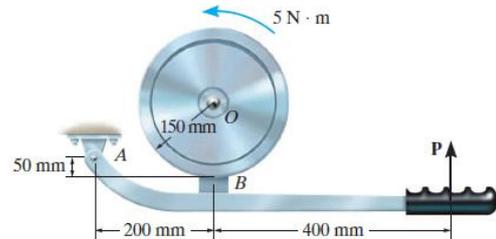


CHAPTER VIII

FRICTION

8-8.

The block brake consists of a pin-connected lever and friction block at B . The coefficient of static friction between the wheel and the lever is $\mu_s = 0.3$, and a torque of $5 \text{ N}\cdot\text{m}$ is applied to the wheel. Determine if the brake can hold the wheel stationary when the force applied to the lever is (a) $P = 30 \text{ N}$, (b) $P = 70 \text{ N}$.



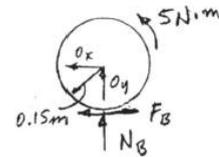
SOLUTION

To hold lever:

$$\zeta + \sum M_O = 0; \quad -F_B(0.15) + 5 = 0; \quad F_B = 33.333 \text{ N}$$

Require

$$N_B = \frac{33.333 \text{ N}}{0.3} = 111.1 \text{ N}$$



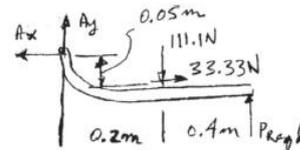
Lever,

$$\zeta + \sum M_A = 0; \quad P_{\text{Reqd}}(0.6) - 111.1(0.2) + 33.333(0.05) = 0$$

$$P_{\text{Reqd}} = 34.26 \text{ N}$$

a) $P = 30 \text{ N} < 34.26 \text{ N}$ No

b) $P = 70 \text{ N} > 34.26 \text{ N}$ Yes



Ans.

Ans.

If a torque of $M = 300 \text{ N}\cdot\text{m}$ is applied to the flywheel, determine the force that must be developed in the hydraulic cylinder CD to prevent the flywheel from rotating. The coefficient of static friction between the friction pad at B and the flywheel is $\mu_s = 0.4$.

SOLUTION

Free-Body Diagram: First we will consider the equilibrium of the flywheel using the free-body diagram shown in Fig. *a*. Here, the frictional force F_B must act to the left to produce the counterclockwise moment opposing the impending clockwise rotational motion caused by the $300 \text{ N}\cdot\text{m}$ couple moment. Since the wheel is required to be on the verge of slipping, then $F_B = \mu_s N_B = 0.4 N_B$. Subsequently, the free-body diagram of member ABC shown in Fig. *b* will be used to determine F_{CD} .

Equations of Equilibrium: We have

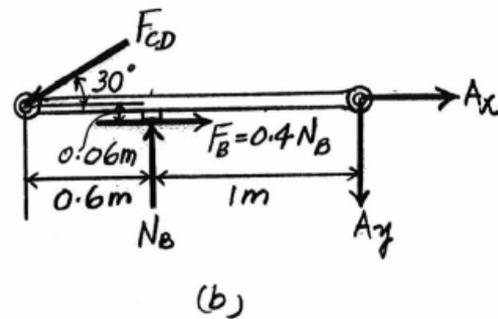
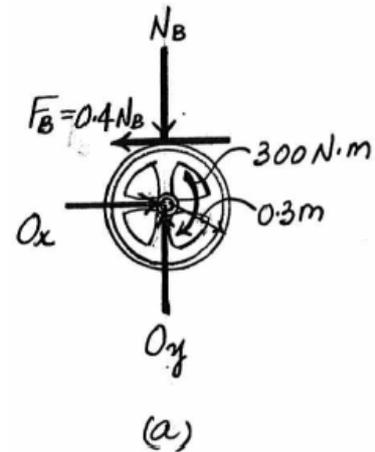
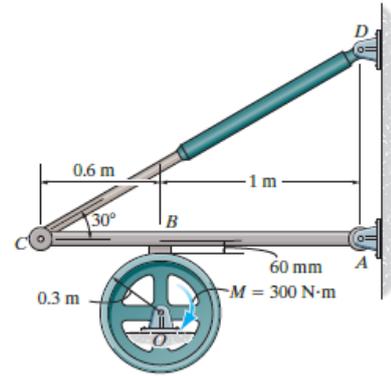
$$\zeta + \sum M_O = 0; \quad 0.4 N_B(0.3) - 300 = 0 \quad N_B = 2500 \text{ N}$$

Using this result,

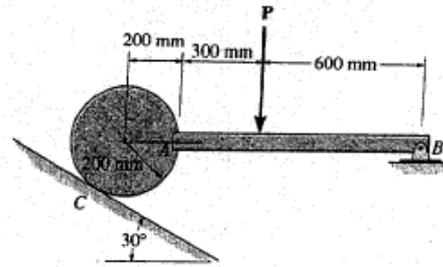
$$\zeta + \sum M_A = 0; \quad F_{CD} \sin 30^\circ(1.6) + 0.4(2500)(0.06) - 2500(1) = 0$$

$$F_{CD} = 3050 \text{ N} = 3.05 \text{ kN}$$

Ans.



8-14. A 35-kg disk rests on an inclined surface for which $\mu_s = 0.2$. Determine the maximum vertical force P that may be applied to link AB without causing the disk to slip at C .



Equations of Equilibrium: From FBD (a).

$$\sum M_B = 0; \quad P(600) - A_y(900) = 0 \quad A_y = 0.6667P$$

From FBD (b).

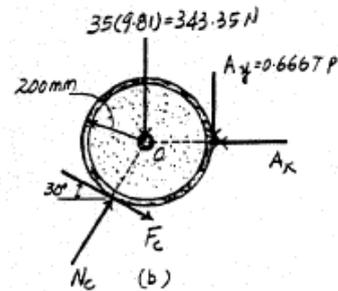
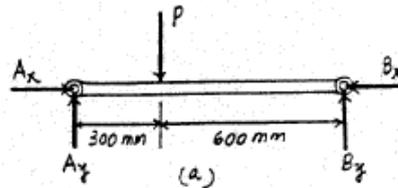
$$+\uparrow \sum F_y = 0 \quad N_C \sin 60^\circ - F_C \sin 30^\circ - 0.6667P - 343.35 = 0 \quad [1]$$

$$\sum M_O = 0; \quad F_C(200) - 0.6667P(200) = 0 \quad [2]$$

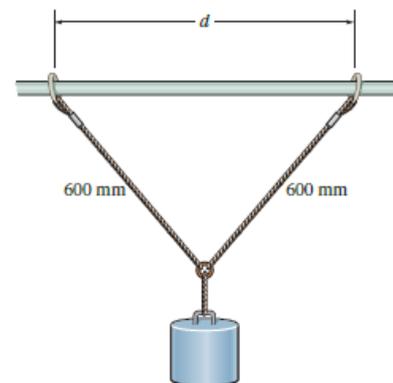
Friction: If the disk is on the verge of moving, slipping would have to occur at point C . Hence, $F_C = \mu_s N_C = 0.2N_C$. Substituting this value into Eqs. [1] and [2] and solving, we have

$$P = 182 \text{ N} \\ N_C = 606.60 \text{ N}$$

Ans.



The 5-kg cylinder is suspended from two equal-length cords. The end of each cord is attached to a ring of negligible mass that passes along a horizontal shaft. If the rings can be separated by the greatest distance $d = 400 \text{ mm}$ and still support the cylinder, determine the coefficient of static friction between each ring and the shaft.



SOLUTION

Equilibrium of the Cylinder: Referring to the FBD shown in Fig. a,

$$+\uparrow \sum F_y = 0; \quad 2 \left[T \left(\frac{\sqrt{32}}{6} \right) \right] - m(9.81) = 0 \quad T = 5.2025 \text{ m}$$

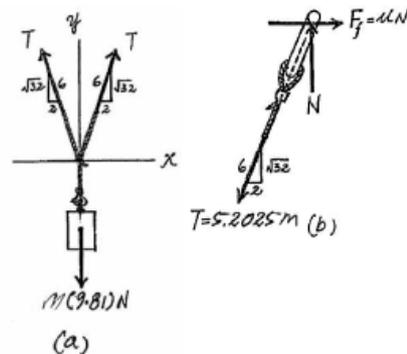
Equilibrium of the Ring: Since the ring is required to be on the verge to slide, the frictional force can be computed using friction formula $F_f = \mu N$ as indicated in the FBD of the ring shown in Fig. b. Using the result of T ,

$$+\uparrow \sum F_y = 0; \quad N - 5.2025 \text{ m} \left(\frac{\sqrt{32}}{6} \right) = 0 \quad N = 4.905 \text{ m}$$

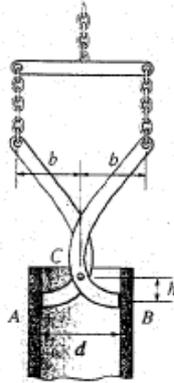
$$\pm \sum F_x = 0; \quad \mu(4.905 \text{ m}) - 5.2025 \text{ m} \left(\frac{2}{6} \right) = 0$$

$$\mu = 0.354$$

Ans.



8-20. The pipe is hoisted using the tongs. If the coefficient of static friction at A and B is μ_s , determine the smallest dimension b so that any pipe of inner diameter d can be lifted.



Require:

$$F_f = \frac{W}{2} \leq \mu_s N_f$$

$$+\Sigma M_C = 0; \quad -\frac{W}{2}\left(\frac{d}{2}\right) - N_A(h) + b\left(\frac{W}{2}\right) = 0$$

$$N_A = \frac{W}{2h}\left(b - \frac{d}{2}\right)$$

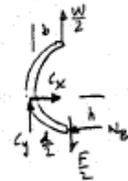
Thus,

$$\frac{W}{2} \leq \frac{\mu_s W}{2h}\left(b - \frac{d}{2}\right)$$

$$h \leq \left(b - \frac{d}{2}\right)\mu_s$$

$$b \geq \frac{h}{\mu_s} + \frac{d}{2}$$

$$b = \frac{h}{\mu_s} + \frac{d}{2} \quad \text{Ans.}$$



A 35-kg disk rests on an inclined surface for which $\mu_s = 0.3$. Determine the maximum vertical force P that may be applied to link AB without causing the disk to slip at C .

SOLUTION

Equations of Equilibrium: From FBD (a),

$$\zeta + \Sigma M_B = 0; \quad P(600) - A_y(900) = 0 \quad A_y = 0.6667P$$

From FBD (b),

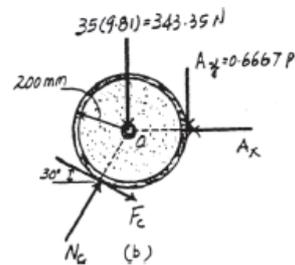
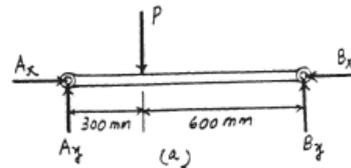
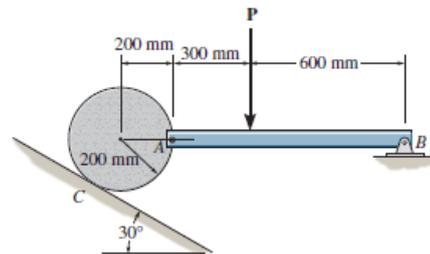
$$+\uparrow \Sigma F_y = 0 \quad N_C \sin 60^\circ - F_C \sin 30^\circ - 0.6667P - 343.35 = 0 \quad (1)$$

$$\zeta + \Sigma M_O = 0; \quad F_C(200) - 0.6667P(200) = 0 \quad (2)$$

Friction: If the disk is on the verge of moving, slipping would have to occur at point C . Hence, $F_C = \mu_s N_C = 0.3N_C$. Substituting this value into Eqs. (1) and (2) and solving, we have

$$P = 371.4 \text{ N}$$

$$N_C = 825.3 \text{ N}$$



Ans.

If $\theta = 30^\circ$ determine the minimum coefficient of static friction at A and B so that equilibrium of the supporting frame is maintained regardless of the mass of the cylinder C . Neglect the mass of the rods.

SOLUTION

Free-Body Diagram: Due to the symmetrical loading and system, ends A and B of the rod will slip simultaneously. Since end B tends to move to the right, the friction force F_B must act to the left as indicated on the free-body diagram shown in Fig. a .

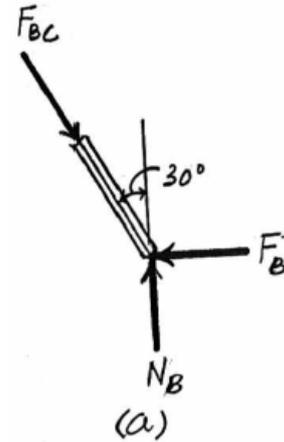
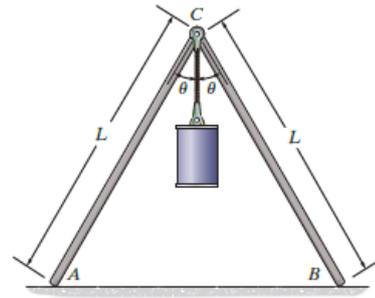
Equations of Equilibrium: We have

$$\begin{aligned} \pm \Sigma F_x = 0; & \quad F_{BC} \sin 30^\circ - F_B = 0 & \quad F_B = 0.5F_{BC} \\ + \uparrow \Sigma F_y = 0; & \quad N_B - F_{BC} \cos 30^\circ = 0 & \quad N_B = 0.8660 F_{BC} \end{aligned}$$

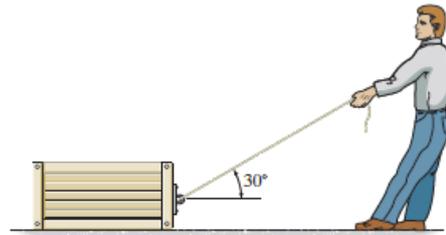
Therefore, to prevent slipping the coefficient of static friction ends A and B must be at least

$$\mu_s = \frac{F_B}{N_B} = \frac{0.5F_{BC}}{0.8660F_{BC}} = 0.577$$

Ans.



The coefficient of static friction between the 150-kg crate and the ground is $\mu_s = 0.3$, while the coefficient of static friction between the 80-kg man's shoes and the ground is $\mu_s' = 0.4$. Determine if the man can move the crate.



SOLUTION

Free-Body Diagram: Since \mathbf{P} tends to move the crate to the right, the frictional force F_C will act to the left as indicated on the free-body diagram shown in Fig. *a*. Since the crate is required to be on the verge of sliding the magnitude of F_C can be computed using the friction formula, i.e. $F_C = \mu_s N_C = 0.3 N_C$. As indicated on the free-body diagram of the man shown in Fig. *b*, the frictional force F_m acts to the right since force \mathbf{P} has the tendency to cause the man to slip to the left.

Equations of Equilibrium: Referring to Fig. *a*,

$$+\uparrow \Sigma F_y = 0; \quad N_C + P \sin 30^\circ - 150(9.81) = 0$$

$$\pm \Sigma F_x = 0; \quad P \cos 30^\circ - 0.3N_C = 0$$

Solving,

$$P = 434.49 \text{ N}$$

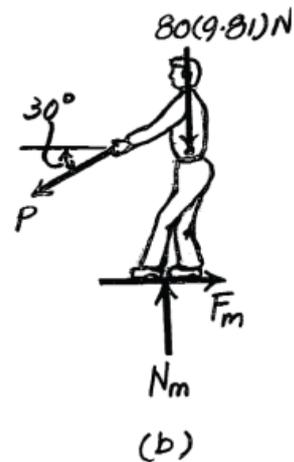
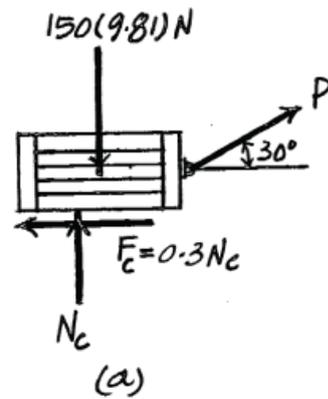
$$N_C = 1254.26 \text{ N}$$

Using the result of P and referring to Fig. *b*, we have

$$+\uparrow \Sigma F_y = 0; \quad N_m - 434.49 \sin 30^\circ - 80(9.81) = 0 \quad N_m = 1002.04 \text{ N}$$

$$\pm \Sigma F_x = 0; \quad F_m - 434.49 \cos 30^\circ = 0 \quad F_m = 376.28 \text{ N}$$

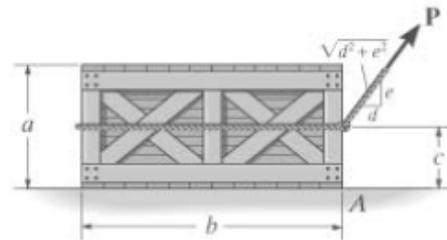
Since $F_m < F_{m_{\max}} = \mu_s' N_m = 0.4(1002.04) = 400.82 \text{ N}$, the man does not slip. Thus, **he can move the crate.** Ans.



Determine the magnitude of force \mathbf{P} needed to start towing the crate of mass M . Also determine the location of the resultant normal force acting on the crate, measured from point A .

Given:

$$\begin{aligned} M &= 40 \text{ kg} & c &= 200 \text{ mm} \\ \mu_s &= 0.3 & d &= 3 \\ a &= 400 \text{ mm} & e &= 4 \\ b &= 800 \text{ mm} \end{aligned}$$



Solution:

Initial guesses: $N_C = 200 \text{ N}$ $P = 50 \text{ N}$

Given

$$\Sigma F_x = 0; \quad \left(\frac{d}{\sqrt{d^2 + e^2}} \right) P - \mu_s N_C = 0$$

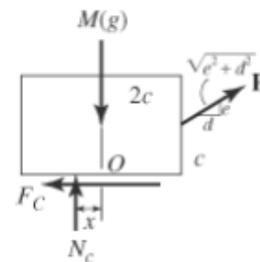
$$\Sigma F_y = 0; \quad N_C - Mg + \frac{eP}{\sqrt{d^2 + e^2}} = 0$$

$$\begin{pmatrix} N_C \\ P \end{pmatrix} = \text{Find}(N_C, P)$$

$$N_C = 280.2 \text{ N}$$

$$P = 140 \text{ N}$$

Ans.



$$\Sigma M_O = 0; \quad -\mu_s N_C \left(\frac{a}{2} \right) - N_I x + \left(\frac{eP}{\sqrt{d^2 + e^2}} \right) \left(\frac{b}{2} \right) = 0$$

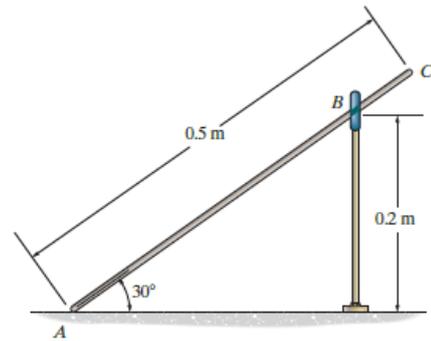
$$x = \frac{-1 \mu_s N_C a \sqrt{d^2 + e^2} - e P b}{2 N_C \sqrt{d^2 + e^2}} \quad x = 123.51 \text{ mm}$$

Thus, the distance from A is $A = x + \frac{b}{2}$ $A = 523.51 \text{ mm}$ Ans.

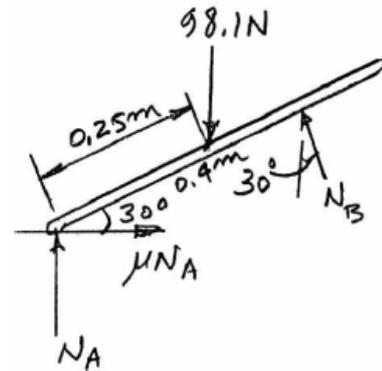
The uniform rod has a mass of 10 kg and rests on the inside of the smooth ring at B and on the ground at A . If the rod is on the verge of slipping, determine the coefficient of static friction between the rod and the ground.

SOLUTION

$$\begin{aligned} \zeta + \sum M_A = 0; & \quad N_B(0.4) - 98.1(0.25 \cos 30^\circ) = 0 \\ & \quad N_B = 53.10 \text{ N} \\ + \uparrow \sum F_y = 0; & \quad N_A - 98.1 + 53.10 \cos 30^\circ = 0 \\ & \quad N_A = 52.12 \text{ N} \\ \rightleftharpoons \sum F_x = 0; & \quad \mu(52.12) - 53.10 \sin 30^\circ = 0 \\ & \quad \mu = 0.509 \end{aligned}$$



Ans.



The beam AB has a negligible mass and thickness and is subjected to a triangular distributed loading. It is supported at one end by a pin and at the other end by a post having a mass of 50 kg and negligible thickness. Determine the minimum force P needed to move the post. The coefficients of static friction at B and C are $\mu_B = 0.4$ and $\mu_C = 0.2$, respectively.

SOLUTION

Member AB :

$$\begin{aligned} \zeta + \sum M_A = 0; & \quad -800\left(\frac{4}{3}\right) + N_B(2) = 0 \\ & \quad N_B = 533.3 \text{ N} \end{aligned}$$

Post:

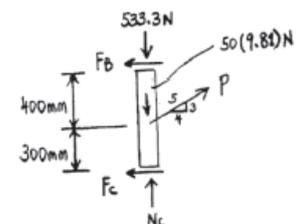
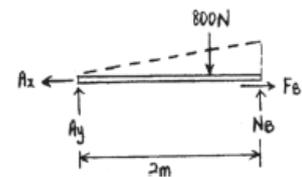
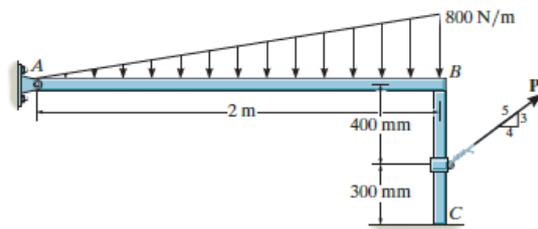
Assume slipping occurs at C ; $F_C = 0.2 N_C$

$$\begin{aligned} \zeta + \sum M_C = 0; & \quad -\frac{4}{5}P(0.3) + F_B(0.7) = 0 \\ \rightleftharpoons \sum F_x = 0; & \quad \frac{4}{5}P - F_B - 0.2N_C = 0 \\ + \uparrow \sum F_y = 0; & \quad \frac{3}{5}P + N_C - 533.3 - 50(9.81) = 0 \\ & \quad P = 355 \text{ N} \end{aligned}$$

$$N_C = 811.0 \text{ N}$$

$$F_B = 121.6 \text{ N}$$

$$(F_B)_{\max} = 0.4(533.3) = 213.3 \text{ N} > 121.6 \text{ N}$$



Ans.

(O.K.!)

