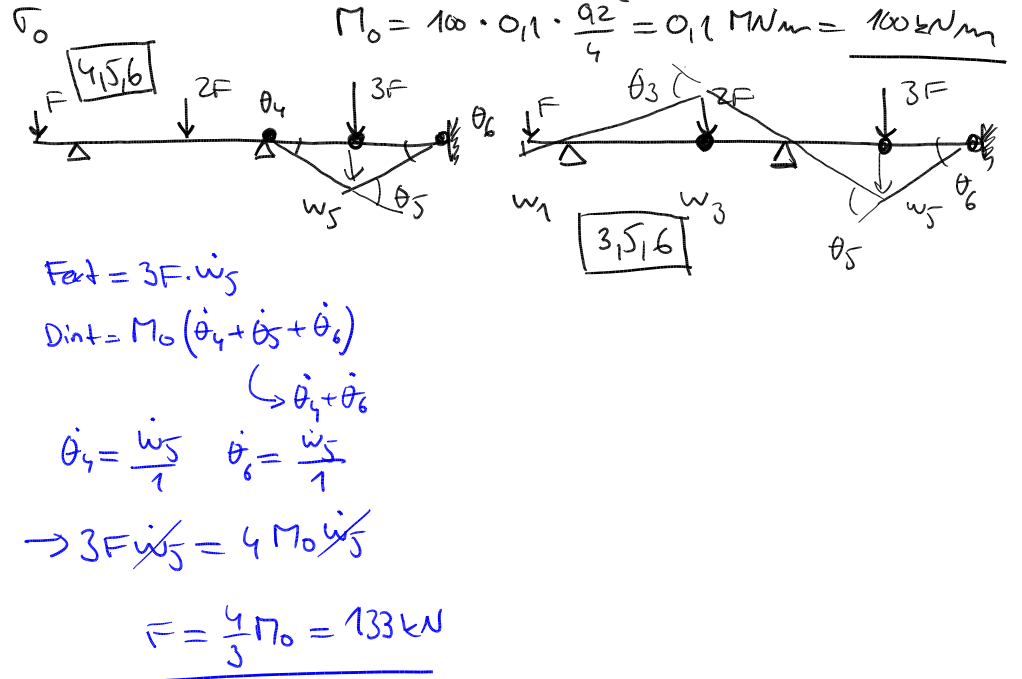
Výpočet mezního plastického momentu

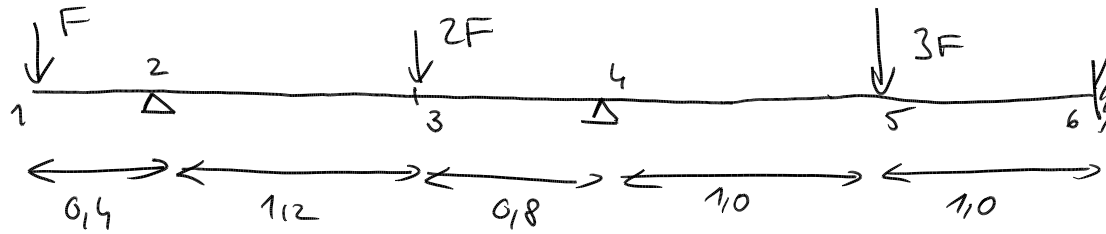


$\rightarrow F = \frac{M_0}{0.4} = \frac{100}{0.4} = 250 \text{ kN}$



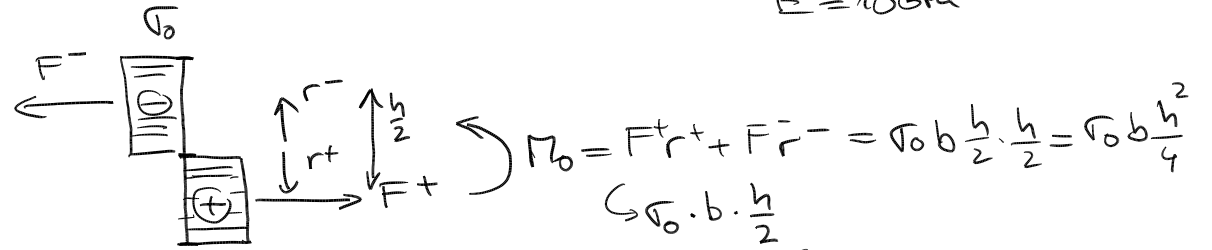
$F_{ext} = -F \cdot \frac{\dot{w}_3 \cdot 0.4}{1.2} + 2F \cdot \dot{w}_3 = \dot{w}_3 \left(-\frac{1}{3} + 2 \right) \cdot F$
 $D_{int} = M_0 \left[\left(\frac{1}{1.2} + \frac{1}{0.8} \right) \dot{w}_3 + \frac{\dot{w}_3}{0.8} \right]$
 $F_{ext} = D_{int}$
 $\rightarrow \frac{5}{3} \cdot F \dot{w}_3 = \frac{10}{3} M_0 \dot{w}_3$
 $F = 2 M_0 = 200 \text{ kNm}$



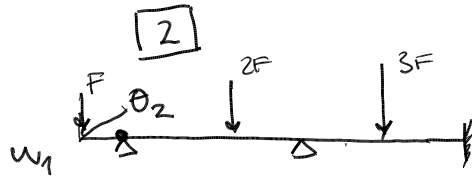


obdelnikový prvek
 $\sigma_0 = 100 \text{ MPa}$
 $E = 10 \text{ GPa}$

Výpočet mezního plastického momentu



$$M_0 = 100 \cdot 0,1 \cdot \frac{0,2^2}{4} = 0,1 \text{ MNm} = 100 \text{ kNm}$$



$$F_{ext} = F \cdot \dot{w}_1$$

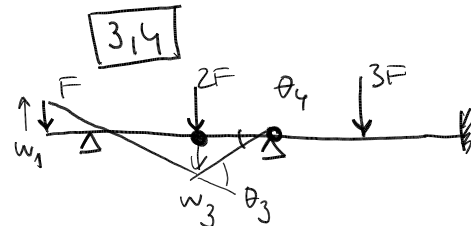
$$D_{int} = M_0 \cdot \dot{\theta}_2$$

$$\dot{\theta}_2 = \frac{\dot{w}_1}{0,4}$$

$$F_{ext} = D_{int}$$

$$F \dot{w}_1 = M_0 \frac{\dot{w}_1}{0,4}$$

$$\rightarrow F = \frac{M_0}{0,4} = \frac{100}{0,4} = 250 \text{ kN}$$



$$F_{ext} = -F \dot{w}_1 + 2F \dot{w}_3$$

$$D_{int} = M_0 (\dot{\theta}_3 + \dot{\theta}_4)$$

$$\dot{w}_1 = \dot{\theta}_2 \cdot 0,4 \quad \dot{\theta}_4 = \frac{\dot{w}_3}{0,8}$$

$$\dot{\theta}_3 = \dot{\theta}_2 + \dot{\theta}_4 = \dot{w}_3 \left(\frac{1}{1,2} + \frac{1}{0,8} \right)$$

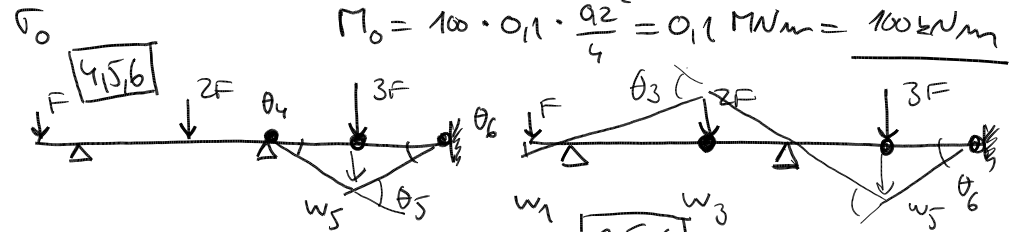
$$F_{ext} = -F \cdot \frac{\dot{w}_3 \cdot 0,4}{1,2} + 2F \cdot \dot{w}_3 = \dot{w}_3 \left(-\frac{1}{3} + 2 \right) \cdot F$$

$$D_{int} = M_0 \left[\left(\frac{1}{1,2} + \frac{1}{0,8} \right) \dot{w}_3 + \frac{\dot{w}_3}{0,8} \right]$$

$$F_{ext} = D_{int}$$

$$\rightarrow \frac{5}{3} \cdot F \dot{w}_3 = \frac{10}{3} M_0 \dot{w}_3$$

$$F = 2M_0 = 200 \text{ kNm}$$



$$F_{ext} = 3F \cdot \dot{w}_5$$

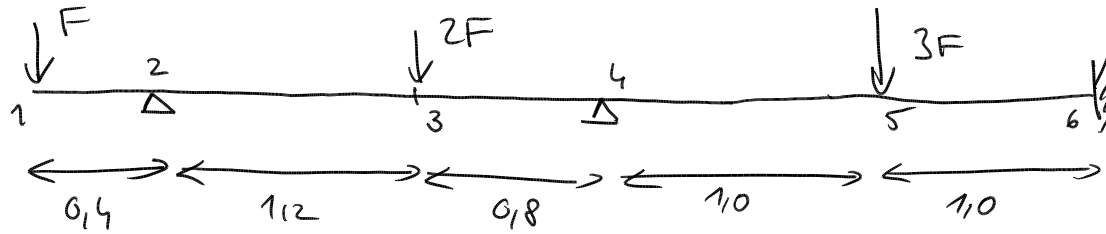
$$D_{int} = M_0 (\dot{\theta}_4 + \dot{\theta}_5 + \dot{\theta}_6)$$

$$\hookrightarrow \dot{\theta}_4 + \dot{\theta}_6$$

$$\dot{\theta}_4 = \frac{\dot{w}_5}{1} \quad \dot{\theta}_6 = \frac{\dot{w}_5}{1}$$

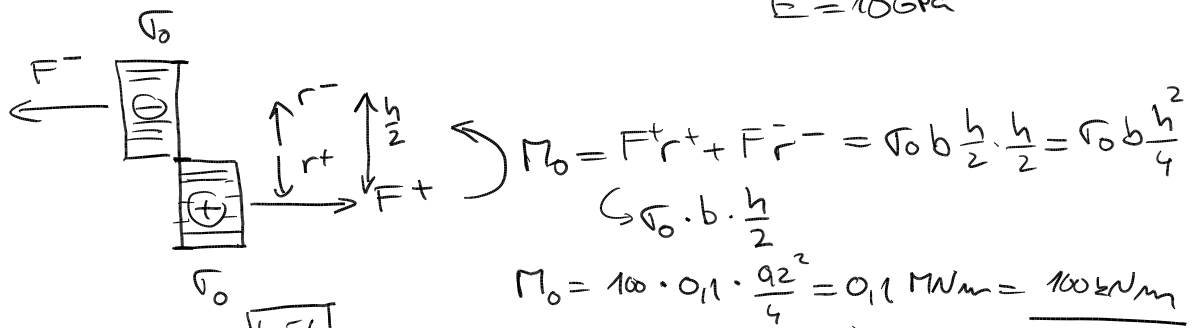
$$\rightarrow 3F \dot{w}_5 = 4 M_0 \dot{w}_5$$

$$F = \frac{4}{3} M_0 = 133 \text{ kN}$$



obdelnikový prvek
 $\sigma_0 = 100 \text{ MPa}$
 $E = 10 \text{ GPa}$

Výpočet mezního plastického momentu



2

$F_{ext} = F \cdot \dot{w}_1$
 $D_{int} = M_0 \cdot \dot{\theta}_2$
 $\dot{\theta}_2 = \frac{\dot{w}_1}{0.4}$
 $F_{ext} = D_{int}$
 $F \dot{w}_1 = M_0 \frac{\dot{w}_1}{0.4}$
 $\rightarrow F = \frac{M_0}{0.4} = \frac{100}{0.4} = 250 \text{ kN}$

3,4

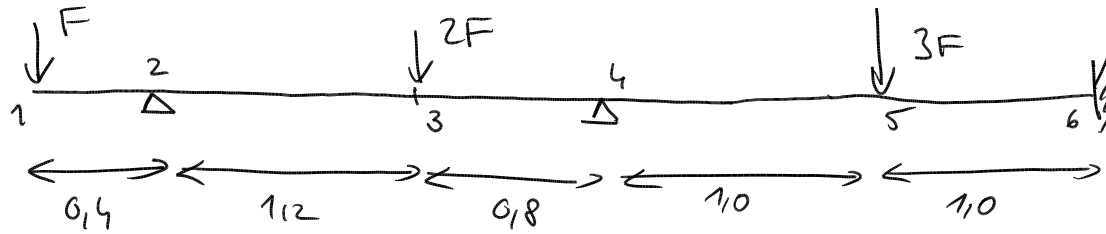
$F_{ext} = -F \dot{w}_1 + 2F \dot{w}_3$
 $D_{int} = M_0 (\dot{\theta}_3 + \dot{\theta}_4)$
 $\dot{w}_1 = \dot{\theta}_2 \cdot 0.4$
 $\dot{\theta}_4 = \frac{\dot{w}_3}{0.8}$
 $\dot{\theta}_3 = \dot{\theta}_2 + \dot{\theta}_4 = \dot{w}_3 \left(\frac{1}{1.2} + \frac{1}{0.8} \right)$
 $F_{ext} = -F \cdot \frac{\dot{w}_3 \cdot 0.4}{1.2} + 2F \cdot \dot{w}_3 = \dot{w}_3 \left(-\frac{1}{3} + 2 \right) \cdot F$
 $D_{int} = M_0 \left[\left(\frac{1}{1.2} + \frac{1}{0.8} \right) \dot{w}_3 + \frac{\dot{w}_3}{0.8} \right]$
 $F_{ext} = D_{int}$
 $\rightarrow \frac{5}{3} \cdot F \dot{w}_3 = \frac{10}{3} M_0 \dot{w}_3$
 $F = 2 M_0 = 200 \text{ kNm}$

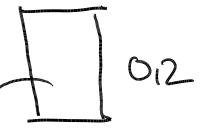
4,5,6

$F_{ext} = 3F \cdot \dot{w}_5$
 $D_{int} = M_0 (\dot{\theta}_4 + \dot{\theta}_5 + \dot{\theta}_6)$
 $\dot{\theta}_4 = \frac{\dot{w}_5}{1}$
 $\dot{\theta}_6 = \frac{\dot{w}_5}{1}$
 $\rightarrow 3F \dot{w}_5 = 4 M_0 \dot{w}_5$
 $F = \frac{4}{3} M_0 = 133 \text{ kN}$

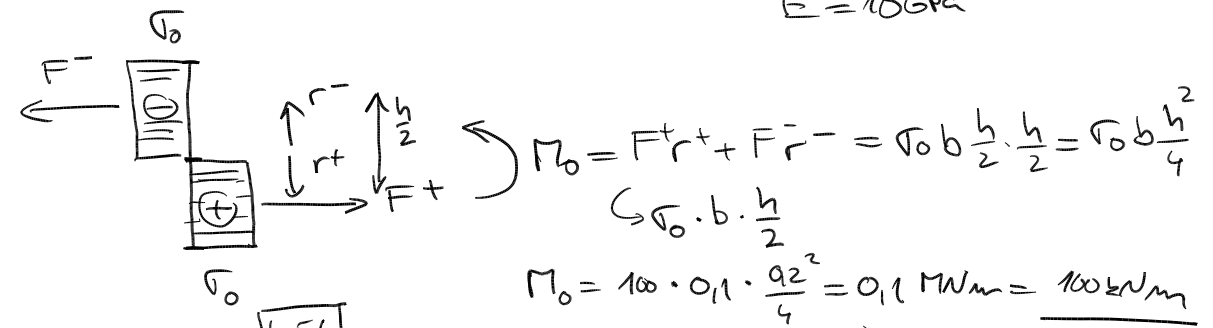
3,5,6

$F_{ext} = F \cdot \dot{w}_1 - 2F \dot{w}_3 + 3F \dot{w}_5$
 $D_{int} = M_0 (\dot{\theta}_3 + \dot{\theta}_5 + \dot{\theta}_6)$
 $\dot{w}_1 = \frac{\dot{w}_3}{3}$
 $\dot{w}_5 = 1.25 \dot{w}_3$
 $\dot{\theta}_5 = \dot{\theta}_4 + \dot{\theta}_6 \rightarrow \frac{\dot{w}_5}{1} = 1.25 \dot{w}_3$
 $\dot{\theta}_3 = \dot{\theta}_2 + \dot{\theta}_4$
 $\dot{\theta}_3 = \frac{\dot{w}_3}{1.2} + \frac{\dot{w}_3}{0.8}$

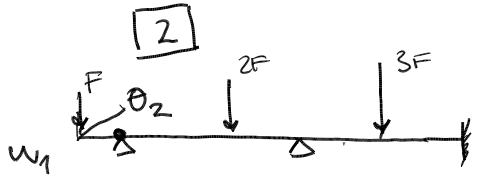


obdelnikovy prevez 
 $\sigma_0 = 100 \text{ MPa}$
 $E = 10 \text{ GPa}$

Vypočet mezního plastického momentu



2



$$F_{ext} = F \cdot \dot{w}_1$$

$$D_{int} = M_0 \cdot \dot{\theta}_2$$

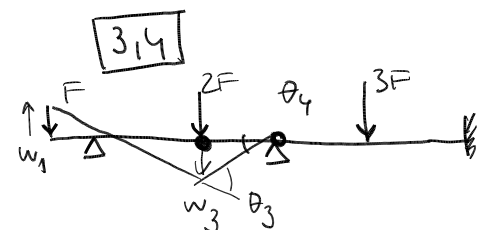
$$\dot{\theta}_2 = \frac{\dot{w}_1}{0.4}$$

$$F_{ext} = D_{int}$$

$$F \dot{w}_1 = M_0 \frac{\dot{w}_1}{0.4}$$

$$\rightarrow F = \frac{M_0}{0.4} = \frac{100}{0.4} = 250 \text{ kN}$$

3,4



$$F_{ext} = -F \dot{w}_1 + 2F \dot{w}_3$$

$$D_{int} = M_0 (\dot{\theta}_3 + \dot{\theta}_4)$$

$$\dot{w}_1 = \dot{\theta}_2 \cdot 0.4 \quad \dot{\theta}_4 = \frac{\dot{w}_3}{0.8}$$

$$\hookrightarrow \frac{\dot{w}_3}{1.2}$$

$$\dot{\theta}_3 = \dot{\theta}_2 + \dot{\theta}_4 = \dot{w}_3 \left(\frac{1}{1.2} + \frac{1}{0.8} \right)$$

$$F_{ext} = -F \cdot \frac{\dot{w}_3 \cdot 0.4}{1.2} + 2F \cdot \dot{w}_3 = \dot{w}_3 \left(-\frac{1}{3} + 2 \right) \cdot F$$

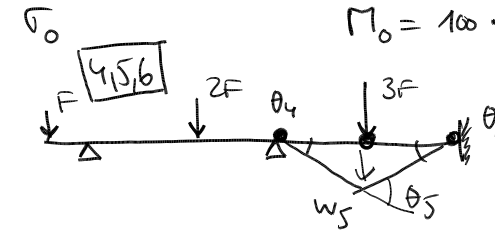
$$D_{int} = M_0 \left[\left(\frac{1}{1.2} + \frac{1}{0.8} \right) \dot{w}_3 + \frac{\dot{w}_3}{0.8} \right]$$

$$F_{ext} = D_{int}$$

$$\rightarrow \frac{5}{3} \cdot F \dot{w}_3 = \frac{10}{3} M_0 \dot{w}_3$$

$$F = 2 M_0 = 200 \text{ kNm}$$

4,5,6



$$F_{ext} = 3F \cdot \dot{w}_5$$

$$D_{int} = M_0 (\dot{\theta}_4 + \dot{\theta}_5 + \dot{\theta}_6)$$

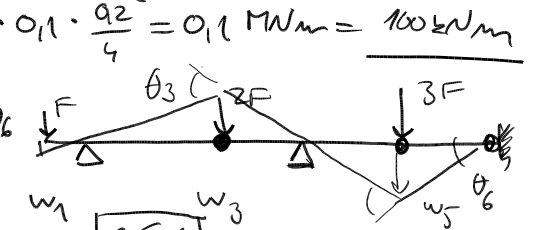
$$\hookrightarrow \dot{\theta}_4 + \dot{\theta}_6$$

$$\dot{\theta}_4 = \frac{\dot{w}_5}{1} \quad \dot{\theta}_6 = \frac{\dot{w}_5}{1}$$

$$\rightarrow 3F \dot{w}_5 = 4 M_0 \dot{w}_5$$

$$F = \frac{4}{3} M_0 = 133 \text{ kN}$$

3,5,6



$$F_{ext} = F \cdot \dot{w}_1 - 2F \dot{w}_3 + 3F \dot{w}_5$$

$$D_{int} = M_0 (\dot{\theta}_3 + \dot{\theta}_5 + \dot{\theta}_6)$$

$$\dot{w}_1 = \frac{\dot{w}_3}{3}$$

$$\dot{w}_5 = 1.25 \dot{w}_3$$

$$\dot{\theta}_5 = \dot{\theta}_4 + \dot{\theta}_6 \rightarrow \frac{\dot{w}_3}{1} = 1.25 \dot{w}_3$$

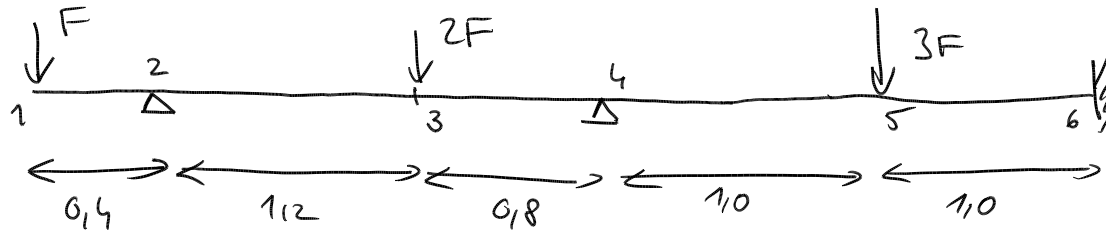
$$\hookrightarrow \frac{\dot{w}_3}{0.8}$$

$$\dot{\theta}_3 = \dot{\theta}_2 + \dot{\theta}_4 \rightarrow \frac{\dot{w}_3}{1.2} + \frac{\dot{w}_3}{0.8}$$

$$\dot{w}_3 F \left(\frac{1}{3} - 2 + 3.75 \right) = M_0 \dot{w}_3 \left[\left(\frac{1}{1.2} + \frac{1}{0.8} \right) + \left(\frac{1}{0.8} + 1.25 \right) + 1.25 \right]$$

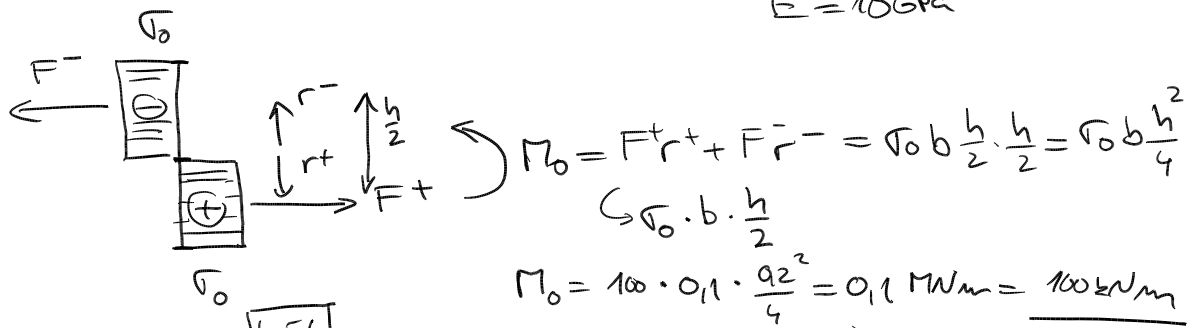
$$2.0833 F = 100 \cdot 5.833$$

$$\rightarrow F = 280 \text{ kN}$$



obdelnikový prvek
 $\sigma_0 = 100 \text{ MPa}$
 $E = 10 \text{ GPa}$

Výpočet mezního plastického momentu



2

$F_{ext} = F \cdot \dot{w}_1$
 $D_{int} = M_0 \cdot \dot{\theta}_2$
 $\dot{\theta}_2 = \frac{\dot{w}_1}{0.4}$
 $F_{ext} = D_{int}$
 $F \dot{w}_1 = M_0 \frac{\dot{w}_1}{0.4}$
 $\rightarrow F = \frac{M_0}{0.4} = \frac{100}{0.4} = 250 \text{ kN}$

3,4

$F_{ext} = -F \dot{w}_1 + 2F \dot{w}_3$
 $D_{int} = M_0 (\dot{\theta}_3 + \dot{\theta}_4)$
 $\dot{w}_1 = \dot{\theta}_2 \cdot 0.4$
 $\dot{\theta}_4 = \frac{\dot{w}_3}{0.8}$
 $\dot{\theta}_3 = \dot{\theta}_2 + \dot{\theta}_4 = \dot{w}_3 \left(\frac{1}{1.2} + \frac{1}{0.8} \right)$
 $F_{ext} = -F \cdot \frac{\dot{w}_3 \cdot 0.4}{1.2} + 2F \cdot \dot{w}_3 = \dot{w}_3 \left(-\frac{1}{3} + 2 \right) \cdot F$
 $D_{int} = M_0 \left[\left(\frac{1}{1.2} + \frac{1}{0.8} \right) \dot{w}_3 + \frac{\dot{w}_3}{0.8} \right]$
 $F_{ext} = D_{int}$
 $\rightarrow \frac{5}{3} \cdot F \dot{w}_3 = \frac{10}{3} M_0 \dot{w}_3$
 $F = 2 M_0 = 200 \text{ kNm}$

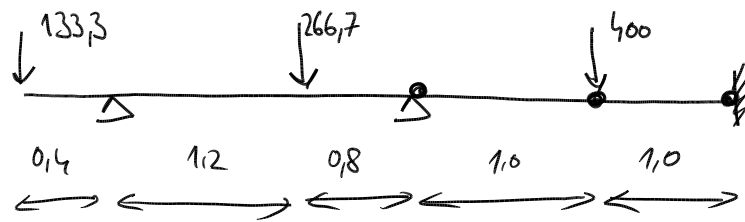
4,5,6

$F_{ext} = 3F \cdot \dot{w}_5$
 $D_{int} = M_0 (\dot{\theta}_4 + \dot{\theta}_5 + \dot{\theta}_6)$
 $\dot{\theta}_4 = \frac{\dot{w}_5}{1}$
 $\dot{\theta}_6 = \frac{\dot{w}_5}{1}$
 $\rightarrow 3F \dot{w}_5 = 4 M_0 \dot{w}_5$
 $F = \frac{4}{3} M_0 = 133 \text{ kN}$

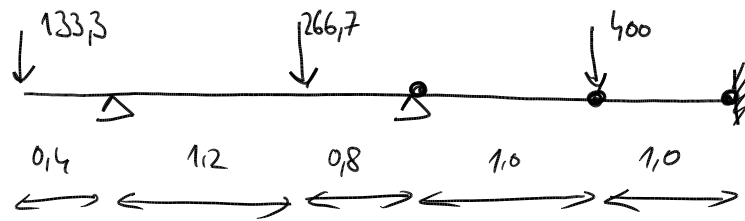
3,5,6

$F_{ext} = F \cdot \dot{w}_1 - 2F \dot{w}_3 + 3F \dot{w}_5$
 $D_{int} = M_0 (\dot{\theta}_3 + \dot{\theta}_5 + \dot{\theta}_6)$
 $\dot{w}_1 = \frac{\dot{w}_3}{3}$
 $\dot{w}_5 = 1.25 \dot{w}_3$
 $\dot{\theta}_5 = \dot{\theta}_4 + \dot{\theta}_6 \rightarrow \frac{\dot{w}_5}{1} = 1.25 \dot{w}_3$
 $\dot{\theta}_3 = \dot{\theta}_2 + \dot{\theta}_4$
 $\dot{\theta}_3 = \frac{\dot{w}_3}{1.2} + \frac{\dot{w}_3}{0.8}$
 $\dot{\theta}_5 = \frac{\dot{w}_3}{1.2} + \frac{\dot{w}_3}{0.8}$
 $\dot{\theta}_6 = 1.25 \dot{w}_3$
 $\dot{w}_3 F \left(\frac{1}{3} - 2 + 3.75 \right) = M_0 \dot{w}_3 \left[\left(\frac{1}{1.2} + \frac{1}{0.8} \right) + \left(\frac{1}{0.8} + 1.25 \right) + 1.25 \right]$
 $2.0833 F = 100 \cdot 5.833$
 $\rightarrow F = 280 \text{ kN}$

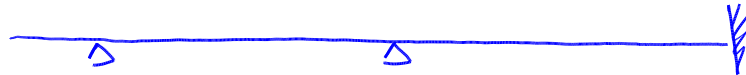
$F = 133,3 \text{ kN}$, plast. klouby v průřezech 4,5,6



$F = 133,3 \text{ kN}$, plast. klauzy v průřezeh 4,5,6



$M [\text{kNm}]$



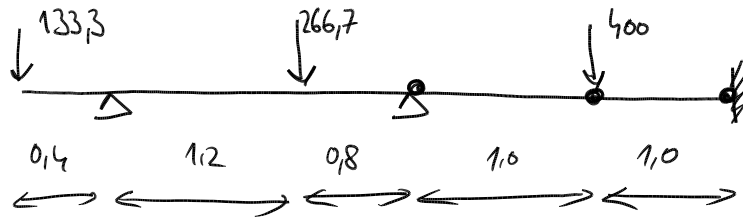
$V [\text{kN}]$



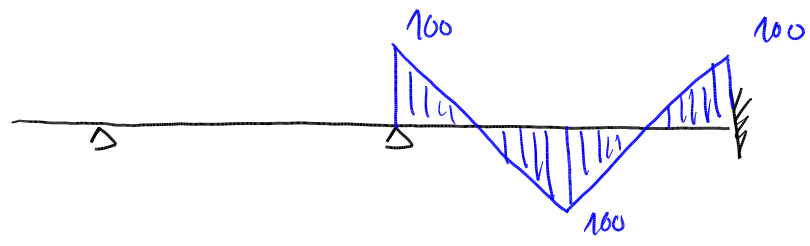
Reakce
[kN, kNm]



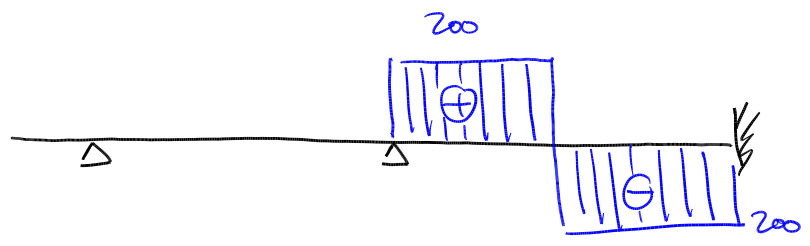
$F = 133,3 \text{ kN}$, plast. klauzy v průřezeh 4,5,6



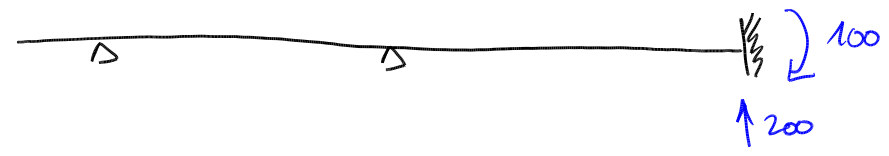
$M [\text{kNm}]$



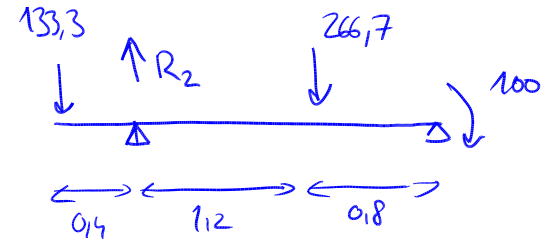
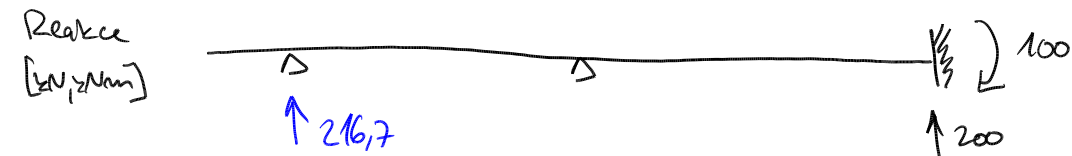
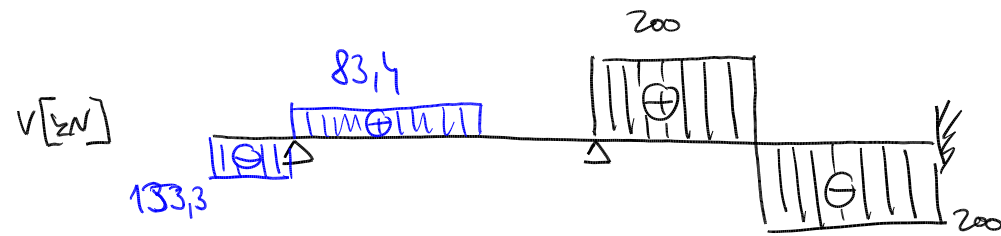
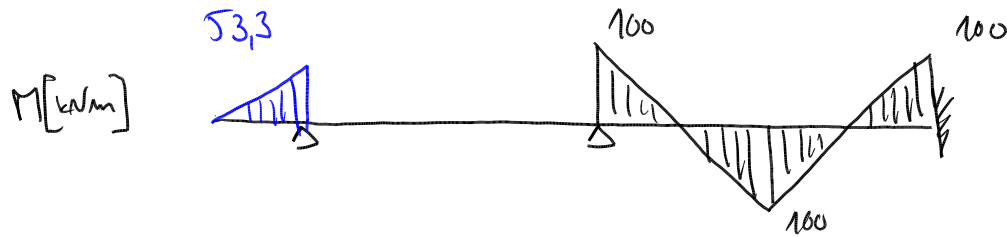
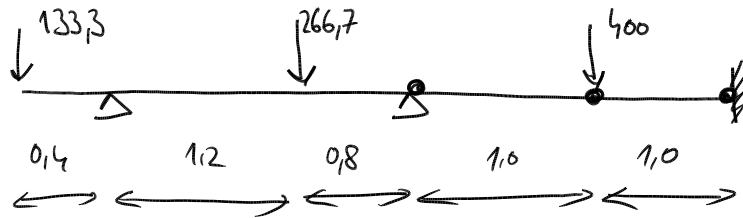
$V [\text{kN}]$



Reakce
[kN, kNm]

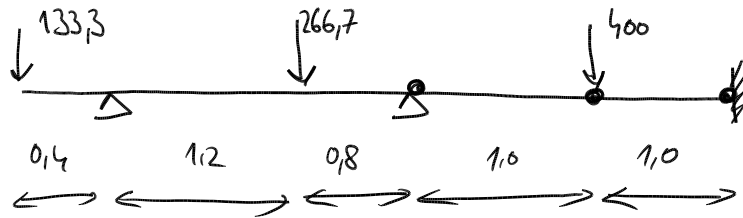


$F = 133,3 \text{ kN}$, plast. klauzy v průřezech 4,5,6

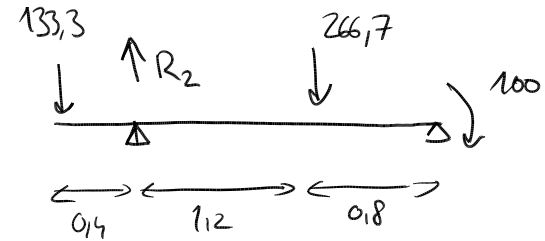
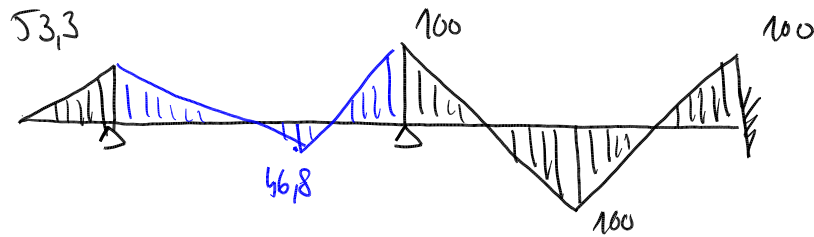


$$R_2 = \frac{133,3 \cdot 2,4 + 266,7 \cdot 0,8 - 100}{2,0} = 216,7 \text{ kN}$$

$F = 133,3 \text{ kN}$, plast. klauzy v průřezeh 4,5,6

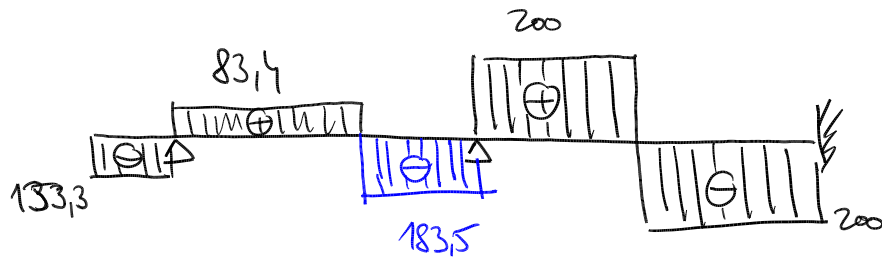


$M [\text{kNm}]$

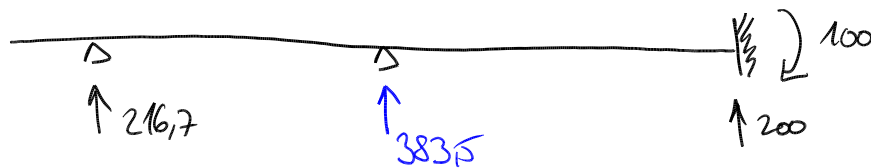


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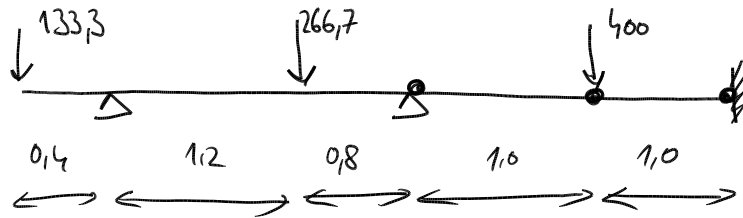
$V [\text{kN}]$



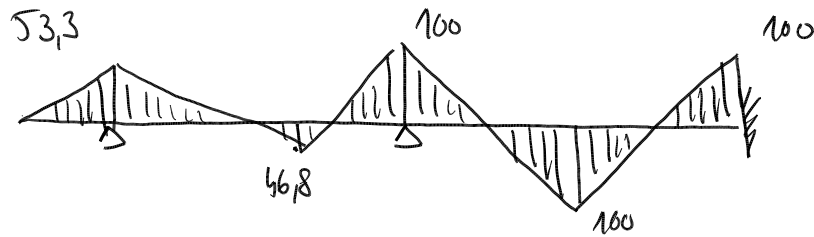
Reakce
[kN, kNm]



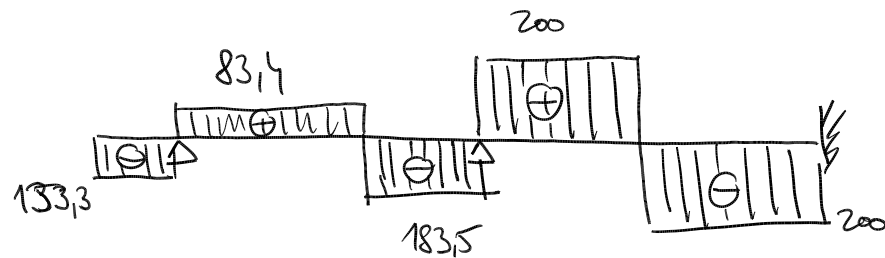
$F = 133,3 \text{ kN}$, plast. klauzy v průřezech 4,5,6



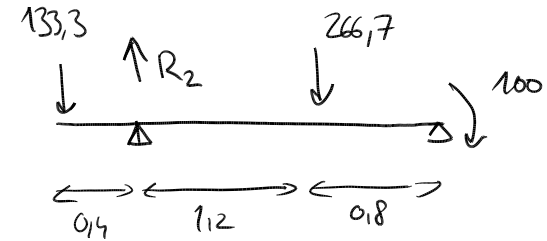
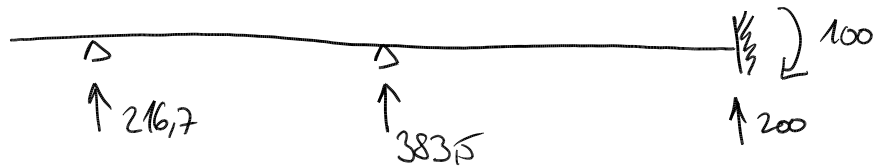
$M [\text{kNm}]$



$V [\text{kN}]$



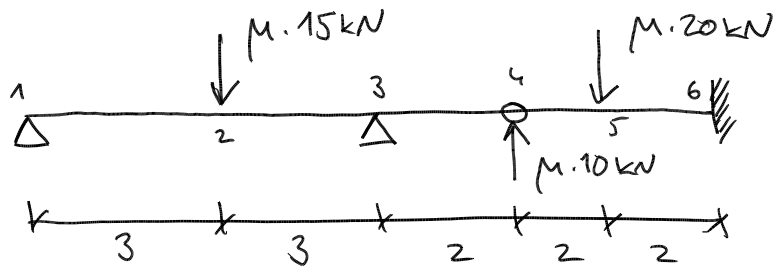
Reakce
[kN, kNm]



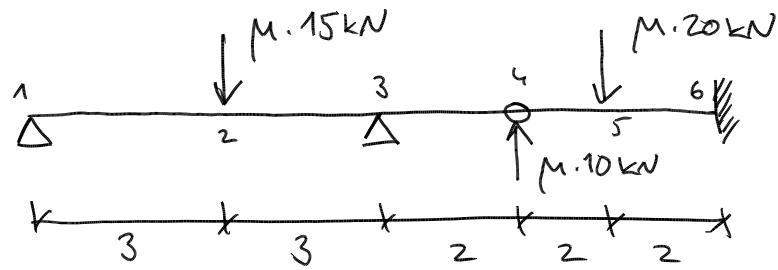
$$R_2 = \frac{133,3 \cdot 2,4 + 266,7 \cdot 0,8 - 100}{2,0} = 216,7 \text{ kN}$$

kontrola - podminuty rovnou 2x

PT



Pr

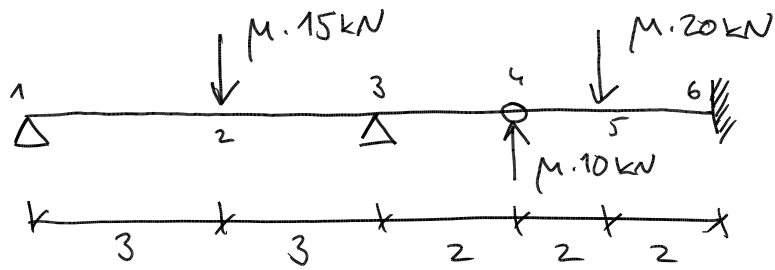


Možný vznik plast. kloubů: 2, 3, 5, 6 $\sum s = N$

Stat. neurčitost (dřív) 1x \rightarrow 2 plast. klouby pro kolaps $(s+1)$

$$\rightarrow \text{počet kombinací } \binom{N}{s+1} = \frac{N!}{(s+1)!(N-(s+1))!} = \frac{4!}{2! \cdot 2!} = 6$$

Pr

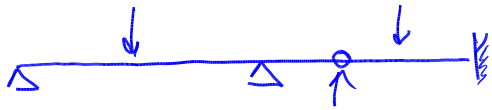


Možný vznik plast. kĺobov: 2, 3, 5, 6 $\sum 4 = N$

Stat. neurčitost (dôjč) 1x \rightarrow 2 plast. kĺobov pro kolaps (S+1)

$$\rightarrow \text{počet kombináci' } (N)_{(S+1)} = \frac{N!}{(S+1)!(N-(S+1))!} = \frac{4!}{2! \cdot 2!} = 6$$

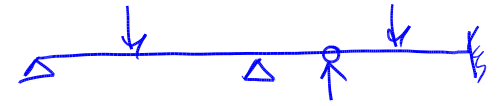
2,3



2,5



2,6



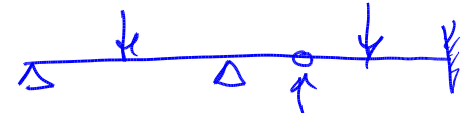
3,5



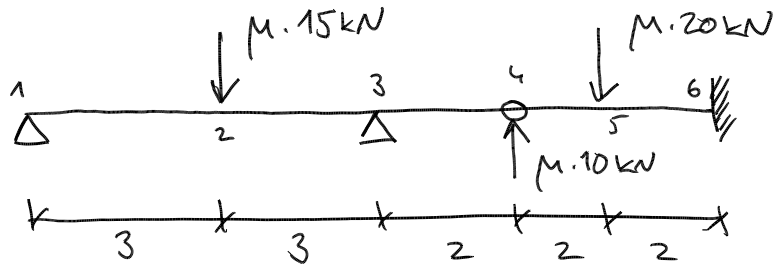
3,6



5,6



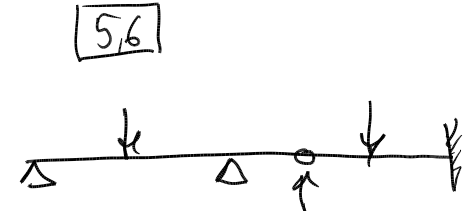
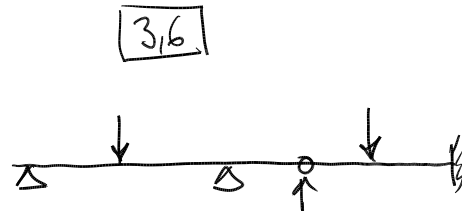
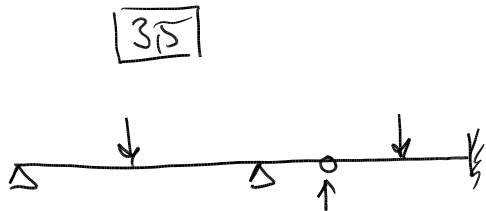
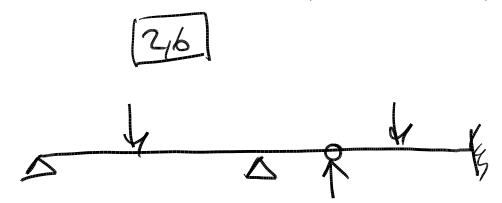
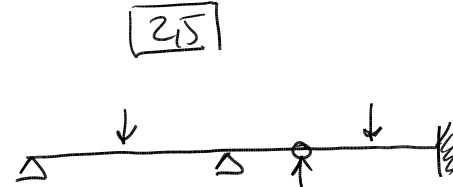
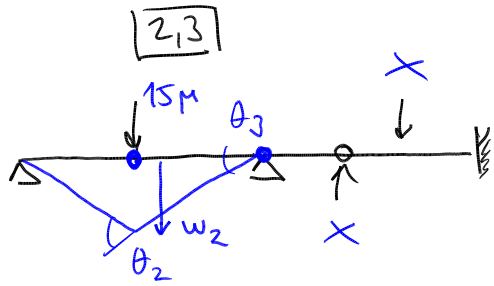
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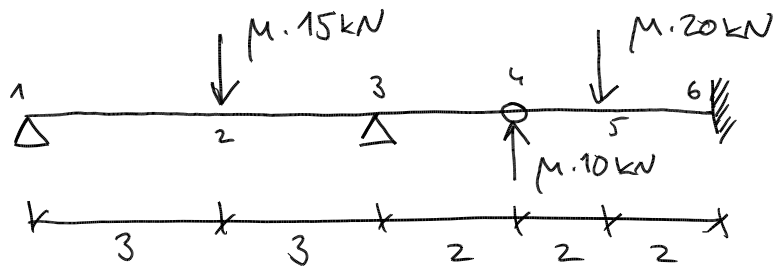
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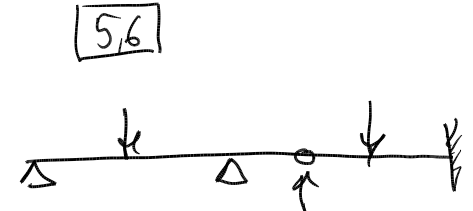
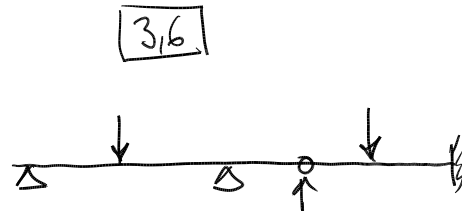
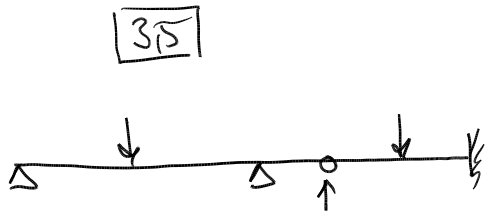
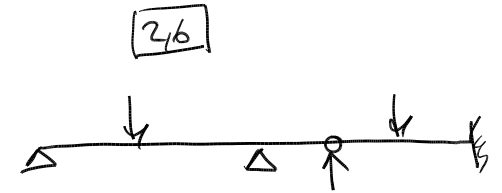
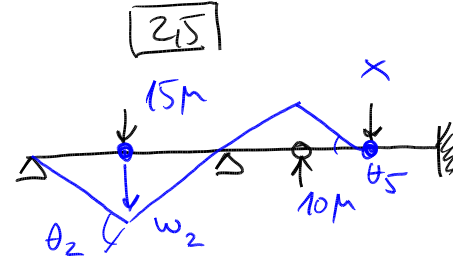
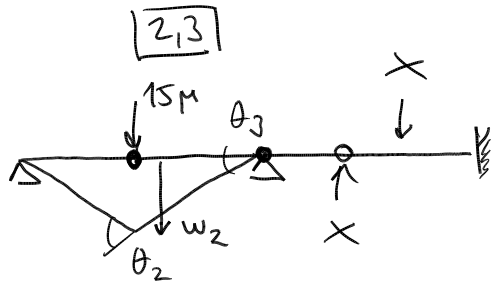
Pr



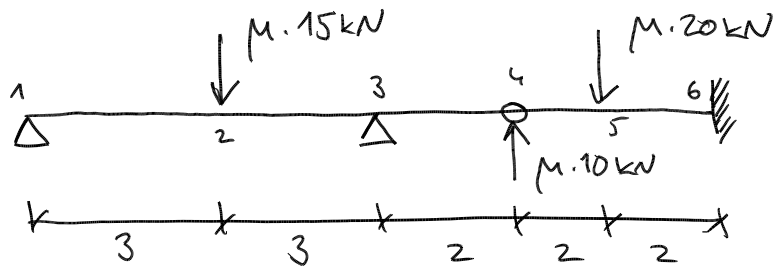
Možný vznik plast. kĺobov: 2, 3, 5, 6 $\Sigma 4 = N$

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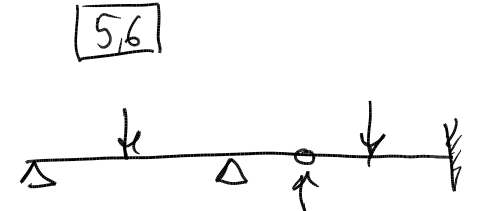
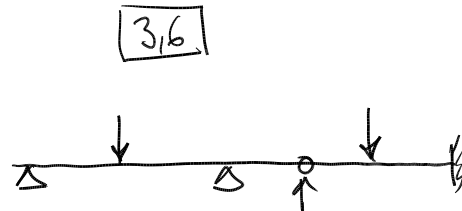
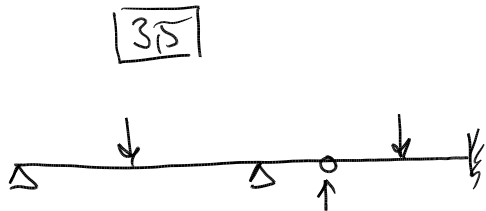
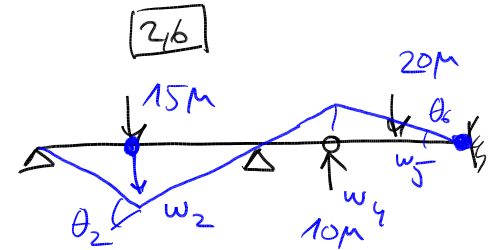
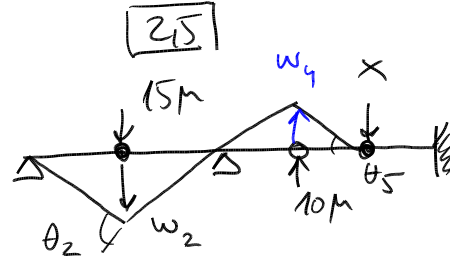
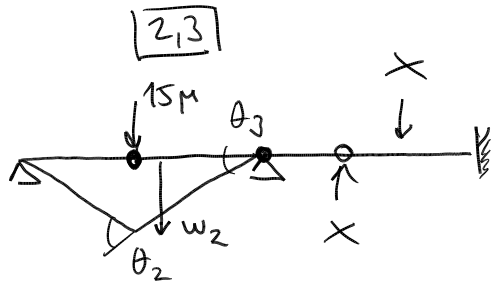
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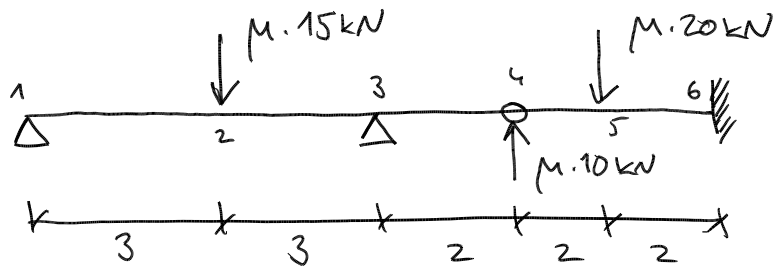
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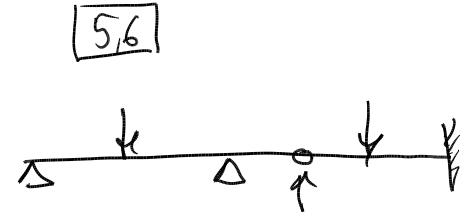
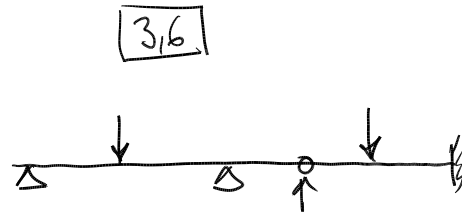
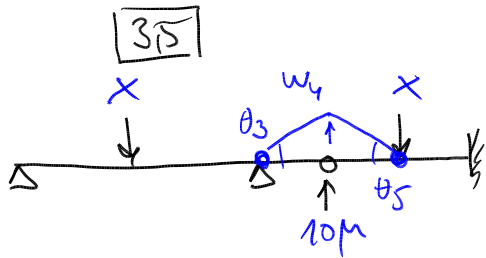
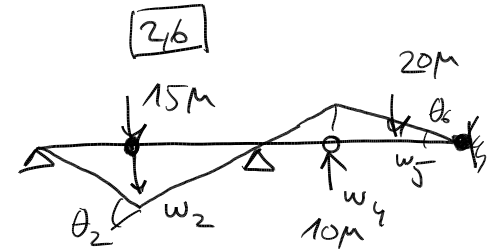
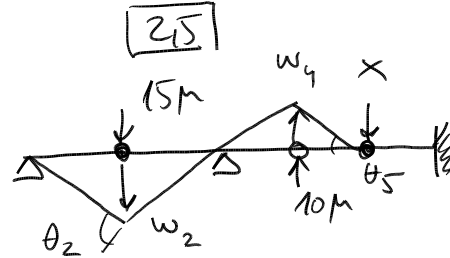
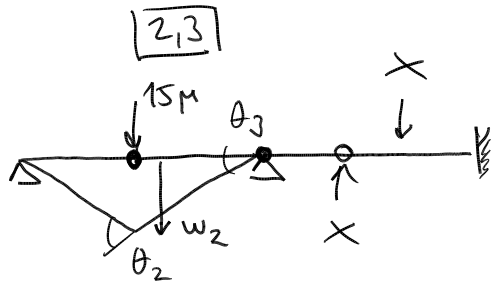
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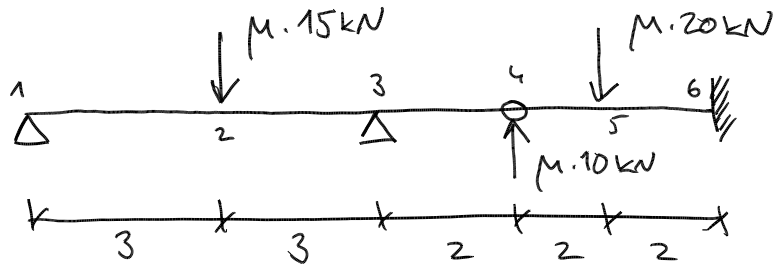
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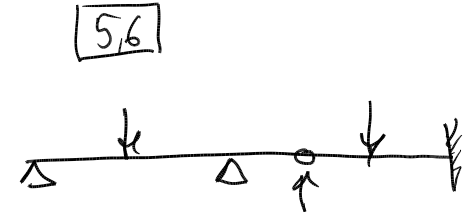
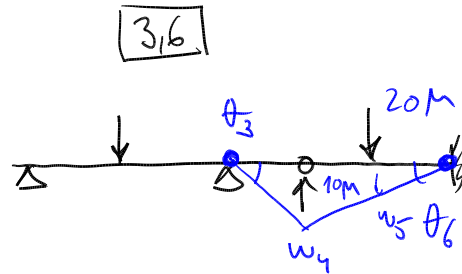
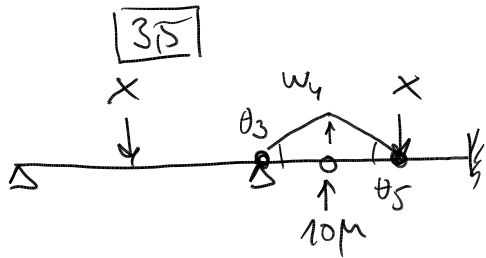
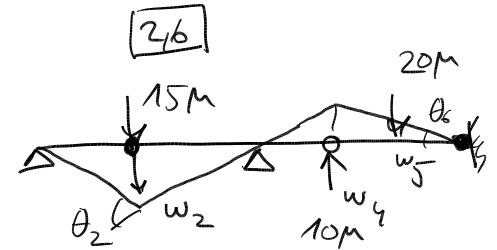
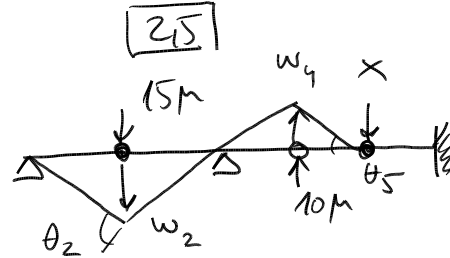
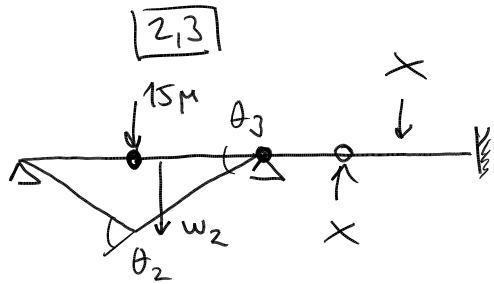
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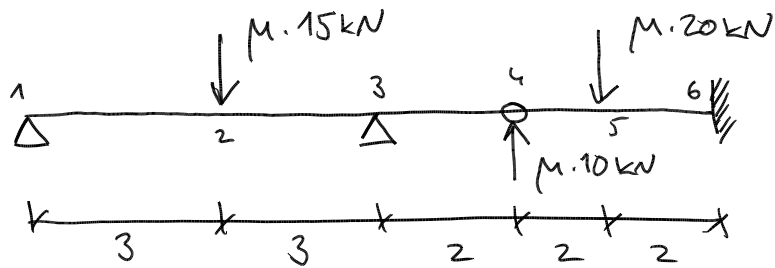
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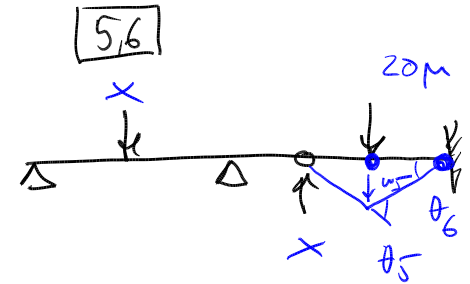
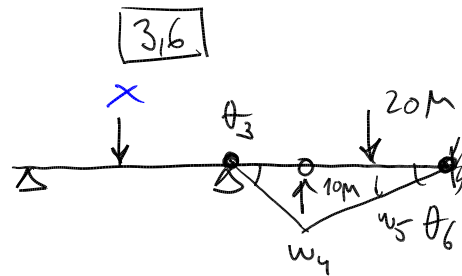
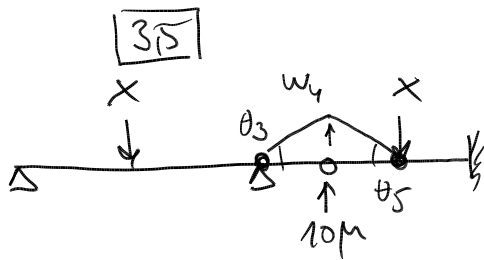
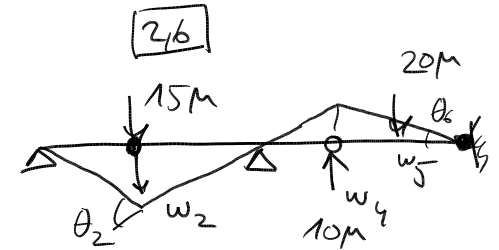
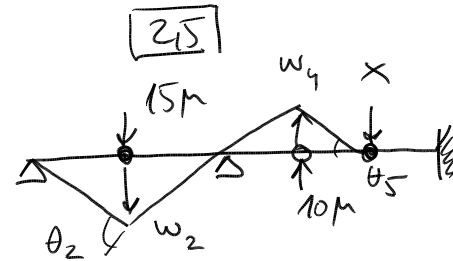
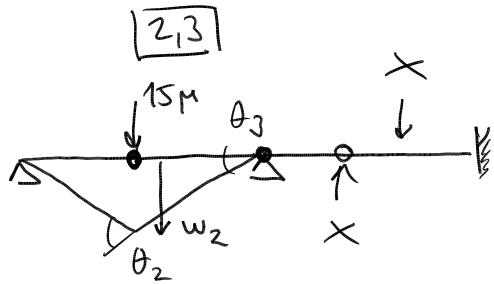
Pr



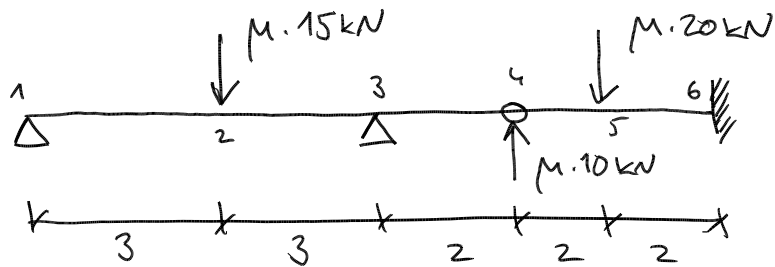
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Pr

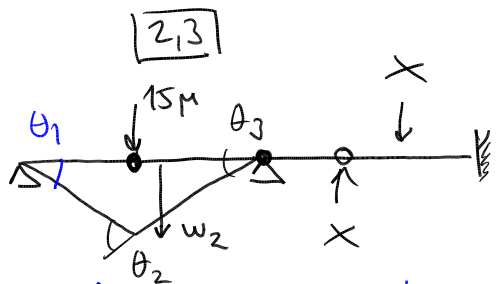


$M_0 = 150 \text{ kNm}$

Možný vznik plast. kloubů: 2, 3, 5, 6 $\Sigma 4 = N$

Stat. neurčitost (dobyb) $1x \rightarrow 2 \text{ plast. klouby pro kolaps } (S+1)$

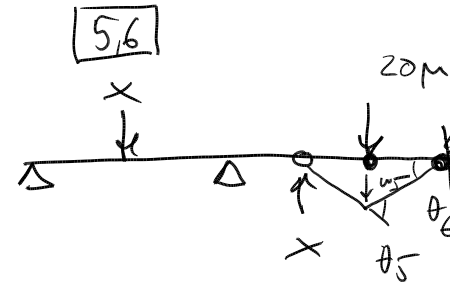
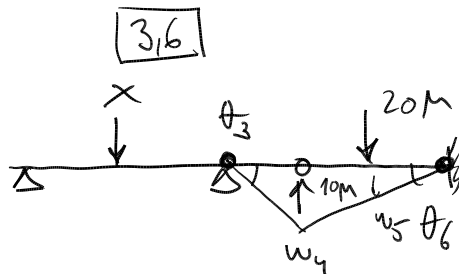
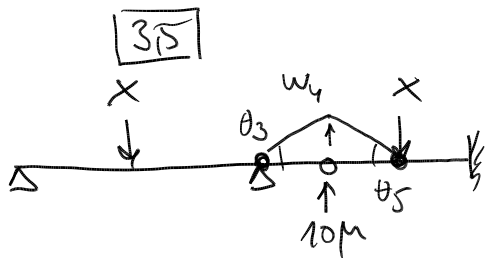
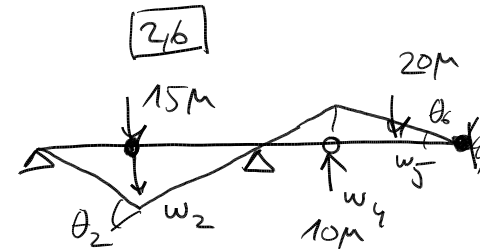
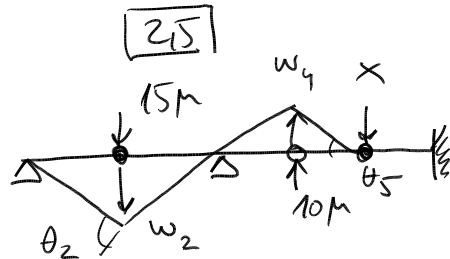
$\rightarrow \text{počet kombinací } (N) = \frac{N!}{(S+1)!(N-(S+1))!} = \frac{4!}{2! \cdot 2!} = 6$



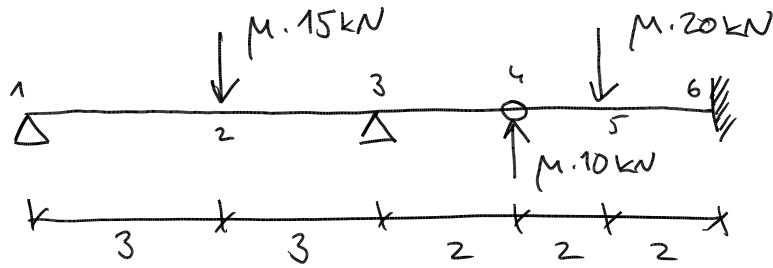
$\dot{\theta}_3 = \frac{\dot{w}_2}{3}$ $\dot{\theta}_1 = \frac{\dot{w}_2}{3}$ $\dot{\theta}_2 = \dot{\theta}_1 + \dot{\theta}_3 = \frac{2\dot{w}_2}{3}$

$15M \dot{w}_2 = M_0 [\dot{\theta}_2 + \dot{\theta}_3] = M_0 \left[\frac{1}{3} + \frac{2}{3} \right] \dot{w}_2$

$M = M_0 / 15 = 10$



Pr



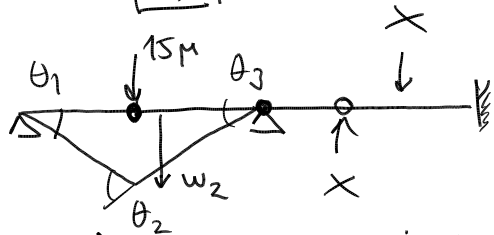
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2,3

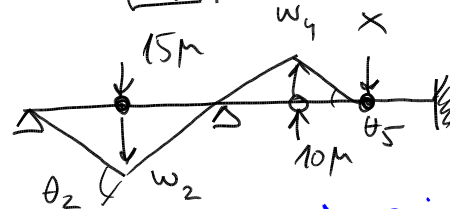


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2,5

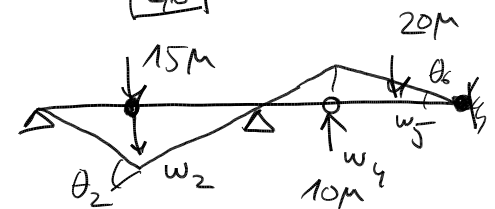


$\dot{\theta}_5 = \frac{\dot{w}_4}{2} \Leftrightarrow \dot{w}_4 = \frac{2}{3} \dot{w}_2$ $\dot{\theta}_2 = \frac{2\dot{w}_2}{3}$

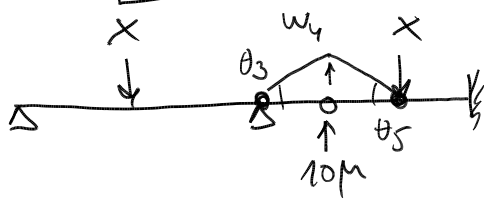
$15M \dot{w}_2 + 10M \cdot \frac{2}{3} \dot{w}_2 = M_0 \dot{w}_2 \left[\frac{2}{3} + \frac{1}{2} \cdot \frac{2}{3} \right]$

$\frac{65}{3} M = 150 \cdot 1 \rightarrow M = 6,923$

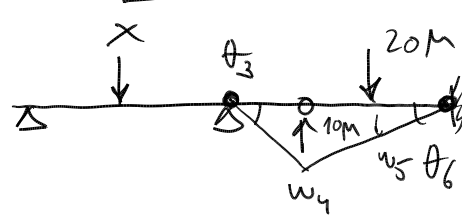
2,6



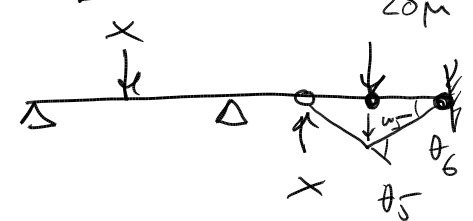
3,5



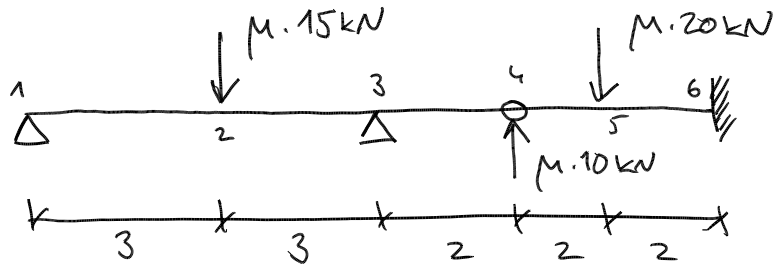
3,6



5,6



Pr



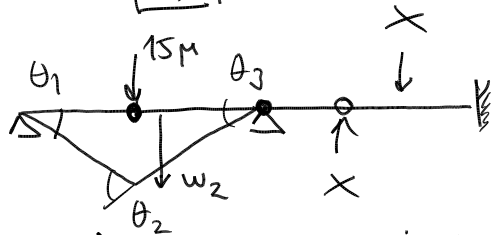
$M_0 = 150 \text{ kNm}$

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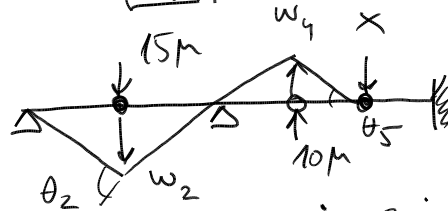


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2,5

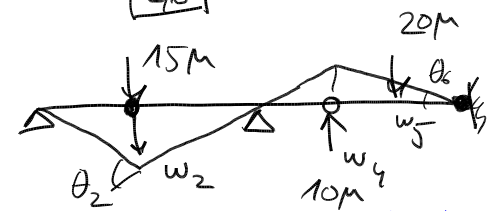


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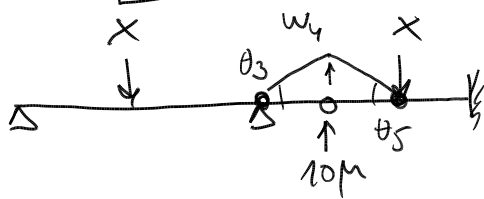


$\dot{\theta}_6 = \frac{\dot{w}_5}{4} = \frac{2}{3} \cdot \frac{1}{4} \dot{w}_2$ $\dot{w}_5 = \frac{\dot{w}_4}{2} = \frac{1}{2} \cdot \frac{2}{3} \dot{w}_2 = \frac{1}{3} \dot{w}_2$

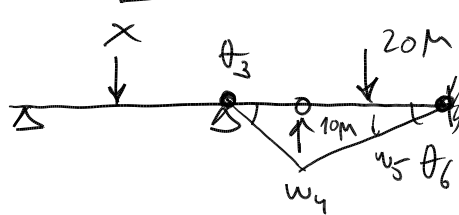
$15M \cdot \dot{w}_2 + 10M \cdot \frac{2}{3} \dot{w}_2 - 20M \cdot \frac{1}{3} \dot{w}_2 = M_0 \dot{w}_2 \left(\frac{2}{3} + \frac{1}{6} \right)$

$15M = 150 \cdot \frac{5}{6} \rightarrow M = \frac{50}{6} = 8,333$

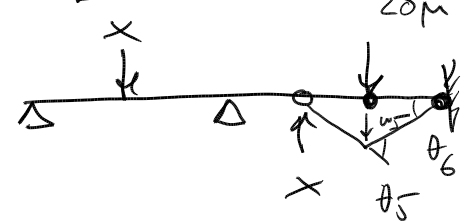
3,5



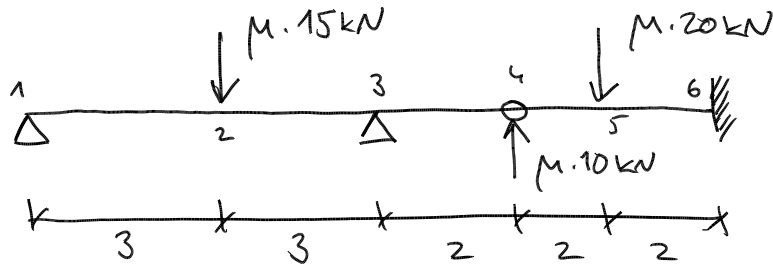
3,6



5,6



PT



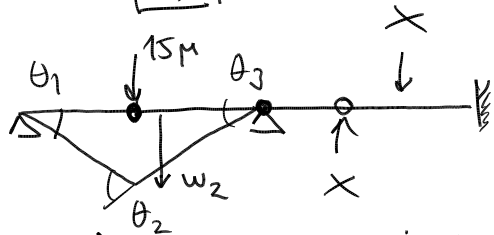
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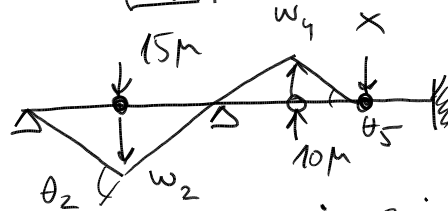


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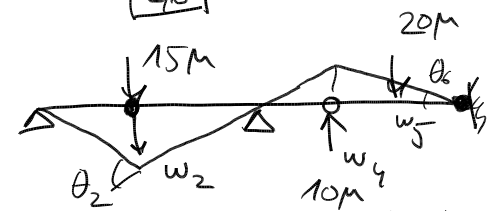


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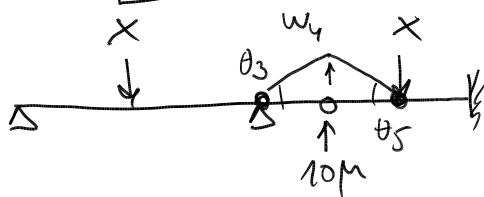


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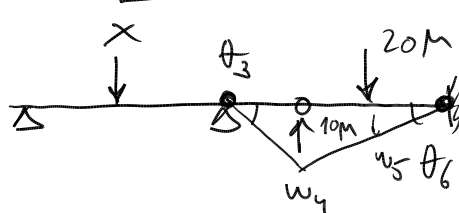


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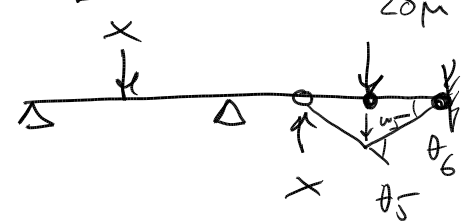
$10M \cdot \dot{w}_4 = M_0 \dot{w}_4 \left(\frac{1}{2} + \frac{1}{2} \right)$

$M = \frac{150}{10} = 15$

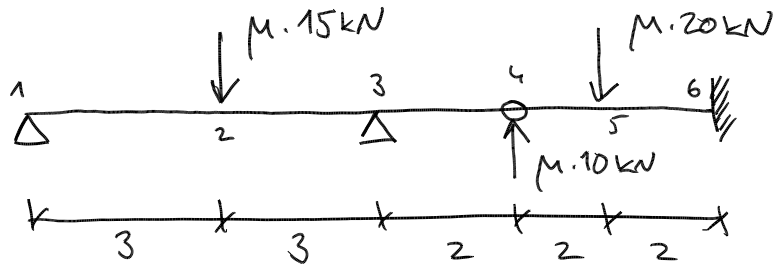
3,6



5,6



PT



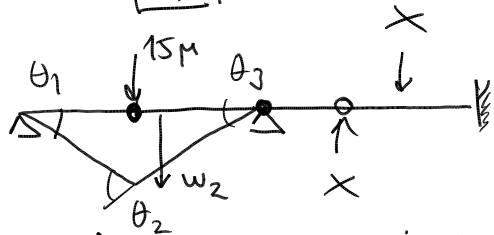
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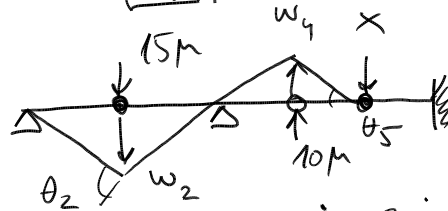


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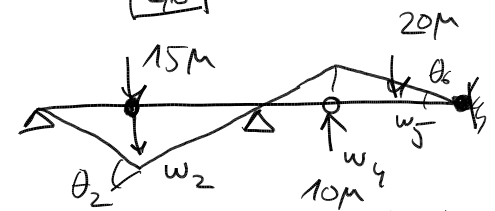


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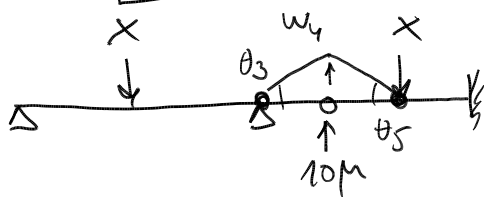


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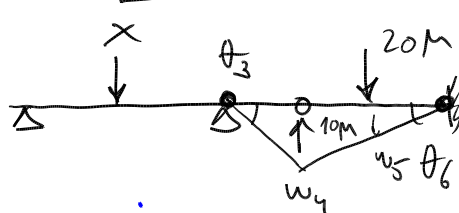


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3,6

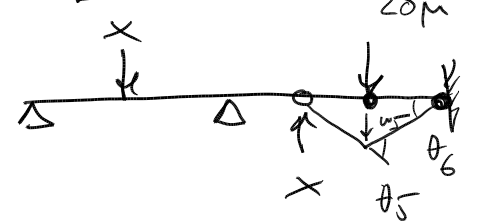


$\dot{w}_5 = \frac{\dot{w}_4}{2}$

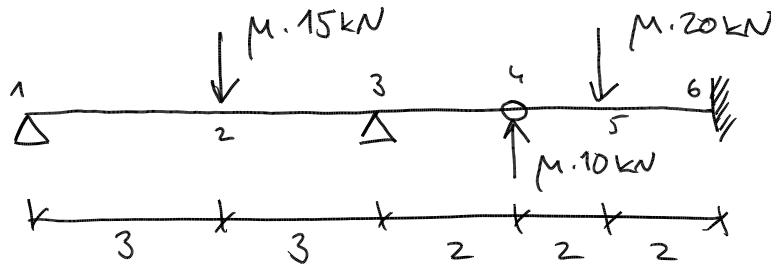
Fact = $10M \cdot \frac{\dot{w}_4}{2} - 20M \cdot \frac{\dot{w}_4}{2} = 0$

\rightarrow nutný výkon největší síl

5,6



PT



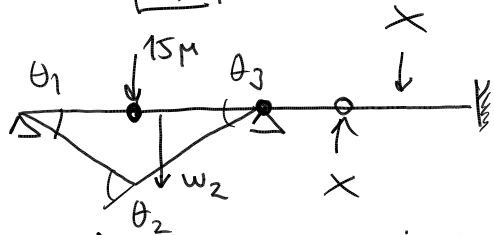
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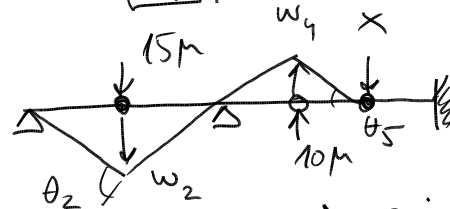


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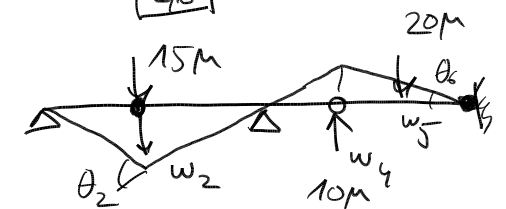


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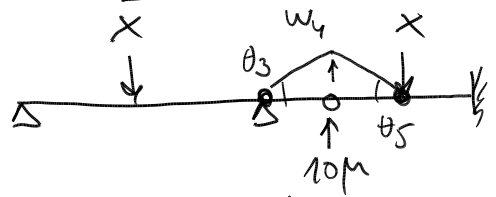


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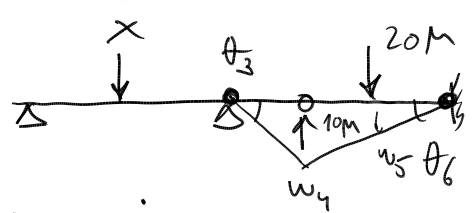


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3,6

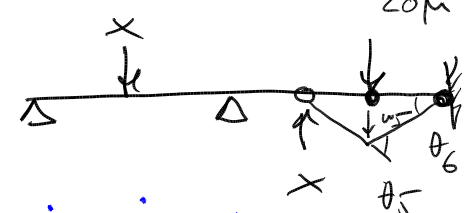


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5,6



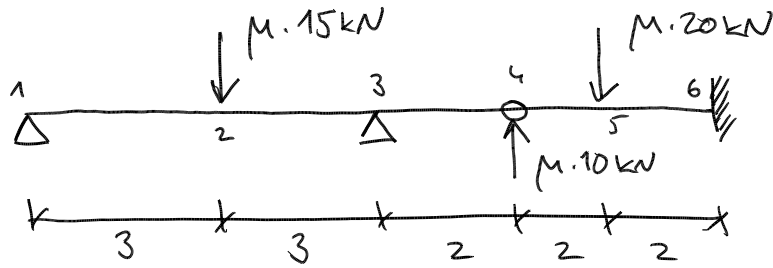
$\dot{\theta}_6 = \frac{\dot{w}_5}{2}$ $\dot{\theta}_5 = \dot{\theta}_6 + \dot{\theta}_4$ $\dot{\theta}_4 = \frac{\dot{w}_5}{2}$

$20M \cdot \dot{w}_5 = M_0 \dot{w}_5 \left[\frac{1}{2} + 2 \cdot \frac{1}{2} \right]$

$20M = 150 \cdot \frac{3}{2}$

$\rightarrow M = 11,25$

PT



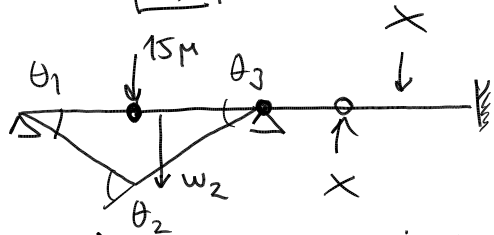
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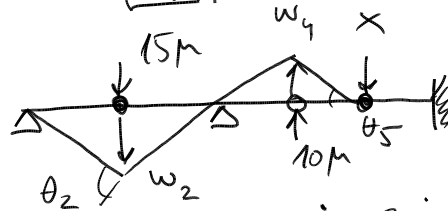


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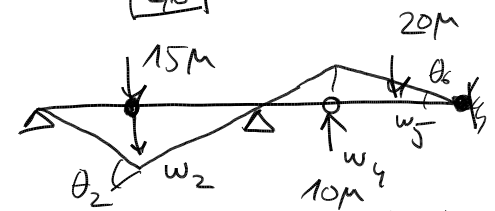


$\dot{\theta}_5 = \frac{\dot{w}_4}{2} \Leftrightarrow \dot{w}_4 = \frac{2}{3} \dot{w}_2$ $\dot{\theta}_2 = \frac{2\dot{w}_2}{3}$

$15 \text{ m} \dot{w}_2 + 10 \text{ m} \cdot \frac{2}{3} \dot{w}_2 = M_0 \dot{w}_2 \left[\frac{2}{3} + \frac{1}{2} \cdot \frac{2}{3} \right]$

$\frac{65}{3} \text{ m} = 150 \cdot 1 \rightarrow M = 6,923$

2,6

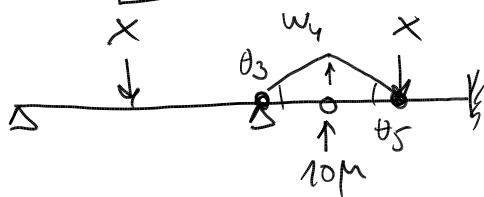


$\dot{\theta}_6 = \frac{\dot{w}_4}{4} = \frac{2}{3} \cdot \frac{1}{4} \dot{w}_2$ $\dot{w}_5 = \frac{\dot{w}_4}{2} = \frac{1}{2} \cdot \frac{2}{3} \dot{w}_2 = \frac{1}{3} \dot{w}_2$

$15 \text{ m} \cdot \dot{w}_2 + 10 \text{ m} \cdot \frac{2}{3} \dot{w}_2 - 20 \text{ m} \cdot \frac{1}{3} \dot{w}_2 = M_0 \dot{w}_2 \left(\frac{2}{3} + \frac{1}{6} \right)$

$15 \text{ m} = 150 \cdot \frac{5}{6} \rightarrow M = \frac{50}{6} = 8,333$

3,5

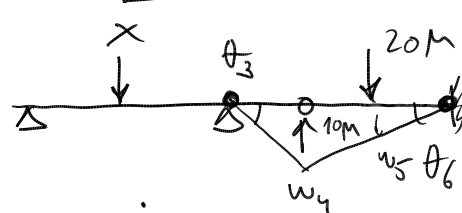


$\dot{\theta}_3 = \frac{\dot{w}_4}{2}$ $\dot{\theta}_5 = \frac{\dot{w}_4}{2}$

$10 \text{ m} \cdot \dot{w}_4 = M_0 \dot{w}_4 \left(\frac{1}{2} + \frac{1}{2} \right)$

$M = \frac{150}{10} = 15$

3,6

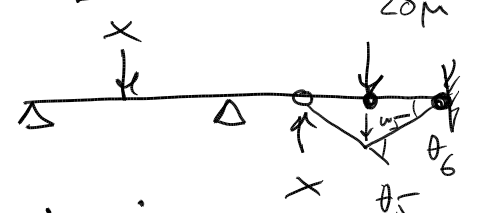


$\dot{w}_5 = \frac{\dot{w}_4}{2}$

Fact = $10 \text{ m} \cdot \frac{\dot{w}_4}{2} - 20 \text{ m} \cdot \frac{\dot{w}_4}{2} = 0$

\rightarrow nulový výkon největší síly

5,6



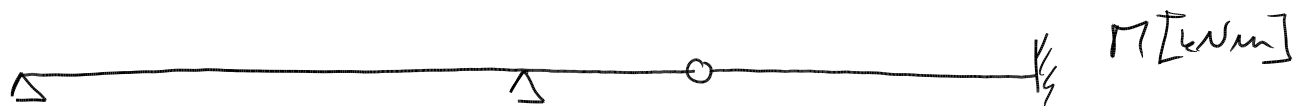
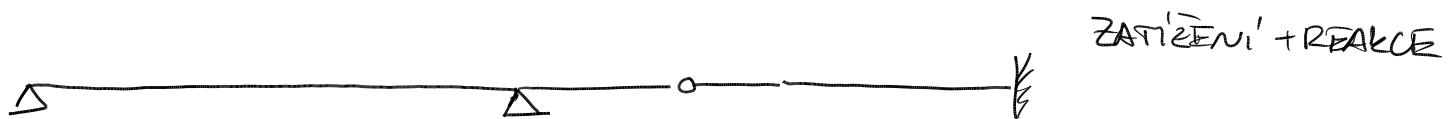
$\dot{\theta}_6 = \frac{\dot{w}_5}{2}$ $\dot{\theta}_5 = \dot{\theta}_6 + \dot{\theta}_4$ $\dot{\theta}_4 = \frac{\dot{w}_5}{2}$

$20 \text{ m} \cdot \dot{w}_5 = M_0 \dot{w}_5 \left[\frac{1}{2} + 2 \cdot \frac{1}{2} \right]$

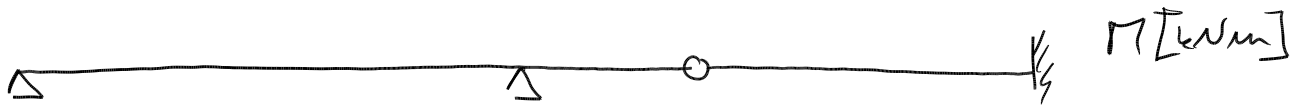
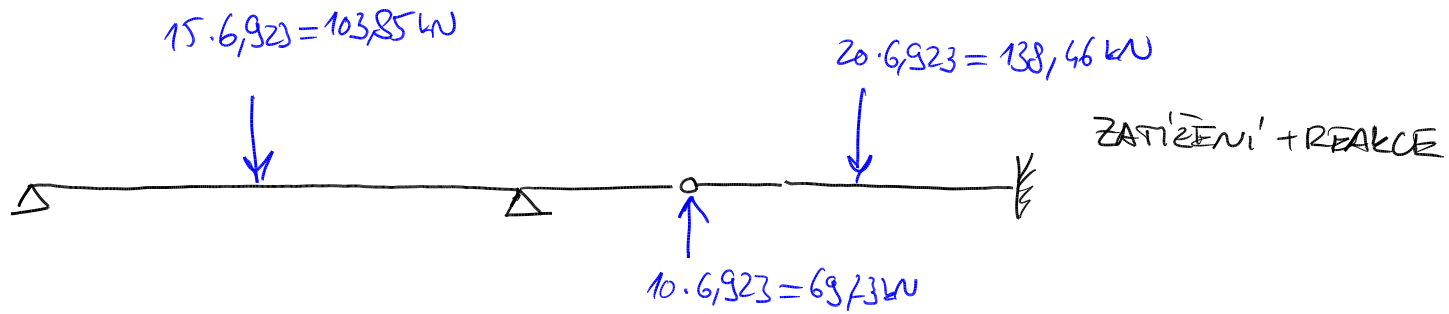
$20 \text{ m} = 150 \cdot \frac{3}{2}$

$\rightarrow M = 11,25$

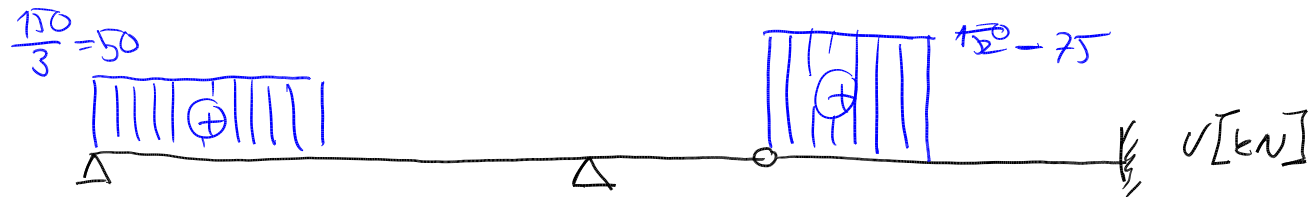
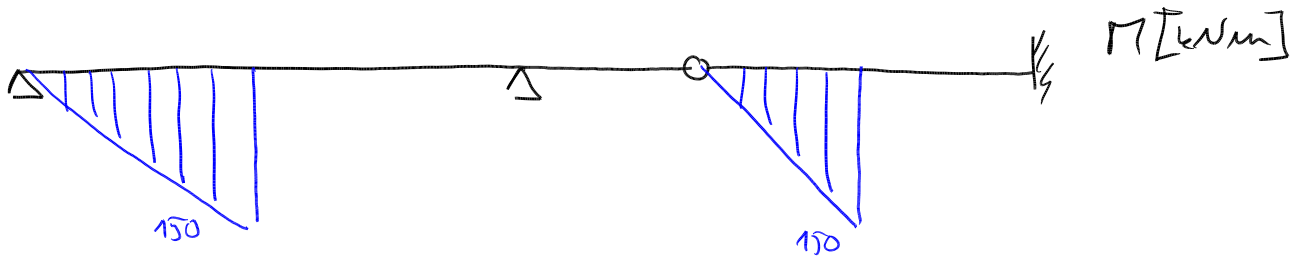
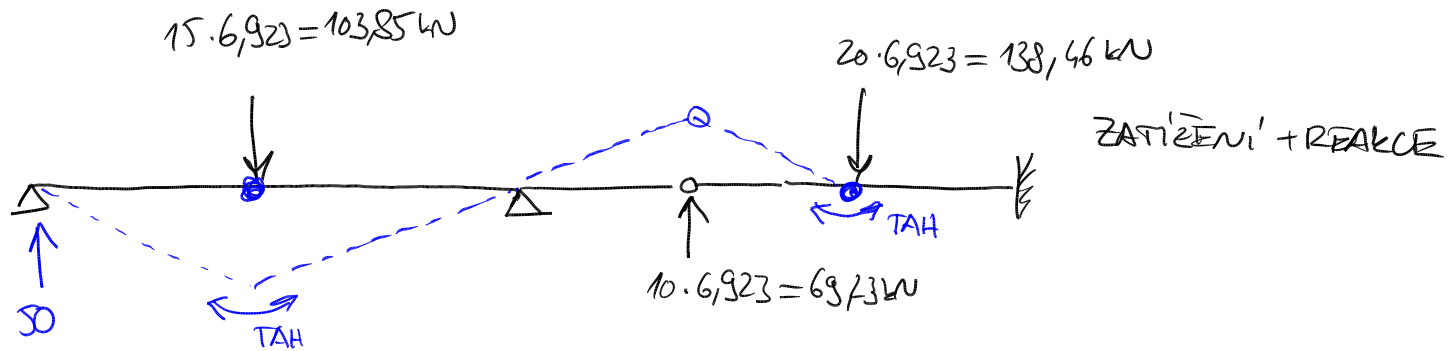
VYKRESLENÍ VNITĚRNÍCH SIL



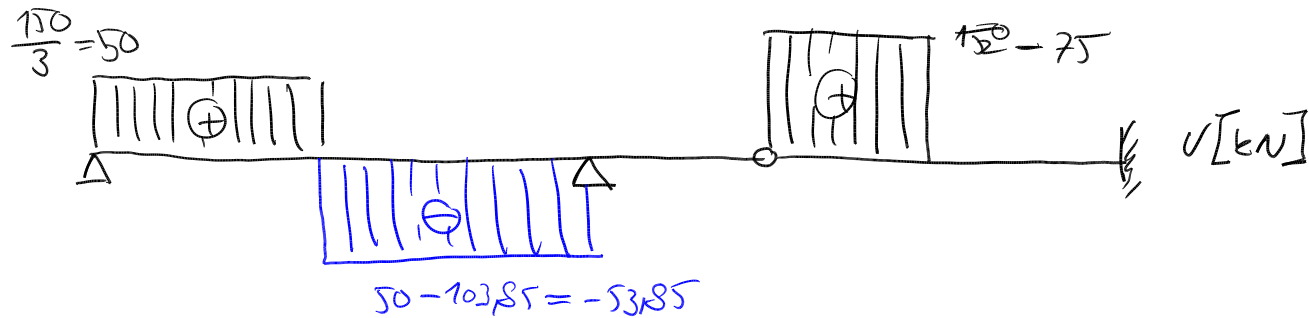
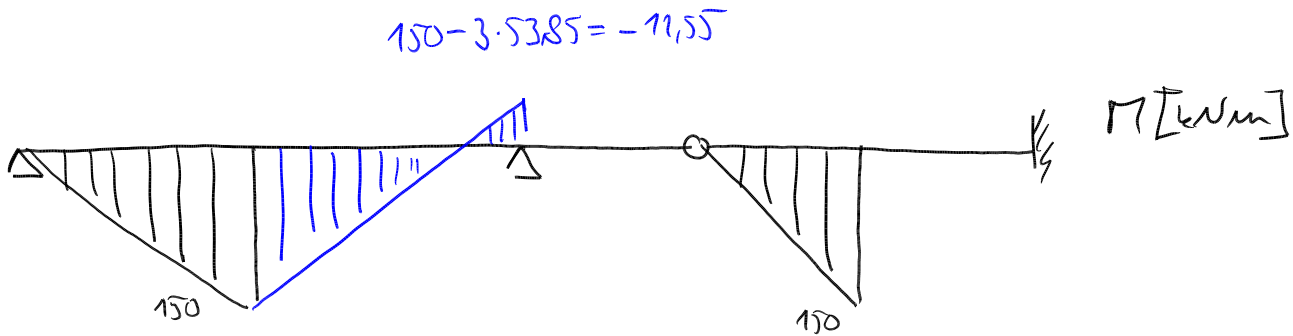
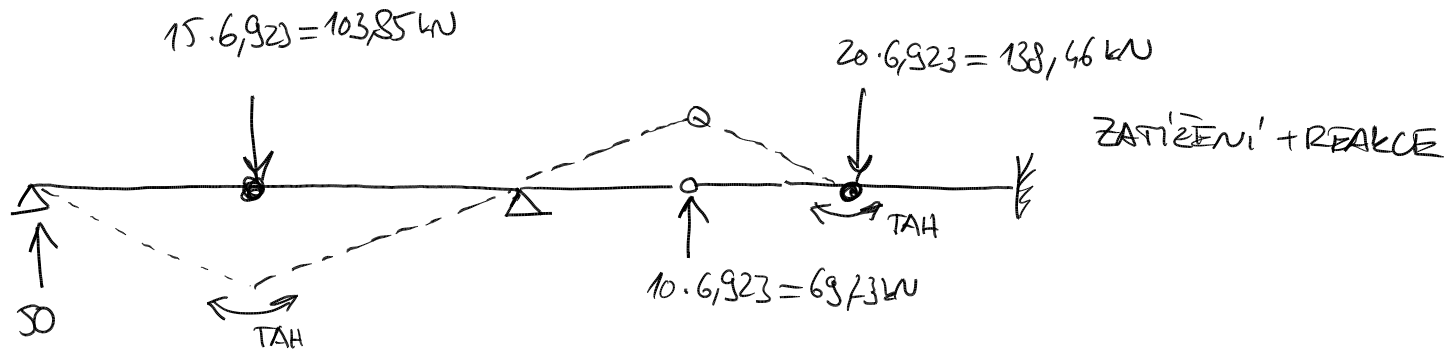
VYKRESLENÍ VNITŘNÍCH SIL



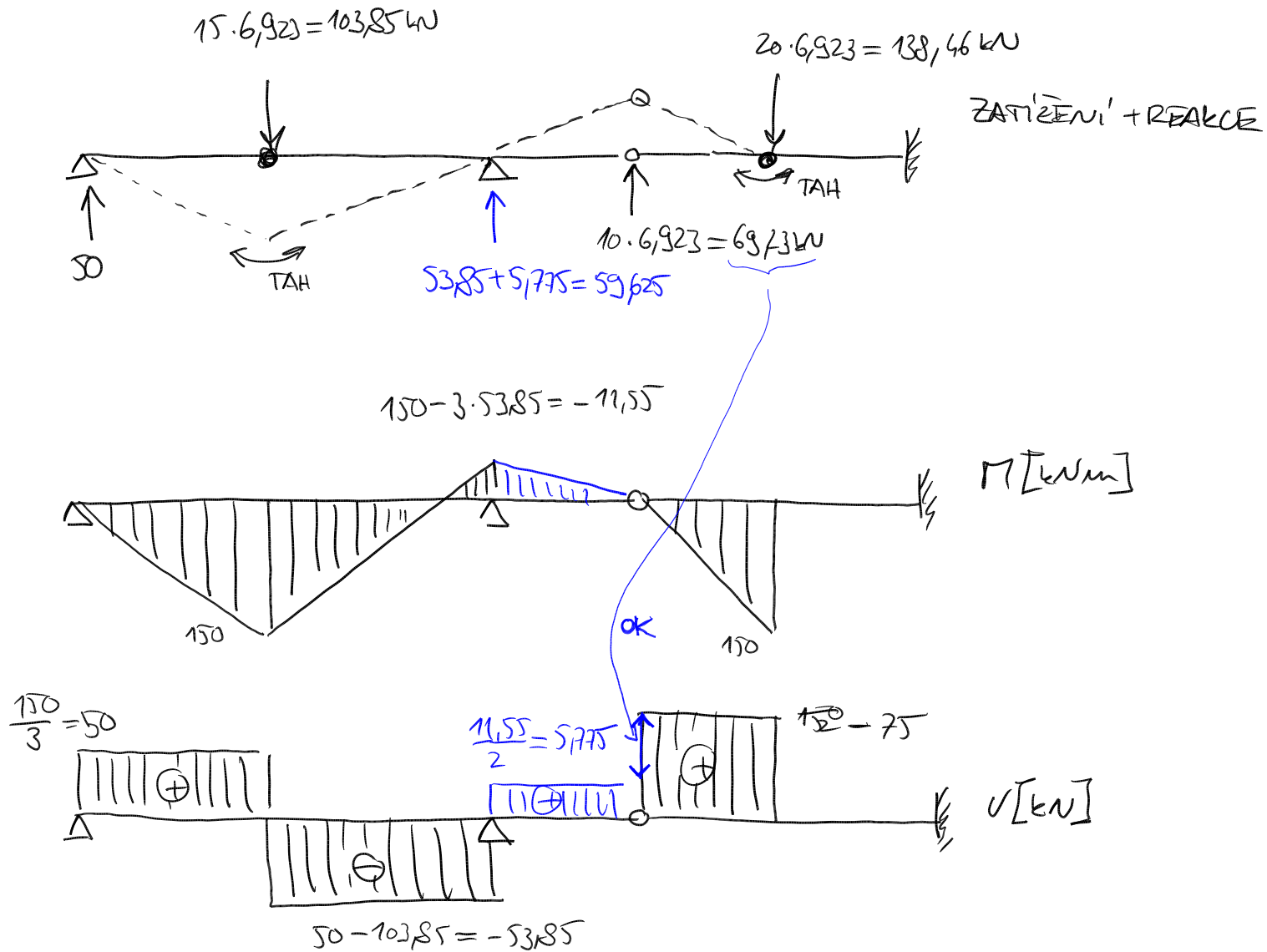
VYKRESLENÍ VNITŘNÍCH SIL



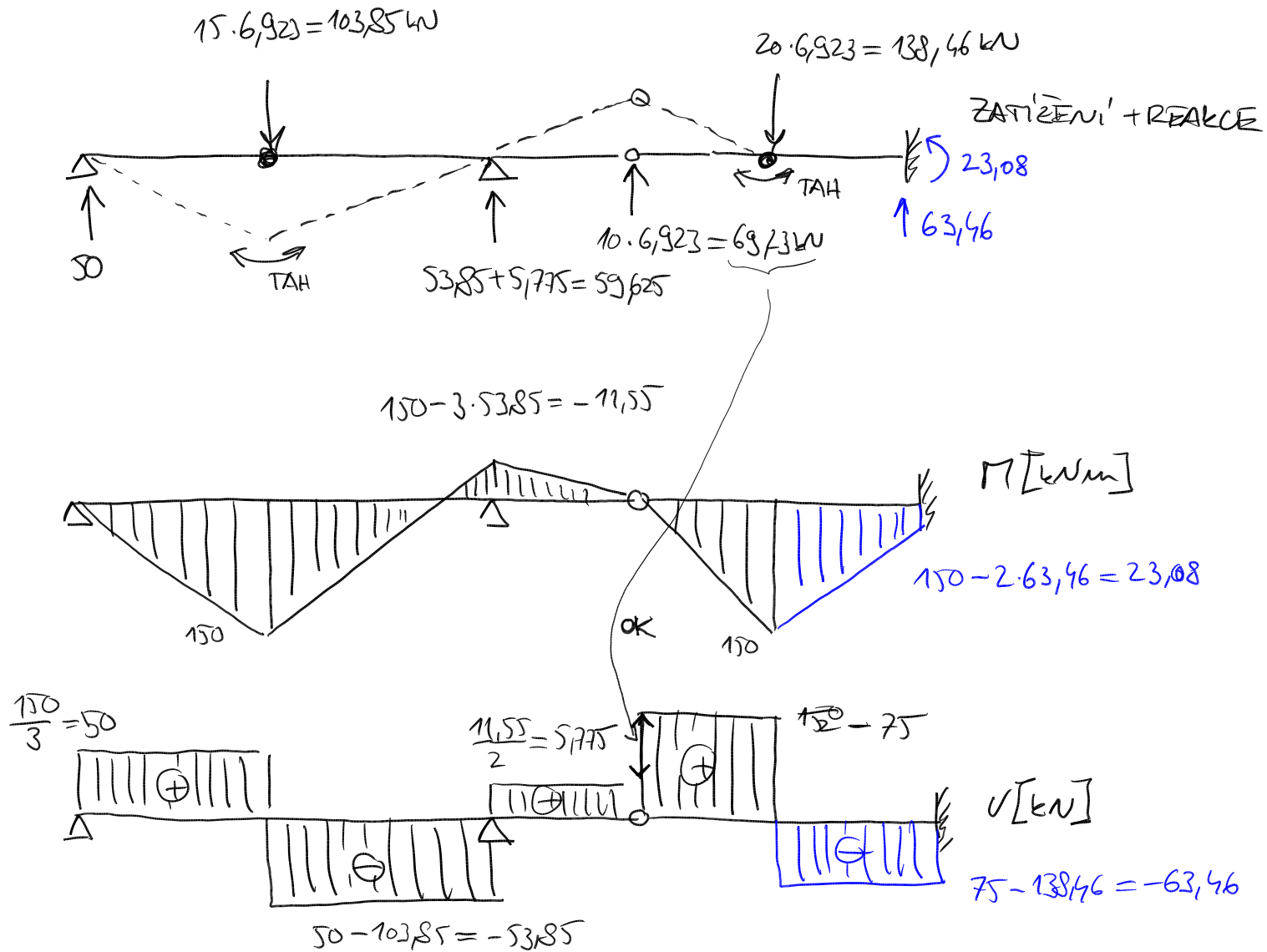
VYKRESLENÍ VNITŘNÍCH SIL



VYKRESLENÍ Vnitřníka sil



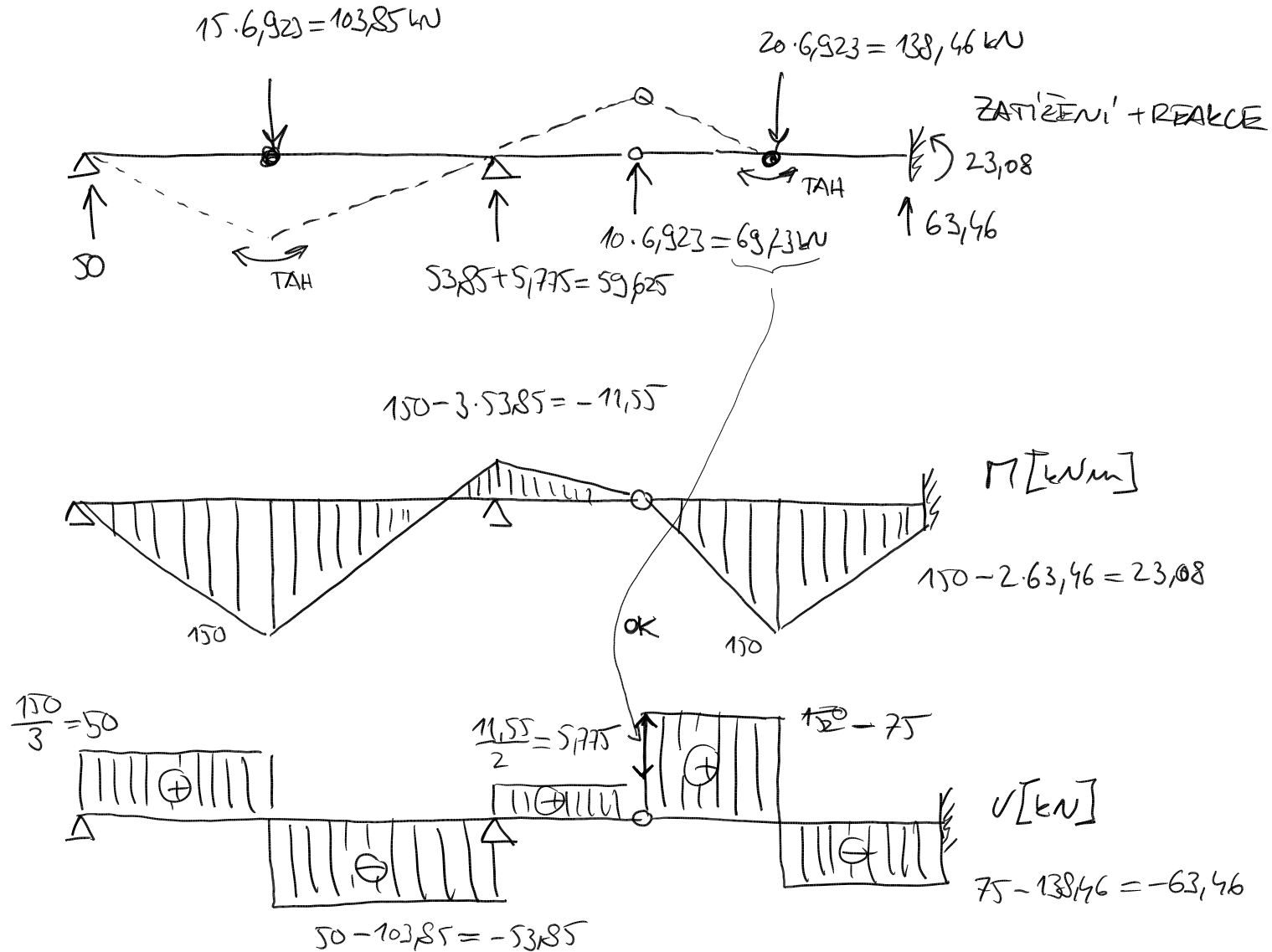
VYKRESLENÍ VNITŘNÍCH SIL



VYKRESLENÍ VNITŘNÍCH SIL

KONTROLA: $50 + 59,625 + 63,46 = 103,85 + 138,46 - 69,23$

$173,085 \approx 173,08 \quad \checkmark$



VYKRESLENÍ UNITÉRNÍCH SIL

KONTROLA: $50 + 59,625 + 63,46 = 103,85 + 138,46 - 69,23$ \uparrow
 $173,085 \approx 173,08 \quad \checkmark$

$\textcircled{6}$: $50 \cdot 12 + 59,625 \cdot 6 - 23,08 - 103,85 \cdot 9 + 69,23 \cdot 4 - 138,46 \cdot 2 = 0,02 \checkmark$

