Chapter 8: Friction

8.1 - 8.2 Coulomb Friction Model

Thus far we have been considering problems in equilibrium without friction. In reality, friction is always present between any two surfaces in contact which may be moving with respect to each other or impending to move.

There are two types of friction: Coulomb friction (dry) and fluid friction. Fluid friction applies to lubricated mechanisms. The present discussion is limited to dry friction between nonlubricated surfaces.

Consider the block resting on a flat surface:

\[ F_{\text{static}} \leq F_{\text{max}} = \mu_s N \]

\[ F_{\text{kinetic}} = \mu_k N \]

<table>
<thead>
<tr>
<th>Table 8.1. Approximate Values of Coefficient of Static Friction for Dry Surfaces</th>
</tr>
</thead>
<tbody>
<tr>
<td>Material</td>
</tr>
<tr>
<td>Metal on metal</td>
</tr>
<tr>
<td>Metal on wood</td>
</tr>
<tr>
<td>Metal on stone</td>
</tr>
<tr>
<td>Metal on leather</td>
</tr>
<tr>
<td>Wood on wood</td>
</tr>
<tr>
<td>Wood on leather</td>
</tr>
<tr>
<td>Stone on stone</td>
</tr>
<tr>
<td>Earth on earth</td>
</tr>
<tr>
<td>Rubber on concrete</td>
</tr>
</tbody>
</table>

Note: Friction forces are

- Always opposes relative motion between two surfaces.
- Limited in magnitude and will not prevent motion if sufficiently large forces are applied.
- Dependent on type and condition of contact surfaces
- Proportional to the normal force
- Independent of contact area

- No friction, \( (P_x = 0) \)
- No motion, \( (P_x < F_m) \)
- Motion impending, \( (P_x = F_m) \)
- Motion, \( (P_x > F_m) \)
8.3 - 8.4 Angles of Friction; Dry Friction

The frictional force between two surfaces can also be expressed as an angle. - the angle that the resultant makes with direction of the normal force.

\[
\tan \phi_s = \frac{F_s}{N} = \frac{\mu_s N}{N}
\]
\[
\tan \phi_k = \frac{F_k}{N} = \frac{\mu_k N}{N}
\]

Another way to visualize the angles of static and kinetic friction is with a block resting on an incline.

For problems involving Friction:
- Assume equilibrium and draw FBD including the required friction forces for equilibrium.
- Check if the required friction forces are less than \( F_{\text{max}} \) (Static).
  - If less \( \Rightarrow \) analysis correct; DONE.
  - If more \( \Rightarrow \) equilibrium does NOT hold; REDO with kinetic friction and DYNAMICS.
Read Examples 8.1, 8.2 and 8.3.

Exercise 8.10

\( \mu_s = 0.25 \) and \( \mu_k = 0.20 \)

Find the force required to pull the belt
- to the left
- to the right.

1. **Moving to the left**:

\[ F_x = 0 \]
\[ \Rightarrow -\mu_s N_1 + AB_1 \cos 30^\circ = 0 \]
\[ F_y = 0 \]
\[ \Rightarrow N_1 - 80 + AB_1 \sin 30^\circ = 0 \]

\[ N_1 = 71.72 \text{ lb} \]
and \( AB_1 = 16.56 \text{ lb} \)

\[ P = F_1 = 14.34 \text{ lb} \]

2. **Moving to the right**:

\[ F_x = 0 \]
\[ \Rightarrow \mu_k N_2 - AB_2 \cos 30^\circ = 0 \]
\[ F_y = 0 \]
\[ \Rightarrow N_2 - 80 - AB_2 \sin 30^\circ = 0 \]

\[ N_2 = 90.44 \text{ lb} \]
and \( AB_2 = 20.89 \text{ lb} \)

\[ P = F_2 = 18.09 \text{ lb} \]
8.5 - 8.6 Wedges and Threaded Screws

Wedges are used to make small adjustments in height for heavy objects. The force required to lift the object is usually much smaller than its weight. The force required to lower the object is even smaller.

Wedges are usually self-locking i.e. upon the removal of the force $P$, the wedge stays in place.

Consider the FBD of the block and the wedge for different cases:

Case (I) Raising the block:

Case (II) Block under self weight and self-locking wedge:

Read Example 8.4

Exercise 8.48 & 8.49

Determine $P$, $\mu_s = 0.3$
Square Threaded Screws

Square-threaded screws frequently used in jacks, presses, etc. Analysis similar to block on inclined plane. Recall friction force does not depend on area of contact.

Imagine the socket in the "base" of the figure as a spiral ramp. Think of one revolution of the thread block in the spiral:

- **Impending motion upwards.** Solve for \( Q \) to lower load.
- **Self-locking, solve for \( Q \) to hold load.**
- **Non-locking, solve for \( Q \) to hold load.**

\[
M_{\text{shaft}} = 0 \\
\Rightarrow Qr = Pa \\
\Rightarrow Q = Pa/r
\]

Moment of force \( P \) is equal to moment of force \( Q \) about the shaft of the screw:

\[
Qr = Pa
\]

Thus solve for \( Q \) and calculate the sequined \( P \) by:

\[
\Rightarrow P = \frac{Qr}{a}
\]
Read example 8.5.

Exercise 8.67

Worm gear AB has mean radius 1.5 in. and a lead of 0.375 in. $\mu_s = 0.12$

Determine the couple-moment that must be applied to the shaft AB to rotate the big gear counterclockwise.

$$W = \frac{7.2}{12} = 0.6 \text{kips}$$

Unwrap

$$\tan \theta = \left( \frac{0.375}{1.5} \right)$$

rotate key 90°

\[ \begin{aligned}
\sum F_x &= Q - F \cos \theta - N \sin \theta = 0 \\
\sum F_y &= -W - F \sin \theta + N \cos \theta = 0
\end{aligned} \]

Unknowns: $N, Q$

\[ M = Q \times = ? \]

\[ \Rightarrow \text{Couple moment required} \]

$$M = Q \times$$