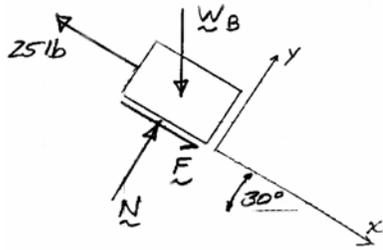


Chapter 8, Solution 1.

FBD Block B:



Tension in cord is equal to $W_A = 25$ lb from FBD's of block A and pulley.

$$\nearrow \Sigma F_y = 0: \quad N - W_B \cos 30^\circ = 0, \quad N = W_B \cos 30^\circ \nearrow$$

(a) For smallest W_B , slip impends up the incline, and

$$F = \mu_s N = 0.35 W_B \cos 30^\circ$$

$$\searrow \Sigma F_x = 0: \quad F - 25 \text{ lb} + W_B \sin 30^\circ = 0$$

$$(0.35 \cos 30^\circ + \sin 30^\circ) W_B = 25 \text{ lb}$$

$$W_{B \min} = 31.1 \text{ lb} \blacktriangleleft$$

(b) For largest W_B , slip impends down the incline, and

$$F = -\mu_s N = -0.35 W_B \cos 30^\circ$$

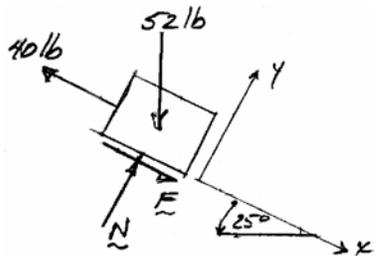
$$\searrow \Sigma F_x = 0: \quad F_s + W_B \sin 30^\circ - 25 \text{ lb} = 0$$

$$(\sin 30^\circ - 0.35 \cos 30^\circ) W_B = 25 \text{ lb}$$

$$W_{B \max} = 127.0 \text{ lb} \blacktriangleleft$$

Chapter 8, Solution 2.

FBD Block B:



Tension in cord is equal to $W_A = 40$ lb from FBD's of block A and pulley.

$$(a) \nearrow \Sigma F_y = 0: \quad N - (52 \text{ lb}) \cos 25^\circ = 0, \quad \mathbf{N = 47.128 \text{ lb} \nearrow}$$

$$F_{\max} = \mu_s N = 0.35(47.128 \text{ lb}) = 16.495 \text{ lb}$$

$$\searrow \Sigma F_x = 0: \quad F_{\text{eq}} - 40 \text{ lb} + (52 \text{ lb}) \sin 25^\circ = 0$$

So, for equilibrium, $F_{\text{eq}} = 18.024$ lb

Since $F_{\text{eq}} > F_{\max}$, the block must slip (up since $F > 0$)

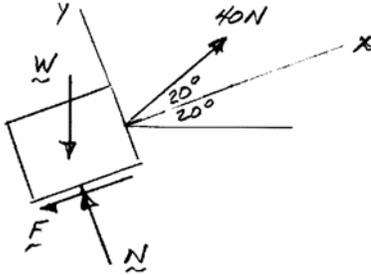
\therefore There is no equilibrium ◀

$$(b) \text{ With slip,} \quad F = \mu_k N = 0.25(47.128 \text{ lb})$$

$$\mathbf{F = 11.78 \text{ lb} \searrow 35^\circ \blacktriangleleft}$$

Chapter 8, Solution 3.

FBD Block:



Tension in cord is equal to $P = 40$ N, from FBD of pulley.

$$W = (10 \text{ kg})(9.81 \text{ m/s}^2) = 98.1 \text{ N}$$

$$\Sigma F_y = 0: \quad N - (98.1 \text{ N})\cos 20^\circ + (40 \text{ N})\sin 20^\circ = 0$$

$$N = 78.503 \text{ N}$$

$$F_{\max} = \mu_s N = (0.30)(78.503 \text{ N}) = 23.551 \text{ N}$$

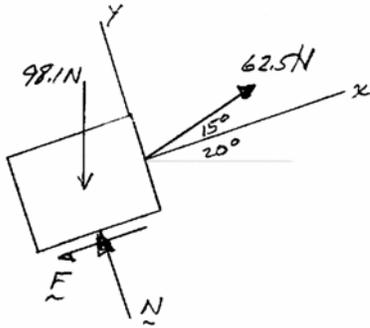
$$\text{For equilibrium: } \Sigma F_x = 0: \quad (40 \text{ N})\cos 20^\circ - (98.1 \text{ N})\sin 20^\circ - F = 0$$

$$F_{\text{eq}} = 4.0355 \text{ N} < F_{\max}, \quad \therefore \text{Equilibrium exists} \blacktriangleleft$$

$$F = F_{\text{eq}}$$

$$F = 4.04 \text{ N} \nearrow 20^\circ \blacktriangleleft$$

Chapter 8, Solution 4.



Tension in cord is equal to $P = 62.5$ N, from FBD of pulley.

$$\mathbf{W} = (10 \text{ kg})(9.81 \text{ m/s}^2) = 98.1 \text{ N}$$

$$\sum F_y = 0: \quad N - (98.1 \text{ N})\cos 20^\circ + (62.5 \text{ N})\sin 15^\circ = 0$$

$$N = 76.008 \text{ N}$$

$$F_{\max} = \mu_s N = (0.30)(76.008 \text{ N}) = 22.802 \text{ N}$$

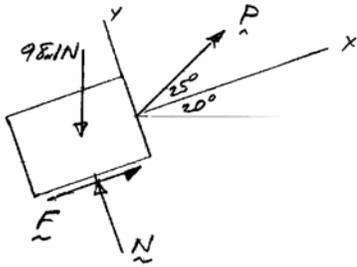
$$\text{For equilibrium: } \sum F_x = 0: \quad (62.5 \text{ N})\cos 15^\circ - (98.1 \text{ N})\sin 20^\circ - F = 0$$

$$F_{\text{eq}} = 26.818 \text{ N} > F_{\max} \quad \text{so no equilibrium,} \\ \text{and block slides up the incline } \blacktriangleleft$$

$$F_{\text{slip}} = \mu_x N = (0.25)(76.008 \text{ N}) = 19.00 \text{ N}$$

$$\mathbf{F} = 19.00 \text{ N } \nearrow 20^\circ \blacktriangleleft$$

Chapter 8, Solution 5.



Tension in cord is equal to P from FBD of pulley.

$$\mathbf{W} = (10 \text{ kg})(9.81 \text{ m/s}^2) = 98.1 \text{ N}$$

$$\sum F_y = 0: \quad N - (98.1 \text{ N})\cos 20^\circ + P \sin 25^\circ = 0 \quad (1)$$

$$\sum F_x = 0: \quad P \cos 25^\circ - (98.1 \text{ N})\sin 20^\circ + F = 0 \quad (2)$$

For impending slip down the incline, $F = \mu_s N = 0.3 \text{ N}$ and solving (1) and (2),

$$P_D = 7.56 \text{ N}$$

For impending slip up the incline, $F = -\mu_s N = -0.3 \text{ N}$ and solving (1) and (2),

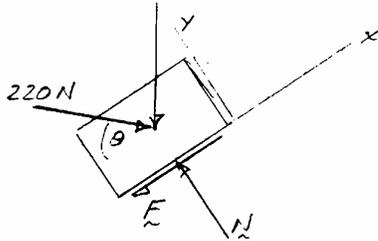
$$P_U = 59.2 \text{ N}$$

so, for equilibrium

$$7.56 \text{ N} \leq P \leq 59.2 \text{ N} \quad \blacktriangleleft$$

Chapter 8, Solution 6.

FBD Block:



$$W = (20 \text{ kg})(9.81 \text{ m/s}^2) = 196.2 \text{ N}$$

For θ_{\min} motion will impend up the incline, so F is downward and
 $F = \mu_s N$

$$\nearrow \Sigma F_y = 0: \quad N - (220 \text{ N})\sin\theta - (196.2 \text{ N})\cos 35^\circ = 0$$

$$F = \mu_s N = 0.3(220 \sin\theta + 196.2 \cos 35^\circ) \text{ N} \quad (1)$$

$$\nearrow \Sigma F_x = 0: \quad (220 \text{ N})\cos\theta - F - (196.2 \text{ N})\sin 35^\circ = 0 \quad (2)$$

$$\begin{aligned} (1) + (2): \quad & 0.3(220 \sin\theta + 196.2 \cos\theta) \text{ N} \\ & = (220 \cos\theta) \text{ N} - (196.2 \sin 35^\circ) \text{ N} \end{aligned}$$

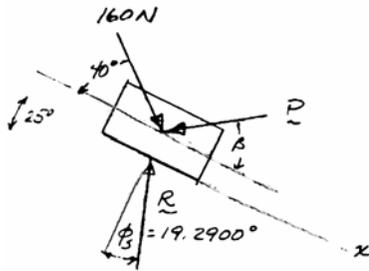
$$\text{or} \quad 220 \cos\theta - 66 \sin\theta = 160.751$$

Solving numerically:

$$\theta = 28.9^\circ \blacktriangleleft$$

Chapter 8, Solution 7.

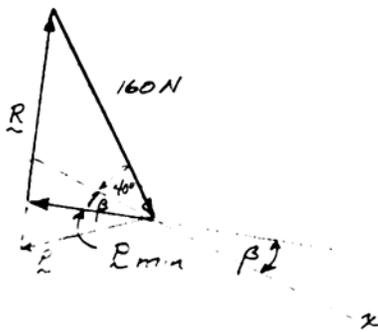
FBD Block:



For P_{\min} motion will impend down the incline, and the reaction force \mathbf{R} will make the angle

$$\phi_s = \tan^{-1} \mu_s = \tan^{-1}(0.35) = 19.2900^\circ$$

with the normal, as shown.



Note, for minimum \mathbf{P} , \mathbf{P} must be \perp to \mathbf{R} , i.e. $\beta = \phi_s$ (angle between \mathbf{P} and x equals angle between \mathbf{R} and normal).

(b)

$$\beta = 19.29^\circ \blacktriangleleft$$

$$\text{then } P = (160 \text{ N}) \cos(\beta + 40^\circ)$$

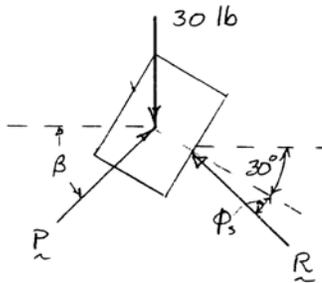
$$= (160 \text{ N}) \cos 59.29^\circ = 81.71 \text{ N}$$

(a)

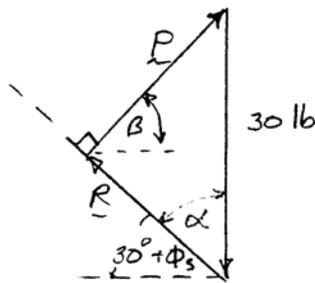
$$P_{\min} = 81.7 \text{ N} \blacktriangleleft$$

Chapter 8, Solution 8.

FBD block (impending motion downward)



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



(a) Note: For minimum P , $\mathbf{P} \perp \mathbf{R}$

So $\beta = \alpha = 90^\circ - (30^\circ + 14.036^\circ) = 45.964^\circ$

and $P = (30 \text{ lb}) \sin \alpha = (30 \text{ lb}) \sin(45.964^\circ) = 21.567 \text{ lb}$

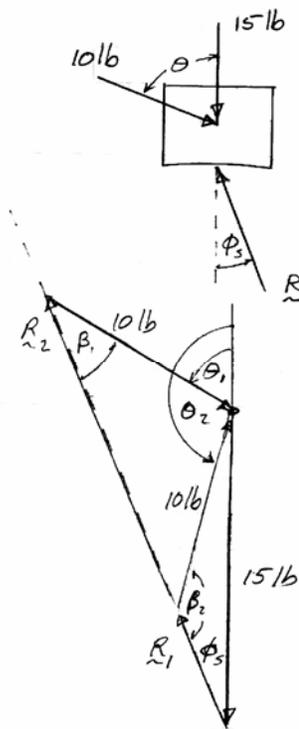
$P = 21.6 \text{ lb} \blacktriangleleft$

(b)

$\beta = 46.0^\circ \blacktriangleleft$

Chapter 8, Solution 9.

FBD Block:



For impending motion. $\phi_s = \tan^{-1} \mu_s = \tan^{-1}(0.40)$

$$\phi_s = 21.801^\circ$$

Note $\beta_{1,2} = \theta_{1,2} - \phi_s$

From force triangle:

$$\frac{10 \text{ lb}}{\sin \phi_s} = \frac{15 \text{ lb}}{\sin \beta_{1,2}}$$

$$\beta_{1,2} = \sin^{-1} \left[\frac{15 \text{ lb}}{10 \text{ lb}} \sin(21.801^\circ) \right] = \begin{cases} 33.854^\circ \\ 146.146^\circ \end{cases}$$

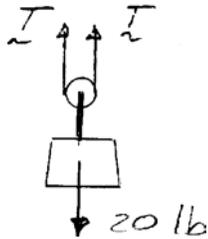
$$\text{So } \theta_{1,2} = \beta_{1,2} + \phi_s = \begin{cases} 55.655^\circ \\ 167.947^\circ \end{cases}$$

So (a) equilibrium for $0 \leq \theta \leq 55.7^\circ$ ◀

(b) equilibrium for $167.9^\circ \leq \theta \leq 180^\circ$ ◀

Chapter 8, Solution 10.

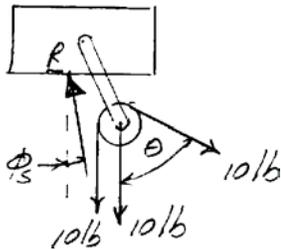
FBD A with pulley:



Tension in cord is T throughout from pulley FBD's

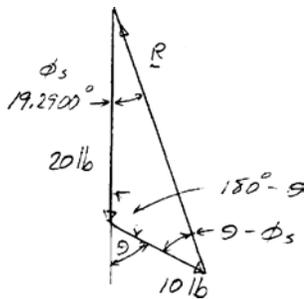
$$\uparrow \Sigma F_y = 0: \quad 2T - 20 \text{ lb} = 0, \quad T = 10 \text{ lb}$$

FBD E with pulley:



For θ_{\max} , motion impends to right, and

$$\phi_s = \tan^{-1} \mu_s = \tan^{-1}(0.35) = 19.2900^\circ$$



From force triangle,

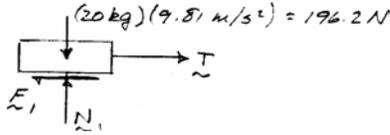
$$\frac{20 \text{ lb}}{\sin(\theta - \phi_s)} = \frac{10 \text{ lb}}{\sin \phi_s}, \quad 2 \sin \phi_s = \sin(\theta - \phi_s)$$

$$\theta = \sin^{-1}(2 \sin 19.2900^\circ) + 19.2900^\circ = 60.64^\circ$$

$$\theta_{\max} = 60.6^\circ \blacktriangleleft$$

Chapter 8, Solution 11.

FBD top block:



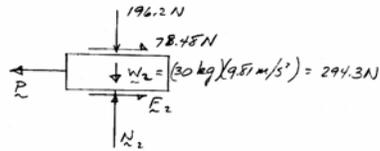
$$\uparrow \Sigma F_y = 0: \quad N_1 - 196.2 \text{ N} = 0$$

$$N_1 = 196.2 \text{ N} \uparrow$$

(a) With cable in place, impending motion of bottom block requires impending slip between blocks, so $F_1 = \mu_s N_1 = 0.4(196.2 \text{ N})$

$$F_1 = 78.48 \text{ N} \leftarrow$$

FBD bottom block:



$$\uparrow \Sigma F_y = 0: \quad N_2 - 196.2 \text{ N} - 294.3 \text{ N} = 0$$

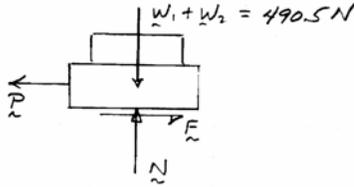
$$N_2 = 490.5 \text{ N} \uparrow$$

$$F_2 = \mu_s N_2 = 0.4(490.5 \text{ N}) = 196.2 \text{ N}$$

$$\rightarrow \Sigma F_x = 0: \quad -P + 78.48 \text{ N} + 196.2 \text{ N} = 0$$

$$P = 275 \text{ N} \leftarrow \blacktriangleleft$$

FBD block:



(b) Without cable AB , top and bottom blocks will move together

$$\uparrow \Sigma F_y = 0: \quad N - 490.5 \text{ N} = 0, \quad N = 490.5 \text{ N}$$

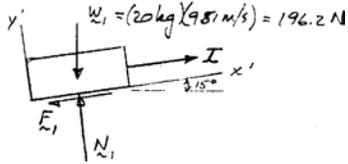
Impending slip: $F = \mu_s N = 0.40(490.5 \text{ N}) = 196.2 \text{ N}$

$$\rightarrow \Sigma F_x = 0: \quad -P + 196.2 \text{ N} = 0$$

$$P = 196.2 \text{ N} \leftarrow \blacktriangleleft$$

Chapter 8, Solution 12.

FBD top block:



Note that, since $\phi_s = \tan^{-1} \mu_s = \tan^{-1}(0.40) = 21.8^\circ > 15^\circ$, no motion will impend if $P = 0$, with or without cable AB .

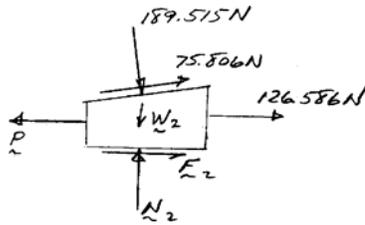
(a) With cable, impending motion of bottom block requires impending slip between blocks, so $F_1 = \mu_s N$

$$\uparrow \Sigma F_{y'} = 0: \quad N_1 - W_1 \cos 15^\circ = 0, \quad N_1 = W_1 \cos 15^\circ = 189.515 \text{ N}$$

$$F_1 = \mu_s N_1 = (0.40)W_1 \cos 15^\circ = 0.38637W_1$$

$$F_1 = 75.806 \text{ N} \leftarrow$$

FBD bottom block:



$$\rightarrow \Sigma F_{x'} = 0: \quad T - F_1 - W_1 \sin 15^\circ = 0$$

$$T = 75.806 \text{ N} + 50.780 \text{ N} = 126.586 \text{ N}$$

$$W_2 = (30 \text{ kg})(9.81 \text{ m/s}^2) = 294.3 \text{ N}$$

$$\uparrow \Sigma F_y = 0: \quad N_2 - (189.515 \text{ N}) \cos(15^\circ) - 294.3 \text{ N} + (75.806 \text{ N}) \sin 15^\circ = 0$$

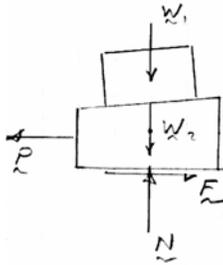
$$N_2 = 457.74 \text{ N} \uparrow$$

$$F_2 = \mu_s N_2 = (0.40)(457.74 \text{ N}) = 183.096 \text{ N}$$

$$\rightarrow \Sigma F_x = 0: \quad -P + (189.515 \text{ N}) + (75.806 \text{ N}) \cos 15^\circ + 126.586 \text{ N} + 183.096 \text{ N} = 0$$

$$P = 361 \text{ N} \leftarrow \blacktriangleleft$$

FBD block:



(b) Without cable, blocks remain together

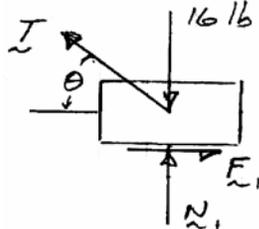
$$\uparrow \Sigma F_y = 0: \quad N - W_1 - W_2 = 0 \quad N = 196.2 \text{ N} + 294.3 \text{ N} = 490.5 \text{ N}$$

$$F = \mu_s N = (0.40)(490.5 \text{ N}) = 196.2 \text{ N}$$

$$\rightarrow \Sigma F_x = 0: \quad -P + 196.2 \text{ N} = 0$$

$$P = 196.2 \text{ N} \leftarrow \blacktriangleleft$$

Chapter 8, Solution 13.

FBD A:


Note that slip must impend at both surfaces simultaneously.

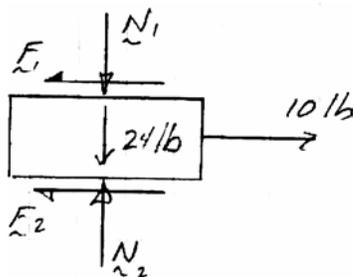
$$\uparrow \Sigma F_y = 0: \quad N_1 + T \sin \theta - 16 \text{ lb} = 0$$

$$N_1 = 16 \text{ lb} - T \sin \theta$$

Impending slip: $F_1 = \mu_s N_1 = (0.20)(16 \text{ lb} - T \sin \theta)$

$$F_1 = 3.2 \text{ lb} - (0.2)T \sin \theta \quad (1)$$

$$\rightarrow \Sigma F_x = 0: \quad F_1 - T \cos \theta = 0 \quad (2)$$

FBD B:


$$\uparrow \Sigma F_y = 0: \quad N_2 - N_1 - 24 \text{ lb} = 0, \quad N_2 = N_1 + 24 \text{ lb}$$

$$= 30 \text{ lb} - T \sin \theta$$

Impending slip: $F_2 = \mu_s N_2 = (0.20)(30 \text{ lb} - T \sin \theta)$

$$= 6 \text{ lb} - 0.2T \sin \theta$$

$$\rightarrow \Sigma F_x = 0: \quad 10 \text{ lb} - F_1 - F_2 = 0$$

$$10 \text{ lb} = \mu_s (N_1 + N_2) = (0.2)[N_1 + (N_1 + 24 \text{ lb})]$$

$$10 \text{ lb} = 0.4 N_1 + 4.8 \text{ lb}, \quad N_1 = 13 \text{ lb}$$

Then $F_1 = \mu_s N_1 = (0.2)(13 \text{ lb}) = 2.6 \text{ lb}$

Then (1): $T \sin \theta = 3.0 \text{ lb}$

(2): $T \cos \theta = 2.6 \text{ lb}$

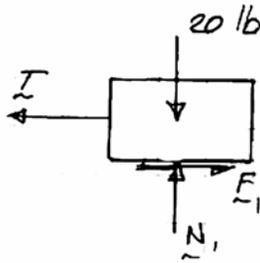
Dividing $\tan \theta = \frac{3}{2.6}, \quad \theta = \tan^{-1} \frac{3}{2.6} = 49.1^\circ$

$$\theta = 49.1^\circ \blacktriangleleft$$

Chapter 8, Solution 14.

FBD's:

A:



Note: Slip must impend at both surfaces simultaneously.

$$\uparrow \Sigma F_y = 0: \quad N_1 - 20 \text{ lb} = 0, \quad N_1 = 20 \text{ lb}$$

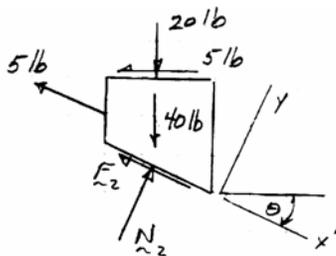
Impending slip: $F_1 = \mu_s N_1 = (0.25)(20 \text{ lb}) = 5 \text{ lb}$

$$\rightarrow \Sigma F_x = 0: \quad -T + 5 \text{ lb} = 0, \quad T = 5 \text{ lb}$$

$$\nearrow \Sigma F_{y'} = 0: \quad N_2 - (20 \text{ lb} + 40 \text{ lb}) \cos \theta - (5 \text{ lb}) \sin \theta = 0$$

$$N_2 = (60 \text{ lb}) \cos \theta - (5 \text{ lb}) \sin \theta$$

B:



Impending slip: $F_2 = \mu_s N_2 = (0.25)(60 \cos \theta - 5 \sin \theta) \text{ lb}$

$$\searrow \Sigma F_{x'} = 0: \quad -F_2 - 5 \text{ lb} - (5 \text{ lb}) \cos \theta + (20 \text{ lb} + 40 \text{ lb}) \sin \theta = 0$$

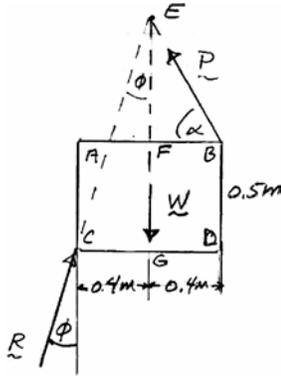
$$-20 \cos \theta + 58.75 \sin \theta - 5 = 0$$

Solving numerically,

$$\theta = 23.4^\circ \blacktriangleleft$$

Chapter 8, Solution 15.

FBD:



For impending tip the floor reaction is at C.

$$W = (40 \text{ kg})(9.81 \text{ m/s}^2) = 392.4 \text{ N}$$

For impending slip $\phi = \phi_s = \tan^{-1} \mu_s = \tan^{-1}(0.35)$

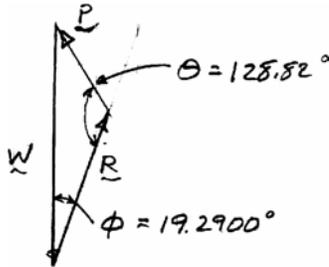
$$\phi = 19.2900^\circ$$

$$\tan \phi = \frac{0.8 \text{ m}}{EG}, \quad \overline{EG} = \frac{0.4 \text{ m}}{0.35} = 1.14286 \text{ m}$$

$$\overline{EF} = \overline{EG} - 0.5 \text{ m} = 0.64286 \text{ m}$$

$$(a) \quad \alpha_s = \tan^{-1} \frac{\overline{EF}}{0.4 \text{ m}} = \tan^{-1} \frac{0.64286 \text{ m}}{0.4 \text{ m}} = 58.109^\circ$$

$$\alpha_s = 58.1^\circ \blacktriangleleft$$



$$(b) \quad \frac{P}{\sin 19.29^\circ} = \frac{W}{\sin 128.82^\circ}$$

$$P = (392.4 \text{ N})(0.424) = 166.379 \text{ N}$$

$$P = 166.4 \text{ N} \blacktriangleleft$$

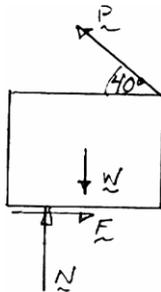
Once slipping begins, ϕ will reduce to $\phi_k = \tan^{-1} \mu_k$.

Then α_{\max} will increase.

Chapter 8, Solution 16.

First assume slip impends without tipping, so $F = \mu_s N$

FBD



$$\uparrow \Sigma F_y = 0: \quad N + P \sin 40^\circ - W = 0, \quad N = W - P \sin 40^\circ$$

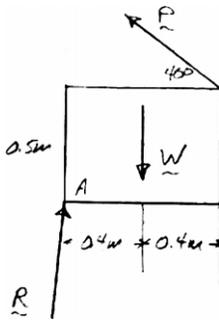
$$F = \mu_s N = 0.35(W - P \sin 40^\circ)$$

$$\rightarrow \Sigma F_x = 0: \quad F - P \cos 40^\circ = 0$$

$$0.35W = P(\cos 40^\circ + 0.35 \sin 40^\circ)$$

$$P_s = 0.35317W \quad (1)$$

Next assume tip impends without slipping, \mathbf{R} acts at C .



$$\curvearrowleft \Sigma M_A = 0: \quad (0.8 \text{ m})P \sin 40^\circ + (0.5 \text{ m})P \cos 40^\circ - (0.4 \text{ m})W = 0$$

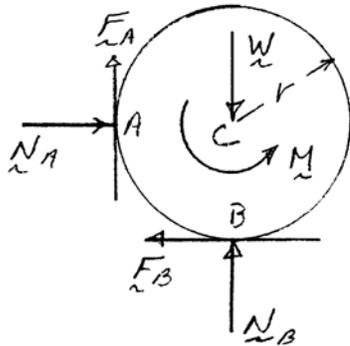
$$P_t = 0.4458W > P_s \text{ from (1)}$$

$$\begin{aligned} \therefore P_{\max} &= P_s = 0.35317(40 \text{ kg})(9.81 \text{ m/s}^2) \\ &= 138.584 \text{ N} \end{aligned}$$

$$(a) \quad P_{\max} = 138.6 \text{ N} \quad \blacktriangleleft$$

$$(b) \quad \text{Slip is impending} \quad \blacktriangleleft$$

Chapter 8, Solution 17.

FBD Cylinder:

 For maximum M , motion impends at both A and B

$$F_A = \mu_A N_A; \quad F_B = \mu_B N_B$$

$$\rightarrow \Sigma F_x = 0: \quad N_A - F_B = 0 \quad N_A = F_B = \mu_B N_B$$

$$F_A = \mu_A N_A = \mu_A \mu_B N_B$$

$$\uparrow \Sigma F_y = 0: \quad N_B + F_A - W = 0 \quad N_B(1 + \mu_A \mu_B) = W$$

or

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

and

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

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

$$\left(\Sigma M_C = 0: \quad M - r(F_A + F_B) = 0 \quad M = Wr \mu_B \frac{1 + \mu_A}{1 + \mu_A \mu_B} \right.$$

$$(a) \text{ For } \quad \mu_A = 0 \quad \text{and} \quad \mu_B = 0.36$$

$$M = 0.360Wr \blacktriangleleft$$

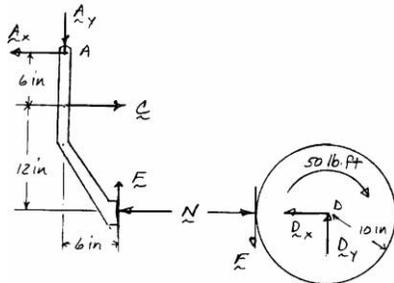
$$(b) \text{ For } \quad \mu_A = 0.30 \quad \text{and} \quad \mu_B = 0.36$$

$$M = 0.422Wr \blacktriangleleft$$

Chapter 8, Solution 18.

FBD's:

(a)



FBD Drum:

$$\curvearrowleft \Sigma M_D = 0: \quad \left(\frac{10}{12}\text{ft}\right)F - 50 \text{ lb}\cdot\text{ft} = 0$$

$$F = 60 \text{ lb}$$

$$\text{Impending slip: } N = \frac{F}{\mu_s} = \frac{60 \text{ lb}}{0.40} = 150 \text{ lb}$$

FBD arm:

$$\curvearrowleft \Sigma M_A = 0: \quad (6 \text{ in.})C + (6 \text{ in.})F - (18 \text{ in.})N = 0$$

$$C = -60 \text{ lb} + 3(150 \text{ lb}) = 390 \text{ lb}$$

$$C_{\text{cw}} = 390 \text{ lb} \blacktriangleleft$$

(b) Reversing the 50 lb·ft couple reverses the direction of F , but the magnitudes of F and N are not changed.

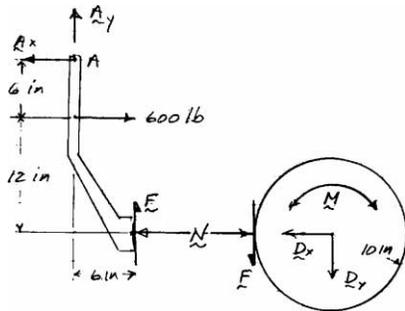
$$\text{Then, using the FBD arm: } \curvearrowleft \Sigma M_A = 0: \quad (6 \text{ in.})C - (6 \text{ in.})F - (18 \text{ in.})N = 0$$

$$C = 60 \text{ lb} + 3(150 \text{ lb}) = 510 \text{ lb}$$

$$C_{\text{ccw}} = 510 \text{ lb} \blacktriangleleft$$

Chapter 8, Solution 19.

FBD's:



For slipping, $F = \mu_k N = 0.30 N$

(a) For cw rotation of drum, the friction force F is as shown.

From *FBD* arm:

$$\left(\sum M_A = 0: \quad (6 \text{ in.})(600 \text{ lb}) + (6 \text{ in.})F - (18 \text{ in.})N = 0 \right.$$

$$600 \text{ lb} + F - 3 \frac{F}{0.30} = 0$$

$$F = \frac{600}{9} \text{ lb}$$

Moment about $D = (10 \text{ in.})F = 666.67 \text{ lb}\cdot\text{in.}$

$$\mathbf{M}_{\text{cw}} = 55.6 \text{ lb}\cdot\text{ft} \quad \blacktriangleleft$$

(b) For ccw rotation of drum, the friction force F is reversed

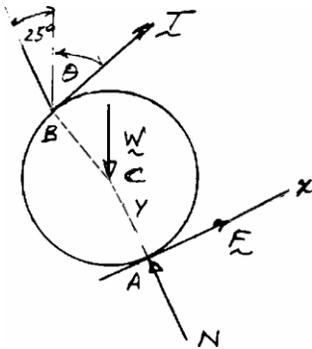
$$\left(\sum M_A = 0: \quad (6 \text{ in.})(600 \text{ lb}) - (6 \text{ in.})F - (18 \text{ in.})N = 0 \right.$$

$$600 \text{ lb} - F - 3 \frac{F}{0.30} = 0$$

$$F = \frac{600}{11} \text{ lb}$$

$$\text{Moment about } D = \left(\frac{10}{12} \text{ ft} \right) \left(\frac{600}{11} \text{ lb} \right) = 45.45 \text{ lb}\cdot\text{ft}$$

$$\mathbf{M}_{\text{ccw}} = 45.5 \text{ lb}\cdot\text{ft} \quad \blacktriangleleft$$

Chapter 8, Solution 20.
FBD:


$$(a) \quad \curvearrowleft \Sigma M_C = 0: \quad r(F - T) = 0, \quad T = F$$

$$\text{Impending slip: } F = \mu_s N \quad \text{or} \quad N = \frac{F}{\mu_s} = \frac{T}{\mu_s}$$

$$\nearrow \Sigma F_x = 0: \quad F + T \cos(25^\circ + \theta) - W \sin 25^\circ = 0$$

$$T[1 + \cos(25^\circ + \theta)] = W \sin 25^\circ \quad (1)$$

$$\nwarrow \Sigma F_y = 0: \quad N - W \cos 25^\circ + T \sin(25^\circ + \theta) = 0$$

$$T \left[\frac{1}{0.35} + \sin(25^\circ + \theta) \right] = W \cos 25^\circ \quad (2)$$

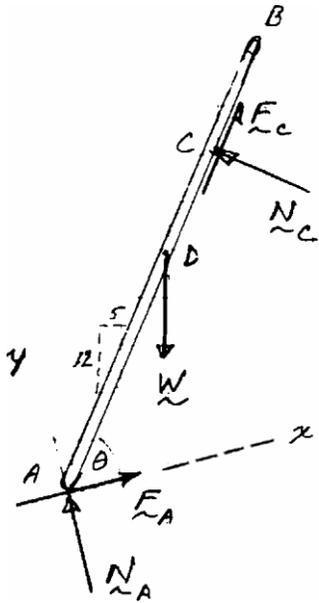
$$\text{Dividing (1) by (2):} \quad \frac{1 + \cos(25^\circ + \theta)}{\frac{1}{0.35} + \sin(25^\circ + \theta)} = \tan 25^\circ$$

$$\text{Solving numerically, } 25^\circ + \theta = 42.53^\circ$$

$$\theta = 17.53^\circ \quad \blacktriangleleft$$

$$(b) \text{ From (1) } T(1 + \cos 42.53^\circ) = W \sin 25^\circ$$

$$T = 0.252W \quad \blacktriangleleft$$

Chapter 8, Solution 21.
FBD ladder:


Note: slope of ladder $= \frac{4.5 \text{ m}}{1.875 \text{ m}} = \frac{12}{5}$, so $\overline{AC} = (4.5 \text{ m}) \frac{13}{12} = 4.875$

$$L = 6.5 \text{ m, so } \overline{AC} = \frac{4.875 \text{ m}}{6.5 \text{ m}} = \frac{3}{4}L, \quad \overline{AD} = \frac{1}{2}L$$

$$\text{and } \overline{DC} = \overline{BD} = \frac{1}{4}L$$

For impending slip: $F_A = \mu_s N_A$, $F_C = \mu_s N_C$

Also $\theta = \tan^{-1}\left(\frac{12}{5}\right) - 15^\circ = 52.380^\circ$

$$\nearrow \Sigma F_x = 0: \quad F_A - W \sin 15^\circ + F_C \cos \theta - N_C \sin \theta = 0$$

$$F_A = W \sin 15^\circ - \mu_s \frac{10}{39} W \cos \theta + \frac{10}{39} W \sin \theta$$

$$= (0.46192 - 0.15652\mu_s)W$$

$$\uparrow \Sigma F_y = 0: \quad N_A - W \cos 15^\circ + F_C \sin \theta + N_C \cos \theta = 0$$

$$N_A = W \cos 15^\circ - \mu_s \frac{10}{39} W \sin \theta - \frac{10}{39} W \cos \theta$$

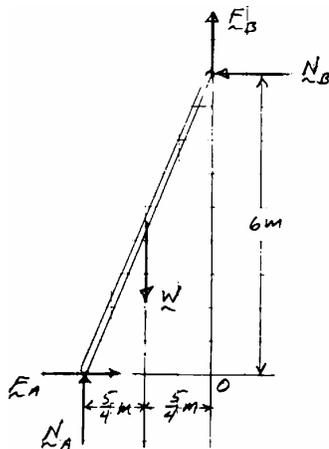
$$= (0.80941 - 0.20310\mu_s)W$$

But $F_A = \mu N_A$: $0.46192 - 0.15652\mu_s = 0.80941\mu_s - 0.20310\mu_s^2$

$$\mu_s^2 - 4.7559\mu_s + 2.2743$$

$$\mu_s = 0.539, 4.2166$$

$$\mu_{s \text{ min}} = 0.539 \blacktriangleleft$$

Chapter 8, Solution 22.
FBD ladder:

 Slip impends at both A and B , $F_A = \mu_s N_A$, $F_B = \mu_s N_B$

$$\nearrow \Sigma F_x = 0: \quad F_A - N_B = 0, \quad N_B = F_A = \mu_s N_A$$

$$\uparrow \Sigma F_y = 0: \quad N_A - W + F_B = 0, \quad N_A + F_B = W$$

$$N_A + \mu_s N_B = W$$

$$N_A(1 + \mu_s^2) = W$$

$$\curvearrowleft \Sigma M_O = 0: \quad (6 \text{ m})N_B + \left(\frac{5}{4} \text{ m}\right)W - \left(\frac{5}{2} \text{ m}\right)N_A = 0$$

$$6\mu_s N_A + \frac{5}{4} N_A(1 + \mu_s^2) - \frac{5}{2} N_A = 0$$

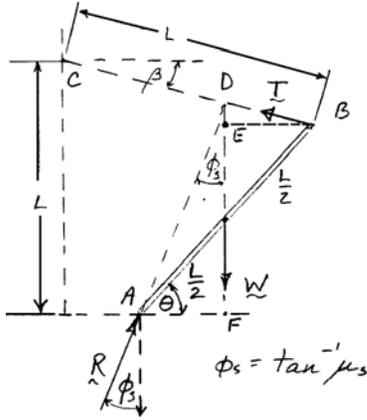
$$\mu_s^2 + \frac{24}{5} \mu_s - 1 = 0$$

$$\mu_s = -2.4 \pm 2.6$$

$$\mu_{s \min} = 0.200 \blacktriangleleft$$

Chapter 8, Solution 23.

FBD rod:



(a) Geometry: $BE = \frac{L}{2} \cos \theta$ $DE = \left(\frac{L}{2} \cos \theta \right) \tan \beta$

$EF = L \sin \theta$ $DF = \frac{L \cos \theta}{2 \tan \phi_s}$

So $L \left(\frac{1}{2} \cos \theta \tan \beta + \sin \theta \right) = \frac{L \cos \theta}{2 \tan \phi_s}$

or $\tan \beta + 2 \tan \theta = \frac{1}{\tan \phi_s} = \frac{1}{\mu_s} = \frac{1}{0.4} = 2.5$ (1)

Also, $L \sin \theta + L \sin \beta = L$

or $\sin \theta + \sin \beta = 1$ (2)

Solving Eqs. (1) and (2) numerically $\theta_1 = 4.62^\circ$ $\beta_1 = 66.85^\circ$

$\theta_2 = 48.20^\circ$ $\beta_2 = 14.75^\circ$

Therefore, $\theta = 4.62^\circ$ and $\theta = 48.2^\circ$ ◀

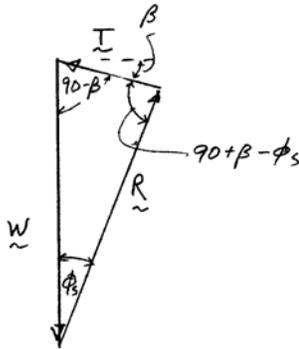
(b) Now $\phi_s = \tan^{-1} \mu_s = \tan^{-1} 0.4 = 21.801^\circ$

and $\frac{T}{\sin \phi_s} = \frac{W}{\sin(90 + \beta - \phi_s)}$

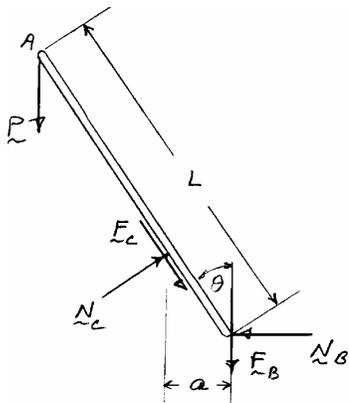
or $T = W \frac{\sin \phi_s}{\sin(90 + \beta - \phi_s)}$

For $\theta = 4.62^\circ$ $T = 0.526W$ ◀

$\theta = 48.2^\circ$ $T = 0.374W$ ◀



Chapter 8, Solution 24.

FBD:

 Assume the weight of the slender rod is negligible compared to P .

 First consider impending slip upward at B . The friction forces will be directed as shown and $F_{B,C} = \mu_s N_{B,C}$

$$\left(\sum M_B = 0: \quad (L \sin \theta)P - \left(\frac{a}{\sin \theta} \right) N_C = 0 \right.$$

$$N_C = P \frac{L}{a} \sin^2 \theta$$

$$\rightarrow \sum F_x = 0: \quad N_C \sin \theta + F_C \cos \theta - N_B = 0$$

$$N_C (\sin \theta + \mu_s \cos \theta) = N_B$$

$$\text{so} \quad N_B = P \frac{L}{a} \sin^2 \theta (\sin \theta + \mu_s \cos \theta)$$

$$\uparrow \sum F_y = 0: \quad -P + N_C \cos \theta - F_C \sin \theta - F_B = 0$$

$$P = N_C \cos \theta - \mu_s N_C \sin \theta - \mu_s N_B$$

$$\text{so } P = P \frac{L}{a} \sin^2 \theta (\cos \theta - \mu_s \sin \theta) - \mu_s P \frac{L}{a} \sin^2 \theta (\sin \theta + \mu_s \cos \theta) \quad (1)$$

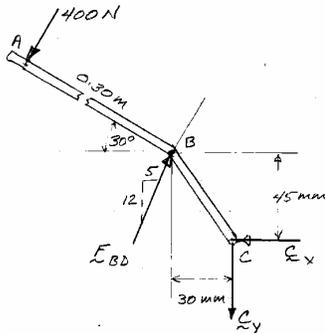
 Using $\theta = 35^\circ$ and $\mu_s = 0.20$, solve for $\frac{L}{a} = 13.63$.

 To consider impending slip downward at B , the friction forces will be reversed. This can be accomplished by substituting $\mu_s = -0.20$ in equation (1). Then solve for $\frac{L}{a} = 3.46$.

 Thus, equilibrium is maintained for $3.46 \leq \frac{L}{a} \leq 13.63 \blacktriangleleft$

Chapter 8, Solution 25.

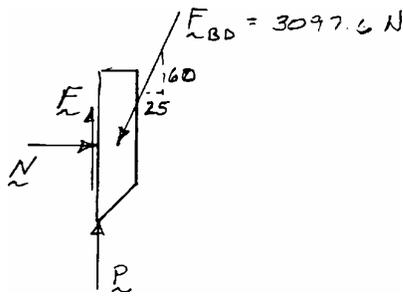
FBD ABC:



$$\begin{aligned} \sum M_C = 0: & \quad [0.045 \text{ m} + (0.30 \text{ m})\sin 30^\circ][(400 \text{ N})\sin 30^\circ] \\ & \quad + [0.030 \text{ m} + (0.30 \text{ m})\cos 30^\circ][(400 \text{ N})\cos 30^\circ] \\ & \quad - (0.03 \text{ m})\left(\frac{12}{13}F_{BD}\right) - (0.045 \text{ m})\left(\frac{5}{13}F_{BD}\right) = 0 \end{aligned}$$

$$F_{BD} = 3097.64 \text{ N}$$

FBD Blade:



$$\rightarrow \sum F_x = 0: \quad N - \frac{25}{65}(3097.6 \text{ N}) = 0 \quad N = 1191.4$$

$$F = \mu_s N = 0.20(1191.4 \text{ N}) = 238.3 \text{ N}$$

$$\uparrow \sum F_y = 0: \quad P + F - \frac{60}{65}(3097.6 \text{ N}) = 0$$

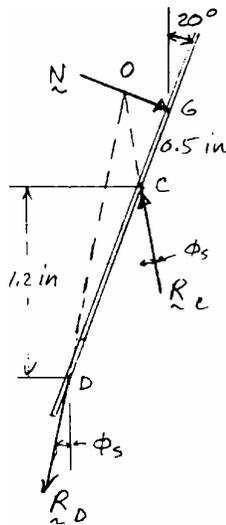
$$P = 2859.3 - 238.3 = 2621.0 \text{ N}$$

Force by blade

$$\mathbf{P = 2620 \text{ N} \downarrow \blacktriangleleft}$$

Chapter 8, Solution 26.

FBD CD:



Note: The plate is a 3-force member, and for minimum μ_s , slip impends at C and D, so the reactions there are at angle ϕ_s from the normal.

From the FBD, $\angle OCG = 20^\circ + \phi_s$

and $\angle ODG = 20^\circ - \phi_s$

Then $\overline{OG} = (0.5 \text{ in.}) \tan(20^\circ + \phi_s)$

and $\overline{OG} = \left(\frac{1.2 \text{ in.}}{\sin 70^\circ} + 0.5 \text{ in.} \right) \tan(20^\circ - \phi_s)$

Equating, $\tan(20^\circ + \phi_s) = 3.5540 \tan(20^\circ - \phi_s)$

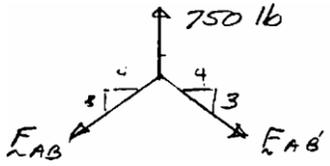
Solving numerically, $\phi_s = 10.5652^\circ$

$\mu_s = \tan \phi_s = \tan(10.5652^\circ)$

$\mu_s = 0.1865 \blacktriangleleft$

Chapter 8, Solution 27.

FBD pin A:

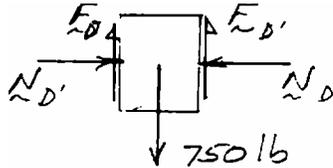


From FBD Whole the force at $A = 750 \text{ lb}$

$$\rightarrow \Sigma F_x = 0: \quad \frac{4}{5}(F_{AB'} - F_{AB}) = 0, \quad F_{AB'} = F_{AB}$$

$$\uparrow \Sigma F_y = 0: \quad 750 \text{ lb} - 2\frac{3}{5}F_{AB} = 0, \quad F_{AB} = 625 \text{ lb}$$

FBD Casting:



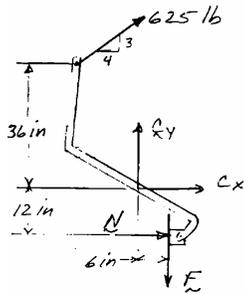
$$\rightarrow \Sigma F_x = 0: \quad N_{D'} - N_D = 0, \quad N_{D'} = N_D = N$$

Impending slip $F_D = F_{D'} = \mu N_D$, or $N_D = \frac{F_D}{\mu_s}$

$$\uparrow \Sigma F_y = 0: \quad 2F_D - 750 \text{ lb} = 0, \quad F_D = 375 \text{ lb}$$

$$N_D = \frac{375 \text{ lb}}{\mu_s}$$

FBD ABCD:



$$\curvearrowleft \Sigma M_C = 0: \quad (12 \text{ in.})N - (6 \text{ in.})F - (42.75 \text{ in.})\frac{4}{5}(625 \text{ lb}) = 0$$

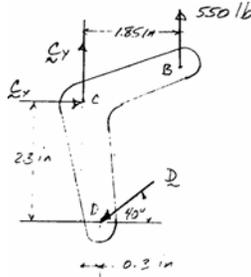
$$(12 \text{ in.})\frac{375 \text{ lb}}{\mu_s} = (6 \text{ in.})(375 \text{ lb}) + (42.75 \text{ in.})\frac{4}{5}(625 \text{ lb}) = 0$$

$$\mu_s = 0.1900 \quad \blacktriangleleft$$

Chapter 8, Solution 28.

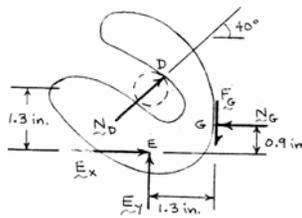
From FBD Whole, and neglecting weight of clamp compared to 550 lb plate, $\mathbf{P} = -\mathbf{W}$ Since AB is a two-force member, B is vertical and $B = W$.

FBD BCD:



$$\begin{aligned} \sum M_C = 0: & \quad (1.85 \text{ in.})W - (2.3 \text{ in.})D \cos 40^\circ \\ & \quad - (0.3 \text{ in.})D \sin 40^\circ = 0, \quad D = 0.94642W \end{aligned}$$

FBD EG:

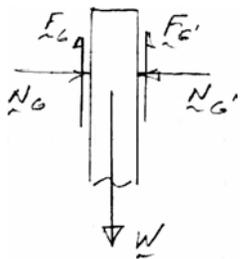


$$\sum M_E = 0: \quad (0.9 \text{ in.})N_G - (1.3 \text{ in.})F_G - (1.3 \text{ in.})N_D \cos 40^\circ = 0$$

Impending slip: $F_G = \mu_s N_G$

$$\text{Solving: } (0.9 - 1.3\mu_s)N_G = 0.94250W \quad (1)$$

FBD Plate:



By symmetry $N_G = N_{G'}$, $F_G = F_{G'} = \mu_s N_G$

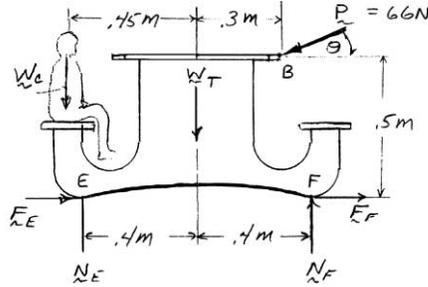
$$\uparrow \sum F_y = 0: \quad 2F_G - W = 0, \quad F_G = \frac{W}{2}, \quad N_G = \frac{W}{2\mu_s}$$

$$\text{Substitute in (1): } (0.9 - 1.3\mu_s) \frac{W}{2\mu_s} = 0.94250W$$

$$\text{Solving, } \mu_s = 0.283, \quad \mu_{sm} = 0.283 \blacktriangleleft$$

Chapter 8, Solution 29.

FBD table + child:



$$W_C = 18 \text{ kg} (9.81 \text{ m/s}^2) = 176.58 \text{ N}$$

$$W_T = 16 \text{ kg} (9.81 \text{ m/s}^2) = 156.96 \text{ N}$$

(a) Impending tipping about E, $N_F = F_F = 0$, and

$$\begin{aligned} \sum M_E = 0: & (0.05 \text{ m})(176.58 \text{ N}) - (0.4 \text{ m})(156.96 \text{ N}) + (0.5 \text{ m})P \cos \theta - (0.7 \text{ m})P \sin \theta = 0 \\ & 33 \cos \theta - 46.2 \sin \theta = 53.955 \end{aligned}$$

Solving numerically $\theta = -36.3^\circ$ and $\theta = -72.6^\circ$

Therefore

$$-72.6^\circ \leq \theta \leq -36.3^\circ \blacktriangleleft$$

Impending tipping about F is not possible

(b) For impending slip: $F_E = \mu_s N_E = 0.2 N_E$ $F_F = \mu_s N_F = 0.2 N_F$

$$\rightarrow \sum F_x = 0: F_E + F_F - P \cos \theta = 0 \quad \text{or} \quad 0.2(N_E + N_F) = (66 \text{ N}) \cos \theta$$

$$\uparrow \sum F_y = 0: N_E + N_F - 176.58 \text{ N} - 156.96 \text{ N} - P \sin \theta = 0$$

$$N_E + N_F = (66 \sin \theta + 333.54) \text{ N}$$

So $330 \cos \theta = 66 \sin \theta + 333.54$

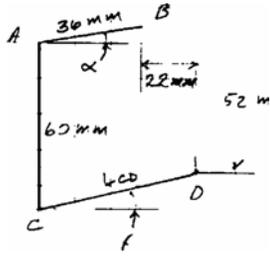
Solving numerically, $\theta = -3.66^\circ$ and $\theta = -18.96^\circ$

Therefore,

$$-18.96^\circ \leq \theta \leq -3.66^\circ \blacktriangleleft$$

Chapter 8, Solution 30.

Geometry of four-bar:



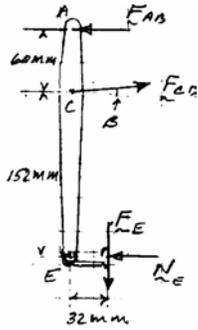
Considering the geometry when $\alpha = 0$,

$$L_{CD} = \left[(60 \text{ mm} - 52 \text{ mm})^2 + (36 \text{ mm} + 22 \text{ mm})^2 \right]^{1/2} = 58.549 \text{ mm}$$

In general, $52 \text{ mm} - (36 \text{ mm})\sin \alpha = 60 \text{ mm} - (58.549 \text{ mm})\sin \beta$

$$\text{so } \beta = \sin^{-1} \left(\frac{36 \sin \alpha + 8}{58.549} \right)$$

(a) **FBD ACE:** $\alpha = 0$ $\beta = 7.8533^\circ$, note that the links at E and K are prevented from pivoting downward by the small blocks



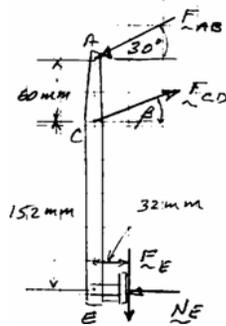
$$\uparrow \Sigma F_y = 0: \quad F_{CD} \sin \beta - F_E = 0, \quad F_{CD} = \frac{F_E}{\sin 7.8533^\circ}$$

$$\left(\Sigma M_A = 0: \quad (60 \text{ mm}) \left(\frac{F_E}{\sin 7.8533^\circ} \right) \cos 7.8533^\circ - (32 \text{ mm}) F_E - (212 \text{ mm}) N_E = 0 \right.$$

Impending slip on pad $N_E = \frac{F_E}{\mu_s}$, so

$$\left(435.00 - 32 - \frac{212}{\mu_s} \right) F_E = 0 \quad \mu_s = 0.526 \blacktriangleleft$$

(b) $\alpha = 30^\circ$, $\beta = 26.364^\circ$



$$\rightarrow \Sigma F_x = 0: \quad -\frac{\sqrt{3}}{2} F_{AB} + F_{CD} \cos 26.364^\circ - N_E = 0$$

$$\uparrow \Sigma F_y = 0: \quad -\frac{1}{2} F_{AB} + F_{CD} \sin 26.364^\circ - F_E = 0$$

$$\text{Eliminating } F_{AB}, \quad F_{CD} (0.89599 - 0.76916) - N_E + F_E = 0$$

$$\text{Impending slip } F_E = \mu_s N_E, \text{ so } 0.126834 F_E = (1 - \mu_s) N_E$$

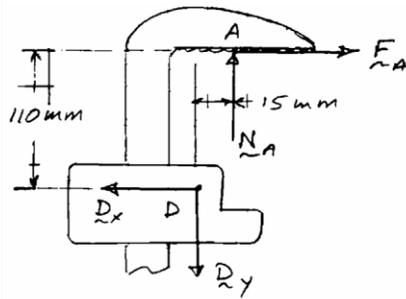
$$\left(\Sigma M_A = 0: \quad (60 \text{ mm}) F_{CD} \cos 26.364^\circ - (212 \text{ mm}) N_E - (32 \text{ mm}) \mu_s N_E = 0 \right.$$

$$53.759 F_{CD} = (212 - 32 \mu_s) N_E = 0$$

$$\frac{212 - 32 \mu_s}{1 - \mu_s} = \frac{53.759}{0.12634} \quad \mu_s = 0.277 \blacktriangleleft$$

Chapter 8, Solution 31.

FBD ABD:



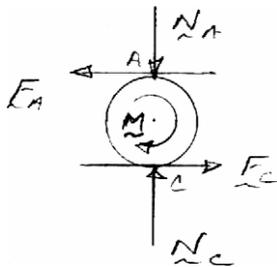
$$\left(\sum M_D = 0: (15 \text{ mm})N_A - (110 \text{ mm})F_A = 0\right)$$

Impending slip: $F_A = \mu_{SA} N_A$

So $15 - 110\mu_{SA} = 0 \quad \mu_{SA} = 0.136364$

$\mu_{SA} = 0.1364 \blacktriangleleft$

FBD Pipe:

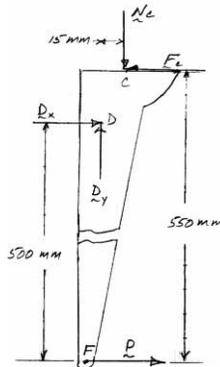


$$\rightarrow \Sigma F_x = 0: F_A - D_x = 0, D_x = F_A = \mu_{SA} N_A$$

$r = 60 \text{ mm}$

$$\uparrow \Sigma F_y = 0: N_C - N_A = 0, N_C = N_A$$

FBD DF:



$$\left(\sum M_F = 0: (550 \text{ mm})F_C - (15 \text{ mm})N_C - (500 \text{ mm})D_x = 0\right)$$

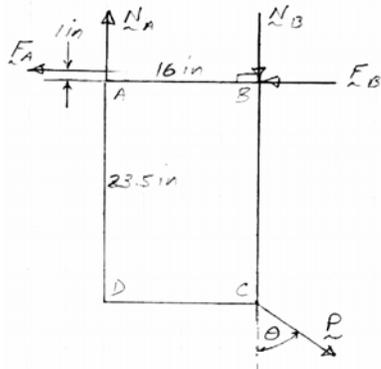
Impending slip: $F_C = \mu_{SC} N_C = \mu_{SC} N_A$

So, $550\mu_{SC} N_A - 15N_A - 500\mu_{SA} N_A = 0$

$$550\mu_{SC} = 15 + 500(0.136364)$$

$\mu_{SC} = 0.1512 \blacktriangleleft$

Chapter 8, Solution 32.

FBD Plate:


Assume reactions as shown, at ends of sleeves,

 For impending slip $F_A = \mu_s N_A$, $F_B = \mu_s N_B$

$$\rightarrow \Sigma F_x = 0: \quad P \sin \theta - \mu_s N_A - \mu_s N_B = 0$$

$$N_A + N_B = 2.5 P \sin \theta$$

$$\uparrow \Sigma F_y = 0: \quad N_A - N_B - P \cos \theta = 0, \quad N_A - N_B = P \cos \theta$$

$$\text{Solving: } N_A = \frac{P}{2}(2.5 \sin \theta + \cos \theta), \quad N_B = \frac{P}{2}(2.5 \sin \theta - \cos \theta) \quad (1)$$

$$\curvearrowleft \Sigma M_B = 0: \quad (23.5 \text{ in.})P \sin \theta - (16 \text{ in.})N_A + (1 \text{ in.})F_A = 0$$

$$(23.5 \text{ in.})P \sin \theta - [16 \text{ in.} - 0.4(1 \text{ in.})] \frac{P}{2}(2.5 \sin \theta + \cos \theta) = 0 \quad (2)$$

$$4 \sin \theta - 7.8 \cos \theta = 0, \quad \theta = 62.9^\circ$$

 For $\theta > 62.9^\circ$, the panel will be self locking, \therefore motion for $\theta \leq 62.9^\circ$.

 As θ decreases, N_B will reverse direction at $2.5 \sin \theta - \cos \theta = 0$, (see equ. 1) or at $\theta = 21.8^\circ$. So for $\theta \leq 21.8^\circ$

$$\rightarrow \Sigma F_x = 0: \quad P \sin \theta - \mu_s (N_A + N_B) = 0$$

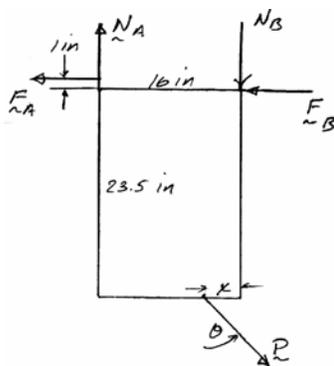
$$N_A + N_B = 2.5 P \sin \theta$$

$$\uparrow \Sigma F_y = 0: \quad N_A + N_B - P \cos \theta = 0, \quad N_A + N_B = P \cos \theta$$

$$\therefore 2.5 \sin \theta = \cos \theta, \quad \theta = 21.8^\circ$$

 So impending motion for $21.8^\circ \leq \theta \leq 62.9^\circ$ ◀

Chapter 8, Solution 33.

FBD Plate:


Assuming reactions as shown, at ends of sleeves,

 For impending slip $F_A = \mu_s N_A$, $F_B = \mu_s F_B$

$$\rightarrow \Sigma F_x = 0: \quad P \sin \theta - \mu_s (N_A + N_B) = 0$$

$$N_A + N_B = 2.5 P \sin \theta \quad (1)$$

$$\uparrow \Sigma F_y = 0: \quad N_A - N_B - P \cos \theta = 0, \quad N_A - N_B = P \cos \theta \quad (2)$$

$$\text{Solving:} \quad N_A = \frac{P}{2}(2.5 \sin \theta + \cos \theta), \quad N_B = \frac{P}{2}(2.5 \sin \theta - \cos \theta)$$

 Note that, for $\theta < 21.8^\circ$, N_B becomes negative, so we must change equ. 2 to

$$N_A + N_B = P \cos \theta, \quad (2')$$

 but equ. (1) does not change. Solving (1) and (2') gives $P \cos \theta = 2.5 P \sin \theta$, or $\theta = 21.8^\circ$, so the lower limit for impending slip is $\theta = 21.8^\circ$.

 For $\theta \geq 21.8^\circ$, the forces are as shown, and

$$\curvearrowleft \Sigma M_B = 0: \quad (23.5 \text{ in.})P \sin \theta + xP \cos \theta + (1 \text{ in.})F_A - (16 \text{ in.})N_A = 0$$

$$(23.5 \text{ in.})P \sin \theta + xP \cos \theta + [0.4(1 \text{ in.}) - (16 \text{ in.})]\frac{P}{2}(2.5 \sin \theta + \cos \theta) = 0$$

$$\text{or} \quad 4 \sin \theta - [(7.8 \text{ in.}) - x] \cos \theta = 0, \quad \tan \theta = 1.950 - \frac{x}{4 \text{ in.}}$$

 (a) For $x = 4 \text{ in.}$, $\tan \theta = 1.950$, $\theta = 43.5^\circ$. For $\theta > 43.5^\circ$ self locking

 \therefore impending motion for $21.8^\circ \leq \theta \leq 43.5^\circ \blacktriangleleft$

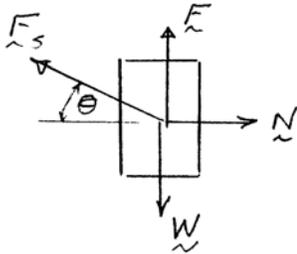
 (b) As x increases from 4 in., the upper bound for θ decreases, becoming 21.8° ($\tan \theta = 0.4000$) when $x = (4 \text{ in.})(1.950 - 0.400) = 6.2 \text{ in.}$

 Thus $x_{\max} = 6.20 \text{ in.} \blacktriangleleft$

 at which θ must equal 21.8° .

Chapter 8, Solution 34.
FBD Collar:

Impending motion down:



$$\text{Stretch of spring } x = \overline{AB} - a = \frac{a}{\cos\theta} - a$$

$$F_s = kx = k\left(\frac{a}{\cos\theta} - a\right) = (1.5 \text{ kN/m})(0.5 \text{ m})\left(\frac{1}{\cos\theta} - 1\right)$$

$$= (0.75 \text{ kN})\left(\frac{1}{\cos\theta} - 1\right)$$

$$\rightarrow \Sigma F_x = 0: \quad N - F_s \cos\theta = 0$$

$$N = F_s \cos\theta = (0.75 \text{ kN})(1 - \cos\theta)$$

$$\text{Impending slip:} \quad F = \mu_s N = (0.4)(0.75 \text{ kN})(1 - \cos\theta)$$

$$= (0.3 \text{ kN})(1 - \cos\theta)$$

+ down, - up

$$\uparrow \Sigma F_y = 0: \quad F_s \sin\theta \pm F - W = 0$$

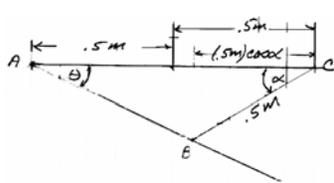
$$(0.75 \text{ kN})(\tan\theta - \sin\theta) \pm (0.3 \text{ kN})(1 - \cos\theta) - W = 0$$

$$\text{or} \quad W = (0.3 \text{ kN})[2.5(\tan\theta - \sin\theta) \pm (1 - \cos\theta)]$$

$$\text{with } \theta = 30^\circ: \quad W_{\text{up}} = 0.01782 \text{ kN} \quad (\text{OK})$$

$$W_{\text{down}} = 0.0982 \text{ kN} \quad (\text{OK})$$

 Equilibrium if $17.82 \text{ N} \leq W \leq 98.2 \text{ N} \blacktriangleleft$

Chapter 8, Solution 35.
Geometry:


$$[1 \text{ m} - (0.5 \text{ m})\cos\alpha] \tan\theta = (0.5 \text{ m})\sin\alpha$$

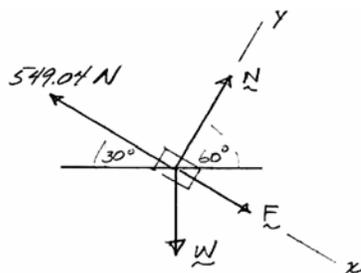
$$\tan\theta(2 - \cos\alpha) = \sin\alpha$$

$$\theta = 30^\circ \rightarrow \alpha = 60^\circ$$

$$\text{then } L_{AB} = (1 \text{ m})\cos 30^\circ = \frac{\sqrt{3}}{2} \text{ m}$$

$$F_s = k(L_{AB} - L_0) = \left(1.5 \frac{\text{kN}}{\text{m}}\right) \left(\frac{\sqrt{3}}{2} \text{ m} - \frac{1}{2} \text{ m}\right)$$

$$F_s = 0.75(\sqrt{3} - 1) \text{ kN} = 549.04 \text{ N}$$

FBD B:


$$\sum F_x = 0: \quad F + W \sin 60^\circ - 549.04 \text{ N} = 0$$

$$F = 549.04 \text{ N} - \frac{W}{2}$$

$$\sum F_y = 0: \quad N - W \cos 60^\circ = 0, \quad N = \frac{\sqrt{3}}{2} W$$

For impending slip upward, F is as shown and $F = \mu_s N$, so

$$549.04 \text{ N} - \frac{W}{2} = 0.40 \frac{\sqrt{3}}{2} W, \quad W_{\min} = 648.61 \text{ N}$$

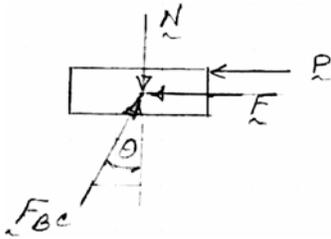
For impending slip downward, F is reversed, or $F = -\mu_s N$, so

$$549.04 \text{ N} - \frac{W}{2} = -0.40 \frac{\sqrt{3}}{2} W, \quad W_{\max} = 3575 \text{ N}$$

$$m = \frac{W}{(9.81 \text{ m/s}^2)} \quad \text{so} \quad 66.1 \text{ kg} \leq m \leq 364 \text{ kg} \blacktriangleleft$$

Chapter 8, Solution 36.

FBD Collar:



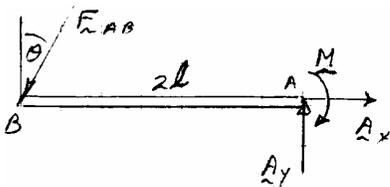
Note: BC is a two-force member, and for M_{\max} , slip will impend to the right.

$$\uparrow \Sigma F_y = 0: \quad F_{BC} \cos \theta - N = 0, \quad N = F_{BC} \cos \theta$$

Impending slip: $F = \mu_s N = \mu_s F_{BC} \cos \theta$

$$\rightarrow \Sigma F_x = 0: \quad F_{BC} \sin \theta - F - P = 0$$

FBD AB:



$$\curvearrowleft \Sigma M_A = 0: \quad M - (2l)F_{AB} \cos \theta = 0$$

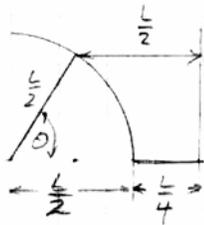
$$M = 2l \cos \theta \frac{P}{\sin \theta - \mu_s \cos \theta}$$

$$M_{\max} = \frac{2Pl}{\tan \theta - \mu_s} \blacktriangleleft$$

$$\left. \begin{array}{l} \text{For } \mu_s = \tan \theta, \quad M_{\max} = \infty \\ \text{For } \mu_s > \tan \theta, \quad M_{\max} < 0 \end{array} \right\} \text{self locking } \blacktriangleleft$$

Chapter 8, Solution 37.

Geometry:



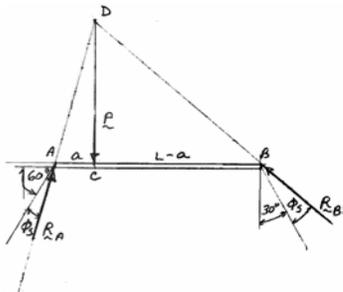
$$\theta = \cos^{-1} \frac{\frac{L}{2} + \frac{L}{4} - \frac{L}{2}}{\frac{L}{2}} = 60^\circ$$

For $\min \frac{a}{L}$ slip will impend to right and reactions will be at

$$\phi_s = \tan^{-1} \mu_s = \tan^{-1}(0.35) = 19.2900^\circ \text{ from normal.}$$

Note: AB is a three-force member

FBD AB:



$$\overline{CD} = a \tan(60 + \phi_s) = (L - a) \tan(60^\circ - \phi_s)$$

$$a \tan(79.29^\circ) = (L - a) \tan(40.71^\circ)$$

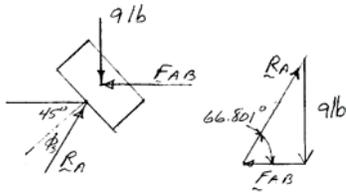
$$6.1449 = \frac{L}{a} - 1$$

$$\frac{a}{L} = 0.13996$$

$$\min \frac{a}{L} = 0.1400 \blacktriangleleft$$

Chapter 8, Solution 38.

FBD A:



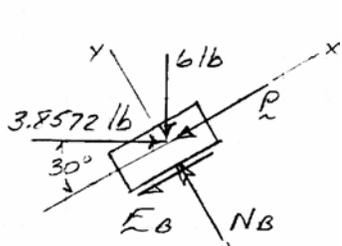
Note: Rod is a two force member. For impending slip the reactions are at angle

$$\phi_s = \tan^{-1} \mu_s = \tan^{-1}(0.40) = 21.801^\circ$$

Consider first impending slip to right

$$F_{AB} = \frac{9 \text{ lb}}{\tan 66.801} = 3.8572 \text{ lb}$$

FBD B:



$$\Sigma F_y = 0: \quad N_B - (3.8522 \text{ lb}) \sin 30^\circ - (6 \text{ lb}) \cos 30^\circ = 0$$

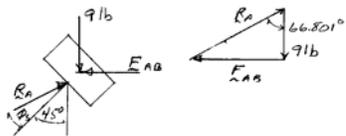
$$N_B = 7.1223 \text{ lb}, \quad F_B = \mu_s N_B = 0.40(7.1223 \text{ lb})$$

$$F_B = 2.8489 \text{ lb}$$

$$\Sigma F_x = 0: \quad -2.8489 \text{ lb} + (3.8572 \text{ lb}) \cos 30^\circ - (6 \text{ lb}) \sin 30^\circ - P = 0$$

$$P_{\min} = -2.508 \text{ lb}$$

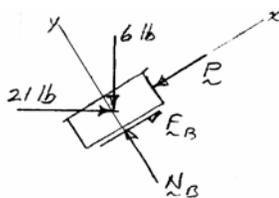
FBD A:



Next consider impending slip to left

$$F_{AB} = (9 \text{ lb}) \tan 66.801^\circ = 21.000 \text{ lb}$$

FBD B:



$$\Sigma F_y = 0: \quad N_B - (21 \text{ lb}) \sin 30^\circ - (6 \text{ lb}) \cos 30^\circ = 0, \quad N_B = 15.6959 \text{ lb}$$

$$F_B = \mu_s N_B = 0.4(15.6959 \text{ lb}) = 6.2784 \text{ lb}$$

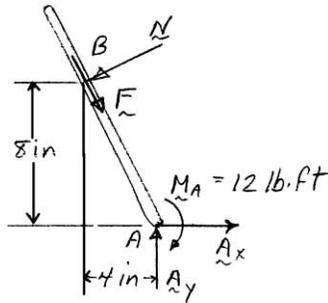
$$\Sigma F_x = 0: \quad 6.2784 \text{ lb} + (21 \text{ lb}) \cos 30^\circ - (6 \text{ lb}) \sin 30^\circ - P = 0$$

$$P_{\max} = 21.465 \text{ lb}$$

equilibrium for $-2.51 \text{ lb} \leq P \leq 21.5 \text{ lb}$ ◀

Chapter 8, Solution 39.

FBD AB:

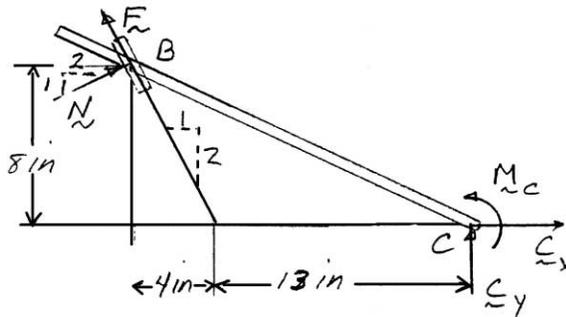


$$\begin{aligned} \left(\sum M_A = 0: \quad \sqrt{8 \text{ in}^2 + 4 \text{ in}^2} (N) - M_A = 0 \right. \\ \left. N = \frac{(12 \text{ lb} \cdot \text{ft})(12 \text{ in./ft})}{8.9443 \text{ in.}} = 16.100 \text{ lb} \right. \end{aligned}$$

Impending motion: $F = \mu_s N = 0.3(16.100 \text{ lb}) = 4.83 \text{ lb}$

Note: For max M_C , need F in direction shown; see FBD BC.

FBD BC + collar:



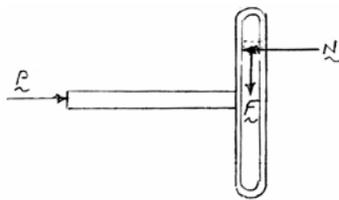
$$\left(\sum M_C = 0: \quad M_C - (17 \text{ in.}) \frac{1}{\sqrt{5}} N - (8 \text{ in.}) \frac{2}{\sqrt{5}} N - (13 \text{ in.}) \frac{2}{\sqrt{5}} F = 0 \right.$$

or
$$M_C = \frac{17 \text{ in.}}{\sqrt{5}} (16.100 \text{ lb}) + \frac{16 \text{ in.}}{\sqrt{5}} (16.100 \text{ lb}) + \frac{26 \text{ in.}}{\sqrt{5}} (4.830 \text{ lb}) = 293.77 \text{ lb} \cdot \text{in.}$$

$$(\mathbf{M}_C)_{\max} = 24.5 \text{ lb} \cdot \text{ft} \quad \blacktriangleleft$$

Chapter 8, Solution 40.

FBD yoke:



$$\rightarrow \Sigma F_x = 0: \quad P - N = 0, \quad N = P = 8 \text{ lb}$$

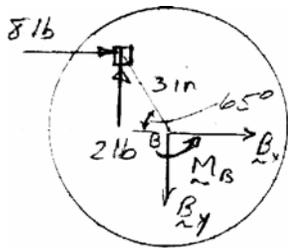
For impending slip, $F = \mu_s N = 125(8 \text{ lb})$

$$F = 2 \text{ lb}$$

For M_{\max} , F on yoke is down as shown

For M_{\min} , F on yoke is up.

FBD wheel and slider:



(a) For M_{\max} the 2 lb force is up as shown.

$$\curvearrowleft \Sigma M_B = 0: \quad M_B - [(3 \text{ in.}) \sin 65^\circ](8 \text{ lb}) - [(3 \text{ in.}) \cos 65^\circ](2 \text{ lb}) = 0$$

$$\mathbf{M}_{B_{\max}} = 24.3 \text{ lb}\cdot\text{in.} \quad \blacktriangleleft$$

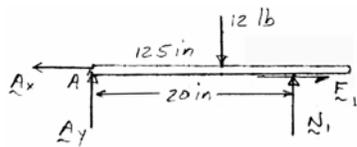
(b) For M_{\min} the 2 lb force is reversed, and

$$\curvearrowleft \Sigma M_B = 0: \quad M_B - [(3 \text{ in.}) \sin 65^\circ](8 \text{ lb}) + [(3 \text{ in.}) \cos 65^\circ](2 \text{ lb}) = 0$$

$$\mathbf{M}_{B_{\min}} = 19.22 \text{ lb}\cdot\text{in.} \quad \blacktriangleleft$$

Chapter 8, Solution 41.

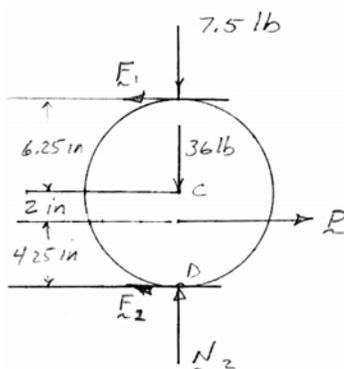
FBD Rod:



$$\left(\sum M_A = 0: \quad (20 \text{ in.})N_1 - (12.5 \text{ in.})(12 \text{ lb}) = 0 \right.$$

$$\left. N_1 = 7.5 \text{ lb.} \right.$$

FBD Cylinder:



$$\uparrow \sum F_y = 0: \quad N_2 - 7.5 \text{ lb} - 36 \text{ lb} = 0, \quad N_2 = 43.5 \text{ lb}$$

since $\mu_1 = \mu_2$ and $N_1 < N_2$, slip will impend at top of cylinder first, so $F_1 = \mu_s N_1$.

$$F_1 = 0.35(7.5 \text{ lb}) = 2.625 \text{ lb}$$

$$\left(\sum M_D = 0: \quad (4.25 \text{ in.})P - (12.5 \text{ in.})(2.625 \text{ lb}) = 0, \quad P = 7.7206 \text{ lb} \right.$$

$$\left. P_{\max} = 7.72 \text{ lb} \leftarrow \right.$$

To check slip analysis above, $\uparrow \sum F_y = 0: \quad N_2 - 36 \text{ lb} - 7.5 \text{ lb} = 0$

$$N_2 = 43.5 \text{ lb}$$

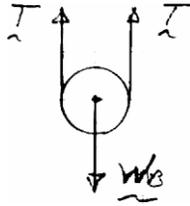
$$F_{2\max} = \mu_s N_2 = 0.35(43.5 \text{ lb}) = 15.225 \text{ lb}$$

$$\rightarrow \sum F_x = 0: \quad P - F_1 - F_2 = 0, \quad 7.72 \text{ lb} - 2.625 \text{ lb} - F_2 = 0$$

$$F_2 = 5.095 \text{ lb} < F_{\max}, \quad \text{OK}$$

Chapter 8, Solution 42.

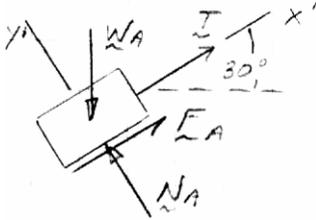
FBD pulley:



Note that $\phi_{SA} = \tan^{-1} \mu_{SA} = \tan^{-1}(0.5) = 26.565^\circ < 30^\circ$, Cable is needed to keep A from sliding downward.

$$\uparrow \Sigma F_y = 0: \quad 2T - W_B = 0, \quad T = \frac{W_B}{2}, \quad W_B = 2T \quad (1)$$

FBD block A:



(a) For minimum W_B , there will be impending slip of block A downward, and $F_A = \mu_{SA} N_A$ as shown.

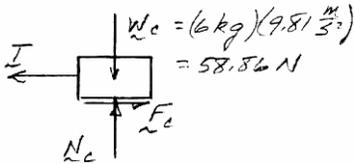
$$\nearrow \Sigma F_{y'} = 0: \quad N_A - W_A \cos 30^\circ = 0, \quad N_A = W_A \cos 30^\circ$$

$$= 23.544 \text{ N} \cos 30^\circ = 20.390 \text{ N}$$

$$W_A = (2.4 \text{ kg})(9.81 \text{ m/s}^2) = 23.544 \text{ N}$$

$$F_A = (0.50)(20.390 \text{ N}) = 10.195 \text{ N}$$

FBD block C:



$$\nearrow \Sigma F_{x'} = 0: \quad T - W_A \sin 30^\circ + F_A = 0$$

$$T = (23.544 \text{ N}) \sin 30^\circ - 10.195 \text{ N} = 1.577 \text{ N}$$

$$\text{From (1)} \quad W_B = 2T = 3.154 \text{ N}, \quad m_B = \frac{3.154 \text{ N}}{9.81 \text{ (m/s}^2\text{)}} = 0.322 \text{ kg},$$

$$m_{B\text{min}} = 322 \text{ g} \blacktriangleleft$$

$$\uparrow \Sigma F_y = 0: \quad N_C - W_C = 0, \quad N_C = 58.86 \text{ N}$$

$$F_{C\text{max}} = \mu_{SC} N_C = 0.30(58.86 \text{ N}) = 17.658 \text{ N}$$

Since $T = 1.577 \text{ N} < F_{C\text{max}}$, block B doesn't slip and above answer for $m_{B\text{min}}$ is correct.

(b) For $m_{B \max}$ assume impending slip of block C to left, $F_C = F_{\max}$

$$\rightarrow \Sigma F_x = 0: \quad -T + F_C = 0, \quad T = F_C = F_{C \max} = 17.658 \text{ N}$$

$$\text{From (1) } W_B = 2T = 35.316 \text{ N}, \quad m_B = \frac{W_B}{g} = \frac{35.316 \text{ N}}{9.81 \text{ m/s}^2} = 3.6 \text{ kg}$$

From FBD block A ,

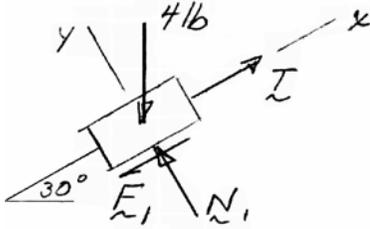
$$\rightarrow \Sigma F_x = 0: \quad T - W_A \sin 30^\circ + F_A = 0, \quad F_A = W_A \sin 30^\circ - T$$

$$F_A = (23.544 \text{ N}) \sin 30^\circ - 17.658 \text{ N} = -5.886, \quad F_{A \max} = 10.195 \text{ N}$$

Since $|F_A| < F_{A \max}$, A does not slip $M_{B \max} = 3.6 \text{ kg} \blacktriangleleft$

Chapter 8, Solution 43.

FBD A:



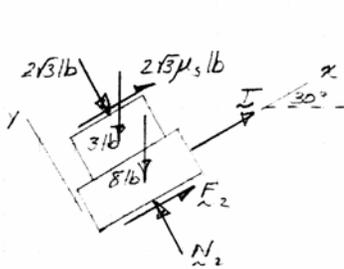
For impending motion *A* must start up and *C* down the incline. Since the normal force between *A* and *B* is less than that between *B* and *C*, and the friction coefficients are the same, F_{\max} will be reached first between *A* and *B*, and *B* and *C* will stay together.

$$\sum F_y = 0: \quad N_1 - (4 \text{ lb})\cos 30^\circ = 0, \quad N_1 = 2\sqrt{3} \text{ lb}$$

Impending slip: $F_1 = \mu_s N_1 = 2\sqrt{3}\mu_s \text{ lb}$

$$\sum F_x = 0: \quad T - (4 \text{ lb})\sin 30^\circ - 2\sqrt{3}\mu_s \text{ lb} = 0$$

FBD B and C:



$$\sum F_y = 0: \quad N_2 - 2\sqrt{3} \text{ lb} - (3 \text{ lb} + 8 \text{ lb})\cos 30^\circ = 0$$

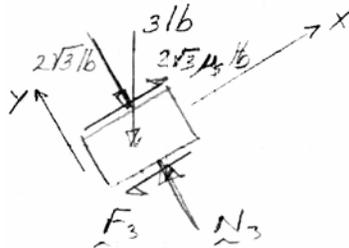
$$N_2 = \frac{15}{2}\sqrt{3} \text{ lb}$$

Impending slip: $F_2 = \mu_s N_2 = \frac{15}{2}\sqrt{3}\mu_s \text{ lb}$

$$\sum F_x = 0: \quad T + \left[\left(2\sqrt{3} + \frac{15}{2}\sqrt{3} \right) \mu_s \right] \text{ lb} - (3 + 8) \text{ lb} \sin 30^\circ = 0$$

$$T = \left(\frac{11}{2} - \frac{19}{2}\sqrt{3}\mu_s \right) \text{ lb} \tag{2}$$

FBD B:



Equating (1) and (2): $4(1 + \sqrt{3}\mu_s) \text{ lb} = 11 - 19\sqrt{3}\mu_s$

$$23\sqrt{3}\mu_s = 7, \quad \mu_{s \min} = 0.1757 \blacktriangleleft$$

To check slip reasoning above:

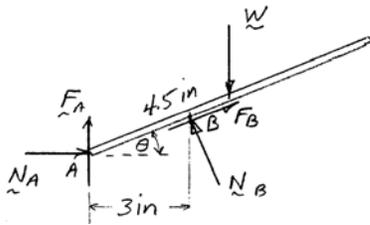
$$\sum F_y = 0: \quad N_3 - 2\sqrt{3} \text{ lb} - (3 \text{ lb})\cos 30^\circ = 0, \quad N_3 = \frac{7}{2}\sqrt{3} \text{ lb}$$

$$F_{3\max} = \mu_s N_3 = \frac{7}{2}\sqrt{3}\mu_s$$

$$\sum F_x = 0: \quad -(3 \text{ lb})\sin 30^\circ + 2\sqrt{3}\mu_s \text{ lb} - F_3 = 0$$

$$F_3 = 2\sqrt{3}(0.1757) \text{ lb} - \frac{3}{2} \text{ lb} = -0.891 \text{ lb}$$

$$|F_3| < F_{3\max}, \text{ OK}$$

Chapter 8, Solution 44.
FBD rod:


$$\left(\sum M_A = 0: \quad \frac{3 \text{ in.}}{\cos \theta} N_B - [(4.5 \text{ in.}) \cos \theta] W = 0 \right.$$

or
$$N_B = (1.5 \cos^2 \theta) W$$

Impending motion:
$$F_B = \mu_s N_B = (1.5 \mu_s \cos^2 \theta) W$$

$$= (0.3 \cos^2 \theta) W$$

$$\rightarrow \sum F_x = 0: \quad N_A - N_B \sin \theta + F_B \cos \theta = 0$$

or
$$N_A = (1.5 \cos^2 \theta) W (\sin \theta - 0.2 \cos \theta)$$

Impending motion:
$$F_A = \mu_s N_A$$

$$= (0.3 \cos^2 \theta) W (\sin \theta - 0.2 \cos \theta)$$

$$\uparrow \sum F_y = 0: \quad F_A + N_B \cos \theta + F_B \sin \theta - W = 0$$

or
$$F_A = W (1 - 1.5 \cos^3 \theta - 0.3 \cos^2 \theta \sin \theta)$$

 Equating F_A 's

$$0.3 \cos^2 \theta (\sin \theta - 0.2 \cos \theta) = 1 - 1.5 \cos^3 \theta - 0.3 \cos^2 \theta \sin \theta$$

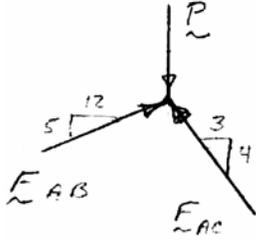
$$0.6 \cos^2 \theta \sin \theta + 1.44 \cos^3 \theta = 1$$

Solving numerically

$$\theta = 35.8^\circ \blacktriangleleft$$

Chapter 8, Solution 45.

FBD pin A:

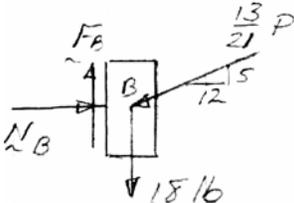


$$\rightarrow \Sigma F_x = 0: \quad \frac{12}{13}F_{AB} - \frac{3}{5}F_{AC} = 0$$

$$\uparrow \Sigma F_y = 0: \quad \frac{5}{13}F_{AB} + \frac{4}{5}F_{AC} - P = 0$$

Solving: $F_{AB} = \frac{13}{21}P, \quad F_{AC} = \frac{20}{21}P$

FBD B:



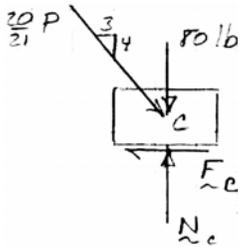
$$\rightarrow \Sigma F_x = 0: \quad N_B - \frac{12}{13} \cdot \frac{13}{21}P = 0, \quad N_B = \frac{12}{21}P$$

For P_{\min} slip of B impends down, so $F_B = \mu_s N_B = \frac{11}{20}N_B$

$$\uparrow \Sigma F_y = 0: \quad \frac{11}{20} \cdot \frac{12}{21}P - \frac{5}{13} \cdot \frac{13}{21}P - 18 \text{ lb} = 0, \quad P_{\min} = 236.25 \text{ lb}$$

(For $P < 236.25 \text{ lb}$, A will slip down)

FBD C:



$$\uparrow \Sigma F_y = 0: \quad N_C - 80 \text{ lb} - \frac{4}{5} \cdot \frac{20}{21}P = 0, \quad N_C = 80 \text{ lb} + \frac{16}{21}P$$

For P_{\max} slip of C impends to right, $F_C = \mu_s N_C$

or $F_C = \frac{11}{20} \left(80 \text{ lb} + \frac{16}{21}P \right) = 44 \text{ lb} + \frac{44}{105}P$

$$\rightarrow \Sigma F_x = 0: \quad \frac{3}{5} \cdot \frac{20}{21}P - F_C = 0, \quad \frac{12}{21}P = 44 \text{ lb} + \frac{44}{105}P$$

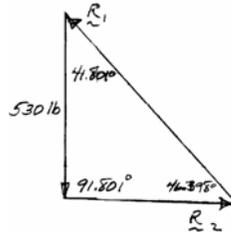
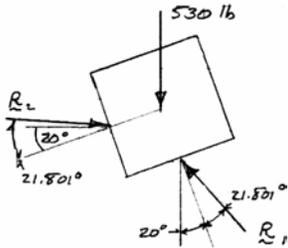
$$P_{\max} = 288.75 \text{ lb}$$

\therefore equilibrium $236 \leq P \leq 289 \blacktriangleleft$

Chapter 8, Solution 46.

$\phi_s = \tan^{-1} \mu_s = \tan^{-1}(0.4) = 21.801^\circ$, slip impends at wedge/block wedge/wedge and block/incline

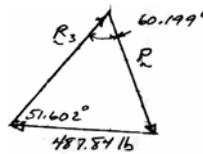
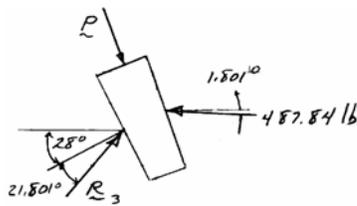
FBD Block:



$$\frac{R_2}{\sin 41.801^\circ} = \frac{530 \text{ lb}}{\sin 46.398^\circ}$$

$$R_2 = 487.84 \text{ lb}$$

FBD Wedge:



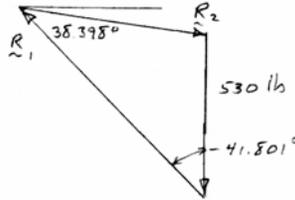
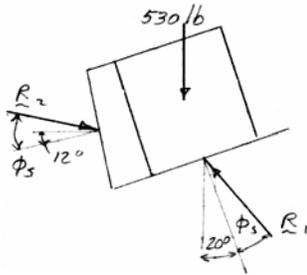
$$\frac{P}{\sin 51.602^\circ} = \frac{487.84 \text{ lb}}{\sin 60.199^\circ}$$

$$P = 441 \text{ lb} \quad \blacktriangleleft$$

Chapter 8, Solution 47.

$\phi_s = \tan^{-1} \mu_s = \tan^{-1}(0.40) = 21.801^\circ$, and slip impends at wedge/lower block, wedge/wedge, and upper block/incline interfaces.

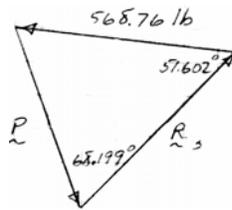
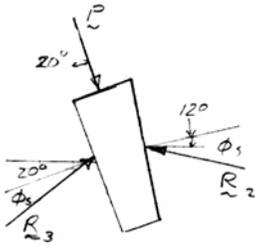
FBD Upper block and wedge:



$$\frac{R_2}{\sin 41.801^\circ} = \frac{530 \text{ lb}}{\sin 38.398^\circ}$$

$$R_2 = 568.76 \text{ lb}$$

FBD Lower wedge:



$$\frac{P}{\sin 51.602^\circ} = \frac{568.76 \text{ lb}}{\sin 68.199^\circ}$$

$P = 480 \text{ lb} \blacktriangleleft$

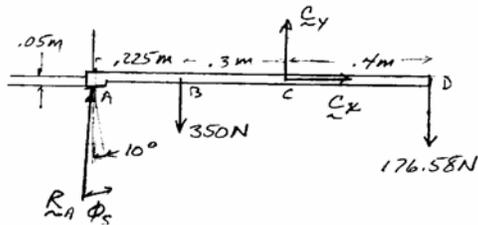
Chapter 8, Solution 48.

$$W_D = (18 \text{ kg})(9.81 \text{ m/s}^2) = 176.58 \text{ N}$$

$$F_s = kx = (3.5 \text{ kN/m})(0.1 \text{ m}) = 0.35 \text{ kN} = 350 \text{ N}$$

$$\phi_s = \tan^{-1} \mu_s = \tan^{-1}(0.25) = 14.0362^\circ$$

FBD Lever:



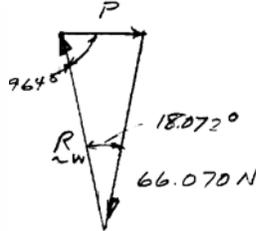
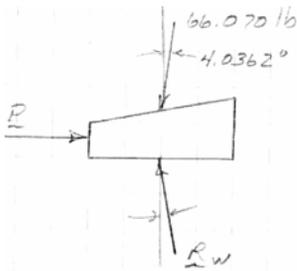
$$\begin{aligned} \sum M_C = 0: & \quad (0.3 \text{ m})(350 \text{ N}) - (0.4 \text{ m})(176.58 \text{ N}) \\ & \quad - (0.525 \text{ m})R_A \cos 4.0362^\circ \\ & \quad + (0.05 \text{ m})R_A \sin 4.0362^\circ = 0 \end{aligned}$$

$$R_A = 66.070 \text{ N}$$

$$\rightarrow \sum F_x = 0: \quad (66.07 \text{ N})\sin 4.0362^\circ + C_x = 0, \quad C_x = -4.65 \text{ N}$$

$$\uparrow \sum F_y = 0: \quad (66.07 \text{ N})\cos 4.0362^\circ - 350 \text{ N} - 176.58 \text{ N} = 0$$

FBD Wedge:



$$\frac{P}{\sin 18.072^\circ} = \frac{66.070 \text{ N}}{\sin 75.964^\circ}$$

$$P = 21.1 \text{ lb}$$

(a) $P = 21.1 \text{ lb} \leftarrow$

(b) $C_x = 4.65 \text{ N} \leftarrow$

$C_y = 461 \text{ N} \uparrow$

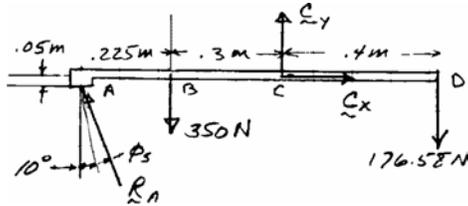
Chapter 8, Solution 49.

$$W_D = (18 \text{ kg})(9.81 \text{ m/s}^2) = 176.58 \text{ N}$$

$$F_s = kx = (3.5 \text{ kN/m})(0.1 \text{ m}) = 0.35 \text{ kN} = 350 \text{ N}$$

$$\phi_s = \tan^{-1} \mu_s = \tan^{-1}(0.25) = 14.0362^\circ$$

FBD Lever:



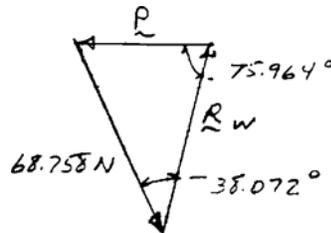
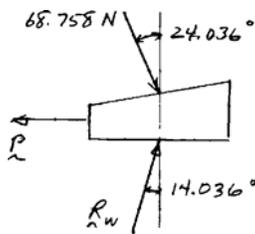
$$\begin{aligned} \sum M_C = 0: & \quad (0.3 \text{ m})(350 \text{ N}) - (0.4 \text{ m})(176.58 \text{ N}) \\ & \quad - (0.525 \text{ m})R_A \cos 24.036^\circ \\ & \quad - (0.05 \text{ m})R_A \sin 24.036^\circ = 0 \\ & \quad R_A = 68.758 \text{ N} \end{aligned}$$

$$\rightarrow \sum F_x = 0: \quad C_x - (68.758 \text{ N})\sin 24.036^\circ = 0, \quad C_x = 28.0 \text{ N}$$

$$\uparrow \sum F_y = 0: \quad C_y - 350 \text{ N} - 176.58 \text{ N} + (68.758 \text{ N})\cos 24.036^\circ = 0$$

$$C_y = 464 \text{ N}$$

FBD Wedge:



$$\frac{P}{\sin 38.072^\circ} = \frac{68.758 \text{ N}}{\sin 75.964^\circ}$$

$$(a) \quad P = 43.7 \text{ N} \quad \leftarrow$$

$$(b) \quad C_x = 28.0 \text{ N} \quad \leftarrow$$

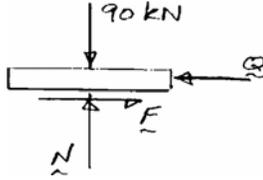
$$C_y = 464 \text{ N} \quad \uparrow$$

Chapter 8, Solution 50.

For steel/steel contact, $\phi_{s_1} = \tan^{-1} \mu_{s_1} = \tan^{-1}(0.3) = 16.6992^\circ$

For steel/concrete interface, $\phi_{s_2} = \tan^{-1} \mu_{s_2} = \tan^{-1}(0.6) = 30.964^\circ$

FBD Plate CD:

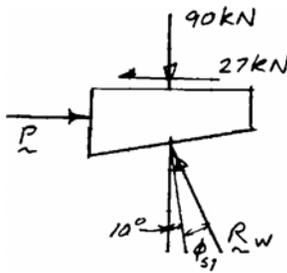


$$\uparrow \Sigma F_y = 0: \quad N - 90 \text{ kN} = 0, \quad F = 90 \text{ kN}$$

$$\text{Impending slip: } F = \mu_{s_1} N = 0.3(90 \text{ kN}) = 27 \text{ kN}$$

$$\rightarrow \Sigma F_x = 0: \quad F - Q = 0, \quad Q = F = 27 \text{ kN}$$

FBD Top wedge assuming impending slip between wedges:



$$\uparrow \Sigma F_y = 0: \quad R_w \cos 26.699^\circ - 90 \text{ kN} = 0, \quad R_w = 100.74 \text{ kN}$$

$$\rightarrow \Sigma F_x = 0: \quad P - 27 \text{ kN} - (100.74 \text{ kN}) \sin 26.699^\circ = 0$$

$$P = 72.265 \text{ kN}, \quad (a) \quad \mathbf{P} = 72.3 \text{ kN} \rightarrow \blacktriangleleft$$

$$(b) \quad \mathbf{Q} = 27.0 \text{ kN} \leftarrow \blacktriangleleft$$

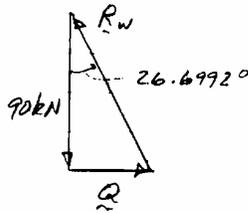
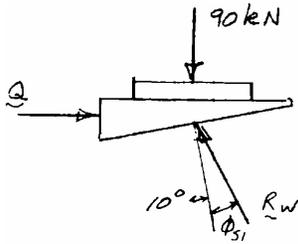
To check above assumption; note that bottom wedge is a two-force member so the reaction of the floor on that wedge is \mathbf{R}_w , at 26.699° from the vertical. This is less than $\phi_{s_2} = 30.964^\circ$, so the bottom wedge doesn't slip on the concrete.

Chapter 8, Solution 51.

For steel/steel contact, $\phi_{s1} = \tan^{-1} \mu_{s1} = \tan^{-1}(0.30) = 16.6992^\circ$

For steel/concrete contact, $\phi_{s2} = \tan^{-1} \mu_{s2} = \tan^{-1}(0.60) = 30.964^\circ$

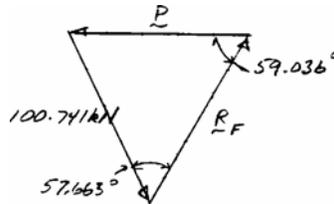
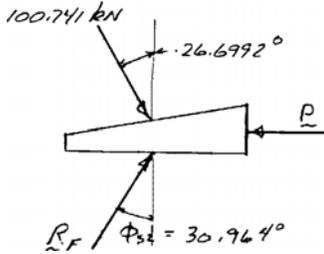
FBD Plate CD and top wedge:



$$Q = 90 \text{ kN} \tan 26.6992^\circ = 45.264 \text{ kN}$$

$$R_w = \frac{90 \text{ kN}}{\cos 26.6992^\circ} = 100.741 \text{ kN}$$

FBD Bottom wedge: slip impends at both surfaces



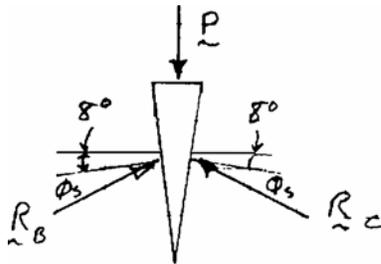
$$\frac{P}{\sin 57.663^\circ} = \frac{100.714 \text{ kN}}{\sin 59.036^\circ}$$

(a) $\mathbf{P} = 99.3 \text{ kN} \leftarrow \blacktriangleleft$

(b) $\mathbf{Q} = 45.3 \text{ kN} \rightarrow \blacktriangleright$

Chapter 8, Solution 52.

FBD Wedge:

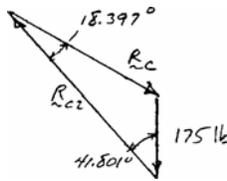
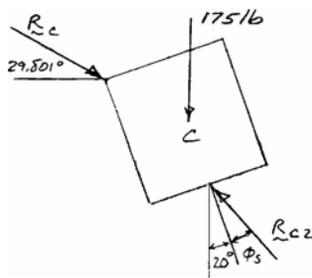


$$\phi_s = \tan^{-1} \mu_s = \tan^{-1}(0.4) = 21.801^\circ$$

By symmetry $R_B = R_C$

$$\uparrow \Sigma F_y = 0: \quad 2R_C \sin(29.801^\circ) - P = 0, \quad P = 0.9940 R_C$$

FBD Block C:



$$\frac{R_C}{\sin 41.801^\circ} = \frac{175 \text{ lb}}{\sin 18.397^\circ}, \quad P = 367.3 \text{ lb}$$

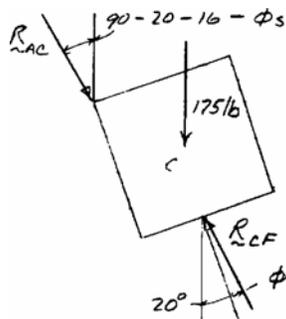
(a) $P = 367 \text{ lb} \blacktriangleleft$

b) Note: That increasing friction between B and the incline will mean that block B will not slip, but the above calculations will not change.

(b) $P = 367 \text{ lb} \blacktriangleleft$

Chapter 8, Solution 53.

FBD Block C:



$$\phi_s = \tan^{-1} \mu_s = \tan^{-1}(0.4) = 21.8014^\circ$$

$$\rightarrow \Sigma F_x = 0: \quad R_{ACx} - R_{CFx} = 0$$

$$\uparrow \Sigma F_y = 0: \quad R_{CFy} - R_{ACy} - 175 \text{ lb} = 0$$

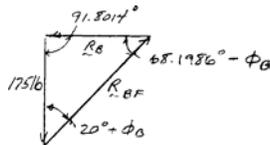
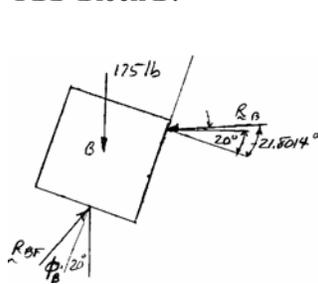
so
$$\frac{R_{CFy}}{R_{CFx}} = \frac{R_{ACy}}{R_{ACx}} = \frac{175 \text{ lb}}{R_{ACx}}$$

$$\cot(20^\circ + \phi) - \cot(32.2^\circ) > 0$$

$$\phi < 12.2^\circ < \phi_s = 21.8^\circ$$

so block C does not slip (or impend)

FBD Block B:



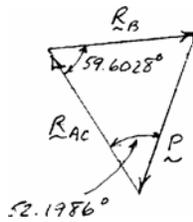
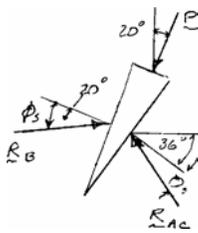
$$(a) \quad \phi_B = \tan^{-1} \mu_B = \tan^{-1}(0.4) = 21.8014^\circ$$

$$\frac{R_B}{\sin 41.8014^\circ} = \frac{175 \text{ lb}}{\sin 46.3972^\circ}, \quad R_B = 161.083 \text{ lb}$$

$$(b) \quad \phi_B = \tan^{-1} \mu_B = \tan^{-1}(0.6) = 30.9638^\circ$$

$$\frac{R_B}{\sin 50.9638^\circ} = \frac{175 \text{ lb}}{\sin 37.2330^\circ}, \quad R_B = 224.65 \text{ lb}$$

FBD Wedge:



$$\frac{P}{\sin 59.6028^\circ} = \frac{R_B}{\sin 52.1986^\circ}, \quad P = 1.09163 R_B$$

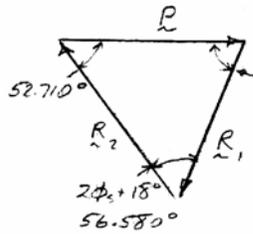
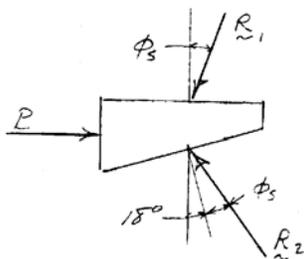
$$(a) \quad R_B = 161.083 \text{ lb}, \quad P = 175.8 \text{ lb} \quad \blacktriangleleft$$

$$(b) \quad R_B = 224.65 \text{ lb}, \quad P = 245 \text{ lb} \quad \blacktriangleleft$$

Chapter 8, Solution 54.

Since vertical forces are equal and $\mu_s \text{ ground} > \mu_s \text{ wood}$, assume no impending motion of board. Then there will be impending slip at all wood/wood contacts, $\phi_s = \tan^{-1} \mu_s = \tan^{-1}(0.35) = 19.2900^\circ$

FBD Top wedge:



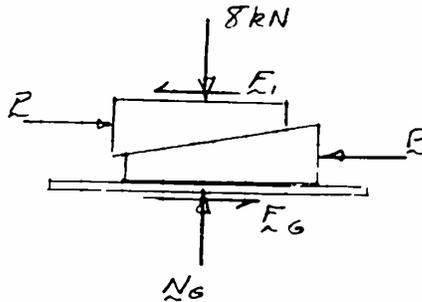
$$R_1 = \frac{8 \text{ kN}}{\cos 19.29^\circ} = 8.4758 \text{ kN}$$

$$\frac{R_1}{\sin 52.710^\circ} = \frac{P}{\cos 56.580^\circ}$$

$$P = 8.892 \text{ kN}$$

To check assumption, consider

FBD wedges + board:



$$F_1 = \mu_1 8 \text{ kN} = 0.35(8 \text{ kN}) = 2.8 \text{ kN}$$

$$\uparrow \Sigma F_y = 0: \quad N_G - 8 \text{ kN} = 0, \quad N_G = 8 \text{ kN}$$

$$F_{G \text{ max}} = \mu_G N_G = (0.6)(8 \text{ kN}) = 4.8 \text{ kN}$$

$$\rightarrow \Sigma F_x = 0: \quad F_G - F_1 = 0, \quad F_G = F_1 = 2.8 \text{ kN}$$

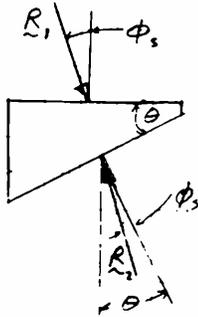
$$F_G < F_{G \text{ max}}, \quad \text{OK}$$

$$\therefore P = 8.89 \text{ kN} \blacktriangleleft$$

Chapter 8, Solution 55.

Assume no impending motion of board on ground. Then there will be impending slip at all wood/wood interfaces.

FBD Top wedge:



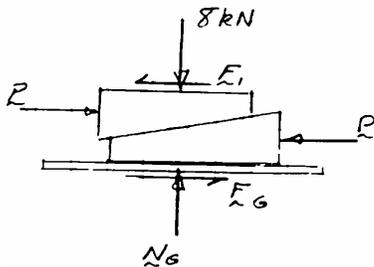
Wedge is a two-force member so $\mathbf{R}_2 = -\mathbf{R}_1$

$$\text{and } \theta = 2\phi_s = 2 \tan^{-1} \mu_s = 2 \tan^{-1}(0.35)$$

$$\theta = 38.6^\circ \blacktriangleleft$$

To check assumption, consider

FBD wedges + board:



$$F_1 = \mu_1 8 \text{ kN} = 0.35(8 \text{ kN}) = 2.8 \text{ kN}$$

$$\uparrow \Sigma F_y = 0: \quad N_G - 8 \text{ kN} = 0, \quad N_G = 8 \text{ kN}$$

$$F_{G \max} = \mu_G N_G = (0.6)(8 \text{ kN}) = 4.8 \text{ kN}$$

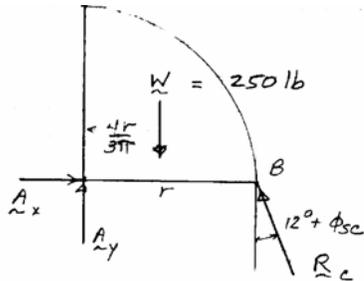
$$\rightarrow \Sigma F_x = 0: \quad F_G - F_1 = 0, \quad F_G = F_1 = 2.8 \text{ kN}$$

$$F_G < F_{G \max}, \quad \text{OK}$$

$$\therefore P = 8.89 \text{ kN} \blacktriangleleft$$

Chapter 8, Solution 56.

FBD Cylinder:



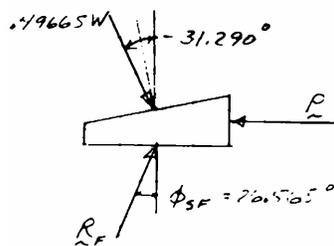
Slip impends at B

$$\phi_{SC} = \tan^{-1}(0.35) = 19.2900^\circ$$

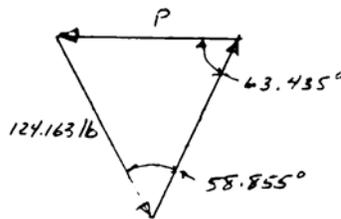
$$\left(\sum M_A = 0: \quad r R_C \cos(12^\circ + 19.29^\circ) - \frac{4r}{3\pi} W = 0 \right.$$

$$R_C = 0.49665, \quad W = 124.163 \text{ lb}$$

FBD Wedge:



$$\phi_{SF} = \tan^{-1} \mu_{SF} = \tan^{-1}(0.50) = 26.565^\circ$$

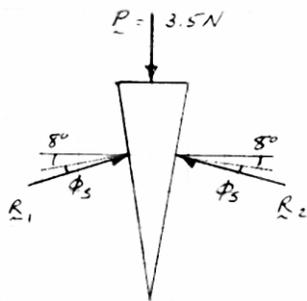


$$\frac{P}{\sin 58.855^\circ} = \frac{124.163 \text{ lb}}{\sin 63.435^\circ}$$

$$P = 117.5 \text{ lb} \quad \blacktriangleleft$$

Chapter 8, Solution 57.

FBD tip of screwdriver:



$$\phi_s = \tan^{-1} \mu_s = \tan^{-1}(0.12) = 6.8428^\circ$$

by symmetry $R_1 = R_2$

$$\uparrow \Sigma F_y = 0: \quad 2R_1 \sin(6.8428^\circ + 8^\circ) - 3.5 \text{ N} = 0$$

$$R_1 = R_2 = 6.8315 \text{ N}$$

If P is removed quickly, the vertical components of R_1 and R_2 vanish, leaving the horizontal components

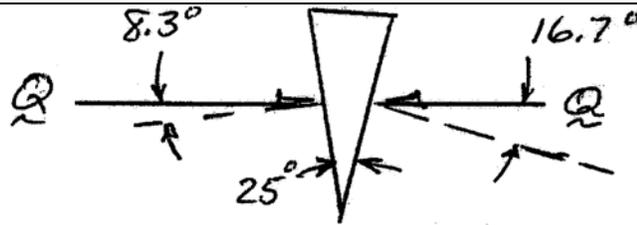
$$H_1 = H_2 = (6.8315 \text{ N}) \cos 14.8428^\circ$$

$$= 6.6035 \text{ N}$$

Side forces = 6.60 N ◀

This is only instantaneous, since $8^\circ > \phi_s$, so the screwdriver will be forced out.

Chapter 8, Solution 58.

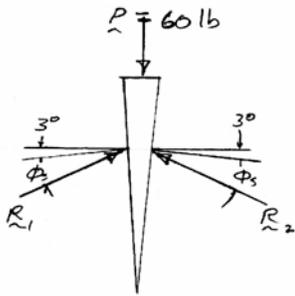


As the plates are moved, the angle θ will decrease.

- (a) $\phi_s = \tan^{-1} \mu_s = \tan^{-1} 0.2 = 11.31^\circ$. As θ decreases, the minimum angle at the contact approaches $12.5^\circ > \phi_s = 11.31^\circ$, so the wedge will slide up and out from the slot. ◀
- (b) $\phi_s = \tan^{-1} \mu_s = \tan^{-1} 0.3 = 16.70^\circ$. As θ decreases, the angle at one contact reaches 16.7° . (At this time the angle at the other contact is $25^\circ - 16.7^\circ = 8.3^\circ < \phi_s$) The wedge binds in the slot. ◀

Chapter 8, Solution 59.

FBD Wedge:



$$\phi_s = \tan^{-1} \mu_s = \tan^{-1}(0.35) = 19.2900^\circ$$

by symmetry $R_1 = R_2$

$$\uparrow \Sigma F_y = 0: \quad 2R_1 \sin 22.29^\circ - 60 \text{ lb} = 0$$

$$R_2 = 79.094 \text{ lb}$$

When \mathbf{P} is removed, the vertical component of R_1 and R_2 will vanish, leaving the horizontal components

$$H_1 = H_2 = (79.094 \text{ lb}) \cos 22.29^\circ$$

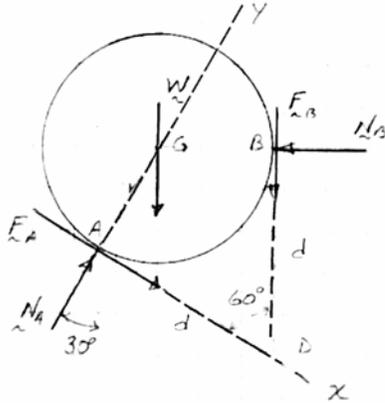
$$= 73.184 \text{ lb}$$

Final forces $H_1 = H_2 = 73.2 \text{ lb} \blacktriangleleft$

Since these are at $3^\circ (< \phi_s)$ from the normal, the wedge is self-locking and will remain in place.

Chapter 8, Solution 60.

FBD Cylinder:



$$W = (80 \text{ kg})(9.81 \text{ m/s}^2) = 784.8 \text{ N}$$

$$\left(\sum M_G = 0: F_A - F_B = 0, F_A = F_B \right) \quad (1)$$

$$\left(\sum M_D = 0: dN_B - dN_A + rW = 0, N_A = N_B + \frac{W}{\sqrt{3}} \right) \quad (2)$$

so $N_A > N_B, F_{A\max} > F_{B\max}$

\therefore slip impends first at B. $F_B = \mu_s N_B = 0.25 N_B$

$$\left(\sum M_A = 0: (r \cos 30^\circ) N_B - (r \sin 30^\circ) W - r(1 + \sin 30^\circ)(0.25 N_B) = 0 \right)$$

$$N_B = 1.01828 W = 799.15 \text{ N}$$

$$F_B = 0.25 N_B = 199.786 \text{ N}$$

From (2) above, $N_A = 799.15 \text{ N} + \frac{784.8 \text{ N}}{\sqrt{3}} = 1252.25 \text{ N}$

From (1), $F_A = F_B = 199.786 \text{ N}$

$$\nearrow \sum F_y = 0: N_C - (1252.25 \text{ N}) \cos 10^\circ + 199.786 \text{ N} \sin 10^\circ = 0$$

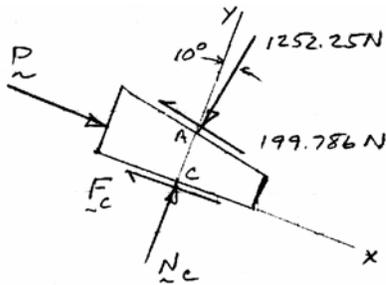
$$N_C = 1198.53 \text{ N}$$

Impending slip $F_C = \mu_s N_C = 0.25(1198.53 \text{ N}) = 299.63 \text{ N}$

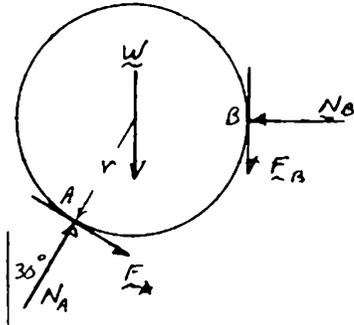
$$\searrow \sum F_x = 0: P - 299.63 \text{ N} - (199.786 \text{ N}) \cos 10^\circ - (1252.25 \text{ N}) \sin 10^\circ = 0$$

$$P = 714 \text{ N} \quad \swarrow 20.0^\circ \quad \blacktriangleleft$$

FBD Wedge:



Chapter 8, Solution 61.

FBD Cylinder:


$$W = (80 \text{ kg})(9.81 \text{ m/s}^2) = 784.8 \text{ N}$$

For impending slip at B, $F_B = \mu_{sB}N_B = 0.30N_B$

$$\begin{aligned} \left(\sum M_A = 0: \right. & \quad (r \cos 30^\circ)N_B - r(1 + \sin 30^\circ)(0.30N_B) \\ & \quad \left. - r \sin 30^\circ W = 0 \right. \end{aligned}$$

$$N_B = 1.20185W = 943.21 \text{ N}$$

$$F_B = 0.30N_B = 0.36055W$$

$$\left(\sum M_G = 0: \right. \quad r(F_A - F_B) = 0, \quad F_A = F_B = 0.36055W$$

$$\rightarrow \sum F_x = 0: \quad N_A \sin 30^\circ + F_A \cos 30^\circ - N_B = 0$$

$$N_A = \frac{-(0.36055W) \cos 30^\circ + 1.20185W}{\sin 30^\circ}$$

$$N_A = 1.77920W$$

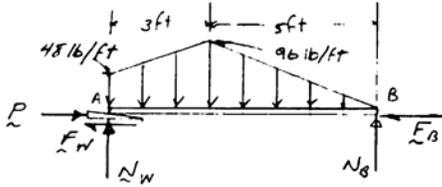
 For minimum μ_A , slip impends at A, so

$$\mu_{A \min} = \frac{F_A}{N_A} = \frac{0.36055W}{1.77920W} = 0.2026$$

$$\mu_{A \min} = 0.203 \blacktriangleleft$$

Chapter 8, Solution 62.

FBD plank + wedge:



$$\begin{aligned} \sum M_A = 0: & \quad (8 \text{ ft})N_B - (1.5 \text{ ft})(48 \text{ lb/ft})(3 \text{ ft}) \\ & \quad - (2 \text{ ft})\frac{1}{2}(48 \text{ lb/ft})(3 \text{ ft}) \\ & \quad - \left[\left(3 + \frac{5}{3} \right) \text{ft} \right] \frac{1}{2}(96 \text{ lb/ft})(5 \text{ ft}) = 0 \\ & \quad N_B = 185 \text{ lb} \end{aligned}$$

$$\begin{aligned} \uparrow \sum F_y = 0: & \quad N_W + 185 \text{ lb} - \left(\frac{48 + 96}{2} \text{ lb/ft} \right)(3 \text{ ft}) \\ & \quad + \frac{1}{2}(96 \text{ lb/ft})(5 \text{ ft}) = 0 \\ & \quad N_W = 271 \text{ lb} \end{aligned}$$

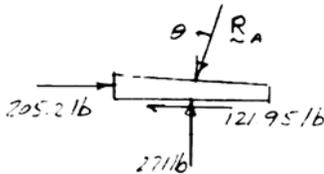
Since $N_W > N_B$, and all μ_s are equal, assume slip impends at B and between wedge and floor, and not at A .

Then $F_W = \mu_s N_W = 0.45(271 \text{ lb}) = 121.95 \text{ lb}$

$F_B = \mu_s N_B = 0.45(185 \text{ lb}) = 83.25 \text{ lb}$

$\rightarrow \sum F_x = 0: \quad P - 121.95 \text{ lb} - 83.25 \text{ lb} = 0, \quad P = 205.20 \text{ lb}$

Check Wedge for assumption



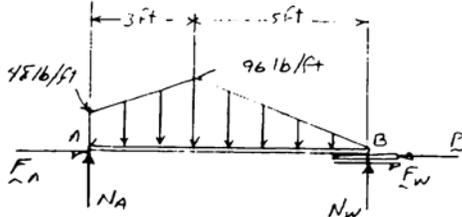
$$\begin{aligned} \uparrow \sum F_y = 0: & \quad 271 \text{ lb} - R_A \cos \theta = 0 \\ \rightarrow \sum F_x = 0: & \quad 205.2 \text{ lb} - 121.95 \text{ lb} - R_A \sin \theta = 0 \\ \text{so } \tan \theta = & \quad \frac{83.25}{271} = 0.3072 < \mu_s + \tan 9^\circ \end{aligned}$$

so no slip here

- \therefore (a) $\mathbf{P} = 205 \text{ lb} \rightarrow \blacktriangleleft$
- (b) impending slip at $B \blacktriangleleft$

Chapter 8, Solution 63.

FBD plank + wedge:



$$\begin{aligned} \sum M_A = 0: & \quad (8 \text{ ft})N_B - (1.5 \text{ ft})(48 \text{ lb/ft})(3 \text{ ft}) \\ & \quad - (2 \text{ ft})\frac{1}{2}(48 \text{ lb/ft})(3 \text{ ft}) \\ & \quad - \left[\left(3 + \frac{5}{3} \right) \text{ft} \right] (96 \text{ lb/ft})(5 \text{ ft}) = 0 \end{aligned}$$

$$N_W = 185 \text{ lb}$$

$$\begin{aligned} \uparrow \sum F_y = 0: & \quad N_A + 185 \text{ lb} - \left(\frac{48 + 96}{2} \text{ lb/ft} \right) (3 \text{ ft}) \\ & \quad - \frac{1}{2} (96 \text{ lb/ft})(5 \text{ ft}) = 0 \end{aligned}$$

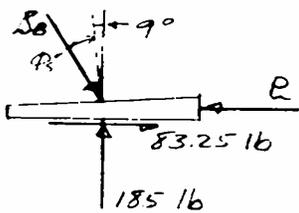
$$N_A = 271 \text{ lb}$$

Since $N_A > N_W$, and all μ_s are equal, assume impending slip at top and bottom of wedge and not at A. Then

$$F_W = \mu_s N_W = 0.45(185 \text{ N})$$

$$F_W = 83.25 \text{ lb}$$

FBD Wedge:



$$\phi_s = \tan^{-1} \mu_s = \tan^{-1}(0.45) = 24.228^\circ$$

$$\uparrow \sum F_y = 0: \quad 185 \text{ lb} - R_B \cos(24.228^\circ + 9^\circ) = 0$$

$$R_B = 221.16 \text{ lb}$$

$$\rightarrow \sum F_x = 0: \quad (221.16 \text{ lb}) \sin 33.228^\circ + 83.25 \text{ lb} - P = 0$$

$$P = 204.44 \text{ lb}$$

Check assumption using plank/wedge FBD

$$\rightarrow \sum F_x = 0: \quad F_A + F_W - P = 0, \quad F_A = 204.44 \text{ lb} - 83.25 \text{ lb} = 121.19 \text{ lb}$$

$$F_{A \max} = \mu_s N_A = 0.45(271 \text{ lb}) = 121.95 \text{ lb}$$

$$F_A < F_{A \max}, \text{ OK}$$

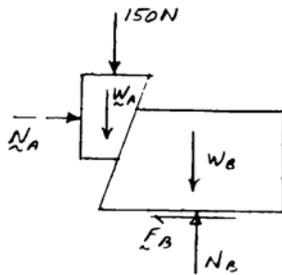
$$\therefore (a) \quad \mathbf{P = 204 \text{ lb} \rightarrow \blacktriangleleft}$$

$$(b) \quad \text{no impending slip at A} \blacktriangleleft$$

Chapter 8, Solution 64.

$$W_A = (10 \text{ kg})(9.81 \text{ m/s}^2) = 98.1 \text{ N}, \quad W_B = (50 \text{ kg})(9.81 \text{ m/s}^2) = 490.5 \text{ N}$$

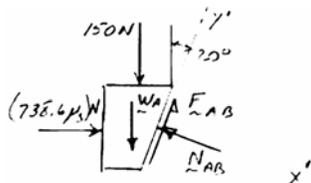
Slip must impend at all surfaces simultaneously, $F = \mu_s N$

FBD I: A + B


$$\uparrow \Sigma F_y = 0: \quad N_B - 150 \text{ N} - 98.1 \text{ N} - 490.5 \text{ N} = 0, \quad N_B = 738.6 \text{ N}$$

impending slip: $F_B = \mu_s N_B = (738.6 \text{ N})\mu_s$

$$\rightarrow \Sigma F_x = 0: \quad N_A - F_B = 0, \quad N_A = (738.6 \text{ N})\mu_s$$

FBD II: A


$$\nearrow \Sigma F_{y'} = 0: \quad F_{AB} + [(738.6\mu_s)\text{N}] \sin 20^\circ - (150 \text{ N} + 98.1 \text{ N}) \cos 20^\circ = 0$$

$$F_{AB} = [233.14 - (252.62)\mu_s]\text{N}$$

$$\searrow \Sigma F_{x'} = 0: \quad [(738.6\mu_s)\text{N}] \cos 20^\circ - (150 \text{ N} + 98.1 \text{ N}) \sin 20^\circ - N_{AB} = 0$$

$$N_{AB} = [84.855 + (694.06)\mu_s]\text{N}$$

$$\mu_s = \frac{F_{AB}}{N_{AB}} = \frac{233.14 - 252.62\mu_s}{84.855 + 694.06\mu_s}$$

$$\mu_s^2 = 0.48623\mu_s - 0.33591 = 0$$

$$\mu_s = -0.24312 \pm 0.62850$$

Positive root

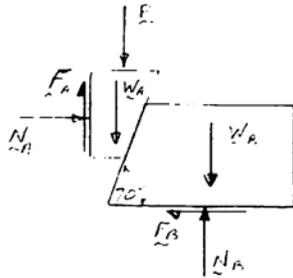
$$\mu_s = 0.385 \blacktriangleleft$$

Chapter 8, Solution 65.

$$W_A = (10 \text{ kg})(9.81 \text{ m/s}^2) = 98.1 \text{ N}, \quad W_B = (50 \text{ kg})(9.81 \text{ m/s}^2) = 490.5 \text{ N}$$

Slip impends at all surfaces simultaneously

FBD I: A + B



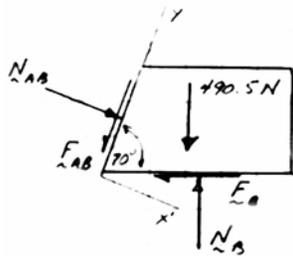
$$\rightarrow \Sigma F_x = 0: \quad N_A - F_B = 0, \quad N_A = F_B = \mu_s N_B \quad (1)$$

$$\uparrow \Sigma F_y = 0: \quad F_A - (150 \text{ N} + 98.1 \text{ N} + 490.5 \text{ N}) + N_B = 0$$

$$\mu_s N_A + N_B = 738.6 \text{ N} \quad (2)$$

$$\text{Solving (1) and (2)} \quad N_B = \frac{738.6 \text{ N}}{1 + \mu_s^2}, \quad F_B = \frac{738.6 \mu_s \text{ N}}{1 + \mu_s^2}$$

FBD II: B



$$\swarrow \Sigma F_{x'} = 0: \quad N_{AB} + (490.5 \text{ N}) \cos 70^\circ - N_B \cos 70^\circ - F_B \sin 70^\circ = 0$$

$$N_{AB} = \frac{738.6 \text{ N}}{1 + \mu_s^2} (\cos 70^\circ + \mu_s \sin 70^\circ) - (490.5 \text{ N}) \cos 70^\circ \quad (1)$$

$$\nearrow \Sigma F_{y'} = 0: \quad -F_{AB} - (490.5 \text{ N}) \sin 70^\circ + N_B \sin 70^\circ - F_B \cos 70^\circ = 0$$

$$F_{AB} = \frac{738.6 \text{ N}}{1 + \mu_s^2} (\sin 70^\circ - \mu_s \cos 70^\circ) - (490.5 \text{ N}) \sin 70^\circ = 0$$

Setting $F_{AB} = \mu_s N_{AB}$,

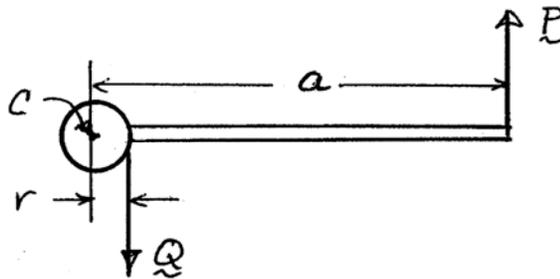
$$\mu_s^3 - 6.8847 \mu_s^2 - 2.0116 \mu_s + 1.38970 = 0$$

Solving numerically, $\mu_s = -0.586, 0.332, 7.14$

Physically meaningful solution: $\mu_s = 0.332 \blacktriangleleft$

Chapter 8, Solution 66.

FBD jack handle:



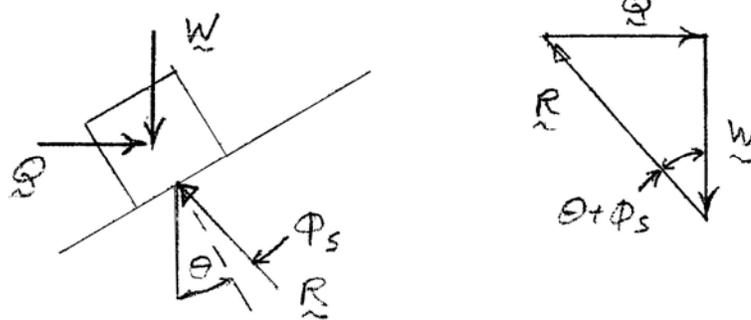
See Section 8.6

$$\left(\sum M_C = 0: \quad aP - rQ = 0 \text{ or } P = \frac{r}{a}Q \right)$$

FBD block on incline:

(a)

Raising load



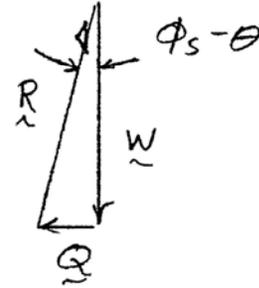
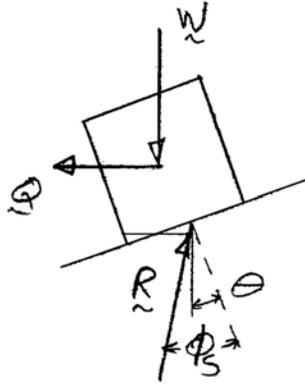
$$Q = W \tan(\theta + \phi_s)$$

$$P = \frac{r}{a} W \tan(\theta + \phi_s) \blacktriangleleft$$

continued

PROBLEM 8.66 CONTINUED

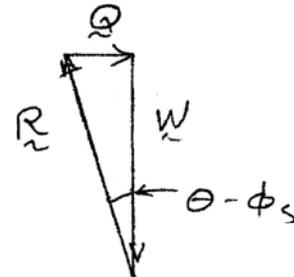
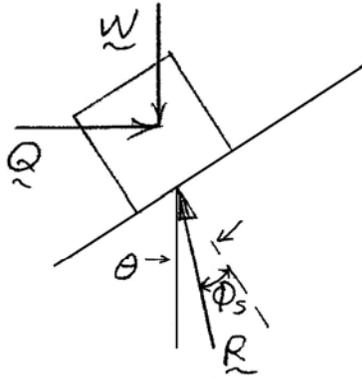
(b) Lowering load if screw is self-locking (i.e.: if $\phi_s > \theta$)



$$Q = W \tan(\phi_s - \theta)$$

$$P = \frac{r}{a} W \tan(\phi_s - \theta) \blacktriangleleft$$

(c) Holding load if screw is not self-locking (i.e.: if $\phi_s < \theta$)

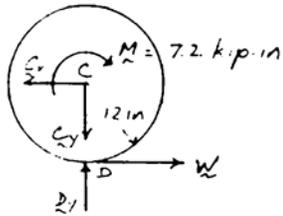


$$Q = W \tan(\theta - \phi_s)$$

$$P = \frac{r}{a} W \tan(\theta - \phi_s) \blacktriangleleft$$

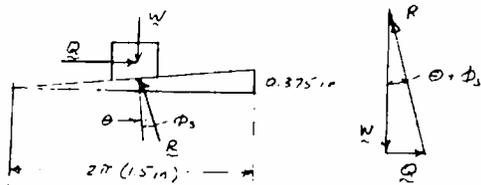
Chapter 8, Solution 67.

FBD large gear:



$$\left(\sum M_C = 0: \quad (12 \text{ in.})W - 7.2 \text{ kip}\cdot\text{in.} = 0, \quad W = 0.600 \text{ kips} \right. \\ \left. = 600 \text{ lb} \right.$$

Block on incline:



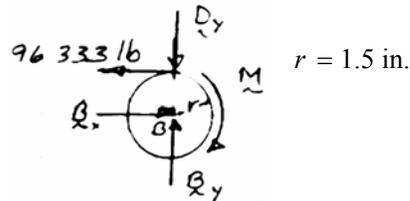
$$\theta = \tan^{-1} \frac{0.375 \text{ in.}}{2\pi(1.5 \text{ in.})} = 2.2785^\circ$$

$$\phi_s = \tan^{-1} \mu_s = \tan^{-1} 0.12 = 6.8428^\circ$$

$$Q = W \tan(\theta + \phi_s)$$

$$= (600 \text{ lb}) \tan 9.1213^\circ = 96.333 \text{ lb}$$

FBD worm gear:

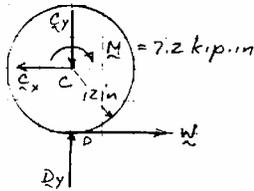


$$\left(\sum M_B = 0: \quad (1.5 \text{ in.})(96.333 \text{ lb}) - M = 0 \right.$$

$$M = 144.5 \text{ lb}\cdot\text{in.} \quad \blacktriangleleft$$

Chapter 8, Solution 68.

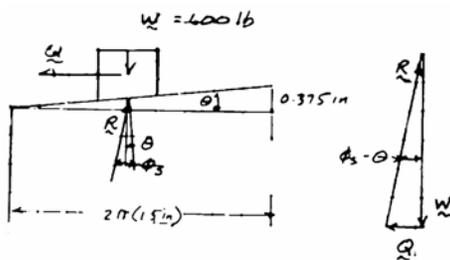
FBD large gear:



$$\left(\sum M_C = 0: \quad (12 \text{ in.})W - 7.2 \text{ kip}\cdot\text{in.} = 0 \right.$$

$$W = 0.600 \text{ kips} = 600 \text{ lb}$$

Block on incline:



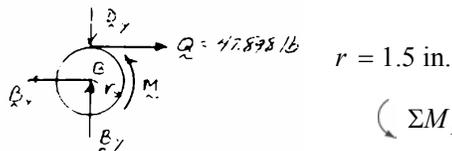
$$\theta = \tan^{-1} \frac{0.375 \text{ in.}}{2\pi(1.5 \text{ in.})} = 2.2785^\circ$$

$$\phi_s = \tan^{-1} \mu_s = \tan^{-1} 0.12 = 6.8428^\circ$$

$$Q = W \tan(\phi_s - \theta)$$

$$= (600 \text{ lb}) \tan 4.5643^\circ = 47.898 \text{ lb}$$

FBD worm gear:



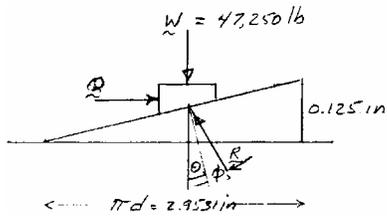
$$r = 1.5 \text{ in.}$$

$$\left(\sum M_B = 0: \quad M - (1.5 \text{ in.})(47.898 \text{ lb}) = 0 \right.$$

$$M = 71.8 \text{ lb}\cdot\text{in.} \blacktriangleleft$$

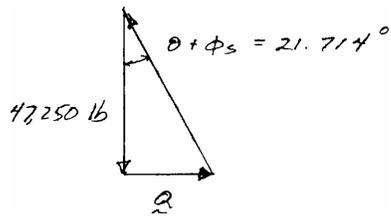
Chapter 8, Solution 69.

Block/incline analysis:



$$\theta = \tan^{-1} \frac{0.125 \text{ in.}}{2.9531 \text{ in.}} = 2.4238^\circ$$

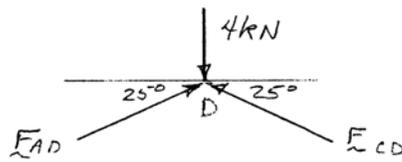
$$\phi_s = \tan^{-1}(0.35) = 19.2900^\circ$$



$$Q = 47250 \tan(21.714^\circ) = 18.816 \text{ lb}$$

$$\text{Couple} = \frac{d}{2} Q = \left(\frac{0.94}{2} \text{ in.} \right) (18.816 \text{ lb}) = 8844 \text{ lb}\cdot\text{in.}$$

$$\text{Couple} = 7.37 \text{ lb}\cdot\text{ft} \quad \blacktriangleleft$$

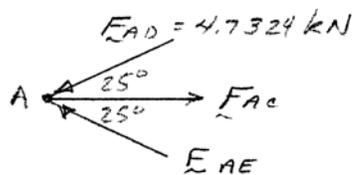
Chapter 8, Solution 70.
FBD joint D:


By symmetry:

$$F_{AD} = F_{CD}$$

$$\uparrow \Sigma F_y = 0: 2F_{AD} \sin 25^\circ - 4 \text{ kN} = 0$$

$$F_{AD} = F_{CD} = 4.7324 \text{ kN}$$

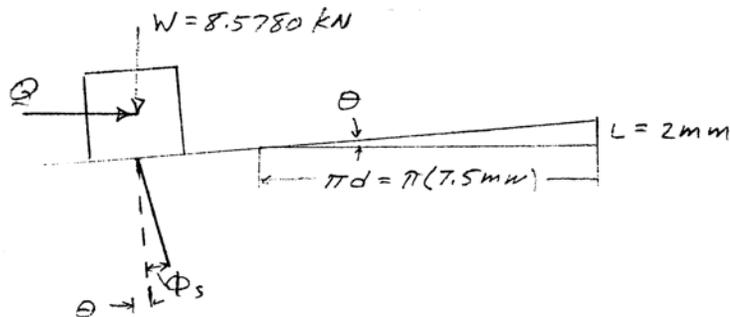
FBD joint A:


By symmetry:

$$F_{AE} = F_{AD}$$

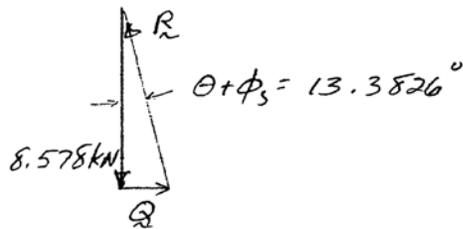
$$\rightarrow \Sigma F_x = 0: F_{AC} - 2(4.7324 \text{ kN}) \cos 25^\circ = 0$$

$$F_{AC} = 8.5780 \text{ kN}$$

Block and incline A:


$$\theta = \tan^{-1} \frac{2 \text{ mm}}{\pi(7.5 \text{ mm})} = 4.8518^\circ$$

$$\phi_s = \tan^{-1} \mu_s = \tan^{-1} 0.15 = 8.5308^\circ$$

PROBLEM 8.70 CONTINUED

$$Q = (8.578 \text{ kN}) \tan(13.3826^\circ)$$

$$= 2.0408 \text{ kN}$$

Couple at A :

$$M_A = rQ$$

$$= \left(\frac{7.5}{2} \text{ mm} \right) (2.0408 \text{ kN})$$

$$= 7.653 \text{ N}\cdot\text{m}$$

By symmetry: Couple at C :

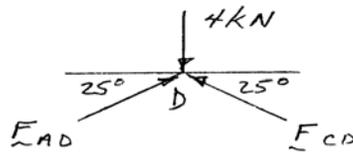
$$M_C = 7.653 \text{ N}\cdot\text{m}$$

$$\text{Total couple } M = 2(7.653 \text{ N}\cdot\text{m})$$

$$M = 15.31 \text{ N}\cdot\text{m} \quad \blacktriangleleft$$

Chapter 8, Solution 71.

FBD joint D:



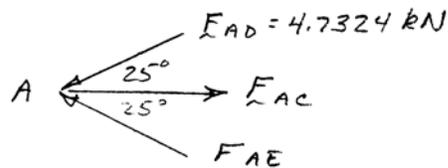
By symmetry:

$$F_{AD} = F_{CD}$$

$$\uparrow \Sigma F_y = 0: 2F_{AD} \sin 25^\circ - 4 \text{ kN} = 0$$

$$F_{AD} = F_{CD} = 4.7324 \text{ kN}$$

FBD joint A:



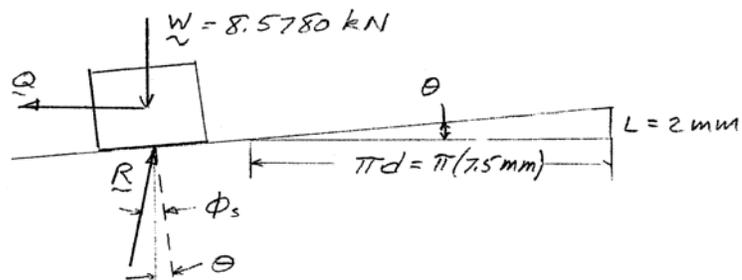
By symmetry:

$$F_{AE} = F_{AD}$$

$$\rightarrow \Sigma F_x = 0: F_{AC} - 2(4.7324 \text{ kN}) \cos 25^\circ = 0$$

$$F_{AC} = 8.5780 \text{ kN}$$

Block and incline at A:

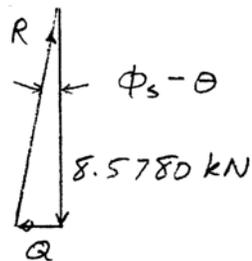


PROBLEM 8.71 CONTINUED

$$\theta = \tan^{-1} \frac{2 \text{ mm}}{\pi(7.5 \text{ mm})} = 4.8518^\circ$$

$$\phi_s = \tan^{-1} \mu_s = \tan^{-1} 0.15$$

$$\phi_s = 8.5308^\circ$$



$$\phi_s - \theta = 3.679^\circ$$

$$Q = (8.5780 \text{ kN}) \tan 3.679^\circ$$

$$Q = 0.55156 \text{ kN}$$

Couple at A: $M_A = Qr$

$$= (0.55156 \text{ kN}) \left(\frac{7.5 \text{ mm}}{2} \right)$$

$$= 2.0683 \text{ N}\cdot\text{m}$$

By symmetry:

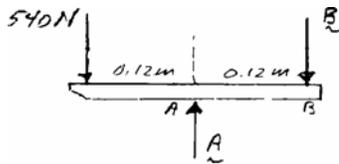
Couple at C: $M_C = 2.0683 \text{ N}\cdot\text{m}$

Total couple $M = 2(2.0683 \text{ N}\cdot\text{m})$

$M = 4.14 \text{ N}\cdot\text{m} \blacktriangleleft$

Chapter 8, Solution 72.

FBD lower jaw:

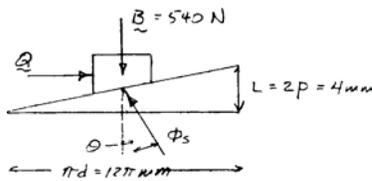


By symmetry $B = 540 \text{ N}$

$$\uparrow \Sigma F_y = 0: \quad -540 \text{ N} + A - 540 \text{ N} = 0, \quad A = 1080 \text{ N}$$

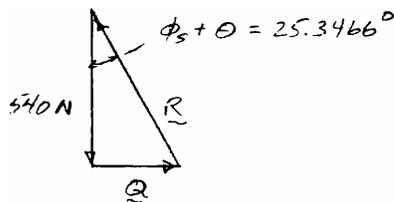
(a) since $A > B$ when finished, adjust A first when there will be no force ◀

Block/incline at B:



$$(b) \quad \theta = \tan^{-1} \frac{4 \text{ mm}}{12\pi \text{ mm}} = 6.0566^\circ$$

$$\phi_s = \tan^{-1} \mu_s = \tan^{-1}(0.35) = 19.2900^\circ$$



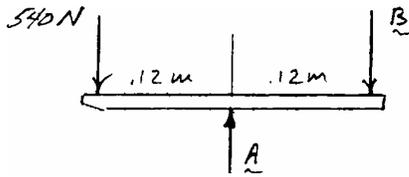
$$Q = (540 \text{ N}) \tan 25.3466^\circ = 255.80 \text{ N}$$

$$\text{Couple} = rQ = (6 \text{ mm})(255.80 \text{ N}) = 1535 \text{ N}\cdot\text{mm}$$

$$M = 1.535 \text{ N}\cdot\text{m} \quad \blacktriangleleft$$

Chapter 8, Solution 73.

FBD lower jaw:

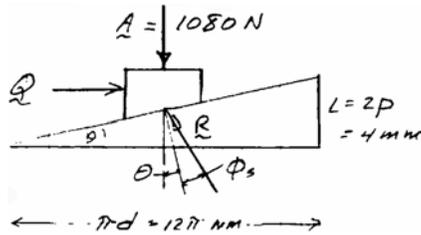


By symmetry $B = 540 \text{ N}$

$$\uparrow \Sigma F_y = 0: \quad -540 \text{ N} + A - 540 \text{ N} = 0, \quad A = 1080 \text{ N}$$

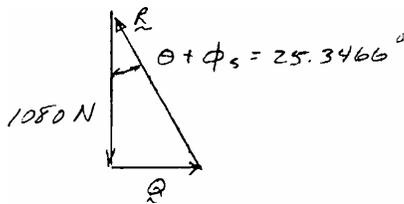
since $A > B$, A should be adjusted first when no force is required. If instead, B is adjusted first,

Block/incline at A:



$$\theta = \tan^{-1} \frac{4 \text{ mm}}{12\pi \text{ mm}} = 6.0566^\circ$$

$$\phi_s = \tan^{-1} \mu_s = \tan^{-1}(0.35) = 19.2900^\circ$$



$$Q = (1080 \text{ N}) \tan 25.3466^\circ = 511.59 \text{ N}$$

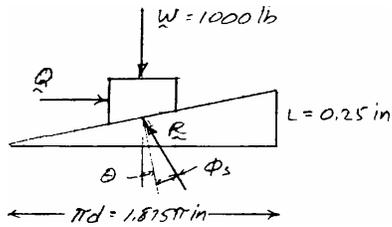
$$\text{Couple} = rQ = (6 \text{ mm})(511.59 \text{ N}) = 3069.5 \text{ N}\cdot\text{mm}$$

$$M = 3.07 \text{ N}\cdot\text{m} \quad \blacktriangleleft$$

Note that this is twice that required if A is adjusted first.

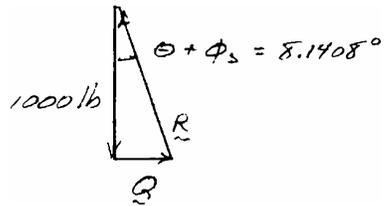
Chapter 8, Solution 74.

Block/incline:



$$\theta = \tan^{-1} \frac{0.25 \text{ in.}}{1.875\pi \text{ in.}} = 2.4302^\circ$$

$$\phi_s = \tan^{-1} \mu_s = \tan^{-1}(0.10) = 5.7106^\circ$$



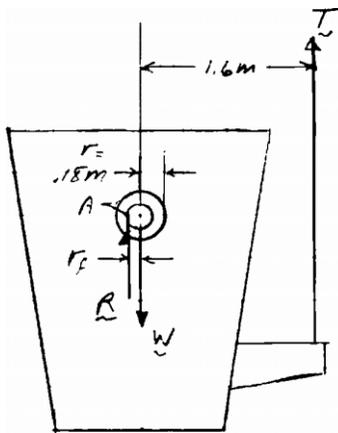
$$Q = (1000 \text{ lb}) \tan(8.1408^\circ) = 143.048 \text{ lb}$$

$$\text{Couple} = rQ = (0.9375 \text{ in.})(143.048 \text{ lb}) = 134.108 \text{ lb}\cdot\text{in.}$$

$$M = 134.1 \text{ lb}\cdot\text{in.} \quad \blacktriangleleft$$

Chapter 8, Solution 75.

FBD Bucket:



$$r_f = r \sin \phi_s = r \sin(\tan^{-1} \mu_s)$$

$$= (0.18 \text{ m}) \sin(\tan^{-1} 0.30) = 0.05172 \text{ m}$$

$$\left(\sum M_A = 0: \quad (1.6 \text{ m} + 0.05172 \text{ m})T - (0.05172 \text{ m})W = 0 \right.$$

$$T = 0.031314W$$

$$= 0.031314(50 \text{ Mg}) \left(9.81 \frac{\text{kN}}{\text{Mg}} \right)$$

$$= 15.360 \text{ kN}$$

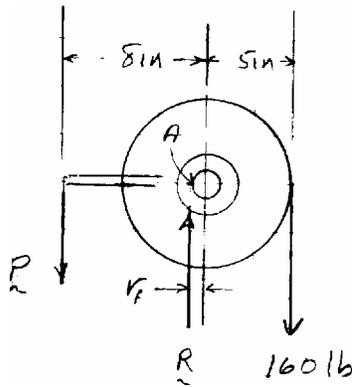
$$T = 15.36 \text{ kN} \quad \blacktriangleleft$$

NOTE FOR PROBLEMS 8.75–8.89

Note to instructors: In this manual, the simplification $\sin(\tan^{-1} \mu) \approx \mu$ is NOT used in the solution of journal bearing and axle friction problems. While this approximation may be valid for very small values of μ , there is little if any reason to use it, and the error may be significant. For example, in Problems 8.76–8.79, $\mu_s = 0.50$, and the error made by using the approximation is about 11.8%.

Chapter 8, Solution 76.

FBD Windlass:



$$r_f = r_b \sin \phi_s = r_b \sin (\tan^{-1} \mu_s)$$

$$= (1.5 \text{ in.}) \sin (\tan^{-1} 0.5) = 0.67082 \text{ in.}$$

$$\left(\sum M_A = 0: \quad [(8 - 0.67082) \text{ in.}] P - [(5 + 0.67082) \text{ in.}] 160 \text{ lb} = 0 \right.$$

$$P = 123.797 \text{ lb}$$

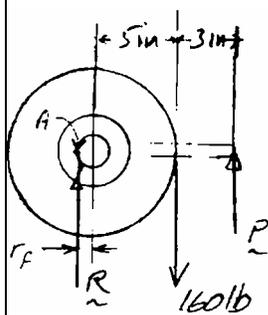
$$P = 123.8 \text{ lb} \blacktriangleleft$$

NOTE FOR PROBLEMS 8.75–8.89

Note to instructors: In this manual, the simplification $\sin (\tan^{-1} \mu) \approx \mu$ is NOT used in the solution of journal bearing and axle friction problems. While this approximation may be valid for very small values of μ , there is little if any reason to use it, and the error may be significant. For example, in Problems 8.76–8.79, $\mu_s = 0.50$, and the error made by using the approximation is about 11.8%.

Chapter 8, Solution 77.

FBD Windlass:



$$r_f = r \sin \phi_s = r \sin (\tan^{-1} \mu_s)$$

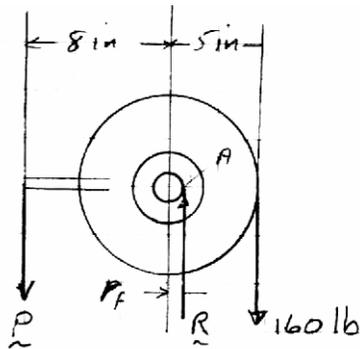
$$= (1.5 \text{ in.}) \sin (\tan^{-1} 0.5) = 0.67082 \text{ in.}$$

$$\left(\sum M_A = 0: \quad [(8 + 0.67082) \text{ in.}] P - [(5 + 0.67082) \text{ in.}] (160 \text{ lb}) = 0 \right.$$

$$P = 104.6 \text{ lb} \blacktriangleleft$$

NOTE FOR PROBLEMS 8.75–8.89

Note to instructors: In this manual, the simplification $\sin (\tan^{-1} \mu) \approx \mu$ is NOT used in the solution of journal bearing and axle friction problems. While this approximation may be valid for very small values of μ , there is little if any reason to use it, and the error may be significant. For example, in Problems 8.76–8.79, $\mu_s = 0.50$, and the error made by using the approximation is about 11.8%.

Chapter 8, Solution 78.
FBD Windlass:


$$r_f = r \sin \phi_s = r \sin(\tan^{-1} \mu_s)$$

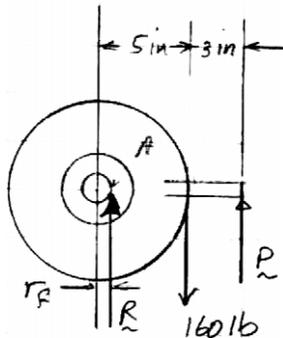
$$= (1.5 \text{ in.}) \sin(\tan^{-1} 0.50) = 0.67082 \text{ in.}$$

$$\left(\sum M_A = 0: \quad [(8 + 0.67082) \text{ in.}]P - [(5 - 0.67082) \text{ in.}](160 \text{ lb}) = 0 \right.$$

$$P = 79.9 \text{ lb} \blacktriangleleft$$

NOTE FOR PROBLEMS 8.75–8.89

Note to instructors: In this manual, the simplification $\sin(\tan^{-1} \mu) \approx \mu$ is NOT used in the solution of journal bearing and axle friction problems. While this approximation may be valid for very small values of μ , there is little if any reason to use it, and the error may be significant. For example, in Problems 8.76–8.79, $\mu_s = 0.50$, and the error made by using the approximation is about 11.8%.

Chapter 8, Solution 79.
FBD Windlass:


$$r_f = r \sin \phi_s = r \sin(\tan^{-1} \mu_s)$$

$$= (1.5 \text{ in.}) \sin(\tan^{-1} 0.50) = 0.67082 \text{ in.}$$

$$\left(\sum M_A = 0: \quad [(8 - 0.67082) \text{ in.}] P - [(5 - 0.67082) \text{ in.}] (160 \text{ lb}) = 0 \right.$$

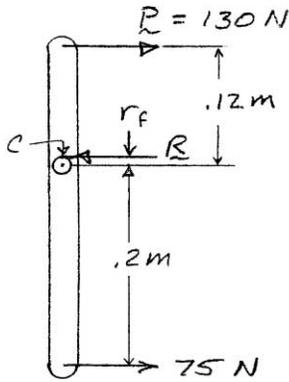
$$P = 94.5 \text{ lb} \blacktriangleleft$$

NOTE FOR PROBLEMS 8.75–8.89

Note to instructors: In this manual, the simplification $\sin(\tan^{-1} \mu) \approx \mu$ is NOT used in the solution of journal bearing and axle friction problems. While this approximation may be valid for very small values of μ , there is little if any reason to use it, and the error may be significant. For example, in Problems 8.76–8.79, $\mu_s = 0.50$, and the error made by using the approximation is about 11.8%.

Chapter 8, Solution 80.

(a) **FBD lever** (Impending *CW* rotation):



$$\left(\sum M_C = 0: \quad (0.2 \text{ m} + r_f)(75 \text{ N}) - (0.12 \text{ m} - r_f)(130 \text{ N}) = 0\right.$$

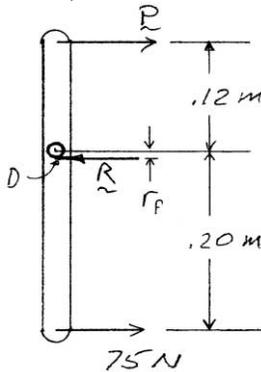
$$r_f = 0.0029268 \text{ m} = 2.9268 \text{ mm}$$

$$\sin \phi_s = \frac{r_f}{r_s}$$

$$\begin{aligned} \mu_s = \tan \phi_s &= \tan \left(\sin^{-1} \frac{r_f}{r_s} \right) = \tan \left(\sin^{-1} \frac{2.9268 \text{ mm}}{18 \text{ mm}} \right)^* \\ &= 0.34389 \end{aligned}$$

$$\mu_s = 0.344 \blacktriangleleft$$

(b) **FBD lever** (Impending *CCW* rotation):



$$\left(\sum M_D = 0: \quad (0.20 \text{ m} - 0.0029268 \text{ m})(75 \text{ N})\right.$$

$$\left. - (0.12 \text{ m} + 0.0029268 \text{ m})P = 0\right.$$

$$P = 120.2 \text{ N} \blacktriangleleft$$

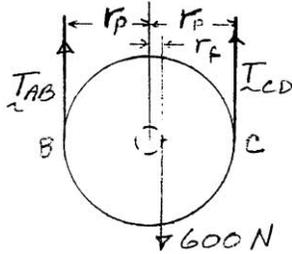
NOTE FOR PROBLEMS 8.75–8.89

Note to instructors: In this manual, the simplification $\sin(\tan^{-1} \mu) \approx \mu$ is NOT used in the solution of journal bearing and axle friction problems. While this approximation may be valid for very small values of μ , there is little if any reason to use it, and the error may be significant. For example, in Problems 8.76–8.79, $\mu_s = 0.50$, and the error made by using the approximation is about 11.8%.

Chapter 8, Solution 81.

Pulley FBD's:

Left:



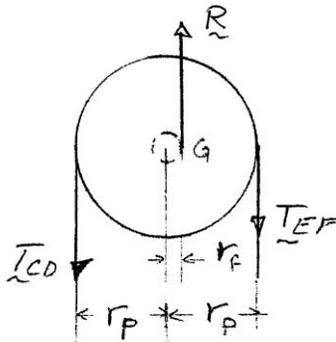
$$r_p = 30 \text{ mm}$$

$$\begin{aligned} r_f &= r_{\text{axle}} \sin \phi_k = r_{\text{axle}} \sin(\tan^{-1} \mu_k)^* \\ &= (5 \text{ mm}) \sin(\tan^{-1} 0.2) \\ &= 0.98058 \text{ mm} \end{aligned}$$

Left:

$$\left(\sum M_C = 0: \quad (r_p - r_f)(600 \text{ lb}) - 2r_p T_{AB} = 0 \right.$$

Right:



or

$$T_{AB} = \frac{30 \text{ mm} - 0.98058 \text{ mm}}{2(30 \text{ mm})} (600 \text{ N}) = 290.19 \text{ N}$$

$$T_{AB} = 290 \text{ N} \blacktriangleleft$$

$$\uparrow \sum F_y = 0: \quad 290.19 \text{ N} - 600 \text{ N} + T_{CD} = 0$$

or

$$T_{CD} = 309.81 \text{ N}$$

$$T_{CD} = 310 \text{ N} \blacktriangleleft$$

Right:

$$\left(\sum M_G = 0: \quad (r_p + r_f)T_{CD} - (r_p - r_f)T_{EF} = 0 \right.$$

or

$$T_{EF} = \frac{30 \text{ mm} + 0.98058 \text{ mm}}{30 \text{ mm} - 0.98058 \text{ mm}} (309.81 \text{ N}) = 330.75 \text{ N}$$

$$T_{EF} = 331 \text{ N} \blacktriangleleft$$

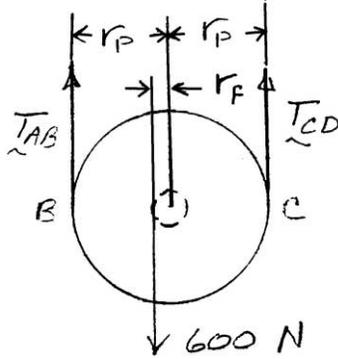
NOTE FOR PROBLEMS 8.75–8.89

Note to instructors: In this manual, the simplification $\sin(\tan^{-1} \mu) \approx \mu$ is NOT used in the solution of journal bearing and axle friction problems. While this approximation may be valid for very small values of μ , there is little if any reason to use it, and the error may be significant. For example, in Problems 8.76–8.79, $\mu_s = 0.50$, and the error made by using the approximation is about 11.8%.

Chapter 8, Solution 82.

Pulley FBDs:

Left:



$$r_p = 30 \text{ mm}$$

$$\begin{aligned} r_f &= r_{\text{axle}} \sin \phi_k = r_{\text{axle}} \sin(\tan^{-1} \mu_k)^* \\ &= (5 \text{ mm}) \sin(\tan^{-1} 0.2) \\ &= 0.98058 \text{ mm} \end{aligned}$$

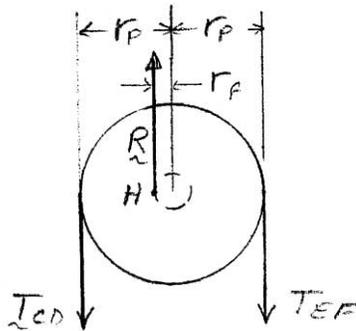
$$\left(\sum M_C = 0: \quad (r_p + r_f)(600 \text{ N}) - 2r_p T_{AB} = 0 \right.$$

or

$$T_{AB} = \frac{30 \text{ mm} + 0.98058 \text{ mm}}{2(30 \text{ mm})}(600 \text{ N}) = 309.81 \text{ N}$$

$T_{AB} = 310 \text{ N} \blacktriangleleft$

Right:



$$\uparrow \sum F_y = 0: \quad T_{AB} - 600 \text{ N} + T_{CD} = 0$$

or

$$T_{CD} = 600 \text{ N} - 309.81 \text{ N} = 290.19 \text{ N}$$

$T_{CD} = 290 \text{ N} \blacktriangleleft$

$$\left(\sum M_H = 0: \quad (r_p - r_f)T_{CD} - (r_p + r_f)T_{EF} = 0 \right.$$

or

$$T_{EF} = \frac{30 \text{ mm} - 0.98058 \text{ mm}}{30 \text{ mm} + 0.98058 \text{ mm}}(290.19 \text{ N})$$

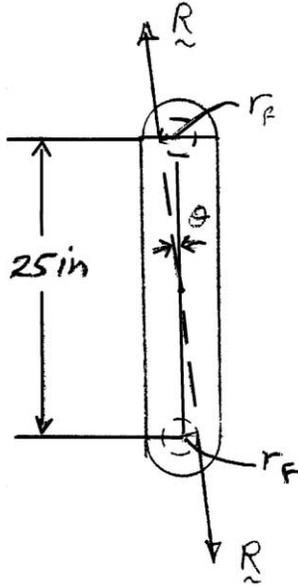
$T_{EF} = 272 \text{ N} \blacktriangleleft$

NOTE FOR PROBLEMS 8.75–8.89

Note to instructors: In this manual, the simplification $\sin(\tan^{-1} \mu) \approx \mu$ is NOT used in the solution of journal bearing and axle friction problems. While this approximation may be valid for very small values of μ , there is little if any reason to use it, and the error may be significant. For example, in Problems 8.76–8.79, $\mu_s = 0.50$, and the error made by using the approximation is about 11.8%.

Chapter 8, Solution 83.

FBD link AB:



Note: That AB is a two-force member. For impending motion, the pin forces are tangent to the friction circles.

$$\theta = \sin^{-1} \frac{r_f}{25 \text{ in.}}$$

where $r_f = r_p \sin \phi_s = r_p \sin(\tan^{-1} \mu_s)^*$

$$= (1.5 \text{ in.}) \sin(\tan^{-1} 0.2) = 0.29417 \text{ in.}$$

Then $\theta = \sin^{-1} \frac{0.29417 \text{ in.}}{12.5 \text{ in.}} = 1.3485^\circ$

(b) $\theta = 1.349^\circ \blacktriangleleft$

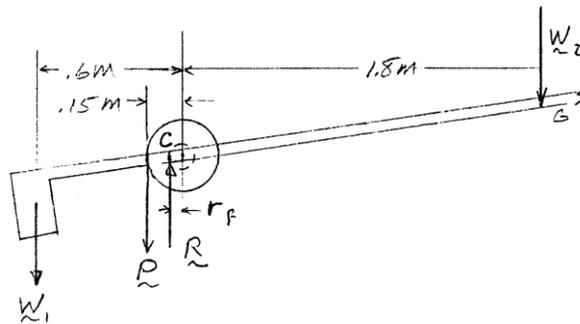
$$R_{\text{vert}} = R \cos \theta \quad R_{\text{horiz}} = R \sin \theta$$

$$R_{\text{horiz}} = R_{\text{vert}} \tan \theta = (50 \text{ kips}) \tan 1.3485^\circ = 1.177 \text{ kips}$$

(a) $R_{\text{horiz}} = 1.177 \text{ kips} \blacktriangleleft$

NOTE FOR PROBLEMS 8.75–8.89

Note to instructors: In this manual, the simplification $\sin(\tan^{-1} \mu) \approx \mu$ is NOT used in the solution of journal bearing and axle friction problems. While this approximation may be valid for very small values of μ , there is little if any reason to use it, and the error may be significant. For example, in Problems 8.76–8.79, $\mu_s = 0.50$, and the error made by using the approximation is about 11.8%.

Chapter 8, Solution 84.
FBD gate:


$$W_1 = 66 \text{ kg}(9.81 \text{ m/s}^2) = 647.46 \text{ N}$$

$$W_2 = 24 \text{ kg}(9.81 \text{ m/s}^2) = 235.44 \text{ N}$$

$$\begin{aligned} r_f &= r_s \sin \phi_s = r_s \sin(\tan^{-1} \mu_s) \\ &= (0.012 \text{ m}) \sin(\tan^{-1} 0.2) = 0.0023534 \text{ m} \end{aligned}$$

$$\left(\sum M_C = 0: \quad (0.6 \text{ m} - r_f)W_1 + (0.15 \text{ m} - r_f)P - (1.8 \text{ m} + r_f)W_2 = 0 \right.$$

$$P = \frac{(1.80235 \text{ m})(235.44 \text{ N}) - (0.59765 \text{ m})(647.46 \text{ N})}{(0.14765 \text{ m})}$$

$$= 253.2 \text{ N}$$

$$P = 253 \text{ N} \blacktriangleleft$$

NOTE FOR PROBLEMS 8.75–8.89

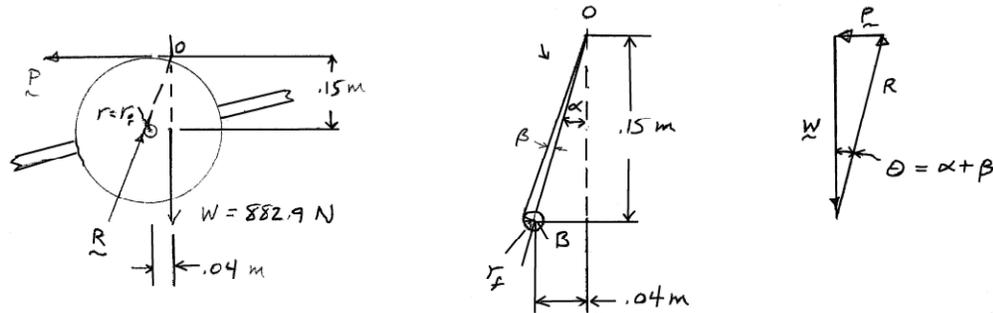
Note to instructors: In this manual, the simplification $\sin(\tan^{-1} \mu) \approx \mu$ is NOT used in the solution of journal bearing and axle friction problems. While this approximation may be valid for very small values of μ , there is little if any reason to use it, and the error may be significant. For example, in Problems 8.76–8.79, $\mu_s = 0.50$, and the error made by using the approximation is about 11.8%.

Chapter 8, Solution 85.

It is convenient to replace the $(66 \text{ kg})g$ and $(24 \text{ kg})g$ weights with a single combined weight of $(90 \text{ kg})(9.81 \text{ m/s}^2) = 882.9 \text{ N}$, located at a distance $x = \frac{(1.8 \text{ m})(24 \text{ kg}) - (0.6 \text{ m})(66 \text{ kg})}{90 \text{ kg}} = 0.04 \text{ m}$ to the right of B .

$$r_f = r_s \sin \phi_s = r_s \sin(\tan^{-1} \mu_s)^* = (0.012 \text{ m}) \sin(\tan^{-1} 0.2) = 0.0023534 \text{ m}$$

FBD pulley + gate:



$$\alpha = \tan^{-1} \frac{0.04 \text{ m}}{0.15 \text{ m}} = 14.931^\circ \quad OB = \frac{0.15}{\cos \alpha} = 0.15524 \text{ m}$$

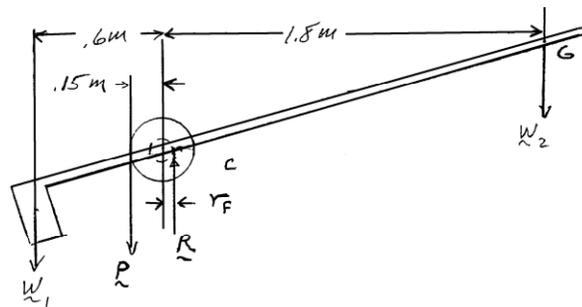
$$\beta = \sin^{-1} \frac{r_f}{OB} = \sin^{-1} \frac{0.0023534 \text{ m}}{0.15524 \text{ m}} = 0.8686^\circ \quad \text{then} \quad \theta = \alpha + \beta = 15.800^\circ$$

$$P = W \tan \theta = 249.8 \text{ N}$$

$$P = 250 \text{ N} \blacktriangleleft$$

NOTE FOR PROBLEMS 8.75–8.89

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Chapter 8, Solution 86.
FBD gate:


$$W_1 = 66 \text{ kg}(9.81 \text{ m/s}^2) = 647.46 \text{ N}$$

$$W_2 = 24 \text{ kg}(9.81 \text{ m/s}^2) = 235.44 \text{ N}$$

$$\begin{aligned} r_f &= r_s \sin \phi_s = r_s \sin(\tan^{-1} \mu_s)^* \\ &= (0.012 \text{ m}) \sin(\tan^{-1} 0.2) = 0.0023534 \text{ m} \end{aligned}$$

$$\left(\sum M_C = 0: \quad (0.6 \text{ m} + r_f)W_1 + (0.15 \text{ m} + r_f)P - (1.8 \text{ m} - r_f)W_2 = 0 \right.$$

$$P = \frac{(1.79765 \text{ m})(235.44 \text{ N}) - (0.60235 \text{ m})(647.46 \text{ N})}{0.15235 \text{ m}}$$

$$= 218.19 \text{ N}$$

$$P = 218 \text{ N} \blacktriangleleft$$

NOTE FOR PROBLEMS 8.75–8.89

Note to instructors: In this manual, the simplification $\sin(\tan^{-1} \mu) \approx \mu$ is NOT used in the solution of journal bearing and axle friction problems. While this approximation may be valid for very small values of μ , there is little if any reason to use it, and the error may be significant. For example, in Problems 8.76–8.79, $\mu_s = 0.50$, and the error made by using the approximation is about 11.8%.

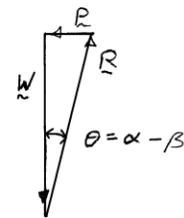
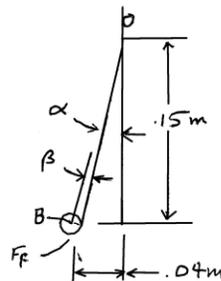
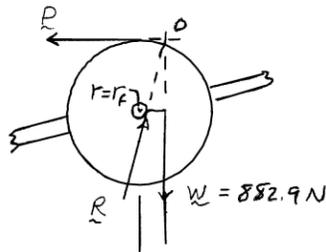
Chapter 8, Solution 87.

It is convenient to replace the (66 kg)g and (24 kg)g weights with a single weight of (90 kg)(9.81 N/kg) = 882.9 N, located at a distance $x = \frac{(1.8 \text{ m})(24 \text{ kg}) - (0.15 \text{ m})(66 \text{ kg})}{90 \text{ kg}} = 0.04 \text{ m}$ to the right of B.

FBD pulley + gate:

$$r_f = r_s \sin \phi_s = r_s \sin(\tan^{-1} \mu_s)^* = (0.012 \text{ m}) \sin(\tan^{-1} 0.2)$$

$$r_f = 0.0023534 \text{ m}$$



$$\alpha = \tan^{-1} \frac{0.04 \text{ m}}{0.15 \text{ m}} = 14.931^\circ \quad OB = \frac{0.15 \text{ m}}{\cos \alpha} = 0.15524 \text{ m}$$

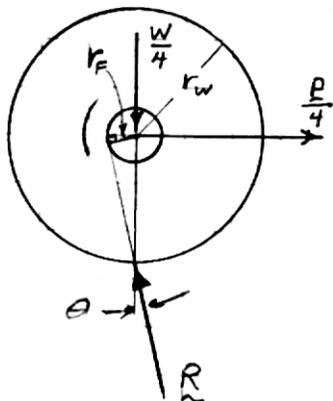
$$\beta = \sin^{-1} \frac{r_f}{OB} = \sin^{-1} \frac{0.0023534 \text{ m}}{0.15524 \text{ m}} = 0.8686^\circ \quad \text{then} \quad \theta = \alpha - \beta = 14.062^\circ$$

$$P = W \tan \theta = 221.1 \text{ N}$$

$$P = 221 \text{ N} \blacktriangleleft$$

NOTE FOR PROBLEMS 8.75–8.89

Note to instructors: In this manual, the simplification $\sin(\tan^{-1} \mu) \approx \mu$ is NOT used in the solution of journal bearing and axle friction problems. While this approximation may be valid for very small values of μ , there is little if any reason to use it, and the error may be significant. For example, in Problems 8.76–8.79, $\mu_s = 0.50$, and the error made by using the approximation is about 11.8%.

Chapter 8, Solution 88.
FBD Each wheel:


$$r_f = r_{axle} \sin \phi = r_{axle} \sin(\tan^{-1} \mu)$$

$$\rightarrow \Sigma F_x = 0: \quad \frac{P}{4} - R \sin \theta = 0$$

$$\uparrow \Sigma F_y = 0: \quad R \cos \theta - \frac{W}{4} = 0$$

$$\therefore \tan \theta = \frac{P}{W} \quad \text{or} \quad P = W \tan \theta$$

$$\text{but} \quad \sin \theta = \frac{r_f}{r_w} = \frac{r_{axle}}{r_w} \sin(\tan^{-1} \mu)$$

(a) For impending motion, use $\mu_s = 0.12$

$$\sin \theta = \frac{0.5 \text{ in.}}{5 \text{ in.}} \sin(\tan^{-1} 0.12) \quad \theta = 0.68267^\circ$$

$$P = W \tan \theta = (500 \text{ lb}) \tan(0.68267^\circ)$$

$$P = 5.96 \text{ lb} \quad \blacktriangleleft$$

(b) For constant speed, use $\mu_k = 0.08$

$$\sin \theta = \frac{1}{10} \sin(\tan^{-1} 0.08) \quad \theta = 0.45691^\circ$$

$$P = (500 \text{ lb}) \tan(0.45691^\circ)$$

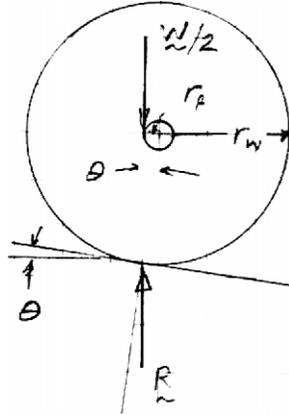
$$P = 3.99 \text{ lb} \quad \blacktriangleleft$$

NOTE FOR PROBLEMS 8.75–8.89

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Chapter 8, Solution 89.

FBD Each wheel:



For equilibrium (constant speed) the two forces \mathbf{R} and $\frac{\mathbf{W}}{2}$ must be equal and opposite, tangent to the friction circle, so

$$\sin \theta = \frac{r_f}{r_w} \text{ where } \theta = \tan^{-1}(\text{slope})$$

$$\sin(\tan^{-1} 0.03) = \frac{r_B \sin(\tan^{-1} \mu_k)}{r_w}$$

$$r_w = (12.5 \text{ mm}) \frac{\sin(\tan^{-1} 0.12)}{\sin(\tan^{-1} 0.03)} = 49.666 \text{ mm}$$

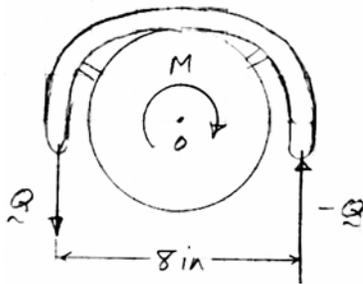
$$d_w = 99.3 \text{ mm} \blacktriangleleft$$

NOTE FOR PROBLEMS 8.75–8.89

Note to instructors: In this manual, the simplification $\sin(\tan^{-1} \mu) \approx \mu$ is NOT used in the solution of journal bearing and axle friction problems. While this approximation may be valid for very small values of μ , there is little if any reason to use it, and the error may be significant. For example, in Problems 8.76–8.79, $\mu_s = 0.50$, and the error made by using the approximation is about 11.8%.

Chapter 8, Solution 90.

FBD



$$\left(\sum M_O = 0: \quad (8 \text{ in.})Q - M = 0, \quad Q = \frac{M}{8 \text{ in.}} \right.$$

but, from equ. 8.9,

$$M = \frac{2}{3} \mu_k WR = \frac{2}{3} (0.60)(10.1 \text{ lb}) \left(\frac{7 \text{ in.}}{2} \right)$$

$$= 14.14 \text{ lb}$$

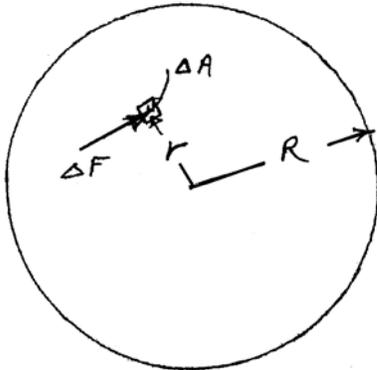
so, $Q = \frac{14.14}{8},$ $Q = 1.768 \text{ lb} \blacktriangleleft$

Chapter 8, Solution 91.

Eqn. 8.8 gives
$$M = \frac{2}{3} \mu_s P \frac{R_2^3 - R_1^3}{R_2^2 - R_1^2} = \frac{1}{3} \mu_s P \frac{D_2^3 - D_1^3}{D_2^2 - D_1^2}$$

so
$$M = \frac{1}{3} (0.15) (80 \text{ kg}) (9.81 \text{ m/s}^2) \frac{(0.030 \text{ m})^3 - (0.024 \text{ m})^3}{(0.030 \text{ m})^2 - (0.024 \text{ m})^2}$$

$$M = 1.596 \text{ N}\cdot\text{m} \quad \blacktriangleleft$$

Chapter 8, Solution 92.


Let the normal force on ΔA be ΔN , and $\frac{\Delta N}{\Delta A} = \frac{k}{r}$

As in the text $\Delta F = \mu \Delta N$, $\Delta M = r \Delta F$

The total normal force

$$P = \lim_{\Delta A \rightarrow 0} \Sigma \Delta N = \int_0^{2\pi} \left(\int_0^R \frac{k}{r} r dr \right) d\theta$$

$$P = 2\pi \left(\int_0^R k dr \right) = 2\pi k R \quad \text{or} \quad k = \frac{P}{2\pi R}$$

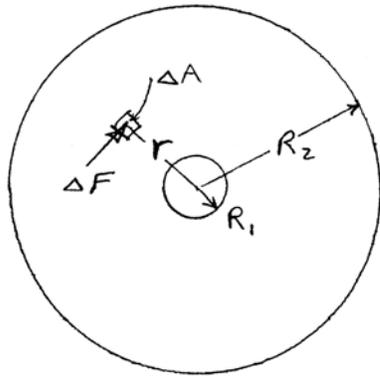
The total couple $M_{\text{worn}} = \lim_{\Delta A \rightarrow 0} \Sigma \Delta M = \int_0^{2\pi} \left(\int_0^R r \mu \frac{k}{r} r dr \right) d\theta$

$$M_{\text{worn}} = 2\pi \mu k \int_0^R r dr = 2\pi \mu k \frac{R^2}{2} = 2\pi \mu \frac{P}{2\pi R} \frac{R^2}{2}$$

or $M_{\text{worn}} = \frac{1}{2} \mu P R$

Now $M_{\text{new}} = \frac{2}{3} \mu P R$ [Eq. (8.9)]

Thus $\frac{M_{\text{worn}}}{M_{\text{new}}} = \frac{\frac{1}{2} \mu P R}{\frac{2}{3} \mu P R} = \frac{3}{4} = 75\% \blacktriangleleft$

Chapter 8, Solution 93.


Let normal force on ΔA be ΔN , and $\frac{\Delta N}{\Delta A} = \frac{k}{r}$

As in the text $\Delta F = \mu \Delta N$, $\Delta M = r \Delta F$

The total normal force P is

$$P = \lim_{\Delta A \rightarrow 0} \sum \Delta N = \int_0^{2\pi} \left(\int_{R_1}^{R_2} \frac{k}{r} r dr \right) d\theta$$

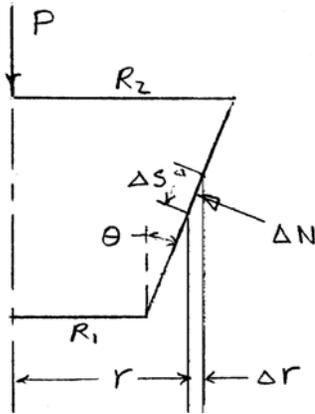
$$P = 2\pi \int_{R_1}^{R_2} k dr = 2\pi k (R_2 - R_1) \quad \text{or} \quad k = \frac{P}{2\pi (R_2 - R_1)}$$

The total couple is $M_{\text{worn}} = \lim_{\Delta A \rightarrow 0} \sum \Delta M = \int_0^{2\pi} \left(\int_{R_1}^{R_2} r \mu \frac{k}{r} r dr \right) d\theta$

$$M_{\text{worn}} = 2\pi \mu k \int_{R_1}^{R_2} (r dr) = \pi \mu k (R_2^2 - R_1^2) = \frac{\pi \mu P (R_2^2 - R_1^2)}{2\pi (R_2 - R_1)}$$

$$M_{\text{worn}} = \frac{1}{2} \mu P (R_2 + R_1) \quad \blacktriangleleft$$

Chapter 8, Solution 94.



Let normal force on ΔA be ΔN , and $\frac{\Delta N}{\Delta A} = k$,

so $\Delta N = k\Delta A$ $\Delta A = r\Delta s\Delta\phi$ $\Delta s = \frac{\Delta r}{\sin\theta}$

where ϕ is the azimuthal angle around the symmetry axis of rotation

$$\Delta F_y = \Delta N \sin\theta = kr\Delta r\Delta\phi$$

Total vertical force $P = \lim_{\Delta A \rightarrow 0} \Sigma \Delta F_y$

$$P = \int_0^{2\pi} \left(\int_{R_1}^{R_2} krdr \right) d\phi = 2\pi k \int_{R_1}^{R_2} r dr$$

$$P = \pi k (R_2^2 - R_1^2) \quad \text{or} \quad k = \frac{P}{\pi (R_2^2 - R_1^2)}$$

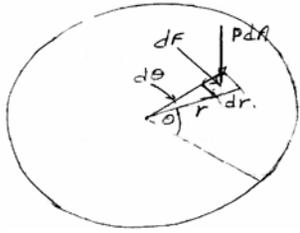
Friction force $\Delta F = \mu\Delta N = \mu k\Delta A$

Moment $\Delta M = r\Delta F = r\mu k r \frac{\Delta r}{\sin\theta} \Delta\phi$

Total couple $M = \lim_{\Delta A \rightarrow 0} \Sigma \Delta M = \int_0^{2\pi} \left(\int_{R_1}^{R_2} \frac{\mu k}{\sin\theta} r^2 dr \right) d\phi$

$$M = 2\pi \frac{\mu k}{\sin\theta} \int_{R_1}^{R_2} r^2 dr = \frac{2}{3} \frac{\pi\mu}{\sin\theta} \frac{P}{\pi (R_2^2 - R_1^2)} (R_2^3 - R_1^3)$$

$$M = \frac{2}{3} \frac{\mu P}{\sin\theta} \frac{R_2^3 - R_1^3}{R_2^2 - R_1^2} \quad \blacktriangleleft$$

Chapter 8, Solution 95.


If normal force per unit area (pressure) of the center is P_O , then as a function of r , $P = P_O \left(1 - \frac{r}{R}\right)$

$$\Sigma F_N = W = \int PdA = \int_0^{2\pi} \int_0^R P_O \left(1 - \frac{r}{R}\right) r dr d\theta$$

$$W = P_O \int_0^{2\pi} \left(\frac{R^2}{2} - \frac{R^3}{3R}\right) d\theta = 2\pi P_O \frac{R^2}{6}$$

$$\text{so } P_O = \frac{3W}{\pi R^2}$$

For slipping, $dF = \mu_k (PdA)$

$$\text{Moment} = \int r dF = \mu_k P_O \int_0^{2\pi} \int_0^R r \left(1 - \frac{r}{R}\right) r dr d\theta$$

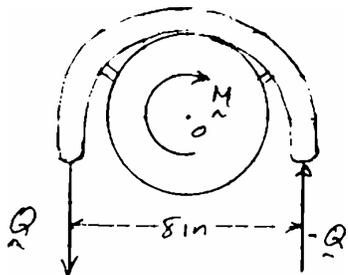
$$= \mu_k P_O \int_0^{2\pi} \left(\frac{R^3}{3} - \frac{R^4}{4R}\right) d\theta = 2\pi \mu_k P_O \frac{R^3}{12}$$

$$\text{so } M = 2\pi \mu_k \frac{3W}{\pi R^2} \frac{R^3}{12} = \frac{1}{2} \mu_k WR$$

$$\left(\Sigma M_O = 0: \quad (8 \text{ in.})Q - M = 0\right)$$

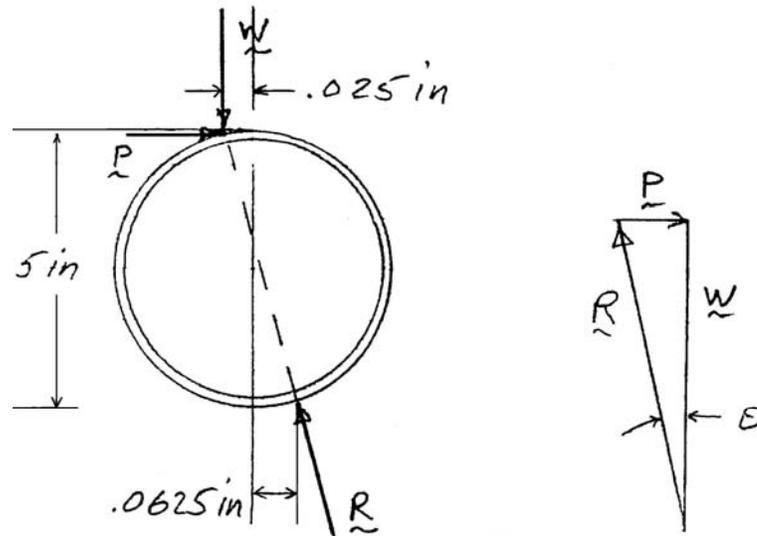
$$Q = \frac{M}{(8 \text{ in.})} = \frac{\frac{1}{2}(0.6)(10.1 \text{ lb})\left(\frac{7 \text{ in.}}{2}\right)}{8 \text{ in.}}$$

$$Q = 1.326 \text{ lb} \blacktriangleleft$$



Chapter 8, Solution 96.

FBD pipe:



$$\theta = \sin^{-1} \frac{0.025 \text{ in.} + 0.0625 \text{ in.}}{5 \text{ in.}} = 1.00257^\circ$$

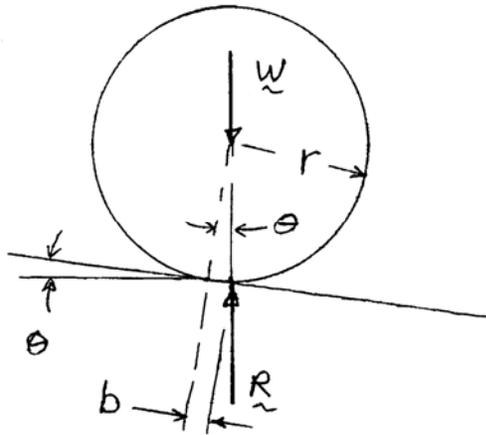
$$P = W \tan \theta \text{ for each pipe, so also for total}$$

$$P = (2000 \text{ lb}) \tan(1.00257^\circ)$$

$$P = 35.0 \text{ lb} \blacktriangleleft$$

Chapter 8, Solution 97.

FBD disk:



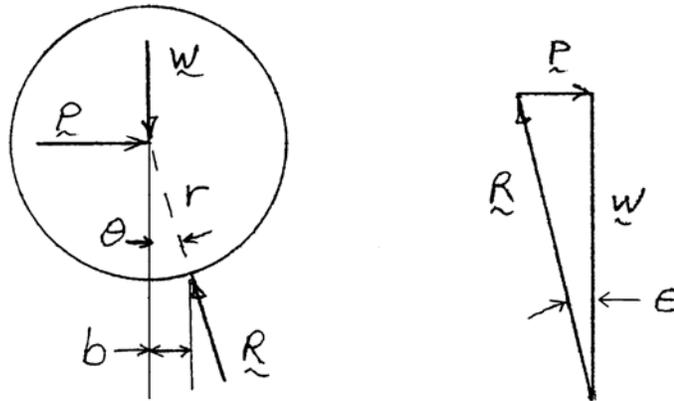
$$\tan \theta = \text{slope} = 0.02$$

$$b = r \tan \theta = (60 \text{ mm})(0.02)$$

$$b = 1.200 \text{ mm} \blacktriangleleft$$

Chapter 8, Solution 98.

FBD wheel:



$$r = 230 \text{ mm}$$

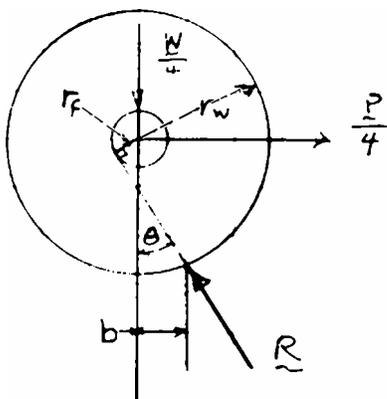
$$b = 1 \text{ mm}$$

$$\theta = \sin^{-1} \frac{b}{r}$$

$$P = W \tan \theta = W \tan \left(\sin^{-1} \frac{b}{r} \right) \text{ for each wheel, so for total}$$

$$P = (1000 \text{ kg})(9.81 \text{ m/s}^2) \tan \left(\sin^{-1} \frac{1}{230} \right)$$

$$P = 42.7 \text{ N} \blacktriangleleft$$

Chapter 8, Solution 99.
FBD wheel:


$$r_f = r_{\text{axle}} \sin \phi = r_{\text{axle}} \sin(\tan^{-1} \mu), \quad \mu_s \text{ or } \mu_k$$

$$r_w = \frac{r_f}{\sin \theta} + \frac{b}{\tan \theta}$$

$$\text{For small } \theta, \sin \theta \approx \tan \theta, \text{ so } \tan \theta \approx \frac{r_f + b}{r_w}$$

$$\uparrow \Sigma F_y = 0: \quad R \cos \theta - \frac{W}{4} = 0$$

$$\rightarrow \Sigma F_x = 0: \quad -R \sin \theta + \frac{P}{4} = 0$$

$$\text{Solving: } \tan \theta = \frac{P}{W}$$

$$\text{so } P = W \tan \theta = W \frac{r_f + b}{r_w}$$

$$(a) \text{ For impending slip, use } \mu_s, \quad r_f = \left(\frac{0.5 \text{ in.}}{2} \right) \sin(\tan^{-1} 0.12) = 0.029786 \text{ in.}$$

$$\text{so } P = (500 \text{ lb}) \frac{0.029786 \text{ in.} + 0.25 \text{ in.}}{2.5 \text{ in.}} = 55.96 \text{ lb}$$

$$P = 56.0 \text{ lb} \blacktriangleleft$$

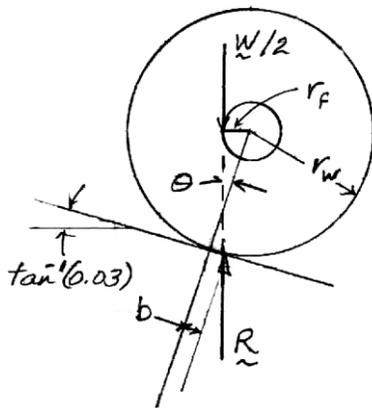
$$(b) \text{ For constant speed, use } \mu_k, \quad r_f = \left(\frac{0.5 \text{ in.}}{2} \right) \sin(\tan^{-1} 0.08) = 0.019936 \text{ in.}$$

$$\text{so } P = (500 \text{ lb}) \frac{(0.019936 + 0.25) \text{ in.}}{2.5 \text{ in.}} = 53.99 \text{ lb}$$

$$P = 54.0 \text{ lb} \blacktriangleleft$$

Chapter 8, Solution 100.

FBD wheel:



$\tan \theta = \text{slope}$

For equilibrium (constant speed), \mathbf{R} and $\frac{\mathbf{W}}{2}$ are equal and opposite and tangent to the friction circle as shown

$$r_f = r_{\text{axle}} \sin(\tan^{-1} \mu_k) = (12.5 \text{ mm}) \sin(\tan^{-1} 0.12)$$

$$r_f = 1.48932 \text{ mm}$$

From diagram, $r_w = \frac{r_f}{\sin \theta} + \frac{b}{\tan \theta}$

For small θ , $\sin \theta \approx \tan \theta$, so $r_w \approx \frac{r_f + b}{\tan \theta}$

$$r_w = \frac{1.48932 \text{ mm} + 1.75 \text{ mm}}{0.03} = 107.977 \text{ mm}$$

$$d_w = 216 \text{ mm} \blacktriangleleft$$

Chapter 8, Solution 101.Two full turns of rope \rightarrow

$$\beta = 4\pi \text{ rad}$$

$$(a) \quad \mu_s \beta = \ln \frac{T_2}{T_1} \quad \text{or} \quad \mu_s = \frac{1}{\beta} \ln \frac{T_2}{T_1}$$

$$\mu_s = \frac{1}{4\pi} \ln \frac{20\,000 \text{ N}}{320 \text{ N}} = 0.329066$$

$$\mu_s = 0.329 \blacktriangleleft$$

$$(b) \quad \beta = \frac{1}{\mu_s} \ln \frac{T_2}{T_1}$$

$$= \frac{1}{0.329066} \ln \frac{80\,000 \text{ N}}{320 \text{ N}}$$

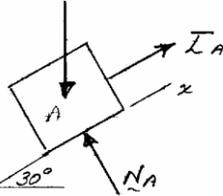
$$= 16.799 \text{ rad}$$

$$\beta = 2.67 \text{ turns} \blacktriangleleft$$

Chapter 8, Solution 102.

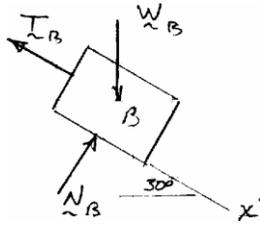
FBD A:

$$W_A = (10 \text{ kg})(9.81 \text{ m/s}^2) = 98.1 \text{ N}$$



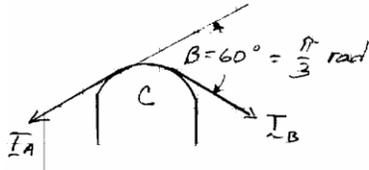
$$\nearrow \Sigma F_x = 0: \quad T_A - W_A \sin 30^\circ = 0, \quad T_A = \frac{W_A}{2}$$

FBD B:



$$\searrow \Sigma F_{x'} = 0: \quad W_B \sin 30^\circ - T_B = 0, \quad T_B = \frac{W_B}{2}$$

(a) Motion of B impends up incline and $m_B = 8 \text{ kg}$



$$\begin{aligned} \frac{T_A}{T_B} &= e^{\mu_s \beta}, \quad \mu_s = \frac{1}{\beta} \ln \frac{T_A}{T_B} = \frac{1}{\beta} \ln \frac{W_A}{W_B} \\ &= \frac{1}{\beta} \ln \frac{m_A}{m_B} = \frac{3}{\pi} \ln \left(\frac{10 \text{ kg}}{8 \text{ kg}} \right) \end{aligned}$$

From hint, β is not dependent on shape of support

$$\mu_s = 0.21309$$

$$\mu_s = 0.213 \blacktriangleleft$$

(b) For maximum m_B , motion of B impend down incline

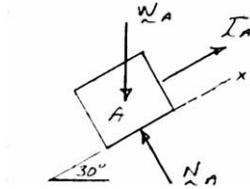
$$\frac{T_B}{T_A} = e^{\mu_s \beta}, \quad T_B = T_A e^{0.21309 \frac{\pi}{3}} = 1.250 T_A$$

$$\therefore W_B = 1.25 W_A \text{ and } m_B = 1.25 m_A = 1.25(10 \text{ kg})$$

$$m_{B \text{ max}} = 12.50 \text{ kg} \blacktriangleleft$$

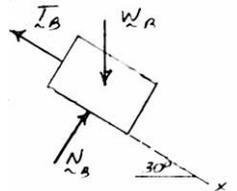
Chapter 8, Solution 103.

FBD A:



$$\rightarrow \Sigma F_x = 0: \quad T_A - W_A \sin 30^\circ = 0, \quad T_A = \frac{W_A}{2}$$

FBD B:



$$\rightarrow \Sigma F_{x'} = 0: \quad W_B \sin 30^\circ - T_B = 0, \quad T_B = \frac{W_B}{2}$$

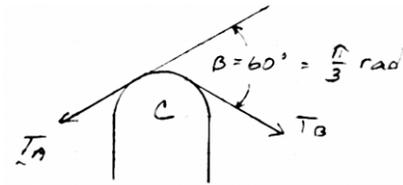
For $m_{B \min}$, motion of B impends up incline

$$\text{And } \frac{T_A}{T_B} = e^{0.50 \frac{\pi}{3}} = 1.68809$$

$$\text{But } \frac{m_A}{m_B} = \frac{W_A}{W_B} = \frac{T_A}{T_B} = 1.68809$$

$$\text{so } m_{B \min} = 5.9238 \text{ kg}$$

From hint, β is not dependent on shape of C



For $m_{B \max}$, motion of B impends down incline

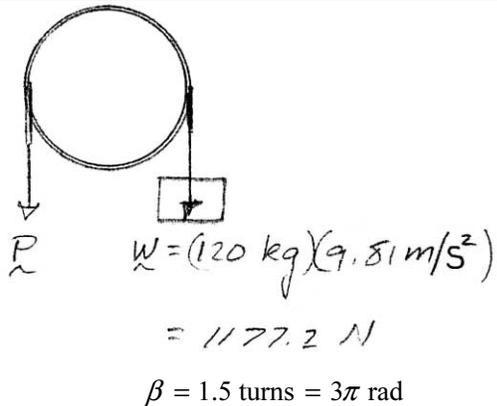
$$\text{so } \frac{m_B}{m_A} = \frac{W_B}{W_A} = \frac{T_B}{T_A} = e^{\mu_s \beta} = e^{0.50 \frac{\pi}{3}} = 1.68809$$

$$\text{so } m_{B \max} = 16.881 \text{ kg}$$

For equilibrium

$$5.92 \text{ kg} \leq m_B \leq 16.88 \text{ kg} \blacktriangleleft$$

Chapter 8, Solution 104.



For impending motion of W up

$$P = We^{\mu_s \beta} = (1177.2 \text{ N})e^{(0.15)3\pi}$$
$$= 4839.7 \text{ N}$$

For impending motion of W down

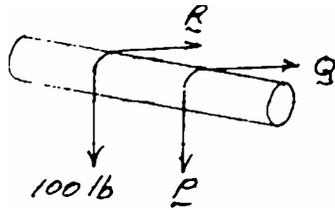
$$P = We^{-\mu_s \beta} = (1177.2 \text{ N})e^{-(0.15)3\pi}$$
$$= 286.3 \text{ N}$$

For equilibrium

$$286 \text{ N} \leq P \leq 4.84 \text{ kN} \blacktriangleleft$$

Chapter 8, Solution 105.

Horizontal pipe:



Contact angles $\beta_H = \frac{\pi}{2}$

$$\mu_{sH} = 0.25$$

For **P** to impend downward,

$$P = \left(e^{\mu_{sH} \frac{\pi}{2}} \right) Q = \left(e^{\mu_{sH} \frac{\pi}{2}} \right) \left(e^{\mu_{sV} \pi} \right) R = \left(e^{\mu_{sH} \frac{\pi}{2}} \right) \left(e^{\mu_{sV} \pi} \right) \left(e^{\mu_{sH} \frac{\pi}{2}} \right) (100 \text{ lb})$$

$$P_{\max} = \left[e^{\pi(\mu_{sH} + \mu_{sV})} \right] (100 \text{ lb}) = (100 \text{ lb}) e^{0.45\pi} = 411.12 \text{ lb}$$

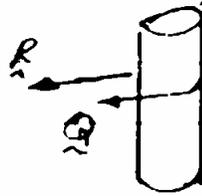
For 100 lb to impend downward, the ratios are reversed, so

$$100 \text{ lb} = P e^{0.45\pi}, \quad P_{\min} = 24.324 \text{ lb}$$

So, for equilibrium,

$$24.3 \text{ lb} \leq P \leq 411 \text{ lb} \blacktriangleleft$$

Vertical pipe

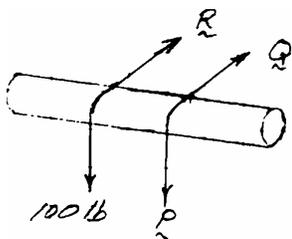


Contact angle $\beta_V = \pi$

$$\mu_{sV} = 0.2$$

Chapter 8, Solution 106.

Horizontal pipe



Contact angles $\beta_H = \frac{\pi}{2}$

$$\mu_{sH} = 0.30$$

For P_{\min} , the 100 lb force impends downward, and

$$100 \text{ lb} = \left(e^{\mu_{sH} \frac{\pi}{2}} \right) R = \left(e^{\mu_{sH} \frac{\pi}{2}} \right) \left(e^{\mu_{sV} \pi} \right) Q = \left(e^{\mu_{sH} \frac{\pi}{2}} \right) \left(e^{\mu_{sV} \pi} \right) \left(e^{\mu_{sH} \frac{\pi}{2}} \right) P$$

$$100 \text{ lb} = \left[e^{\pi(0.30 + \mu_{sV})} \right] (20 \text{ lb}), \text{ so } e^{\pi(0.30 + \mu_{sV})} = 5$$

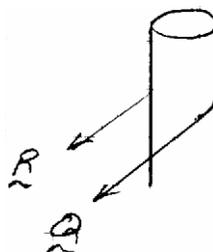
(a) For P_{\max} the force **P** impends downward, and the ratios are reversed, so $P_{\max} = 5(100 \text{ lb}) = 500 \text{ lb} \blacktriangleleft$

(b) $\pi(0.30 + \mu_{sV}) = \ln 5$

$$\mu_{sV} = \frac{1}{\pi} \ln 5 - 0.30 = 0.21230$$

$$\mu_{sV} = 0.212 \blacktriangleleft$$

Vertical pipe

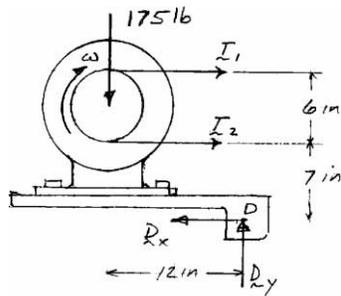


Contact angle $\beta_V = \pi$

$$\mu_{sV} = ?$$

Chapter 8, Solution 107.

FBD motor and mount:



Impending belt slip: cw rotation

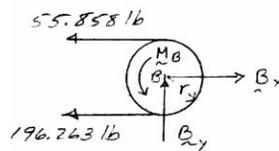
$$T_2 = T_1 e^{\mu_s \beta} = T_1 e^{0.40\pi} = 3.5136 T_1$$

$$\left(\sum M_D = 0: \quad (12 \text{ in.})(175 \text{ lb}) - (7 \text{ in.})T_2 - (13 \text{ in.})T_1 = 0 \right.$$

$$2100 \text{ lb} = [(7 \text{ in.})(3.5136) + 13 \text{ in.}]T_1$$

$$T_1 = 55.858 \text{ lb}, \quad T_2 = 3.5136 T_1 = 196.263 \text{ lb}$$

FBD drum at B:



$$r = 3 \text{ in.}$$

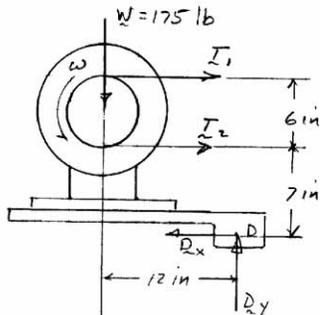
$$\left(\sum M_B = 0: \quad M_B - (3 \text{ in.})(196.263 \text{ lb} - 55.858 \text{ lb}) = 0 \right.$$

$$M_B = 421 \text{ lb}\cdot\text{in.} \blacktriangleleft$$

(Compare to 857 lb·in. using V-belt, Problem 8.130)

Chapter 8, Solution 108.

FBD motor and mount:



Impending belt slip: ccw rotation

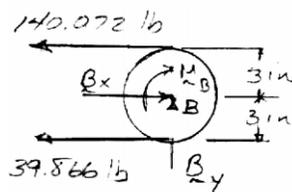
$$T_1 = T_2 e^{\mu_s \beta} = T_2 e^{0.40\pi} = 3.5136 T_2$$

$$\left(\sum M_D = 0: \quad (12 \text{ in.})(175 \text{ lb}) - (13 \text{ in.})T_1 - (7 \text{ in.})T_2 = 0 \right.$$

$$2100 \text{ lb} = [(13 \text{ in.})(3.5136) + 7 \text{ in.}]T_2 = 0$$

$$T_2 = 39.866 \text{ lb}, \quad T_1 = 3.5136 T_2 = 140.072 \text{ lb}$$

FBD drum at B:

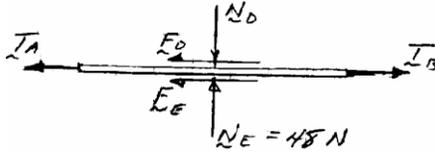


$$\left(\sum M_B = 0: \quad (3 \text{ in.})(140.072 \text{ lb} - 39.866 \text{ lb}) - M_B = 0 \right.$$

$$M_B = 301 \text{ lb}\cdot\text{in.} \quad \blacktriangleleft$$

Chapter 8, Solution 109.

FBD lower portion of belt:



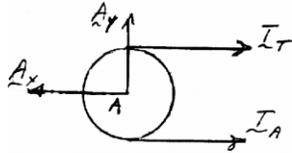
$$\uparrow \Sigma F_y = 0: \quad 48 \text{ N} - N_D = 0, \quad N_D = 48 \text{ N}$$

Slip on both platen and wood

$$F_D = \mu_{kD} N_D = 0.10(48 \text{ N}) = 4.8 \text{ N}$$

$$F_E = \mu_{kE} N_E = (48 \text{ N}) \mu_{kE}$$

FBD Drum A (assume free to rotate)

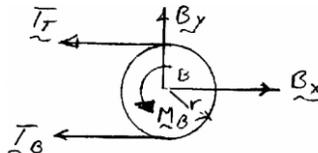


$$\rightarrow \Sigma F_x = 0: \quad T_A - T_B - 4.8 \text{ N} - \mu_{kE}(48 \text{ N}) = 0$$

$$T_B = T_A + 4.8 \text{ N} + \mu_{kE}(48 \text{ N}) \quad (1)$$

$$\curvearrowleft \Sigma M_A = 0: \quad r_A(T_A - T_T) = 0, \quad T_T = T_A \quad (2)$$

FBD Drive drum B



$$M_B = 2.4 \text{ N}\cdot\text{m}$$

$$r = 0.025 \text{ m}$$

$$\curvearrowleft \Sigma M_B = 0: \quad M_B + r(T_T - T_B) = 0$$

$$T_B = T_T + \frac{2.4 \text{ N}\cdot\text{m}}{0.025 \text{ m}} = T_T + 96 \text{ N}$$

Impending slip on drum, $T_B = T_T e^{\mu_s \beta} = T_T e^{0.35\pi}$

so $T_T + 96 \text{ N} = T_T e^{0.35\pi}$, $T_T = 47.932 \text{ N}$

$$T_B = 143.932 \text{ N}$$

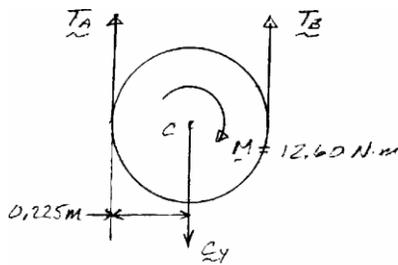
From (2) above, $T_A = T_T$, so

$$(a) \quad T_{\text{min lower}} = 47.9 \text{ N} \blacktriangleleft$$

From (1) above, $143.932 \text{ N} = 47.932 \text{ N} + 4.8 \text{ N} + \mu_{kE}(48 \text{ N})$

So (b)

$$\mu_{kE} = 1.900 \blacktriangleleft$$

Chapter 8, Solution 110.
FBD Flywheel:


$$\left(\sum M_C = 0: \quad (0.225 \text{ m})(T_B - T_A) - 12.60 \text{ N}\cdot\text{m} = 0 \right.$$

$$T_B - T_A = 56 \text{ N}, \quad T_B = T_A + 56 \text{ N}$$

Also, since the belt doesn't change length, the additional stretch in spring B equals the decrease in stretch of spring A . Thus the increase in T_B equals the decrease in T_A .

$$\text{Thus } T_B + T_A = (70 \text{ N} + \Delta T) + (70 \text{ N} - \Delta T) = 140 \text{ N}$$

$$(T_A + 56 \text{ N}) + T_A = 140 \text{ N}, \quad T_A = 42 \text{ N}$$

$$T_B = 42 \text{ N} + 56 \text{ N} = 98 \text{ N}$$

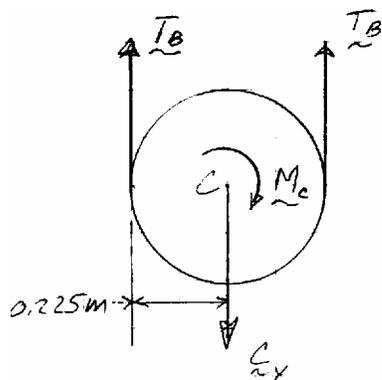
$$(a) \quad T_A = 42.0 \text{ N} \blacktriangleleft$$

$$T_B = 98.0 \text{ N} \blacktriangleleft$$

$$\text{For slip } T_B = T_A e^{\mu_k \beta}, \text{ or } \mu_k = \frac{1}{\beta} \ln \frac{T_B}{T_A}$$

$$\mu_k = \frac{1}{\pi} \ln \frac{98}{42} = 0.2697$$

$$(b) \quad \mu_k = 0.230 \blacktriangleleft$$

Chapter 8, Solution 111.
FBD Flywheel:


Slip of belt: $T_B = T_A e^{\mu_k \beta} = T_A e^{0.20\pi}$

Also, since the belt doesn't change length, the increase in stretch of spring B equals the decrease in stretch of spring A . Therefore the increase in T_B equals the decrease in T_A , and the sum is unchanged, so $T_A + T_B = 80 \text{ N} + 80 \text{ N} = 160 \text{ N}$

$$\therefore T_A (1 + e^{0.20\pi}) = 160 \text{ N}, \text{ so } T_A = 55.663 \text{ N}$$

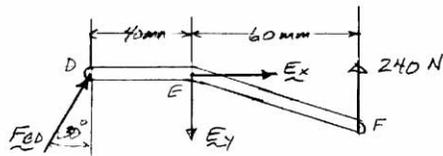
$$T_B = 104.337 \text{ N} \quad (a) \quad T_A = 55.7 \text{ N} \blacktriangleleft$$

$$T_B = 104.3 \text{ N} \blacktriangleleft$$

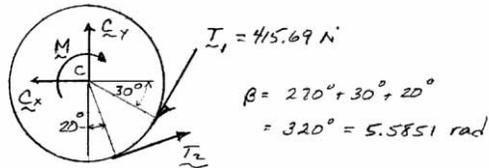
$$\curvearrowleft \Sigma M_C = 0: \quad (0.225 \text{ m})(T_B - T_A) - M_C = 0$$

$$M_C = (0.225 \text{ m})(104.337 \text{ N} - 55.663 \text{ N})$$

$$(b) \quad M_C = 10.95 \text{ N}\cdot\text{m} \blacktriangleleft$$

Chapter 8, Solution 112.
FBD Lever:


$$\begin{aligned} \sum M_E = 0: & \quad (60 \text{ mm})(240 \text{ N}) - (40 \text{ mm})F_{BD} \cos 30^\circ = 0 \\ & \quad F_{BD} = 415.69 \text{ N} \end{aligned}$$

FBD Drum:


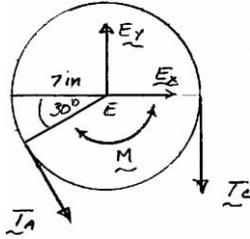
$$\begin{aligned} \text{Belt slip: } T_2 &= T_1 e^{\mu_k \beta} \\ &= (415.69 \text{ N}) e^{0.25(5.5851)} \\ &= 1679.44 \text{ N} \end{aligned}$$

$$\begin{aligned} \sum M_C = 0: & \quad r(T_2 - T_1) - M = 0 \\ & \quad (0.08 \text{ m})(1679.44 \text{ N} - 415.69 \text{ N}) - M = 0 \end{aligned}$$

$$M = 101.1 \text{ N}\cdot\text{m} \quad \blacktriangleleft$$

Chapter 8, Solution 113.

FBD Drum:



(a) With $M_E = 125 \text{ lb}\cdot\text{ft}$

$$\left(\sum M_E = 0: \quad (7 \text{ in.})(T_A - T_C) - (125 \text{ lb}\cdot\text{ft}) = 0 \right.$$

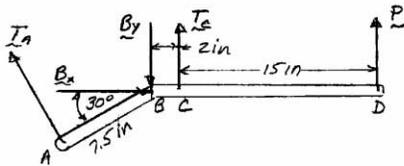
$$T_A - T_C = 214.29 \text{ lb}$$

$$\text{Belt slip: } T_A = T_C e^{\mu_k \beta} = T_C e^{0.30 \left(\frac{7\pi}{6} \right)} = 3.0028 T_C$$

$$\text{so } 2.0028 T_C = 214.9 \text{ lb}, \quad T_C = 106.995 \text{ lb}$$

$$T_A = 321.28 \text{ lb}$$

FBD Lever:



$$\left(\sum M_B = 0: \quad (15 \text{ in.})P + (2 \text{ in.})T_C - (7.5 \text{ in.})T_A = 0 \right. \quad (1)$$

$$P = \frac{(7.5 \text{ in.})(321.28 \text{ lb}) - (2 \text{ in.})(106.995 \text{ lb})}{17 \text{ in.}}$$

$$P = 129.2 \text{ lb} \quad \blacktriangleleft$$

(b) With $M_E = 125 \text{ lb}\cdot\text{ft}$, the drum analysis will be reversed, and will yield $T_A = 106.995 \text{ lb}$,

$$T_C = 321.28 \text{ lb}$$

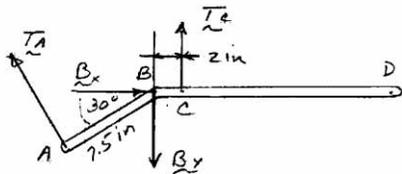
Eqn. (1) will remain the same, so

$$P = \frac{(7.5 \text{ in.})(106.995 \text{ lb}) - (2 \text{ in.})(321.28 \text{ lb})}{17 \text{ in.}}$$

$$P = 9.41 \text{ lb} \quad \blacktriangleleft$$

Chapter 8, Solution 114.

FBD Lever:



If brake is self-locking, no force P is required

$$\left(\sum M_B = 0: \quad (2 \text{ in.})T_C - (7.5 \text{ in.})T_A = 0 \right.$$

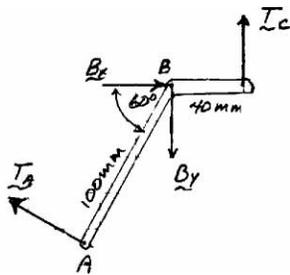
$$T_C = 3.75T_A$$

For impending slip on drum: $T_C = T_A e^{\mu_s \beta}$

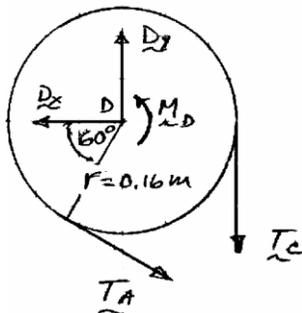
$$\therefore e^{\mu_s \beta} = 3.75, \text{ or } \mu_s = \frac{1}{\beta} \ln 3.75$$

$$\text{With } \beta = \frac{7\pi}{6},$$

$$\mu_s = 0.361 \blacktriangleleft$$

Chapter 8, Solution 115.
FBD Lever:


$$\left(\sum M_B = 0: (40 \text{ mm})T_C - (100 \text{ mm})T_A = 0, \quad T_C = 2.5T_A \right.$$

FBD Drum:


(a) For impending slip ccw: $T_C = T_{\max} = 4.5 \text{ kN}$

$$\text{so } T_A = \frac{T_C}{2.5} = 1.8 \text{ kN}$$

$$\left(\sum M_D = 0: M_D + (0.16 \text{ m})(1.8 \text{ kN} - 4.5 \text{ kN}) = 0 \right.$$

$$M_D = 0.432 \text{ kN}\cdot\text{m}$$

$$M_D = 432 \text{ N}\cdot\text{m} \quad \blacktriangleleft$$

(b) For impending slip ccw, $T_C = T_A e^{\mu_s \beta}$

$$\text{or } \mu_s = \frac{1}{\beta} \ln \frac{T_C}{T_A} = \frac{3}{4\pi} \ln 2.5 = 0.21875$$

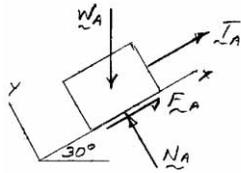
$$\mu_s = 0.219 \quad \blacktriangleleft$$

Chapter 8, Solution 116.

(a) For minimum m_C with blocks at rest, impending slip of A is down/left.

Note: $\phi_s = \tan^{-1} \mu_s = \tan^{-1} 0.30 = 16.7^\circ < 30^\circ$, so $m_{C\min} > 0$

FBD A:



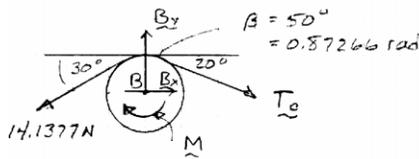
$$W_A = (6 \text{ kg})(9.81 \text{ m/s}^2) = 58.86 \text{ N}$$

$$\sum F_y = 0: \quad N_A - W_A \cos 30^\circ = 0, \quad N_A = W_A \cos 30^\circ$$

Impending slip: $F_A = \mu_s N_A = 0.30 W_A \cos 30^\circ$

$$\sum F_x = 0: \quad T_A + F_A - W_A \sin 30^\circ = 0, \quad T_A = W_A (\sin 30^\circ - 0.30 \cos 30^\circ) = 14.1377 \text{ N}$$

FBD Drum:

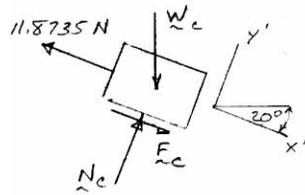


If blocks don't move, belt slips on drum, so

$$14.1377 \text{ N} = T_A = T_C e^{\mu_k \beta} = T_C e^{0.2(0.87266)} = 1.19069 T_C$$

so $T_C = 11.8735 \text{ N}$

FBD C:



$$\sum F_{y'} = 0: \quad N_C - W_C \cos 20^\circ = 0, \quad N_C = W_C \cos 20^\circ$$

Impending slip: $F_C = \mu_s N_C = 0.30 W_C \cos 20^\circ$

$$\sum F_{x'} = 0: \quad 0.30 W_C \cos 20^\circ + W_C \sin 20^\circ - 11.8735 \text{ N} = 0$$

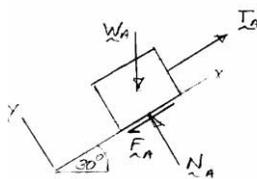
$$W_C = 19.0302 \text{ N}, \quad m_C = \frac{W_C}{9.81 \text{ m/s}^2} = 1.93988 \text{ kg}$$

$$m_C = 1.940 \text{ kg} \blacktriangleleft$$

continued

(b) For motion of A to impend up/right

FBD A:



As in part (a) $N_A = W_A \cos 30^\circ$, $F_A = 0.30 W_A \cos 30^\circ$

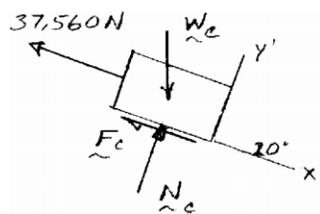
$$\nearrow \Sigma F_x = 0: \quad T_A - W_A (\sin 30^\circ + 0.30 \cos 30^\circ) = 0$$

$$T_A = 44.722 \text{ N}$$

Also, as in part (a) $T_A = T_C e^{\mu_k \beta} = 1.19069 T_C$, so $T_C = \frac{44.722 \text{ N}}{1.19069}$

$$T_C = 37.560 \text{ N}$$

FBD C:



As in part (a) $F_C = 0.30 W_C \cos 20^\circ$

$$\searrow \Sigma F_{x'} = 0: \quad W_C (\sin 20^\circ - 0.30 \cos 20^\circ) - 37.560 \text{ N} = 0$$

$$W_C = 624.83 \text{ N}, \quad m_C = \frac{W_C}{9.81 \text{ m/s}^2} = 63.69 \text{ kg}$$

$$m_C = 63.7 \text{ kg} \blacktriangleleft$$

(c) For uniform motion of A up and B down, and minimum m_C , there will be impending slip of the rope on the drum.

FBD A is same as in (b) but $F_A = \mu_k N_A = 0.20 W_A \cos 30^\circ$

$$\text{and } \nearrow \Sigma F_x = 0: \quad T_A - W_A (\sin 30^\circ + 0.20 \cos 30^\circ) = 0, \quad T_A = 39.625 \text{ N}$$

Drum analysis, with impending slip, $T_A = T_C e^{\mu_s \beta}$

$$39.625 \text{ N} = T_C e^{0.30(0.87266)} = 1.29926 T_C$$

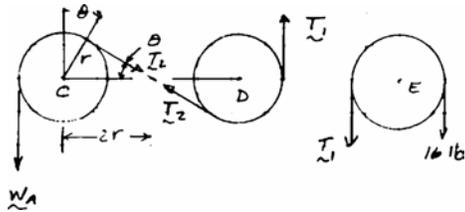
$$\text{or } T_C = 30.498 \text{ N}$$

FBD C is same as in (b), but $F_C = \mu_k N_C = 0.20 W_C \cos 20^\circ$

$$\text{and } \searrow \Sigma F_{x'} = 0: \quad W_C (\sin 20^\circ - 0.20 \cos 20^\circ) - T_C = 0$$

$$W_C = \frac{30.498 \text{ N}}{0.154082} = 197.933 \text{ N}, \quad m_C = \frac{197.934 \text{ N}}{9.81 \text{ m/s}^2}$$

$$m_C = 20.2 \text{ kg} \blacktriangleleft$$

Chapter 8, Solution 118.
Geometry and force notation:


Note: $\theta = \sin^{-1} \frac{r}{2r} = 30^\circ = \frac{\pi}{6}$ rad, so contact angles are:

$$\beta_C = \beta_D = \frac{\pi}{2} + \frac{\pi}{6} = \frac{2\pi}{3}, \quad \beta_E = \pi$$

(a) For all pulleys locked, slip impends at all contacts

If W_A impends downward, $T_1 = (16 \text{ lb})e^{\mu_s \beta_E}$, $T_2 = T_1 e^{\mu_s \beta_D}$, $W_A = T_2 e^{\mu_s \beta_C}$

so $W_A = (16 \text{ lb})e^{\mu_s(\beta_C + \beta_D + \beta_E)} = (16 \text{ lb})e^{0.20(\frac{7\pi}{3})} = 69.315 \text{ lb}$

If W_A impends upward all ratios are inverted, so $W_A = (16 \text{ lb})e^{-0.20(\frac{7\pi}{3})}$
 $= 3.6933 \text{ lb}$

For equilibrium,

$$3.69 \text{ lb} \leq W_A \leq 69.3 \text{ lb} \blacktriangleleft$$

(b) If pulley D is free to rotate, $T_1 = T_2$ while the other ratios remain as in (a)

For W_A impending down $W_A = (16 \text{ lb})e^{\mu_s(\beta_C + \beta_E)} = (16 \text{ lb})e^{0.20(\frac{5\pi}{3})}$

$$W_A = 45.594 \text{ lb}$$

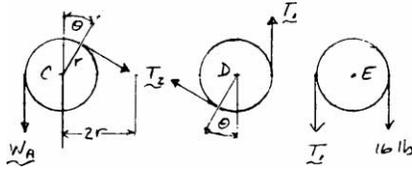
For W_A impending upward, $W_A = (16 \text{ lb})e^{-0.20(\frac{5\pi}{3})} = 5.6147 \text{ lb}$

For equilibrium

$$5.61 \text{ lb} \leq W_A \leq 45.6 \text{ lb} \blacktriangleleft$$

Chapter 8, Solution 119.

Geometry and force notation:



$$\theta = \sin^{-1} \frac{r}{2r} = 30^\circ = \frac{\pi}{6}, \text{ so contact angles are:}$$

$$\beta_C = \beta_D = \frac{\pi}{2} + \frac{\pi}{6} = \frac{2\pi}{3}, \quad \beta_E = \pi$$

(a) *D* and *E* fixed, so slip on these surfaces. For maximum N_A , slip impends on pulley *C*

$$W_A = T_2 e^{\mu_s \beta_C}, \text{ and } T_1 = T_2 e^{\mu_k \beta_D}, \quad (16 \text{ lb}) = T_1 e^{\mu_k \beta_E}$$

$$\text{so } W_A = (16 \text{ lb}) e^{-\mu_k (\beta_E + \beta_D)} e^{\mu_s \beta_C} = (16 \text{ lb}) e^{-0.15 \left(\frac{5\pi}{3}\right)} e^{0.20 \left(\frac{2\pi}{3}\right)} = 11.09 \text{ lb} \blacktriangleleft$$

(b) *C* and *D* fixed, so slip there. For maximum W_A , slip impends on *E*

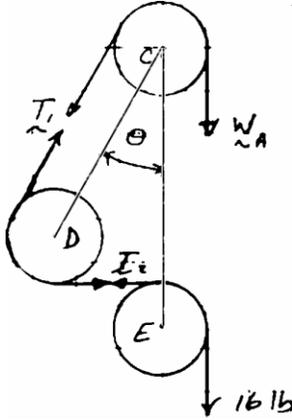
$$\text{so } T_1 = (16 \text{ lb}) e^{\mu_s \beta_E}, \quad T_1 = T_2 e^{\mu_k \beta_D}, \quad T_2 = W_A e^{\mu_k \beta_C}$$

$$\text{so } W_A = (16 \text{ lb}) e^{\mu_s \beta_E} e^{-\mu_k (\beta_C + \beta_D)} = (16 \text{ lb}) e^{0.20\pi} e^{-0.15 \left(\frac{4\pi}{3}\right)} = 16 \text{ lb}$$

$$W_A = 16.00 \text{ lb} \blacktriangleleft$$

Chapter 8, Solution 120.

Geometry and force notation:



$$\theta = \sin^{-1} \frac{5 \text{ in.}}{10 \text{ in.}} = 30^\circ = \frac{\pi}{6} \text{ rad, so contact angles are:}$$

$$\beta_C = \pi - \frac{\pi}{6} = \frac{5\pi}{6}, \quad \beta_D = \frac{\pi}{2} + \frac{\pi}{6} = \frac{2\pi}{3}, \quad \beta_E = \frac{\pi}{2}$$

(a) All pulleys locked with impending slip at all.

If W_A impends upward, $T_1 = W_A e^{\mu_s \beta_C}$,

$$T_2 = T_1 e^{\mu_s \beta_D}, \quad (16 \text{ lb}) = T_2 e^{\mu_s \beta_E}, \text{ so}$$

$$W_A = (16 \text{ lb}) e^{-\mu_s (\beta_C + \beta_D + \beta_E)} = (16 \text{ lb}) e^{-0.20 \left(\frac{5}{6} + \frac{4}{6} + \frac{3}{6} \right) \pi}$$

$$W_A = 4.5538 \text{ lb}$$

If W_A impends downward all ratios are inverted

$$\text{so } W_A = (16 \text{ lb}) e^{+0.20(2\pi)} = 56.217 \text{ lb}$$

For equilibrium,

$$4.55 \text{ lb} \leq W_A \leq 56.2 \text{ lb} \blacktriangleleft$$

(b) Pulley D is free to rotate so $T_1 = T_2$, other ratios are the same

If W_A impends upward, $W_A = (16 \text{ lb}) e^{-\mu_s (\beta_C + \beta_E)} = (16 \text{ lb}) e^{-0.20 \left(\frac{4\pi}{3} \right)}$

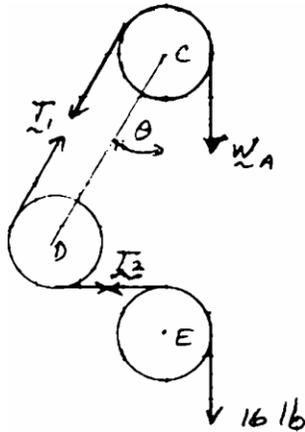
$$W_A = 6.9229 \text{ lb}$$

If W_A impends downward, ratios are inverted, $W_A = (16 \text{ lb}) e^{+0.20 \left(\frac{4\pi}{3} \right)}$

$$W_A = 36.979 \text{ lb}$$

For equilibrium

$$6.92 \text{ lb} \leq W_A \leq 37.0 \text{ lb} \blacktriangleleft$$

Chapter 8, Solution 121.
Geometry and force notation:


$$\theta = \sin^{-1} \frac{5 \text{ in.}}{10 \text{ in.}} = 30^\circ = \frac{\pi}{6} \text{ rad, so contact angles are:}$$

$$\beta_C = \pi - \frac{\pi}{6} = \frac{5\pi}{6}, \quad \beta_D = \frac{\pi}{2} + \frac{\pi}{6} = \frac{2\pi}{3}, \quad \beta_E = \frac{\pi}{2}$$

(a) *D* and *E* fixed, so slip at these surfaces,

For maximum W_A , slip impends on *C*.

$$W_A = T_1 e^{\mu_s \beta_C}, \quad T_2 = T_1 e^{\mu_k \beta_D}, \quad 16 \text{ lb} = T_2 e^{\mu_k \beta_E}$$

$$\text{so } W_A = (16 \text{ lb}) e^{-\mu_k (\beta_D + \beta_E)} e^{\mu_s \beta_C}$$

$$= (16 \text{ lb}) e^{-0.15 \left(\frac{2\pi}{3}\right)} e^{0.20 \left(\frac{5\pi}{6}\right)} = 15.5866 \text{ lb}$$

$$W_{A \max} = 15.59 \text{ lb} \quad \blacktriangleleft$$

(b) *C* and *D* fixed, so slip at these surfaces—impending slip on *E*

$$T_1 = W_A e^{\mu_k \beta_C}, \quad T_2 = T_1 e^{\mu_k \beta_D}, \quad T_2 = (16 \text{ lb}) e^{\mu_s \beta_E}$$

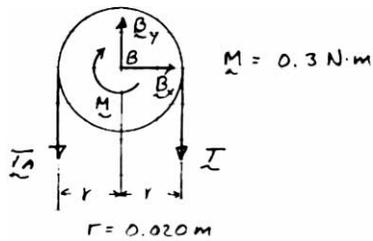
$$\text{so } W_A = (16 \text{ lb}) e^{-\mu_k (\beta_C + \beta_D)} e^{\mu_s \beta_E} = (16 \text{ lb}) e^{-0.15 \left(\frac{3\pi}{2}\right)} e^{0.20 \left(\frac{\pi}{2}\right)}$$

$$W_A = 10.8037 \text{ lb,}$$

$$W_{A \max} = 10.80 \text{ lb} \quad \blacktriangleleft$$

Chapter 8, Solution 122.

FBD drum B:



$$\left(\sum M_B = 0: \quad (0.02 \text{ m})(T_A - T) - 0.30 \text{ N}\cdot\text{m} = 0 \right.$$

$$T_A - T = \frac{0.30 \text{ N}\cdot\text{m}}{0.02 \text{ m}} = 15 \text{ N}$$

Impending slip: $T_A = T e^{\mu_s \beta} = T e^{0.40\pi}$

Solving; $T(e^{0.40\pi} - 1) = 15 \text{ N}$

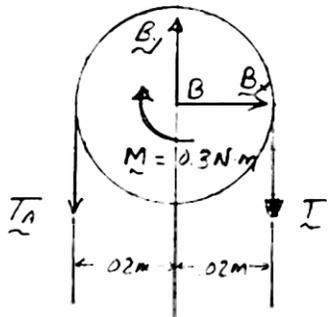
$$T = 5.9676 \text{ N}$$

If C is free to rotate $P = T$

$$P_{\min} = 5.97 \text{ N} \blacktriangleleft$$

Chapter 8, Solution 123.

FBD drum B:



$$\left(\sum M_B = 0: \quad (0.02 \text{ m})(T_A - T) - 0.3 \text{ N}\cdot\text{m} = 0 \right.$$

$$T_A - T = 15 \text{ N}$$

Impending slip: $T_A = T e^{\mu_s \beta_B} = T e^{0.40\pi}$

Solving, $T(e^{0.40\pi} - 1) = 15 \text{ N}$

$$T = 5.9676 \text{ N}$$

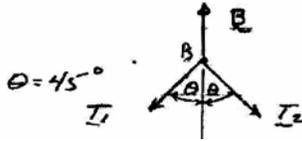
If C is frozen, tape must slip there, so

$$P = T e^{\mu_k \beta_C} = (5.9676 \text{ N}) e^{0.30(\frac{\pi}{2})} = 9.5599 \text{ N}$$

$$P_{\min} = 9.56 \text{ N} \blacktriangleleft$$

Chapter 8, Solution 124.

FBD pin B:



(a) By symmetry: $T_1 = T_2$

$$\uparrow \Sigma F_y = 0: B - 2\left(\frac{\sqrt{2}}{2}T_1\right) = 0 \quad \text{or} \quad B = \sqrt{2}T_1 = \sqrt{2}T_2 \quad (1)$$

For impending rotation \curvearrowright :

$$T_3 > T_1 = T_2 > T_4, \text{ so } T_3 = T_{\max} = 5.6 \text{ kN}$$

$$\text{Then } T_1 = T_3 e^{-\mu_s \beta_L} = (5.6 \text{ kN}) e^{-0.25\left(\frac{\pi}{4} + \frac{\pi}{6}\right)}$$

$$\text{or } T_1 = 4.03706 \text{ kN} = T_2$$

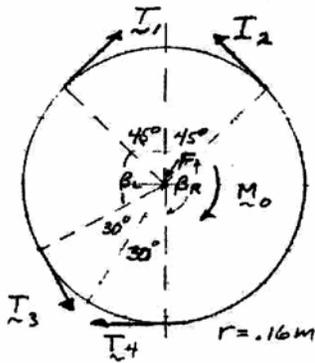
$$\text{and } T_4 = T_2 e^{-\mu_s \beta_R} = (4.03706 \text{ kN}) e^{-0.25\left(\frac{3\pi}{4}\right)}$$

$$\text{or } T_4 = 2.23998 \text{ kN}$$

$$\curvearrowleft \Sigma M_F = 0: M_0 + r(T_4 - T_3 + T_2 - T_1) = 0$$

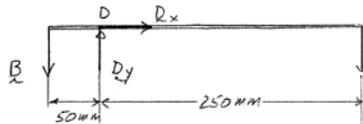
$$\text{or } M_0 = (0.16 \text{ m})(5.6 \text{ kN} - 2.23998 \text{ kN}) = 0.5376 \text{ kN}\cdot\text{m}$$

Drum:



$$M_0 = 538 \text{ N}\cdot\text{m} \quad \curvearrowleft$$

Lever:



(b) Using Equation (1)

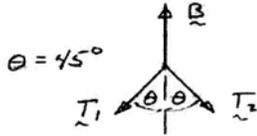
$$B = \sqrt{2}T_1 = \sqrt{2}(4.03706 \text{ kN}) = 5.70927 \text{ kN}$$

$$\curvearrowleft \Sigma M_D = 0: (0.05 \text{ m})(5.70927 \text{ kN}) - (0.25 \text{ m})P = 0$$

$$P = 1.142 \text{ kN} \quad \downarrow$$

Chapter 8, Solution 125.

FBD pin B:



(a) By symmetry: $T_1 = T_2$

$$\uparrow \Sigma F_y = 0: B - 2\left(\frac{\sqrt{2}}{2}T_1\right) = 0 \quad \text{or} \quad B = \sqrt{2}T_1 \quad (1)$$

For impending rotation \curvearrowright :

$$T_4 > T_2 = T_1 > T_3, \text{ so } T_4 = T_{\max} = 5.6 \text{ kN}$$

Then $T_2 = T_4 e^{-\mu_s \beta_R} = (5.6 \text{ kN})e^{-0.25\left(\frac{3\pi}{4}\right)}$

or $T_2 = 3.10719 \text{ kN} = T_1$

and $T_3 = T_1 e^{-\mu_s \beta_L} = (3.10719 \text{ kN})e^{-0.25\left(\frac{\pi}{4} + \frac{\pi}{6}\right)}$

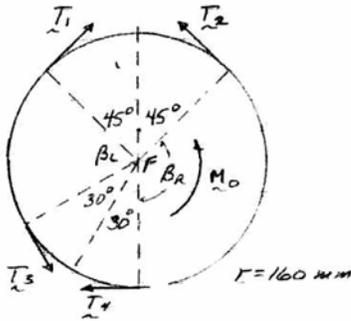
or $T_3 = 2.23999 \text{ kN}$

$$\curvearrowleft \Sigma M_F = 0: M_0 + r(T_2 - T_1 + T_3 - T_4) = 0$$

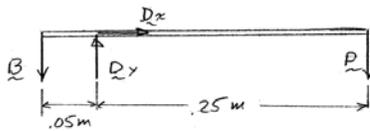
$$M_0 = (160 \text{ mm})(5.6 \text{ kN} - 2.23999 \text{ kN}) = 537.6 \text{ N}\cdot\text{m}$$

$$M_0 = 538 \text{ N}\cdot\text{m} \quad \curvearrowleft$$

FBD Drum:



FBD Lever:



(b) Using Equation (1)

$$B = \sqrt{2}T_1 = \sqrt{2}(3.10719 \text{ kN})$$

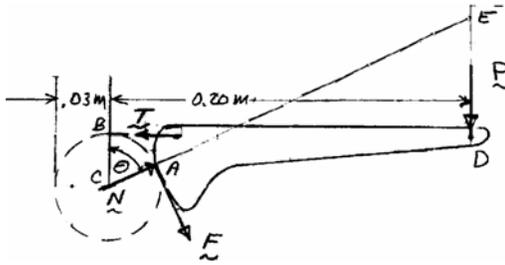
$$B = 4.3942 \text{ kN}$$

$$\curvearrowleft \Sigma M_D = 0: (0.05 \text{ m})(4.3942 \text{ kN}) - (0.25 \text{ m})P = 0$$

$$P = 879 \text{ N} \quad \downarrow$$

Chapter 8, Solution 126.

FBD wrench:



Note: $EC = \frac{(0.2 \text{ m})}{\sin 65^\circ}$, $EA = EC - 0.03 \text{ m}$

$\theta = 65^\circ$

so $\beta = 295^\circ = 5.1487 \text{ rad}$

$$\left(\sum M_E = 0: \left(\frac{0.20 \text{ m}}{\sin 65^\circ} - 0.03 \text{ m} \right) F - \left(\frac{0.20 \text{ m}}{\sin 65^\circ} \cos 65^\circ - 0.03 \text{ m} \right) T = 0 \right.$$

$$T = 3.01408F$$

$$\rightarrow \sum F_x = 0: N \sin 65^\circ + F \cos 65^\circ - T = 0$$

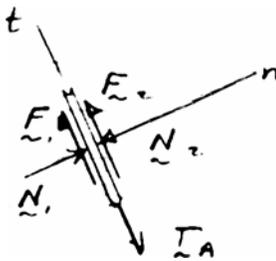
Impending slip: $N = \frac{F}{\mu_s}$, so $F = \left(\frac{\sin 65^\circ}{\mu_s} + \cos 65^\circ \right) T$

$$\text{or } \frac{\sin 65^\circ}{\mu_s} + \cos 65^\circ = 3.01408$$

$$\mu_s = 0.3497$$

Must still check slip of belt on pipe

FBD small portion of belt at A:



$$\nearrow \sum F_n = 0: N_1 - N_2 = 0$$

Impending slip, both sides: $F_1 = \mu_s N_1$, $F_2 = \mu_s N_2$

so $F_1 = F_2 = F$

$$\searrow \sum F_t = 0: 2F - T_A = 0, T_A = 2F$$

Impending slip of belt on pipe: $T = T_A e^{\mu_s \beta}$

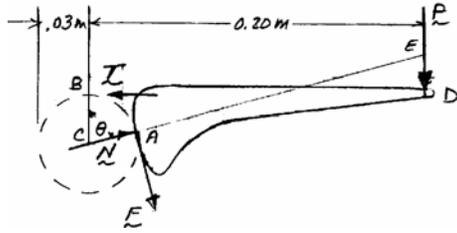
$$\text{or } \mu_s = \frac{1}{\beta} \ln \frac{T}{2F} = \frac{1}{5.1487} \ln \frac{3.01408}{2} = 0.0797$$

Above controls, so for self-locking, need

$$\mu_s = 0.350 \blacktriangleleft$$

Chapter 8, Solution 127.

FBD wrench



Note: $EC = \frac{(0.20 \text{ m})}{\sin 75^\circ}$, $EA = EC - 0.03 \text{ m}$

$\theta = 75^\circ$

so $\beta = 285^\circ = 4.9742 \text{ rad}$

$$\left(\sum M_E = 0: \left(\frac{0.20 \text{ m}}{\sin 75^\circ} - 0.03 \text{ m} \right) F - \left(\frac{0.20 \text{ m}}{\sin 75^\circ} \cos 75^\circ - 0.03 \text{ m} \right) T = 0 \right.$$

$$T = 7.5056F$$

$$\rightarrow \sum F_x = 0: N \sin 75^\circ + F \cos 75^\circ - T = 0$$

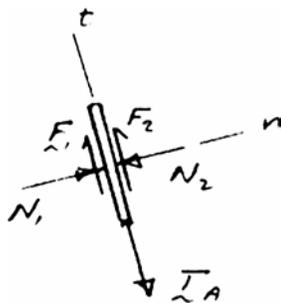
Impending slip: $N = \frac{F}{\mu_s}$, so $F = \left(\frac{\sin 75^\circ}{\mu_s} + \cos 75^\circ \right) T = 7.5056F$

$$\frac{\sin 75^\circ}{\mu_s} + \cos 75^\circ = 7.5056$$

$$\mu_s = 0.1333$$

Must still check impending slip of belt on pipe

FBD small portion of belt at A



$$\nearrow \sum F_n = 0: N_1 - N_2 = 0$$

Impending slip $F_1 = \mu_s N_1$, $F_2 = \mu_s N_2$

so $F_1 = F_2 = F$

$$\searrow \sum F_t = 0: 2F - T_A = 0, T_A = 2F$$

Impending slip of belt on pipe $T = T_A e^{\mu_s \beta}$

$$\text{or } \mu_s = \frac{1}{\beta} \ln \frac{T}{2F} = \frac{1}{4.9742} \ln \frac{7.5056}{2} = 0.2659$$

This controls, so for self locking,

$$\mu_{s \text{ min}} = 0.267 \blacktriangleleft$$

Chapter 8, Solution 128.

or

$$\uparrow \Sigma F_n = 0: \quad \Delta N - [T + (T + \Delta T)] \sin \frac{\Delta \theta}{2} = 0$$

$$\Delta N = (2T + \Delta T) \sin \frac{\Delta \theta}{2}$$

→ $\Sigma F_t = 0: \quad [(T + \Delta T) - T] \cos \frac{\Delta \theta}{2} - \Delta F = 0$

or

$$\Delta F = \Delta T \cos \frac{\Delta \theta}{2}$$

Impending slipping: $\Delta F = \mu_s \Delta N$

So

$$\Delta T \cos \frac{\Delta \theta}{2} = \mu_s 2T \sin \frac{\Delta \theta}{2} + \mu_s \Delta T \frac{\sin \Delta \theta}{2}$$

In limit as $\Delta \theta \rightarrow 0: \quad dT = \mu_s T d\theta, \quad \text{or} \quad \frac{dT}{T} = \mu_s d\theta$

So

$$\int_{T_1}^{T_2} \frac{dT}{T} = \int_0^\beta \mu_s d\theta;$$

and

$$\ln \frac{T_2}{T_1} = \mu_s \beta$$

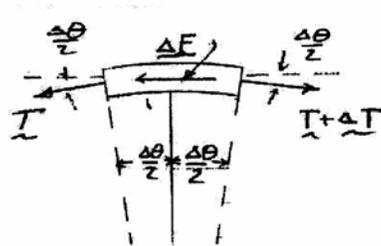
or $T_2 = T_1 e^{\mu_s \beta} \blacktriangleleft$

Note: Nothing above depends on the shape of the surface, except it is assumed to be a smooth curve.

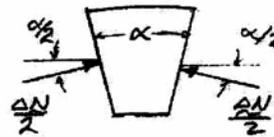
Chapter 8, Solution 129.

Small belt section:

Side view:



End view:



$$\uparrow \Sigma F_y = 0: \quad 2 \frac{\Delta N}{2} \sin \frac{\alpha}{2} - [T + (T + \Delta T)] \sin \frac{\Delta \theta}{2} = 0$$

$$\rightarrow \Sigma F_x = 0: \quad [(T + \Delta T) - T] \cos \frac{\Delta \theta}{2} - \Delta F = 0$$

Impending slipping:

$$\Delta F = \mu_s \Delta N \Rightarrow \Delta T \cos \frac{\Delta \theta}{2} = \mu_s \frac{2T + \Delta T}{\sin \frac{\alpha}{2}} \sin \frac{\Delta \theta}{2}$$

 In limit as $\Delta \theta \rightarrow 0$:

$$dT = \frac{\mu_s T d\theta}{\sin \frac{\alpha}{2}} \quad \text{or} \quad \frac{dT}{T} = \frac{\mu_s}{\sin \frac{\alpha}{2}} d\theta$$

So

$$\int_{T_1}^{T_2} \frac{dT}{T} = \frac{\mu_s}{\sin \frac{\alpha}{2}} \int_0^\beta d\theta$$

or

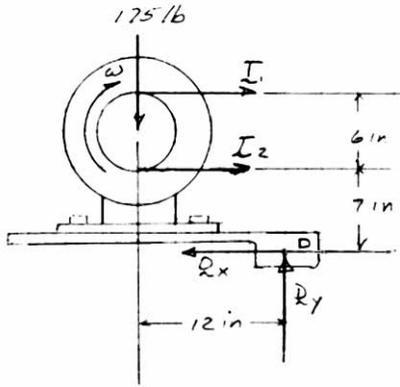
$$\ln \frac{T_2}{T_1} = \frac{\mu_s \beta}{\sin \frac{\alpha}{2}}$$

or

$$T_2 = T_1 e^{\mu_s \beta / \sin \frac{\alpha}{2}} \quad \blacktriangleleft$$

Chapter 8, Solution 130.

FBD motor and mount:



Impending belt slip, cw rotation

$$T_2 = T_1 e^{\frac{\mu_s \beta}{\sin \frac{\alpha}{2}}}$$

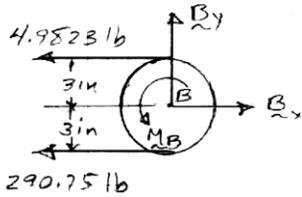
$$T_2 = T_1 e^{\frac{(0.40\pi)}{\sin 18^\circ}} = 58.356 T_1$$

$$\left(\sum M_D = 0: \quad (12 \text{ in.})(175 \text{ lb}) - (13 \text{ in.})T_1 - (7 \text{ in.})T_2 = 0 \right.$$

$$2100 \text{ lb} = [13 \text{ in.} + (7 \text{ in.})(58.356)]T_1$$

$$T_1 = 4.9823 \text{ lb}, \quad T_2 = 58.356 T_1 = 290.75 \text{ lb}$$

FBD drum at B:



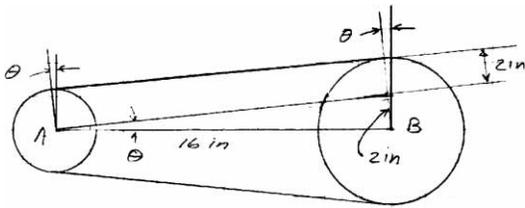
$$\left(\sum M_B = 0: \quad M_B + (3 \text{ in.})(4.9823 \text{ lb} - 290.75 \text{ lb}) = 0 \right.$$

$$M_B = 857 \text{ lb}\cdot\text{in.} \blacktriangleleft$$

(Compare to 421 lb·in. using flat belt, Problem 8.107)

Chapter 8, Solution 131.

Geometry:

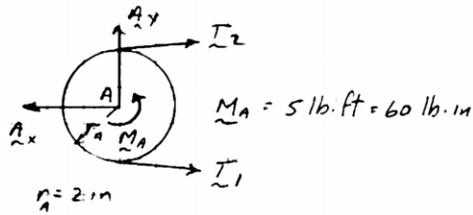


$$\theta = \sin^{-1} \frac{2 \text{ in.}}{16 \text{ in.}} = 7.1808^\circ = 0.12533 \text{ rad}$$

$$\beta_A = \pi - 2\theta = 2.8909 \text{ rad}$$

Since $\beta_B > \beta_A$, impending slip on A will control the maximum couple transmitted

FBD A:



$$\sum M_A = 0: \quad 60 \text{ lb}\cdot\text{in.} + (2 \text{ in.})(T_1 - T_2) = 0$$

$$T_2 - T_1 = 30 \text{ lb}$$

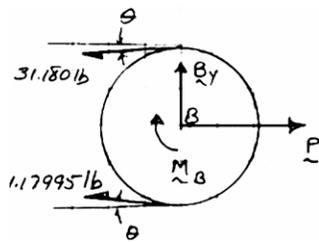
Impending slip: $T_2 = T_1 e^{\frac{\mu_s \beta}{\sin \frac{\alpha}{2}}}$

$$\text{so } T_1 \left(e^{\frac{(0.35)(2.8909)}{\sin 18^\circ}} - 1 \right) = 30 \text{ lb}$$

$$T_1 = 1.17995 \text{ lb}$$

$$T_2 = 31.180 \text{ lb}$$

FBD B:

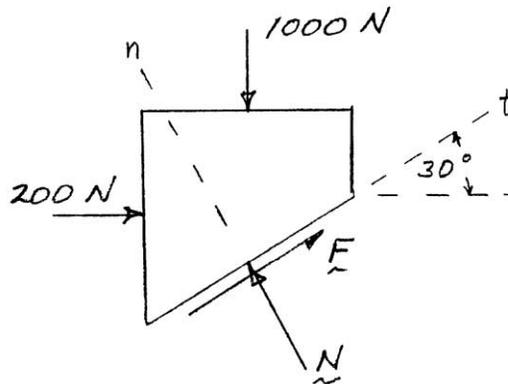


$$\rightarrow \sum F_x = 0: \quad P - (31.180 \text{ lb} + 1.17995 \text{ lb}) \cos 7.1808^\circ = 0$$

$$P = 32.1 \text{ lb} \blacktriangleleft$$

Chapter 8, Solution 132.

FBD block:



$$\begin{aligned} \nearrow \Sigma F_n = 0: \quad N - (1000 \text{ N})\cos 30^\circ - (200 \text{ N})\sin 30^\circ &= 0 \\ N &= 966.03 \text{ N} \end{aligned}$$

Assume equilibrium:

$$\begin{aligned} \nearrow \Sigma F_t = 0: \quad F + (200 \text{ N})\cos 30^\circ - (1000 \text{ N})\sin 30^\circ &= 0 \\ F &= 326.8 \text{ N} = F_{\text{eq.}} \end{aligned}$$

But

$$F_{\text{max}} = \mu_s N = (0.3)966 \text{ N} = 290 \text{ N}$$

$$F_{\text{eq.}} > F_{\text{max}} \quad \text{impossible} \Rightarrow \text{Block moves} \blacktriangleleft$$

and

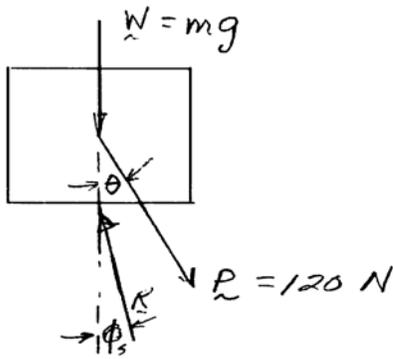
$$\begin{aligned} F &= \mu_k N \\ &= (0.2)(966.03 \text{ N}) \end{aligned}$$

Block slides down

$$\mathbf{F} = 193.2 \text{ N} \nearrow \blacktriangleleft$$

Chapter 8, Solution 133.

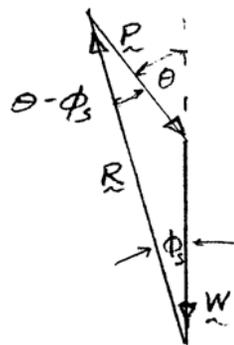
FBD block (impending motion to the right)



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

$$\frac{P}{\sin \phi_s} = \frac{W}{\sin(\theta - \phi_s)}$$

$$\sin(\theta - \phi_s) = \frac{W}{P} \sin \phi_s \quad W = mg$$



$$(a) \quad m = 30 \text{ kg: } \theta - \phi_s = \sin^{-1} \left[\frac{(30 \text{ kg})(9.81 \text{ m/s}^2)}{120 \text{ N}} \sin 14.036^\circ \right]$$

$$= 36.499^\circ$$

$$\therefore \theta = 36.499^\circ + 14.036^\circ \quad \text{or } \theta = 50.5^\circ \blacktriangleleft$$

$$(b) \quad m = 40 \text{ kg: } \theta - \phi_s = \sin^{-1} \left[\frac{(40 \text{ kg})(9.81 \text{ m/s}^2)}{120 \text{ N}} \sin 14.036^\circ \right]$$

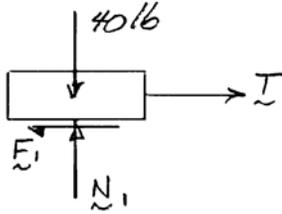
$$= 52.474^\circ$$

$$\therefore \theta = 52.474^\circ + 14.036^\circ \quad \text{or } \theta = 66.5^\circ \blacktriangleleft$$

Chapter 8, Solution 134.

FBDs

Top block:



(a) Note: With the cable, motion must impend at both contact surfaces.

$$\uparrow \Sigma F_y = 0: \quad N_1 - 40 \text{ lb} = 0 \quad N_1 = 40 \text{ lb}$$

Impending slip: $F_1 = \mu_s N_1 = 0.4(40 \text{ lb}) = 16 \text{ lb}$

$$\rightarrow \Sigma F_x = 0: \quad T - F_1 = 0 \quad T - 16 \text{ lb} = 0 \quad T = 16 \text{ lb}$$

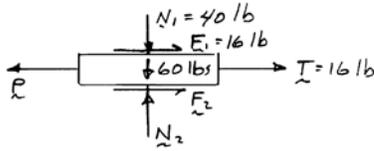
$$\uparrow \Sigma F_y = 0: \quad N_2 - 40 \text{ lb} - 60 \text{ lb} = 0 \quad N_2 = 100 \text{ lb}$$

Impending slip: $F_2 = \mu_s N_2 = 0.4(100 \text{ lb}) = 40 \text{ lb}$

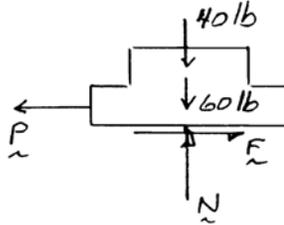
$$\rightarrow \Sigma F_x = 0: \quad -P + 16 \text{ lb} + 16 \text{ lb} + 40 \text{ lb} = 0$$

$$P = 72.0 \text{ lb} \leftarrow \blacktriangleleft$$

Bottom block:



FBD blocks:



(b) Without the cable, both blocks will stay together and motion will impend only at the floor.

$$\uparrow \Sigma F_y = 0: \quad N - 40 \text{ lb} - 60 \text{ lb} = 0 \quad N = 100 \text{ lb}$$

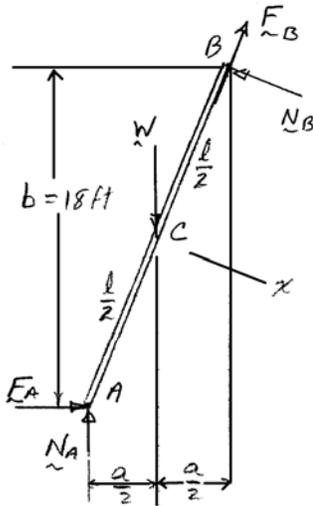
Impending slip: $F = \mu_s N = 0.4(100 \text{ lb}) = 40 \text{ lb}$

$$\rightarrow \Sigma F_x = 0: \quad 40 \text{ lb} - P = 0$$

$$P = 40.0 \text{ lb} \leftarrow \blacktriangleleft$$

Chapter 8, Solution 135.

FBD ladder:



$$a = 7.5 \text{ ft}$$

$$l = 19.5 \text{ ft}$$

$$\frac{a}{l} = \frac{5}{13}$$

$$\frac{b}{l} = \frac{12}{13}$$

Motion impends at both A and B , so

$$F_A = \mu_s N_A \quad \text{and} \quad F_B = \mu_s N_B$$

$$\left(\sum M_A = 0: \quad l N_B - \frac{a}{2} W = 0 \quad \text{or} \quad N_B = \frac{a}{2l} W = \frac{7.5 \text{ ft}}{39 \text{ ft}} W \right)$$

or

$$N_B = \frac{2.5}{13} W$$

Then

$$F_B = \mu_s N_B = \mu_s \frac{2.5W}{13}$$

$$\rightarrow \sum F_x = 0: \quad F_A + \frac{5}{13} F_B - \frac{12}{13} N_B = 0$$

$$\mu_s N_A + \frac{12.5}{(13)^2} \mu_s W - \frac{30}{(13)^2} W = 0$$

$$N_A - \frac{W}{(13)^2} \frac{(30 - 12.5\mu_s)}{\mu_s}$$

$$\uparrow \sum F_y = 0: \quad N_A - W + \frac{12}{13} F_B + \frac{5}{13} N_B = 0$$

$$\left(\frac{30 - 12.5\mu_s}{\mu_s} + 30\mu_s + 12.5 \right) \frac{W}{(13)^2} = W$$

or

$$\mu_s^2 - 5.6333\mu_s + 1 = 0$$

$$\mu_s = 2.8167 \pm 2.6332$$

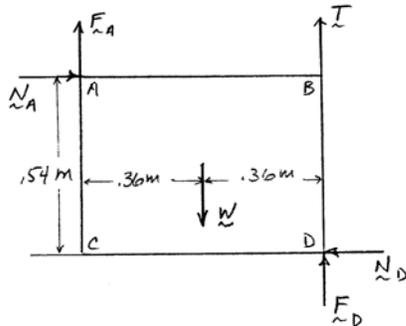
or

$$\mu_s = 0.1835 \quad \text{and} \quad \mu_s = 5.45$$

The larger value is very unlikely unless the surface is treated with some "non-skid" material.

In any event, the smallest value for equilibrium is $\mu_s = 0.1835$ ◀

Chapter 8, Solution 136.

FBD window:


$$W = (4 \text{ kg})(9.81 \text{ m/s}^2) = 39.24 \text{ N}$$

$$T = (2 \text{ kg})(9.81 \text{ m/s}^2) = 19.62 \text{ N} = \frac{W}{2}$$

$$\rightarrow \Sigma F_x = 0: \quad N_A - N_D = 0 \quad N_A = N_D$$

$$\text{Impending motion:} \quad F_A = \mu_s N_A \quad F_D = \mu_s N_D$$

$$\curvearrowleft \Sigma M_D = 0: \quad (0.36 \text{ m})W - (0.54 \text{ m})N_A - (0.72 \text{ m})F_A = 0$$

$$W = \frac{3}{2}N_A + 2\mu_s N_A$$

$$N_A = \frac{2W}{3 + 4\mu_s}$$

$$\uparrow \Sigma F_y = 0: \quad F_A - W + T + F_D = 0$$

$$F_A + F_D = W - T$$

$$= \frac{W}{2}$$

$$\text{Now} \quad F_A + F_D = \mu_s(N_A + N_D) = 2\mu_s N_A$$

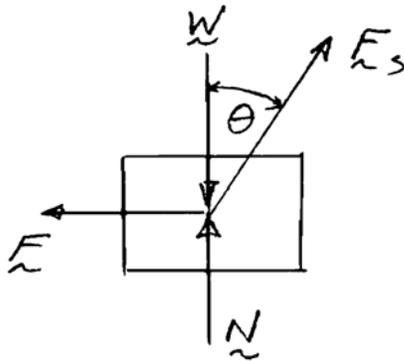
$$\text{Then} \quad \frac{W}{2} = 2\mu_s \frac{2W}{3 + 4\mu_s}$$

or

$$\mu_s = 0.750 \blacktriangleleft$$

Chapter 8, Solution 137.

FBD Collar:


 Stretch of spring $x = \overline{AB} - a = \frac{a}{\cos\theta} - a$

$$F_s = k \left(\frac{a}{\cos\theta} - a \right) = (1.5 \text{ kN/m})(0.5 \text{ m}) \left(\frac{1}{\cos\theta} - 1 \right)$$

$$= (0.75 \text{ kN}) \left(\frac{1}{\cos\theta} - 1 \right) = (750 \text{ N})(\sec\theta - 1)$$

$$\uparrow \Sigma F_y = 0: \quad F_s \cos\theta - W + N = 0$$

or
$$W = N + (750 \text{ N})(1 - \cos\theta)$$

Impending slip:

$$F = \mu_s |N| \quad (F \text{ must be } +, \text{ but } N \text{ may be positive or negative})$$

$$\rightarrow \Sigma F_x = 0: \quad F_s \sin\theta - F = 0$$

or
$$F = F_s \sin\theta = (750 \text{ N})(\tan\theta - \sin\theta)$$

(a) $\theta = 20^\circ: \quad F = (750 \text{ N})(\tan 20^\circ - \sin 20^\circ) = 16.4626 \text{ N}$

Impending motion: $|N| = \frac{F}{\mu_s} = \frac{16.4626 \text{ N}}{0.4} = 41.156 \text{ N}$

 (Note: for $|N| < 41.156 \text{ N}$, motion will occur, equilibrium for $|N| > 41.156$)

But
$$W = N + (750 \text{ N})(1 - \cos 20^\circ) = N + 45.231 \text{ N}$$

 So equilibrium for $W \leq 4.07 \text{ N}$ and $W \geq 86.4 \text{ N} \blacktriangleleft$

(b) $\theta = 30^\circ: \quad F = (750 \text{ N})(\tan 30^\circ - \sin 30^\circ) = 58.013 \text{ N}$

Impending motion: $|N| = \frac{F}{\mu_s} = \frac{58.013}{0.4} = 145.032 \text{ N}$

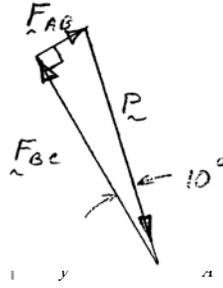
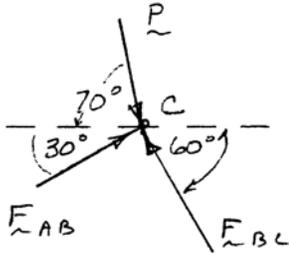
$$W = N + (750 \text{ N})(1 - \cos 30^\circ) = N \pm 145.03 \text{ N}$$

$$= -44.55 \text{ N (impossible)}, 245.51 \text{ N}$$

 Equilibrium for $W \geq 246 \text{ N} \blacktriangleleft$

Chapter 8, Solution 138.

FBD pin C:

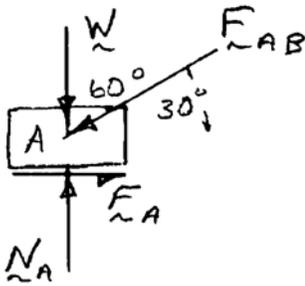


$$F_{AB} = P \sin 10^\circ = 0.173648P$$

$$F_{BC} = P \cos 10^\circ = 0.98481P$$

$$N_A - W - F_{AB} \sin 30^\circ = 0$$

FBD block A:



or
$$N_A = W + 0.173648P \sin 30^\circ = W + 0.086824P$$

$$\rightarrow \Sigma F_x = 0: F_A - F_{AB} \cos 30^\circ = 0$$

or
$$F_A = 0.173648P \cos 30^\circ = 0.150384P$$

For impending motion at A:
$$F_A = \mu_s N_A$$

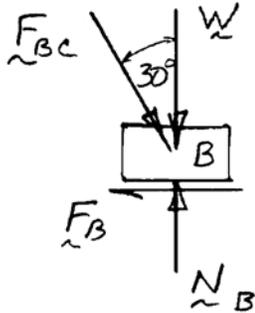
Then
$$N_A = \frac{F_A}{\mu_s}: W + 0.086824P = \frac{0.150384}{0.3}P$$

or
$$P = 2.413W$$

$$\uparrow \Sigma F_y = 0: N_B - W - F_{BC} \cos 30^\circ = 0$$

$$N_B = W + 0.98481P \cos 30^\circ = W + 0.85287P$$

FBD block B:



$$\rightarrow \Sigma F_x = 0: F_{BC} \sin 30^\circ - F_B = 0$$

$$F_B = 0.98481P \sin 30^\circ = 0.4924P$$

For impending motion at B:
$$F_B = \mu_s N_B$$

Then
$$N_B = \frac{F_B}{\mu_s}: W + 0.85287P = \frac{0.4924P}{0.3}$$

or
$$P = 1.268W$$

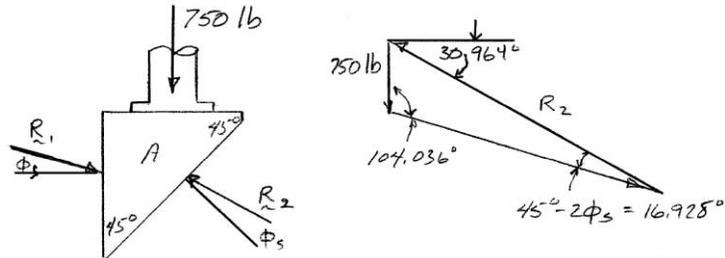
Thus, maximum P for equilibrium

$$P_{\max} = 1.268W \blacktriangleleft$$

Chapter 8, Solution 139.

$$\phi_s = \tan^{-1} \mu_s = \tan^{-1} 0.25 = 14.036^\circ$$

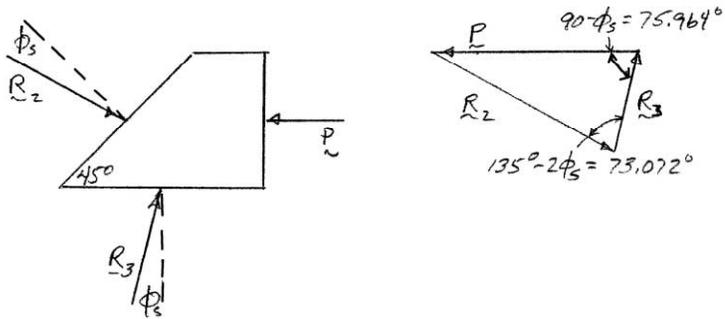
FBD block A:



$$\frac{R_2}{\sin 104.036^\circ} = \frac{750 \text{ lb}}{\sin 16.928^\circ}$$

$$R_2 = 2499.0 \text{ lb}$$

FBD wedge B:



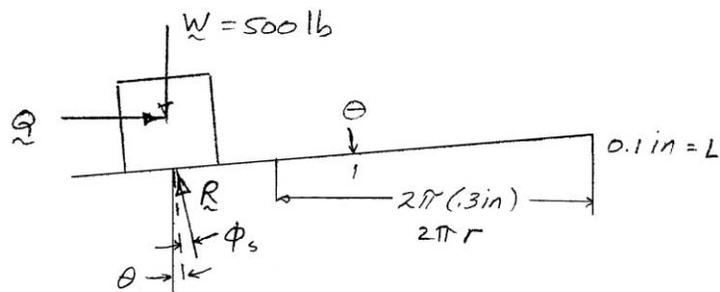
$$\frac{P}{\sin 73.072^\circ} = \frac{2499.0}{\sin 75.964^\circ}$$

$$P = 2464 \text{ lb}$$

$$P = 2.46 \text{ kips} \leftarrow \blacktriangleleft$$

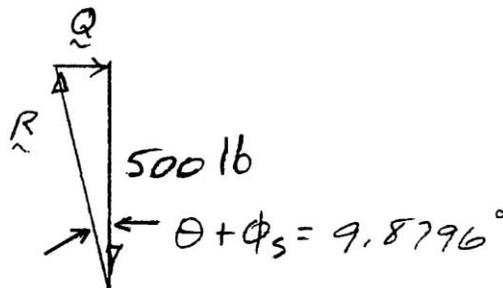
Chapter 8, Solution 140.

Block on incline:



$$\theta = \tan^{-1} \frac{0.1 \text{ in.}}{2\pi(0.3 \text{ in.})} = 3.0368^\circ$$

$$\phi_s = \tan^{-1} \mu_s = \tan^{-1} 0.12 = 6.8428^\circ$$



$$Q = (500 \text{ lb}) \tan 9.8796^\circ = 87.08 \text{ lb}$$

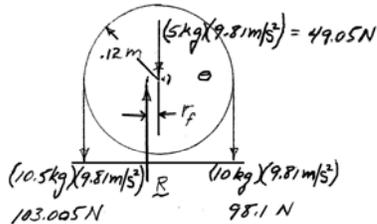
Couple on each side

$$M = rQ = (0.3 \text{ in.})(87.08 \text{ lb}) = 26.12 \text{ lb}\cdot\text{in.}$$

$$\text{Couple to turn} = 2M = 52.2 \text{ lb}\cdot\text{in.} \blacktriangleleft$$

Chapter 8, Solution 141.

FBD pulley:



$$\uparrow \Sigma F_y = 0: \quad R - 103.005 \text{ N} - 49.05 \text{ N} - 98.1 \text{ N} = 0$$

$$R = 250.155 \text{ N}$$

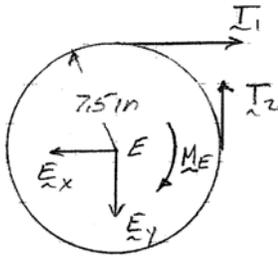
$$\curvearrowleft \Sigma M_O = 0: \quad (0.12 \text{ m})(103.005 \text{ N} - 98.1 \text{ N}) - r_f(250.155 \text{ N}) = 0$$

$$r_f = 0.0023529 \text{ m} = 2.3529 \text{ mm}$$

$$\phi_s = \sin^{-1} \frac{r_f}{r_s}$$

$$\mu_s = \tan \phi_s = \tan \left(\sin^{-1} \frac{r_f}{r_s} \right) = \tan \left(\sin^{-1} \frac{2.3529 \text{ mm}}{30 \text{ mm}} \right)$$

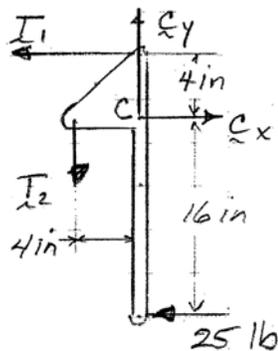
$$\mu_s = 0.0787 \blacktriangleleft$$

Chapter 8, Solution 142.
FBD wheel:


$$\left(\sum M_E = 0: \quad -M_E + (7.5 \text{ in.})(T_2 - T_1) = 0 \right.$$

or

$$M_E = (7.5 \text{ in.})(T_2 - T_1)$$

FBD lever:


$$\left(\sum M_C = 0: \quad (4 \text{ in.})(T_1 + T_2) - (16 \text{ in.})(25 \text{ lb}) = 0 \right.$$

or

$$T_1 + T_2 = 100 \text{ lb}$$

Impending slipping:

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

or

$$T_2 = T_1 e^{0.25 \left(\frac{3\pi}{2} \right)} = 3.2482 T_1$$

So

$$T_1 (1 + 3.2482) = 100 \text{ lb}$$

$$T_1 = 23.539 \text{ lb}$$

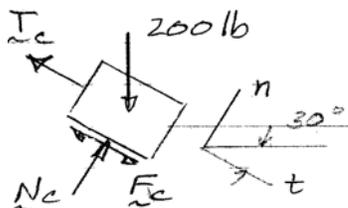
and

$$M_E = (7.5 \text{ in.})(3.2482 - 1)(23.539 \text{ lb}) = 396.9 \text{ lb}\cdot\text{in.}$$

$$M_E = 397 \text{ lb}\cdot\text{in.} \quad \blacktriangleleft$$

Changing the direction of rotation will change the direction of M_E and will switch the magnitudes of T_1 and T_2 .

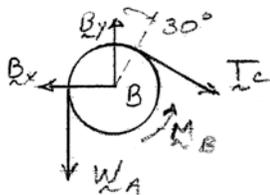
The magnitude of the couple applied will not change. \blacktriangleleft

Chapter 8, Solution 143.
FBD block:


$$\uparrow \Sigma F_n = 0: \quad N_C - (200 \text{ lb}) \cos 30^\circ = 0; \quad N = 100\sqrt{3} \text{ lb}$$

$$\searrow \Sigma F_t = 0: \quad T_C - (200 \text{ lb}) \sin 30^\circ \mp F_C = 0$$

$$T_C = 100 \text{ lb} \pm F_C \quad (1)$$

FBD Drum:

 where the upper signs apply when F_C acts \searrow

 (a) For impending motion of block \searrow , $F_C \swarrow$, and

$$F_C = \mu_s N_C = 0.35(100\sqrt{3} \text{ lb}) = 35\sqrt{3} \text{ lb}$$

$$\text{So, from Equation (1):} \quad T_C = (100 - 35\sqrt{3}) \text{ lb}$$

$$\text{But belt slips on drum, so} \quad T_C = W_A e^{\mu_k \beta}$$

$$W_A = [(100 - 35\sqrt{3}) \text{ lb}] e^{-0.25(\frac{2\pi}{3})}$$

$$W_A = 23.3 \text{ lb} \blacktriangleleft$$

 (b) For impending motion of block \swarrow , $F_C \searrow$ and $F_C = \mu_s N_C = 35\sqrt{3} \text{ lb}$

$$\text{From Equation (1):} \quad T_C = (100 + 35\sqrt{3}) \text{ lb}$$

$$\text{Belt still slips, so} \quad W_A = T_C e^{-\mu_k \beta} = [(100 + 35\sqrt{3}) \text{ lb}] e^{-0.25(\frac{2\pi}{3})}$$

$$W_A = 95.1 \text{ lb} \blacktriangleleft$$

continued

PROBLEM 8.143 CONTINUED

(c) For steady motion of block \searrow , $F_C \searrow$, and $F_C = \mu_k N_C = 25\sqrt{3}$ lb

Then, from Equation (1): $T = (100 + 25\sqrt{3})$ lb.

Also, belt is not slipping on drum, so

$$W_A = T_C e^{-\mu_s \beta} = \left[(100 + 25\sqrt{3}) \text{ lb} \right] e^{-0.35 \left(\frac{2\pi}{3} \right)}$$

$$W_A = 68.8 \text{ lb} \blacktriangleleft$$