Friction

Normal and Tangential Axes

- **normal axis** is perpendicular to surface
- **tangential axis** is parallel to surface

Laws of Dry Friction:

**Static:** maximum static friction

}\[ F_{\text{static}} = \mu_{\text{static}} F_{\text{normal}} \]

**Kinetic:** maximum kinetic friction

}\[ F_{\text{kinetic}} = \mu_{\text{kinetic}} F_{\text{normal}} \]

Coefficients of Static Dry Friction

<table>
<thead>
<tr>
<th>Surface Combination</th>
<th>Coefficient Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Metal on metal</td>
<td>0.15 - 0.60</td>
</tr>
<tr>
<td>Metal on wood</td>
<td>0.20 - 0.60</td>
</tr>
<tr>
<td>Metal on stone</td>
<td>0.30 - 0.70</td>
</tr>
<tr>
<td>Wood on wood/leather</td>
<td>0.25 - 0.50</td>
</tr>
<tr>
<td>Stone on stone</td>
<td>0.40 - 0.70</td>
</tr>
<tr>
<td>Earth on earth</td>
<td>0.20 - 1.00</td>
</tr>
<tr>
<td>Rubber on concrete</td>
<td>0.60 - 0.90</td>
</tr>
<tr>
<td>Nylon on nylon</td>
<td>0.15 - 0.25</td>
</tr>
<tr>
<td>Bone on bone (cartilage)</td>
<td>0.10 - 0.20</td>
</tr>
<tr>
<td>Steel on Teflon</td>
<td>0.04 - 0.05</td>
</tr>
<tr>
<td>Metal of ice</td>
<td>0.02 - 0.05</td>
</tr>
</tbody>
</table>
Forces of Friction:

Example: If \( F_{\text{applied}} = 25.0 \text{ N} \), \( F_{\text{static}} = 100 \text{ N} \), \( W = 30.0 \text{ N} \), compute \( F_{\text{friction}} \).

\[
\sum F_t = 0: F_{\text{friction}} + F_{\text{applied}} \cos 20^\circ = 0
\]

therefore \( F_{\text{friction}} = -25.0 \cos 20^\circ = -23.5 \text{ N} \)

(note answer must be > 100 newtons, i.e., max. static friction)
Relationship between Applied Force and Friction:

- as applied force increases friction increases until a maximum is reached and slipping occurs
- maximum is called $F_{\text{static}}$
- after body starts to move frictional force drops to a new level called $F_{\text{kinetic}}$
- any further increase in the applied force is resisted by $F_{\text{kinetic}}$
Empirical Method for Calculating Coefficient of Static Friction:

- cover a load and incline with two surfaces to be tested
- place load on an incline that can be raised at one end
- make sure incline and load are flat and clean
- increase incline until load just starts to slip
- measure angle of incline, \( \theta \)
- repeat and obtain average angle
- coefficient of static friction = \( \mu_{\text{static}} = \tan \theta \)
- proof follows

At instant of impending motion: \( \mu_{\text{static}} = \tan \theta \)

- coefficient of kinetic friction is more difficult to obtain
- tan of angle that keeps load moving at constant velocity
Angles of Friction

- angle of an incline at the point of **impending motion**
- tangent (tan) of this angle is the same as the coefficient of static friction

Proof:

\[ \sum F_n = 0: \quad F_{\text{normal}} - W \cos \theta = 0 \]

\[ F_{\text{normal}} = W \cos \theta \]

\[ \sum F_t = 0: \quad F_{\text{static}} - W \sin \theta = 0 \]

\[ F_{\text{static}} = W \sin \theta \]

\[ \mu_{\text{static}} = \frac{F_{\text{static}}}{F_{\text{normal}}} = \frac{W \sin \theta}{W \cos \theta} = \tan \theta \]

- to compute the **coefficient of kinetic friction**, lower the incline slowly until the mass just stops–this is the angle of kinetic friction
- as above the tan of this angle is the coefficient of kinetic friction
Frictional States

(a) no friction

(b) no motion \((F_x < F_{static})\)

(c) motion impending \((F_x = F_{static})\)

(d) motion \((F_x > F_{static})\)
Measuring Friction using Force Platforms

- line load and force platform with surfaces to be tested
- pull load across clean level force platform
- record maximum horizontal force \( (F_x) \) at point load starts to move
- \( \mu_{static} = \text{horizontal force} / \text{vertical force} \)
- record horizontal force when load is moving
- \( \mu_{kinetic} = \text{horizontal force} / \text{vertical force} \)