

# Friction

dry friction

$$|F| \leq \mu |N|$$



$$F = \mu N$$

$$\begin{cases} \text{slip} \Rightarrow F = \mu N \\ \text{stick} \Rightarrow F \leq \mu N \end{cases}$$

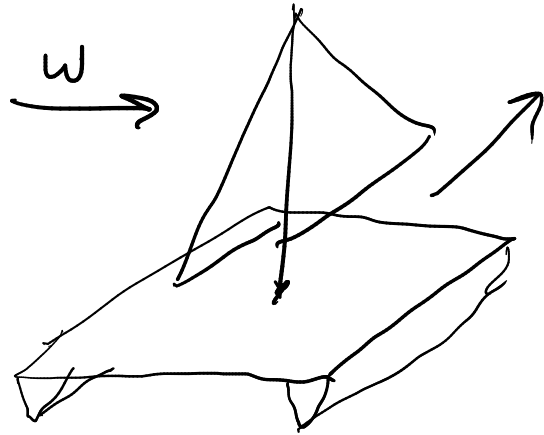
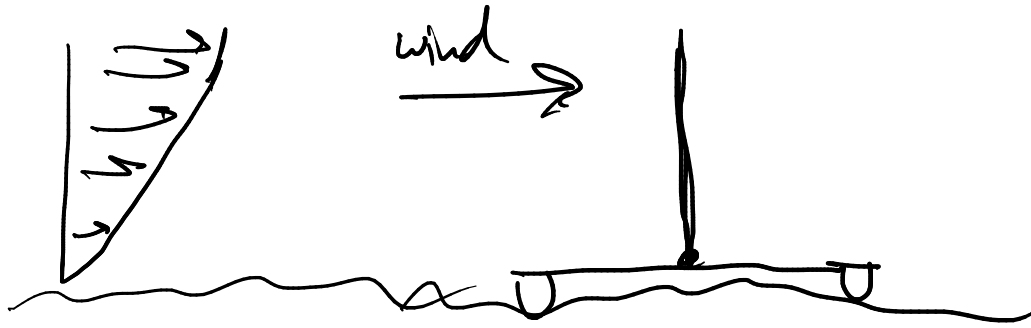
$F$  acts  
opposite  
to contact  
 $v$ .

$$\begin{cases} F < \mu N \Rightarrow \text{stick} \\ F = \mu N \Rightarrow \text{slipping or} \\ \quad \text{immanent slip.} \end{cases}$$

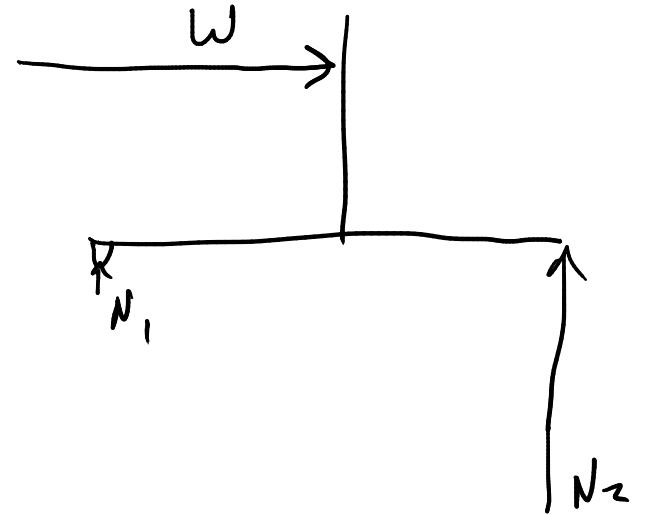
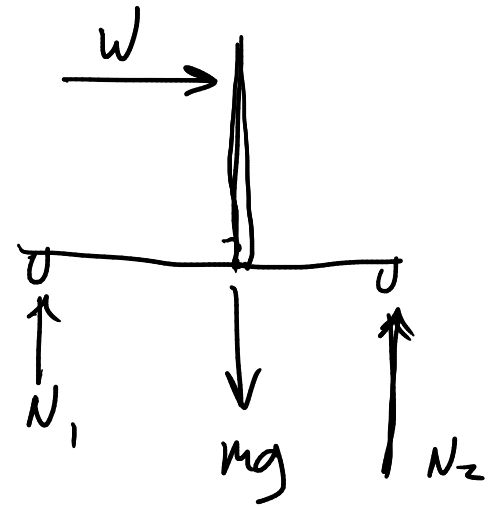
wet friction

$$F_D = \frac{1}{2} \rho v^2 C_D A$$

no stick/slip



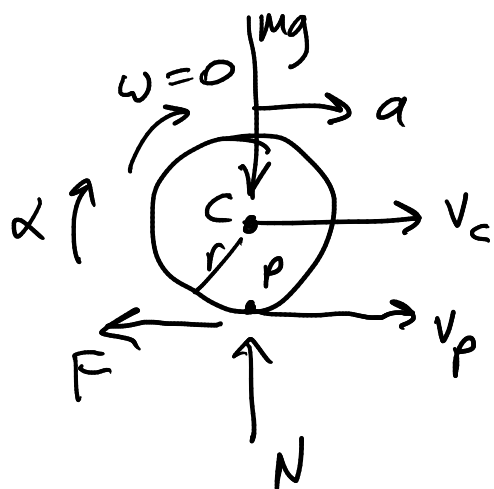
FBP



ex dry friction : bowling.



$$V = \omega r$$



$$\vec{F}_{\text{friction}} \cdot \vec{v}_{\text{contact}} \leq 0$$

$$\begin{aligned} \vec{a} &= a \hat{i} \\ \vec{\alpha} &= -\alpha \hat{k} \\ \vec{F} &= -F \hat{i} \end{aligned} \quad \left| \quad \begin{aligned} \Sigma \vec{F} &= m \vec{a} \\ -F \hat{i} - mg \hat{j} + N \hat{j} &= m a \hat{i} \\ \Rightarrow N &= mg \\ a &= -\frac{F}{m} \end{aligned} \right.$$

$a = r\alpha$  ← true if rolling without slipping.

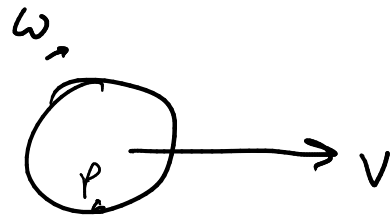
A : true

B : not true

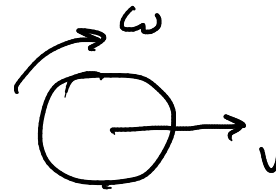
$$\text{slip} \Rightarrow F = \mu N$$

$$\Sigma \vec{M} = I_c \vec{\alpha}$$

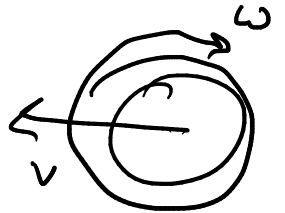
$$-F_r \hat{k} = -I_c \alpha \hat{k} \Rightarrow \alpha = \frac{F_r}{I_c}$$



$t=0$



$t=2$



above is true while slipping

$$\vec{V}_p = v_p \hat{c}$$

i.e. while  $v_p > 0$

$$v_p = v_c - \omega r$$

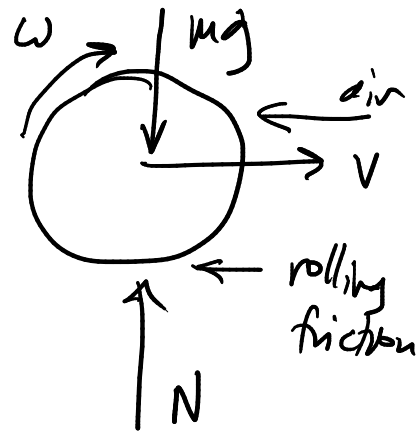
$$\vec{V}_p = \vec{V}_c + \vec{\omega} \times \vec{r}_{cp}$$

slipping continues until

$$v_p = 0 = v_c - \omega r$$

$$v_c = \omega r \Rightarrow \text{stuck}$$

Sticking



$$\begin{array}{lcl} F & \leftarrow & A \\ F & \rightarrow & B \end{array} \quad \left. \vphantom{\begin{array}{l} A \\ B \end{array}} \right\}$$

$$\begin{array}{ll} a=0 & \Sigma F=0 \\ \alpha=0 & \Sigma M=0 \end{array}$$