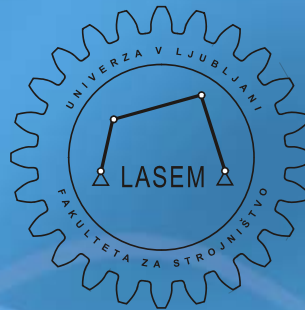


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Fakulteta za strojništvo



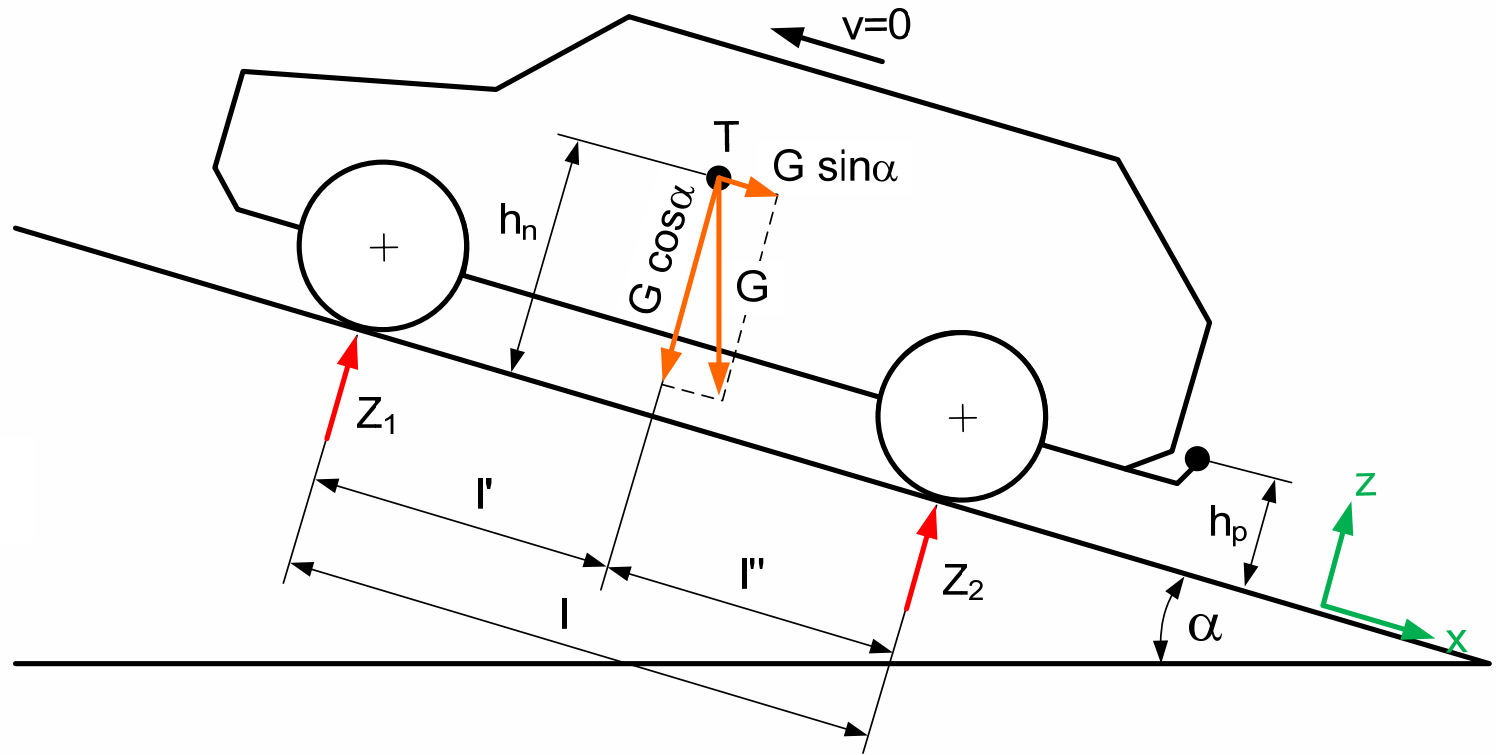
Katedra za strojne elemente in razvojna vrednotenja



DINAMIKA VOZIL – Ravnotežje sil na vozilu

Izr. prof. dr. Jernej Klemenc

Statično ravnotežje sil na strmini



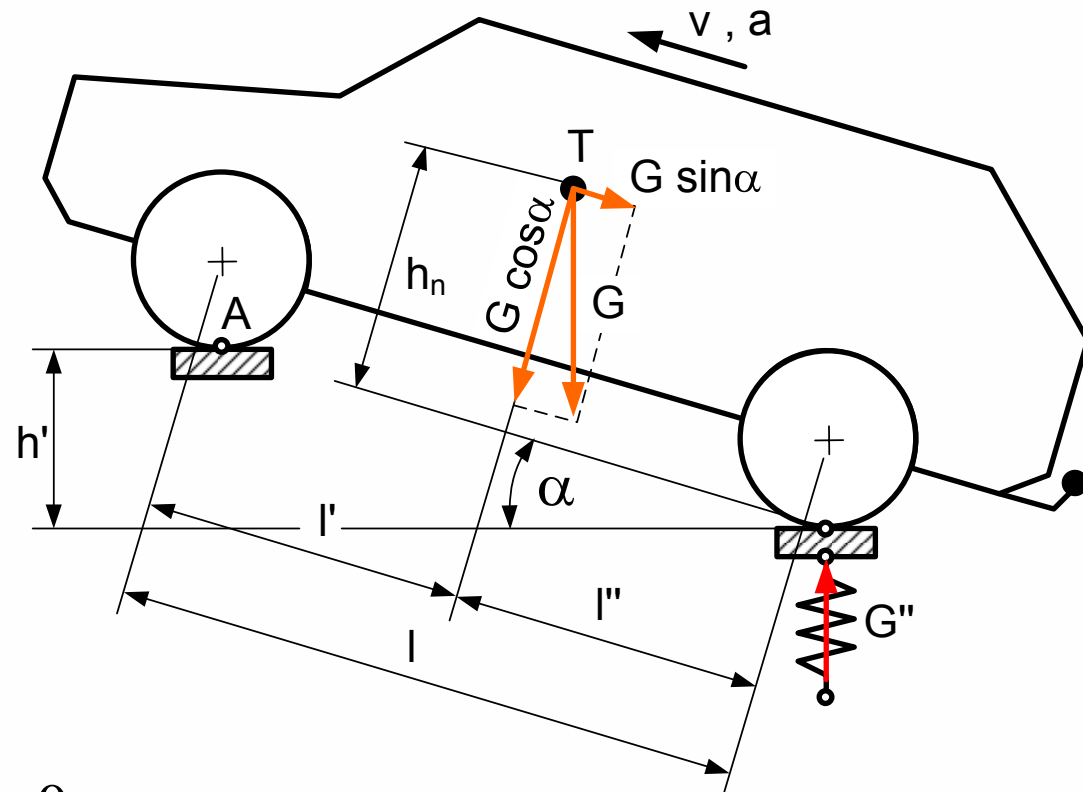
$$Z_1 = \frac{l''}{l} \cdot G \cdot \cos \alpha - \frac{h_n}{l} \cdot G \cdot \sin \alpha$$

$$Z_2 = \frac{l'}{l} \cdot G \cdot \cos \alpha + \frac{h_n}{l} \cdot G \cdot \sin \alpha$$



Statično ravnotežje sil na strmini

- Določitev višine težišča:



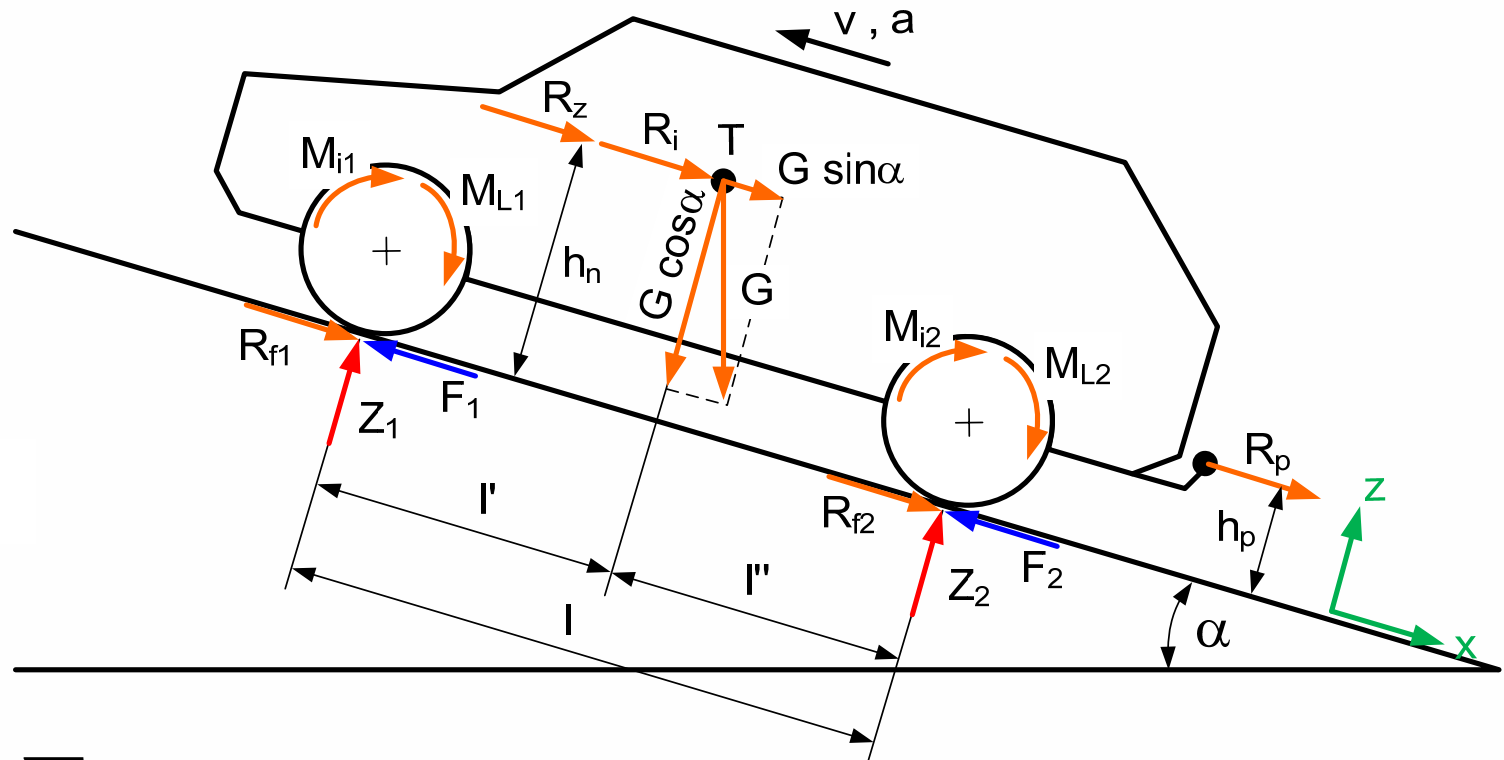
$$\sum M_A = 0:$$

$$l \cdot G'' \cdot \cos \alpha - l' \cdot G \cdot \cos \alpha - h_n \cdot G \cdot \sin \alpha = 0$$

$$h_n = \left(\frac{G''}{G} \cdot l - l' \right) \cdot \operatorname{ctg} \alpha$$



Dinamično ravnotežje sil na strmini pri pospeševanju



$$\sum M_{(2)} = 0:$$

$$Z_1 \cdot l = l'' \cdot G \cdot \cos \alpha - h_n \cdot (G \cdot \sin \alpha + R_i + R_z) - (h_p \cdot R_p) - \underbrace{M_{i1} - M_{i2} - M_{L1} - M_{L2}}_{\approx 0}$$



Dinamično ravnotežje sil na strmini pri pospeševanju

$$\sum F_{x(2)} = 0:$$

$$F_1 + F_2 - R_{f1} - R_{f2} = G \cdot \sin \alpha + R_i + R_z + (R_p)$$

$$F_1 + F_2 = F; R_{f1} + R_{f2} = R_f = f \cdot G \cdot \cos \alpha; R_p = 0$$

$$Z_1 = G \cdot \cos \alpha \cdot \left(\frac{l''}{l} + \frac{f \cdot h_n}{l} \right) - \frac{h_n}{l} \cdot F - \frac{M_{L1} + M_{L2}}{l}$$

$$\frac{Z_1}{G} = \cos \alpha \cdot \left(\frac{l''}{l} + \frac{f \cdot h_n}{l} \right) - \frac{h_n}{l \cdot G} \cdot F - \frac{M_{L1} + M_{L2}}{l \cdot G}$$

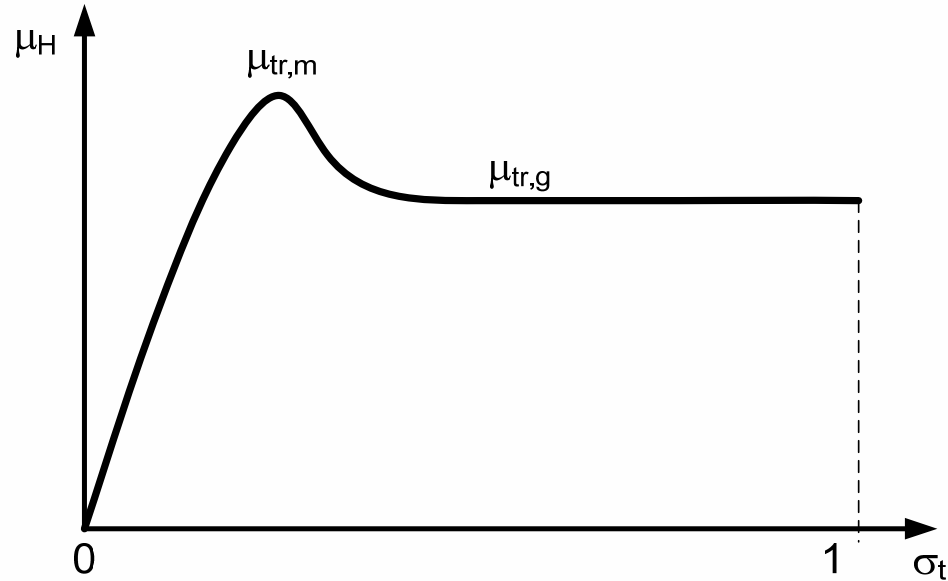
$$Z_2 = G \cdot \cos \alpha \cdot \left(\frac{l'}{l} - \frac{f \cdot h_n}{l} \right) + \frac{h_n}{l} \cdot F + \frac{M_{L1} + M_{L2}}{l}$$

$$\frac{Z_2}{G} = \cos \alpha \cdot \left(\frac{l'}{l} - \frac{f \cdot h_n}{l} \right) + \frac{h_n}{l \cdot G} \cdot F + \frac{M_{L1} + M_{L2}}{l \cdot G}$$



Maksimalne pogonske sile

- Pogon na sprednja kolesa:



$$F_{1,\max} = Z_1 \cdot \mu_{H,\max} = Z_1 \cdot \mu_{tr,m}$$

$$F_{1,\max} = \mu_{tr,m} \cdot \left[\frac{l''}{l} \cdot G \cdot \cos \alpha - \frac{h_n}{l} \cdot (F_{1,\max} - f \cdot G \cdot \cos \alpha) \right]$$

$$\frac{F_{1,\max}}{G} = \mu_{tr,m} \cdot \cos \alpha \cdot \frac{l'' + h_n \cdot f}{l + h_n \cdot \mu_{tr,m}}$$



Maksimalne pogonske sile

- Pogon na zadnja kolesa:

$$F_{2,\max} = Z_2 \cdot \mu_{H,\max} = Z_2 \cdot \mu_{tr,m}$$

$$F_{2,\max} = \mu_{tr,m} \cdot \left[\frac{l'}{l} \cdot G \cdot \cos \alpha + \frac{h_n}{l} \cdot (F_{1,\max} - f \cdot G \cdot \cos \alpha) \right]$$

$$\frac{F_{2,\max}}{G} = \mu_{tr,m} \cdot \cos \alpha \cdot \frac{l' - h_n \cdot f}{l - h_n \cdot \mu_{tr,m}}$$

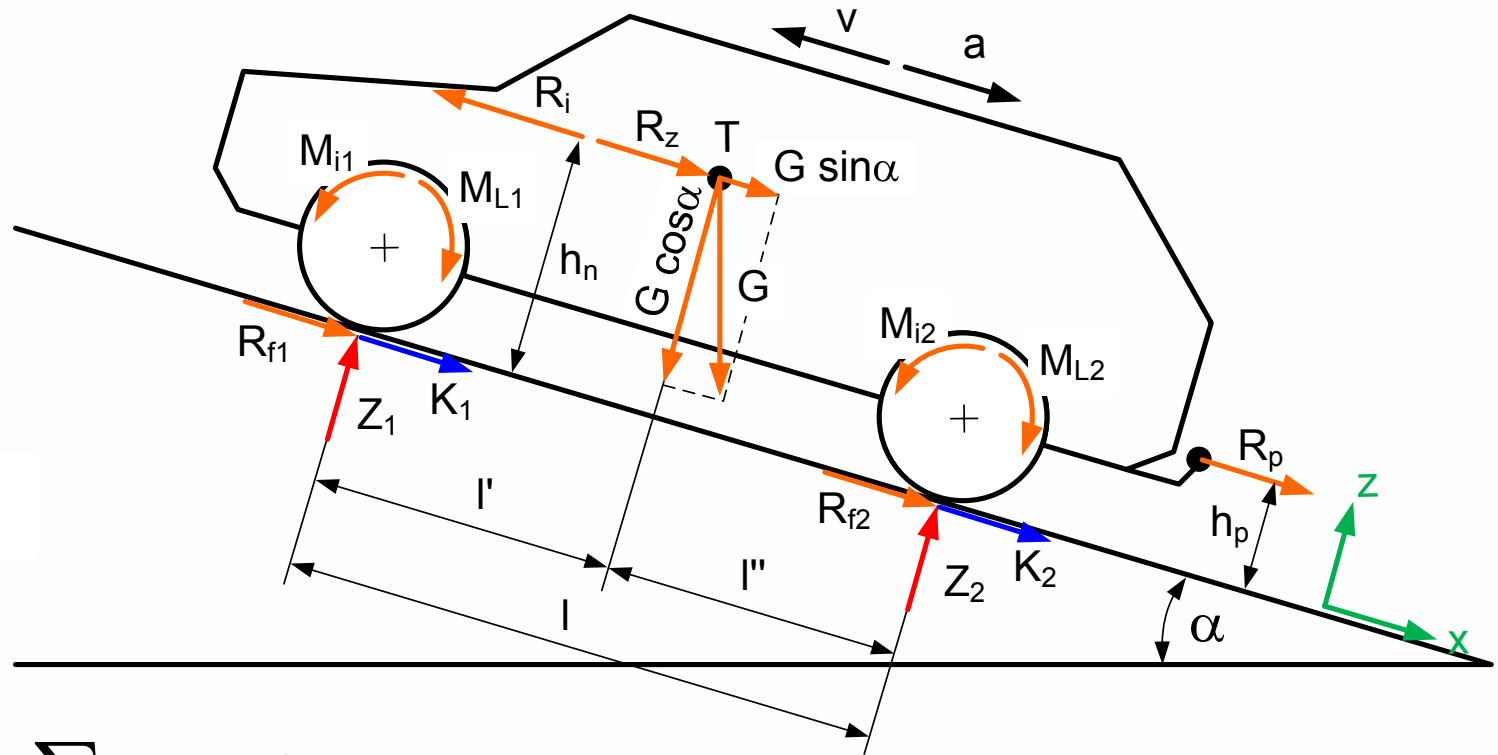
- Pogon na vsa štiri kolesa:

$$\frac{F_{4x4,\max}}{G} = \mu_{tr,m} \cdot \cos \alpha$$

$$\frac{F_{4x4,1}}{F_{4x4,2}} = \frac{Z_1}{Z_2}$$



Dinamično ravnotežje sil na strmini pri zaviranju



$$\sum M_{(2)} = 0:$$

$$Z_1 \cdot l = l''' \cdot G \cdot \cos \alpha + h_n \cdot (R_i - G \cdot \sin \alpha - R_z) -$$

$$- (h_p \cdot R_p) + \underbrace{M_{i1} + M_{i2}}_{\approx 0} - M_{L1} - M_{L2}$$



Dinamično ravnotežje sil na strmini pri zaviranju

$$\sum F_{x(2)} = 0:$$

$$K_1 + K_2 + R_{f1} + R_{f2} = R_i - \left[G \cdot \sin \alpha + R_z + (R_p) \right]$$

$$K_1 + K_2 = K; R_{f1} + R_{f2} = R_f = f \cdot G \cdot \cos \alpha; R_p = 0$$

$$Z_1 = G \cdot \cos \alpha \cdot \left(\frac{l''}{l} + \frac{f \cdot h_n}{l} \right) + \frac{h_n}{l} \cdot K - \frac{M_{L1} + M_{L2}}{l}$$

$$\frac{Z_1}{G} = \cos \alpha \cdot \left(\frac{l''}{l} + \frac{f \cdot h_n}{l} \right) + \frac{h_n}{l \cdot G} \cdot K - \frac{M_{L1} + M_{L2}}{l \cdot G}$$

$$Z_2 = G \cdot \cos \alpha \cdot \left(\frac{l'}{l} - \frac{f \cdot h_n}{l} \right) - \frac{h_n}{l} \cdot K + \frac{M_{L1} + M_{L2}}{l}$$

$$\frac{Z_2}{G} = \cos \alpha \cdot \left(\frac{l'}{l} - \frac{f \cdot h_n}{l} \right) - \frac{h_n}{l \cdot G} \cdot K + \frac{M_{L1} + M_{L2}}{l \cdot G}$$



Maksimalne zavorne sile

$$M_{L1} + M_{L2} \approx 0$$

$$K_1 = Z_1 \cdot \mu_H$$

$$K_2 = Z_2 \cdot \mu_H$$

$$K_1 + K_2 = K = Z_1 \cdot \mu_H + Z_2 \cdot \mu_H = \mu_H \cdot G \cdot \cos \alpha$$

$$\frac{Z_1}{G \cdot \cos \alpha} = \frac{l''}{l} + \frac{h_n}{l} \cdot (f + \mu_H)$$

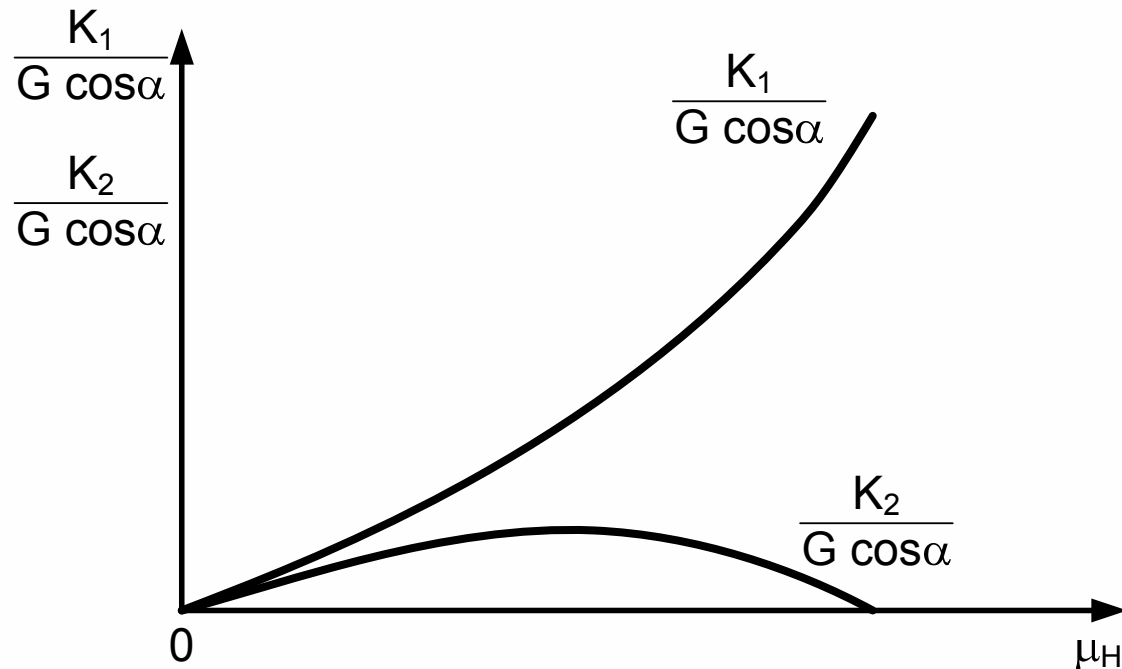
$$\frac{Z_2}{G \cdot \cos \alpha} = \frac{l'}{l} - \frac{h_n}{l} \cdot (f + \mu_H)$$



Maksimalne zavorne sile

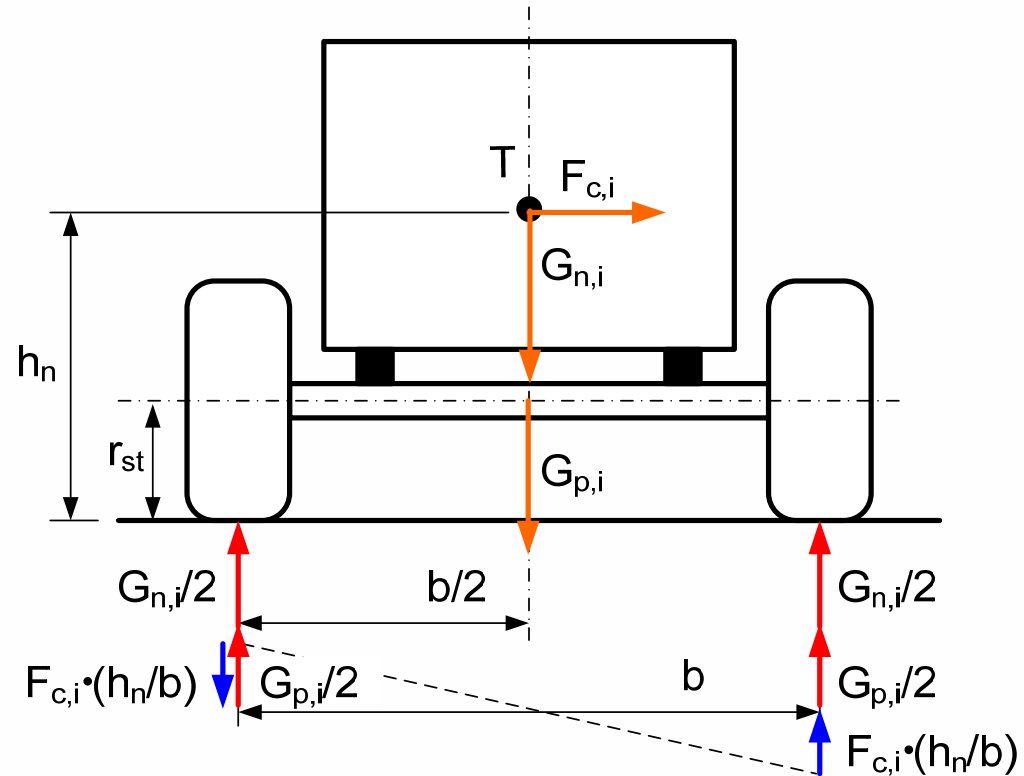
$$\frac{K_1}{G \cdot \cos \alpha} = \frac{\mu_H \cdot Z_1}{G \cdot \cos \alpha} = \mu_H \cdot \left(\frac{l''}{l} + \frac{h_n}{l} \cdot f \right) + \mu_H^2 \cdot \frac{h_n}{l}$$

$$\frac{K_2}{G \cdot \cos \alpha} = \frac{\mu_H \cdot Z_2}{G \cdot \cos \alpha} = \mu_H \cdot \left(\frac{l'}{l} - \frac{h_n}{l} \cdot f \right) - \mu_H^2 \cdot \frac{h_n}{l}$$



Ravnotežje sil na premo vozila pri vožnji v ovinek

- Nevzmetena nadgradnja:



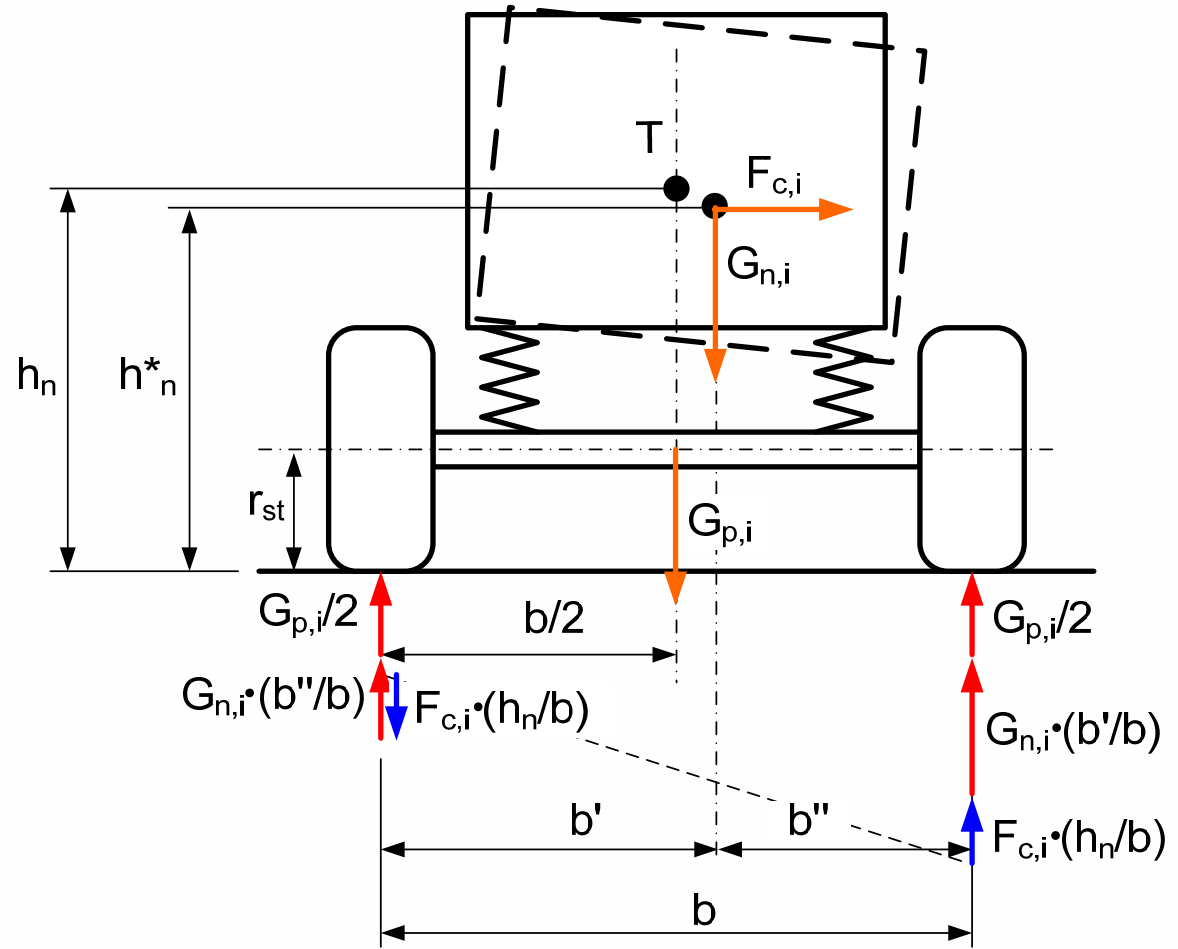
$$G_{n,1} = G \cdot \frac{l''}{l}; G_{n,2} = G \cdot \frac{l'}{l}$$

$$F_c = m_{n+p} \cdot \frac{v^2}{R_{ov}}; F_{c,1} = F_c \cdot \frac{l''}{l}; F_{c,2} = F_c \cdot \frac{l'}{l}$$



Ravnotežje sil na premo vozila pri vožnji v ovinek

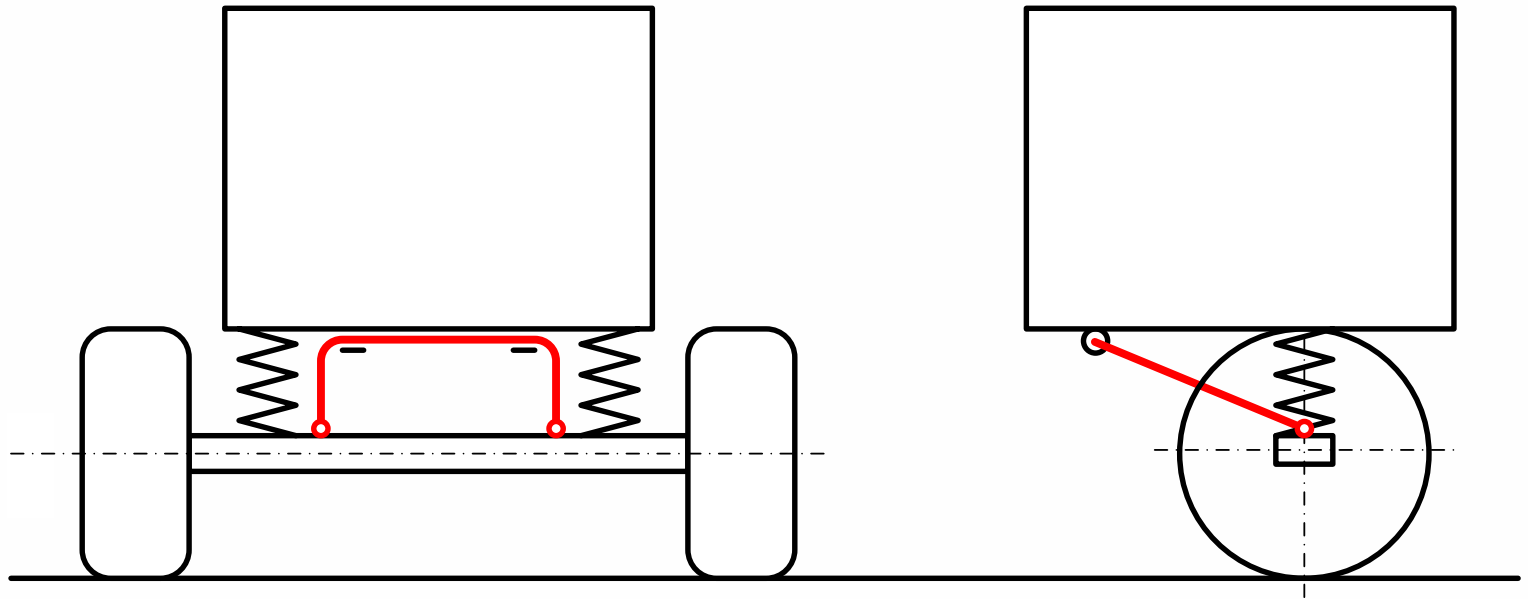
- Vzmetena nadgradnja:



$$h_n^* \approx h_n; b' \neq b'' \neq b/2$$

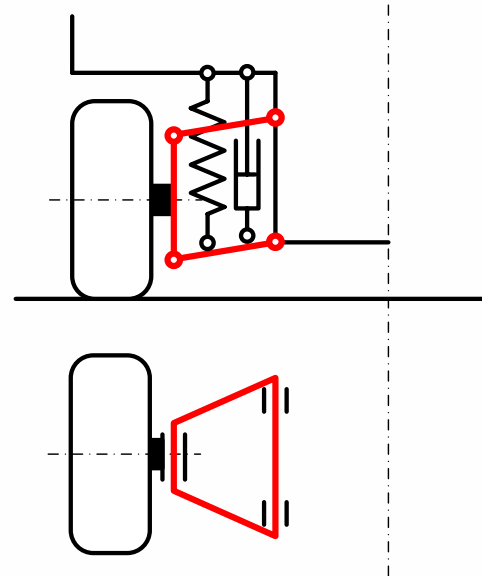


Prečni stabilizator na premi

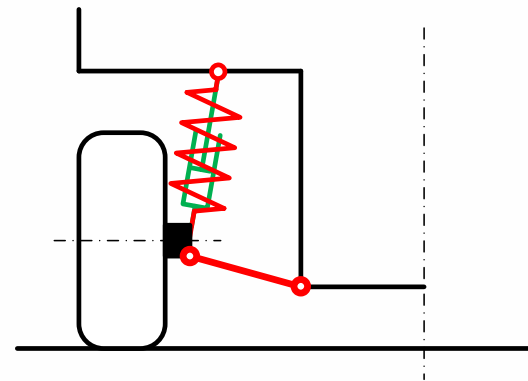


Tipi obešenja koles na vozilu

- Posamično obešenje koles z dvema prečnima vodiloma:

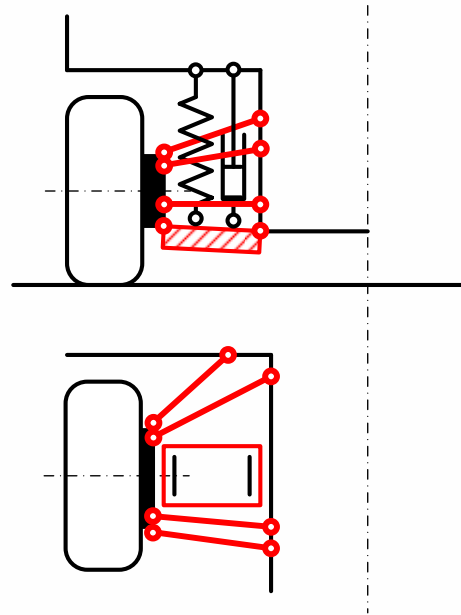


- Posamično obešenje z McPhersonovo vzmetno nogo:

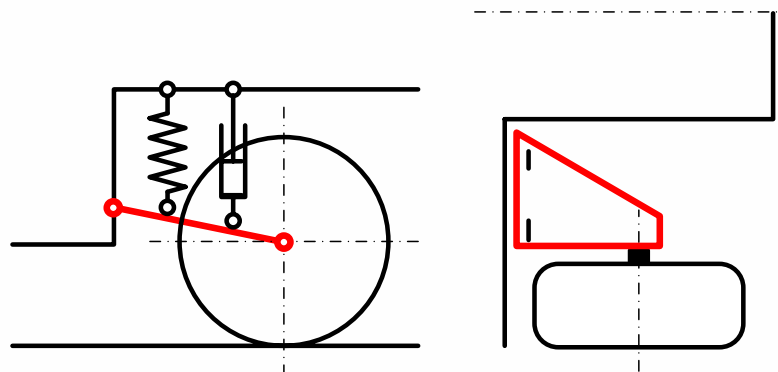


Tipi obešenja koles na vozilu

- Posamično obešenje z “multi-link” vodilom:

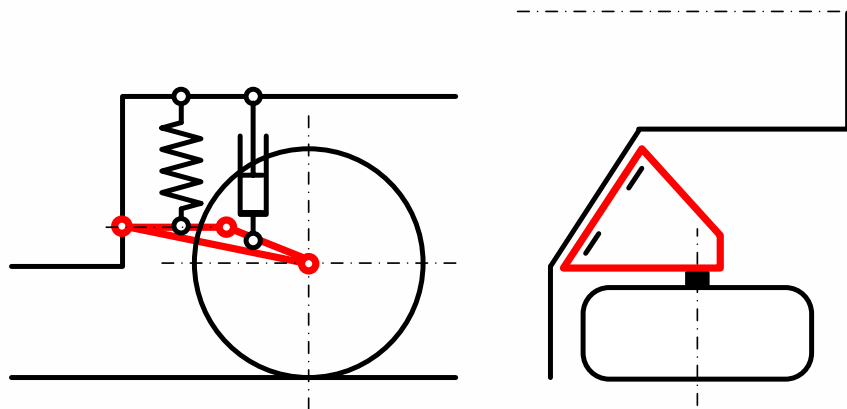


- Posamično obešenje z enojnimi vzdolžnimi vodili:

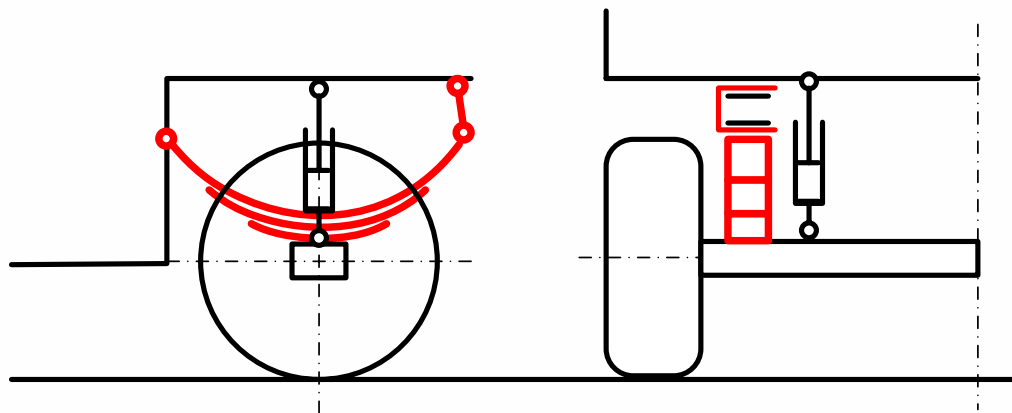


Tipi obešenja koles na vozilu

- Posamično obešenje s poševnimi vodili:

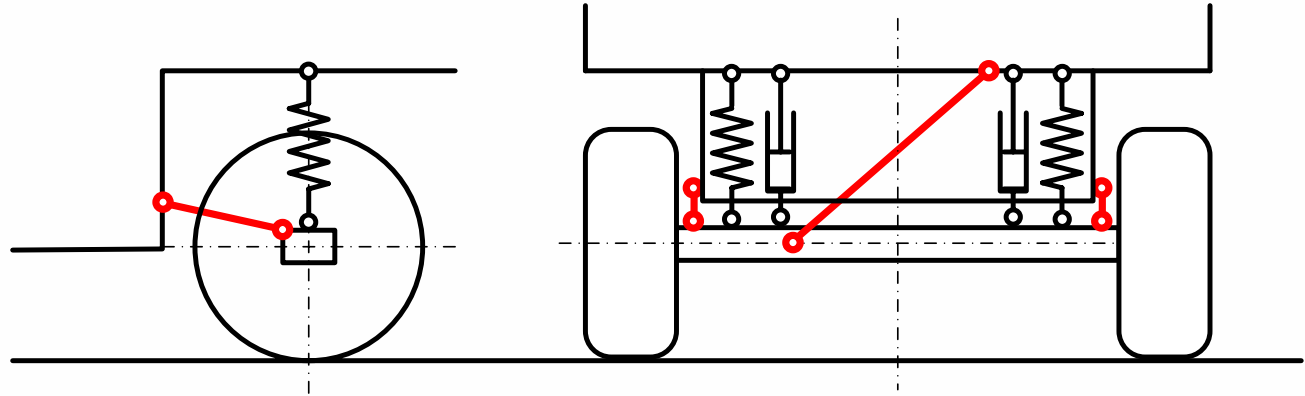


- Toga prema z listnatimi vzmetmi:

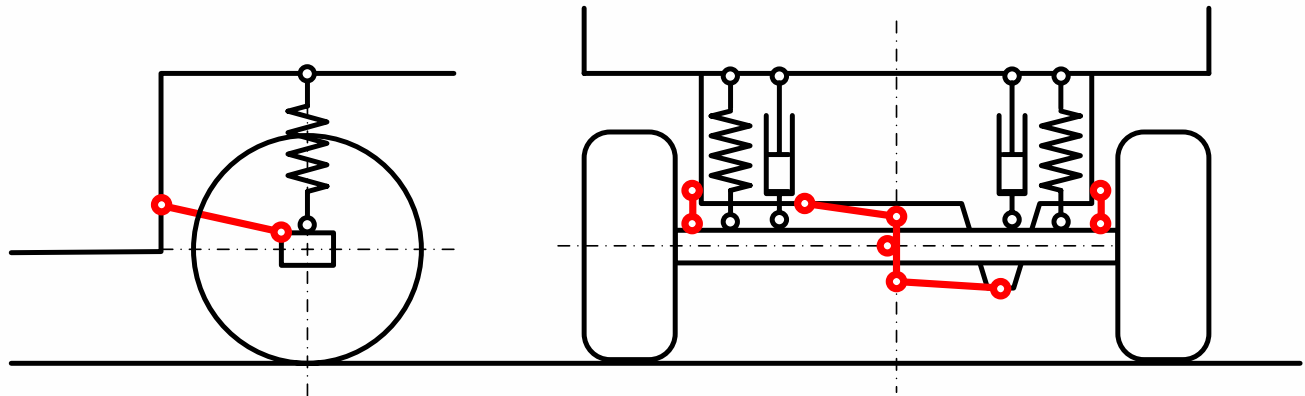


Tipi obešenja koles na vozilu

- Toga prema s Panhardovim drogom:

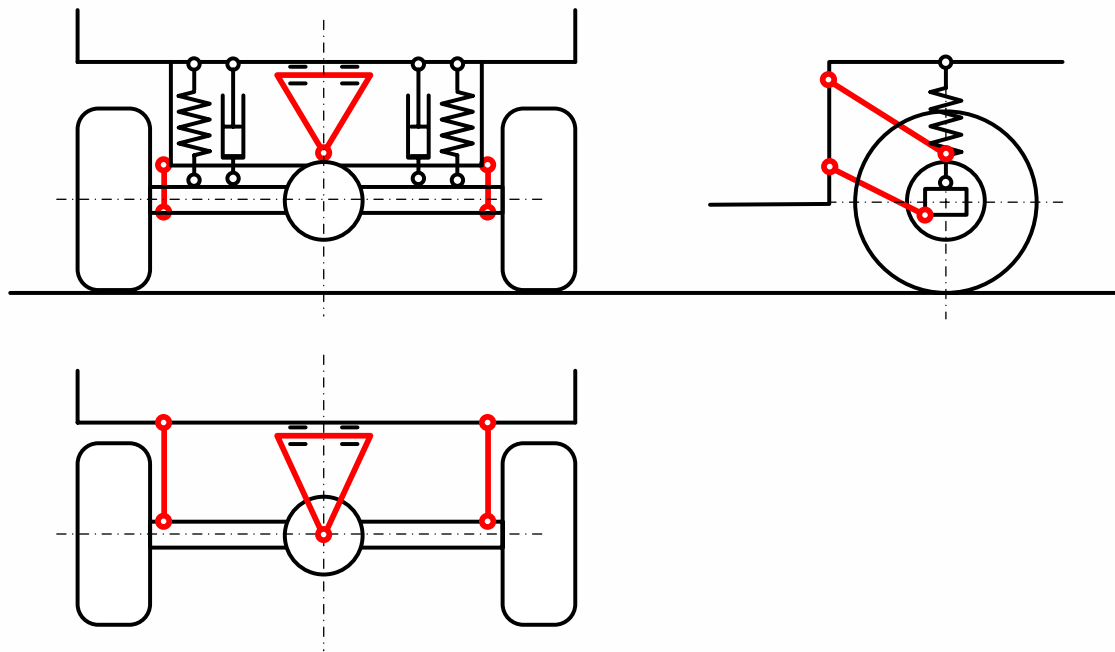


- Toga prema z Wattovim mehanizmom:

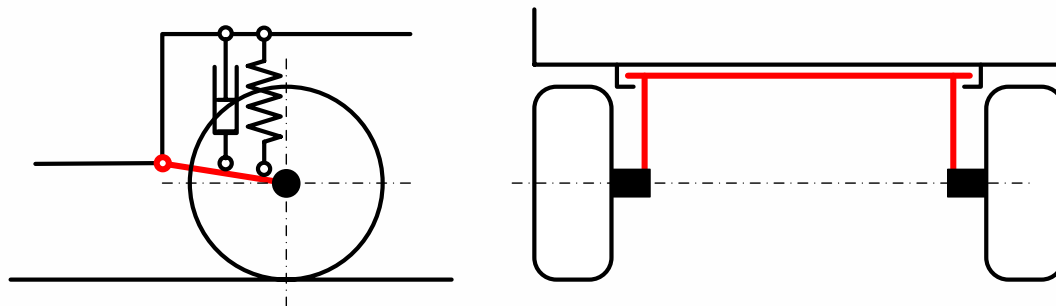


Tipi obešenja koles na vozilu

- Toga prema z vzdolžnimi vodili:

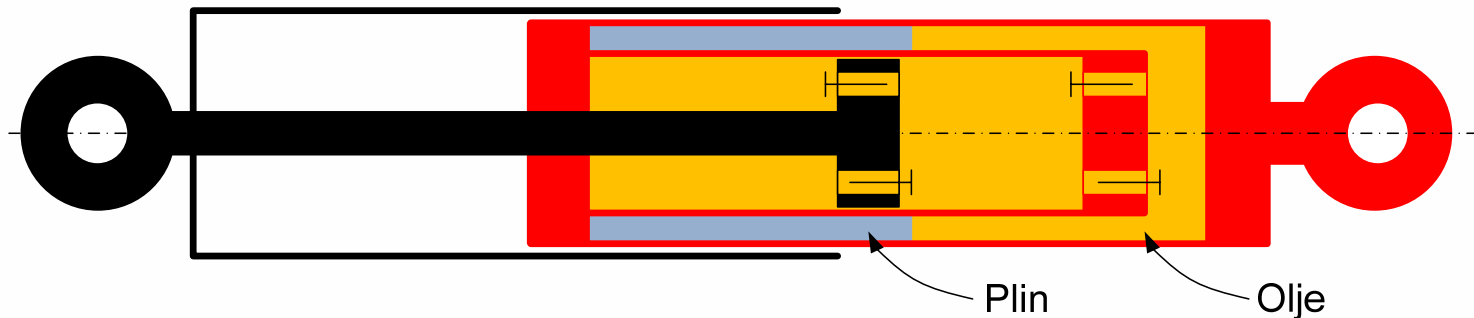


- Poltoga prema z vijačnimi vzmetmi:



Tipi vzmetenja na vozilu

- Dvocevni oljni blažilnik:

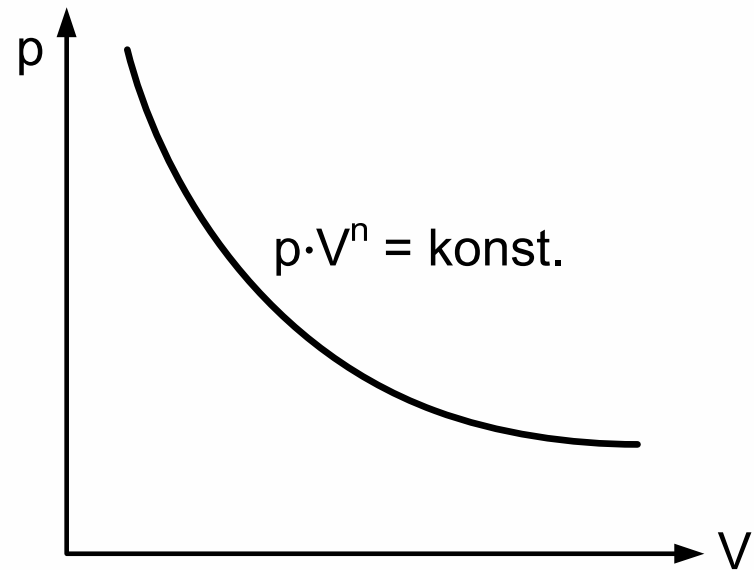
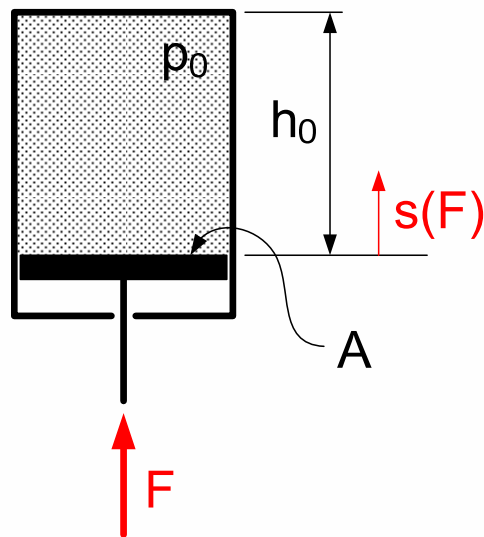


- Jeklene kovinske vzmeti:
 - Paket listnatih upogibnih vzmeti (vozila za gradbeništvo);
 - Torzijska palična vzmet (Renault 4, 5-1);
 - Torzijska vijačna vzmet (prevladujoči tip vzmetenja na modernih vozilih).
- Kompozitna upogibna vzmet (epoxy smola + steklena vlakna) – Chevrolet Corvette.



Tipi vzmetenja na vozilu

- Pnevmatško in hidro-pnevmatško vzmetenje – togostna karakteristika pnevmatske vzmeti:



$n = 1,4 \Rightarrow$ izentropa

$n \approx 1,3 \Rightarrow$ politropa



Tipi vzmetenja na vozilu

- Pnevmatško in hidro-pnevmatško vzmetenje – togostna karakteristika pnevmatske vzmeti:

$$p_0 \cdot V_0^n = p \cdot V^n$$

$$p_0 \cdot A^n \cdot h_0^n = \frac{F}{A} \cdot A^n \cdot (h_0 - s)^n$$

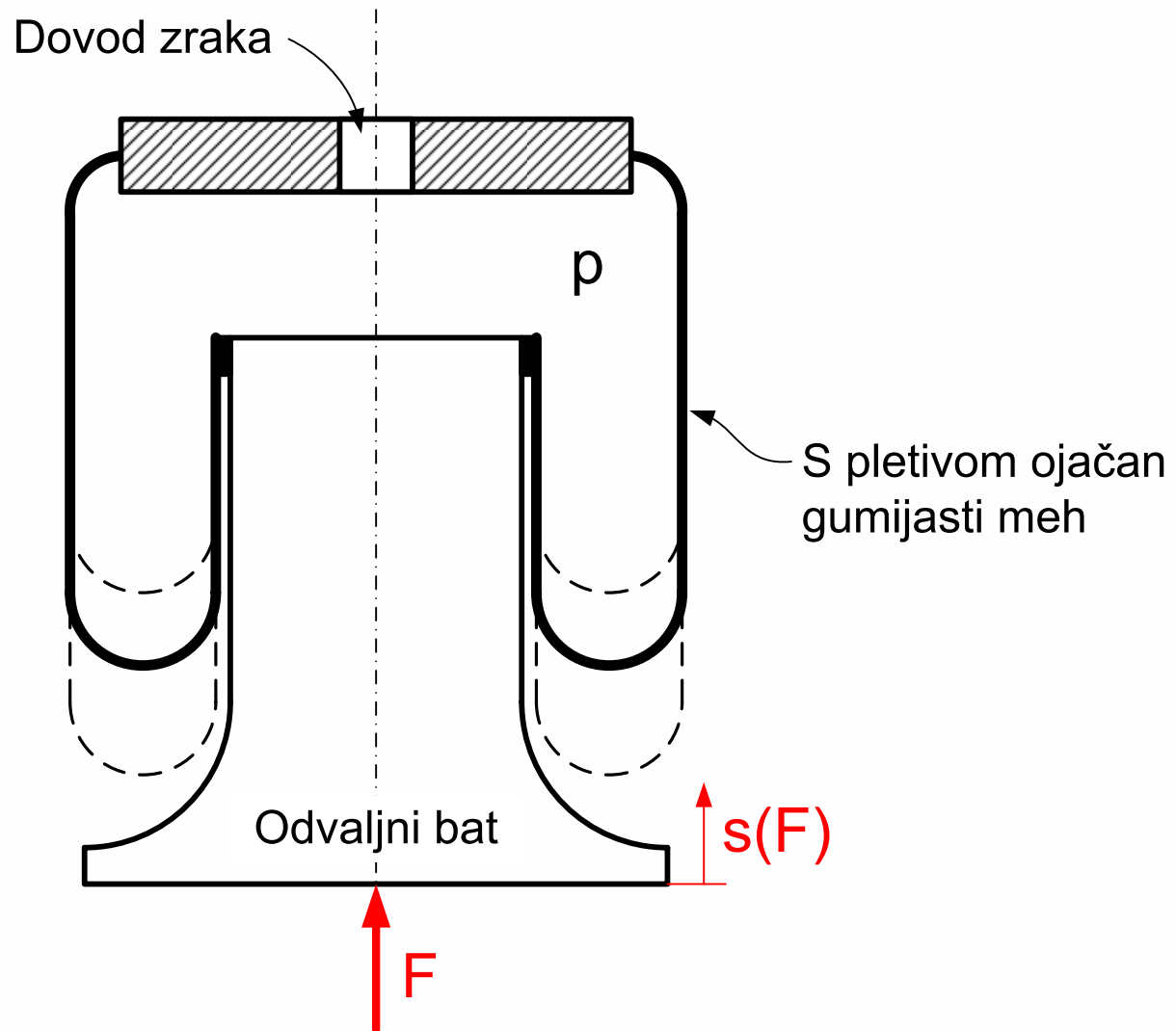
$$F = \frac{p_0 \cdot A \cdot h_0^n}{(h_0 - s)^n}$$

$$c = \frac{dF}{ds} = \frac{n \cdot p_0 \cdot A \cdot h_0^n}{(h_0 - s)^{n+1}}$$



Tipi vzmetenja na vozilu

- Pnevmatika vzmet z odvaljnim batom:



Tipi vzmetenja na vozilu

- Citröenov hidro-pnevmatski sistem vzmetenja (ena prema):

