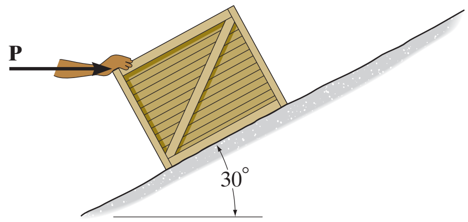
•8–1. Determine the minimum horizontal force P required to hold the crate from sliding down the plane. The crate has a mass of 50 kg and the coefficient of static friction between the crate and the plane is $\mu_s = 0.25$.



Free - Body Diagram. When the crate is on the verge of sliding down the plane, the frictional force **F** will act up the plane as indicated on the free - body diagram of the crate shown in Fig. a.

Equations of Equilibrium.

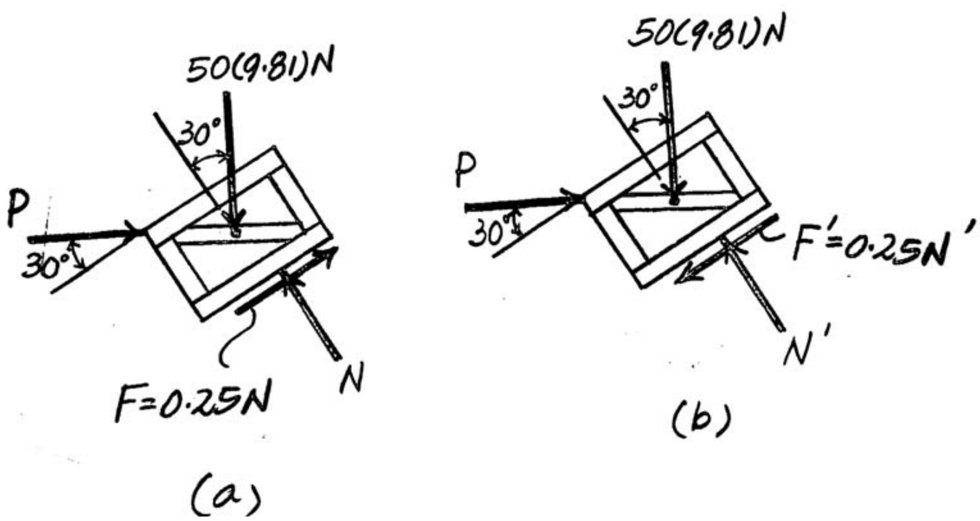
$\Sigma F_{y'} = 0;\ N - P\sin 30° - 50(9.81)\cos 30° = 0$

$\Sigma F_{x'} = 0;\ P\cos 30° + 0.25N - 50(9.81)\sin 30° = 0$

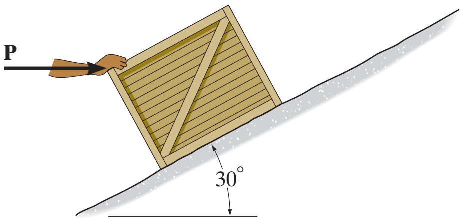
Solving

$P = 140\text{ N}$ **Ans.**

$N = 494.94\text{ N}$



8–2. Determine the minimum force P required to push the crate up the plane. The crate has a mass of 50 kg and the coefficient of static friction between the crate and the plane is $\mu_s = 0.25$.



When the crate is on the verge of sliding up the plane, the frictional force F' will act down the plane as indicated on the free-body diagram of the crate shown in Fig. b. Thus, $F = \mu_s N = 0.25N$ and $F' = \mu_s N' = 0.25N'$.
By referring to Fig. b,

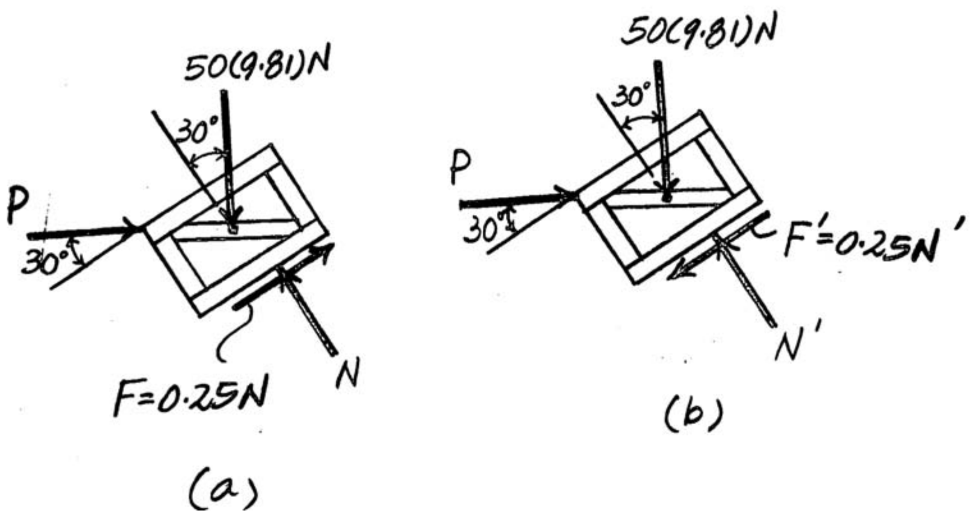
$\Sigma F_{y'} = 0;\quad N' - P\sin 30° - 50(9.81)\cos 30° = 0$

$\Sigma F_{x'} = 0;\quad P\cos 30° - 0.25N' - 50(9.81)\sin 30° = 0$

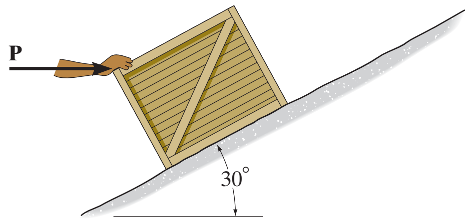
Solving,

$P = 474\text{ N}$ **Ans.**

$N' = 661.92\text{ N}$



8–3. A horizontal force of $P = 100$ N is just sufficient to hold the crate from sliding down the plane, and a horizontal force of $P = 350$ N is required to just push the crate up the plane. Determine the coefficient of static friction between the plane and the crate, and find the mass of the crate.



Free - Body Diagram. When the crate is subjected to a force of $P = 100$ N, it is on the verge of slipping down the plane. Thus, the frictional force F will act up the plane as indicated on the free - body diagram of the crate shown in Fig. *a*. When $P = 350$ N, it will cause the crate to be on the verge of slipping up the plane, and so the frictional force F' acts down the plane as indicated on the free - body diagram of the crate shown in Fig. *a*. Thus, $F = \mu_s N$ and $F' = \mu_s N'$.

Equations of Equilibrium.

$+\nwarrow \Sigma F_{y'} = 0;\ N - 100\sin 30° - m(9.81)\cos 30° = 0$

$+\nearrow \Sigma F_{x'} = 0;\ \mu_s N + 100\cos 30° - m(9.81)\sin 30° = 0$

Eliminating N,
$$\mu_s = \frac{4.905m - 86.603}{8.496m + 50} \qquad (1)$$

Also, by referring to Fig. *b*, we can write

$+\nwarrow \Sigma F_{y'} = 0;\ N' - m(9.81)\cos 30° - 350\sin 30° = 0$

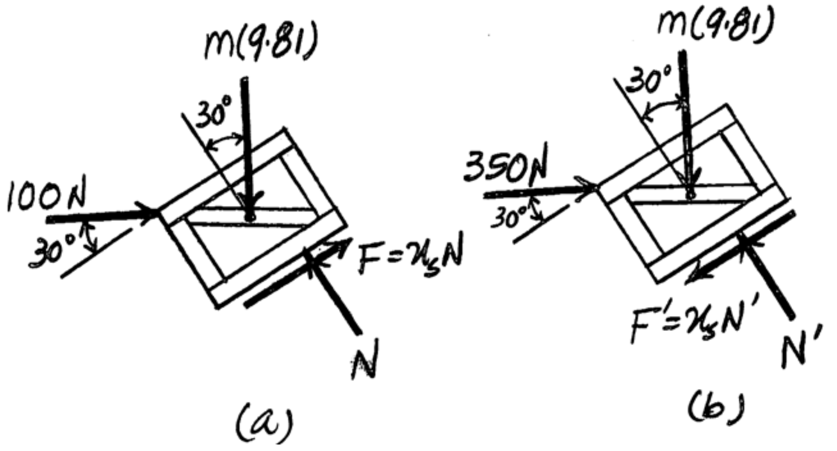
$+\nearrow \Sigma F_{x'} = 0;\ 350\cos 30° - m(9.81)\sin 30° - \mu_s N' = 0$

Eliminating N',
$$\mu_s = \frac{303.11 - 4.905m}{175 + 8.496m} \qquad (2)$$

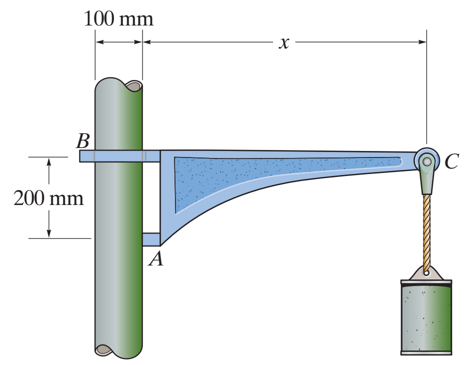
Solving Eqs. (1) and (2) yields

$m = 36.46$ kg

$\mu_s = 0.256$ **Ans.**



***8–4.** If the coefficient of static friction at A is $\mu_s = 0.4$ and the collar at B is smooth so it only exerts a horizontal force on the pipe, determine the minimum distance x so that the bracket can support the cylinder of any mass without slipping. Neglect the mass of the bracket.



Free - Body Diagram. The weight of cylinder tends to cause the bracket to slide downward. Thus, the frictional force $\mathbf{F}_A$ must act upwards as indicated in the free - body diagram shown in Fig. *a*. Here the bracket is required to be on the verge of slipping so that $F_A = \mu_s N_A = 0.4N_A$.

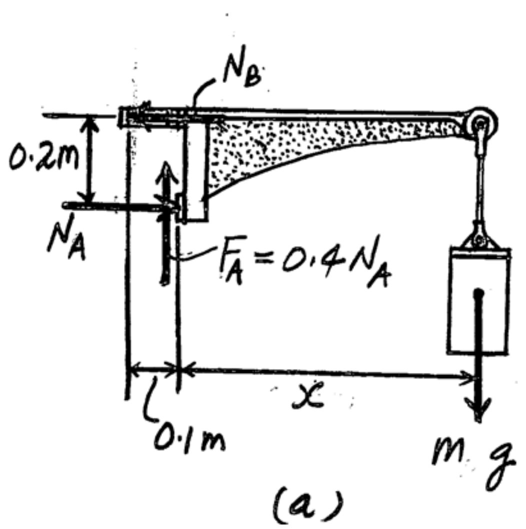
Equations of Equilibrium.

$+\uparrow \Sigma F_y = 0;$ $\quad 0.4N_A - m\,g = 0 \qquad N_A = 2.5m\,g$

$\circlearrowleft + \Sigma M_B = 0;$ $\quad 2.5mg(0.2) + 0.4(2.5m\,g)(0.1) - m\,(g)(x + 0.1) = 0$

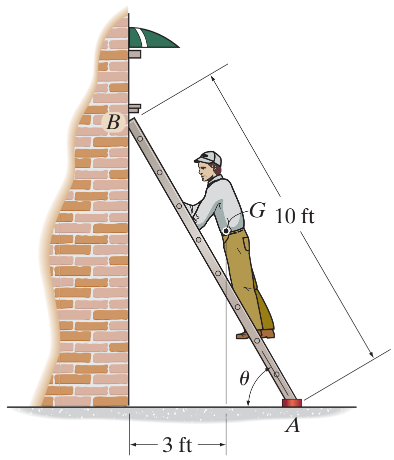
$x = 0.5\text{ m}$ **Ans.**

Note: Since x is independent of the mass of the cylinder, the bracket will not slip regardless of the mass of the cylinder provided $x > 0.5$ m.



(a)

•**8–5.** The 180-lb man climbs up the ladder and stops at the position shown after he senses that the ladder is on the verge of slipping. Determine the inclination θ of the ladder if the coefficient of static friction between the friction pad A and the ground is $\mu_s = 0.4$. Assume the wall at B is smooth. The center of gravity for the man is at G. Neglect the weight of the ladder.



Free - Body Diagram. Since the weight of the man tends to cause the friction pad A to slide to the right, the frictional force $\mathbf{F}_A$ must act to the left as indicated on the free - body diagram of the ladder, Fig. *a*. Here, the ladder is on the verge of slipping. Thus, $F_A = \mu_s N_A$.

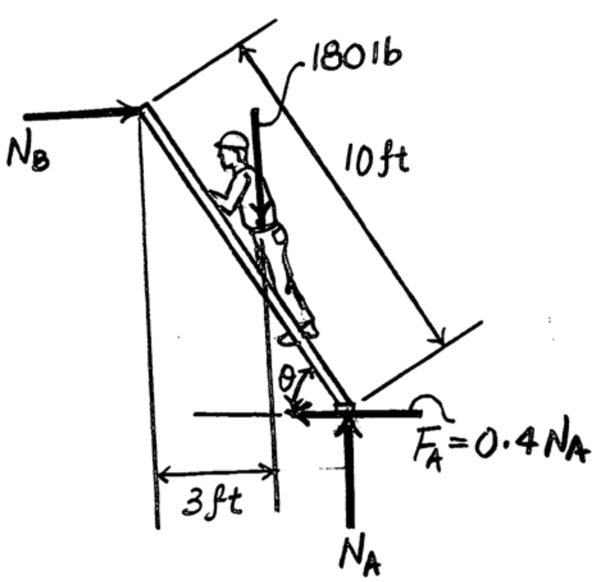
Equations of Equilibrium.

$+\uparrow \Sigma F_y = 0;$ $\quad N_A - 180 = 0 \quad\quad N_A = 180 \text{ lb}$

$+\Sigma M_B = 0;$ $\quad 180(10\cos 60°) - \mu_s(180)(10\sin 60°) - 180(3) = 0$

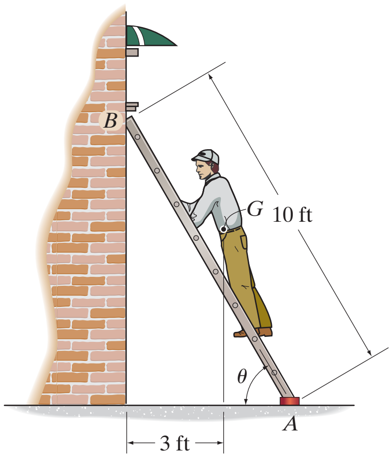
$10\cos 60° - \mu_s 10\sin 60° = 3$

$\mu_s = 0.231$ **Ans.**



(a)

8–6. The 180-lb man climbs up the ladder and stops at the position shown after he senses that the ladder is on the verge of slipping. Determine the coefficient of static friction between the friction pad at A and ground if the inclination of the ladder is $\theta = 60°$ and the wall at B is smooth. The center of gravity for the man is at G. Neglect the weight of the ladder.



Free - Body Diagram. Since the weight of the man tends to cause the friction pad A to slide to the right, the frictional force $\mathbf{F}_A$ must act to the left as indicated on the free - body diagram of the ladder, Fig. *a*. Here, the ladder is on the verge of slipping. Thus, $F_A = \mu_s N_A$.

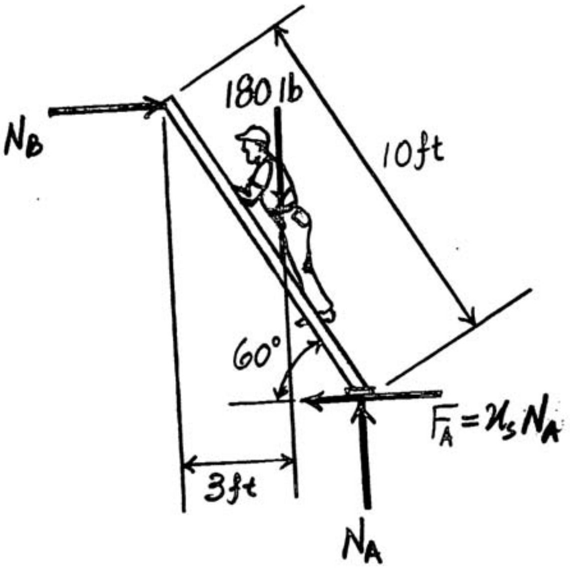
Equations of Equilibrium.

$+\uparrow \Sigma F_y = 0;$ $\quad N_A - 180 = 0 \qquad N_A = 180 \text{ lb}$

$\circlearrowleft + \Sigma M_B = 0;$ $\quad 180(10\cos 60°) - \mu_s(180)(10\sin 60°) - 180(3) = 0$

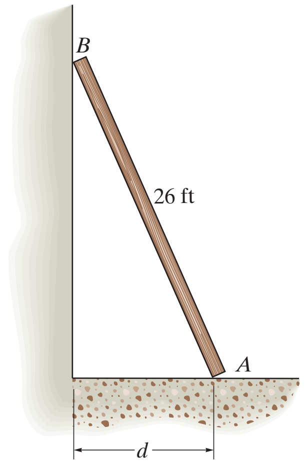
$180\cos\theta - 72\sin\theta = 54$

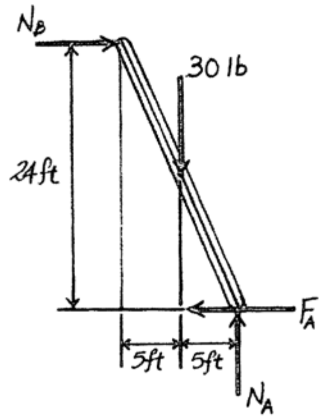
$\mu_s = 0.231$ **Ans.**



(a)

8–7. The uniform thin pole has a weight of 30 lb and a length of 26 ft. If it is placed against the smooth wall and on the rough floor in the position $d = 10$ ft, will it remain in this position when it is released? The coefficient of static friction is $\mu_s = 0.3$.





$\circlearrowleft + \Sigma M_A = 0; \quad 30(5) - N_B(24) = 0$

$N_B = 6.25$ lb

$\xrightarrow{+} \Sigma F_x = 0; \quad 6.25 - F_A = 0$

$F_A = 6.25$ lb

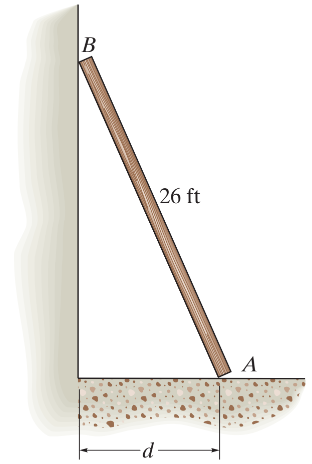
$+\uparrow \Sigma F_y = 0; \quad N_A - 30 = 0$

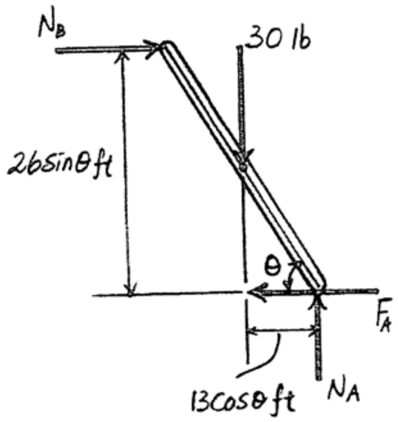
$N_A = 30$ lb

$(F_A)_{max} = 0.3(30) = 9 \text{ lb} > 6.25 \text{ lb}$

Yes, the pole will remain stationary. **Ans**

***8–8.** The uniform pole has a weight of 30 lb and a length of 26 ft. Determine the maximum distance d it can be placed from the smooth wall and not slip. The coefficient of static friction between the floor and the pole is $\mu_s = 0.3$.





$+\uparrow \Sigma F_y = 0; \quad N_A - 30 = 0$

$N_A = 30 \text{ lb}$

$F_A = (F_A)_{max} = 0.3\,(30) = 9 \text{ lb}$

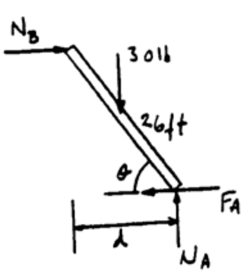
$\xrightarrow{+} \Sigma F_x = 0; \quad N_B - 9 = 0$

$N_B = 9 \text{ lb}$

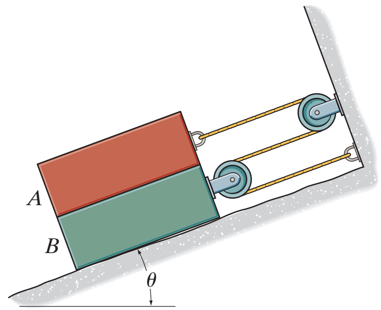
$\circlearrowleft + \Sigma M_A = 0; \quad 30\,(13 \cos \theta) - 9\,(26 \sin \theta) = 0$

$\theta = 59.04°$

$d = 26 \cos 59.04° = 13.4 \text{ ft}$ **Ans**



•8–9. If the coefficient of static friction at all contacting surfaces is μ_s, determine the inclination θ at which the identical blocks, each of weight W, begin to slide.



Free - Body Diagram. Here, we will assume that the impending motion of the upper block is down the plane while the impending motion of the lower block is up the plane. Thus, the frictional force F acting on the upper block acts up the plane while the friction forces **F** and F' acting on the lower block act down the plane as indicated on the free - body diagram of the upper and lower blocks shown in Figs. *a* and *b*, respectively. Since both block are required to be on the verge of slipping, then $F = \mu_s N$ and $F' = \mu_s N'$.

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

$+\nwarrow \Sigma F_{y'} = 0;\quad N - W\cos\theta = 0 \qquad N = W\cos\theta$

$+\nearrow \Sigma F_{x'} = 0;\quad T + \mu_s(W\cos\theta) - W\sin\theta = 0 \qquad T = W\sin\theta - \mu_s W\cos\theta$

Using these results and referring to Fig. *b*,

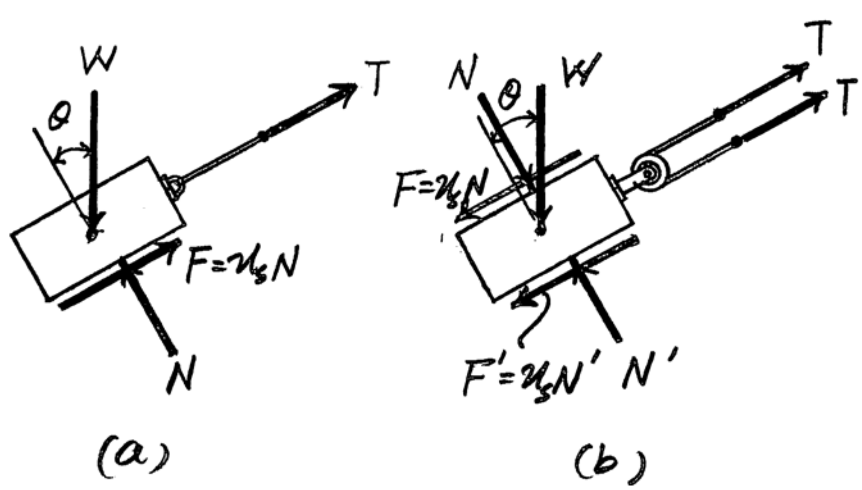
$+\nwarrow \Sigma F_{y'} = 0;\quad N' - W\cos\theta - W\cos\theta = 0 \qquad N' = 2W\cos\theta$

$+\nearrow \Sigma F_{x'} = 0;\quad 2(W\sin\theta - \mu_s W\cos\theta) - \mu_s W\cos\theta - \mu_s(2W\cos\theta) - W\sin\theta = 0$

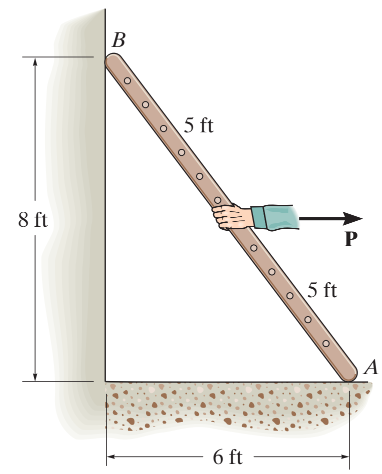
$$\sin\theta - 5\mu_s\cos\theta = 0$$

$$\theta = \tan^{-1} 5\mu_s$$ **Ans.**

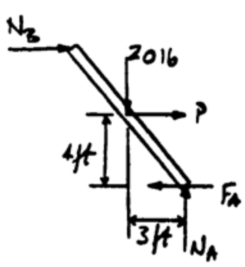
Since the analysis yields a positive θ, the above assumption is correct.

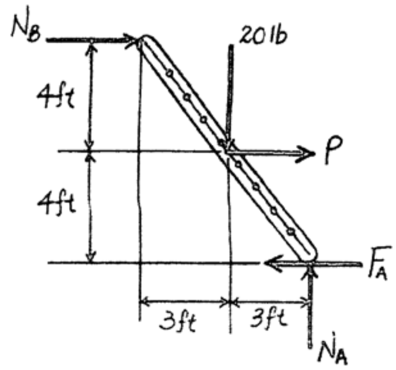


8–10. The uniform 20-lb ladder rests on the rough floor for which the coefficient of static friction is $\mu_s = 0.8$ and against the smooth wall at B. Determine the horizontal force P the man must exert on the ladder in order to cause it to move.



Assume that the ladder tips about A:





$N_B = 0;$

$\xrightarrow{+} \Sigma F_x = 0; \quad P - F_A = 0$

$+\uparrow \Sigma F_y = 0; \quad -20 + N_A = 0$

$N_A = 20 \text{ lb}$

$\circlearrowleft + \Sigma M_A = 0; \quad 20(3) - P(4) = 0$

$P = 15 \text{ lb}$

Thus

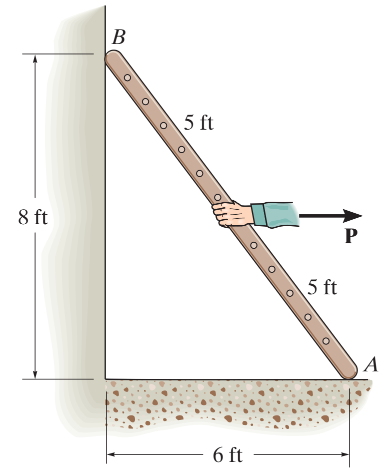
$F_A = 15 \text{ lb}$

$(F_A)_{max} = 0.8(20) = 16 \text{ lb} > 15 \text{ lb} \quad \text{OK}$

Ladder tips as assumed.

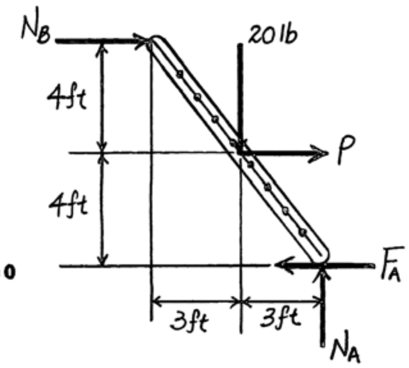
$P = 15 \text{ lb}$ **Ans**

8–11. The uniform 20-lb ladder rests on the rough floor for which the coefficient of static friction is $\mu_s = 0.4$ and against the smooth wall at B. Determine the horizontal force P the man must exert on the ladder in order to cause it to move.



Assume that the ladder slips at A:

$F_A = 0.4 N_A$



$+\uparrow \Sigma F_y = 0;\quad N_A - 20 = 0$

$N_A = 20 \text{ lb}$

$F_A = 0.4(20) = 8 \text{ lb}$

$\circlearrowleft + \Sigma M_B = 0;\quad P(4) - 20(3) + 20(6) - 8(8) = 0$

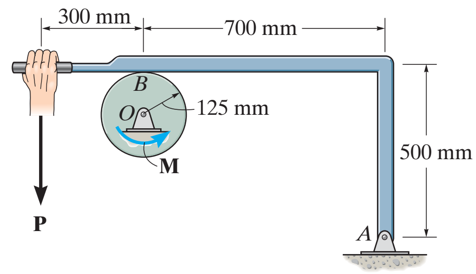
$P = 1 \text{ lb}$ **Ans**

$\xrightarrow{+} \Sigma F_x = 0;\quad N_B + 1 - 8 = 0$

$N_B = 7 \text{ lb} > 0$ OK

The ladder will remain in contact with the wall.

***8–12.** The coefficients of static and kinetic friction between the drum and brake bar are $\mu_s = 0.4$ and $\mu_k = 0.3$, respectively. If $M = 50\ \text{N}\cdot\text{m}$ and $P = 85$ N determine the horizontal and vertical components of reaction at the pin O. Neglect the weight and thickness of the brake. The drum has a mass of 25 kg.



Equations of Equilibrium **: From FBD (b),**

$$\circlearrowleft + \Sigma M_O = 0 \qquad 50 - F_B(0.125) = 0 \qquad F_B = 400\ \text{N}$$

From FBD (a),

$$\circlearrowleft + \Sigma M_A = 0; \qquad 85(1.00) + 400(0.5) - N_B(0.7) = 0$$
$$N_B = 407.14\ \text{N}$$

Friction **: Since $F_B > (F_B)_{max} = \mu_s N_B = 0.4(407.14) = 162.86$ N, the drum slips at point B and rotates. Therefore, the coefficient of kinetic friction should be used. Thus, $F_B = \mu_k N_B = 0.3 N_B$.**

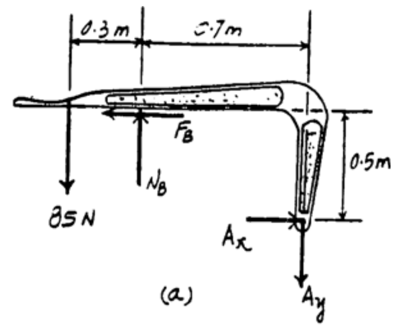
Equations of Equilibrium **: From FBD (b),**

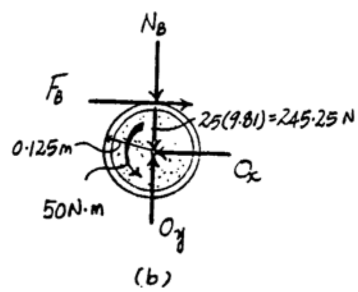
$$\circlearrowleft + \Sigma M_A = 0; \qquad 85(1.00) + 0.3N_B(0.5) - N_B(0.7) = 0$$
$$N_B = 154.54\ \text{N}$$

From FBD (b),

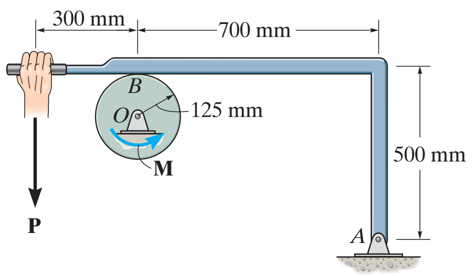
$$+\uparrow \Sigma F_y = 0; \qquad O_y - 245.25 - 154.54 = 0 \qquad O_y = 400\ \text{N} \qquad \textbf{Ans}$$

$$\overset{+}{\rightarrow} \Sigma F_x = 0; \qquad 0.3(154.54) - O_x = 0 \qquad O_x = 46.4\ \text{N} \qquad \textbf{Ans}$$





•**8–13.** The coefficient of static friction between the drum and brake bar is $\mu_s = 0.4$. If the moment $M = 35\ \text{N}\cdot\text{m}$, determine the smallest force P that needs to be applied to the brake bar in order to prevent the drum from rotating. Also determine the corresponding horizontal and vertical components of reaction at pin O. Neglect the weight and thickness of the brake bar. The drum has a mass of 25 kg.



Equations of Equilibrium : From FBD (b),

$\curvearrowleft + \Sigma M_O = 0 \qquad 35 - F_B(0.125) = 0 \qquad F_B = 280\ \text{N}$

From FBD (a),

$\curvearrowleft + \Sigma M_A = 0; \qquad P(1.00) + 280(0.5) - N_B(0.7) = 0$

Friction : When the drum is on the verge of rotating,

$$F_B = \mu_s N_B$$
$$280 = 0.4 N_B$$
$$N_B = 700\ \text{N}$$

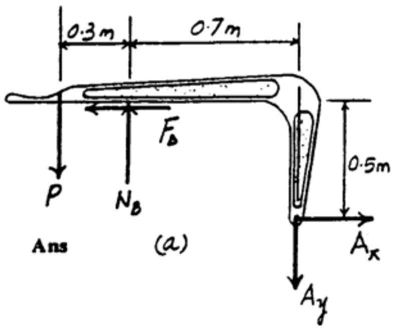
Substituting $N_B = 700$ N into Eq.[1] yields

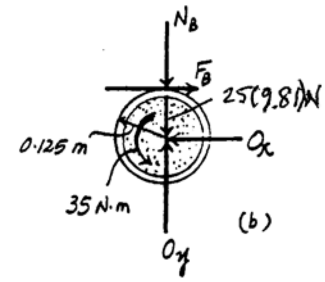
$$P = 350\ \text{N} \qquad \textbf{Ans}$$

Equations of Equilibrium : From FBD (b),

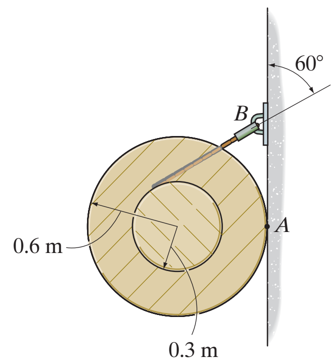
$+\uparrow \Sigma F_y = 0; \qquad O_y - 245.25 - 700 = 0 \qquad O_y = 945\ \text{N} \qquad$ **Ans**

$\xrightarrow{+} \Sigma F_x = 0; \qquad 280 - O_x = 0 \qquad O_x = 280\ \text{N} \qquad$ **Ans**





8–14. Determine the minimum coefficient of static friction between the uniform 50-kg spool and the wall so that the spool does not slip.



Free - Body Diagram. Here, the frictional force $\mathbf{F}_A$ must act upwards to produce the counterclockwise moment about the center of mass of the spool, opposing the impending clockwise rotational motion caused by force $\mathbf{T}$ as indicated on the free - body diagram of the spool, Fig. a. Since the spool is required to be on the verge of slipping, then $F_A = \mu_s N_A$.

Equations of Equilibrium. Referring to Fig. a,

$\circlearrowleft + \Sigma M_A = 0;$ $mg(0.6) - T\cos 60°(0.3\cos 60° + 0.6) - T\sin 60°(0.3\sin 60°) = 0$

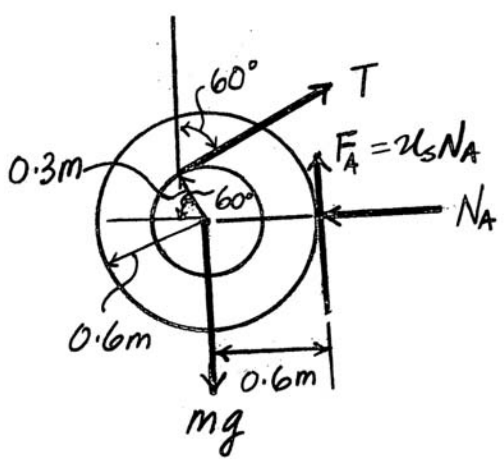
$T = mg$

$\overset{+}{\rightarrow} \Sigma F_x = 0;$ $mg\sin 60° - N_A = 0$ $\quad N_A = 0.8660mg$

$+\uparrow \Sigma F_y = 0;$ $\mu_s(0.8660mg) + mg\cos 60° - mg = 0$

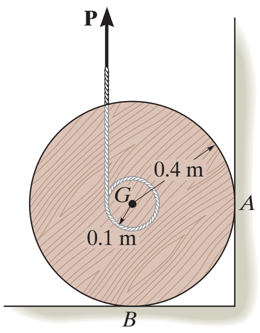
$\mu_s = 0.577$ **Ans.**

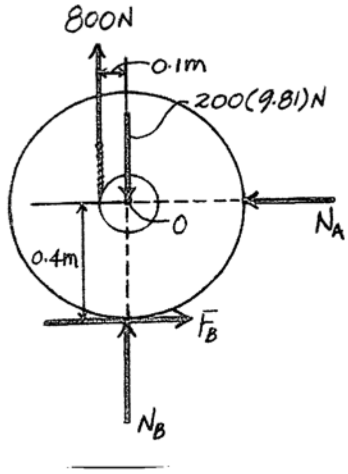
Note: Since μ_s is independent of the mass of the spool, it will not slip regardless of its mass provided $\mu_s > 0.577$.



(a)

8–15. The spool has a mass of 200 kg and rests against the wall and on the floor. If the coefficient of static friction at B is $(\mu_s)_B = 0.3$, the coefficient of kinetic friction is $(\mu_k)_B = 0.2$, and the wall is smooth, determine the friction force developed at B when the vertical force applied to the cable is $P = 800$ N.





$\xrightarrow{+} \Sigma F_x = 0; \qquad F_B - N_A = 0$

$+\uparrow \Sigma F_y = 0; \qquad 800 - 200(9.81) + N_B = 0$

$\circlearrowleft + \Sigma M_O = 0; \qquad -800(0.1) + F_B(0.4) = 0$

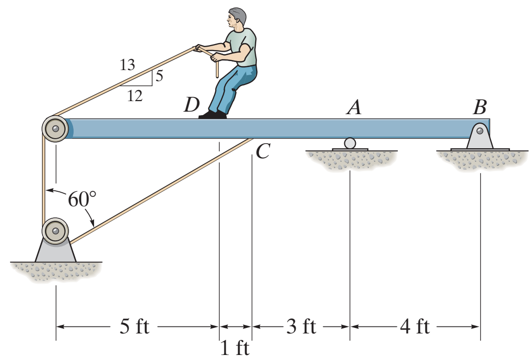
$F_B = 200$ N

$N_B = 1162$ N

$(F_B)_{max} = 0.3(1162) = 348.6 \text{ N} > 200 \text{ N}$

Thus, $\qquad F_B = 200$ N **Ans**

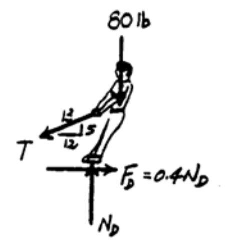
***8–16.** The 80-lb boy stands on the beam and pulls on the cord with a force large enough to just cause him to slip. If the coefficient of static friction between his shoes and the beam is $(\mu_s)_D = 0.4$, determine the reactions at A and B. The beam is uniform and has a weight of 100 lb. Neglect the size of the pulleys and the thickness of the beam.



Equations of Equilibrium and Friction : When the boy is on the verge to slipping, then $F_D = (\mu_s)_D N_D = 0.4N_D$. From FBD (a),

$$+\uparrow \Sigma F_y = 0; \quad N_D - T\left(\frac{5}{13}\right) - 80 = 0 \qquad [1]$$

$$\xrightarrow{+} \Sigma F_x = 0; \quad 0.4N_D - T\left(\frac{12}{13}\right) = 0 \qquad [2]$$

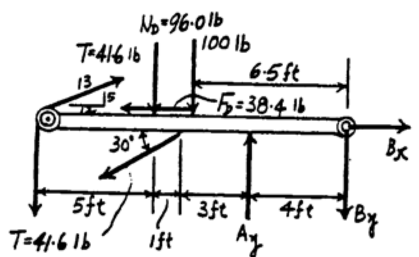


(a)

Solving Eqs. [1] and [2] yields

$$T = 41.6 \text{ lb} \qquad N_D = 96.0 \text{ lb}$$

Hence, $F_D = 0.4(96.0) = 38.4$ lb. From FBD (b),



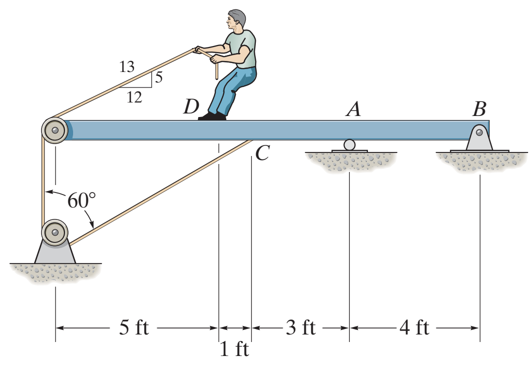
(b)

$$\curvearrowleft + \Sigma M_B = 0; \quad 100(6.5) + 96.0(8) - 41.6\left(\frac{5}{13}\right)(13)$$
$$+ 41.6(13) + 41.6\sin 30°(7) - A_y(4) = 0$$
$$A_y = 474.1 \text{ lb} = 474 \text{ lb} \qquad \textbf{Ans}$$

$$\xrightarrow{+} \Sigma F_x = 0; \quad B_x + 41.6\left(\frac{12}{13}\right) - 38.4 - 41.6\cos 30° = 0$$
$$B_x = 36.0 \text{ lb} \qquad \textbf{Ans}$$

$$+\uparrow \Sigma F_y = 0; \quad 474.1 + 41.6\left(\frac{5}{13}\right) - 41.6$$
$$- 41.6\sin 30° - 96.0 - 100 - B_y = 0$$
$$B_y = 231.7 \text{ lb} = 232 \text{ lb} \qquad \textbf{Ans}$$

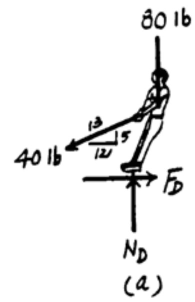
•8–17. The 80-lb boy stands on the beam and pulls with a force of 40 lb. If $(\mu_s)_D = 0.4$, determine the frictional force between his shoes and the beam and the reactions at A and B. The beam is uniform and has a weight of 100 lb. Neglect the size of the pulleys and the thickness of the beam.



Equations of Equilibrium and Friction: From FBD (a).

$+\uparrow \Sigma F_y = 0; \quad N_D - 40\left(\frac{5}{13}\right) - 80 = 0 \quad N_D = 95.38 \text{ lb}$

$\xrightarrow{+} \Sigma F_x = 0; \quad F_D - 40\left(\frac{12}{13}\right) = 0 \quad F_D = 36.92 \text{ lb}$



Since $(F_D)_{max} = (\mu_s)N_D = 0.4(95.38) = 38.15 \text{ lb} > F_D$, then the boy does not slip. Therefore, the friction force developed is

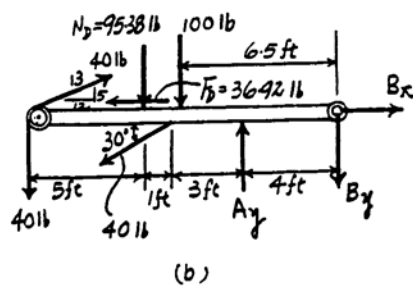
$F_D = 36.92 \text{ lb} = 36.9 \text{ lb}$ **Ans**

From FBD (b).

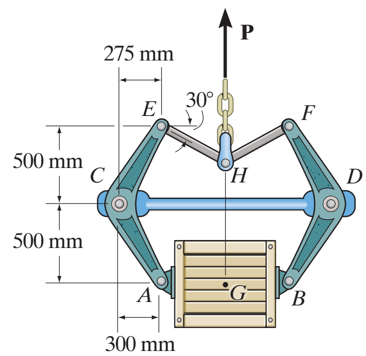
$\circlearrowleft + \Sigma M_B = 0; \quad 100(6.5) + 95.38(8) - 40\left(\frac{5}{13}\right)(13)$
$+ 40(13) + 40\sin 30°(7) - A_y(4) = 0$
$A_y = 468.27 \text{ lb} = 468 \text{ lb}$ **Ans**

$\xrightarrow{+} \Sigma F_x = 0; \quad B_x + 40\left(\frac{12}{13}\right) - 36.92 - 40\cos 30° = 0$
$B_x = 34.64 \text{ lb} = 34.6 \text{ lb}$ **Ans**

$+\uparrow \Sigma F_y = 0; \quad 468.27 + 40\left(\frac{5}{13}\right) - 40$
$- 40\sin 30° - 95.38 - 100 - B_y = 0$
$B_y = 228.27 \text{ lb} = 228 \text{ lb}$ **Ans**



8–18. The tongs are used to lift the 150-kg crate, whose center of mass is at G. Determine the least coefficient of static friction at the pivot blocks so that the crate can be lifted.



Free - Body Diagram. Since the crate is suspended from the tongs, **P** must be equal to the weight of the crate; i.e., $P = 150(9.81)$ N as indicated on the free - body diagram of joint H shown in Fig. a. Since the crate is required to be on the verge of slipping downward, $\mathbf{F}_A$ and $\mathbf{F}_B$ must act upward so that $F_A = \mu_s N_A$ and $F_B = \mu_s N_B$ as indicated on the free - body diagram of the crate shown in Fig. c.

Equations of Equilibrium. Referring to Fig. a,

$\overset{+}{\rightarrow}\Sigma F_x = 0;$ $\quad F_{HE}\cos 30° - F_{HF}\cos 30° = 0 \quad\quad F_{HE} = F_{HF} = F$

$+\uparrow \Sigma F_y = 0;$ $\quad 150(9.81) - 2F\sin 30° = 0 \quad\quad F = 1471.5\text{ N}$

Referring to Fig. b,

$\circlearrowleft + \Sigma M_C = 0;$ $\quad 1471.5\cos 30°(0.5) + 1471.5\sin 30°(0.275) - N_A(0.5) - \mu_s N_A(0.3) = 0$

$$0.5N_A + 0.3\mu_s N_A = 839.51 \quad\quad (1)$$

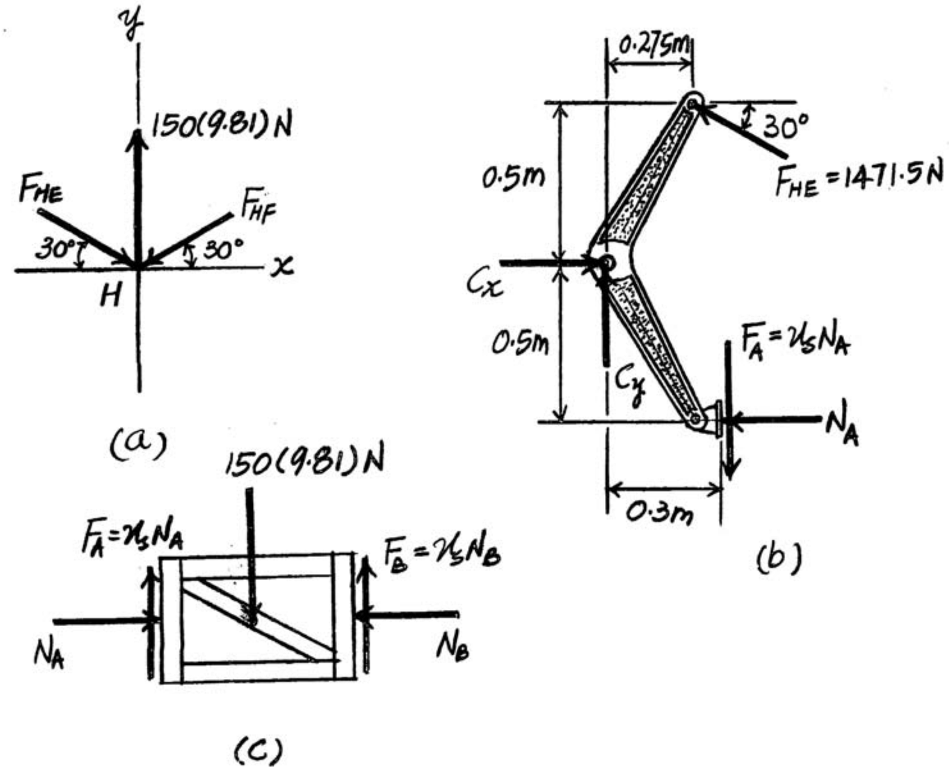
Due to the symmetry of the system and loading, $N_B = N_A$. Referring to Fig. c,

$+\uparrow \Sigma F_y = 0;$ $\quad 2\mu_s N_A - 150(9.81) = 0 \quad\quad (2)$

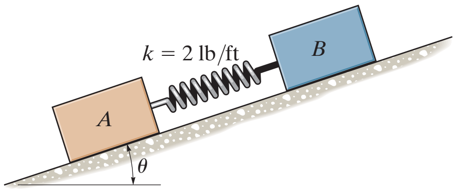
Solving Eqs. (1) and (2), yields

$$N_A = 1237.57\text{ N}$$

$$\mu_s = 0.595 \quad\quad \textbf{Ans.}$$



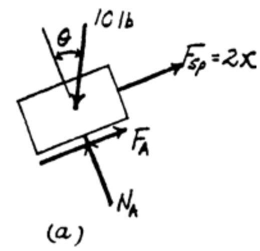
8–19. Two blocks A and B have a weight of 10 lb and 6 lb, respectively. They are resting on the incline for which the coefficients of static friction are $\mu_A = 0.15$ and $\mu_B = 0.25$. Determine the incline angle θ for which both blocks begin to slide. Also find the required stretch or compression in the connecting spring for this to occur. The spring has a stiffness of $k = 2$ lb/ft.



Equations of Equilibrium : Using the spring force formula, $F_{sp} = kx = 2x$. From FBD (a),

$$+\nearrow \Sigma F_{x'} = 0; \quad 2x + F_A - 10\sin\theta = 0 \qquad [1]$$

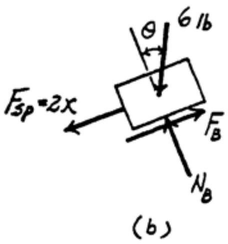
$$+\nwarrow \Sigma F_{y'} = 0; \quad N_A - 10\cos\theta = 0 \qquad [2]$$



From FBD (b),

$$+\nearrow \Sigma F_{x'} = 0; \quad F_B - 2x - 6\sin\theta = 0 \qquad [3]$$

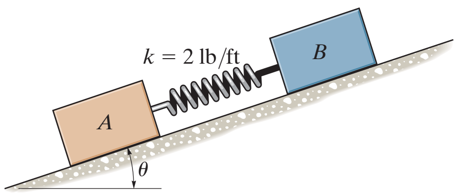
$$+\nwarrow \Sigma F_{y'} = 0; \quad N_B - 6\cos\theta = 0 \qquad [4]$$



Friction : If block A and B are on the verge to move, slipping would have to occur at point A and B. Hence, $F_A = \mu_{s_A} N_A = 0.15N_A$ and $F_B = \mu_{s_B} N_B = 0.25N_B$. Substituting these values into Eqs. [1], [2], [3] and [4] and solving, we have

$$\theta = 10.6^\circ \qquad x = 0.184 \text{ ft} \qquad \textbf{Ans}$$
$$N_A = 9.829 \text{ lb} \qquad N_B = 5.897 \text{ lb}$$

***8–20.** Two blocks A and B have a weight of 10 lb and 6 lb, respectively. They are resting on the incline for which the coefficients of static friction are $\mu_A = 0.15$ and $\mu_B = 0.25$. Determine the angle θ which will cause motion of one of the blocks. What is the friction force under each of the blocks when this occurs? The spring has a stiffness of $k = 2$ lb/ft and is originally unstretched.



Equations of Equilibrium : Since Block A and B is either not moving or on the verge of moving, the spring force $F_{sp} = 0$. From FBD (a),

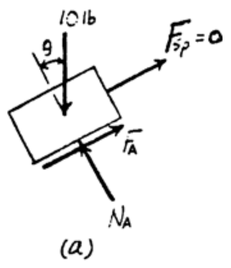
$$+\Sigma F_{x'} = 0; \quad F_A - 10\sin\theta = 0 \qquad [1]$$

$$+\Sigma F_{y'} = 0; \quad N_A - 10\cos\theta = 0 \qquad [2]$$

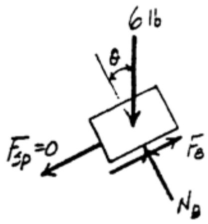
From FBD (b),

$$+\Sigma F_{x'} = 0; \quad F_B - 6\sin\theta = 0 \qquad [3]$$

$$+\Sigma F_{y'} = 0; \quad N_B - 6\cos\theta = 0 \qquad [4]$$



(a)



Friction : Assuming block A is on the verge of slipping, then

$$F_A = \mu_{s\,A} N_A = 0.15 N_A \qquad [5]$$

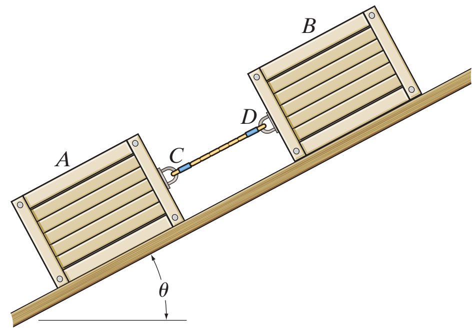
Solving Eqs. [1], [2], [3], [4] and [5] yields

$$\theta = 8.531^\circ \quad N_A = 9.889 \text{ lb} \quad F_A = 1.483 \text{ lb}$$
$$F_B = 0.8900 \text{ lb} \quad N_B = 5.934 \text{ lb}$$

Since $(F_B)_{max} = \mu_{s\,B} N_B = 0.25(5.934) = 1.483 \text{ lb} > F_B$, block B does not slip. Therefore, the above assumption is correct. Thus

$$\theta = 8.53^\circ \quad F_A = 1.48 \text{ lb} \quad F_B = 0.890 \text{ lb} \qquad \textbf{Ans}$$

•8–21. Crates A and B weigh 200 lb and 150 lb, respectively. They are connected together with a cable and placed on the inclined plane. If the angle θ is gradually increased, determine θ when the crates begin to slide. The coefficients of static friction between the crates and the plane are $\mu_A = 0.25$ and $\mu_B = 0.35$.



Free - Body Diagram. Since both crates are required to be on the verge of sliding down the plane, the frictional forces $\mathbf{F}_A$ and $\mathbf{F}_B$ must act up the plane so that $F_A = \mu_A N_A = 0.25N_A$ and $F_B = \mu_B N_B = 0.35N_B$ as indicated on the free - body diagram of the crates shown in Figs. *a* and *b*.

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

$+\Sigma F_{y'} = 0; \quad N_A - 200\cos\theta = 0 \qquad N_A = 200\cos\theta$

$+\Sigma F_{x'} = 0; \quad F_{CD} + 0.25(200\cos\theta) - 200\sin\theta = 0 \qquad (1)$

Also, by referring to Fig. *b*,

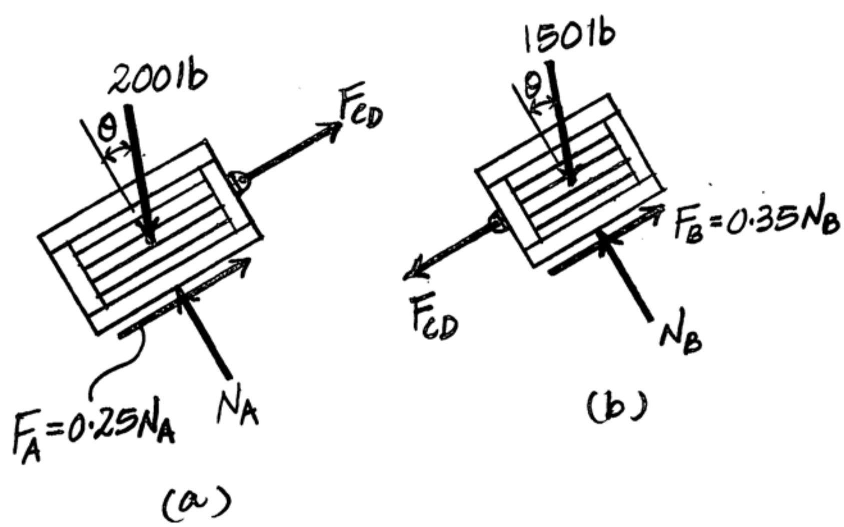
$+\Sigma F_{y'} = 0; \quad N_B - 150\cos\theta = 0 \qquad N_B = 150\cos\theta$

$+\Sigma F_{x'} = 0; \quad 0.35(150\cos\theta) - F_{CD} - 150\sin\theta = 0 \qquad (2)$

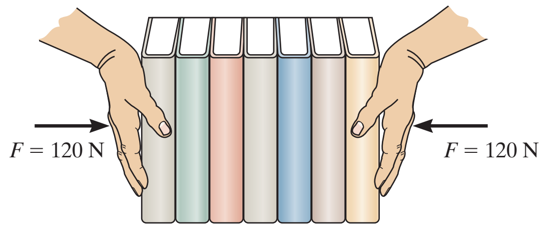
Solving Eqs. (1) and (2), yields

$\theta = 16.3°$ **Ans.**

$F_{CD} = 8.23$ lb



8–22. A man attempts to support a stack of books horizontally by applying a compressive force of $F = 120$ N to the ends of the stack with his hands. If each book has a mass of 0.95 kg, determine the greatest number of books that can be supported in the stack. The coefficient of static friction between the man's hands and a book is $(\mu_s)_h = 0.6$ and between any two books $(\mu_s)_b = 0.4$.



Equations of Equilibrium and Friction : Let n' be the number of books that are on the verge of sliding together between the two books at the edge. Thus, $F_b = (\mu_s)_b N = 0.4(120) = 48.0$ N. From FBD (a),

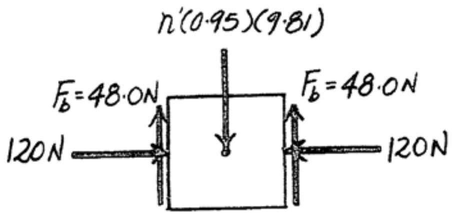
$$+\uparrow \Sigma F_y = 0; \quad 2(48.0) - n'(0.95)(9.81) = 0 \qquad n' = 10.30$$

Let n be the number of books are on the verge of sliding together in the stack between the hands. Thus, $F_h = (\mu_s)_h N = 0.6(120) = 72.0$ N. From FBD (b),

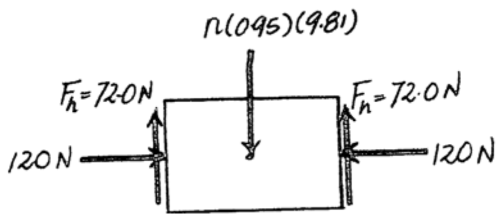
$$+\uparrow \Sigma F_y = 0; \quad 2(72.0) - n(0.95)(9.81) = 0 \qquad n = 15.45$$

Thus, the maximum number of books can be supported in stack is

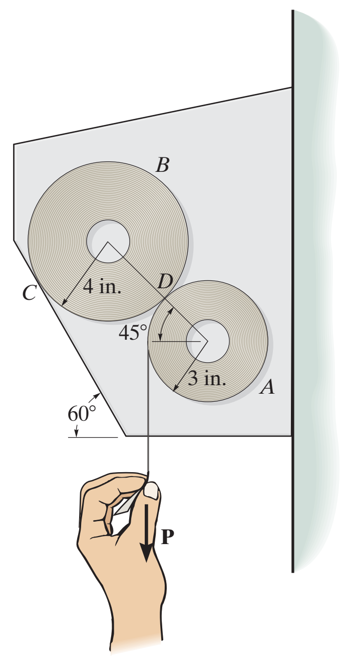
$$n = 10 + 2 = 12 \qquad \textbf{Ans}$$



(a)



8–23. The paper towel dispenser carries two rolls of paper. The one in use is called the stub roll A and the other is the fresh roll B. They weigh 2 lb and 5 lb, respectively. If the coefficients of static friction at the points of contact C and D are $(\mu_s)_C = 0.2$ and $(\mu_s)_D = 0.5$, determine the initial vertical force P that must be applied to the paper on the stub roll in order to pull down a sheet. The stub roll is pinned in the center, whereas the fresh roll is not. Neglect friction at the pin.



Equations of Equilibrium : From FBD (a),

$$\circlearrowleft + \Sigma M_E = 0; \quad P(3) - F_D(3) = 0 \qquad [1]$$

From FBD (b),

$$\circlearrowleft + \Sigma M_F = 0; \quad F_C(4) - F_D(4) = 0 \qquad [2]$$

$$+\uparrow \Sigma F_y = 0; \quad N_C \sin 30° + N_D \sin 45° - F_C \sin 60° - F_D \sin 45° - 5 = 0 \qquad [3]$$

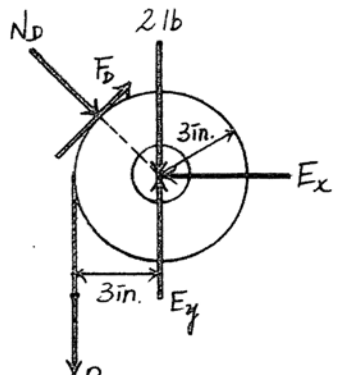
$$\overset{+}{\rightarrow} \Sigma F_x = 0; \quad N_C \cos 30° + F_C \cos 60° - N_D \cos 45° - F_D \cos 45° = 0 \qquad [4]$$

Friction : Assume slipping occurs at point C. Hence, $F_C = \mu_{s\,C} N_C = 0.2 N_C$. Substituting this value into Eqs. [1], [2], [3] and [4] and solving we have

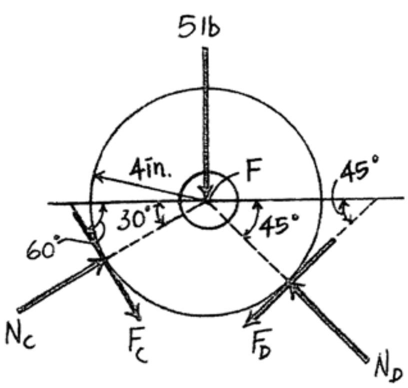
$N_D = 5.773$ lb $\quad N_C = 4.951$ lb $\quad F_D = 0.9901$ lb

$P = 0.990$ lb **Ans**

Since $F_D < (F_D)_{max} = (\mu_s)_D N_D = 0.5(5.773) = 2.887$ lb, then slipping does not occur at point D. Therefore, the above assumption is correct.

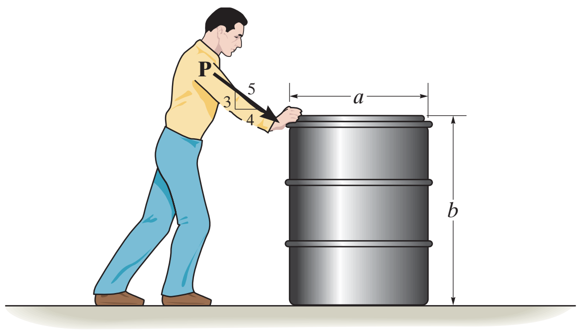


(a)



(b)

***8–24.** The drum has a weight of 100 lb and rests on the floor for which the coefficient of static friction is $\mu_s = 0.6$. If $a = 2$ ft and $b = 3$ ft, determine the smallest magnitude of the force P that will cause impending motion of the drum.



Assume that the drum tips :

$x = 1$ ft

$\curvearrowleft + \Sigma M_O = 0; \quad 100(1) + P\left(\frac{3}{5}\right)(2) - P\left(\frac{4}{5}\right)(3) = 0$

$P = 83.3$ lb

$\xrightarrow{+} \Sigma F_x = 0; \quad -F + 83.3\left(\frac{4}{5}\right) = 0$

$F = 66.7$ lb

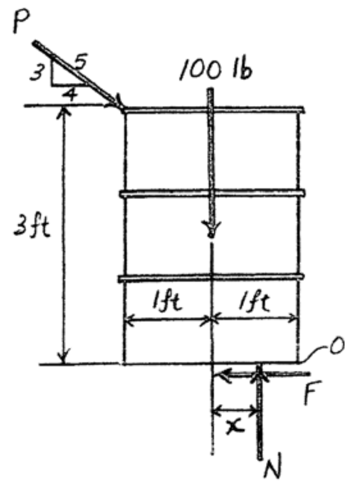
$+\uparrow \Sigma F_y = 0; \quad N - 100 - 83.3\left(\frac{3}{5}\right) = 0$

$N = 150$ lb

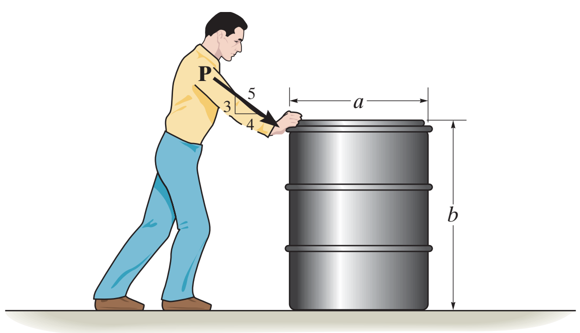
$F_{max} = 0.6(150) = 90 \text{ lb} > 66.7 \quad$ OK

Drum tips as assumed.

$P = 83.3$ lb **Ans**



•8–25. The drum has a weight of 100 lb and rests on the floor for which the coefficient of static friction is $\mu_s = 0.5$. If $a = 3$ ft and $b = 4$ ft, determine the smallest magnitude of the force P that will cause impending motion of the drum.



Assume that the drum slips :

$F = 0.5N$

$\xrightarrow{+} \Sigma F_x = 0; \quad -0.5N + P\left(\frac{4}{5}\right) = 0$

$+\uparrow \Sigma F_y = 0; \quad -P\left(\frac{3}{5}\right) - 100 + N = 0$

$P = 100$ lb

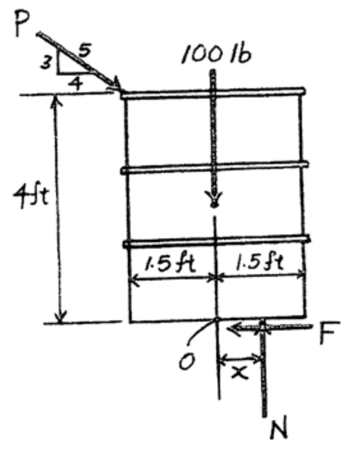
$N = 160$ lb

$\curvearrowleft + \Sigma M_O = 0; \quad 160(x) + 100\left(\frac{3}{5}\right)(1.5) - 100\left(\frac{4}{5}\right)(4) = 0$

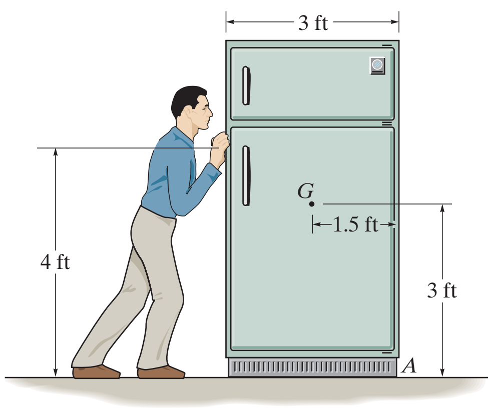
$x = 1.44 \text{ ft} < 1.5 \text{ ft} \quad$ OK

Drum slips as assumed.

$P = 100$ lb **Ans**



8–26. The refrigerator has a weight of 180 lb and rests on a tile floor for which $\mu_s = 0.25$. If the man pushes horizontally on the refrigerator in the direction shown, determine the smallest magnitude of horizontal force needed to move it. Also, if the man has a weight of 150 lb, determine the smallest coefficient of friction between his shoes and the floor so that he does not slip.



Equations of Equilibrium : From FBD (a),

$$+\uparrow \Sigma F_y = 0; \quad N - 180 = 0 \quad N = 180 \text{ lb}$$

$$\xrightarrow{+} \Sigma F_x = 0; \quad P - F = 0 \qquad [1]$$

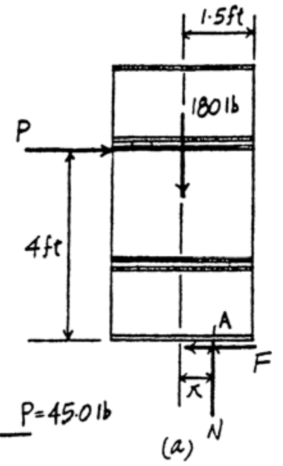
$$\circlearrowleft + \Sigma M_A = 0; \quad 180(x) - P(4) = 0 \qquad [2]$$

Friction : Assuming the refrigerator is on the verge of slipping, then $F = \mu N = 0.25(180) = 45$ lb. Substituting this value into Eqs. [1], and [2] and solving yields

$$P = 45.0 \text{ lb} \qquad x = 1.00 \text{ ft}$$

Since $x < 1.5$ ft, the refrigerator does not tip. Therefore, the above assumption is correct. Thus

$$P = 45.0 \text{ lb} \qquad \textbf{Ans}$$



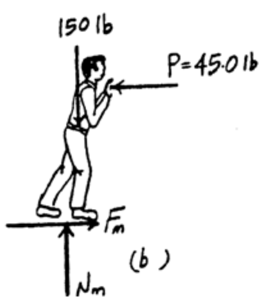
From FBD (b),

$$+\uparrow \Sigma F_y = 0; \quad N_m - 150 = 0 \quad N_m = 150 \text{ lb}$$

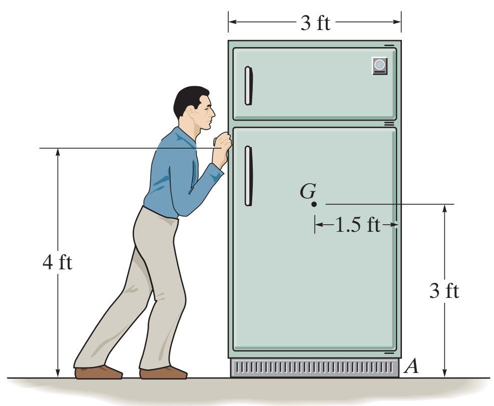
$$\xrightarrow{+} \Sigma F_x = 0; \quad F_m - 45.0 = 0 \quad F_m = 45.0 \text{ lb}$$

When the man is on the verge of slipping, then

$$F_m = \mu_s' N_m$$
$$45.0 = \mu_s'(150)$$
$$\mu_s' = 0.300 \qquad \textbf{Ans}$$



8–27. The refrigerator has a weight of 180 lb and rests on a tile floor for which $\mu_s = 0.25$. Also, the man has a weight of 150 lb and the coefficient of static friction between the floor and his shoes is $\mu_s = 0.6$. If he pushes horizontally on the refrigerator, determine if he can move it. If so, does the refrigerator slip or tip?



Equations of Equilibrium : From FBD (a),

$+\uparrow \Sigma F_y = 0; \quad N - 180 = 0 \quad N = 180 \text{ lb}$

$\xrightarrow{+} \Sigma F_x = 0; \quad P - F = 0 \qquad [1]$

$\circlearrowleft + \Sigma M_A = 0; \quad 180(x) - P(4) = 0 \qquad [2]$

Friction : Assuming the refrigerator is on the verge of slipping, then $F = \mu N = 0.25(180) = 45$ lb. Substituting this value into Eqs. [1], and [2] and solving yields

$$P = 45.0 \text{ lb} \qquad x = 1.00 \text{ ft}$$

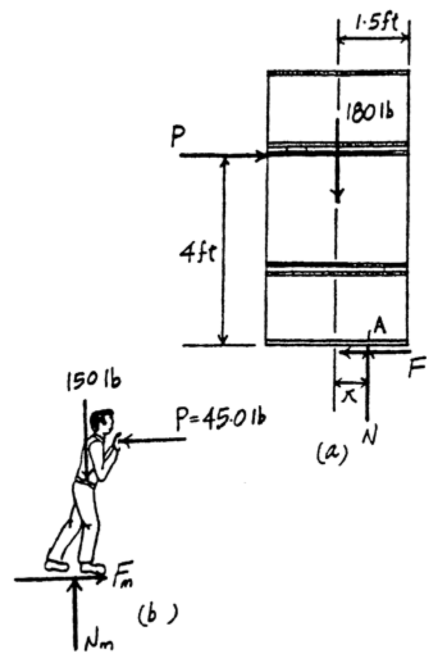
Since $x < 1.5$ ft, the refrigerator does not tip. Therefore, the above assumption is correct. Thus, **the refrigerator slips.** **Ans**

From FBD (b),

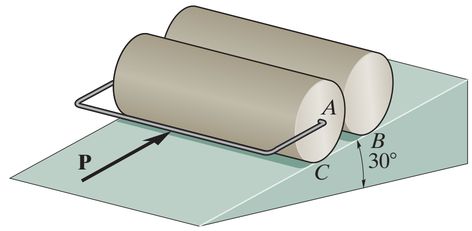
$+\uparrow \Sigma F_y = 0; \quad N_m - 150 = 0 \quad N_m = 150 \text{ lb}$

$\xrightarrow{+} \Sigma F_x = 0; \quad F_m - 45.0 = 0 \quad F_m = 45.0 \text{ lb}$

Since $(F_m)_{max} = \mu_s' N_m = 0.6(150) = 90.0 \text{ lb} > F_m$, then the man does not slip. Thus, **The man is capable of moving the refrigerator.** **Ans**



***8–28.** Determine the minimum force P needed to push the two 75-kg cylinders up the incline. The force acts parallel to the plane and the coefficients of static friction of the contacting surfaces are $\mu_A = 0.3$, $\mu_B = 0.25$, and $\mu_C = 0.4$. Each cylinder has a radius of 150 mm.



Equations of Equilibrium : From FBD (a),

$$+\Sigma F_{x'} = 0; \quad P - N_A - F_C - 735.75\sin 30° = 0 \quad [1]$$

$$+\Sigma F_{y'} = 0; \quad N_C + F_A - 735.75\cos 30° = 0 \quad [2]$$

$$+\Sigma M_O = 0; \quad F_A(r) - F_C(r) = 0 \quad [3]$$

From FBD (b),

$$+\Sigma F_{x'} = 0; \quad N_A - F_B - 735.75\sin 30° = 0 \quad [4]$$

$$+\Sigma F_{y'} = 0; \quad N_B - F_A - 735.75\cos 30° = 0 \quad [5]$$

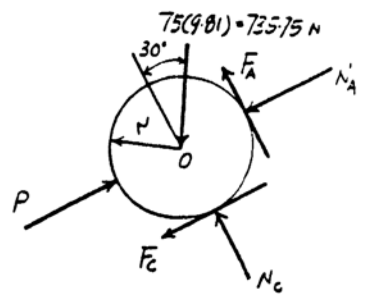
$$+\Sigma M_O = 0; \quad F_A(r) - F_B(r) = 0 \quad [6]$$

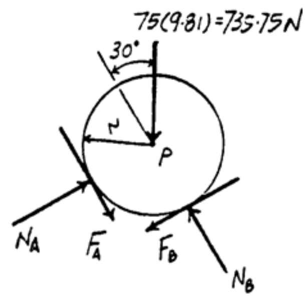
Friction : Assuming slipping occur at point A, then $F_A = \mu_{s\,A} N_A = 0.3N_A$. Substituting this value into Eqs. [1], [2], [3], [4], [5] and [6] and solving, we have

$$N_A = 525.54\text{ N} \qquad N_B = 794.84\text{ N}$$
$$N_C = 479.52\text{ N} \qquad F_C = F_B = 157.66\text{ N}$$

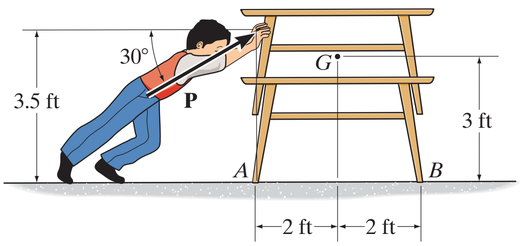
$$P = 1051.07\text{ N} = 1.05\text{ kN} \qquad \textbf{Ans}$$

Since $(F_C)_{max} = \mu_{s\,C} N_C = 0.4(479.52) = 191.81\text{ N} > F_C$ and $(F_B)_{max} = \mu_{s\,B} N_B = 0.25(794.84) = 198.71\text{ N} > F_B$, slipping do not occur at points C and B. Therefore the above assumption is correct.





•**8–29.** If the center of gravity of the stacked tables is at G, and the stack weighs 100 lb, determine the smallest force P the boy must push on the stack in order to cause movement. The coefficient of static friction at A and B is $\mu_s = 0.3$. The tables are locked together.



Free - Body Diagram. The impending motion of the stack could be due to either sliding or tipping about point B. We will assume that sliding occurs. Thus, $F_A = \mu_s N_A = 0.3N_A$ and $F_B = \mu_s N_B = 0.3N_B$.

Equations of Equilibrium. Referring to the free - body diagram of the stack shown in Fig. a,

$\overset{+}{\rightarrow}\Sigma F_x = 0;$ $\quad P\cos 30° - 0.3N_A - 0.3N_B = 0$

$+\uparrow \Sigma F_y = 0;$ $\quad N_A + N_B + P\sin 30° - 100 = 0$

$\circlearrowleft + \Sigma M_A = 0;$ $\quad N_B(4) - P\cos 30°(3.5) - 100(2) = 0$

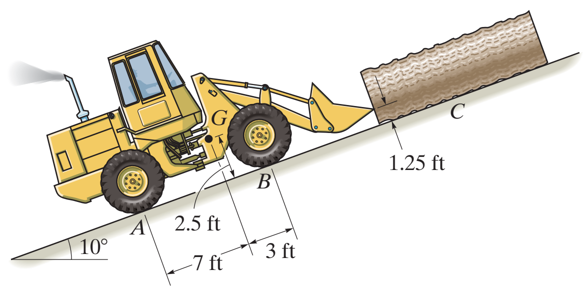
Solving,

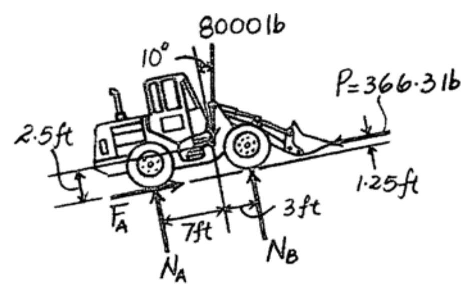
$P = 29.5\text{ N}$ **Ans.**

$N_A = 12.9\text{ N}$ $\quad N_B = 72.4\text{ N}$

Since the result for N_A is a positive quantity, the leg of the chair at A still remains in contact with the floor. This means that the stack will not tip. Thus, the above assumption is correct.

8–30. The tractor has a weight of 8000 lb with center of gravity at G. Determine if it can push the 550-lb log up the incline. The coefficient of static friction between the log and the ground is $\mu_s = 0.5$, and between the rear wheels of the tractor and the ground $\mu_s' = 0.8$. The front wheels are free to roll. Assume the engine can develop enough torque to cause the rear wheels to slip.





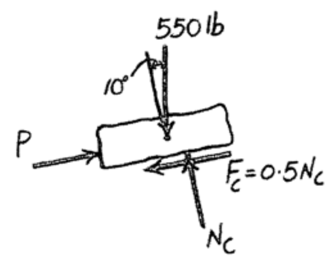
Log:

$+\nwarrow \Sigma F_y = 0;\quad N_C - 550 \cos 10° = 0$

$N_C = 541.6 \text{ lb}$

$+\nearrow \Sigma F_x = 0;\quad -0.5(541.6) - 550 \sin 10° + P = 0$

$P = 366.3 \text{ lb}$



Tractor:

$\circlearrowleft + \Sigma M_B = 0;\quad 366.3(1.25) + 8000(\cos 10°)(3) + 8000(\sin 10°)(2.5) - N_A(10) = 0$

$N_A = 2757 \text{ lb}$

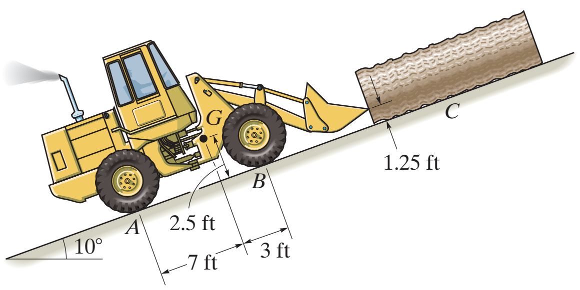
$+\nearrow \Sigma F_x = 0;\quad F_A - 8000 \sin 10° - 366.3 = 0$

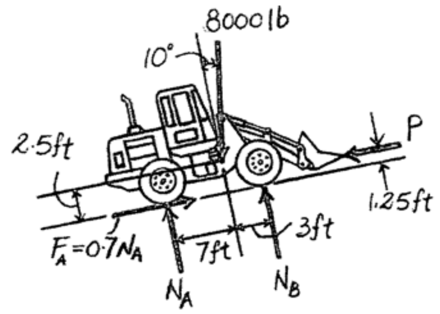
$F_A = 1756 \text{ lb}$

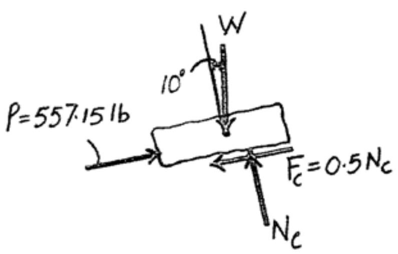
$(F_A)_{max} = 0.8(2757) = 2205 \text{ lb} > 1756 \text{ lb}$

Tractor can move log. **Ans**

8–31. The tractor has a weight of 8000 lb with center of gravity at G. Determine the greatest weight of the log that can be pushed up the incline. The coefficient of static friction between the log and the ground is $\mu_s = 0.5$, and between the rear wheels of the tractor and the ground $\mu_s' = 0.7$. The front wheels are free to roll. Assume the engine can develop enough torque to cause the rear wheels to slip.







Tractor:

$\circlearrowleft + \Sigma M_B = 0;\quad 8000(\cos 10°)(3) + 8000(\sin 10°)(2.5) + P(1.25) - N_A(10) = 0$

$N_A - P(0.125) = 2710.8$

$+\nearrow \Sigma F_x = 0;\quad 0.7N_A - 8000 \sin 10° - P = 0$

$0.7N_A - P = 1389.2$

$N_A = 2780 \text{ lb}$

$P = 557.15 \text{ lb}$

Log:

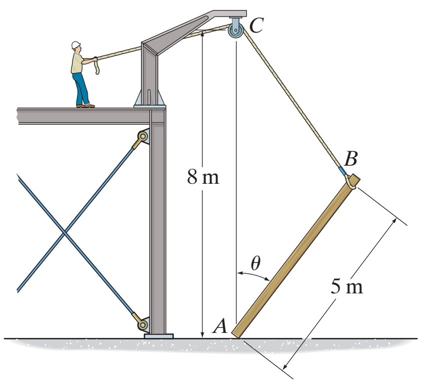
$+\nwarrow \Sigma F_y = 0;\quad N_C - W \cos 10° = 0$

$+\nearrow \Sigma F_x = 0;\quad 557.15 - W \sin 10° - 0.5N_C = 0$

$N_C = 824 \text{ lb}$

$W = 836 \text{ lb}$ **Ans**

***8–32.** The 50-kg uniform pole is on the verge of slipping at A when $\theta = 45°$. Determine the coefficient of static friction at A.



Free - Body Diagram. By referring to the geometry shown in Fig. a,

$$\tan\alpha = \frac{8 - 5\cos 45°}{5\sin 45°} \qquad \alpha = 51.62°$$

$$\phi = 180° - 45° - \alpha = 83.38°$$

Since the end A of the pole is on the verge of sliding to the left due to $\mathbf{T}_{BC}$, the frictional force $\mathbf{F}_A$ must act to the right such that $F_A = \mu_s N_A$ as indicated on the free-body diagram of the pole, Fig. *b*.

Equations of Equilibrium. Referring to Fig. *b*,

$\circlearrowleft + \Sigma M_A = 0;$ $\quad T_{BC}\sin 83.38°(5) - 50(9.81)\sin 45°(2.5) = 0$

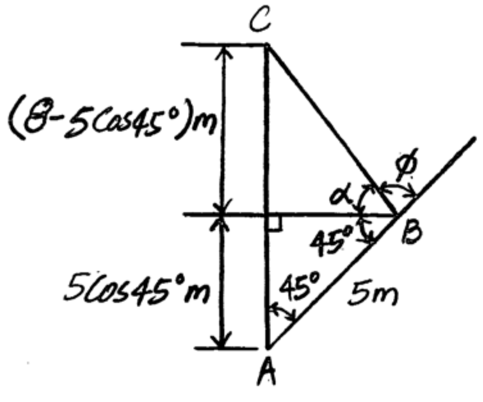
$T_{BC} = 175\text{N}$

$+\uparrow \Sigma F_y = 0;$ $\quad N_A + 209.50\sin 51.62° - 50(9.81) = 0$

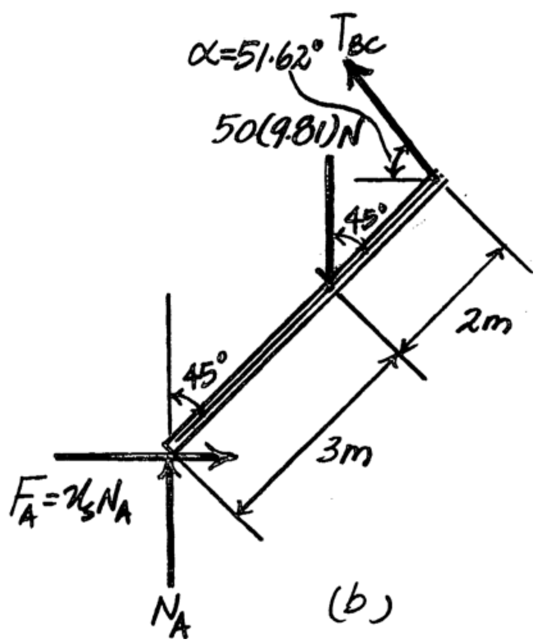
$N_A = 353.6\text{ N}$

$\overset{+}{\rightarrow} \Sigma F_x = 0;$ $\quad \mu_s(326.26) - 209.50\cos 51.62° = 0$

$\mu_s = 0.306$ **Ans.**

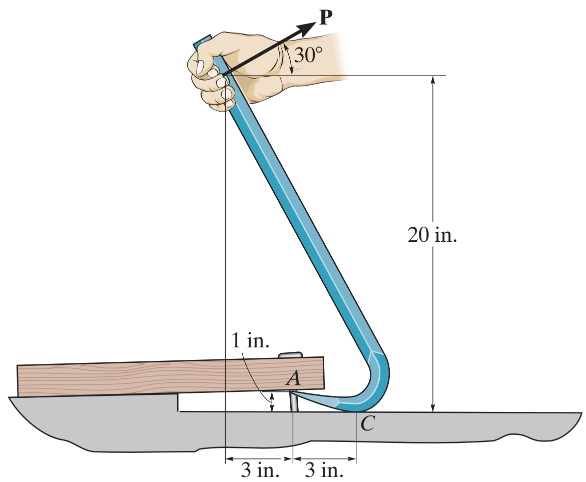


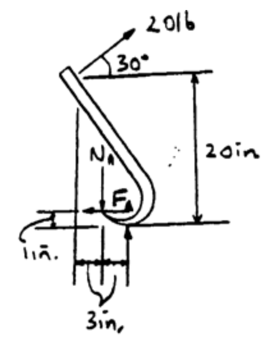
(a)

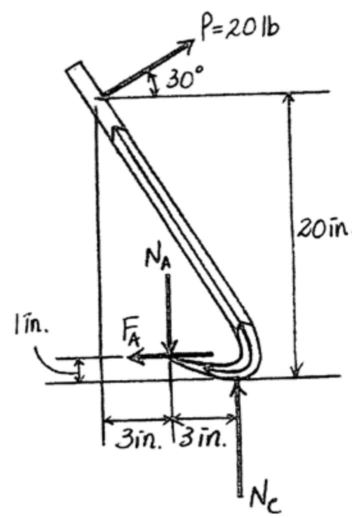


(b)

•8–33. A force of $P = 20$ lb is applied perpendicular to the handle of the gooseneck wrecking bar as shown. If the coefficient of static friction between the bar and the wood is $\mu_s = 0.5$, determine the normal force of the tines at A on the upper board. Assume the surface at C is smooth.







$\xrightarrow{+} \Sigma F_x = 0; \quad 20 \cos 30° - F_A = 0$

$F_A = 17.32 \text{ lb}$

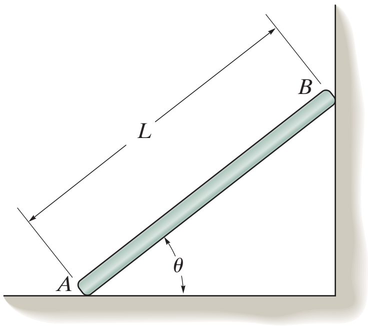
$\circlearrowleft + \Sigma M_C = 0; \quad N_A (3) + 17.32 (1) - 20 \cos 30° (20) - 20 \sin 30° (6) = 0$

$N_A = 129.7 \text{ lb} = 130 \text{ lb}$ **Ans**

$F_{max} = 0.5 (129.7) = 64.8 \text{ lb} > 17.32 \text{ lb}$

The bar will not slip.

8–34. The thin rod has a weight W and rests against the floor and wall for which the coefficients of static friction are μ_A and μ_B, respectively. Determine the smallest value of θ for which the rod will not move.

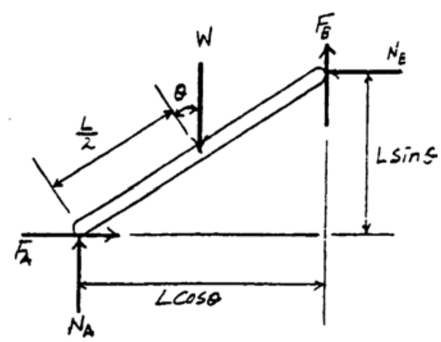


Equations of Equilibrium :

$$\xrightarrow{+} \Sigma F_x = 0; \quad F_A - N_B = 0 \qquad [1]$$

$$+\uparrow \Sigma F_y = 0 \quad N_A + F_B - W = 0 \qquad [2]$$

$$\curvearrowleft + \Sigma M_A = 0; \quad N_B\,(L\sin\theta) + F_B\,(\cos\theta)L - W\cos\theta\left(\frac{L}{2}\right) = 0 \qquad [3]$$

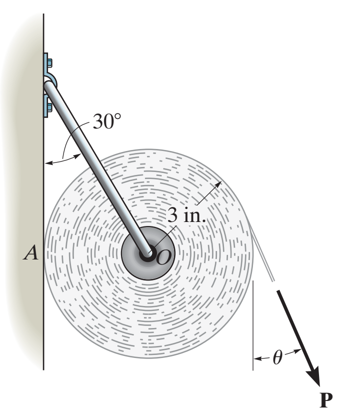


Friction : If the rod is on the verge of moving, slipping will have to occur at points A and B. Hence, $F_A = \mu_A N_A$ and $F_B = \mu_B N_B$ .Substituting these values into Eqs. [1], [2] and [3] and solving we have

$$N_A = \frac{W}{1+\mu_A\mu_B} \qquad N_B = \frac{\mu_A W}{1+\mu_A\mu_B}$$

$$\theta = \tan^{-1}\left(\frac{1-\mu_A\mu_B}{2\mu_A}\right) \qquad \textbf{Ans}$$

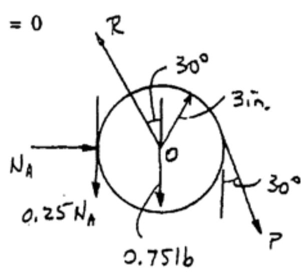
8–35. A roll of paper has a uniform weight of 0.75 lb and is suspended from the wire hanger so that it rests against the wall. If the hanger has a negligible weight and the bearing at O can be considered frictionless, determine the force P needed to start turning the roll if $\theta = 30°$. The coefficient of static friction between the wall and the paper is $\mu_s = 0.25$.



$$\xrightarrow{+} \Sigma F_x = 0; \quad N_A - R\sin 30° + P\sin 30° = 0$$

$$+\uparrow \Sigma F_y = 0; \quad R\cos 30° - 0.75 - P\cos 30° - 0.25\,N_A = 0$$

$$\curvearrowleft + \Sigma M_O = 0; \quad 0.25\,N_A\,(3) - P\,(3) = 0$$



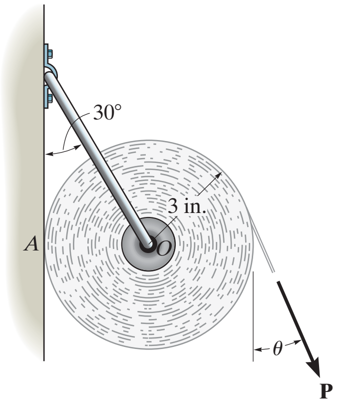
Solving for P,

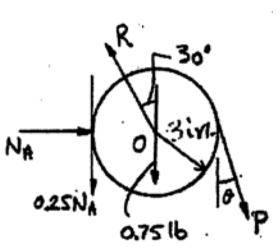
$$R = 1.14 \text{ lb}$$

$$N_A = 0.506 \text{ lb}$$

$$P = 0.127 \text{ lb} \qquad \textbf{Ans}$$

*__8–36.__ A roll of paper has a uniform weight of 0.75 lb and is suspended from the wire hanger so that it rests against the wall. If the hanger has a negligible weight and the bearing at O can be considered frictionless, determine the minimum force P and the associated angle θ needed to start turning the roll. The coefficient of static friction between the wall and the paper is $\mu_s = 0.25$.





$$\xrightarrow{+} \Sigma F_x = 0; \quad N_A - R\sin 30° + P\sin\theta = 0$$

$$+\uparrow \Sigma F_y = 0; \quad R\cos 30° - 0.75 - P\cos\theta - 0.25N_A = 0$$

$$\circlearrowleft + \Sigma M_O = 0; \quad 0.25N_A(3) - P(3) = 0$$

Solving for P,

$$P = \frac{0.433013}{(3.4226 + \sin\theta - 0.57735\cos\theta)} \quad (1)$$

For maximum or minimum P,

$$\frac{dP}{d\theta} = \frac{0 - (0.433013)(\cos\theta + 0.57735\sin\theta)}{(3.4226 + \sin\theta - 0.57735\cos\theta)^2} = 0$$

$$\cos\theta + 0.57735\sin\theta = 0$$

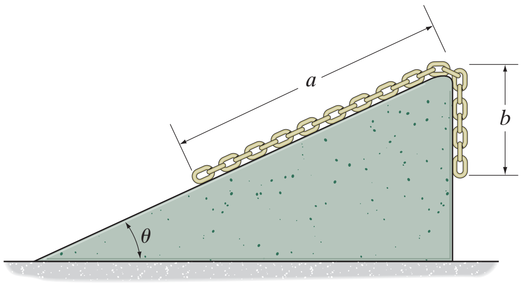
$$\tan\theta = -1.732$$

$$\theta = -60° \text{ or } 120°$$

For minimum P choose $\theta = 120°$, since N_A would be smaller than for $\theta = -60°$. Also, a comparison could be made from substitution into Eq. (1). Using $\theta = 120°$,

$$P = \frac{0.433013}{(3.4226 + \sin 120° - 0.57735\cos 120°)} = 0.0946 \text{ lb} \qquad \text{Ans}$$

•8–37. If the coefficient of static friction between the chain and the inclined plane is $\mu_s = \tan\theta$, determine the overhang length b so that the chain is on the verge of slipping up the plane. The chain weighs w per unit length.



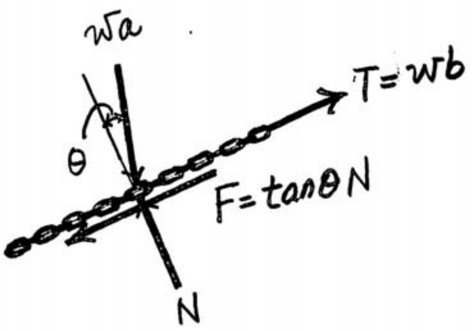
Free - Body Diagram. The tension developed in the chain at the end of the inclined plane is equal to the weight of the overhanging chain, i.e. $T = wb$. Since the chain is required to be on the verge of sliding up the plane, the frictional force **F** must act down the plane so that $F = \mu_s N = \tan\theta N$ as indicated on the free - body diagram of the chain shown in Fig. *a*.

Equations of Equilibrium.

$+\nwarrow \Sigma F_{y'} = 0;\quad N - wa\cos\theta = 0 \qquad N = wa\cos\theta$

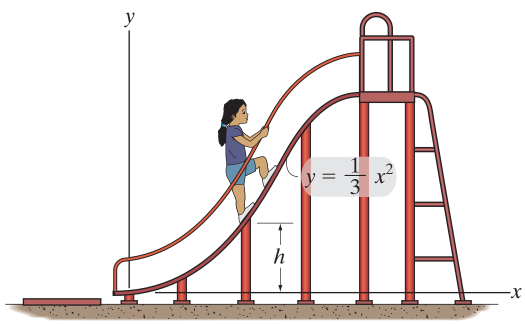
$+\nearrow \Sigma F_{x'} = 0;\quad wb - wa\sin\theta - \tan\theta(wa\cos\theta) = 0$

$b = 2a\sin\theta$ **Ans.**



(a)

8–38. Determine the maximum height h in meters to which the girl can walk up the slide without supporting herself by the rails or by her left leg. The coefficient of static friction between the girl's shoes and the slide is $\mu_s = 0.8$.



Free - Body Diagram. Since the girl is required to be on the verge of slipping down, the frictional force **F** must act upwards so that $F = \mu_s N = 0.8N$ as indicated on the free - body diagram of the girl shown in Fig. *a*.

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

$+\nwarrow \Sigma F_{y'} = 0;\quad N - mg\cos\theta = 0 \qquad N = mg\cos\theta$

$+\nearrow \Sigma F_{x'} = 0;\quad 0.8(mg\cos\theta) - mg\sin\theta = 0 \qquad \tan\theta = 0.8$

From the geometry of the slide, we have $\frac{dy}{dx} = \frac{2}{3}x$. Thus,

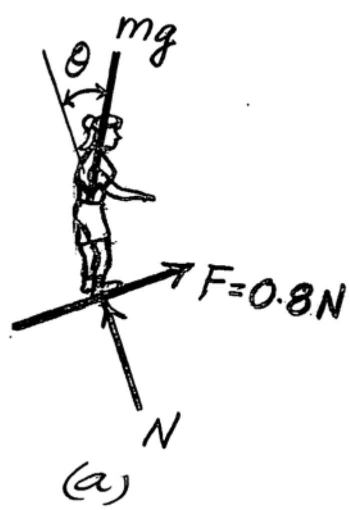
$$\frac{dy}{dx} = \tan\theta$$

$$\frac{2}{3}x = 0.8$$

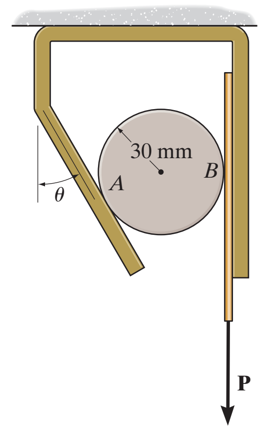
$$x = 1.2\text{ m}$$

Therefore,

$$h = \frac{1}{3}(1.2)^2 = 0.48\text{ m}$$ **Ans.**



8–39. If the coefficient of static friction at B is $\mu_s = 0.3$, determine the largest angle θ and the minimum coefficient of static friction at A so that the roller remains self-locking, regardless of the magnitude of force **P** applied to the belt. Neglect the weight of the roller and neglect friction between the belt and the vertical surface.



Free - Body Diagram. Since the belt is required to be on the verge of slipping downwards, the frictional force $\mathbf{F}_B$ must act downward on the rod so that $F_B = \mu_s N_B = 0.3N_B$ as indicated on the free - body diagram of the cylinder shown in Fig. *a*.

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

$\circlearrowleft + \Sigma M_A = 0;\quad N_B(0.03\sin\theta) - 0.3N_B(0.03 + 0.03\cos\theta) = 0$

$\sin\theta - 0.3\cos\theta = 0.3$

$\theta = 33.40° = 33.4°$ **Ans.**

$\xrightarrow{+} \Sigma F_x = 0;\quad F_A \sin 33.40° + N_A \cos 33.40° - N_B = 0$

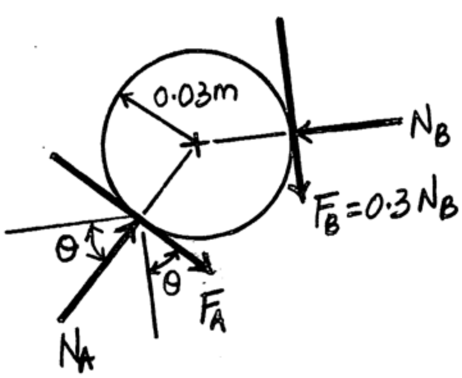
$+\uparrow \Sigma F_y = 0;\quad N_A \sin 33.40° - F_A \cos 33.40° - 0.3N_B = 0$

Solving,

$F_A = 0.3N_B \quad N_A = N_B$

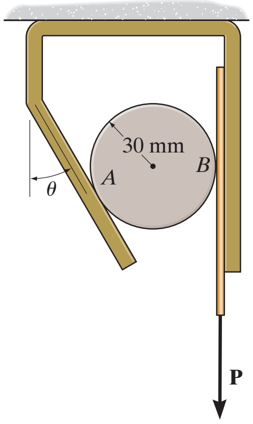
To prevent slipping at *A*, the coefficient of static friction at *A* must be at least

$$\mu_s = \frac{F_A}{N_A} = \frac{0.3N_B}{N_B} = 0.3$$ **Ans.**



(a)

***8–40.** If $\theta = 30°$, determine the minimum coefficient of static friction at A and B so that the roller remains self-locking, regardless of the magnitude of force **P** applied to the belt. Neglect the weight of the roller and neglect friction between the belt and the vertical surface.



Free - Body Diagram. Since the belt is required to be on the verge of slipping downwards, the frictional force $\mathbf{F}_B$ must act downward on the roller so that $F_B = \mu_s N_B$ as indicated on the free - body diagram of the roller shown in Fig. *a*.

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

$\curvearrowleft + \Sigma M_A = 0;$ $\quad N_B(0.03 \sin 30°) - \mu_s N_B(0.03 + 0.03 \cos 30°) = 0$

$\mu_s = 0.2679 = 0.268$ **Ans.**

$\overset{+}{\rightarrow} \Sigma F_x = 0;$ $\quad F_A \sin 30° + N_A \sin 60° - N_B = 0$

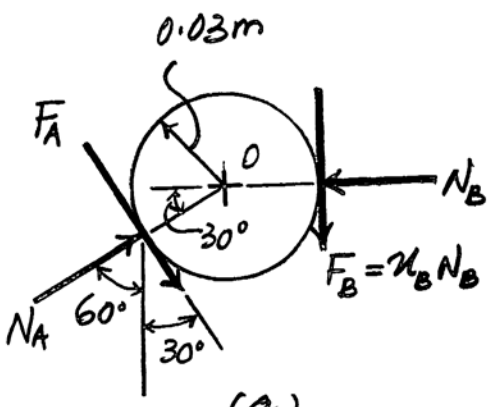
$+\uparrow \Sigma F_y = 0;$ $\quad -F_A \cos 30° + N_A \cos 60° - 0.2679 N_B = 0$

Solving,

$$F_A = 0.2679 N_B \quad N_A = N_B$$

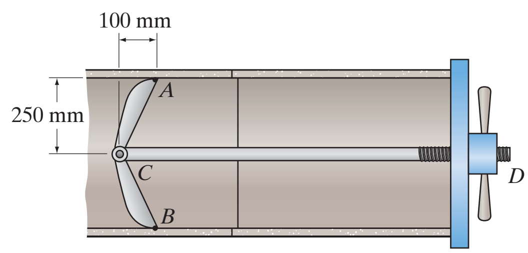
To prevent slipping at A, the coefficient of static friction at A must be at least

$$\mu_s = \frac{F_A}{N_A} = \frac{0.2679 N_B}{N_B} = 0.268$$ **Ans.**



(a)

•8–41. The clamp is used to tighten the connection between two concrete drain pipes. Determine the least coefficient of static friction at *A* or *B* so that the clamp does not slip regardless of the force in the shaft *CD*.



Free - Body Diagram. Since member *CA* tends to move to the right, the frictional force $\mathbf{F}_A$ must act to the left as indicated on the free - body diagram of member *CA* shown in Fig. *a*.

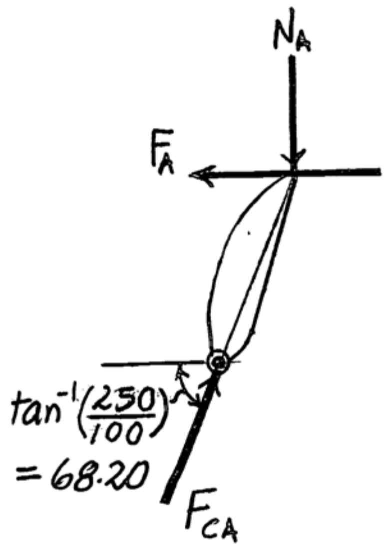
Equations of Equilibrium. Referring to Fig. *a*,

$\xrightarrow{+} \Sigma F_x = 0;\quad F_{CA}\cos 68.20° - F_A = 0\quad F_A = 0.3714F_{CA}$

$+\uparrow \Sigma F_y = 0;\quad F_{CA}\sin 68.20° - N_A = 0\quad N_A = 0.9285F_{CA}$

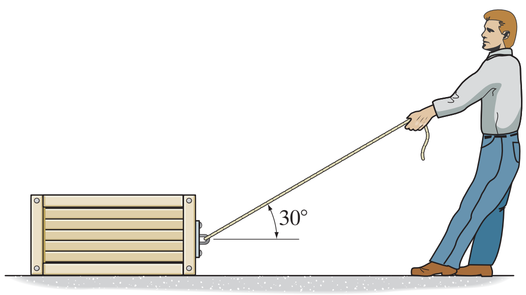
To prevent slipping at *A*, the coefficient of static friction at *A* must be at least

$$\mu_s = \frac{F_A}{N_A} = \frac{0.3714F_{CA}}{0.9285F_{CA}} = 0.4$$ **Ans.**



(a)

8–42. 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.



Free - Body Diagram. Since **P** tends to move the crate to the right, the frictional force $\mathbf{F}_C$ 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 $\mathbf{F}_C$ 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 $\mathbf{F}_m$ acts to the right since force **P** has the tendency to cause the man to slip to the left.

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

$+\uparrow \Sigma F_y = 0; \qquad N_C + P\sin 30° - 150(9.81) = 0$

$\overset{+}{\rightarrow} \Sigma F_x = 0; \qquad P\cos 30° - 0.3N_C = 0$

Solving,

$P = 434.49\text{ N}$

$N_C = 1254.26\text{ N}$

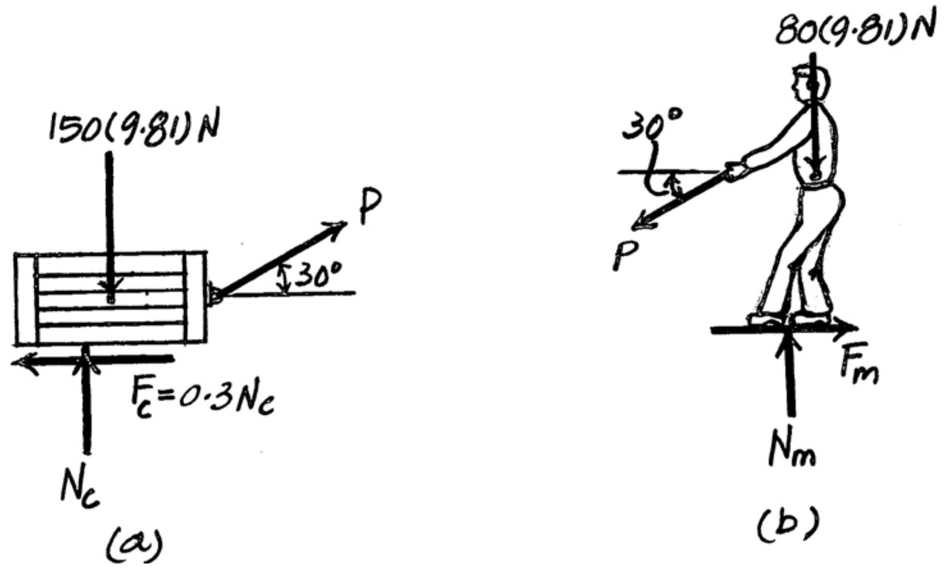
Using the result of P and referring to Fig. *a*, we have

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

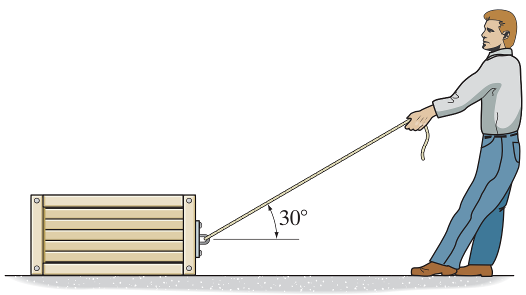
$\overset{+}{\rightarrow} \Sigma F_x = 0; \qquad F_m - 434.49\cos 30° = 0 \qquad F_m = 376.28\text{ N}$

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

he can move the crate. **Ans.**



8–43. If the coefficient of static friction between the crate and the ground is $\mu_s = 0.3$, determine the minimum coefficient of static friction between the man's shoes and the ground so that the man can move the crate.



Free - Body Diagram. Since force **P** tends to move the crate to the right, the frictional force $\mathbf{F}_C$ 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, $F_C = \mu_s N_C = 0.3\,N_C$. As indicated on the free - body diagram of the man shown in Fig. *b*, the frictional force $\mathbf{F}_m$ acts to the right since force **P** has the tendency to cause the man to slip to the left.

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

$+\uparrow \Sigma F_y = 0;\qquad N_C + P\sin 30° - 150(9.81) = 0$

$\overset{+}{\rightarrow} \Sigma F_x = 0;\qquad P\cos 30° - 0.3N_C = 0$

Solving yields

$$P = 434.49\text{ N}$$
$$N_C = 1254.26\text{ N}$$

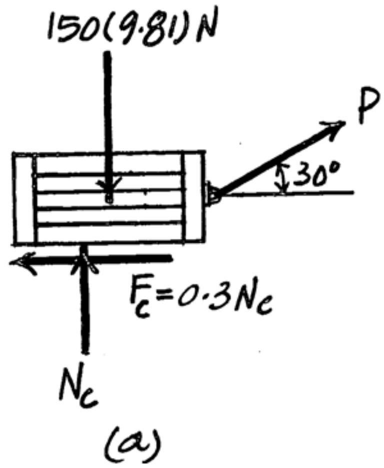
Using the result of **P** and referring to Fig. *a*,

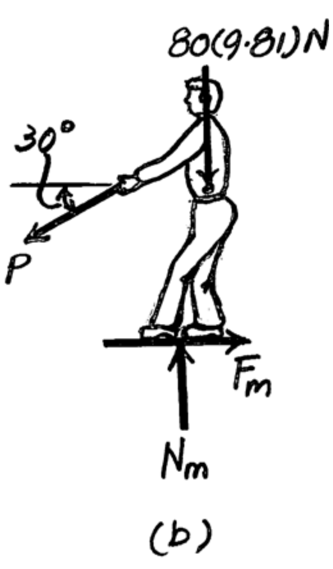
$+\uparrow \Sigma F_y = 0;\qquad N_m - 434.49\sin 30° - 80(9.81) = 0\qquad N_m = 1002.04\text{ N}$

$\overset{+}{\rightarrow} \Sigma F_x = 0;\qquad F_m - 434.49\cos 30° = 0\qquad F_m = 376.28\text{ N}$

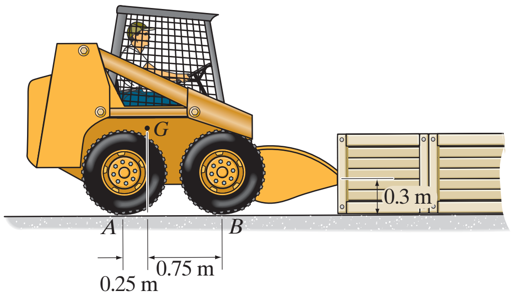
Thus, the required minimum coefficient of static friction between the man's shoes and the ground is given by

$$\mu_s' = \frac{F_m}{N_m} = \frac{376.28}{1002.04} = 0.376 \qquad \textbf{Ans.}$$





***8–44.** The 3-Mg rear-wheel-drive skid loader has a center of mass at G. Determine the largest number of crates that can be pushed by the loader if each crate has a mass of 500 kg. The coefficient of static friction between a crate and the ground is $\mu_s = 0.3$, and the coefficient of static friction between the rear wheels of the loader and the ground is $\mu_s' = 0.5$. The front wheels are free to roll. Assume that the engine of the loader is powerful enough to generate a torque that will cause the rear wheels to slip.



Free - Body Diagram. Since the frictional force $\mathbf{F}_A$ provides the driving force to the skid roller which is about to move to the right, it must act to the right as indicated on the free - body diagram shown in Fig. *a*. Here, $\mathbf{F}_A$ is required to be maximum, i.e., $F_A = \mu_s N_A = 0.5N_A$. Since the crates are required to be on the verge of slipping to the right, the frictional force $\mathbf{F}_C$ must act to the left so that $F_C = \mu_s N_C = 0.3N_C$ as indicated on the free - body diagram of the crate shown in Fig. *b*.

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

$\circlearrowleft + \Sigma M_B = 0; \quad P(0.3) + 3000(9.81)(0.75) - N_A(1) = 0$

$\overset{+}{\rightarrow} \Sigma F_x = 0; \quad 0.5N_A - P = 0$

Solving,

$$P = 12983.82\text{ N} \quad N_A = 25967.65\text{ N}$$

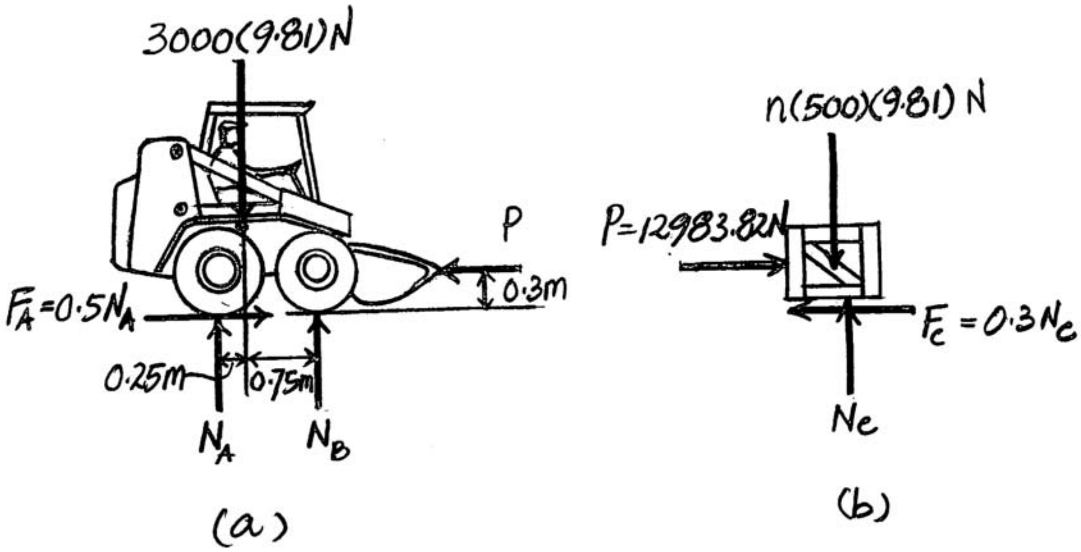
Using the result of **P** and referring to Fig. *b*,

$+\uparrow \Sigma F_y = 0; \quad N_C - n(500)(9.81) = 0 \quad N_C = 4905n$

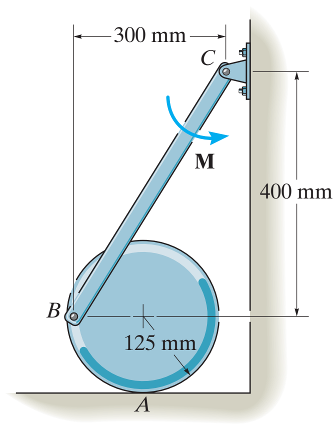
$\overset{+}{\rightarrow} \Sigma F_x = 0; \quad 12983.82 - 0.3(4905n) = 0 \quad n = 8.82$

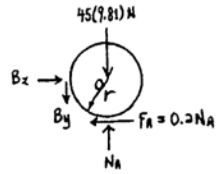
Thus, the largest number of crates that can be pushed by the skid roller is

$$n = 8$$ **Ans.**



•8–45. The 45-kg disk rests on the surface for which the coefficient of static friction is $\mu_A = 0.2$. Determine the largest couple moment M that can be applied to the bar without causing motion.





$\circlearrowleft + \Sigma M_O = 0;$ $\quad F_A = B_y = 0.2\,N_A$

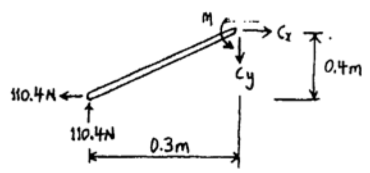
$\overset{+}{\rightarrow} \Sigma F_x = 0;$ $\quad B_x - 0.2N_A = 0$

$+\uparrow \Sigma F_y = 0;$ $\quad N_A - B_y - 45(9.81) = 0$

$N_A = 551.8 \text{ N}$

$B_x = 110.4 \text{ N}$

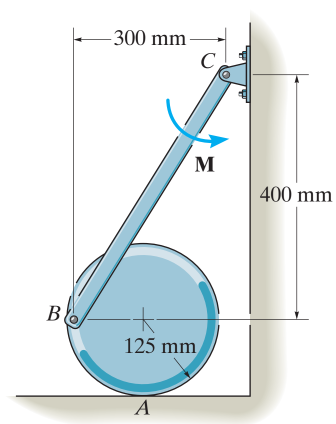
$B_y = 110.4 \text{ N}$



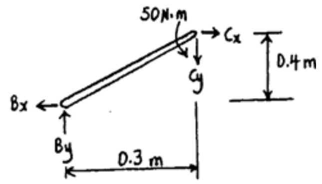
$\circlearrowleft + \Sigma M_C = 0;$ $\quad -110.4(0.3) - 110.4(0.4) + M = 0$

$M = 77.3 \text{ N}\cdot\text{m}$ **Ans**

8–46. The 45-kg disk rests on the surface for which the coefficient of static friction is $\mu_A = 0.15$. If $M = 50 \text{ N}\cdot\text{m}$, determine the friction force at A.



Bar :



$\circlearrowleft + \Sigma M_C = 0;$ $\quad -B_y(0.3) - B_x(0.4) + 50 = 0$

$\overset{+}{\rightarrow} \Sigma F_x = 0;$ $\quad B_x = C_x$

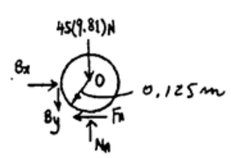
$+\uparrow \Sigma F_y = 0;$ $\quad B_y = C_y$

Disk :

$\overset{+}{\rightarrow} \Sigma F_x = 0;$ $\quad B_x = F_A$

$+\uparrow \Sigma F_y = 0;$ $\quad N_A - B_y - 45(9.81) = 0$

$\circlearrowleft + \Sigma M_O = 0;$ $\quad B_y(0.125) - F_A(0.125) = 0$



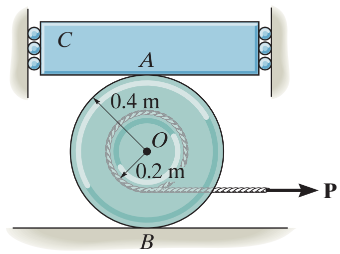
$N_A = 512.9 \text{ N}$

$F_A = 71.4 \text{ N}$ **Ans**

$(F_A)_{max} = 0.15(512.9) = 76.93 \text{ N} > 71.43 \text{ N}$

No motion of disk.

8–47. Block C has a mass of 50 kg and is confined between two walls by smooth rollers. If the block rests on top of the 40-kg spool, determine the minimum cable force P needed to move the spool. The cable is wrapped around the spool's inner core. The coefficients of static friction at A and B are $\mu_A = 0.3$ and $\mu_B = 0.6$.



$+\uparrow \Sigma F_y = 0;\quad N_B - 40(9.81) - 50(9.81) = 0$

$N_B = 882.9\text{ N}$

$\circlearrowleft + \Sigma M_O = 0;\quad F_A(0.4) - F_B(0.4) + P(0.2) = 0$

$\xrightarrow{+} \Sigma F_x = 0;\quad -F_A + P - F_B = 0$

Assume spool slips at A, then

$F_A = 0.3(50)(9.81) = 147.2\text{ N}$

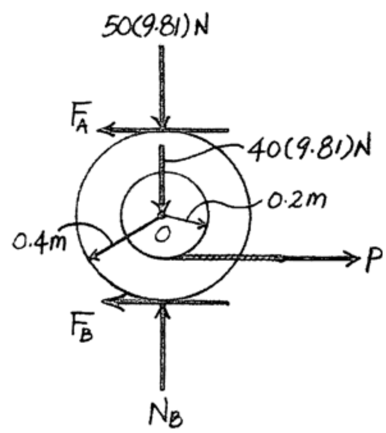
Solving,

$F_B = 441.4\text{ N}$

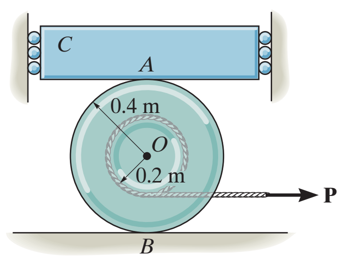
$P = 589\text{ N}$ **Ans**

$N_B = 882.9\text{ N}$

Since $(F_B)_{max} = 0.6(882.9) = 529.7\text{ N} > 441.4\text{ N}$ **OK**



***8–48.** Block C has a mass of 50 kg and is confined between two walls by smooth rollers. If the block rests on top of the 40-kg spool, determine the required coefficients of static friction at A and B so that the spool slips at A and B when the magnitude of the applied force is increased to $P = 300$ N.



$\xrightarrow{+} \Sigma F_x = 0;\quad 300 - F_A - F_B = 0$

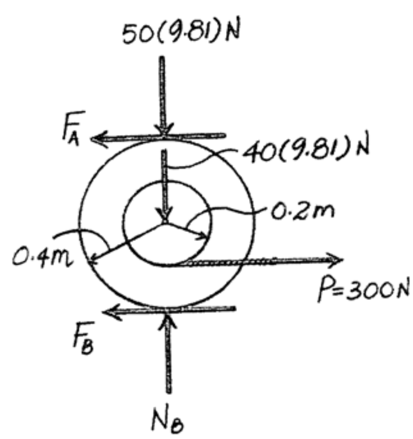
$\circlearrowleft + \Sigma M_B = 0;\quad F_A(0.8) - 300(0.2) = 0$

$F_A = 75\text{ N}$

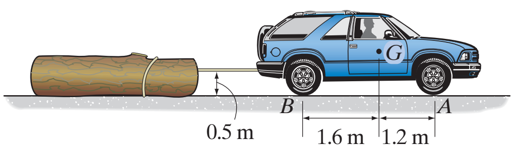
$F_B = 225\text{ N}$

$\mu_A = \frac{F_A}{N_A} = \frac{75}{50(9.81)} = 0.153$ **Ans**

$\mu_B = \frac{F_B}{N_B} = \frac{225}{90(9.81)} = 0.255$ **Ans**



•8–49. The 3-Mg four-wheel-drive truck (SUV) has a center of mass at G. Determine the maximum mass of the log that can be towed by the truck. The coefficient of static friction between the log and the ground is $\mu_s = 0.8$, and the coefficient of static friction between the wheels of the truck and the ground is $\mu_s' = 0.4$. Assume that the engine of the truck is powerful enough to generate a torque that will cause all the wheels to slip.



Free - Body Diagram. Since the truck is about to move to the right, its driving force $\mathbf{F}_t$ provided by the friction of all the wheels must act to the right as indicated on the free - body diagram of the truck shown in Fig. a. Here, $\mathbf{F}_t$ is required to be maximum, thus $F_t = \mu_s'(N_A + N_B) = 0.4(N_A + N_B)$. Since the log is required to be on the verge of sliding to the right, the frictional force $\mathbf{F}_l$ must act to the left such that $F_l = \mu_s N_l = 0.8N_l$.

Equations of Equilibrium. Referring to Fig. a, we have

$+\uparrow \Sigma F_y = 0;$ $\quad N_A + N_B - 3000(9.81) = 0 \qquad N_A + N_B = 29430\text{ N}$

$\overset{+}{\rightarrow} \Sigma F_x = 0;$ $\quad 0.4(29430) - T = 0 \qquad T = 11772\text{ N}$

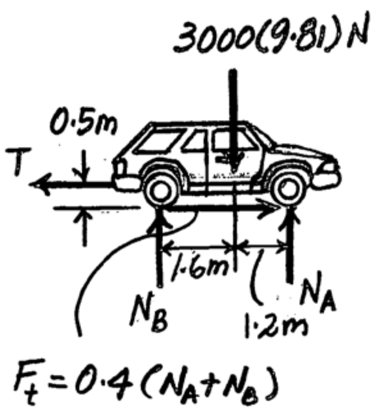
$\circlearrowleft + \Sigma M_B = 0;$ $\quad N_A(2.8) + 11772(0.5) - 3000(9.81)(1.6) = 0$

$N_A = 14715\text{ N} > 0 \text{ (OK!)}$

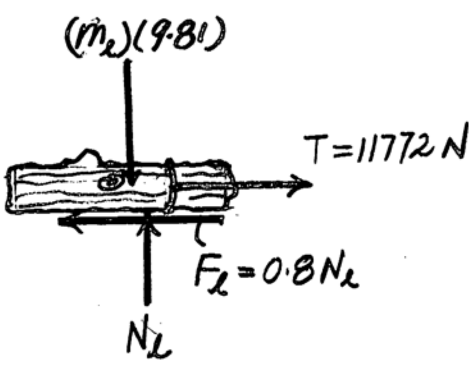
Using the result of $\mathbf{T}$ and referring to Fig. b, we have

$+\uparrow \Sigma F_y = 0;$ $\quad N_l - m_l(9.81) = 0 \qquad N_l = 9.81m_l$

$\overset{+}{\rightarrow} \Sigma F_x = 0;$ $\quad 11772 - 0.8(9.81m_l) = 0 \qquad m_l = 1500\text{ kg}$

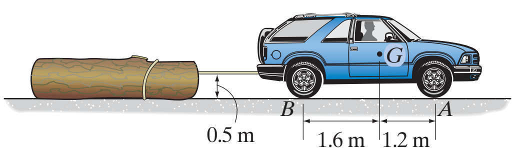


(a)



(b)

8–50. A 3-Mg front-wheel-drive truck (SUV) has a center of mass at G. Determine the maximum mass of the log that can be towed by the truck. The coefficient of static friction between the log and the ground is $\mu_s = 0.8$, and the coefficient of static friction between the front wheels of the truck and the ground is $\mu_s' = 0.4$. The rear wheels are free to roll. Assume that the engine of the truck is powerful enough to generate a torque that will cause the front wheels to slip.



Free - Body Diagram. Since the truck is about to move to the right, its driving force $\mathbf{F}_A$ provided by the friction of the front wheels must act to the right as indicated on the free - body diagram of the truck shown in Fig. *a*. Here, $\mathbf{F}_A$ is required to be maximum, so that $F_A = \mu_s' N_A = 0.4N_A$. Since the log is required to be on the verge of sliding to the right, the frictional force $\mathbf{F}_l$ must act to the left such that $F_l = \mu_s N_l = 0.8N_l$.

Equations of Equilibrium. Referring to Fig. *a*, we have

$\xrightarrow{+} \Sigma F_x = 0;$ $\quad 0.4N_A - T = 0 \quad (1)$

$\circlearrowleft + \Sigma M_B = 0;$ $\quad T(0.5) + N_A(2.8) - 3000(9.81)(1.6) = 0 \quad (2)$

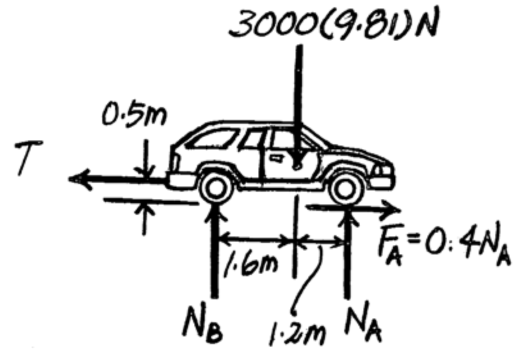
Solving Eqs. (1) and (2) yields

$$N_A = 15\,696 \text{ N} \qquad T = 6278.4 \text{ N}$$

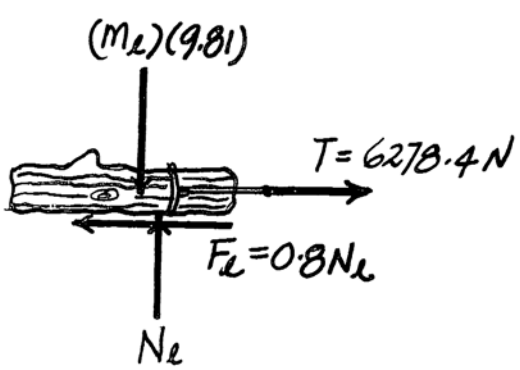
Using the result of $\mathbf{T}$ and referring to Fig. *b*, we have

$+\uparrow \Sigma F_y = 0;$ $\quad N_l - m_l(9.81) = 0 \qquad N_l = 9.81m_l$

$\xrightarrow{+} \Sigma F_x = 0;$ $\quad 6278.4 - 0.8(9.81m_l) = 0 \qquad m_l = 800 \text{ kg}$

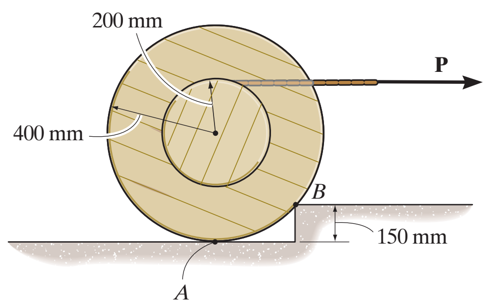


(a)



(b)

8–51. If the coefficients of static friction at contact points A and B are $\mu_s = 0.3$ and $\mu_s' = 0.4$ respectively, determine the smallest force P that will cause the 150-kg spool to have impending motion.



Free - Body Diagram. There are two possible modes of impending motion for the spool. The first mode is as the spool slips at A and B and is on the verge of rotating. The second mode is as point A of the spool just loses contact with the ground and the spool is on the verge of rolling about point B without slipping. We will assume that the first mode of motion occurs. Thus, $F_A = \mu_s N_A = 0.3N_A$ and $F_B = \mu_s' N_B = 0.4N_B$.

Equations of Equilibrium. Referring to the free - body diagram of the spool shown in Fig. a,

$\overset{+}{\rightarrow}\Sigma F_x = 0;$ $\quad 0.3N_A + 0.4N_B \cos 51.32° - N_B \sin 51.32° + P = 0$

$+\uparrow \Sigma F_y = 0;$ $\quad N_A + N_B \cos 51.32° + 0.4N_B \sin 51.32° - 150(9.81) = 0$

$\circlearrowleft + \Sigma M_O = 0;$ $\quad 0.3N_A(0.4) + 0.4N_B(0.4) - P(0.2) = 0$

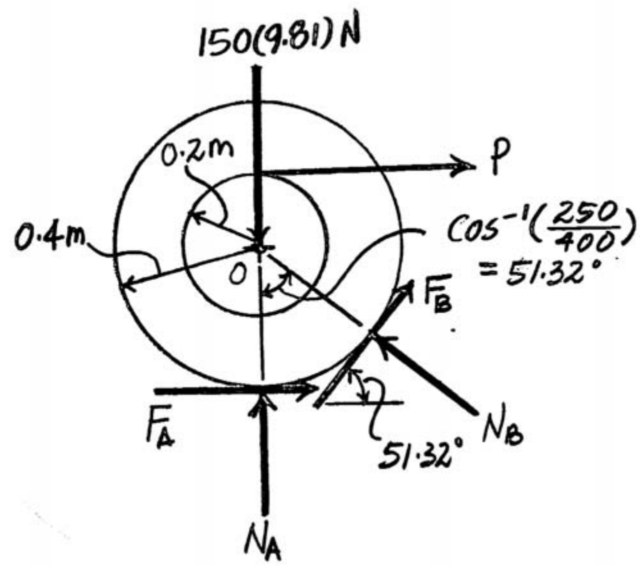
Solving,

$$N_A = -690.39\text{ N} \quad N_B = 2306.63\text{ N} \quad P = 1431.07\text{ N}$$

Since the result of $\mathbf{N}_A$ is a negative quantity, point A loses contact with the ground which indicates that the above assumption is incorrect. Thus, the solution must be reworked based on the second mode of motion. In this case, $N_A = 0$ so that $F_A = 0$. Referring to Fig. a,

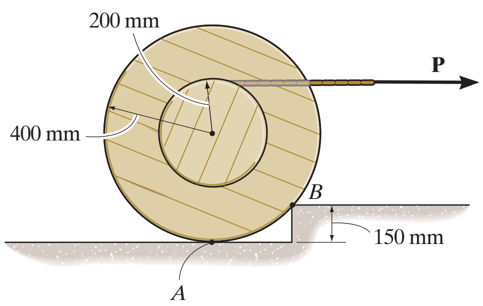
$\circlearrowleft + \Sigma M_B = 0;$ $\quad 150(9.81)(0.4 \sin 51.32°) - P(0.2 + 0.4 \cos 51.32°) = 0$

$P = 1021.05\text{ N} = 1.02\text{ kN}$ **Ans.**



(a)

***8–52.** If the coefficients of static friction at contact points A and B are $\mu_s = 0.4$ and $\mu_s' = 0.2$ respectively, determine the smallest force P that will cause the 150-kg spool to have impending motion.



Free - Body Diagram. There are two possible modes of impending motion for the spool. The first mode is as the spool slips at A and B and is on the verge of rotating. The second mode is as point A of the spool just loses contact with the ground and the spool is on the verge of rolling about point B without slipping. We will assume that the first mode of motion occurs. Thus, $F_A = \mu_s N_A = 0.4N_A$ and $F_B = \mu_s' N_B = 0.2N_B$.

Equations of Equilibrium. Referring to the free - body diagram of the spool shown in Fig. a,

$\overset{+}{\rightarrow}\Sigma F_x = 0;$ $\quad 0.4N_A + 0.2N_B \cos 51.32° - N_B \sin 51.32° + P = 0$

$+\uparrow \Sigma F_y = 0;$ $\quad N_A + 0.2N_B \sin 51.32° + N_B \cos 51.32° - 150(9.81) = 0$

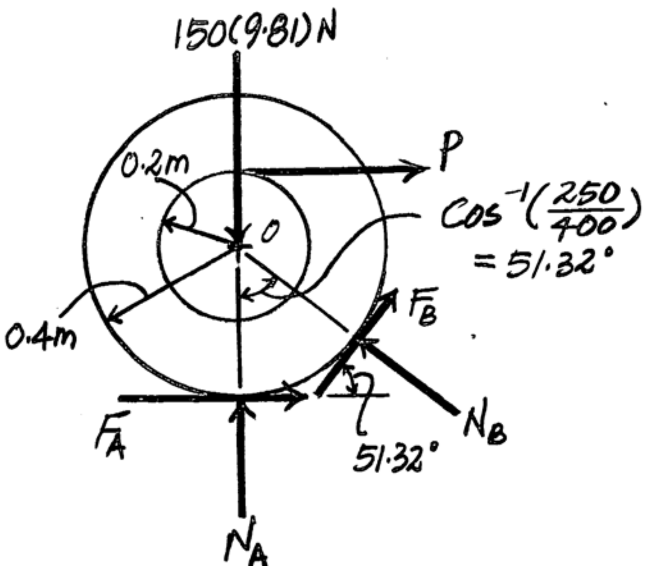
$\circlearrowleft + \Sigma M_O = 0;$ $\quad 0.4N_A(0.4) + 0.2N_B(0.4) - P(0.2) = 0$

Solving,

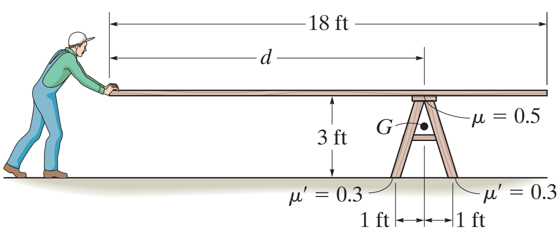
$P = 844 \text{ N}$ **Ans.**

$N_A = 315.31 \text{ N} \quad N_B = 1480.17 \text{ N}$

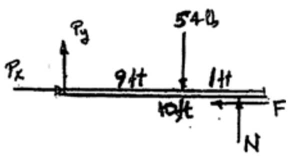
Since the result of $\mathbf{N}_A$ is a positive quantity, point A will remain in contact with the ground. Thus, the above assumption is correct.



•8–53. The carpenter slowly pushes the uniform board horizontally over the top of the saw horse. The board has a uniform weight of 3 lb/ft, and the saw horse has a weight of 15 lb and a center of gravity at G. Determine if the saw horse will stay in position, slip, or tip if the board is pushed forward when $d = 10$ ft. The coefficients of static friction are shown in the figure.



Board:



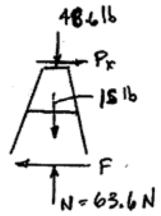
$\circlearrowleft + \Sigma M_P = 0; \quad -54(9) + N(10) = 0$

$N = 48.6 \text{ lb}$

To cause slipping of board on saw horse:

$P_x = F'_{max} = 0.5N = 24.3 \text{ lb}$

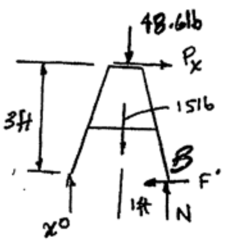
Saw horse:



To cause slipping at ground:

$P_x = F = F_{max} = 0.3(48.6 + 15) = 19.08 \text{ lb}$

To cause tipping:



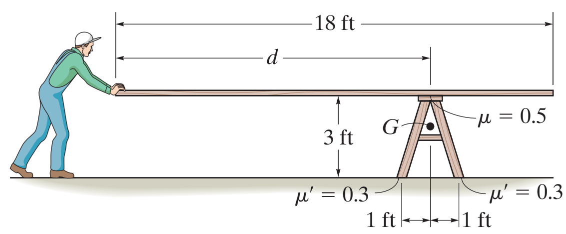
$\circlearrowleft + \Sigma M_B = 0; \quad (48.6 + 15)(1) - P_x(3) = 0$

$P_x = 21.2 \text{ lb}$

Thus, $\quad P_x = 19.1 \text{ lb}$

The saw horse will start to slip. **Ans**

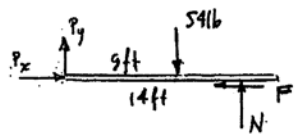
8–54. The carpenter slowly pushes the uniform board horizontally over the top of the saw horse. The board has a uniform weight of 3 lb/ft, and the saw horse has a weight of 15 lb and a center of gravity at G. Determine if the saw horse will stay in position, slip, or tip if the board is pushed forward when $d = 14$ ft. The coefficients of static friction are shown in the figure.



Board:

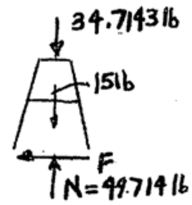
$\circlearrowleft + \Sigma M_P = 0; \quad -54(9) + N(14) = 0$

$N = 34.714$ lb



To cause slipping of board on saw horse:

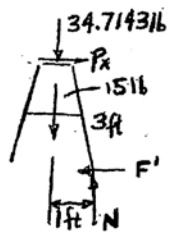
$P_x = F_{max} = 0.5\,N = 17.36$ lb



Saw horse:

To cause slipping at ground:

$P_x = F = F_{max} = 0.3(34.714 + 15) = 14.91$ lb



To cause tipping:

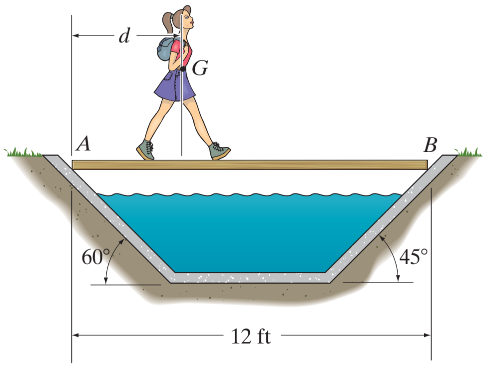
$\circlearrowleft + \Sigma M_B = 0; \quad (34.714 + 15)(1) - P_x(3) = 0$

$P_x = 16.57$ lb

Thus, $\quad P_x = 14.9$ lb

The saw horse will start to slip. **Ans**

8–55. If the 75-lb girl is at position $d = 4$ ft, determine the minimum coefficient of static friction μ_s at contact points A and B so that the plank does not slip. Neglect the weight of the plank.



Free - Body Diagram. Here, we will assume that the plank is on the verge of rotating counterclockwise due to of the girl' s weight. Thus, the frictional forces $\mathbf{F}_A$ and $\mathbf{F}_B$ must act in the direction as indicated on the free - body diagram of the plank shown in Fig. *a* so that $F_A = \mu_s N_A$ and $F_B = \mu_s N_B$.

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

$\circlearrowleft + \Sigma M_A = 0;$ $\quad N_B \sin 45°(12) - \mu_s N_B \sin 45°(12) - 75(4) = 0$

$\circlearrowleft + \Sigma M_B = 0;$ $\quad 75(8) - N_A \sin 30°(12) - \mu_s N_A \sin 60°(12) = 0$

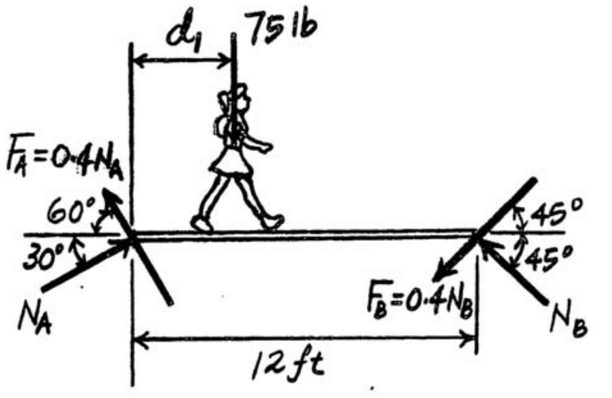
$\rightarrow \Sigma F_x = 0;$ $\quad N_A \cos 30° - \mu_s N_A \cos 60° - N_B \cos 45° - \mu_s N_B \cos 45° = 0$

Solving,

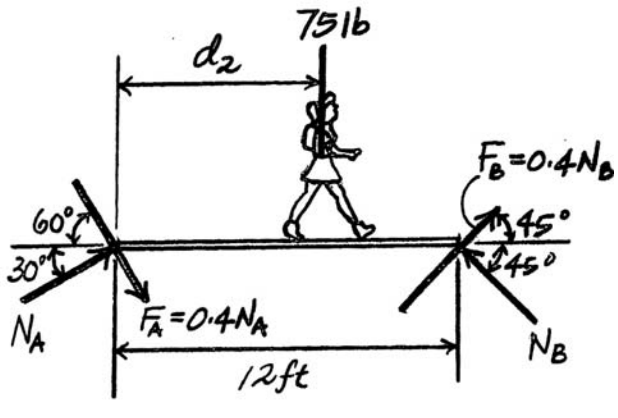
$\mu_s = 0.304$ **Ans.**

$N_A = 65.5$ lb $\quad N_B = 50.77$ lb

Since the result of μ_s is a positive quantity, the above assumption is correct.

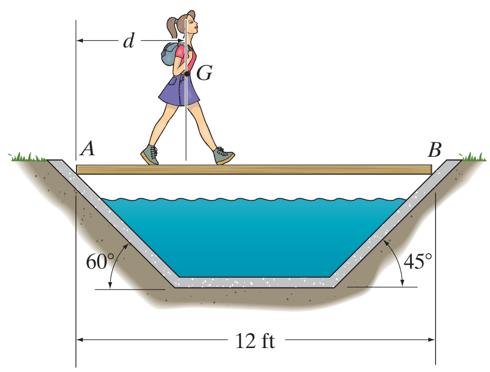


(a)



(b)

***8–56.** If the coefficient of static friction at the contact points A and B is $\mu_s = 0.4$, determine the minimum distance d where a 75-lb girl can stand on the plank without causing it to slip. Neglect the weight of the plank.



Free - Body Diagram. The weight of the girl tends to cause the plank to have counterclockwise and clockwise rotational motion when she is at the position $d = d_1$ and $d = d_2$, respectively. The free - body diagram of the plank for oth cases are shown in Figs. *a* and *b*. Since ends A and B of the plank are required to be on the verge of slipping the frictional forces $\mathbf{F}_A$ and $\mathbf{F}_B$ for both cases can be computed using $F_A = \mu_s N_A = 0.4N_A$ and $F_B = \mu_s N_B = 0.4N_B$.

Equations of Equilibrium. Referring to Fig. *a*, we have

$\circlearrowleft + \Sigma M_A = 0;\quad N_B \sin 45°(12) - 0.4N_B \sin 45°(12) - 75d = 0 \quad (1)$

$\circlearrowleft + \Sigma M_B = 0;\quad 75(12 - d) - N_A \sin 30°(12) - 0.4N_A \sin 60°(12) = 0 \quad (2)$

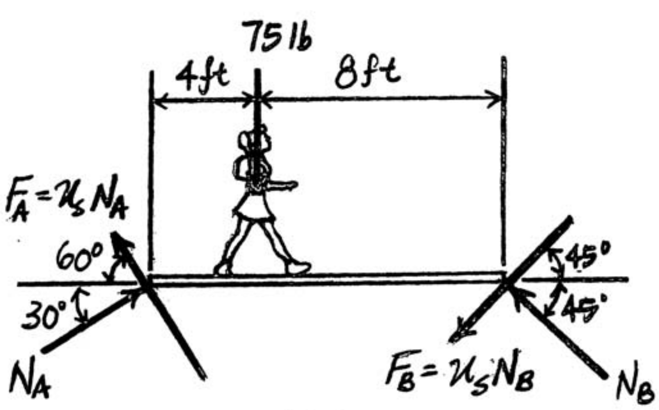
$\rightarrow \Sigma F_x = 0;\quad N_A \cos 30° - 0.4N_A \cos 60° - N_B \cos 45° - 0.4N_B \cos 45° = 0 \quad (3)$

Solving,

$d = 3.03\text{ ft}$ **Ans.**

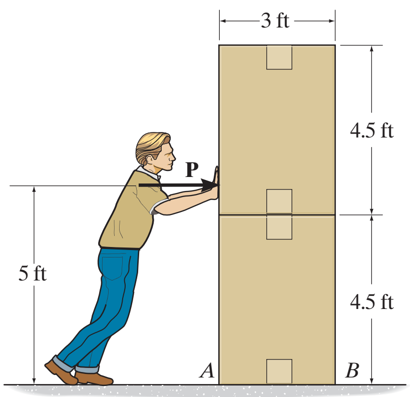
$N_A = 66.26\text{ lb}$

$N_B = 44.58\text{ lb}$



(a)

•8–57. If each box weighs 150 lb, determine the least horizontal force P that the man must exert on the top box in order to cause motion. The coefficient of static friction between the boxes is $\mu_s = 0.5$, and the coefficient of static friction between the box and the floor is $\mu_s' = 0.2$.



Free - Body Diagram. There are three possible motions, namely (1) the top box slides, (2) both boxes slide together as a single unit on the ground, and (3) both boxes tip as a single unit about point B. We will assume that both boxes slide together as a single unit such that $F = \mu_s' N = 0.2N$ as indicated on the free - body diagram shown in Fig. a.

Equations of Equilibrium.

$+\uparrow \Sigma F_y = 0;$ $\quad N - 150 - 150 = 0$

$\overset{+}{\rightarrow} \Sigma F_x = 0;$ $\quad P - 0.2N = 0$

$\circlearrowleft + \Sigma M_O = 0;$ $\quad 150(x) + 150(x) - P(5) = 0$

Solving,

$N = 300 \quad x = 1\text{ ft}$

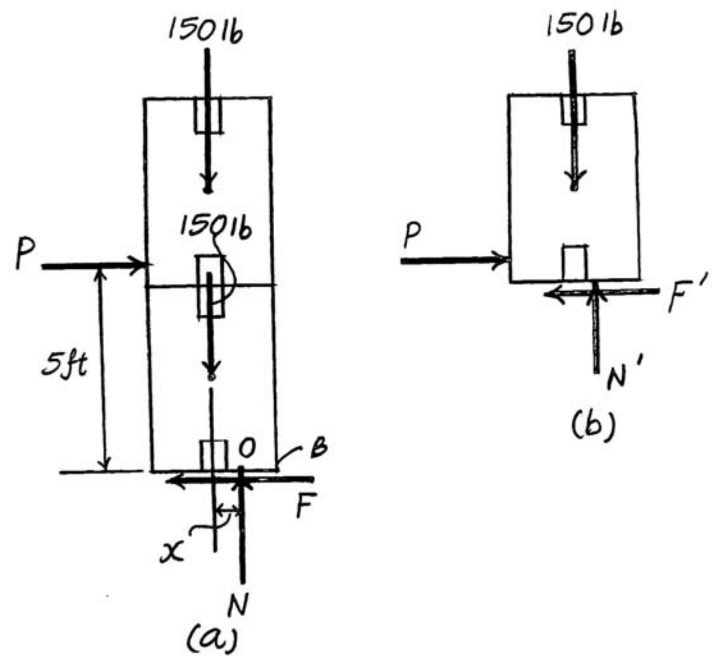
$P = 60\text{ lb}$ **Ans.**

Since $x < 1.5\text{ ft}$, both boxes will not tip about point B. Using the result of **P** and considering the equilibrium of the free - body diagram shown in Fig. b, we have

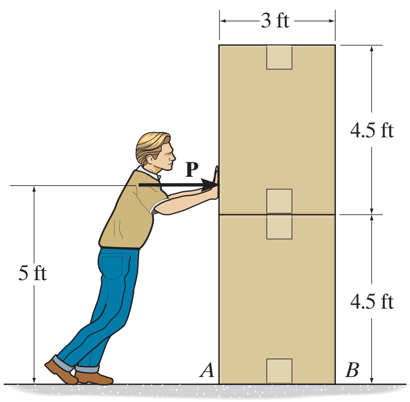
$+\uparrow \Sigma F_y = 0;$ $\quad N' - 150 = 0$ $\quad N' = 150\text{ lb}$

$\overset{+}{\rightarrow} \Sigma F_x = 0;$ $\quad 60 - F' = 0$ $\quad F' = 60\text{ lb}$

Since $F' < F_{max} = \mu_s N' = 0.5(150) = 75\text{ lb}$, the top box will not slide. Thus, the above assumption is correct.



8–58. If each box weighs 150 lb, determine the least horizontal force P that the man must exert on the top box in order to cause motion. The coefficient of static friction between the boxes is $\mu_s = 0.65$, and the coefficient of static friction between the box and the floor is $\mu_s' = 0.35$.



Free - Body Diagram. There are three possible motions, namely (1) the top box slides, (2) both boxes slide together as a single unit on the ground, and (3) both boxes tip as a single unit about point B. We will assume that both boxes tip as a single unit about point B. Thus, $x = 1.5$ ft.

Equations of Equilibrium. Referring to Fig. a,

$+\uparrow \Sigma F_y = 0;\qquad N - 150 - 150 = 0$

$\overset{+}{\rightarrow} \Sigma F_x = 0;\qquad P - F = 0$

$\circlearrowleft + \Sigma M_B = 0;\qquad 150(1.5) + 150(1.5) - P(5) = 0$

Solving,

$P = 90 \text{ lb}$ **Ans.**

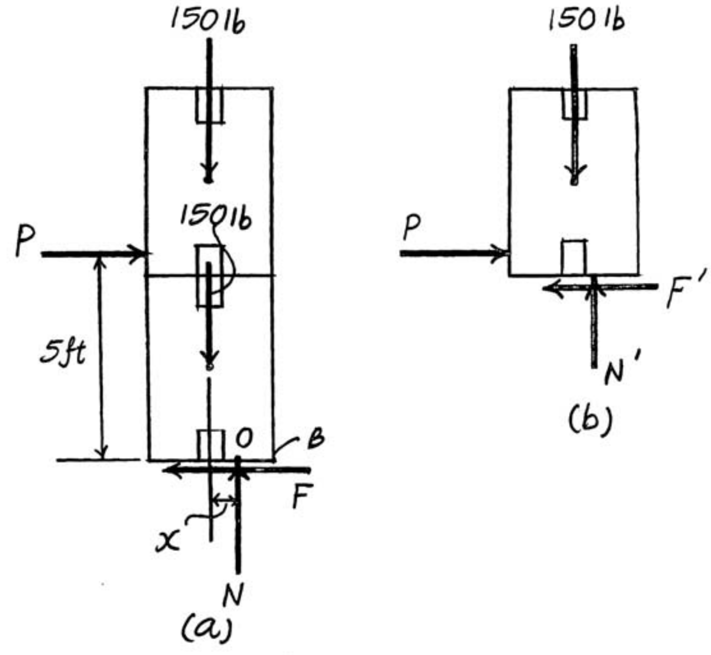
$N = 300 \text{ lb} \qquad F = 90 \text{ lb}$

Since $F < F_{max} = \mu_s N' = 0.35(300) = 105$ lb, both boxes will not slide as a single unit on the floor. Using the result of **P** and considering the equilibrium of the free - body diagram shown in Fig. b,

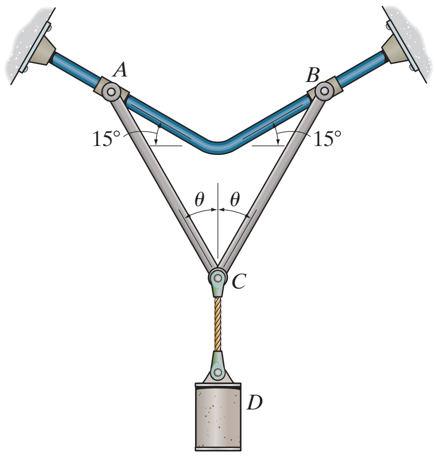
$+\uparrow \Sigma F_y = 0;\qquad N' - 150 = 0 \qquad N' = 150 \text{ lb}$

$\overset{+}{\rightarrow} \Sigma F_x = 0;\qquad 90 - F' = 0 \qquad F' = 90 \text{ lb}$

Since $F' < F_{max} = \mu_s' N' = 0.65(150) = 97.5$ lb, the top box will not slide. Thus, the above assumption is correct.



8–59. If the coefficient of static friction between the collars A and B and the rod is $\mu_s = 0.6$, determine the maximum angle θ for the system to remain in equilibrium, regardless of the weight of cylinder D. Links AC and BC have negligible weight and are connected together at C by a pin.



Free - Body Diagram. Due to the symmetrical loading and system, collars A and B will slip simultaneously. Thus, it is sufficient to consider the equilibrium of either collar. Here, the equilibrium of collar B will be considered. Since collar B is required to be on the verge of sliding down the rod the friction force $\mathbf{F}_B$ must act up the rod such that $F_B = \mu_s N_B = 0.6N_B$ as indicated on the free - body diagram of the collar shown in Fig. a.

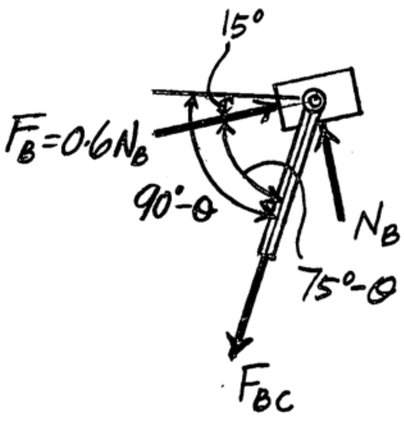
Equations of Equilibrium.

$+\nwarrow \Sigma F_y = 0; \quad N_B - F_{BC}\sin(75° - \theta) = 0 \qquad N_B = F_{BC}\sin(75° - \theta)$

$+\nearrow \Sigma F_x = 0; \quad 0.6[F_{BC}\sin(75° - \theta)] - F_{BC}\cos(75° - \theta) = 0$

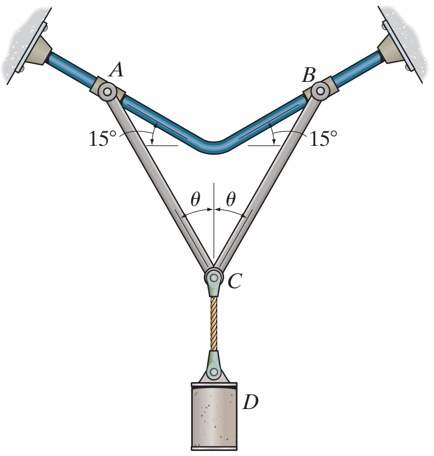
$\tan(75° - \theta) = 1.6667$

$\theta = 16.0°$ **Ans.**



(a)

***8–60.** If $\theta = 15°$, determine the minimum coefficient of static friction between the collars A and B and the rod required for the system to remain in equilibrium, regardless of the weight of cylinder D. Links AC and BC have negligible weight and are connected together at C by a pin.



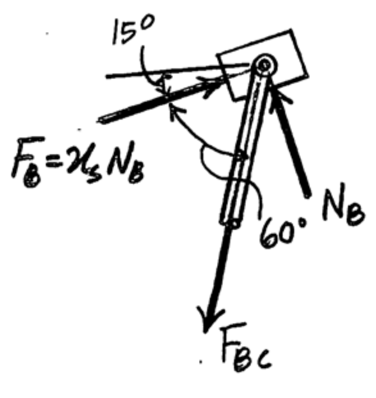
Free - Body Diagram. Due to the symmetrical loading and system, collars A and B will slip simultaneously. Thus, it is sufficient to consider the equilibrium of either collar. Here, the equilibrium of collar B will be considered. Since collar B is required to be on the verge of sliding down the rod the friction force $\mathbf{F}_B$ must up the rod such that $F_B = \mu_s N_B = 0.6N_B$ as indicated on the free - body diagram of the collar shown in Fig. *a*.

Equations of Equilibrium.

$\Sigma F_y = 0;\quad N_B - F_{BC}\sin 60° = 0 \qquad N_B = 0.8660F_{BC}$

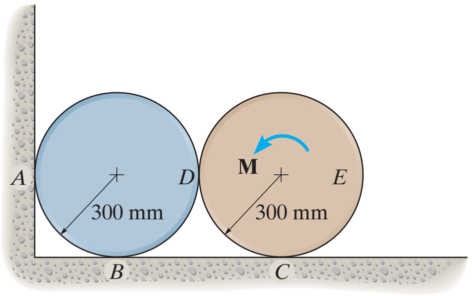
$\Sigma F_x = 0;\quad \mu_s[0.8660F_{BC}] - F_{BC}\cos 60° = 0$

$\mu_s = 0.577$ **Ans.**



(a)

•8–61. Each of the cylinders has a mass of 50 kg. If the coefficients of static friction at the points of contact are $\mu_A = 0.5$, $\mu_B = 0.5$, $\mu_C = 0.5$, and $\mu_D = 0.6$, determine the smallest couple moment M needed to rotate cylinder E.

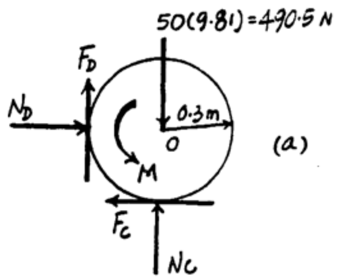


Equations of Equilibrium : From FBD (a),

$$\xrightarrow{+} \Sigma F_x = 0; \quad N_D - F_C = 0 \quad [1]$$

$$+\uparrow \Sigma F_y = 0 \quad N_C + F_D - 490.5 = 0 \quad [2]$$

$$\circlearrowleft + \Sigma M_O = 0; \quad M - F_C(0.3) - F_D(0.3) = 0 \quad [3]$$

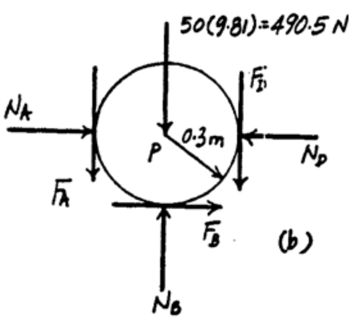


From FBD (b),

$$\xrightarrow{+} \Sigma F_x = 0; \quad N_A + F_B - N_D = 0 \quad [4]$$

$$+\uparrow \Sigma F_y = 0 \quad N_B - F_A - F_D - 490.5 = 0 \quad [5]$$

$$\circlearrowleft + \Sigma M_P = 0; \quad F_A(0.3) + F_B(0.3) - F_D(0.3) = 0 \quad [6]$$



Friction : Assuming cylinder E slips at points C and D and cylinder F does not move, then $F_C = \mu_{s\,C} N_C = 0.5N_C$ and $F_D = \mu_{s\,D} N_D = 0.6N_D$. Substituting these values into Eqs. [1], [2] and [3] and solving, we have

$$N_C = 377.31 \text{ N} \qquad N_D = 188.65 \text{ N}$$

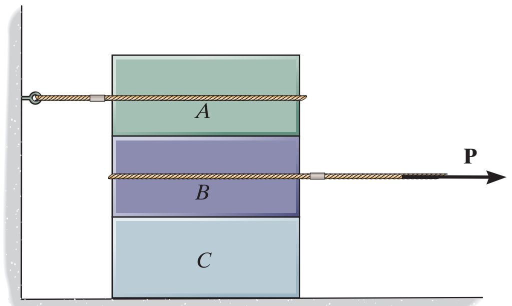
$$M = 90.55 \text{ N}\cdot\text{m} = 90.6 \text{ N}\cdot\text{m} \qquad \textbf{Ans}$$

If cylinder F is on the verge of slipping at point A, then $F_A = \mu_{s\,A} N_A = 0.5N_A$. Substitute this value into Eqs. [4], [5] and [6] and solving, we have

$$N_A = 150.92 \text{ N} \qquad N_B = 679.15 \text{ N} \qquad F_B = 37.73 \text{ N}$$

Since $(F_B)_{max} = \mu_{s\,B} N_B = 0.5(679.15) = 339.58 \text{ N} > F_B$, cylinder F does not move. Therefore the above assumption is correct.

8–62. Blocks A, B, and C have weights of 50 lb, 25 lb, and 15 lb, respectively. Determine the smallest horizontal force P that will cause impending motion. The coefficient of static friction between A and B is $\mu_s = 0.3$, between B and C, $\mu_s' = 0.4$, and between block C and the ground, $\mu_s'' = 0.35$.



Free - Body Diagram. Due to the constraint, block A will not move. Therefore, there are two possible cases of impending motion, namely (1) block B slips on top of block C or (2) blocks B and C slip on the ground and move as a single unit. For both cases, slipping occurs at the contact surface between blocks A and B. By considering the free - body diagram of block A shown in Fig. a, we obtain $N_A = 50$ lb. Thus, $F_A = \mu_s N_A = 0.3(50) = 15$ lb. We will assume that the first case of motion occurs. Thus, $F_B = \mu_s' N_B$.

Equations of Equilibrium. Referring to the free - body diagram of block B shown in Fig. b,

$+\uparrow \Sigma F_y = 0;$ $\quad N_B - 50 - 25 = 0$ $\quad N_B = 75$ lb

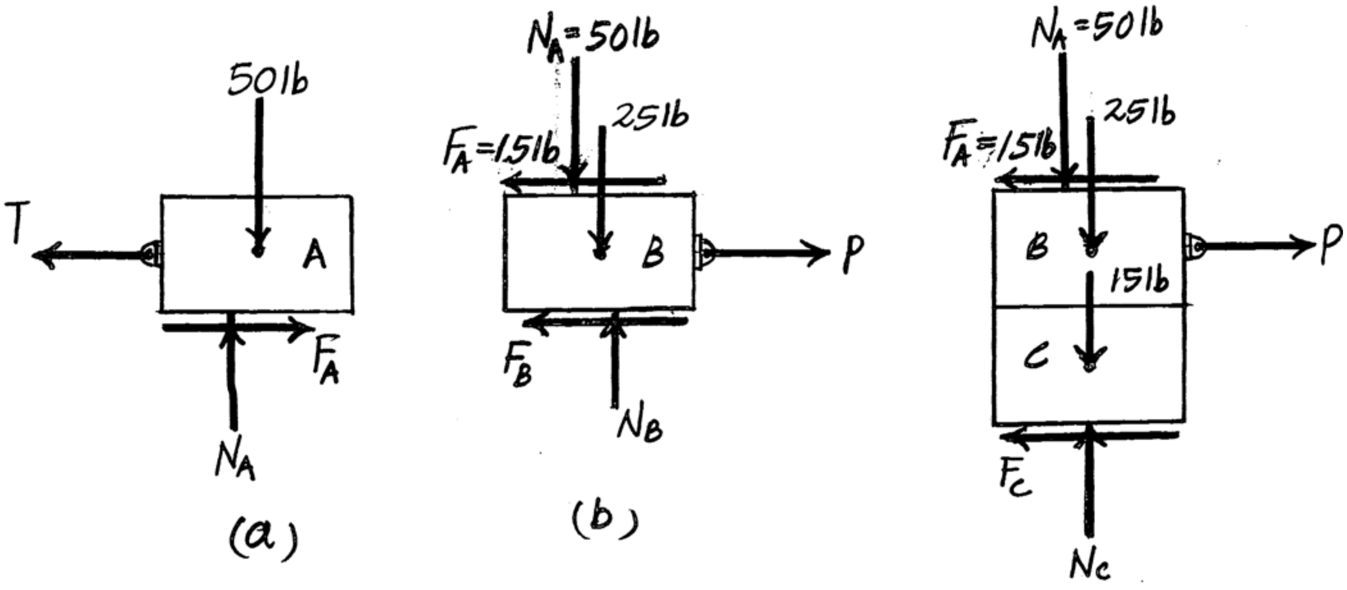
$\overset{+}{\rightarrow} \Sigma F_x = 0;$ $\quad P - 15 - 0.4(75) = 0$ $\quad P = 45$ lb $\quad$ **Ans.**

Using this result and referring to the free - body diagram of blocks B and C shown in Fig. a,

$+\uparrow \Sigma F_y = 0;$ $\quad N_C - 50 - 25 - 15 = 0$ $\quad N_C = 90$ lb

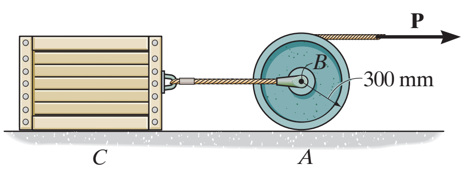
$\overset{+}{\rightarrow} \Sigma F_x = 0;$ $\quad 45 - 15 - F_C = 0$ $\quad F_C = 30$ lb

Since $F_C < (F_C)_{max} = \mu_s'' N_C = 0.35(90) = 31.5$ lb, the system of the blocks B and C will not slip. Thus, the above assumption is correct.



(a) (b) (c)

8–63. Determine the smallest force P that will cause impending motion. The crate and wheel have a mass of 50 kg and 25 kg, respectively. The coefficient of static friction between the crate and the ground is $\mu_s = 0.2$, and between the wheel and the ground $\mu_s' = 0.5$.



Free - Body Diagram. There are two possible motions, namely (1) the crate slips while the wheel rolls without slipping and (2) the wheel slips and rotates while the crate remains stationary. We will assume that the first mode of motion occurs. Thus, $F_C = \mu_s N_C = 0.2 N_C$.

Equations of Equilibrium. Referring to the free - body diagram of the crate shown in Fig. *a*,

$+\uparrow \Sigma F_y = 0;$ $\quad N_C - 50(9.81) = 0$ $\quad N_C = 490.5\text{ N}$

$\xrightarrow{+} \Sigma F_x = 0;$ $\quad T - 0.2(490.5) = 0$ $\quad T = 98.1\text{N}$

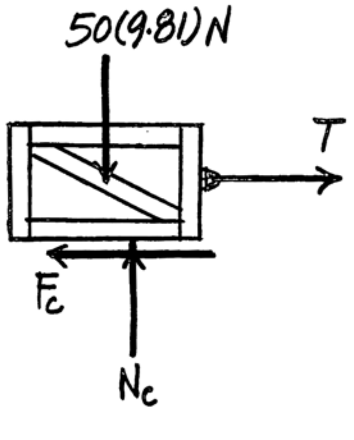
Using the result for T and referring to Fig. *b*,

$+\Sigma M_A = 0;$ $\quad 98.1(0.3) - P(0.6) = 0$ $\quad P = 49.05\text{N} = 49.0\text{N}$ **Ans.**

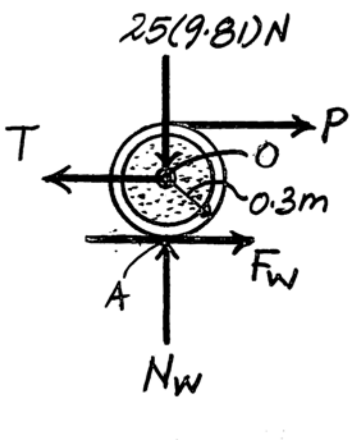
$\xrightarrow{+} \Sigma F_x = 0;$ $\quad F_w + 49.05 - 98.1 = 0$ $\quad F_w = 49.05\text{ N}$

$+\uparrow \Sigma F_y = 0;$ $\quad N_w - 25(9.81) = 0$ $\quad N_w = 245.25$

Since $F_w < F_{max} = \mu_s' N = 0.5(245.25) = 122.63\text{N}$, the wheel will not slip. Thus, the above assumption is correct.

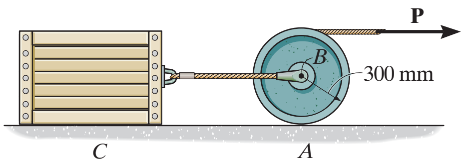


(a)



(b)

***8–64.** Determine the smallest force P that will cause impending motion. The crate and wheel have a mass of 50 kg and 25 kg, respectively. The coefficient of static friction between the crate and the ground is $\mu_s = 0.5$, and between the wheel and the ground $\mu_s' = 0.3$.



Free - Body Diagram. There are two possible motions, namely (1) the crate slips while the wheel rolls without slipping and (2) the whee slips and rotates while the crate remains stationary. We will assume that the second mode of motion occurs. Thus, $F_w = \mu_s' N_w = 0.3N_w$.

Equations of Equilibrium. Referring to the free - body diagram of the wheel shown in Fig. *b*,

$+\uparrow \Sigma F_y = 0;$ $N_w - 25(9.81) = 0$ $N_w = 245.25$ N

$\circlearrowleft + \Sigma M_O = 0;$ $0.3(245.25)(0.3) - P(0.3) = 0$ $P = 73.575 \text{ N} = 73.6 \text{ N}$ **Ans.**

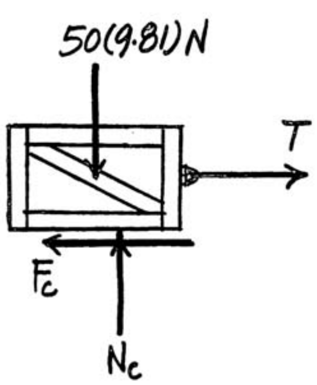
$\overset{+}{\rightarrow} \Sigma F_x = 0;$ $73.575 + 0.3(245.25) - T = 0$ $T = 147.15$ N

Using the result for **T** and referring to the free - body diagram of the crate in Fig. *a*,

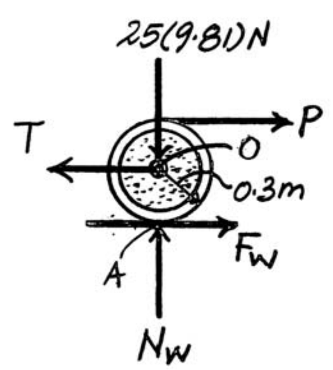
$+\uparrow \Sigma F_y = 0;$ $N_C - 50(9.81) = 0$ $N_C = 490.5$ N

$\overset{+}{\rightarrow} \Sigma F_x = 0;$ $147.15 - F_C = 0$ $F_C = 147.15$ N

Since $F_C < (F_E)_{max} = \mu_s N_C = 0.5(490.5) = 245.25$ N, the crate will not slip. Thus, the above assumption is correct.

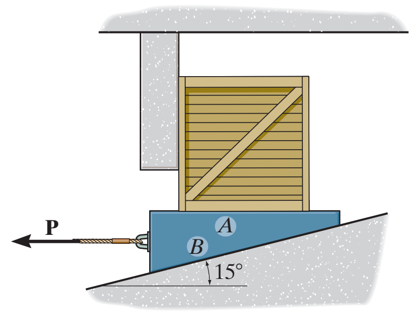


(a)



(b)

•8–65. Determine the smallest horizontal force P required to pull out wedge A. The crate has a weight of 300 lb and the coefficient of static friction at all contacting surfaces is $\mu_s = 0.3$. Neglect the weight of the wedge.



Free - Body Diagram. Since the crate is on the verge of sliding down and the wedge is on the verge of sliding to the left, the frictional force $\mathbf{F}_B$ on the crate must act upward and forces $\mathbf{F}_C$ and $\mathbf{F}_D$ on the wedge must act to the right as indicated on the free - body diagrams as shown in Figs. *a* and *b*. Also, $F_B = \mu_s N_B = 0.3N_B$, $F_C = \mu_s N_C = 0.3N_C$, and $F_D = \mu_s N_D = 0.3N_D$.

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

$\xrightarrow{+} \Sigma F_x = 0;\qquad N_B - 0.3N_C = 0$

$+\uparrow \Sigma F_y = 0;\qquad N_C + 0.3N_B - 300 = 0$

Solving,

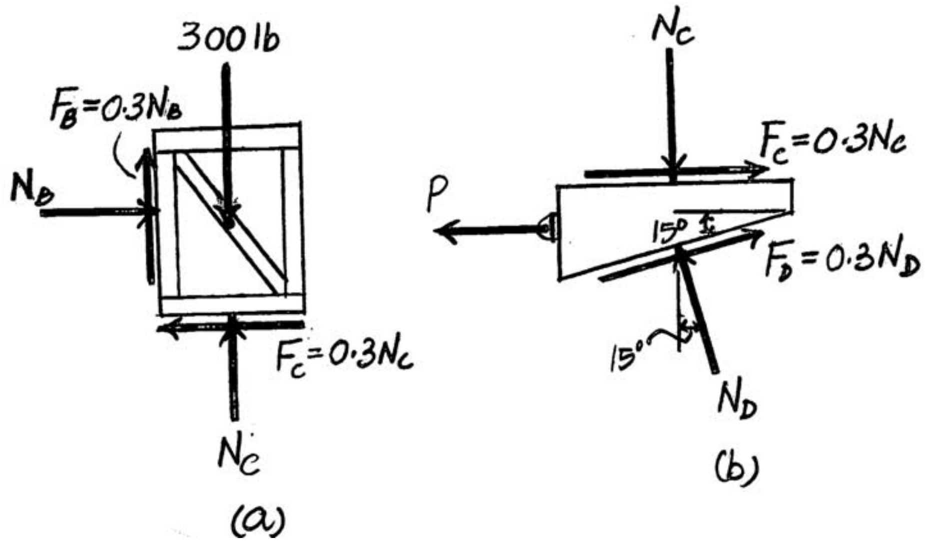
$$N_B = 82.57 \text{ lb} \qquad N_C = 275.23 \text{ lb}$$

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

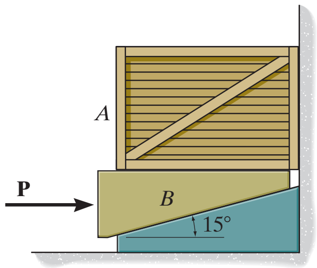
$+\uparrow \Sigma F_y = 0;\qquad N_D \cos 15° + 0.3N_D \sin 15° - 275.23 = 0;\qquad N_D = 263.74 \text{ lb}$

$\xrightarrow{+} \Sigma F_x = 0;\qquad 0.3(275.23) + 0.3(263.74)\cos 15° - 263.74 \sin 15° - P = 0$

$P = 90.7 \text{ lb}$ **Ans.**



8–66. Determine the smallest horizontal force P required to lift the 200-kg crate. The coefficient of static friction at all contacting surfaces is $\mu_s = 0.3$. Neglect the mass of the wedge.



Free - Body Diagram. Since the crate is on the verge of sliding up and the wedge is on the verge of sliding to the right, the frictional force $\mathbf{F}_A$ on the crate must act downward and forces $\mathbf{F}_B$ and $\mathbf{F}_C$ on the wedge must act to the left as indicated on the free - body diagrams as shown in Figs. *a* and *b*. Also, $F_A = \mu_s N_A = 0.3N_A$, $F_B = \mu_s N_B = 0.3N_B$, and $F_C = \mu_s N_C = 0.3N_C$.

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

$\overset{+}{\rightarrow}\Sigma F_x = 0;\qquad 0.3N_B - N_A = 0$

$+\uparrow \Sigma F_y = 0;\qquad N_B - 0.3N_A - 200(9.81) = 0$

Solving,

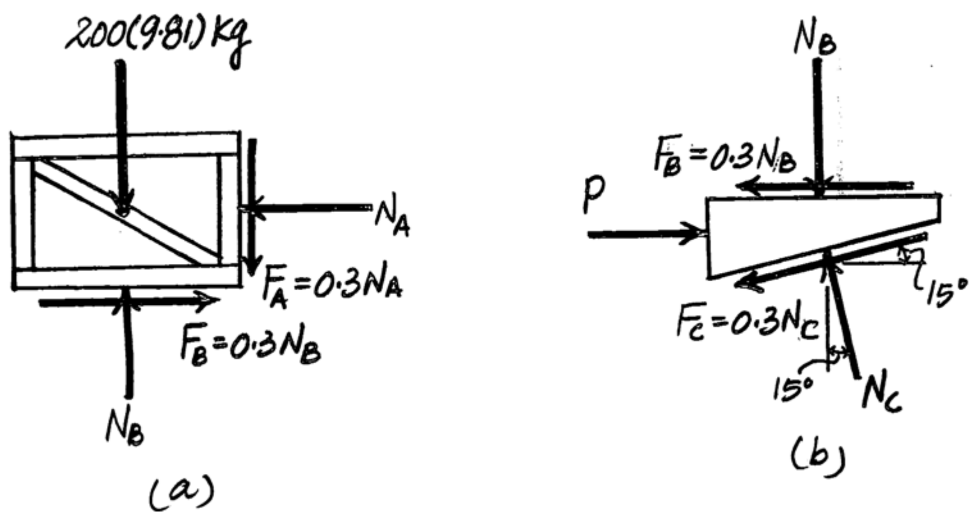
$$N_A = 646.81 \text{ N} \quad N_B = 2156.04 \text{ N}$$

Referring to Fig. *b*,

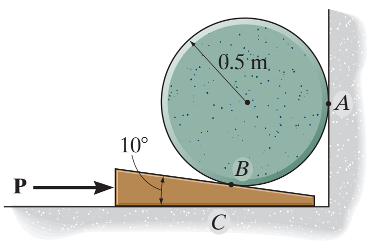
$+\uparrow \Sigma F_y = 0;\qquad N_C \cos 15° - 0.3N_C \sin 15° - 2156.04 = 0 \quad N_C = 2427.21 \text{ N}$

$\overset{+}{\rightarrow}\Sigma F_x = 0;\qquad P - 0.3(2156.04) - 2427.21 \sin 15° - 0.3(2427.21)\cos 15° = 0$

$P = 1978.37 \text{ N} = 1.98 \text{ N}$ **Ans.**



8–67. Determine the smallest horizontal force P required to lift the 100-kg cylinder. The coefficients of static friction at the contact points A and B are $(\mu_s)_A = 0.6$ and $(\mu_s)_B = 0.2$, respectively; and the coefficient of static friction between the wedge and the ground is $\mu_s = 0.3$.



Free - Body Diagram. There are two possible modes of motion for the cylinder, namely (1) the cylinder rolls about point A and slips at B and (2) the cylinder rolls about point B and slips at point A. We will assume that the first mode of motion occurs, thus $F_B = 0.2N_B$. This force acts to the right on the cylinder as indicated on the free - body diagram shown in Fig. *a*. The wedge is on the verge of moving to the right, Fig. *b*.

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

$\overset{+}{\rightarrow}\Sigma F_x = 0;$ $\quad 0.2N_B \cos 10° + N_B \sin 10° - N_A = 0$

$+\uparrow \Sigma F_y = 0;$ $\quad N_B \cos 10° - 0.2N_B \sin 10° - F_A - 100(9.81) = 0$

$\circlearrowleft + \Sigma M_O = 0;$ $\quad 0.2N_B(0.5) - F_A(0.5) = 0$

Solving,

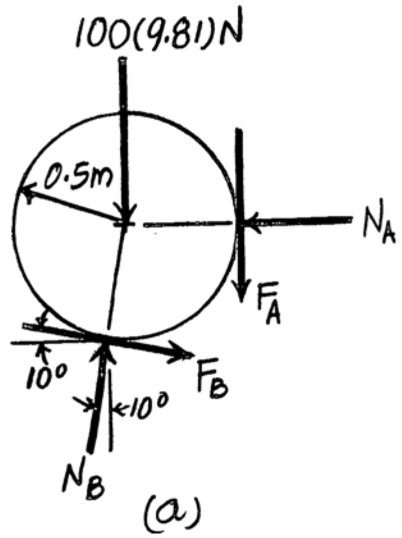
$$N_B = 1308\text{ N} \quad N_A = 488.68\text{ N} \quad F_A = 262\text{ N}$$

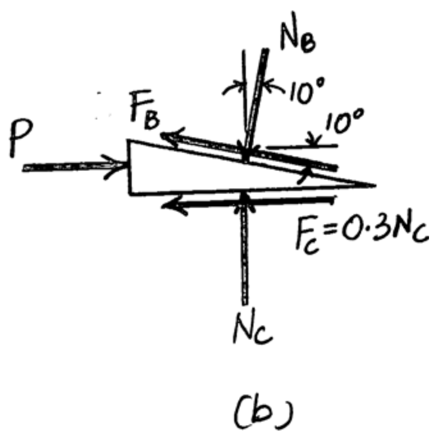
Since $F_A < (F_A)_{max} = (\mu_s)_A N_A = 0.6(488.68) = 293$ N, the cylinder will not slip at A. Thus, the above assumption is correct. Thus, $F_C = 0.3N_C$ and $F_B = 262$ N. Referring to the free - body diagram of the wedge shown in Fig. *b*,

$+\uparrow \Sigma F_y = 0;$ $\quad N_C + 262 \sin 10° - 1308 \cos 10° = 0 \qquad N_C = 1243\text{ N}$

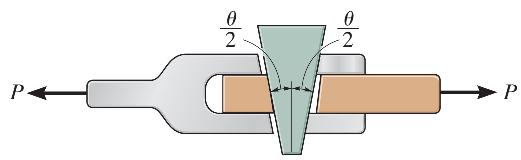
$\overset{+}{\rightarrow}\Sigma F_x = 0;$ $\quad P - 262 \cos 10° - 1308 \sin 10° - 0.3(1243) = 0$

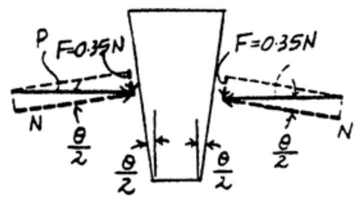
$P = 863\text{ N}$ **Ans.**





***8–68.** The wedge has a negligible weight and a coefficient of static friction $\mu_s = 0.35$ with all contacting surfaces. Determine the largest angle θ so that it is "self-locking." This requires no slipping for any magnitude of the force **P** applied to the joint.



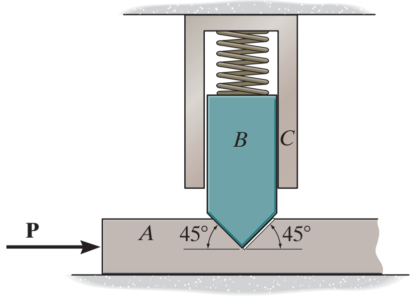


Friction : **When the wedge is on the verge of slipping, then $F = \mu N = 0.35N$. From the force diagram (P is the 'locking' force.),**

$$\tan\frac{\theta}{2} = \frac{0.35N}{N} = 0.35$$

$$\theta = 38.6° \qquad \textbf{Ans}$$

•8–69. Determine the smallest horizontal force P required to just move block A to the right if the spring force is 600 N and the coefficient of static friction at all contacting surfaces on A is $\mu_s = 0.3$. The sleeve at C is smooth. Neglect the mass of A and B.



Free - Body Diagram. Since block A is required to be on the verge of sliding to the right, the frictional forces $\mathbf{F}_A$ and $\mathbf{F}_C$ on block A must act to the left such that $F_A = \mu_s N_A = 0.3N_A$ and $F_C = \mu_s N_C = 0.3N_C$.

Equations of Equilibrium. Referring to the free- body diagram of block B shown in Fig. a,

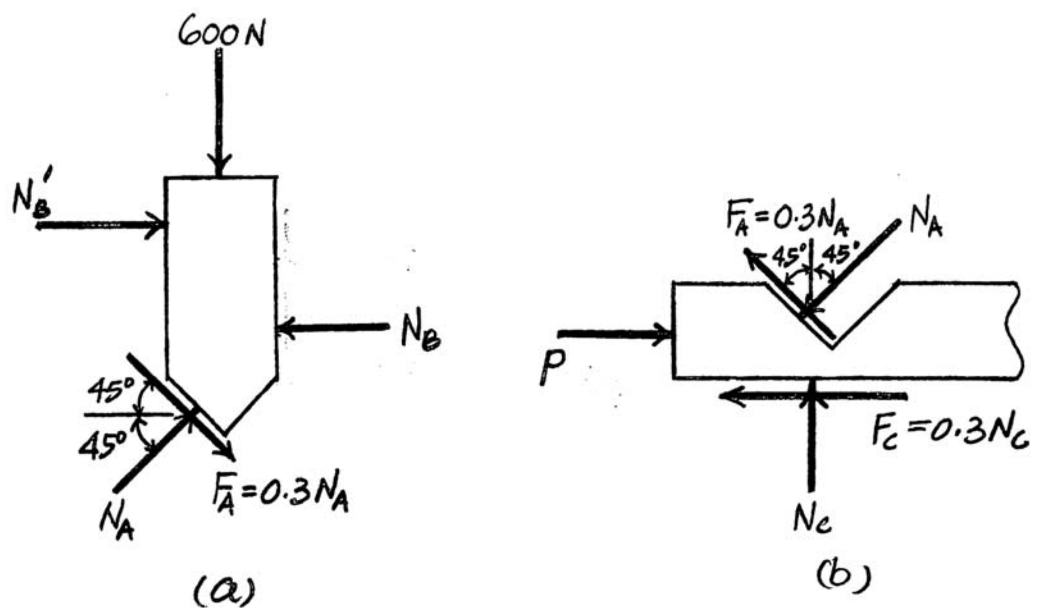
$+\uparrow \Sigma F_y = 0;$ $\quad N_A \sin 45° - 0.3N_A \sin 45° - 600 = 0;$ $\quad N_A = 1212.18\text{ N}$

Using the result of $\mathbf{N}_A$ and referring to the free - body diagram of block A shown in Fig. a,

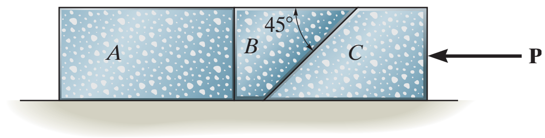
$+\uparrow \Sigma F_y = 0;$ $\quad N_C + 0.3(1212.18)\cos 45° - 1212.18\cos 45° = 0;$ $\quad N_C = 600\text{ N}$

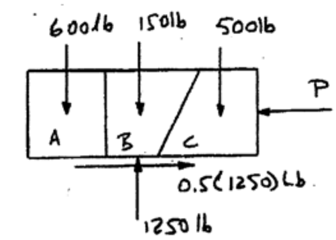
$\overset{+}{\rightarrow} \Sigma F_x = 0;$ $\quad P - 0.3(1212.18)\sin 45° - 1212.18\sin 45° - 0.3(600) = 0$

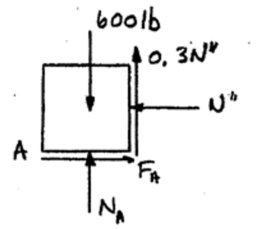
$P = 1294.29\text{ N} = 1.29\text{ kN}$ **Ans.**



8–70. The three stone blocks have weights of $W_A = 600$ lb, $W_B = 150$ lb, and $W_C = 500$ lb. Determine the smallest horizontal force P that must be applied to block C in order to move this block. The coefficient of static friction between the blocks is $\mu_s = 0.3$, and between the floor and each block $\mu_s' = 0.5$.







$\xrightarrow{+} \Sigma F_x = 0;\quad -P + 0.5\,(1250) = 0$

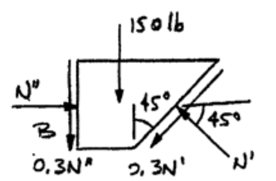
$P = 625$ lb

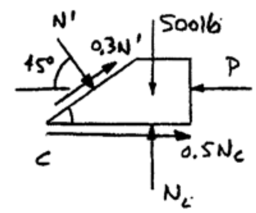
Assume block B slips up, block A does not move.

Block A:

$\xrightarrow{+} \Sigma F_x = 0;\quad F_A - N'' = 0$

$+\uparrow \Sigma F_y = 0;\quad N_A - 600 + 0.3\,N'' = 0$





Block B:

$\xrightarrow{+} \Sigma F_x = 0;\quad N'' - N' \cos 45° - 0.3\,N' \sin 45° = 0$

$+\uparrow \Sigma F_y = 0;\quad N' \sin 45° - 0.3\,N' \cos 45° - 150 - 0.3\,N'' = 0$

Block C:

$\xrightarrow{+} \Sigma F_x = 0;\quad 0.3\,N' \cos 45° + N' \cos 45° + 0.5\,N_C - P = 0$

$+\uparrow \Sigma F_y = 0;\quad N_C - N' \sin 45° + 0.3\,N' \sin 45° - 500 = 0$

Solving,

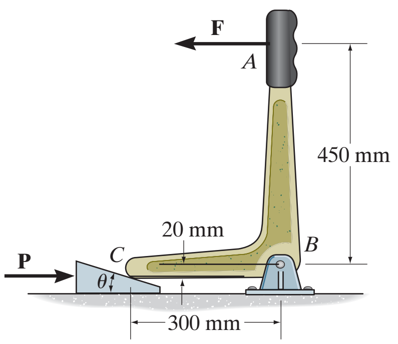
$N'' = 629.0$ lb, $N' = 684.3$ lb, $N_C = 838.7$ lb, $P = 1048$ lb,

$N_A = 411.3$ lb

$F_A = 629.0 \text{ lb} > 0.5\,(411.3) = 205.6$ lb No good

All blocks slip at the same time; $P = 625$ lb **Ans**

8–71. Determine the smallest horizontal force P required to move the wedge to the right. The coefficient of static friction at all contacting surfaces is $\mu_s = 0.3$. Set $\theta = 15°$ and $F = 400$ N. Neglect the weight of the wedge.



Free - Body Diagram. Since the wedge is required to be on the verge of sliding to the right, the frictional forces $\mathbf{F}_C$ and $\mathbf{F}_D$ on the wedge must act to the left such that $F_C = \mu_s N_C = 0.3N_C$ and $F_D = \mu_s N_D = 0.3N_D$.

Equations of Equilibrium. Referring to the free - body diagram of the crank shown in Fig. *a*,

$\circlearrowleft +\Sigma M_B = 0;$ $\quad 400(0.45) + 0.3N_C \cos 15°(0.02) + 0.3N_C \sin 15°(0.3) + N_C \cos 15°(0.3) - N_C \sin 15°(0.02) = 0$

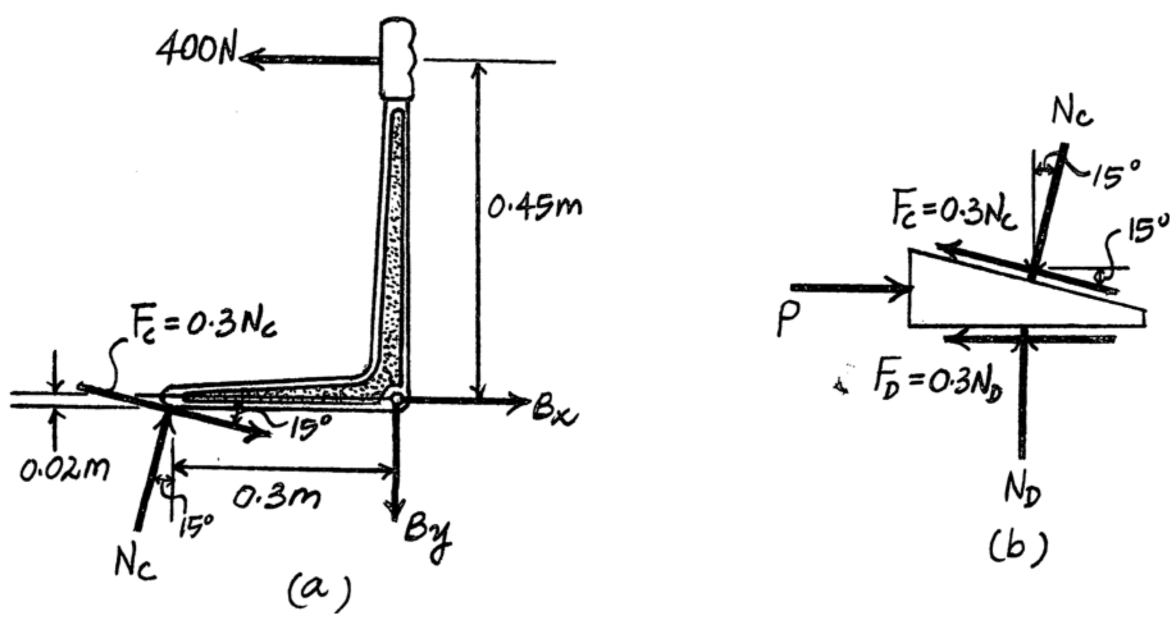
$N_C = 704.47$ N

Referring to the free - body diagram of the wedge shown in Fig. *b*,

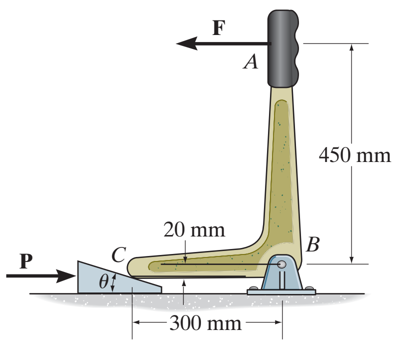
$+\uparrow \Sigma F_y = 0;$ $\quad N_D + 0.3(704.47)\sin 15° - 704.47\cos 15° = 0 \qquad N_D = 625.76$ N

$\overset{+}{\rightarrow} \Sigma F_x = 0;$ $\quad P - 0.3(704.47)\cos 15° - 0.3(625.76) - 704.47 \sin 15° = 0$

$P = 574$ N **Ans.**



***8–72.** If the horizontal force **P** is removed, determine the largest angle θ that will cause the wedge to be self-locking regardless of the magnitude of force **F** applied to the handle. The coefficient of static friction at all contacting surfaces is $\mu_s = 0.3$.



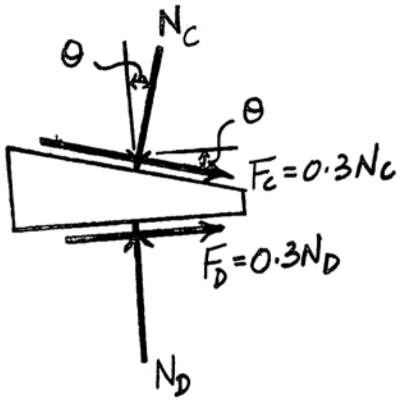
Free - Body Diagram. Since the wedge is required to be on the verge of sliding to the left (just self locking), the frictional forces $\mathbf{F}_C$ and $\mathbf{F}_D$ must act to the right such that $F_C = \mu_s N_C = 0.3N_C$ and $F_D = \mu_s N_D = 0.3N_D$ as indicated on the free - body diagram of the wedge shown in Fig. *a*.

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

$+\uparrow \Sigma F_y = 0;$ $\quad N_D - 0.3N_C \sin\theta - N_C \cos\theta = 0 \qquad N_D = N_C(0.3\sin\theta + \cos\theta)$

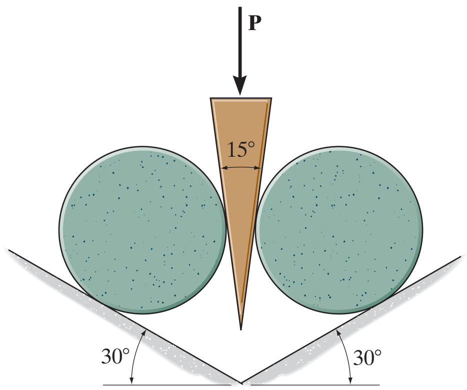
$\overset{+}{\rightarrow} \Sigma F_x = 0;$ $\quad 0.3N_C \cos\theta + 0.3[N_C(0.3\sin\theta + \cos\theta)] - N_C \sin\theta = 0$

$\theta = 33.4°$ **Ans.**



(a)

•8–73. Determine the smallest vertical force P required to hold the wedge between the two identical cylinders, each having a weight of W. The coefficient of static friction at all contacting surfaces is $\mu_s = 0.1$.



Free - Body Diagram. Since the wedge is required to be on the verge of moving upward, the frictional force $\mathbf{F}_A$ on the wedge must act downward. Here, there are two possible modes of motion for the cylinder, namely (1) the cylinder rolls about B and slips at A or (2) the cylinder rolls about A and slips at B. We will assume that the first mode of motion occurs. Thus, $F_A = \mu_s N_A = 0.1N_A$.

Equations of Equilibrium. Referring to the free - body diagram of the cylinder shown in Fig. a,

$\xrightarrow{+} \Sigma F_x = 0;$ $\quad N_A \cos 7.5° + 0.1N_A \sin 7.5° - N_B \sin 30° + F_B \cos 30° = 0$

$+\uparrow \Sigma F_y = 0;$ $\quad N_B \cos 30° + F_B \sin 30° + 0.1N_A \cos 7.5° - N_A \sin 7.5° - W = 0$

$\circlearrowleft + \Sigma M_O = 0;$ $\quad F_B(r) - 0.1N_A(r) = 0$

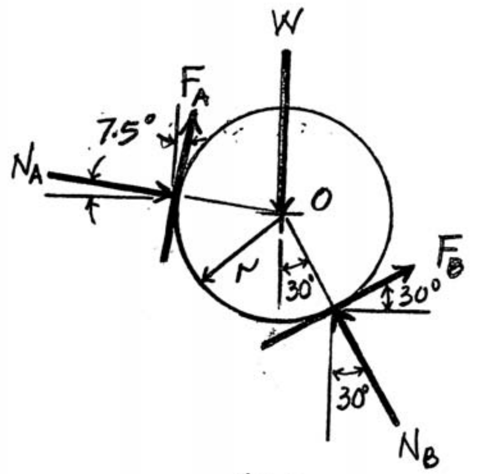
Solving,

$$N_A = 0.5240W \quad N_B = 1.1435W \quad F_B = 0.05240W$$

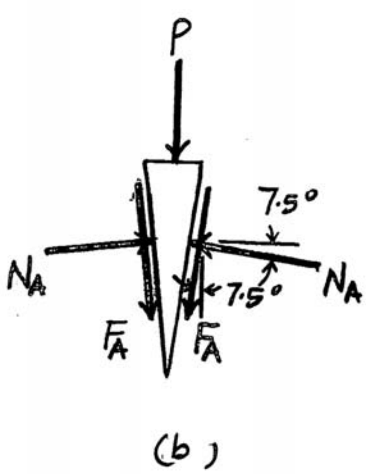
Since $F_B < (F_B)_{max} = \mu_s N_B = 0.1(1.1435W) = 0.11435W$, slipping will not occur at B. Thus, the above assumption is correct. Using the result of N_A, we find that $F_A = 0.1(0.5240W) = 0.05240W$. Referring to the free - body diagram of the wedge shown in Fig. b,

$+\uparrow \Sigma F_y = 0;$ $\quad 2(0.5240W)\sin 7.5° - 2(0.05240W \cos 7.5°) - P = 0$

$$P = 0.0329W$$ **Ans.**

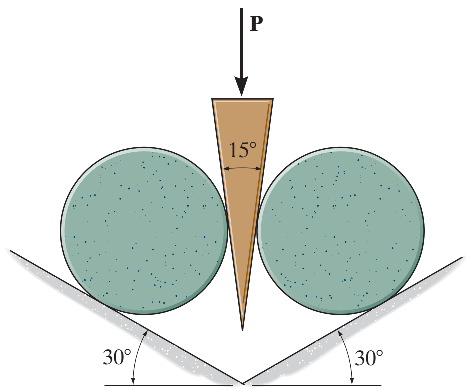


(a)



(b)

8–74. Determine the smallest vertical force P required to push the wedge between the two identical cylinders, each having a weight of W. The coefficient of static friction at all contacting surfaces is $\mu_s = 0.3$.



Free - Body Diagram. Since the wedge is required to be on the verge of moving downward, the frictional force $\mathbf{F}_A$ on the wedge must act upward. Here, there are two possible modes of motion for the cylinder, namely (1) the cylinder rolls about B and slips at A or (2) the cylinder rolls about A and slips at B. We will assume that the first mode of motion occurs. Thus, the magnitude of $\mathbf{F}_A$ can be computed using the friction formula; i.e., $F_A = \mu_s N_A = 0.3N_A$.

Equations of Equilibrium. Referring to the free - body diagram of the cylinder shown in Fig. a,

$\overset{+}{\rightarrow}\Sigma F_x = 0;\qquad N_A \cos 7.5° - 0.3N_A \sin 7.5° - F_B \cos 30° - N_B \sin 30° = 0$

$+\uparrow \Sigma F_y = 0;\qquad N_B \cos 30° - F_B \sin 30° - 0.3N_A \cos 7.5° - N_A \sin 7.5° - W = 0$

$\circlearrowleft + \Sigma M_O = 0;\qquad 0.3N_A(r) - F_B(r) = 0$

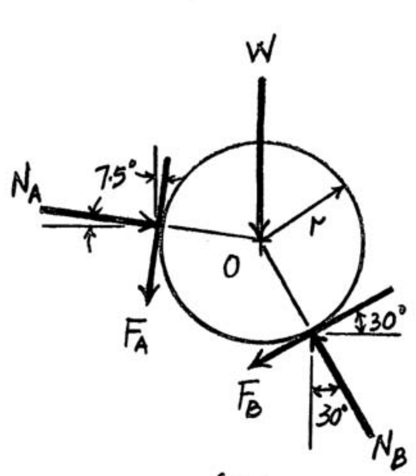
Solving,

$$N_A = 1.609W \quad N_B = 2.229W \quad F_B = 0.4827W$$

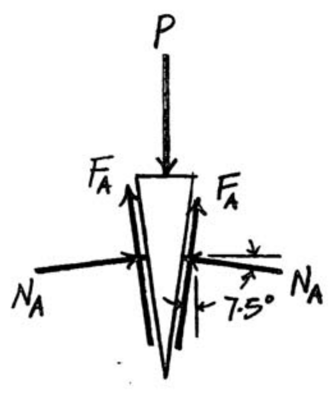
Since $F_B < (F_B)_{max} = \mu_s N_B = 0.3(2.229W) = 0.669W$, slipping will not occur at B. Thus, the above assumption is correct. Using the result of N_A, we find that $F_A = 0.3(1.609W) = 0.4827W$. Referring to the free - body diagram of the wedge shown in Fig. b,

$+\uparrow \Sigma F_y = 0;\qquad 2(1.609W \sin 7.5°) + 2(0.4827W \cos 7.5°) - P = 0$

$P = 1.38W$ **Ans.**

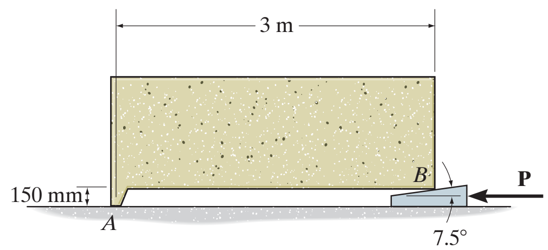


(a)



(b)

8–75. If the uniform concrete block has a mass of 500 kg, determine the smallest horizontal force P needed to move the wedge to the left. The coefficient of static friction between the wedge and the concrete and the wedge and the floor is $\mu_s = 0.3$. The coefficient of static friction between the concrete and floor is $\mu'_s = 0.5$.



Free - Body Diagram. Since the wedge is required to be on the verge of sliding to the left, the frictional forces $\mathbf{F}_B$ and $\mathbf{F}_C$ on the wedge must act to the right such that $F_B = \mu_s N_B = 0.3N_B$ and $F_C = \mu_s N_C = 0.3N_C$.

Equations of Equilibrium. Referring to the free - body diagram of the concrete block shown in Fig. a,

$\circlearrowleft + \Sigma M_A = 0;$ $\quad 0.3N_B \cos 7.5°(0.15) - 0.3N_B \sin 7.5°(3) + N_B \cos 7.5°(3) + N_B \sin 7.5°(0.15) - 500(9.81)(1.5) = 0$

$N_B = 2518.78 \text{ N}$

$+\uparrow \Sigma F_y = 0;$ $\quad F_A - 0.3(2518.78)\cos 7.5° - 2518.78 \sin 7.5° = 0$ $\qquad F_A = 1077.94 \text{ N}$

$\overset{+}{\rightarrow} \Sigma F_x = 0;$ $\quad N_A + 2518.78 \cos 7.5° - 0.3(2518.78)\sin 7.5° - 500(9.81) = 0$

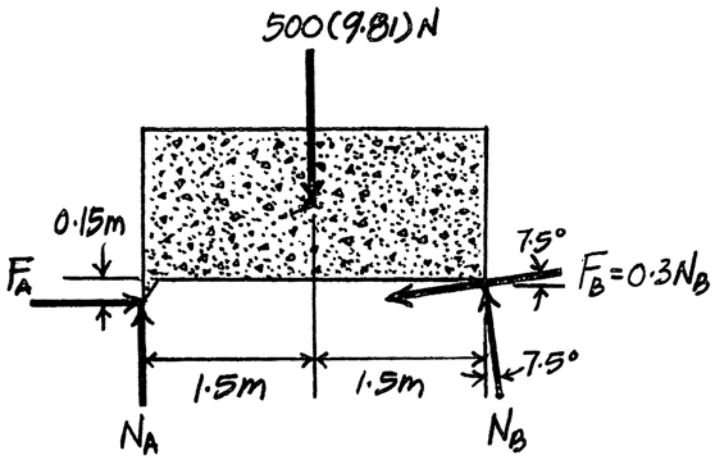
$N_A = 2506.40 \text{ N}$

Since $F_A < (F_A)_{max} = \mu'_s N_A = 0.5(2506.40) = 1253.20 \text{ N}$, the concrete block will not slip at A. Using the result of $\mathbf{N}_B$ and referring to the free - body diagram of the wedge shown in Fig. b,

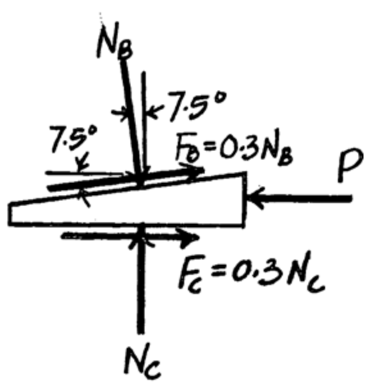
$+\uparrow \Sigma F_y = 0;$ $\quad N_C + 0.3(2518.78)\sin 7.5° - 2518.78 \cos 7.5° = 0$ $\qquad N_C = 2398.60 \text{ N}$

$\overset{+}{\rightarrow} \Sigma F_x = 0;$ $\quad 0.3(2518.78)\cos 7.5° + 2518.78 \sin 7.5° + 0.3(2398.60) - P = 0$

$P = 1797.52 \text{ N} = 1.80 \text{ kN}$ **Ans.**

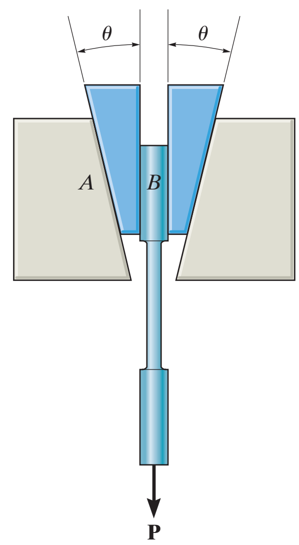


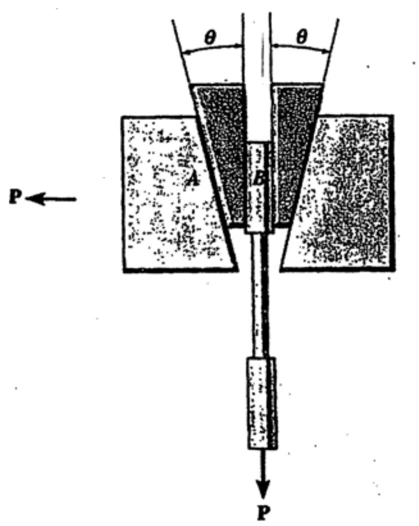
(a)



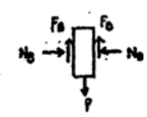
(b)

***8–76.** The wedge blocks are used to hold the specimen in a tension testing machine. Determine the largest design angle θ of the wedges so that the specimen will not slip regardless of the applied load. The coefficients of static friction are $\mu_A = 0.1$ at A and $\mu_B = 0.6$ at B. Neglect the weight of the blocks.





Specimen:

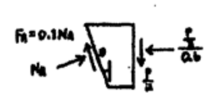


$+\uparrow\Sigma F_y = 0;\quad F_B = \frac{P}{2}$

Wedge:

$\xrightarrow{+}\Sigma F_x = 0;\quad N_A\cos\theta - 0.1N_A\sin\theta - \frac{\frac{P}{2}}{0.6} = 0$

$+\uparrow\Sigma F_y = 0;\quad 0.1N_A\cos\theta + N_A\sin\theta - \frac{P}{2} = 0$



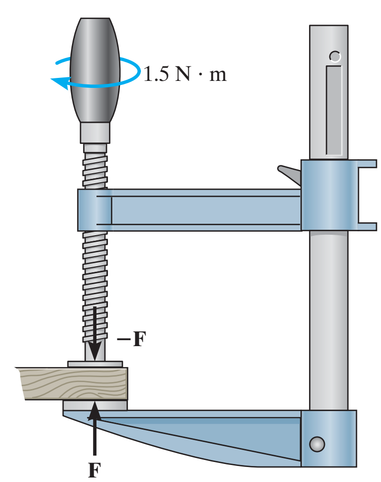
$P = 2N_A(0.1\cos\theta + \sin\theta)$

$0.6N_A(\cos\theta - 0.1\sin\theta) - N_A(0.1\cos\theta + \sin\theta) = 0$

$0.5\cos\theta - 1.06\sin\theta = 0$

$\theta = \tan^{-1}\left(\frac{0.5}{1.06}\right) = 25.3^\circ$ **Ans**

•8–77. The square threaded screw of the clamp has a mean diameter of 14 mm and a lead of 6 mm. If $\mu_s = 0.2$ for the threads, and the torque applied to the handle is 1.5 N · m, determine the compressive force F on the block.



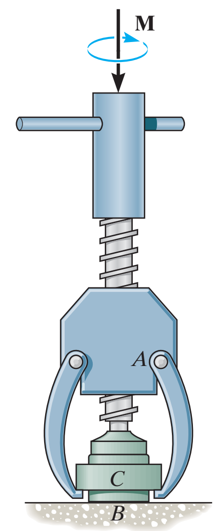
Frictional Forces on Screw : Here, $\theta = \tan^{-1}\left(\frac{l}{2\pi r}\right) = \tan^{-1}\left[\frac{6}{2\pi(7)}\right] = 7.768^\circ$, $W = F$ and $\phi_s = \tan^{-1}\mu_s = \tan^{-1}(0.2) = 11.310^\circ$. Applying Eq. 8–3, we have

$$M = Wr\tan(\theta + \phi)$$
$$1.5 = F(0.007)\tan(7.768^\circ + 11.310^\circ)$$

$$F = 620\text{ N}$$ **Ans**

Note : Since $\phi_s > \theta$, the screw is self-locking. It will not unscrew even if the moment is removed.

8–78. The device is used to pull the battery cable terminal *C* from the post of a battery. If the required pulling force is 85 lb, determine the torque *M* that must be applied to the handle on the screw to tighten it. The screw has square threads, a mean diameter of 0.2 in., a lead of 0.08 in., and the coefficient of static friction is $\mu_s = 0.5$.

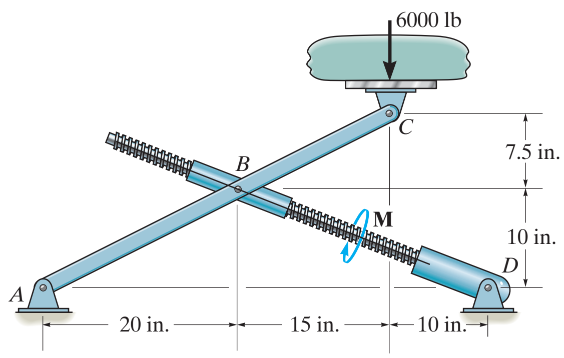


Frictional Forces on Screw : Here, $\theta = \tan^{-1}\left(\frac{l}{2\pi r}\right) = \tan^{-1}\left[\frac{0.08}{2\pi(0.1)}\right] = 7.256°$, $W = 85$ lb and $\phi_s = \tan^{-1}\mu_s = \tan^{-1}(0.5) = 26.565°$. Applying Eq. 8 – 3, we have

$$M = Wr\tan(\theta + \phi)$$
$$= 85(0.1)\tan(7.256° + 26.565°)$$
$$= 5.69 \text{ lb} \cdot \text{in} \qquad \textbf{Ans}$$

Note : Since $\phi_s > \theta$, the screw is self - locking. It will not unscrew even if the moment is removed.

8–79. The jacking mechanism consists of a link that has a square-threaded screw with a mean diameter of 0.5 in. and a lead of 0.20 in., and the coefficient of static friction is $\mu_s = 0.4$. Determine the torque *M* that should be applied to the screw to start lifting the 6000-lb load acting at the end of member *ABC*.

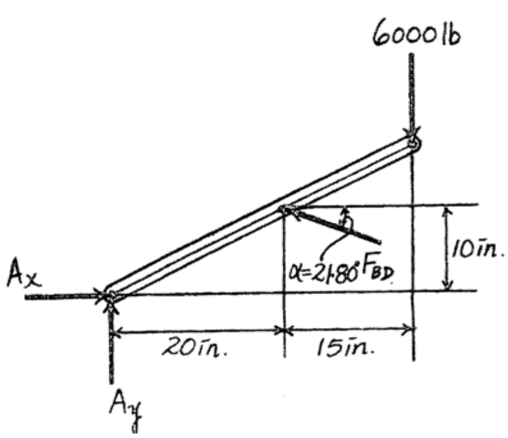


$$\alpha = \tan^{-1}\left(\frac{10}{25}\right) = 21.80°$$

$$\circlearrowleft + \Sigma M_A = 0; \qquad -6000\,(35) + F_{BD}\cos 21.80°\,(10) + F_{BD}\sin 21.80°\,(20) = 0$$

$$F_{BD} = 12\,565 \text{ lb}$$

8-79



$$\phi_s = \tan^{-1}(0.4) = 21.80°$$

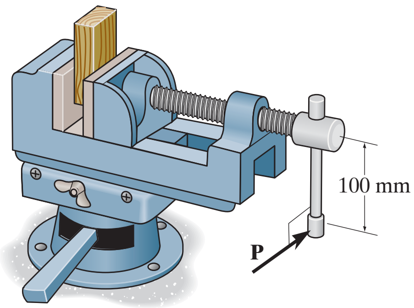
$$\theta = \tan^{-1}\left(\frac{0.2}{2\pi\,(0.25)}\right) = 7.256°$$

$$M = Wr\tan(\theta + \phi)$$

$$M = 12\,565\,(0.25)\tan(7.256° + 21.80°)$$

$$M = 1745 \text{ lb} \cdot \text{in.} = 145 \text{ lb} \cdot \text{ft} \qquad \textbf{Ans}$$

***8–80.** Determine the magnitude of the horizontal force **P** that must be applied to the handle of the bench vise in order to produce a clamping force of 600 N on the block. The single square-threaded screw has a mean diameter of 25 mm and a lead of 7.5 mm. The coefficient of static friction is $\mu_s = 0.25$.



Here, $M = P(0.1)$

$$\theta = \tan^{-1}\left(\frac{L}{2\pi r}\right) = \tan^{-1}\left[\frac{7.5}{2\pi(12.5)}\right] = 5.455°$$

$$\phi_s = \tan^{-1}\mu_s = \tan^{-1}(0.25) = 14.036°$$

$W = 600\text{ N}$

Thus

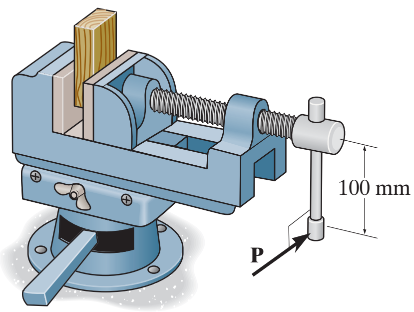
$$M = Wr\tan(\phi_s + \theta)$$

$$P(0.1) = 600(0.0125)\tan(14.036° + 5.455°)$$

$$P = 26.5\text{ N}$$ **Ans.**

Note: Since $\phi_s > \theta$, the screw is self - locking.

•8–81. Determine the clamping force exerted on the block if a force of $P = 30$ N is applied to the lever of the bench vise. The single square-threaded screw has a mean diameter of 25 mm and a lead of 7.5 mm. The coefficient of static friction is $\mu_s = 0.25$.



Here, $M = 30(0.1) = 3\text{ N}\cdot\text{m}$

$$\theta = \tan^{-1}\left(\frac{L}{2\pi r}\right) = \tan^{-1}\left[\frac{7.5}{2\pi(12.5)}\right] = 5.455°$$

$$\phi_s = \tan^{-1}\mu_s = \tan^{-1}(0.25) = 14.036°$$

$W = F$

Thus

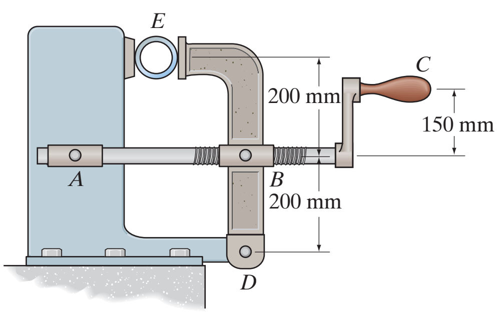
$$M = Wr\tan(\phi_s + \theta)$$

$$3 = F(0.0125)\tan(14.036° + 5.455°)$$

$$F = 678\text{ N}$$ **Ans.**

Note: Since $\phi_s > \theta$, the screw is self - locking.

8–82. Determine the required horizontal force that must be applied perpendicular to the handle in order to develop a 900-N clamping force on the pipe. The single square-threaded screw has a mean diameter of 25 mm and a lead of 5 mm. The coefficient of static friction is $\mu_s = 0.4$. *Note:* The screw is a two-force member since it is contained within pinned collars at A and B.



Referring to the free-body diagram of member ED shown in Fig. a,

$$\circlearrowleft + \Sigma M_D = 0; \qquad F_{AB}(0.2) - 900(0.4) = 0 \qquad F_{AB} = 1800\text{ N}$$

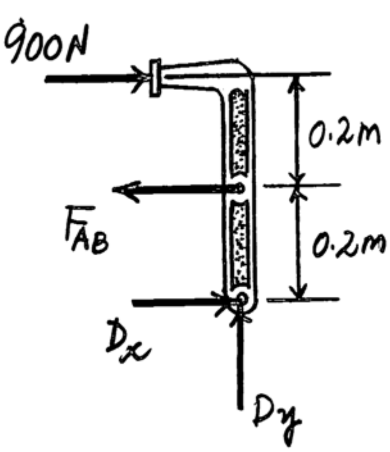
Here, $\theta = \tan^{-1}\left(\frac{L}{2\pi r}\right) = \tan^{-1}\left[\frac{5}{2\pi(12.5)}\right] = 3.643°$

$\phi_s = \tan^{-1}\mu_s = \tan^{-1}(0.4) = 21.801°$

$M = F(0.15)$; and $W = F_{AB} = 1800\text{ N}$

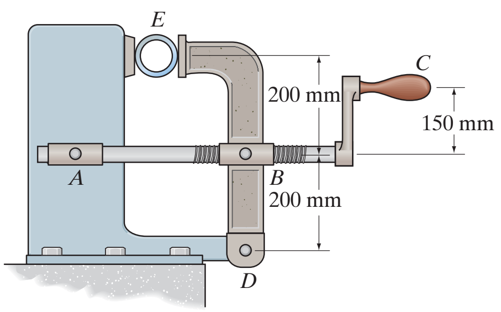
$$M = Wr\tan(\phi_s + \theta)$$
$$F(0.15) = 1800(0.0125)\tan(21.801° + 3.643°)$$
$$F = 71.4\text{ N} \qquad \textbf{Ans.}$$

Note: Since $\phi_s > \theta$, the screw is self-locking.



(a)

8–83. If the clamping force on the pipe is 900 N, determine the horizontal force that must be applied perpendicular to the handle in order to loosen the screw. The single square-threaded screw has a mean diameter of 25 mm and a lead of 5 mm. The coefficient of static friction is $\mu_s = 0.4$. *Note:* The screw is a two-force member since it is contained within pinned collars at A and B.



Referring to the free-body diagram of member ED shown in Fig. *a*,

$+\Sigma M_D = 0; \qquad F_{AB}(0.2) - 900(0.4) = 0 \qquad F_{AB} = 1800\text{ N}$

Here, $\theta = \tan^{-1}\left(\frac{L}{2\pi r}\right) = \tan^{-1}\left[\frac{5}{2\pi(12.5)}\right] = 3.643°$

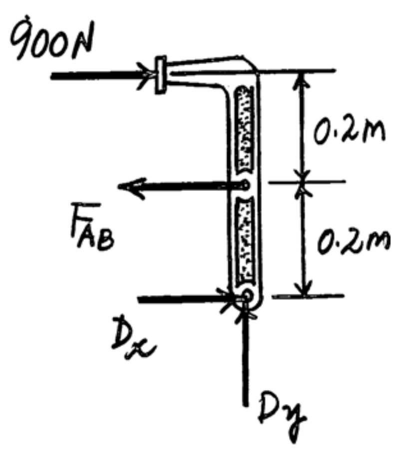
$\phi_s = \tan^{-1}\mu_s = \tan^{-1}(0.4) = 21.801°$

$M = F(0.15)$; and $W = F_{AB} = 1800$ N

$$M = Wr\tan(\phi_s - \theta)$$

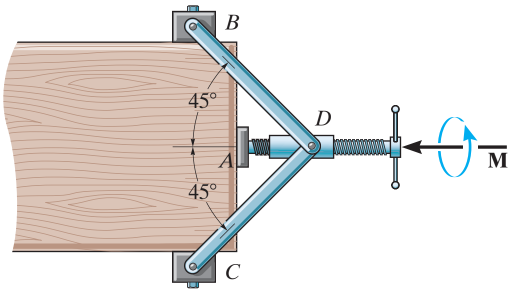
$$F(0.15) = 1800(0.0125)\tan(21.801° - 3.643°)$$

$$F = 49.2\text{ N} \qquad \textbf{Ans.}$$



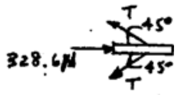
(a)

***8–84.** The clamp provides pressure from several directions on the edges of the board. If the square-threaded screw has a lead of 3 mm, mean radius of 10 mm, and the coefficient of static friction is $\mu_s = 0.4$, determine the horizontal force developed on the board at A and the vertical forces developed at B and C if a torque of $M = 1.5\ \text{N}\cdot\text{m}$ is applied to the handle to tighten it further. The blocks at B and C are pin connected to the board.



$$\phi_s = \tan^{-1}(0.4) = 21.801°$$

$$\theta_p = \tan^{-1}\left[\frac{3}{2\pi(10)}\right] = 2.734°$$



$$M = W(r)\tan(\phi_s + \theta_p)$$

$$1.5 = A_x(0.01)\tan(21.801° + 2.734°)$$

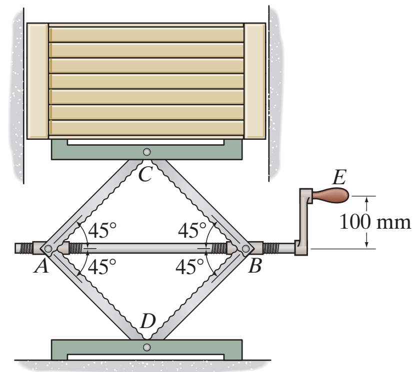
$$A_x = 328.6\ \text{N} \qquad \textbf{Ans}$$

$$\xrightarrow{+} \Sigma F_x = 0; \qquad 328.6 - 2T\cos 45° = 0$$

$$T = 232.36\ \text{N}$$

$$B_y = C_y = 232.36\sin 45° = 164\ \text{N} \qquad \textbf{Ans}$$

•8–85. If the jack supports the 200-kg crate, determine the horizontal force that must be applied perpendicular to the handle at E to lower the crate. Each single square-threaded screw has a mean diameter of 25 mm and a lead of 7.5 mm. The coefficient of static friction is $\mu_s = 0.25$.



The force in rod AB can be obtained by first analyzing the equilibrium of joint C followed by joint B. Referring to the free-body diagram of joint C shown in Fig. a,

$\overset{+}{\rightarrow}\Sigma F_x = 0;\quad F_{CA}\sin 45° - F_{CB}\sin 45° = 0 \qquad F_{CA} = F_{CB} = F$

$+\uparrow \Sigma F_y = 0;\quad 2F\cos 45° - 200(9.81) = 0 \qquad F = 1387.34\text{ N}$

Using the result of F and referring to the free-body diagram of joint B shown in Fig. b,

$+\uparrow \Sigma F_y = 0;\quad F_{BD}\sin 45° - 1387.34\sin 45° = 0 \qquad F_{BD} = 1387.34\text{ N}$

$\overset{+}{\rightarrow}\Sigma F_x = 0;\quad 1387.34\cos 45° + 1387.34\cos 45° - F_{AB} = 0 \qquad F_{AB} = 1962\text{ N}$

Here, $\theta = \tan^{-1}\left(\dfrac{L}{2\pi r}\right) = \tan^{-1}\left[\dfrac{7.5}{2\pi(12.5)}\right] = 5.455°$

$\phi_s = \tan^{-1}\mu_s = \tan^{-1}(0.25) = 14.036°$

$M = F(0.1)$ and $W = F_{AB} = 1962\text{ N}$

Since $\mathbf{M}$ must overcome the friction of two screws,

$$M = 2[Wr\tan(\phi_s - \theta)]$$

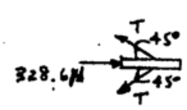
$$F(0.1) = 2[1962(0.0125)\tan(14.036° - 5.455°)]$$

$$F = 74.0\text{ N} \qquad \textbf{Ans.}$$

Note: Since $\phi_s > \theta$, the screws are self-locking.

$\phi_s = \tan^{-1}(0.4) = 21.801°$

$\theta_p = \tan^{-1}\left[\dfrac{3}{2\pi(10)}\right] = 2.734°$



$M = W(r)\tan(\phi_s + \theta_p)$

$1.5 = A_x(0.01)\tan(21.801° + 2.734°)$

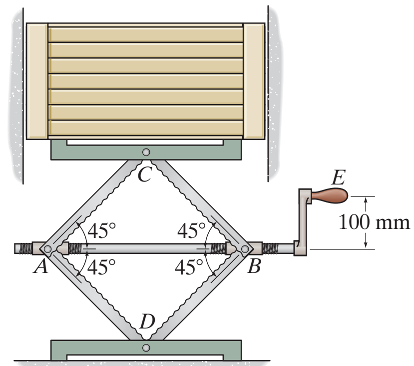
$A_x = 328.6\text{ N}$ **Ans**

$\overset{+}{\rightarrow}\Sigma F_x = 0;\quad 328.6 - 2T\cos 45° = 0$

$T = 232.36\text{ N}$

$B_y = C_y = 232.36\sin 45° = 164\text{ N}$ **Ans**

8–86. If the jack is required to lift the 200-kg crate, determine the horizontal force that must be applied perpendicular to the handle at E. Each single square-threaded screw has a mean diameter of 25 mm and a lead of 7.5 mm. The coefficient of static friction is $\mu_s = 0.25$.



The force in rod AB can be obtained by first analyzing the equilibrium of joint C followed by joint B. Referring to the free-body diagram of joint C shown in Fig. a,

$\xrightarrow{+} \Sigma F_x = 0;$ $\quad F_{CA}\sin 45° - F_{CB}\sin 45° = 0 \quad F_{CA} = F_{CB} = F$

$+\uparrow \Sigma F_y = 0;$ $\quad 2F\cos 45° - 200(9.81) = 0 \quad F = 1387.34\text{ N}$

Using the result of F and referring to the free-body diagram of joint B shown in Fig. b,

$+\uparrow \Sigma F_y = 0;$ $\quad F_{BD}\sin 45° - 1387.34\sin 45° = 0 \quad F_{BD} = 1387.34\text{ N}$

$\xrightarrow{+} \Sigma F_x = 0;$ $\quad 1387.34\cos 45° + 1387.34\cos 45° - F_{AB} = 0 \quad F_{AB} = 1962\text{ N}$

Here, $\theta = \tan^{-1}\left(\frac{L}{2\pi r}\right) = \tan^{-1}\left[\frac{7.5}{2\pi(12.5)}\right] = 5.455°$

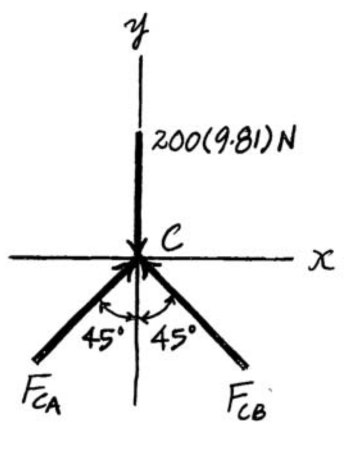
$\phi_s = \tan^{-1}\mu_s = \tan^{-1}(0.25) = 14.036°$

$M = F(0.1)$ and $W = F_{AB} = 1962\text{ N}$

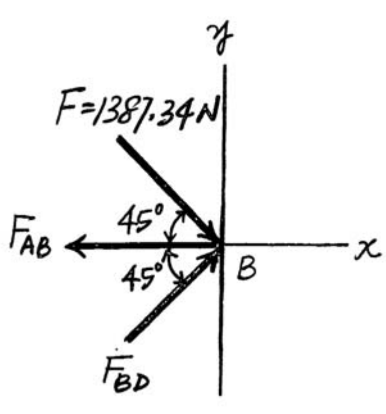
Since **M** must overcome the friction of two screws,

$$M = 2[Wr\tan(\phi_s + \theta)]$$
$$F(0.1) = 2[1962(0.0125)\tan(14.036° + 5.455°)]$$
$$F = 174\text{ N} \qquad \textbf{Ans.}$$

Note: Since $\phi_s > \theta$, the screws are self-locking.

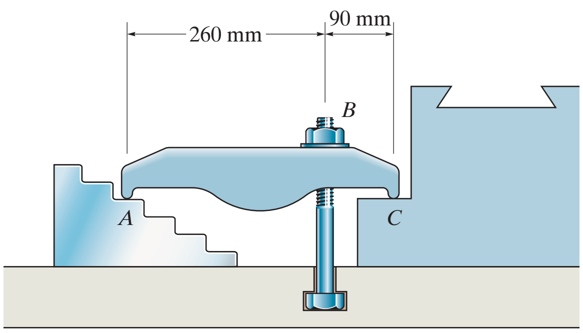


(a)



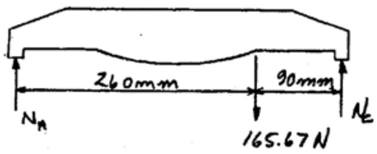
(b)

8–87. The machine part is held in place using the double-end clamp. The bolt at B has square threads with a mean radius of 4 mm and a lead of 2 mm, and the coefficient of static friction with the nut is $\mu_s = 0.5$. If a torque of $M = 0.4\ \text{N}\cdot\text{m}$ is applied to the nut to tighten it, determine the normal force of the clamp at the smooth contacts A and C.



$\phi = \tan^{-1}(0.5) = 26.565°$

$\theta = \tan^{-1}\left(\frac{2}{2\pi(4)}\right) = 4.550°$



$M = Wr\tan(\theta + \phi)$

$0.4 = W(0.004)\tan(4.550° + 26.565°)$

$W = 165.67\ \text{N}$

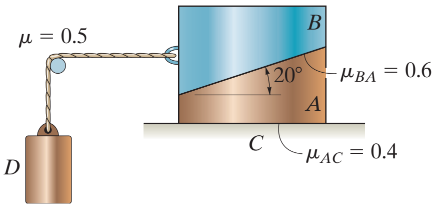
$\circlearrowleft + \Sigma M_A = 0;\quad N_C(350) - 165.67(260) = 0$

$N_C = 123.1 = 123\ \text{N}$ **Ans**

$+\uparrow \Sigma F_y = 0;\quad N_A - 165.67 + 123.1 = 0$

$N_A = 42.6\ \text{N}$ **Ans**

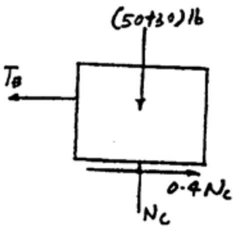
*__8–88.__ Blocks A and B weigh 50 lb and 30 lb, respectively. Using the coefficients of static friction indicated, determine the greatest weight of block D without causing motion.



For block A and B : Assuming block B does not slip

$+\uparrow \Sigma F_y = 0;\quad N_C - (50+30) = 0 \qquad N_C = 80\ \text{lb}$

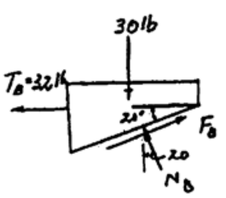
$\xrightarrow{+} \Sigma F_x = 0;\quad 0.4(80) - T_B = 0 \qquad T_B = 32\ \text{lb}$



For block B :

$+\uparrow \Sigma F_y = 0;\quad N_B\cos 20° + F_B\sin 20° - 30 = 0 \qquad [1]$

$\xrightarrow{+} \Sigma F_x = 0;\quad F_B\cos 20° - N_B\sin 20° - 32 = 0 \qquad [2]$



Solving Eqs.[1] and [2] yields :

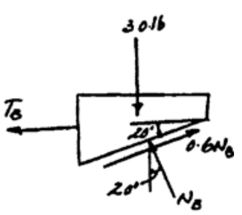
$F_B = 40.32\ \text{lb} \qquad N_B = 17.25\ \text{lb}$

Since $F_B = 40.32\ \text{lb} > \mu N_B = 0.6(17.25) = 10.35\ \text{lb}$, slipping does occur between A and B. Therefore, the assumption is no good .

Since slipping occurs, $F_B = 0.6\,N_B$.

$+\uparrow \Sigma F_y = 0;\quad N_B\cos 20° + 0.6N_B\sin 20° - 30 = 0 \qquad N_B = 26.20\ \text{lb}$

$\xrightarrow{+} \Sigma F_x = 0;\quad 0.6(26.20)\cos 20° - 26.20\sin 20° - T_B = 0 \qquad T_B = 5.812\ \text{lb}$

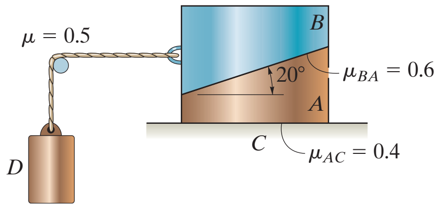


$T_2 = T_1 e^{\mu\beta}$ Where $T_2 = W_D,\ T_1 = T_B = 5.812\ \text{lb},\ \beta = 0.5\pi$ rad

$W_D = 5.812e^{0.5(0.5\pi)}$

$= 12.7\ \text{lb}$ **Ans**

•8–89. Blocks *A* and *B* weigh 75 lb each, and *D* weighs 30 lb. Using the coefficients of static friction indicated, determine the frictional force between blocks *A* and *B* and between block *A* and the floor *C*.



For the rope, $T_2 = T_1 e^{\mu\beta}$, where $T_2 = 30$ lb, $T_1 = T_B$, and $\beta = 0.5\pi$ rad.

$$30 = T_B e^{0.5(0.5\pi)}$$

$$T_B = 13.678 \text{ lb}$$

$$F_C = 13.7 \text{ lb} \qquad \textbf{Ans}$$

For block *B*:

$$+\uparrow \Sigma F_y = 0;\ N_B \cos 20° + F_B \sin 20° - 75 = 0 \qquad [1]$$

$$\overset{+}{\rightarrow} \Sigma F_x = 0;\ F_B \cos 20° - N_B \sin 20° - 13.678 = 0 \qquad [2]$$

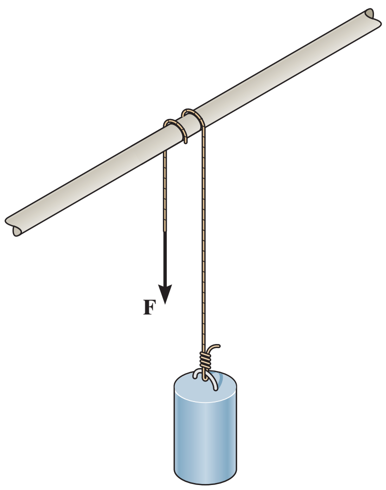
Solving Eqs. [1] and [2] yields:

$$N_B = 65.8 \text{ lb}$$

$$F_B = 38.5 \text{ lb} \qquad \textbf{Ans}$$

Since $F_B = 38.5 \text{ lb} < \mu N_B = 0.6(65.8) = 39.5$ lb, slipping between *A* and *B* does not occur.

8–90. A cylinder having a mass of 250 kg is to be supported by the cord which wraps over the pipe. Determine the smallest vertical force *F* needed to support the load if the cord passes (a) once over the pipe, $\beta = 180°$, and (b) two times over the pipe, $\beta = 540°$. Take $\mu_s = 0.2$.



Frictional Force on Flat Belt : Here, $T_1 = F$ and $T_2 = 250(9.81) = 2452.5$ N. Applying Eq. 8 – 6, we have

a) If $\beta = 180° = \pi$ rad

$$T_2 = T_1 e^{\mu\beta}$$
$$2452.5 = F e^{0.2\pi}$$

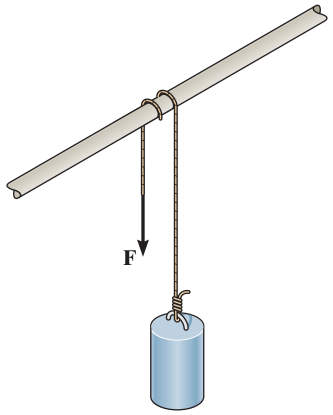
$$F = 1308.38 \text{ N} = 1.31 \text{ kN} \qquad \textbf{Ans}$$

b) If $\beta = 540° = 3\pi$ rad

$$T_2 = T_1 e^{\mu\beta}$$
$$2452.5 = F e^{0.2(3\pi)}$$

$$F = 372.38 \text{ N} = 372 \text{ N} \qquad \textbf{Ans}$$

8–91. A cylinder having a mass of 250 kg is to be supported by the cord which wraps over the pipe. Determine the largest vertical force F that can be applied to the cord without moving the cylinder. The cord passes (a) once over the pipe, $\beta = 180°$, and (b) two times over the pipe, $\beta = 540°$. Take $\mu_s = 0.2$.



Frictional Force on Flat Belt : Here, $T_1 = 250(9.81) = 2452.5$ N and $T_2 = F$. Applying Eq. 8 – 6, we have

a) If $\beta = 180° = \pi$ rad

$$T_2 = T_1 e^{\mu\beta}$$
$$F = 2452.5e^{0.2\pi}$$

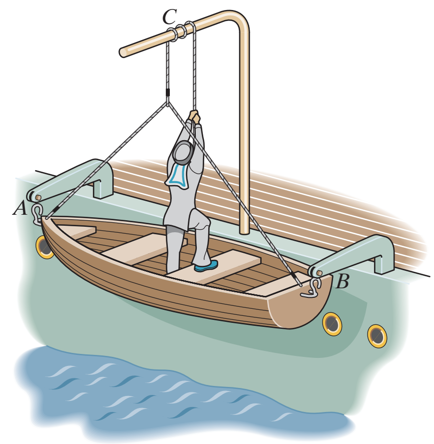
$$F = 4597.10 \text{ N} = 4.60 \text{ kN} \qquad \textbf{Ans}$$

b) If $\beta = 540° = 3\pi$ rad

$$T_2 = T_1 e^{\mu\beta}$$
$$F = 2452.5e^{0.2(3\pi)}$$

$$F = 16152.32 \text{ N} = 16.2 \text{ kN} \qquad \textbf{Ans}$$

***8–92.** The boat has a weight of 500 lb and is held in position off the side of a ship by the spars at A and B. A man having a weight of 130 lb gets in the boat, wraps a rope around an overhead boom at C, and ties it to the end of the boat as shown. If the boat is disconnected from the spars, determine the *minimum number of half turns* the rope must make around the boom so that the boat can be safely lowered into the water at constant velocity. Also, what is the normal force between the boat and the man? The coefficient of kinetic friction between the rope and the boom is $\mu_s = 0.15$. *Hint*: The problem requires that the normal force between the man's feet and the boat be as small as possible.

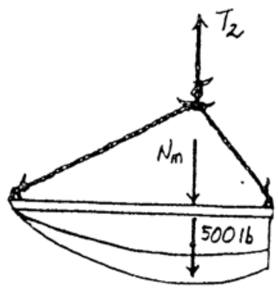


Frictional Force on Flat Belt : If the normal force between the man and the boat is equal to zero, then, $T_1 = 130$ lb and $T_2 = 500$ lb. Applying Eq. 8–6, we have

$$T_2 = T_1 e^{\mu\beta}$$
$$500 = 130e^{0.15\beta}$$
$$\beta = 8.980 \text{ rad}$$

The least number of half turns of the rope required is $\dfrac{8.980}{\pi} = 2.86$ turns. Thus

Use $n = 3$ half turns **Ans**



(a)

Equations of Equilibrium : From FBD (a),

$$+\uparrow \Sigma F_y = 0; \quad T_2 - N_m - 500 = 0 \quad T_2 = N_m + 500$$

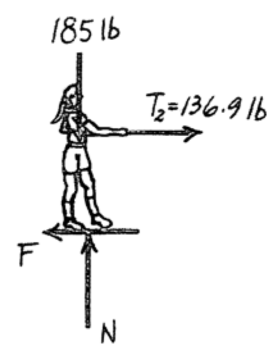
From FBD (b),

$$+\uparrow \Sigma F_y = 0; \quad T_1 + N_m - 130 = 0 \quad T_1 = 130 - N_m$$

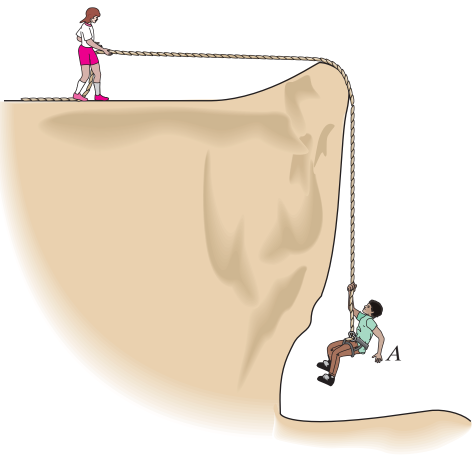
(b)

Frictional Force on Flat Belts : Here, $\beta = 3\pi$ rad. Applying Eq. 8–6, we have

$$T_2 = T_1 e^{\mu\beta}$$
$$N_m + 500 = (130 - N_m)e^{0.15(3\pi)}$$
$$N_m = 6.74 \text{ lb} \qquad \textbf{Ans}$$

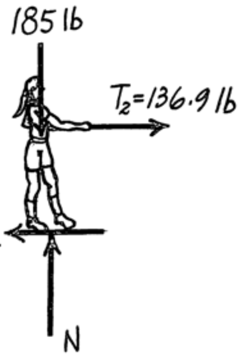


•8–93. The 100-lb boy at A is suspended from the cable that passes over the quarter circular cliff rock. Determine if it is possible for the 185-lb woman to hoist him up; and if this is possible, what smallest force must she exert on the horizontal cable? The coefficient of static friction between the cable and the rock is $\mu_s = 0.2$, and between the shoes of the woman and the ground $\mu_s' = 0.8$.



$\beta = \frac{\pi}{2}$

$T_2 = T_1 e^{\mu\beta} = 100 e^{0.2\frac{\pi}{2}} = 136.9 \text{ lb}$



$+\uparrow \Sigma F_y = 0; \quad N - 185 = 0$

$N = 185 \text{ lb}$

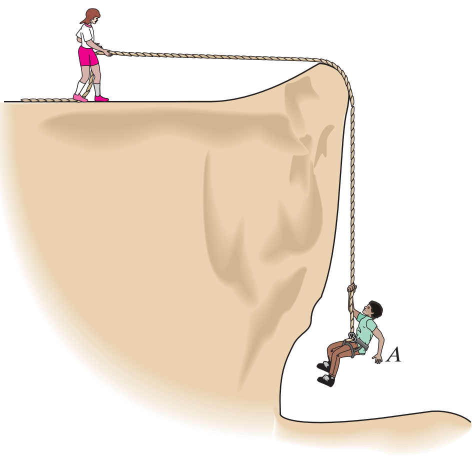
$\xrightarrow{+} \Sigma F_x = 0; \quad 136.9 - F = 0$

$F = 136.9 \text{ lb}$

$F_{max} = 0.8(185) = 148 \text{ lb} > 136.9 \text{ lb}$

Yes, just barely. **Ans**

8–94. The 100-lb boy at A is suspended from the cable that passes over the quarter circular cliff rock. What horizontal force must the woman at A exert on the cable in order to let the boy descend at constant velocity? The coefficients of static and kinetic friction between the cable and the rock are $\mu_s = 0.4$ and $\mu_k = 0.35$, respectively.

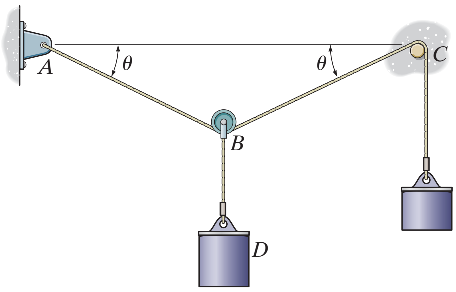


$\beta = \frac{\pi}{2}$

$T_2 = T_1 e^{\mu\beta}; \quad 100 = T_1 e^{0.35\frac{\pi}{2}}$

$T_1 = 57.7 \text{ lb}$ **Ans**

8–95. A 10-kg cylinder D, which is attached to a small pulley B, is placed on the cord as shown. Determine the smallest angle θ so that the cord does not slip over the peg at C. The cylinder at E has a mass of 10 kg, and the coefficient of static friction between the cord and the peg is $\mu_s = 0.1$.



Since pulley B is smooth, the tension in the cord between pegs A and C remains constant. Referring to the free-body diagram of the joint B shown in Fig. a, we have

$$+\uparrow \Sigma F_y = 0; \qquad 2T\sin\theta - 10(9.81) = 0 \qquad T = \frac{49.05}{\sin\theta}$$

In the case where cylinder E is on the verge of ascending, $T_2 = T = \dfrac{49.05}{\sin\theta}$ and $T_1 = 10(9.81)$ N. Here, $\dfrac{\pi}{2} + \theta$, Fig. b. Thus,

$$T_2 = T_1 e^{\mu_s \beta}$$

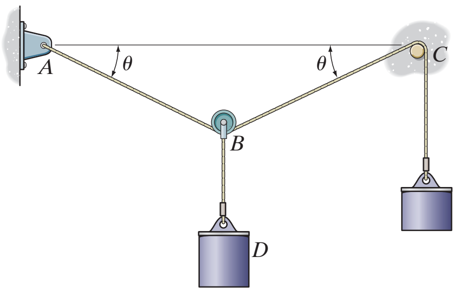
$$\frac{49.05}{\sin\theta} = 10(9.81)e^{0.1\left(\frac{\pi}{2}+\theta\right)}$$

$$\ln\frac{0.5}{\sin\theta} = 0.1\left(\frac{\pi}{2}+\theta\right)$$

Solving by trial and error, yields

$$\theta = 0.4221 \text{ rad} = 24.2^\circ \qquad \textbf{Ans.}$$

***8–96.** A 10-kg cylinder D, which is attached to a small pulley B, is placed on the cord as shown. Determine the largest angle θ so that the cord does not slip over the peg at C. The cylinder at E has a mass of 10 kg, and the coefficient of static friction between the cord and the peg is $\mu_s = 0.1$.



In the case where cylinder E is on the verge of descending, $T_2 = 10(9.81)$ N and $T_1 = \dfrac{49.05}{\sin\theta}$. Here, $\dfrac{\pi}{2} + \theta$. Thus,

$$T_2 = T_1 e^{\mu_s \beta}$$

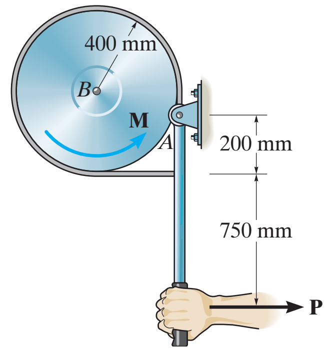
$$10(9.81) = \frac{49.05}{\sin\theta}e^{0.1\left(\frac{\pi}{2}+\theta\right)}$$

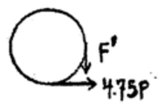
$$\ln(2\sin\theta) = 0.1\left(\frac{\pi}{2}+\theta\right)$$

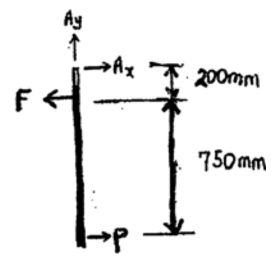
Solving by trial and error, yields

$$\theta = 0.6764 \text{ rad} = 38.8^\circ \qquad \textbf{Ans.}$$

•8–97. Determine the smallest lever force P needed to prevent the wheel from rotating if it is subjected to a torque of $M = 250\ \text{N}\cdot\text{m}$. The coefficient of static friction between the belt and the wheel is $\mu_s = 0.3$. The wheel is pin connected at its center, B.

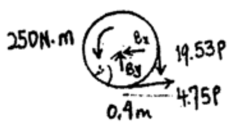






$\circlearrowleft + \Sigma M_A = 0; \qquad -F(200) + P(950) = 0$

$F = 4.75\,P$



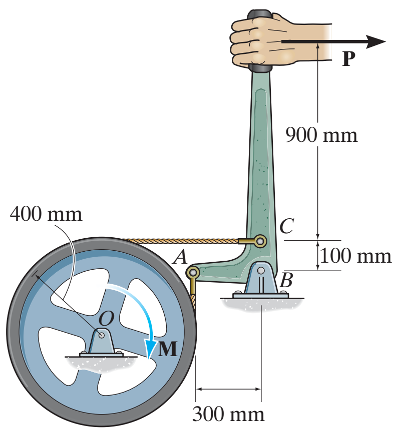
$T_2 = T_1\, e^{\mu\beta}$

$F' = 4.75\,P\, e^{0.3\left(\frac{3\pi}{2}\right)} = 19.53\,P$

$\circlearrowleft + \Sigma M_B = 0; \qquad -19.53\,P\,(0.4) + 250 + 4.75P(0.4) = 0$

$P = 42.3\ \text{N}$ **Ans**

8–98. If a force of $P = 200$ N is applied to the handle of the bell crank, determine the maximum torque M that can be resisted so that the flywheel is not on the verge of rotating clockwise. The coefficient of static friction between the brake band and the rim of the wheel is $\mu_s = 0.3$.



Referring to the free-body diagram of the bell crank shown in Fig. *a* and the flywheel shown in Fig. *b*,

$\curvearrowleft + \Sigma M_B = 0;$ $\quad T_A(0.3) + T_C(0.1) - 200(1) = 0 \quad (1)$

$\curvearrowleft + \Sigma M_O = 0;$ $\quad T_A(0.4) - T_C(0.4) - M = 0 \quad (2)$

By considering the friction between the brake band and the rim of the wheel where $\beta = \frac{270°}{180°}\pi = 1.5\pi$ rad and $T_A > T_C$, we can write

$$T_A = T_C e^{\mu_s \beta}$$

$$T_A = T_C e^{0.3(1.5\pi)}$$

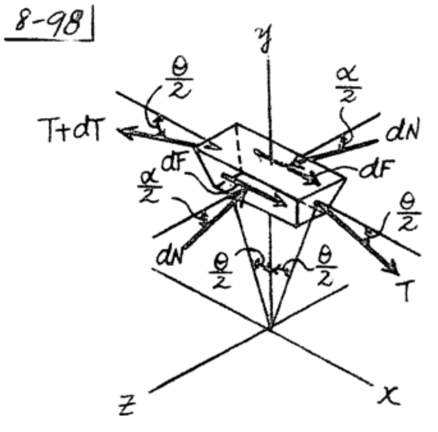
$$T_A = 4.1112 T_C \quad (3)$$

Solving Eqs. (1), (2), and (3) yields

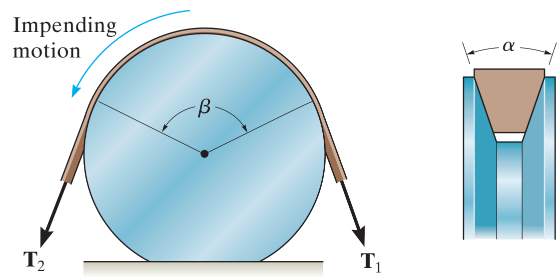
$$M = 187 \text{ N} \cdot \text{m} \qquad \textbf{Ans.}$$

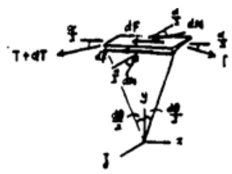
$$T_A = 616.67 \text{ N} \quad T_C = 150.00 \text{ N}$$

8-98



8–99. Show that the frictional relationship between the belt tensions, the coefficient of friction μ, and the angular contacts α and β for the V-belt is $T_2 = T_1 e^{\mu\beta/\sin(\alpha/2)}$.





F.B.D of a section of the belt is shown.
Proceeding in the general manner :

$\Sigma F_x = 0;\qquad -(T+dT)\cos\frac{d\theta}{2} + T\cos\frac{d\theta}{2} + 2\,dF = 0$

$\Sigma F_y = 0;\qquad -(T+dT)\sin\frac{d\theta}{2} - T\sin\frac{d\theta}{2} + 2\,dN\sin\frac{\alpha}{2} = 0$

Replace $\sin\frac{d\theta}{2}$ by $\frac{d\theta}{2}$,

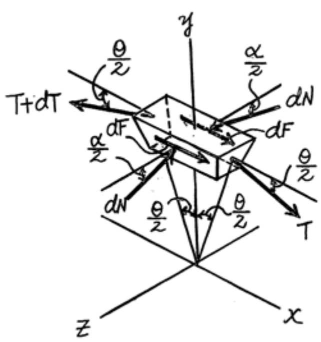
$\cos\frac{d\theta}{2}$ by 1,

$dF = \mu\,dN$

Using this and $(dT)(d\theta) \to 0$, the above relations become

$dT = 2\mu\,dN$

$T\,d\theta = 2\left(dN\sin\frac{\alpha}{2}\right)$



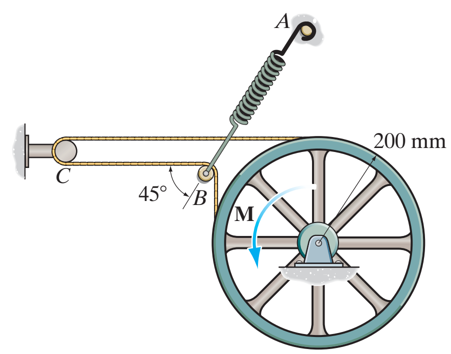
Combine $\qquad \frac{dT}{T} = \mu\frac{d\theta}{\sin\frac{\alpha}{2}}$

Integrate from $\theta = 0,\ T = T_1$
to $\theta = \beta,\ T = T_2$

we get,

$$T_2 = T_1\, e^{\left(\frac{\mu\theta}{\sin\frac{\alpha}{2}}\right)} \qquad \text{Q.E.D}$$

***8–100.** Determine the force developed in spring AB in order to hold the wheel from rotating when it is subjected to a couple moment of $M = 200\ \text{N}\cdot\text{m}$. The coefficient of static friction between the belt and the rim of the wheel is $\mu_s = 0.2$, and between the belt and peg C, $\mu_s' = 0.4$. The pulley at B is free to rotate.



Referring to the free-body diagram of the wheel shown in Fig. a, we have

$$\circlearrowleft +\Sigma M_O = 0; \qquad T_1(0.2) + 200 - T_2(0.2) = 0 \qquad (1)$$

In this case, the belt could slip over the wheel or peg C. We will assume it slips over the wheel. Here, $\beta_1 = \left(\frac{270°}{180°}\right)\pi = 1.5\pi$ rad. Thus,

$$T_2 = T_1 e^{\mu_s \beta}$$
$$T_2 = T_1 e^{0.2(1.5\pi)}$$
$$T_2 = 2.5663T_1 \qquad (2)$$

Solving Eqs. (1) and (2) yields

$$T_1 = 638.43\ \text{N} \qquad T_2 = 1638.43\text{N}$$

Using these results and considering the friction between the belt and peg C, where $\beta_2 = \pi$ rad,

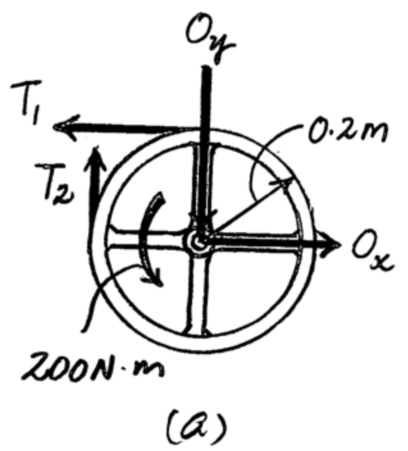
$$T_2 = T_1 e^{(\mu_s)_{req}\beta_2}$$
$$1638.43 = 638.43e^{(\mu_s)_{req}(\pi)}$$
$$(\mu_s)_{req} = 0.3$$

Since the coefficient of static friction between the belt and peg C is greater than $(\mu_s)_{req}$ $(\mu_s' > 0.3)$, the belt will not slip over peg C. Thus, the above assumption is correct. Using the results of $\mathbf{T}_2$ and referring to the free-body diagram of joint B shown in Fig. b,

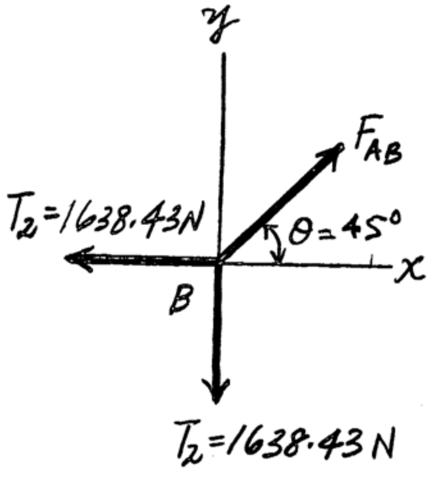
$$\overset{+}{\rightarrow}\Sigma F_x = 0; \qquad F_{AB}\cos 45° - 1638.43 = 0$$

Solving

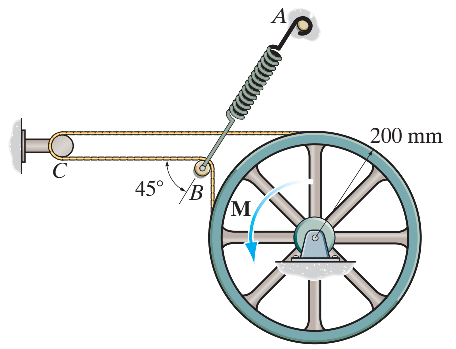
$$F_{AB} = 2317.10\text{N} = 2.32\ \text{kN} \qquad \textbf{Ans.}$$



(a)



•8–101. If the tension in the spring is $F_{AB} = 2.5$ kN, determine the largest couple moment that can be applied to the wheel without causing it to rotate. The coefficient of static friction between the belt and the wheel is $\mu_s = 0.2$, and between the belt the peg $\mu_s' = 0.4$. The pulley B free to rotate.



Referring to the free - body diagram of joint B shown in Fig. a,

$\xrightarrow{+} \Sigma F_x = 0;$ $\quad 2500 \cos 45° - T_2 = 0$

Solving,

$$T_2 = 1767.77 \text{ N}$$

In this case, the belt could slip over the wheel or peg C. We will assume that it slips over the wheel. Here, $\beta_1 = \left(\frac{270°}{180°}\right)\pi = 1.5\pi$ rad and $T_1 > T_2$. Thus,

$$T_2 = T_1 e^{\mu_s \beta_1}$$
$$1767.77 = T_1 e^{0.2(1.5\pi)}$$
$$T_1 = 688.83$$

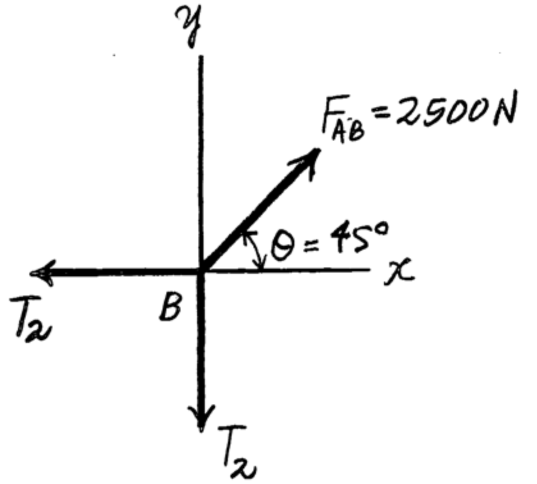
Using the results for T_1 and T_2 and considering the friction between the belt and peg C, where $\beta_2 = \pi$ rad,

$$T_2 = T_1 e^{(\mu_s)_{req} \beta_2}$$
$$1767.77 = 688.83 e^{(\mu_s)_{req}(\pi)}$$
$$(\mu_s)_{req} = 0.3$$

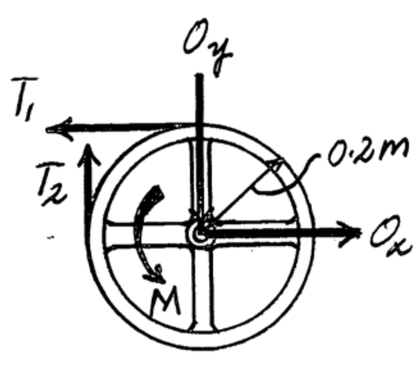
Since the coefficient of static friction between the belt and peg C is greater than $(\mu_s)_{req}$ $(\mu_s' > 0.3)$, the belt will not slip over peg C. Thus, the above assumption is correct. Using the results of T_1 and T_2 and referring to the free - body diagram of the wheel shown in Fig. b,

$\circlearrowleft + \Sigma M_O = 0;$ $\quad 688.83(0.2) + M - 1767.77(0.2) = 0$

$$M = 216 \text{ N} \cdot \text{m} \qquad \textbf{Ans.}$$

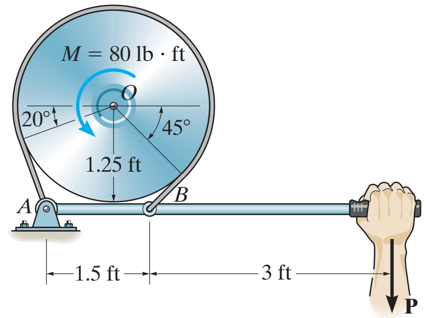


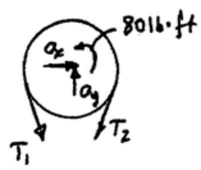
(a)



(b)

8–102. The simple band brake is constructed so that the ends of the friction strap are connected to the pin at A and the lever arm at B. If the wheel is subjected to a torque of $M = 80$ lb·ft, determine the smallest force P applied to the lever that is required to hold the wheel stationary. The coefficient of static friction between the strap and wheel is $\mu_s = 0.5$.





$\beta = 20° + 180° + 45° = 245°$

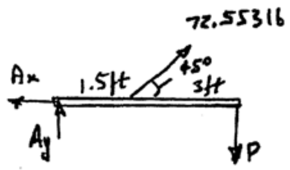
$\circlearrowleft + \Sigma M_O = 0;\quad T_1(1.25) + 80 - T_2(1.25) = 0$

$T_2 = T_1 e^{\mu\beta};\quad T_2 = T_1 e^{0.5(245°)(\frac{\pi}{180°})} = 8.4827T_1$

Solving;

$T_1 = 8.553$ lb

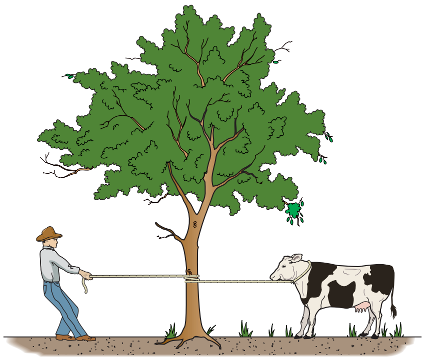
$T_2 = 72.553$ lb



$\circlearrowleft + \Sigma M_A = 0;\quad -72.553(\sin 45°)(1.5) - 4.5P = 0$

$P = 17.1$ lb **Ans**

8–103. A 180-lb farmer tries to restrain the cow from escaping by wrapping the rope two turns around the tree trunk as shown. If the cow exerts a force of 250 lb on the rope, determine if the farmer can successfully restrain the cow. The coefficient of static friction between the rope and the tree trunk is $\mu_s = 0.15$, and between the farmer's shoes and the ground $\mu_s' = 0.3$.



Since the cow is on the verge of moving, the force it exerts on the rope is $T_2 = 250$ lb and the force exerted by the man on the rope is T_1. Here, $\beta = 2(2\pi) = 4\pi$ rad. Thus,

$$T_2 = T_1 e^{\mu_s \beta}$$

$$250 = T_1 e^{0.15(4\pi)}$$

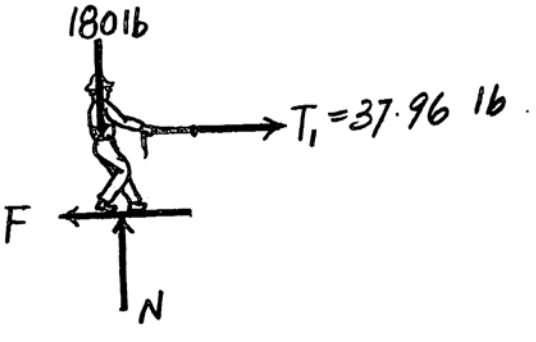
$$T_1 = 37.96 \text{ lb}$$

Using this result and referring to the free - body diagram of the man shown in Fig. *a*,

$+\uparrow \Sigma F_y = 0;$ $\quad N - 180 = 0 \quad N = 180$ lb

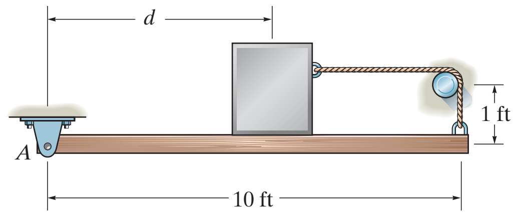
$\overset{+}{\rightarrow} \Sigma F_x = 0;$ $\quad 37.96 - F = 0 \quad F = 37.96$ lb

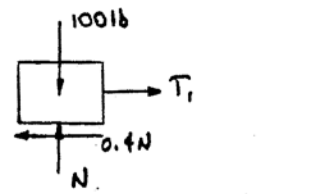
Since $F < F_{max} = \mu_s' N = 0.3(180) = 54$ lb, the man will not slip, and he will successfully restrain the cow.

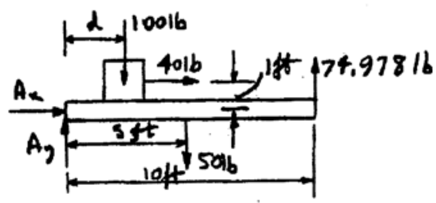


(a)

***8–104.** The uniform 50-lb beam is supported by the rope which is attached to the end of the beam, wraps over the rough peg, and is then connected to the 100-lb block. If the coefficient of static friction between the beam and the block, and between the rope and the peg, is $\mu_s = 0.4$, determine the maximum distance that the block can be placed from A and still remain in equilibrium. Assume the block will not tip.







Block:

$+\uparrow \Sigma F_y = 0; \quad N - 100 = 0$

$N = 100 \text{ lb}$

$\xrightarrow{+} \Sigma F_x = 0; \quad T_1 - 0.4(100) = 0$

$T_1 = 40 \text{ lb}$

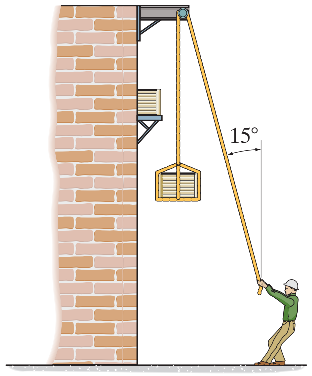
$T_2 = T_1 e^{\mu\beta}; \quad T_2 = 40e^{0.4\left(\frac{\pi}{2}\right)} = 74.978 \text{ lb}$

System:

$\curvearrowleft + \Sigma M_A = 0; \quad -100(d) - 40(1) - 50(5) + 74.978(10) = 0$

$d = 4.60 \text{ ft} \quad$ **Ans**

•8–105. The 80-kg man tries to lower the 150-kg crate using a rope that passes over the rough peg. Determine the least number of full turns in addition to the basic wrap (165°) around the peg to do the job. The coefficients of static friction between the rope and the peg and between the man's shoes and the ground are $\mu_s = 0.1$ and $\mu_s' = 0.4$, respectively.



If the man is on the verge of slipping, $F = \mu_s' N = 0.4N$. Referring to the free-body diagram of the man shown in Fig. *a*,

$\xrightarrow{+} \Sigma F_x = 0; \qquad 0.4N - T\sin 15° = 0$

$+\uparrow \Sigma F_y = 0; \qquad N + T\cos 15° - 80(9.81) = 0$

Solving,

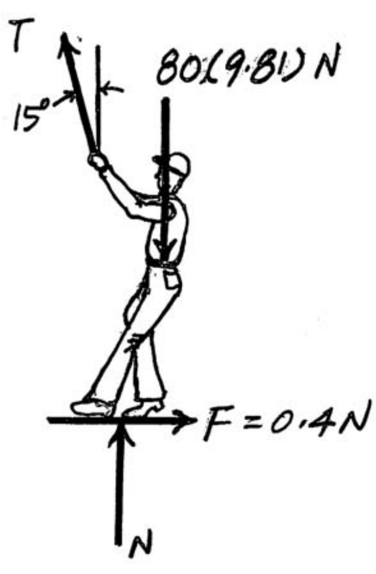
$$T = 486.55\text{ N} \qquad N = 314.82\text{ N}$$

Using the result for **T** and considering the friction between the rope and the peg, where $T_2 = 150(9.81)$ N, $T_1 = T = 486.55$ N and $\beta = n(2\pi) + \left[\left(\frac{90° + 75°}{180°}\right)\pi\right] = (2n + 0.9167)\pi$ rad, Fig. *b*,

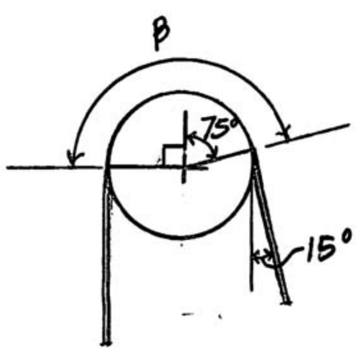
$$T_2 = T_1 e^{\mu_s \beta}$$
$$150(9.81) = 486.55e^{0.1(2n+0.9167)\pi}$$
$$\ln 3.024 = 0.1(2n + 0.9167)\pi$$
$$n = 1.303$$

Thus, the required number of full turns is

$$n = 2 \qquad \textbf{Ans.}$$

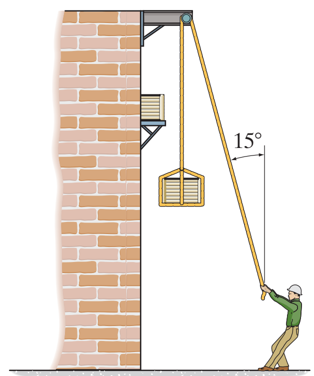


(b)



(b)

8–106. If the rope wraps three full turns plus the basic wrap (165°) around the peg, determine if the 80-kg man can keep the 300-kg crate from moving. The coefficients of static friction between the rope and the peg and between the man's shoes and the ground are $\mu_s = 0.1$ and $\mu_s' = 0.4$, respectively.



If the man is on the verge of slipping, $F = \mu_s{}' N = 0.4N$. Referring to the free-body diagram of the man shown in Fig. *a*,

$\overset{+}{\rightarrow}\Sigma F_x = 0;$ $\qquad 0.4N - T\sin 15° = 0$

$+\uparrow \Sigma F_y = 0;$ $\qquad N + T\cos 15° - 80(9.81) = 0$

Solving,

$$T = 486.55\text{ N} \qquad N = 314.82\text{ N}$$

Using the result for **T** and considering the friction between the rope and the peg, where $T_2 = 300(9.81)$ N, $T_1 = T = 486.55$ N and $\beta = n(2\pi) + \left[\left(\dfrac{90° + 75°}{180°}\right)\pi\right] = (2n + 0.9167)\pi$ rad, Fig. *b*,

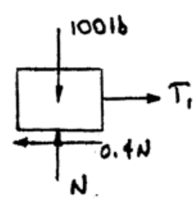
$$T_2 = T_1 e^{\mu_s \beta}$$

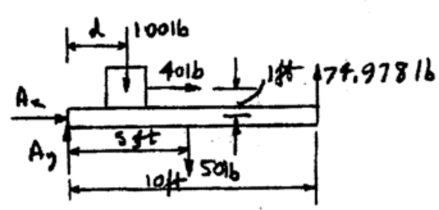
$$300(9.81) = 486.55e^{0.1(2n+0.9167)\pi}$$

$$\ln 6.049 = 0.1(2n + 0.9167)\pi$$

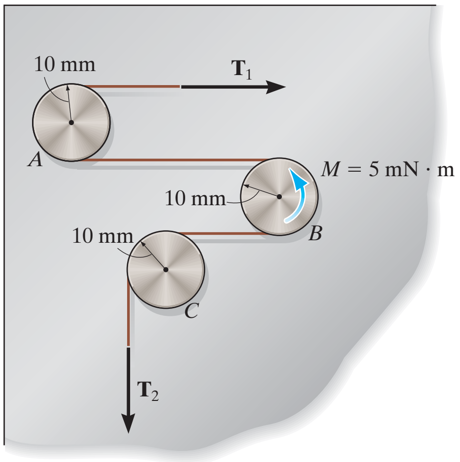
$$n = 2.406$$

Since $n > 3$, the man can hold the crate in equilibrium. **Ans.**





8–107. The drive pulley B in a video tape recorder is on the verge of slipping when it is subjected to a torque of $M = 0.005\ \text{N}\cdot\text{m}$. If the coefficient of static friction between the tape and the drive wheel and between the tape and the fixed shafts A and C is $\mu_s = 0.1$, determine the tensions T_1 and T_2 developed in the tape for equilibrium.



Here $\mathbf{T}_3$ must overcome $\mathbf{T}_4$ and $\mathbf{M}$, so $\mathbf{T}_3 > \mathbf{T}_4$. Also, $\beta = \pi$ rad. Thus,

$$T_3 = T_4 e^{\mu_s \beta}$$
$$T_3 = T_4 e^{0.1(\pi)}$$
$$T_3 = 1.3691 T_4 \qquad (1)$$

Referring to the free-body diagram of pulley B in Fig. a,

$+\Sigma M_O = 0;\qquad 0.005 + T_4(0.01) - T_3(0.01) = 0 \qquad (2)$

Solving Eqs. (1) and (2), yields

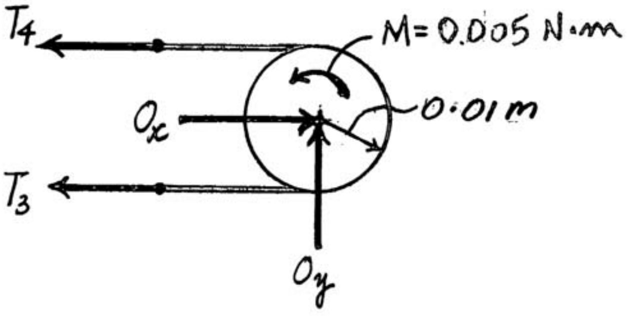
$$T_4 = 1.3546\ \text{N} \qquad T_3 = 1.8546\ \text{N}$$

Using the result of $\mathbf{T}_4$ and considering the friction on the fixed shaft A, where $\mathbf{T}_1 > \mathbf{T}_4$ and $\beta = \pi$ rad,

$$T_1 = T_4 e^{\mu_s \beta}$$
$$= 1.3546 e^{0.1\pi}$$
$$= 1.85\ \text{N} \qquad \textbf{Ans.}$$

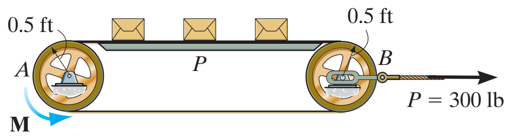
Using the result of $\mathbf{T}_3$ and considering the friction on the fixed shaft C, where $\mathbf{T}_3 > \mathbf{T}_2$ and $\beta = \frac{\pi}{2}$ rad,

$$T_3 = T_2 e^{\mu_s \beta}$$
$$1.8546 = T_2 e^{0.1(\pi/2)}$$
$$T_2 = 1.59\ \text{N} \qquad \textbf{Ans.}$$



(a)

***8–108.** Determine the maximum number of 50-lb packages that can be placed on the belt without causing the belt to slip at the drive wheel A which is rotating with a constant angular velocity. Wheel B is free to rotate. Also, find the corresponding torsional moment **M** that must be supplied to wheel A. The conveyor belt is pre-tensioned with the 300-lb horizontal force. The coefficient of kinetic friction between the belt and platform P is $\mu_k = 0.2$, and the coefficient of static friction between the belt and the rim of each wheel is $\mu_s = 0.35$.



The maximum tension T_2 of the conveyor belt can be obtained by considering the equilibrium of the free-body diagram of the top belt shown in Fig. a.

$+\uparrow \Sigma F_y = 0; \qquad n(50) - N = 0 \qquad N = 50n \quad (1)$

$\overset{+}{\rightarrow} \Sigma F_x = 0; \qquad 150 + 0.2(50n) - T_2 = 0 \qquad T_2 = 150 + 10n \quad (2)$

By considering the case when the drive wheel A is on the verge of slipping, where $\beta = \pi$ rad, $T_2 = 150 + 10n$ and $T_1 = 150$ lb,

$$T_2 = T_1 e^{\mu\beta}$$

$$150 + 10n = 150e^{0.35(\pi)}$$

$$n = 30.04$$

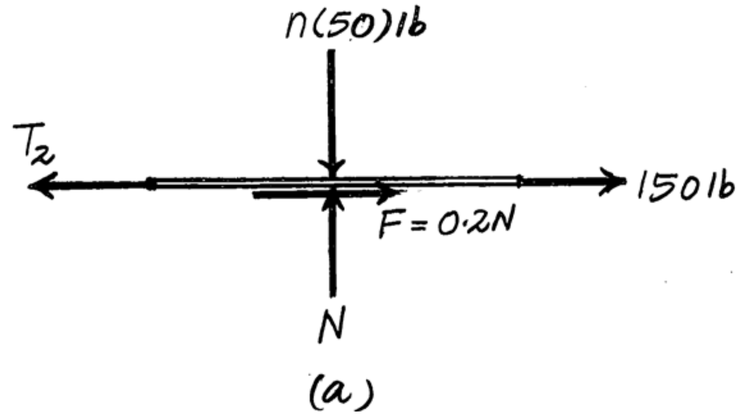
Thus, the maximum allowable number of boxes on the belt is

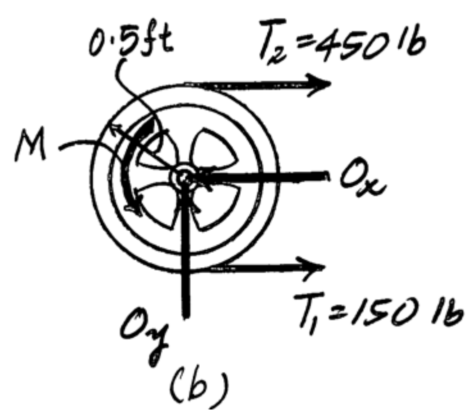
$$n = 30$$ **Ans.**

Substituting $n = 30$ into Eq. (2) gives $T_2 = 450$ lb. Referring to the free-body diagram of the wheel A shown in Fig. b,

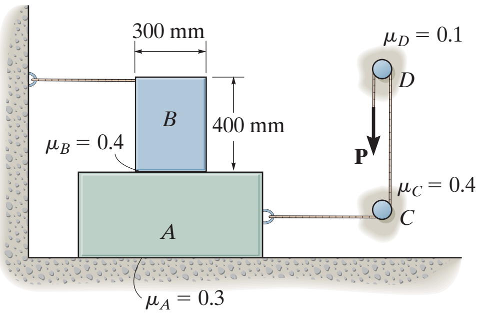
$\circlearrowleft + \Sigma M_O = 0; \qquad M + 150(0.5) - 450(0.5) = 0$

$M = 150 \text{ lb} \cdot \text{ft}$ **Ans.**





•8–109. Blocks A and B have a mass of 7 kg and 10 kg, respectively. Using the coefficients of static friction indicated, determine the largest vertical force P which can be applied to the cord without causing motion.

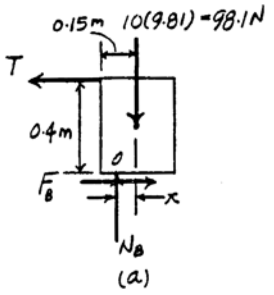


Frictional Forces on Flat Belts : When the cord pass over peg D, $\beta = 180° = \pi$ rad and $T_2 = P$. Applying Eq. 8–6, $T_2 = T_1 e^{\mu\beta}$, we have

$$P = T_1 e^{0.1\pi} \qquad T_1 = 0.7304P$$

When the cord pass over peg C, $\beta = 90° = \frac{\pi}{2}$ rad and $T_2' = T_1 = 0.7304P$. Applying Eq. 8–6, $T_2' = T_1' e^{\mu\beta}$, we have

$$0.7304P = T_1' e^{0.4(\pi/2)} \qquad T_1' = 0.3897P$$



Equations of Equilibrium : From FBD (a),

$$+\uparrow \Sigma F_y = 0; \qquad N_B - 98.1 = 0 \qquad N_B = 98.1 \text{ N}$$

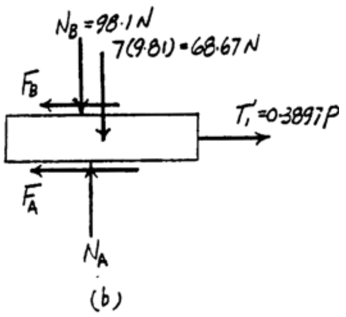
$$\xrightarrow{+} \Sigma F_x = 0; \qquad F_B - T = 0 \qquad [1]$$

$$\circlearrowleft + \Sigma M_O = 0; \qquad T(0.4) - 98.1(x) = 0 \qquad [2]$$

From FBD (b),

$$+\uparrow \Sigma F_y = 0; \qquad N_A - 98.1 - 68.67 = 0 \qquad N_A = 166.77 \text{ N}$$

$$\xrightarrow{+} \Sigma F_x = 0; \qquad 0.3897P - F_B - F_A = 0 \qquad [3]$$



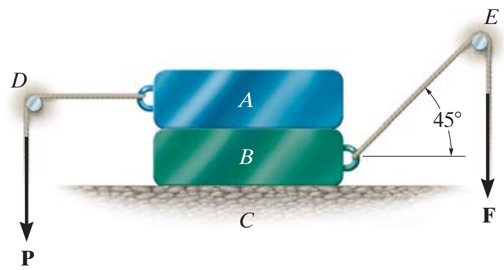
Friction : Assuming the block B is on the verge of tipping, then $x = 0.15$ m. For motion to occur, block A will have slip. Hence, $F_A = (\mu_s)_A N_A = 0.3(166.77) = 50.031$ N. Substituting these values into Eqs. [1], [2] and [3] and solving yields

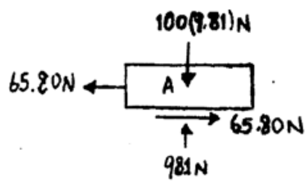
$$P = 222.81 \text{ N} = 223 \text{ N} \qquad \textbf{Ans}$$

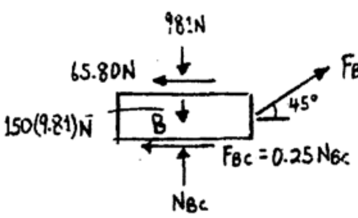
$$F_B = T = 36.79 \text{ N}$$

Since $(F_B)_{max} = (\mu_s)_B N_B = 0.4(98.1) = 39.24 \text{ N} > F_B$, block B does not slip but tips. Therefore, the above assumption is correct.

8–110. Blocks *A* and *B* have a mass of 100 kg and 150 kg, respectively. If the coefficient of static friction between *A* and *B* and between *B* and *C* is $\mu_s = 0.25$, and between the ropes and the pegs *D* and *E* $\mu_s' = 0.5$, determine the smallest force *F* needed to cause motion of block *B* if $P = 30$ N.







Assume no slipping between *A* and *B*.

Peg *D*:

$T_2 = T_1 e^{\mu\beta}; \quad F_{AD} = 30\,e^{0.5\left(\frac{\pi}{2}\right)} = 65.80 \text{ N}$

Block *B*:

$\xrightarrow{+} \Sigma F_x = 0; \quad -65.80 - 0.25 N_{BC} + F_{BE} \cos 45° = 0$

$+\uparrow \Sigma F_y = 0; \quad N_{BC} - 981 + F_{BE} \sin 45° - 150\,(9.81) = 0$

$F_{BE} = 768.1 \text{ N}$

$N_{BC} = 1909.4 \text{ N}$

Peg *E*:

$T_2 = T_1 e^{\mu\beta}; \quad F = 768.1e^{0.5\left(\frac{3\pi}{4}\right)} = 2.49 \text{ kN}$ **Ans**

Note: Since *B* moves to the right,

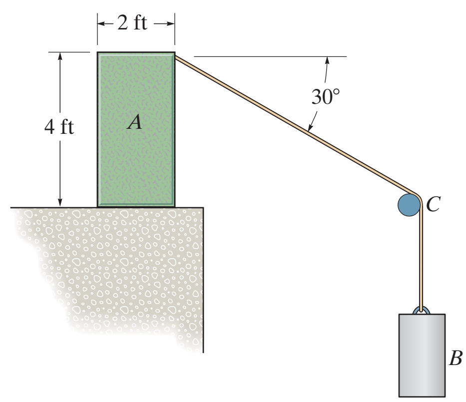
$(F_{AB})_{max} = 0.25\,(981) = 245.25 \text{ N}$

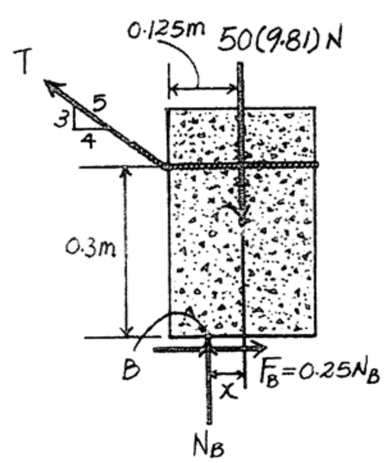
$245.25 = P_{max} e^{0.5\left(\frac{\pi}{2}\right)}$

$P_{max} = 112 \text{ N} > 30 \text{ N}$

Hence, no slipping occurs between *A* and *B* as originally assumed

8–111. Block A has a weight of 100 lb and rests on a surface for which $\mu_s = 0.25$. If the coefficient of static friction between the cord and the fixed peg at C is $\mu_s = 0.3$, determine the greatest weight of the suspended cylinder B without causing motion.





Frictional Force on Flat Belt : Here, $\beta = 60° = \dfrac{\pi}{3}$ rad and $T_2 = W$.

Applying Eq. 8–6, $T_2 = T_1 e^{\mu\beta}$, we have

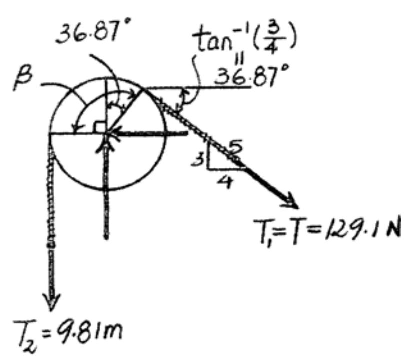
$$W = T_1 e^{0.3(\pi/3)} \qquad T_1 = 0.7304W$$

Equations of Equilibrium : From FBD (b),

$$+\uparrow \Sigma F_y = 0; \qquad N - 0.7304W\sin 30° - 100 = 0 \qquad [1]$$

$$\xrightarrow{+} \Sigma F_x = 0; \qquad 0.7304W\cos 30° - F = 0 \qquad [2]$$

$$\circlearrowleft + \Sigma M_A = 0; \qquad 100(x) - 0.7304W\cos 30°(4) - 0.7304W\sin 30°(1 - x) = 0 \qquad [3]$$



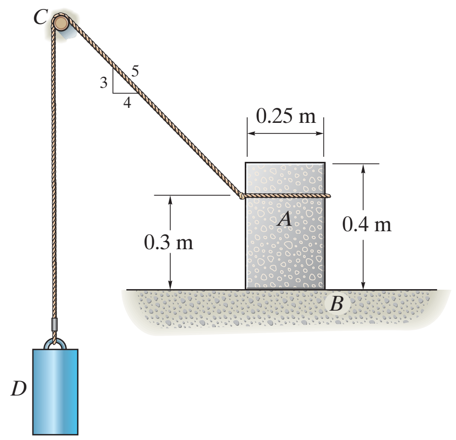
Friction : Assuming the block is on the verge of tipping, then $x = 1$ ft. Substituting this value into Eqs. [1], [2] and [3] and solving yields

$$W = 39.5 \text{ lb} \qquad \textbf{Ans}$$

$$F = 25.0 \text{ lb} \qquad N = 114.43 \text{ lb}$$

Since $F_{max} = \mu_s N = 0.25(114.43) = 28.61 \text{ lb} > F$, the block does not slip but tips. Therefore, the above assumption is correct.

***8–112.** Block A has a mass of 50 kg and rests on surface B for which $\mu_s = 0.25$. If the coefficient of static friction between the cord and the fixed peg at C is $\mu_s' = 0.3$, determine the greatest mass of the suspended cylinder D without causing motion.

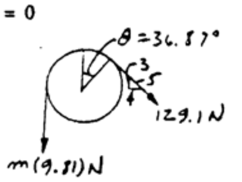


Block A :

Assume block A slips and does not tip.

$+\uparrow \Sigma F_y = 0; \quad N_B + \frac{3}{5}T - 50(9.81) = 0$

$\xrightarrow{+} \Sigma F_x = 0; \quad 0.25\,N_B - \frac{4}{5}T = 0$



$N_B = 413.1\text{ N}$

$T = 129.1\text{ N}$

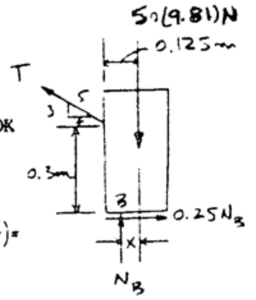
$\circlearrowleft + \Sigma M_B = 0; \quad -50(9.81)\,x + \frac{4}{5}(129.1)(0.3) - \frac{3}{5}(129.1)(0.125 - x) = 0$

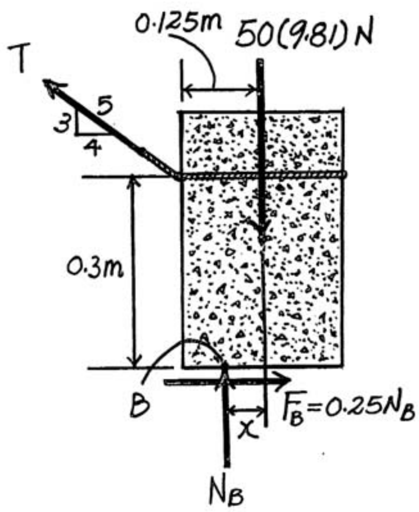
$x = 0.0516\text{ m} < 0.125\text{ m} \quad$ OK

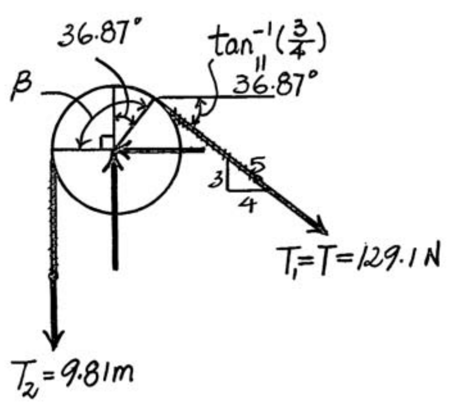
Peg :

$T_2 = T_1 e^{\mu\beta}; \quad 9.81\,m = 129.1\,e^{0.3\left(\frac{90° + 36.87°}{180°}\right)\pi}$

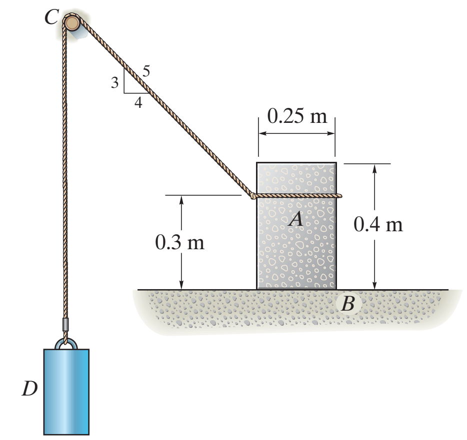
$m = 25.6\text{ kg}$ **Ans**





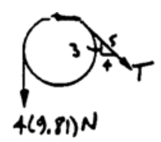


•8–113. Block A has a mass of 50 kg and rests on surface B for which $\mu_s = 0.25$. If the mass of the suspended cylinder D is 4 kg, determine the frictional force acting on A and check if motion occurs. The coefficient of static friction between the cord and the fixed peg at C is $\mu_s' = 0.3$.



$T_2 = T_1 e^{\mu\beta}$; $\quad 4(9.81) = T e^{0.3\left(\frac{90 + 36.87}{180}\right)\pi}$

$T = 20.19$ N



Block A:

$\xrightarrow{+} \Sigma F_x = 0;\quad F_A - \frac{4}{5}(20.19) = 0$

$F_A = 16.2$ N **Ans**

$+\uparrow \Sigma F_y = 0;\quad N_A - 50(9.81) + \frac{3}{5}(20.19) = 0$

$N_A = 478.4$ N

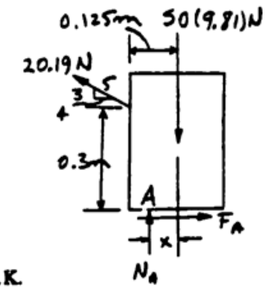
$(F_A)_{max} = 0.25(478.4) = 119.6\text{ N} > 16.16\text{ N}$ O.K.

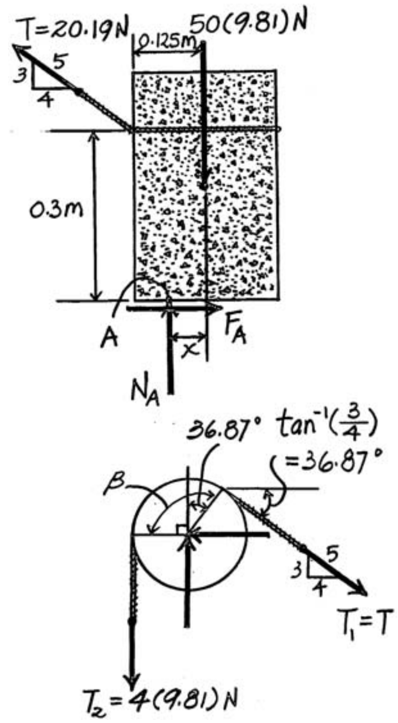
Block does not slip.

$\curvearrowleft +\Sigma M_B = 0;\quad -50(9.81)x + \frac{4}{5}(20.19)(0.3) - \frac{3}{5}(20.19)(0.125 - x) = 0$

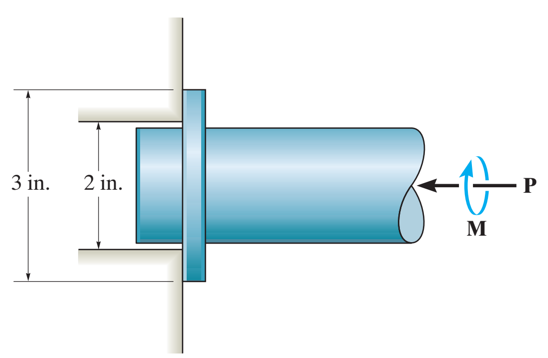
$x = 0.00697\text{ m} < 0.125\text{ m}$ O.K.

No tipping occurs. **Ans**





8–114. The collar bearing uniformly supports an axial force of $P = 800$ lb. If the coefficient of static friction is $\mu_s = 0.3$, determine the torque M required to overcome friction.

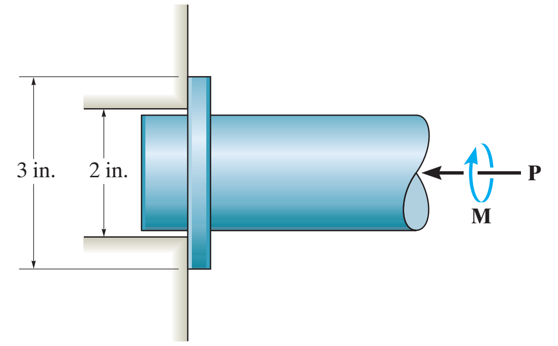


$$M = \frac{2}{3}\mu_s P\left(\frac{R_2^3 - R_1^3}{R_2^2 - R_1^2}\right)$$

$$= \frac{2}{3}(0.3)(800)\left[\frac{(1.5)^3 - 1^3}{(1.5)^2 - 1^2}\right]$$

$= 304$ lb·in. **Ans**

8–115. The collar bearing uniformly supports an axial force of $P = 500$ lb. If a torque of $M = 3$ lb·ft is applied to the shaft and causes it to rotate at constant velocity, determine the coefficient of kinetic friction at the surface of contact.

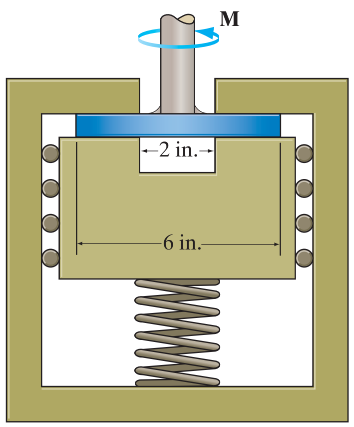


$$M = \frac{2}{3}\mu_k P\left(\frac{R_2^3 - R_1^3}{R_2^2 - R_1^2}\right)$$

$$3(12) = \frac{2}{3}\mu_k(500)\left[\frac{(1.5)^3 - 1^3}{(1.5)^2 - 1^2}\right]$$

$$\mu_k = 0.0568 \qquad \textbf{Ans}$$

***8–116.** If the spring exerts a force of 900 lb on the block, determine the torque M required to rotate the shaft. The coefficient of static friction at all contacting surfaces is $\mu_s = 0.3$.



Here, $R_1 = \frac{2 \text{ in.}}{2} = 1$ in., $R_2 = \frac{6 \text{ in.}}{2} = 3$ in., $\mu_s = 0.3$ and $P = 900$ lb, since **M** is required to overcome the friction of two contacting surfaces. Eq. 8-7 becomes

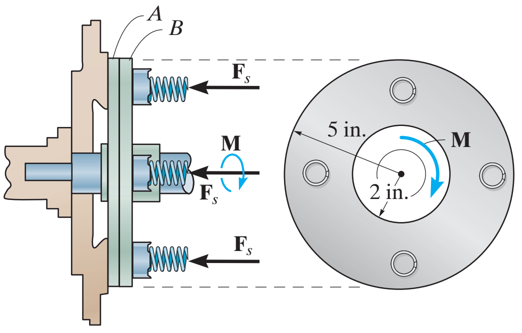
$$M = 2\left[\frac{2}{3}\mu_s P\left(\frac{R_2^3 - R_1^3}{R_2^2 - R_1^2}\right)\right]$$

$$= \frac{4}{3}(0.3)(900)\left(\frac{3^3 - 1^3}{3^2 - 1^2}\right)$$

$$= 1170 \text{ lb}\cdot\text{in} = 97.5 \text{ lb}\cdot\text{ft}$$

Ans.

•8–117. The *disk clutch* is used in standard transmissions of automobiles. If four springs are used to force the two plates A and B together, determine the force in each spring required to transmit a moment of $M = 600$ lb·ft across the plates. The coefficient of static friction between A and B is $\mu_s = 0.3$.



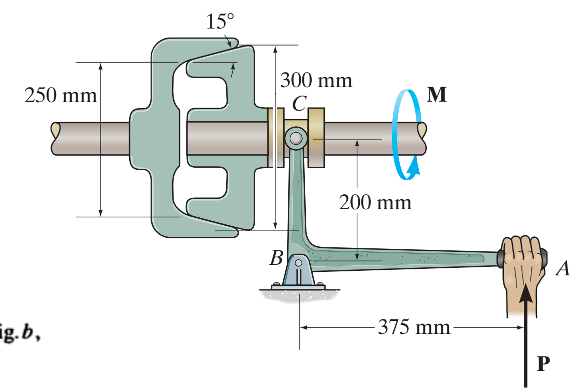
Bearing Friction : Applying Eq. 8-7 with $R_2 = 5$ in., $R_1 = 2$ in., $M = 600(12) = 7200$ lb·in, $\mu_s = 0.3$ and $P = 4F_{sp}$, we have

$$M = \frac{2}{3}\mu_s P\left(\frac{R_2^3 - R_1^3}{R_2^2 - R_1^2}\right)$$

$$7200 = \frac{2}{3}(0.3)(4F_{sp})\left(\frac{5^3 - 2^3}{5^2 - 2^2}\right)$$

$$F_{sp} = 1615.38 \text{ lb} = 1.62 \text{ kip} \qquad \textbf{Ans}$$

8–118. If $P = 900$ N is applied to the handle of the bell crank, determine the maximum torque M the cone clutch can transmit. The coefficient of static friction at the contacting surface is $\mu_s = 0.3$.



Referring to the free-body diagram of the bellcrank shown in Fig. *a*, we have

$+\Sigma M_B = 0;\qquad 900(0.375) - F_C(0.2) = 0 \qquad F_C = 1687.5\text{ N}$

Using this result and referring to the free-body diagram of the cone clutch shown in Fig. *b*,

$\overset{+}{\rightarrow}\Sigma F_x = 0;\qquad 2\left(\frac{N}{2}\sin 15°\right) - 1687.5 = 0 \qquad N = 6520.00\text{ N}$

The area of the differential element shown shaded in Fig. *c* is $dA = 2\pi r\, ds = 2\pi r\frac{dr}{\sin 15°} = \frac{2\pi}{\sin 15°} r\, dr$. Thus,

$A = \int_A dA = \int_{0.125\text{ m}}^{0.15\text{ m}} \frac{2\pi}{\sin 15°} r\, dr = 0.08345\text{ m}^2$. The pressure acting on the cone surface is

$$p = \frac{N}{A} = \frac{6520.00}{0.08345} = 78.13(10^3)\text{ N/m}^2$$

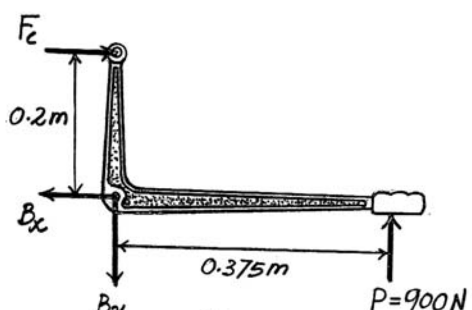
The normal force acting on the differential element dA is $dN = p\, dA = 78.13(10^3)\left[\frac{2\pi}{\sin 15°}\right] r\, dr = 1896.73(10^3) r\, dr$.

Thus, the frictional force acting on this differential element is given by $dF = \mu_s dN = 0.3(1896.73)(10^3) r\, dr = 569.02(10^3) r\, dr$. The moment equation about the axle of the cone clutch gives

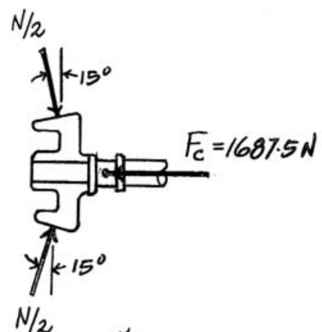
$\Sigma M = 0;\quad M - \int r dF = 0$

$$M = \int r dF = 569.02(10^3)\int_{0.125\text{ m}}^{0.15\text{ m}} r^2\, dr$$

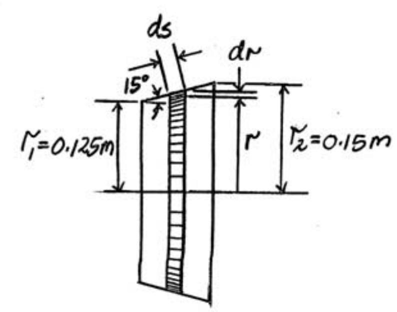
$M = 270\text{ N}\cdot\text{m}$ **Ans.**



(a)

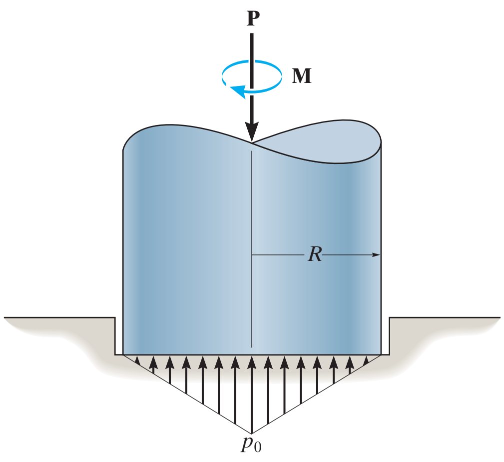


(b)



(c)

8–119. Because of wearing at the edges, the pivot bearing is subjected to a conical pressure distribution at its surface of contact. Determine the torque M required to overcome friction and turn the shaft, which supports an axial force $\mathbf{P}$. The coefficient of static friction is μ_s. For the solution, it is necessary to determine the peak pressure p_0 in terms of P and the bearing radius R.



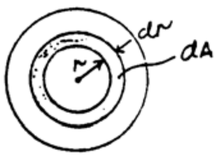
Equations of Equilibrium and Bearing Friction : Using similar triangles, $\frac{p}{R-r} = \frac{p_0}{R}$, $p = \frac{p_0}{R}(R-r)$. Also, $dA = 2\pi r dr$, $dN = p dA$ and $dF = \mu_s dN = \mu_s p dA$.

$$+\uparrow \Sigma F_y = 0; \qquad \int p dA - P = 0$$

$$\int \frac{p_0}{R}(R-r)(2\pi r dr) - P = 0$$

$$\frac{2\pi p_0}{R}\int_0^R r(R-r)\,dr - P = 0$$

$$p_0 = \frac{3P}{\pi R^2} \qquad [1]$$

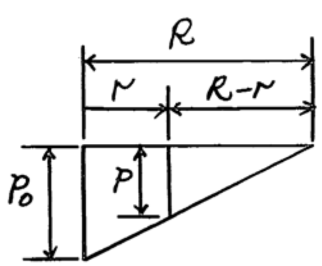


$$\circlearrowleft + \Sigma M_z = 0; \qquad \int (\mu_s p dA) r - M = 0$$

$$\int_0^R \frac{\mu_s p_0}{R}(R-r)(2\pi r dr) r - M = 0$$

$$\frac{2\pi \mu_s p_0}{R}\int_0^R r^2(R-r)\,dr - M = 0$$

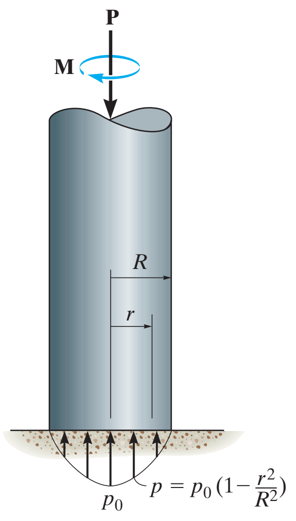
$$M = \frac{\pi \mu_s R^3 p_0}{6} \qquad [2]$$



Substituting Eq. [1] into [2] yields

$$M = \frac{\pi \mu_s R^3}{6}\left(\frac{3P}{\pi R^2}\right) = \frac{\mu_s P R}{2} \qquad \textbf{Ans}$$

***8–120.** The pivot bearing is subjected to a parabolic pressure distribution at its surface of contact. If the coefficient of static friction is μ_s, determine the torque M required to overcome friction and turn the shaft if it supports an axial force **P**.



The differential area $dA = (r\,d\theta)(dr)$

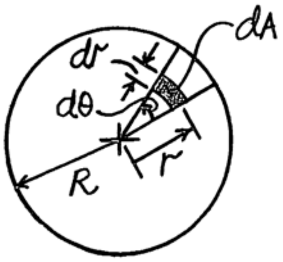
$$P = \int p\,dA = \int p_0\left(1-\frac{r^2}{R^2}\right)(r\,d\theta)(dr) = p_0\int_0^{2\pi} d\theta \int_0^R r\left(1-\frac{r^2}{R^2}\right)dr$$

$$P = \frac{\pi R^2 p_0}{2} \qquad p_0 = \frac{2P}{\pi R^2}$$

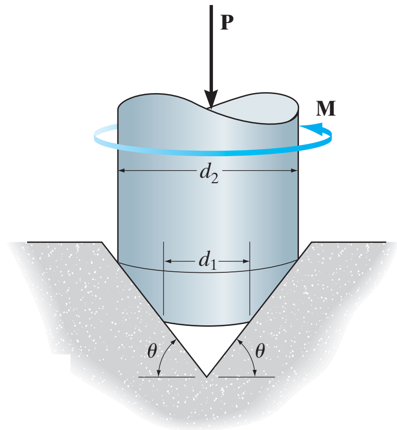
$$dN = p\,dA = \frac{2P}{\pi R^2}\left(1-\frac{r^2}{R^2}\right)(r\,d\theta)(dr)$$

$$M = \int r\,dF = \int \mu_s r\,dN = \frac{2\mu_s P}{\pi R^2}\int_0^{2\pi} d\theta \int_0^R r^2\left(1-\frac{r^2}{R^2}\right)dr$$

$$= \frac{8}{15}\mu_s PR \qquad \textbf{Ans}$$



•8–121. The shaft is subjected to an axial force **P**. If the reactive pressure on the conical bearing is uniform, determine the torque M that is just sufficient to rotate the shaft. The coefficient of static friction at the contacting surface is μ_s.



Referring to the free-body diagram of the shaft shown in Fig. *a*,

$$+\uparrow \Sigma F_y = 0; \qquad 2\left(\frac{N}{2}\cos\theta\right) - P \qquad N = \frac{P}{\cos\theta}$$

The area of the differential element shown shaded in Fig. *b* is $dA = 2\pi r ds = \frac{2\pi}{\cos\theta} r\,dr$. Thus,

$$A = \int_A dA = \int_{d_1/2}^{d_2/2} \frac{2\pi}{\cos\theta} r\,dr = \frac{\pi}{4\cos\theta}\left(d_2^2 - d_1^2\right)$$

Therefore, the pressure acting on the cone surface is

$$p = \frac{N}{A} = \frac{P/\cos\theta}{\frac{\pi}{4\cos\theta}\left(d_2^2 - d_1^2\right)} = \frac{4P}{\pi\left(d_2^2 - d_1^2\right)}$$

The normal force acting on the differential element dA is

$$dN = p\,dA = \frac{4P}{\pi\left(d_2^2 - d_1^2\right)}\left(\frac{2\pi}{\cos\theta} r\,dr\right) = \frac{8P}{\left(d_2^2 - d_1^2\right)\cos\theta} r\,dr$$

Thus, the frictional force acting on this differential element is given by

$$dF = \mu_s dN = \frac{8\mu_s P}{\left(d_2^2 - d_1^2\right)\cos\theta} r\,dr$$

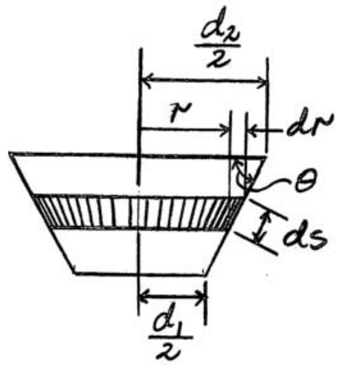
The moment equation about the axle of the shaft gives

$$\Sigma M = 0; \quad M - \int r dF = 0$$

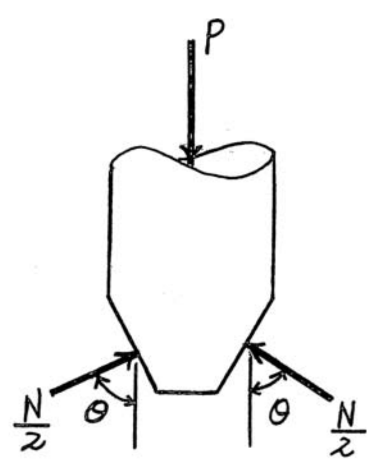
$$M = \int r dF = \frac{8\mu_s P}{\left(d_2^2 - d_1^2\right)\cos\theta}\int_{d_1/2}^{d_2/2} r^2\,dr$$

$$= \frac{\mu_s P}{3\cos\theta}\left(\frac{d_2^3 - d_1^2}{d_2^2 - d_1^2}\right)$$

Ans.

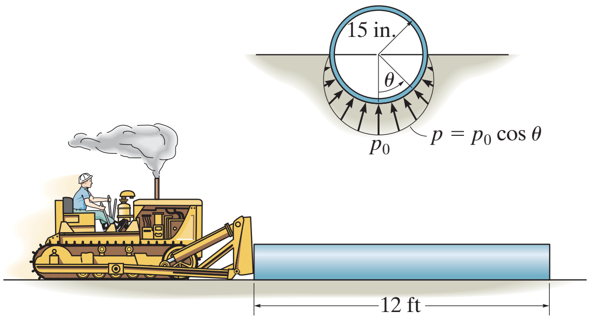


(b)



(a)

8–122. The tractor is used to push the 1500-lb pipe. To do this it must overcome the frictional forces at the ground, caused by sand. Assuming that the sand exerts a pressure on the bottom of the pipe as shown, and the coefficient of static friction between the pipe and the sand is $\mu_s = 0.3$, determine the horizontal force required to push the pipe forward. Also, determine the peak pressure p_0.



$+\uparrow \Sigma F_y = 0; \quad 2l\int_0^{\pi/2} p_0 \cos\theta\,(r\,d\theta)\cos\theta - W = 0$

$2p_0 l r \int_0^{\pi/2} \cos^2\theta\, d\theta = W$

$2p_0 r l\left(\frac{1}{2}\theta + \frac{1}{4}\sin 2\theta\right)\Big|_0^{\frac{\pi}{2}} = W$

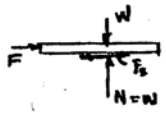
$2(p_0)\, r l\left(\frac{\pi}{4}\right) = W$

$2\,p_0(15)(12)(12)\left(\frac{\pi}{4}\right) = 1500$

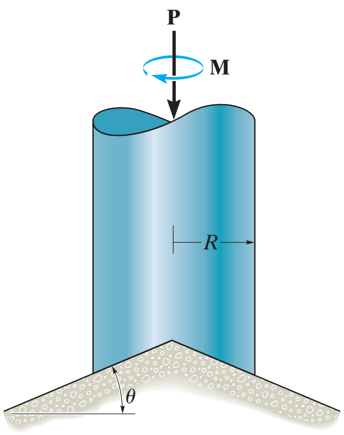
$p_0 = 0.442 \text{ psi}$ **Ans**

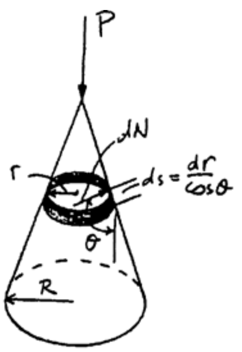
$F = \int_{-\pi/2}^{\pi/2} (0.3)(0.442 \text{ lb/in}^2)\cos\theta\,(12 \text{ ft})(12 \text{ in./ft})(15 \text{ in.})\, d\theta$

$F = 573 \text{ lb}$ **Ans**



8–123. The conical bearing is subjected to a constant pressure distribution at its surface of contact. If the coefficient of static friction is μ_s, determine the torque M required to overcome friction if the shaft supports an axial force **P**.





The differential area (shaded) $dA = 2\pi r\left(\frac{dr}{\cos\theta}\right) = \frac{2\pi r\,dr}{\cos\theta}$

$$P = \int p\cos\theta\,dA = \int p\cos\theta\left(\frac{2\pi r\,dr}{\cos\theta}\right) = 2\pi p\int_0^R r\,dr$$

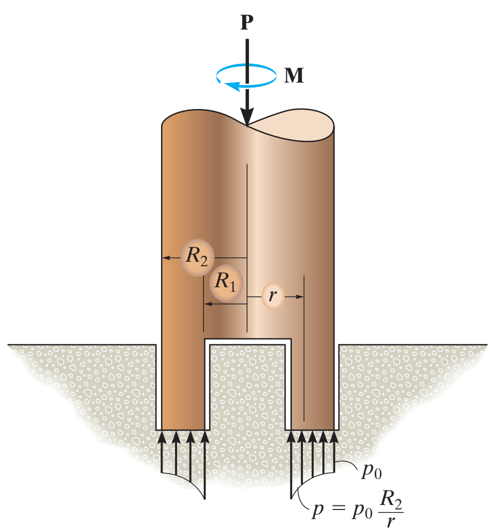
$$P = \pi p R^2 \qquad p = \frac{P}{\pi R^2}$$

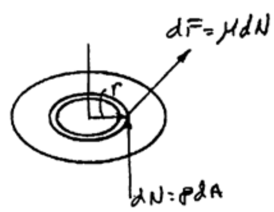
$$dN = p\,dA = \frac{P}{\pi R^2}\left(\frac{2\pi r\,dr}{\cos\theta}\right) = \frac{2P}{R^2\cos\theta}r\,dr$$

$$M = \int r\,dF = \int \mu_s r\,dN = \frac{2\mu_s P}{R^2\cos\theta}\int_0^R r^2\,dr$$

$$= \frac{2\mu_s P}{R^2\cos\theta}\frac{R^3}{3} = \frac{2\mu_s PR}{3\cos\theta} \qquad \textbf{Ans}$$

***8–124.** Assuming that the variation of pressure at the bottom of the pivot bearing is defined as $p = p_0(R_2/r)$, determine the torque M needed to overcome friction if the shaft is subjected to an axial force **P**. The coefficient of static friction is μ_s. For the solution, it is necessary to determine p_0 in terms of P and the bearing dimensions R_1 and R_2.





$$\Sigma F_z = 0; \quad P = \int_A dN = \int_0^{2\pi}\int_{R_1}^{R_2} pr\, dr\, d\theta$$

$$= \int_0^{2\pi}\int_{R_1}^{R_2} p_0\left(\frac{R_2}{r}\right) r\, dr\, d\theta$$

$$= 2\pi p_0 R_2 (R_2 - R_1)$$

Thus, $$p_0 = \frac{P}{[2\pi R_2 (R_2 - R_1)]}$$

$$\Sigma M_z = 0; \quad M = \int_A r\, dF = \int_0^{2\pi}\int_{R_1}^{R_2} \mu_s p r^2\, dr\, d\theta$$

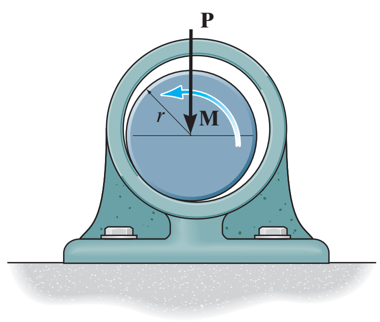
$$= \int_0^{2\pi}\int_{R_1}^{R_2} \mu_s p_0 \left(\frac{R_2}{r}\right) r^2\, dr\, d\theta$$

$$= \mu_s (2\pi p_0) R_2 \frac{1}{2}(R_2^2 - R_1^2)$$

Using Eq. (1):

$$M = \frac{1}{2}\mu_s P (R_2 + R_1) \quad \textbf{Ans}$$

•8–125. The shaft of radius r fits loosely on the journal bearing. If the shaft transmits a vertical force **P** to the bearing and the coefficient of kinetic friction between the shaft and the bearing is μ_k, determine the torque M required to turn the shaft with constant velocity.



From the geometry of the free-body diagram of the shaft shown in Fig. *a*,

$$\tan\phi_k = \frac{\mu_k N}{N} = \mu_k$$

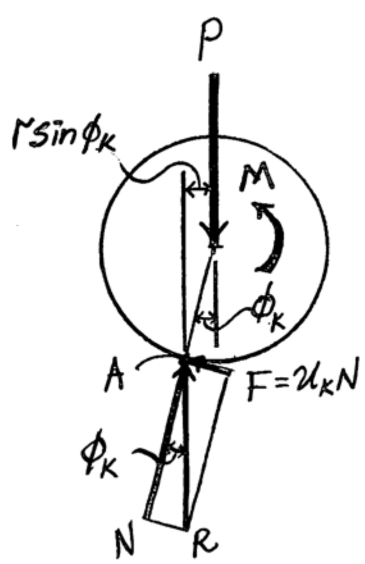
Thus, referring to Fig. *b*, we obtain

$$\sin\phi_k = \frac{\mu_k}{\sqrt{1+\mu_k^2}}$$

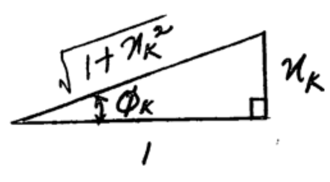
Referring to the free-body diagram of the shaft shown in Fig. *a*,

$$\circlearrowleft +\Sigma M_A = 0; \qquad M - Pr\left(\frac{\mu_k}{\sqrt{1+\mu_k^2}}\right) = 0$$

$$M = \left(\frac{\mu_k}{\sqrt{1+\mu_k^2}}\right)Pr \qquad \textbf{Ans.}$$

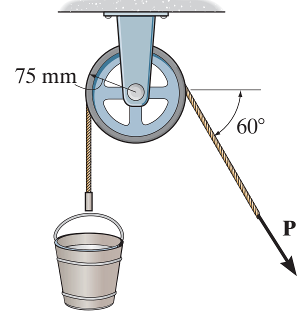


(a)



(b)

8–126. The pulley is supported by a 25-mm-diameter pin. If the pulley fits loosely on the pin, determine the smallest force P required to raise the bucket. The bucket has a mass of 20 kg and the coefficient of static friction between the pulley and the pin is $\mu_s = 0.3$. Neglect the mass of the pulley and assume that the cable does not slip on the pulley.



Referring to the free-body diagram of the pulley shown in Fig. *a*,

$\overset{+}{\rightarrow}\Sigma F_x = 0;$ $\quad P\cos 60° - R_x = 0 \quad R_x = 0.5P$

$+\uparrow \Sigma F_y = 0;$ $\quad R_y - P\sin 60° - 20(9.81) = 0 \quad R_y = 0.8660P + 196.2$

Thus, the magnitude of **R** is

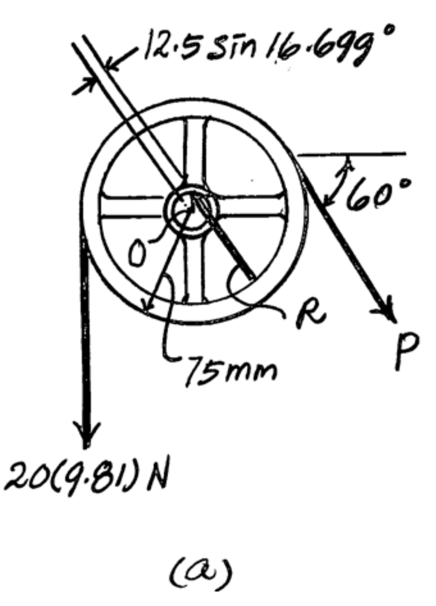
$$R = \sqrt{R_x^{\,2} + R_y^{\,2}} = \sqrt{(0.5P)^2 + (0.8660P + 196.2)^2}$$
$$= \sqrt{P^2 + 339.83P + 38494.44}$$

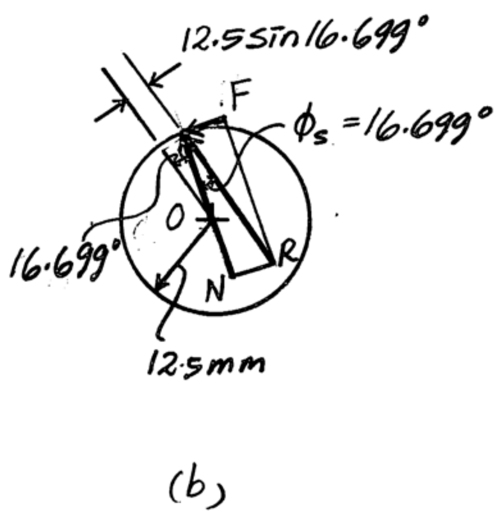
By referring to the geometry shown in Fig. *b*, we find that $\phi_s = \tan^{-1}\mu_s = \tan^{-1}(0.3) = 16.699°$. Thus, the moment arm of **R** from point O is $(12.5\sin 16.699°)$ mm. Using these results and writing the moment equation about point O, Fig. *a*,

$\circlearrowleft +\Sigma M_O = 0;$ $\quad 20(9.81)(75) + \sqrt{P^2 + 339.83P + 38494.44}(12.5\sin 16.699°) - P(75) = 0$

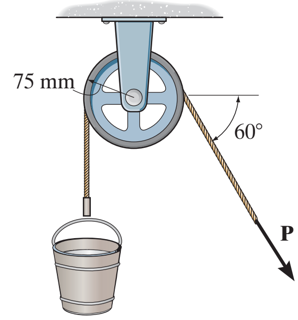
Choosing the root $P > 20(9.81)$ N,

$P = 215$ N **Ans.**





8–127. The pulley is supported by a 25-mm-diameter pin. If the pulley fits loosely on the pin, determine the largest force P that can be applied to the rope and yet lower the bucket. The bucket has a mass of 20 kg and the coefficient of static friction between the pulley and the pin is $\mu_s = 0.3$. Neglect the mass of the pulley and assume that the cable does not slip on the pulley.



Referring to the free-body diagram of the pulley shown in Fig. *a*,

$\overset{+}{\rightarrow}\Sigma F_x = 0;$ $\quad P\cos 60° - R_x = 0 \quad R_x = 0.5P$

$+\uparrow \Sigma F_y = 0;$ $\quad R_y - P\sin 60° - 20(9.81) = 0 \quad R_y = 0.8660P + 196.2$

Thus, the magnitude of **R** is

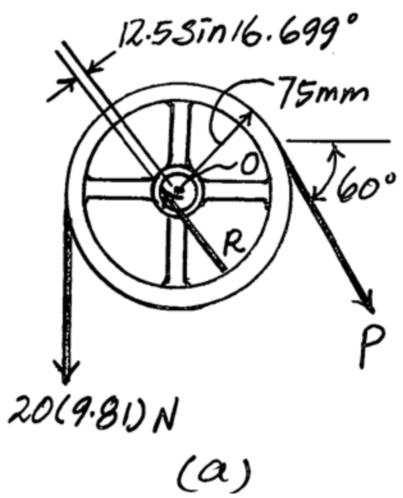
$$R = \sqrt{R_x^2 + R_y^2} = \sqrt{(0.5P)^2 + (0.8660P + 196.2)^2}$$
$$= \sqrt{P^2 + 339.83P + 38494.44}$$

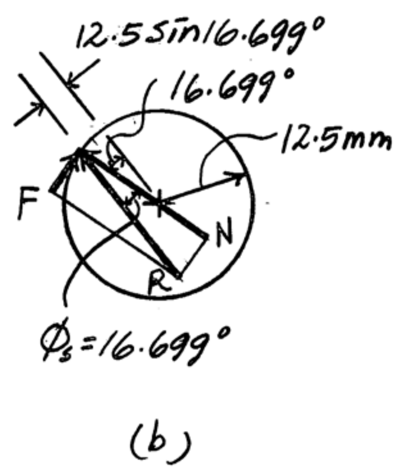
By referring to the geometry shown in Fig. *b*, we find that $\phi_s = \tan^{-1}\mu_s = \tan^{-1}(0.3) = 16.699°$. Thus, the moment arm of **R** from point O is $(12.5\sin 16.699°)$ mm. Using these results and writing the moment equation about point O, Fig. *a*,

$$\circlearrowleft+\Sigma M_O = 0; \quad 20(9.81)(75) - P(75) - \sqrt{P^2 + 339.83P + 38494.44}\,(12.5\sin 16.699°) = 0$$

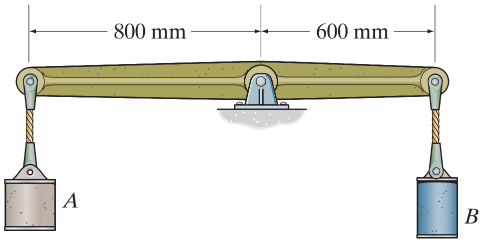
Choosing the root $P < 20(9.81)$ N,

$P = 179$ N **Ans.**





***8–128.** The cylinders are suspended from the end of the bar which fits loosely into a 40-mm-diameter pin. If A has a mass of 10 kg, determine the required mass of B which is just sufficient to keep the bar from rotating clockwise. The coefficient of static friction between the bar and the pin is $\mu_s = 0.3$. Neglect the mass of the bar.

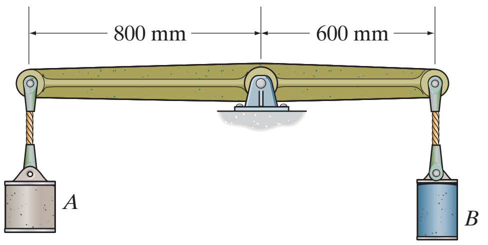


By referring to the geometry, we find that $\phi_s = \tan^{-1}\mu_s = \tan^{-1}(0.3) = 16.699°$. Thus, the moment arm of **R** from point O is $(20\sin 16.699°)$ mm.

$\curvearrowleft + \Sigma M_A = 0;$ $\quad 10(9.81)(800 + 20\sin 16.699°) - m_B(9.81)(600 - 20\sin 16.699°) = 0$

$m_B = 13.6$ kg **Ans.**

•8–129. The cylinders are suspended from the end of the bar which fits loosely into a 40-mm-diameter pin. If A has a mass of 10 kg, determine the required mass of B which is just sufficient to keep the bar from rotating counterclockwise. The coefficient of static friction between the bar and the pin is $\mu_s = 0.3$. Neglect the mass of the bar.

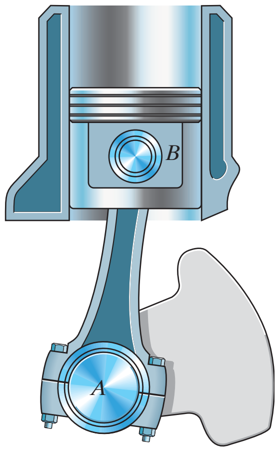


By referring to the geometry, we find that $\phi_s = \tan^{-1}\mu_s = \tan^{-1}(0.3) = 16.699°$. Thus, the moment arm of **R** from point O is $(20\sin 16.699°)$ mm.

$\curvearrowleft + \Sigma M_A = 0;$ $\quad 10(9.81)(800 - 20\sin 16.699°) - m_B(9.81)(600 + 20\sin 16.699°) = 0$

$m_B = 13.1$ kg **Ans.**

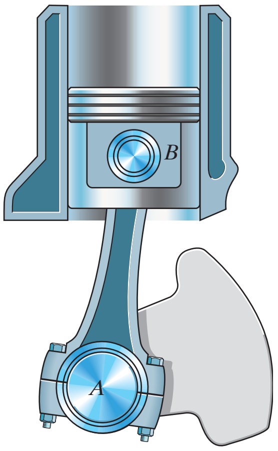
8–130. The connecting rod is attached to the piston by a 0.75-in.-diameter pin at B and to the crank shaft by a 2-in.-diameter bearing A. If the piston is moving downwards, and the coefficient of static friction at the contact points is $\mu_s = 0.2$, determine the radius of the friction circle at each connection.



$(r_f)_A = r_A \mu_s = 0.2$ in. **Ans**

$(r_f)_B = r_B \mu_s = \frac{0.75(0.2)}{2} = 0.075$ in. **Ans**

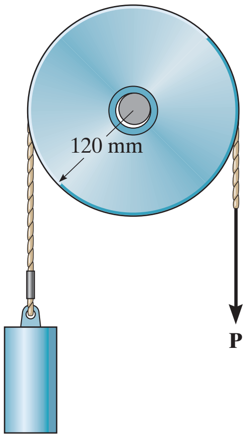
8–131. The connecting rod is attached to the piston by a 20-mm-diameter pin at B and to the crank shaft by a 50-mm-diameter bearing A. If the piston is moving upwards, and the coefficient of static friction at the contact points is $\mu_s = 0.3$, determine the radius of the friction circle at each connection.



$(r_f)_A = r_A \mu_s = 25\,(0.3) = 7.50$ mm **Ans**

$(r_f)_B = r_B \mu_s = 10\,(0.3) = 3$ mm **Ans**

***8–132.** The 5-kg pulley has a diameter of 240 mm and the axle has a diameter of 40 mm. If the coefficient of kinetic friction between the axle and the pulley is $\mu_k = 0.15$, determine the vertical force P on the rope required to lift the 80-kg block at constant velocity.



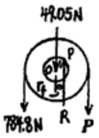
$\mu = 0.15$

$\phi_k = \tan^{-1}(0.15) = 8.531°$

$r_f = r \sin\phi_k = 20 \sin 8.531° = 2.967$ mm

By approximation,

$r_f = r\mu = 20(0.15) = 3.00$ mm



$\curvearrowleft + \Sigma M_P = 0;\quad -784.8(120 + r_f) - 49.05\, r_f + P(120 - r_f) = 0$

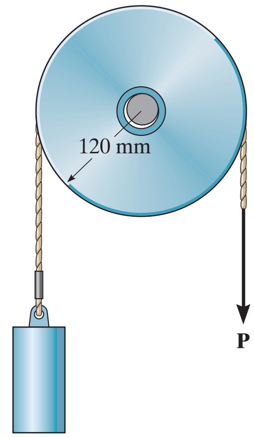
If exact value of r_f (2.967 mm) is used,

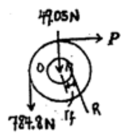
Thus $P = 826$ N **Ans**

If approximate value of r_f (3.00 mm) is used,

also $P = 826$ N **Ans** (approx.)

•8–133. Solve Prob. 8–132 if the force **P** is applied horizontally to the right.





$\phi_k = \tan^{-1}(0.15) = 8.531°$

$r_f = r\sin\phi_k = 20\sin 8.531° = 2.967\text{ mm}$

By approximation,

$r_f = r\mu = 20(0.15) = 3.00\text{ mm}$

$\curvearrowleft +\Sigma M_O = 0;\qquad 784.8(0.120) + R(r_f) - P(0.120) = 0$

$\overset{+}{\rightarrow}\Sigma F_x = 0;\qquad R_x = P$

$+\uparrow\Sigma F_y = 0;\qquad R_y = 833.85$

$R = \sqrt{P^2 + (833.85)^2}$

$-94.18 + 0.12P = \sqrt{P^2 + (833.85)^2}\, r_f$

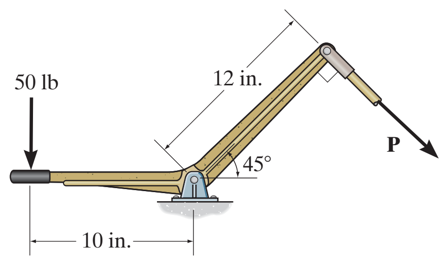
If exact value of r_f (0.002967 m) is used, then

$P = 814\text{ N}$ **Ans**

If approximate value of r_f (0.003 m) is used, then

$P = 814\text{ N}$ **Ans** (approx.)

8–134. The bell crank fits loosely into a 0.5-in-diameter pin. Determine the required force P which is just sufficient to rotate the bell crank clockwise. The coefficient of static friction between the pin and the bell crank is $\mu_s = 0.3$.



$\overset{+}{\rightarrow}\Sigma F_x = 0;\qquad P\cos 45° - R_x = 0\qquad R_x = 0.7071P$

$+\uparrow\Sigma F_y = 0;\qquad R_y - P\sin 45° - 50 = 0\qquad R_y = 0.7071P + 50$

Thus, the magnitude of **R** is

$$R = \sqrt{R_x{}^2 + R_y{}^2} = \sqrt{(0.7071P)^2 + (0.7071P + 50)^2}$$
$$= \sqrt{P^2 + 70.71P + 2500}$$

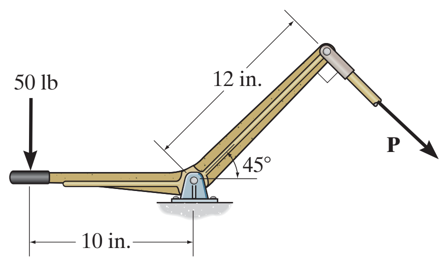
We find that $\phi_s = \tan^{-1}\mu_s = \tan^{-1}(0.3) = 16.699°$. Thus, the moment arm of **R** from point O is $(0.25\sin 16.699°)$ mm. Using these results and writing the moment equation about point O, Fig. a,

$\curvearrowleft +\Sigma M_O = 0;\qquad 50(10) + \sqrt{P^2 + 70.71P + 2500}\,(0.25\sin 16.699°) - P(12) = 0$

Choosing the larger root,

$P = 42.2\text{ lb}$ **Ans.**

8–135. The bell crank fits loosely into a 0.5-in-diameter pin. If $P = 41$ lb, the bell crank is then on the verge of rotating counterclockwise. Determine the coefficient of static friction between the pin and the bell crank.



$\overset{+}{\rightarrow}\Sigma F_x = 0;$ $\quad 41\cos 45° - R_x = 0 \quad R_x = 28.991$ lb

$+\uparrow \Sigma F_y = 0;$ $\quad R_y - 41\sin 45° - 50 = 0 \quad R_y = 78.991$ lb

Thus, the magnitude of **R** is

$$R = \sqrt{R_x^{\,2} + R_y^{\,2}} = \sqrt{28.991^2 + 78.991^2} = 84.144 \text{ lb}$$

We find that the moment arm of **R** from point O is $0.25\sin\phi_s$.

Using these results and writing the moment equation about point O, Fig. a,

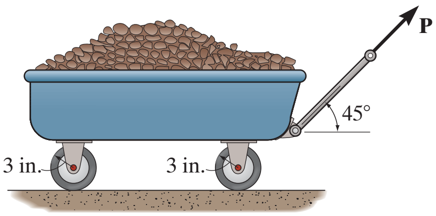
$\circlearrowleft + \Sigma M_O = 0;$ $\quad 50(10) - 41(12) - 84.144(0.25\sin\phi_s) = 0$

$$\phi_s = 22.35°$$

Thus,

$$\mu_s = \tan\phi_s = \tan 22.35° = 0.411 \qquad \textbf{Ans.}$$

***8–136.** The wagon together with the load weighs 150 lb. If the coefficient of rolling resistance is $a = 0.03$ in., determine the force P required to pull the wagon with constant velocity.



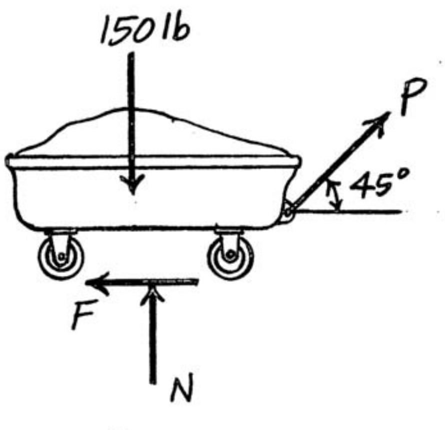
The normal reaction **N** on the wheels can be obtained by referring to the free - body diagram of the wagon shown in Fig. *a*.

$+\uparrow \Sigma F_y = 0; \qquad N + P\sin 45° - 150 = 0 \qquad N = 150 - 0.7071P$

Since the rolling resistance of the wheels is $F = \dfrac{Wa}{r}$, where $W = N = 150 - 0.7071P$, $a = 0.03$ in. and $r = 3$ in., then

$\overset{+}{\rightarrow} \Sigma F_x = 0; \qquad P\cos 45° - \dfrac{(150 - 0.7071P)(0.03)}{3} = 0$

$P = 2.10$ lb **Ans.**



(a)

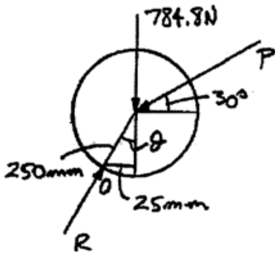
•8–137. The lawn roller has a mass of 80 kg. If the arm *BA* is held at an angle of 30° from the horizontal and the coefficient of rolling resistance for the roller is 25 mm, determine the force *P* needed to push the roller at constant speed. Neglect friction developed at the axle, *A*, and assume that the resultant force **P** acting on the handle is applied along arm *BA*.

$$\theta = \sin^{-1}\left(\frac{25}{250}\right) = 5.74^\circ$$

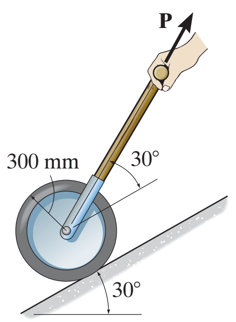
$\curvearrowleft + \Sigma M_O = 0; \quad -25\,(784.8) - P\sin 30^\circ\,(25) + P\cos 30^\circ\,(250\cos 5.74^\circ) = 0$

Solving,

$P = 96.7\text{ N}$ **Ans**



8–138. Determine the force P required to overcome rolling resistance and pull the 50-kg roller up the inclined plane with constant velocity. The coefficient of rolling resistance is $a = 15$ mm.



From the geometry indicated on the free - body diagram of the roller shown in Fig. a, $\theta = \sin^{-1}\left(\dfrac{15}{300}\right) = 2.866°$.

We have

$$+\nearrow \Sigma F_{x'} = 0; \quad P\cos 30° - 50(9.81)\sin 30° - R\sin 2.866° = 0$$

$$+\nwarrow \Sigma F_{y'} = 0; \quad P\sin 30° + R\cos 2.866° - 50(9.81)\cos 30° = 0$$

Solving,

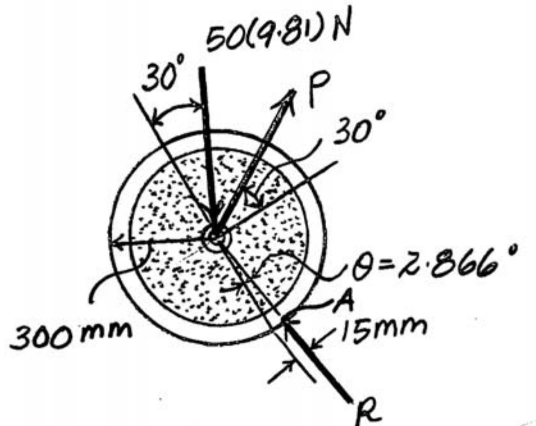
$$P = 299 \text{ N} \qquad \textbf{Ans.}$$

$$R = 275.58 \text{ N}$$

P can also be obtained directly by writing the moment equation of equilibrium about point A. Referring to Fig. a,

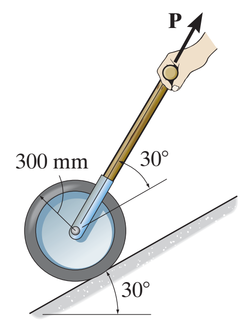
$$\circlearrowleft + \Sigma M_A = 0; \qquad 50(9.81)\sin(30° + 2.866°)(300) - P\cos(30° - 2.866°)(300) = 0$$

$$P = 299 \text{ N} \qquad \textbf{Ans.}$$



(a)

8–139. Determine the force P required to overcome rolling resistance and support the 50-kg roller if it rolls down the inclined plane with constant velocity. The coefficient of rolling resistance is $a = 15$ mm.



From the geometry indicated on the free - body diagram of the roller shown in Fig. a, $\theta = \sin^{-1}\left(\frac{15}{300}\right) = 2.866°$.

$+\nearrow \Sigma F_{x'} = 0;\quad P\cos 30° + R\sin 2.866° - 50(9.81)\sin 30° = 0$

$+\nwarrow \Sigma F_{y'} = 0;\quad P\sin 30° + R\cos 2.866° - 50(9.81)\cos 30° = 0$

Solving,

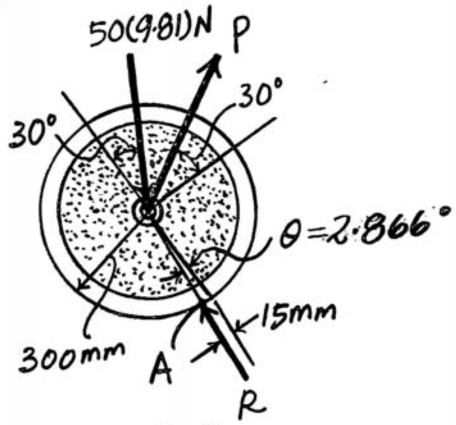
$P = 266\text{ N}$ **Ans.**

$R = 291.98\text{ N}$

P can also be obtained directly by writing the moment equation of equilibrium about point A. Referring to Fig. a,

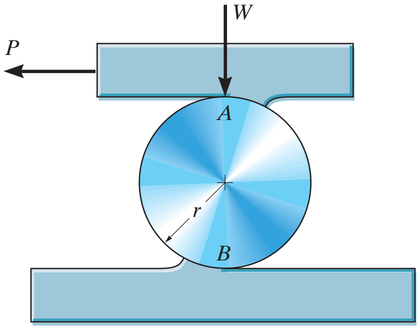
$\circlearrowleft +\Sigma M_A = 0;\quad 50(9.81)\sin(30° - 2.866°)(300) - P\cos(30° + 2.866°)(300) = 0$

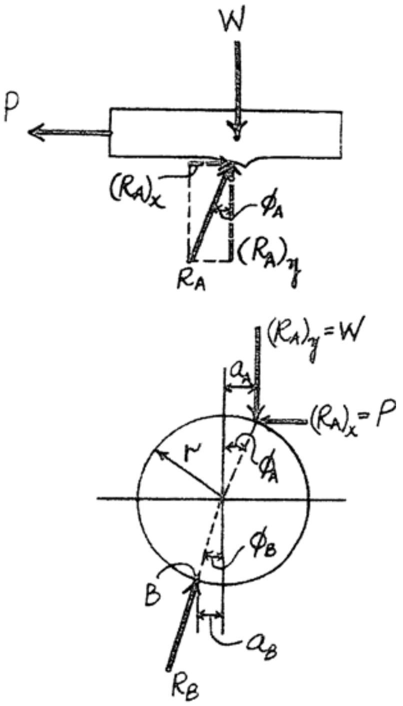
$P = 266\text{ N}$ **Ans.**



(a)

***8–140.** The cylinder is subjected to a load that has a weight W. If the coefficients of rolling resistance for the cylinder's top and bottom surfaces are a_A and a_B, respectively, show that a horizontal force having a magnitude of $P = [W(a_A + a_B)]/2r$ is required to move the load and thereby roll the cylinder forward. Neglect the weight of the cylinder.





$\xrightarrow{+} \Sigma F_x = 0; \quad (R_A)_x - P = 0 \quad (R_A)_x = P$

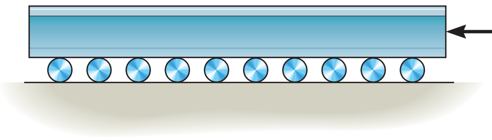
$+\uparrow \Sigma F_y = 0; \quad (R_A)_y - W = 0 \quad (R_A)_y = W$

$\circlearrowleft + \Sigma M_B = 0; \quad P(r\cos\phi_A + r\cos\phi_B) - W(a_A + a_B) = 0 \qquad (1)$

Since ϕ_A and ϕ_B are very small, $\cos\phi_A \approx \cos\phi_B = 1$. Hence, from Eq. (1)

$P = \dfrac{W(a_A + a_B)}{2r}$ **(QED)**

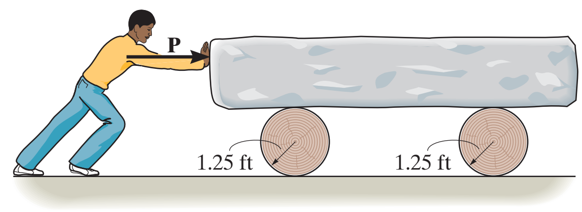
•8–141. The 1.2-Mg steel beam is moved over a level surface using a series of 30-mm-diameter rollers for which the coefficient of rolling resistance is 0.4 mm at the ground and 0.2 mm at the bottom surface of the beam. Determine the horizontal force P needed to push the beam forward at a constant speed. *Hint:* Use the result of Prob. 8–140.



$P = \dfrac{W(a_A + a_B)}{2r} = \dfrac{(1200)(9.81)(0.2 + 0.4)}{2(15)}$

$P = 235\text{ N}$ **Ans**

8–142. Determine the smallest horizontal force P that must be exerted on the 200-lb block to move it forward. The rollers each weigh 50 lb, and the coefficient of rolling resistance at the top and bottom surfaces is $a = 0.2$ in.



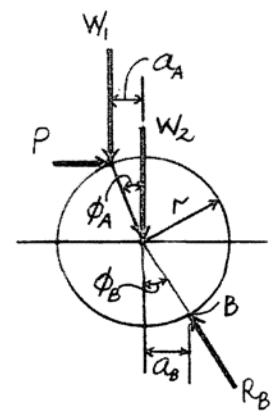
In general :

$\curvearrowleft +\Sigma M_B = 0;\quad P(r\cos\phi_A + r\cos\phi_B) - W_1(a_A + a_B) - W_2\, a_B = 0$

Since ϕ_A and ϕ_B are very small, $\cos\phi_A = \cos\phi_B = 1$. Hence,

$$P(2r) = W_1(a_A + a_B) + W_2\, a_B$$

$$P = \frac{W_1(a_A + a_B) + W_2\, a_B}{2r}$$

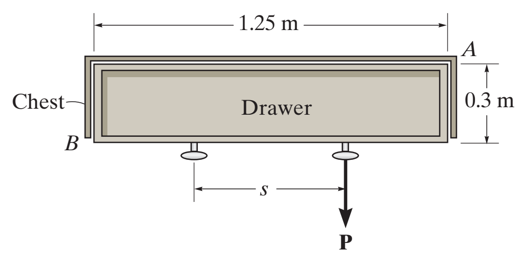


Thus, for the problem,

$$P = \left(\frac{200(0.2 + 0.2) + 2(50)(0.2)}{2(1.25)}\right)$$

$$P = 40 \text{ lb} \qquad \textbf{Ans}$$

8–143. A single force **P** is applied to the handle of the drawer. If friction is neglected at the bottom and the coefficient of static friction along the sides is $\mu_s = 0.4$, determine the largest spacing s between the symmetrically placed handles so that the drawer does not bind at the corners A and B when the force **P** is applied to one of the handles.



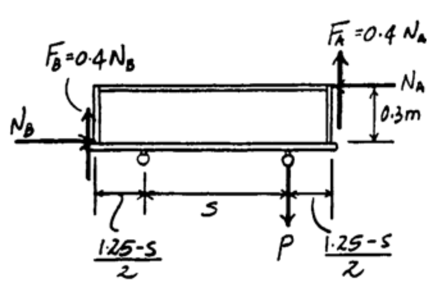
Equations of Equilibrium and Friction : If the drawer does not bind at corners A and B, slipping would have to occur at points A and B. Hence, $F_A = \mu N_A = 0.4N_A$ and $F_B = \mu N_B = 0.4N_B$.

$\xrightarrow{+} \Sigma F_x = 0;\quad N_B - N_A = 0 \qquad N_A = N_B = N$

$+\uparrow \Sigma F_y = 0;\quad 0.4N + 0.4N - P = 0 \qquad P = 0.8N$

$\curvearrowleft + \Sigma M_B = 0;\quad N(0.3) + 0.4N(1.25) - 0.8N\left(\frac{s + 1.25}{2}\right) = 0$

$$N\left[0.3 + 0.5 - 0.8\left(\frac{s + 1.25}{2}\right)\right] = 0$$

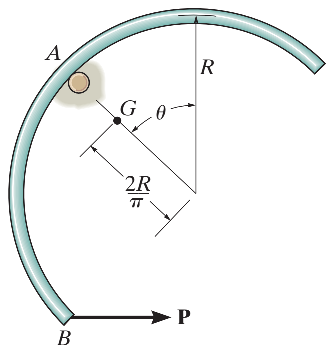


- Since $N \neq 0$, then

$$0.3 + 0.5 - 0.8\left(\frac{s + 1.25}{2}\right) = 0$$

$$s = 0.750 \text{ m} \qquad \textbf{Ans}$$

***8–144.** The semicircular thin hoop of weight W and center of gravity at G is suspended by the small peg at A. A horizontal force $\mathbf{P}$ is slowly applied at B. If the hoop begins to slip at A when $\theta = 30°$, determine the coefficient of static friction between the hoop and the peg.



$\xrightarrow{+} \Sigma F_x = 0; \quad P + F_A \cos 30° - N_A \sin 30° = 0$

$+\uparrow \Sigma F_y = 0; \quad F_A \sin 30° + N_A \cos 30° - W = 0$

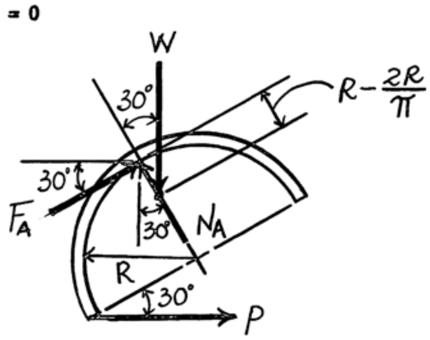
$\circlearrowleft + \Sigma M_A = 0; \quad -W \sin 30° \left(R - \frac{2R}{\pi}\right) + P \sin 30° (R) + P \cos 30° (R) = 0$

$P = 0.1330\, W$

$0.1330 (F_A \sin 30° + N_A \cos 30°) + F_A \cos 30° - N_A \sin 30° = 0$

$F_A (0.9325) - N_A (0.3848) = 0$

$\mu_A = \frac{F_A}{N_A} = \frac{0.3848}{0.9325} = 0.413 \quad$ **Ans**



Also,

$+\nwarrow \Sigma F_x = 0; \quad N_A - W \cos 30° - P \sin 30° = 0$

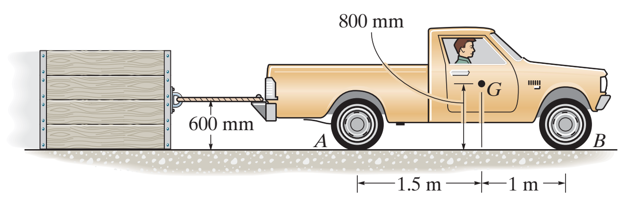
$+\nearrow \Sigma F_y = 0; \quad \mu_A N_A - W \sin 30° + P \cos 30° = 0$

$\circlearrowleft + \Sigma M_A = 0; \quad -W \sin 30° (R) \left(1 - \frac{2}{\pi}\right) + P \cos 30° (R) + P \sin 30° (R) = 0$

$P = 0.133\, W$

$\mu_A = 0.413 \quad$ **Ans**

•**8–145.** The truck has a mass of 1.25 Mg and a center of mass at G. Determine the greatest load it can pull if (a) the truck has rear-wheel drive while the front wheels are free to roll, and (b) the truck has four-wheel drive. The coefficient of static friction between the wheels and the ground is $\mu_s = 0.5$, and between the crate and the ground, it is $\mu_s' = 0.4$.



a) The truck with rear wheel drive.

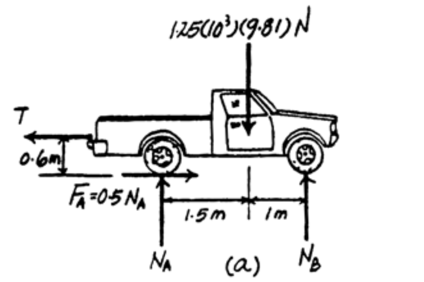
Equations of Equilibrium and Friction : It is required that the rear wheels of the truck slip. Hence $F_A = \mu_s N_A = 0.5N_A$. From FBD (a),

$$\curvearrowleft + \Sigma M_B = 0; \quad 1.25(10^3)(9.81)(1) + T(0.6) - N_A(2.5) = 0 \qquad [1]$$

$$\xrightarrow{+} \Sigma F_x = 0; \quad 0.5N_A - T = 0 \qquad [2]$$

Solving Eqs. [1] and [2] yields

$$N_A = 5573.86 \text{ N} \qquad T = 2786.93 \text{ N}$$



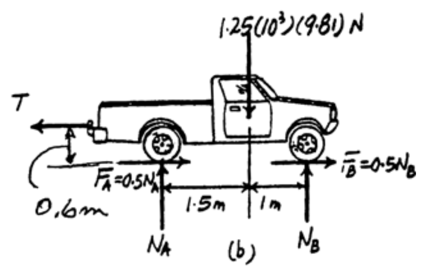
Since the crate moves, $F_C = \mu_s' N_C = 0.4N_C$. From FBD (c),

$$+\uparrow \Sigma F_y = 0; \quad N_C - W = 0 \quad N_C = W$$

$$\xrightarrow{+} \Sigma F_x = 0; \quad 2786.93 - 0.4W = 0$$

$$W = 6967.33 \text{ N} = 6.97 \text{ kN} \qquad \textbf{Ans}$$

b) The truck with four wheel drive.

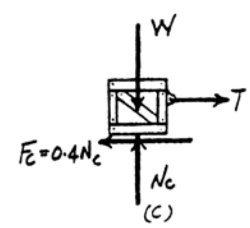


Equations of Equilibrium and Friction : It is required that the rear wheels and front wheels of the truck slip. Hence $F_A = \mu_s N_A = 0.5N_A$ and $F_B = \mu_s N_B = 0.5N_B$. From FBD (b),

$$\curvearrowleft + \Sigma M_B = 0; \quad 1.25(10^3)(9.81)(1) + T(0.6) - N_A(2.5) = 0 \qquad [3]$$

$$\curvearrowleft + \Sigma M_A = 0; \quad N_B(2.5) + T(0.6) - 1.25(10^3)(9.81)(1.5) = 0 \qquad [4]$$

$$\xrightarrow{+} \Sigma F_x = 0; \quad 0.5N_A + 0.5N_B - T = 0 \qquad [5]$$



Solving Eqs. [3], [4] and [5] yields

$$N_A = 6376.5 \text{ N} \qquad N_B = 5886.0 \text{ N} \qquad T = 6131.25 \text{ N}$$

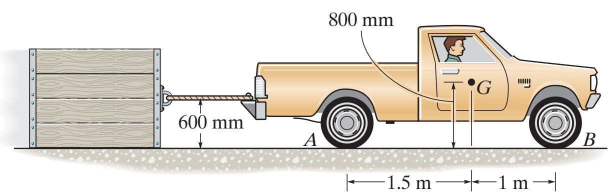
Since the crate moves, $F_C = \mu_s' N_C = 0.4N_C$. From FBD (c),

$$+\uparrow \Sigma F_y = 0; \quad N_C - W = 0 \quad N_C = W$$

$$\xrightarrow{+} \Sigma F_x = 0; \quad 6131.25 - 0.4W = 0$$

$$W = 15328.125 \text{ N} = 15.3 \text{ kN} \qquad \textbf{Ans}$$

8–146. Solve Prob. 8–145 if the truck and crate are traveling up a 10° incline.



a) The truck with rear wheel drive.

Equations of Equilibrium and Friction : It is required that the rear wheel of the truck slip hence $F_A = \mu_s N_A = 0.5N_A$. From FBD (a),

$$\circlearrowleft + \Sigma M_B = 0; \quad 1.25(10^3)(9.81)\cos 10°(1) + 1.25(10^3)(9.81)\sin 10°(0.8) + T(0.6) - N_A(2.5) = 0 \quad [1]$$

$$+\nearrow \Sigma F_{x'} = 0; \quad 0.5N_A - 1.25(10^3)(9.81)\sin 10° - T = 0 \quad [2]$$

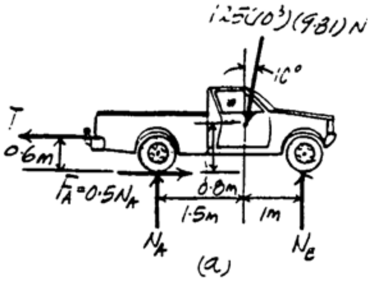
Solving Eqs. [1] and [2] yields

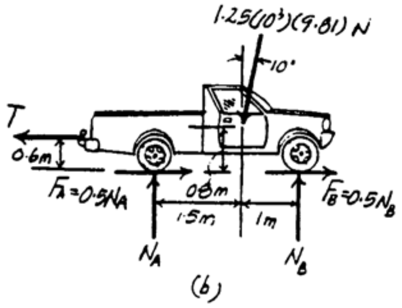
$$N_A = 5682.76\ \text{N} \qquad T = 712.02\ \text{N}$$

Since the crate moves, $F_C = \mu_s' N_C = 0.4N_C$. From FBD (c),

$$\nwarrow + \Sigma F_{y'} = 0; \quad N_C - W\cos 10° = 0 \qquad N_C = 0.9848W$$

$$+\nearrow \Sigma F_x = 0; \quad 712.02 - W\sin 10° - 0.4(0.9848W) = 0$$
$$W = 1254.50\ \text{N} = 1.25\ \text{kN} \qquad \textbf{Ans}$$





b) The truck with four wheel drive.

Equations of Equilibrium and Friction : It is required that the rear wheels of the truck slip hence $F_A = \mu_s N_A = 0.5N_A$. From FBD (b).

$$\circlearrowleft + \Sigma M_B = 0; \quad 1.25(10^3)(9.81)\cos 10°(1) + 1.25(10^3)(9.81)\sin 10°(0.8) + T(0.6) - N_A(2.5) = 0 \quad [3]$$

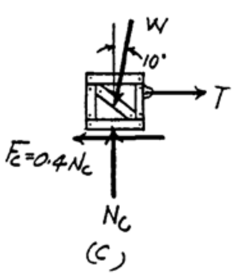
$$\circlearrowleft + \Sigma M_A = 0; \quad -1.25(10^3)(9.81)\cos 10°(1.5) + 1.25(10^3)(9.81)\sin 10°(0.8) + T(0.6) + N_B(2.5) = 0 \quad [4]$$

$$+\nearrow \Sigma F_{x'} = 0; \quad 0.5N_A + 0.5N_B - 1.25(10^3)(9.81)\sin 10° - T = 0 \quad [5]$$

Solving Eqs. [3], [4] and [5] yields

$$N_A = 6449.98\ \text{N} \qquad N_B = 5626.23\ \text{N} \qquad T = 3908.74\ \text{N}$$

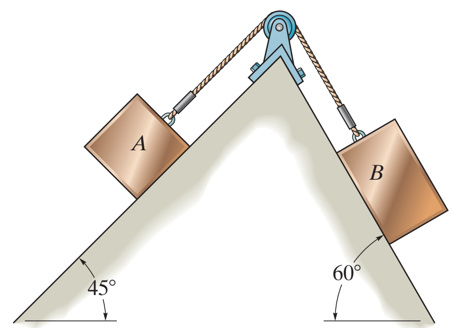
Since the crate moves, $F_C = \mu_s' N_C = 0.4N_C$. From FBD (c),

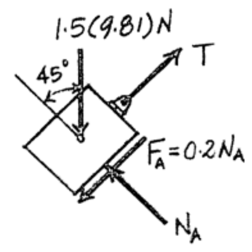


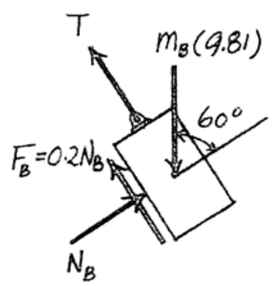
$$\nwarrow + \Sigma F_{y'} = 0; \quad N_C - W\cos 10° = 0 \qquad N_C = 0.9848W$$

$$\xrightarrow{+} \Sigma F_x = 0; \quad 3908.74 - W\sin 10° - 0.4(0.9848W) = 0$$
$$W = 6886.79\ \text{N} = 6.89\ \text{kN} \qquad \textbf{Ans}$$

8–147. If block A has a mass of 1.5 kg, determine the largest mass of block B without causing motion of the system. The coefficient of static friction between the blocks and inclined planes is $\mu_s = 0.2$.







By inspection, B will tend to move down the plane.

Block A:

$+\nearrow \Sigma F_x = 0;\quad T - 0.2N_A - 1.5(9.81)\sin 45° = 0$

$+\nwarrow \Sigma F_y = 0;\quad N_A - 1.5(9.81)\cos 45° = 0$

Block B:

$+\nwarrow \Sigma F_x = 0;\quad T + 0.2N_B - 9.81\,(m_B)\sin 60° = 0$

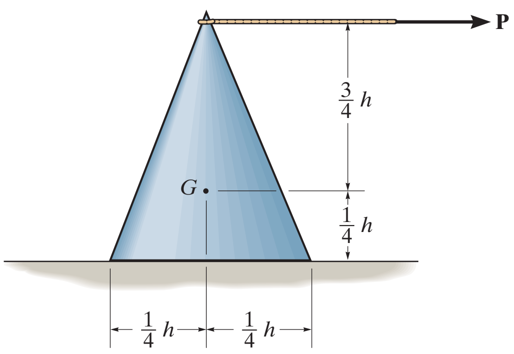
$+\nearrow \Sigma F_y = 0;\quad N_B - 9.81\,(m_B)\cos 60° = 0$

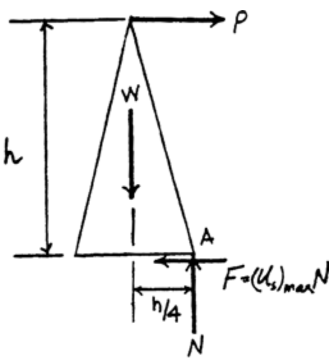
Solving,

$N_A = 10.4\text{ N};\quad N_B = 8.15\text{ N};\quad T = 12.5\text{ N};$

$m_B = 1.66\text{ kg}$ **Ans**

***8–148.** The cone has a weight W and center of gravity at G. If a horizontal force **P** is gradually applied to the string attached to its vertex, determine the maximum coefficient of static friction for slipping to occur.





Equations of Equilibrium : In this case, it is required that the cone slips and about to tip about point A. Hence, $F = (\mu_s)_{max} N$.

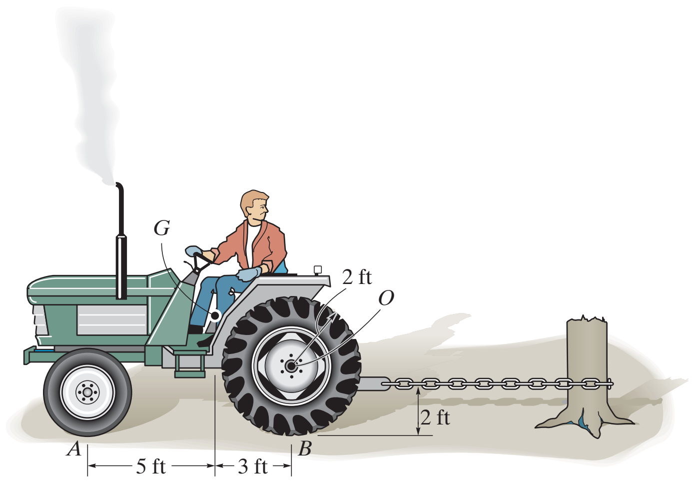
$$\circlearrowleft + \Sigma M_A = 0; \quad W\left(\frac{h}{4}\right) - P(h) = 0 \quad P = \frac{W}{4}$$

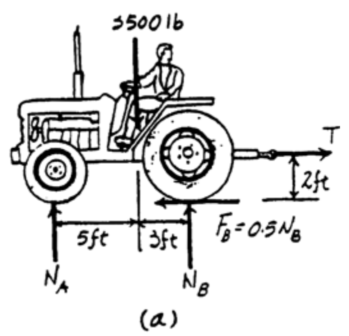
$$+\uparrow \Sigma F_y = 0; \quad N - W = 0 \quad N = W$$

$$\xrightarrow{+} \Sigma F_x = 0; \quad \frac{W}{4} - (\mu_s)_{max} W = 0$$

$$(\mu_s)_{max} = 0.250 \qquad \textbf{Ans}$$

•8–149. The tractor pulls on the fixed tree stump. Determine the torque that must be applied by the engine to the rear wheels to cause them to slip. The front wheels are free to roll. The tractor weighs 3500 lb and has a center of gravity at G. The coefficient of static friction between the rear wheels and the ground is $\mu_s = 0.5$.





Equations of Equilibrium and Friction : Assume that the rear wheels B slip. Hence $F_B = \mu_s N_B = 0.5N_B$.

$$\curvearrowleft + \Sigma M_A = 0 \quad N_B(8) - T(2) - 3500(5) = 0 \qquad [1]$$

$$+\uparrow \Sigma F_y = 0; \quad N_B + N_A - 3500 = 0 \qquad [2]$$

$$\xrightarrow{+} \Sigma F_x = 0; \quad T - 0.5N_B = 0 \qquad [3]$$

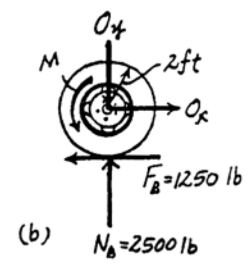
Solving Eqs. [1], [2] and [3] yields

$$N_A = 1000 \text{ lb} \qquad N_B = 2500 \text{ lb} \qquad T = 1250 \text{ lb}$$

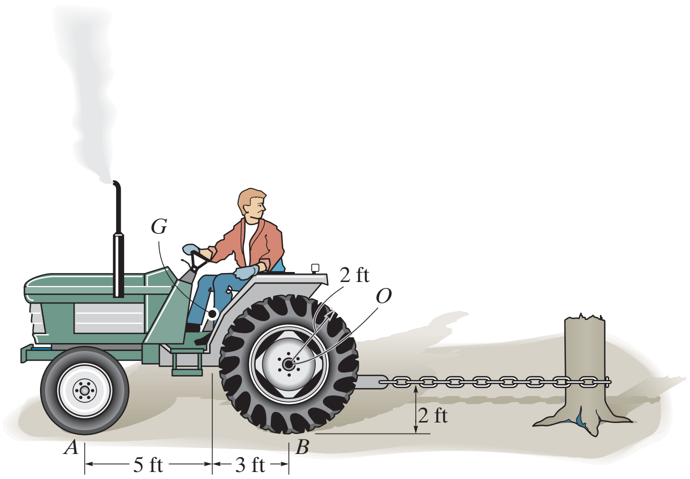
Since $N_A > 0$, the front wheels do not lift up. Therefore the rear wheels slip as assumed. Thus, $F_B = 0.5(2500) = 1250$ lb. From FBD (b),

$$\curvearrowleft + \Sigma M_O = 0, \quad M - 1250(2) = 0$$

$$M = 2500 \text{ lb} \cdot \text{ft} = 2.50 \text{ kip} \cdot \text{ft} \qquad \textbf{Ans}$$



8–150. The tractor pulls on the fixed tree stump. If the coefficient of static friction between the rear wheels and the ground is $\mu_s = 0.6$, determine if the rear wheels slip or the front wheels lift off the ground as the engine provides torque to the rear wheels. What is the torque needed to cause this motion? The front wheels are free to roll. The tractor weighs 2500 lb and has a center of gravity at G.

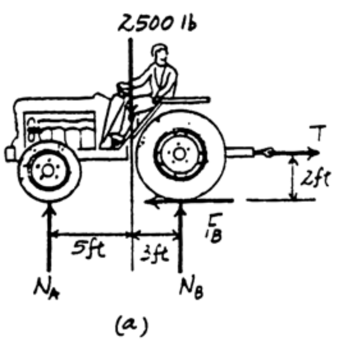


Equations of Equilibrium and Friction : Assume that the rear wheels B slip. Hence $F_B = \mu_s N_B = 0.6N_B$.

$$\circlearrowleft + \Sigma M_A = 0 \quad N_B(8) - T(2) - 2500(5) = 0 \qquad [1]$$

$$+\uparrow \Sigma F_y = 0; \quad N_B + N_A - 2500 = 0 \qquad [2]$$

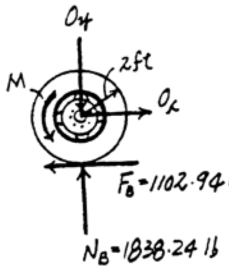
$$\xrightarrow{+} \Sigma F_x = 0; \quad T - 0.6N_B = 0 \qquad [3]$$



Solving Eqs. [1], [2] and [3] yields

$$N_A = 661.76 \text{ lb} \qquad N_B = 1838.24 \text{ lb} \qquad T = 1102.94 \text{ lb}$$

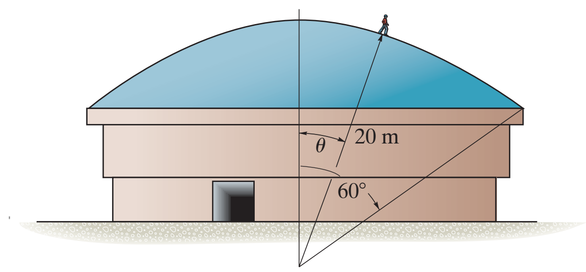
Since $N_A > 0$, **the front wheels do not lift off the ground.** Therefore the rear wheels slip as assumed. Thus, $F_B = 0.6(1838.24) = 1102.94$ lb. From FBD (b),

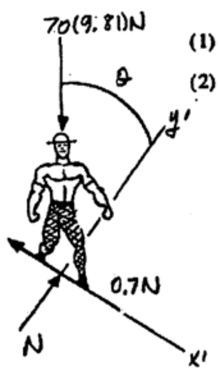


$$+\Sigma M_O = 0, \quad M - 1102.94(2) = 0$$

$$M = 2205.88 \text{ lb} \cdot \text{ft} = 2.21 \text{ kip} \cdot \text{ft} \qquad \textbf{Ans}$$

8–151. A roofer, having a mass of 70 kg, walks slowly in an upright position down along the surface of a dome that has a radius of curvature of $r = 20$ m. If the coefficient of static friction between his shoes and the dome is $\mu_s = 0.7$, determine the angle θ at which he first begins to slip.





$$+\nearrow \Sigma F_{y'} = 0; \quad N - 70(9.81)\cos\theta = 0 \qquad (1)$$

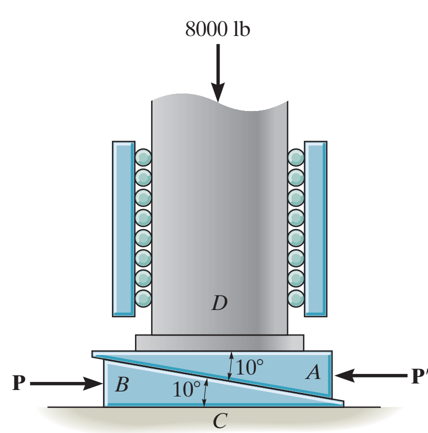
$$+\searrow \Sigma F_{x'} = 0; \quad 70(9.81)\sin\theta - 0.7N = 0 \qquad (2)$$

Solving Eqs. (1) and (2) yields :

$$\theta = 35.0° \qquad \textbf{Ans}$$

$$N = 562.6\text{ N}$$

*8–152. Column D is subjected to a vertical load of 8000 lb. It is supported on two identical wedges A and B for which the coefficient of static friction at the contacting surfaces between A and B and between B and C is $\mu_s = 0.4$. Determine the force P needed to raise the column and the equilibrium force P' needed to hold wedge A stationary. The contacting surface between A and D is smooth.



Wedge *A* :

$$+\uparrow \Sigma F_y = 0; \quad N\cos 10° - 0.4N\sin 10° - 8000 = 0$$

$$N = 8739.8\text{ lb}$$

$$\overset{+}{\rightarrow} \Sigma F_x = 0; \quad 0.4(8739.8)\cos 10° + 8739.8\sin 10° - P' = 0$$

$$P' = 4960\text{ lb} = 4.96\text{ kip} \qquad \textbf{Ans}$$

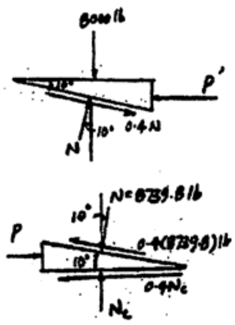
Wedge *B* :

$$+\uparrow \Sigma F_y = 0; \quad N_C + 0.4(8739.8)\sin 10° - 8739.8\cos 10° = 0$$

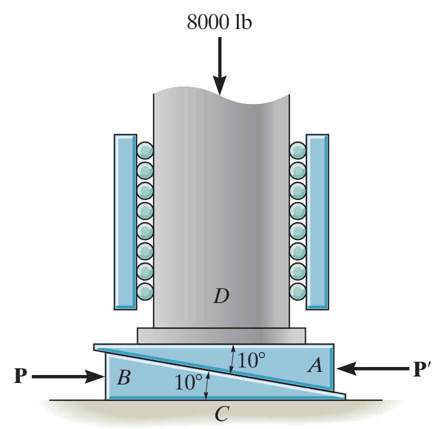
$$N_C = 8000\text{ lb}$$

$$\overset{+}{\rightarrow} \Sigma F_x = 0; \quad P - 0.4(8000) - 8739.8\sin 10° - 0.4(8739.8)\cos 10° = 0$$

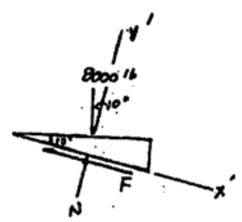
$$P = 8160\text{ lb} = 8.16\text{ kip} \qquad \textbf{Ans}$$



•8–153. Column D is subjected to a vertical load of 8000 lb. It is supported on two identical wedges A and B for which the coefficient of static friction at the contacting surfaces between A and B and between B and C is $\mu_s = 0.4$. If the forces **P** and **P′** are removed, are the wedges self-locking? The contacting surface between A and D is smooth.



Wedge *A* :



$\nearrow + \Sigma F_{y'} = 0; \quad N - 8000\cos 10° = 0$

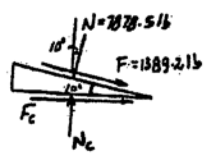
$N = 7878.5$ lb

$\searrow + \Sigma F_{x'} = 0; \quad 8000\sin 10° - F = 0$

$F = 1389.2$ lb

Since $F = 1389.2$ lb $< 0.4(7878.5) = 3151.4$ lb, the wedges do not slip at contact surface AB.

Wedge *B* :



$+\uparrow \Sigma F_y = 0; \quad N_C - 1389.2\sin 10° - 7878.5\cos 10° = 0$

$N_C = 8000$ lb

$\xrightarrow{+} \Sigma F_x = 0; \quad F_C + 1389.2\cos 10° - 7878.5\sin 10° = 0$

$F_C = 0$

Since $F_C = 0$, no slipping occurs at contact surface BC. Therefore, the wedges are self-locking. **Ans**