Announcements

- Concept Inventory/"Hidden Figures" assessment this week at CBTF: extra credit opportunity
- Written Exam – next Thursday, Nov 8, 7-9pm
  - Locations will be posted on Piazza
- This is the last week of TAM 210 (lectures and discussion!)

❑ Upcoming deadlines:

- Friday (11/2)
  - PL HW


Friction

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Objectives

- Introduce the concept of dry friction
- Analyze the equilibrium of rigid bodies subjected to dry friction

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Friction

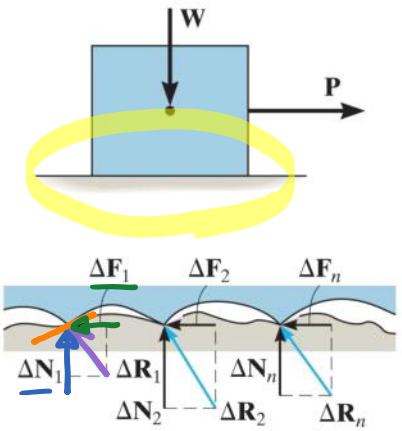
Friction is a force that resists the movement of two contacting surfaces that slide relative to one another. This force acts tangent to the surface at the points of contact and is directed so as to oppose the possible or existing motion between the surfaces.

Dry Friction (or Coulomb friction) occurs between the contacting surfaces of bodies when there is no lubricating fluid.

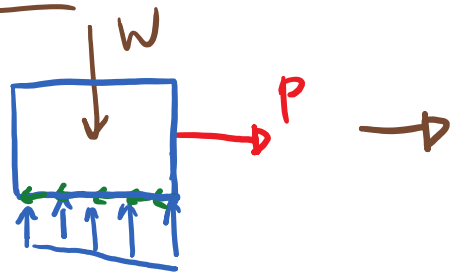
Figure: 08_COC
The effective design of each brake on this railroad wheel requires that it resist the frictional forces developed between it and the wheel. In this chapter we will study dry friction, and show how to analyze friction forces for various engineering applications.

Dry friction

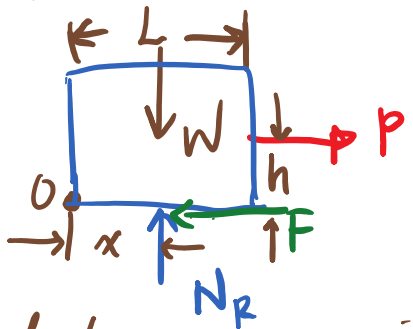
- Consider the effects of pulling horizontally (force **P**) a block of weight **W** which is resting on a **rough** surface.
- The floor exerts an uneven distribution of normal forces ΔN_n and frictional forces ΔF_n along the contacting surface.
- These distributed loads can be represented by their equivalent resultant normal forces N and frictional forces F



FBD



Equivalent FBD



Q: Where should N_R be located to ensure equilibrium for the box when P is applied?

- Is it located at the center of the box ($x = \frac{L}{2}$)?

EoE

$$\Sigma M_o = -W\left(\frac{L}{2}\right) + N_R\left(\frac{L}{2}\right) - P(h) = 0$$

$$\Sigma F_y = N_R - W = 0 \rightarrow W = N_R$$

$$\Sigma M_o = -W\left(\frac{L}{2}\right) + W\left(\frac{L}{2}\right) - P(h) = 0$$

Since $P > 0$, $h > 0$, $Ph \neq 0$, so P will cause the box to move (rotate) if the equivalent N_R from distributed ground support is located at the center. Therefore, N_R location must move to create counter moment to balance Ph.

- If N_R is not located at the center.

$$\Sigma M_o = -W\left(\frac{L}{2}\right) + Nx - Ph = 0$$

$$\rightarrow \quad x = \frac{\frac{WL}{2} + Ph}{N} = \frac{\frac{WL}{2} + Ph}{W} = \underbrace{\frac{L}{2} + \frac{Ph}{2}}.$$

Dry friction

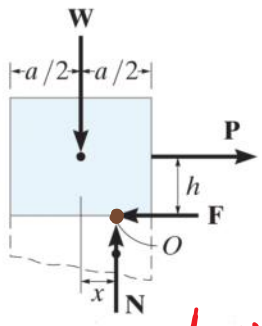
Scenarios of friction analysis to consider:

① $P = 0$, $F_f = 0$, no friction, no motion.

② F_f (friction force) $< F_s$, no motion, $F_f = P$

③ $F_f = F_s$, no motion, but impending

④ $F_f > F_s$, motion.



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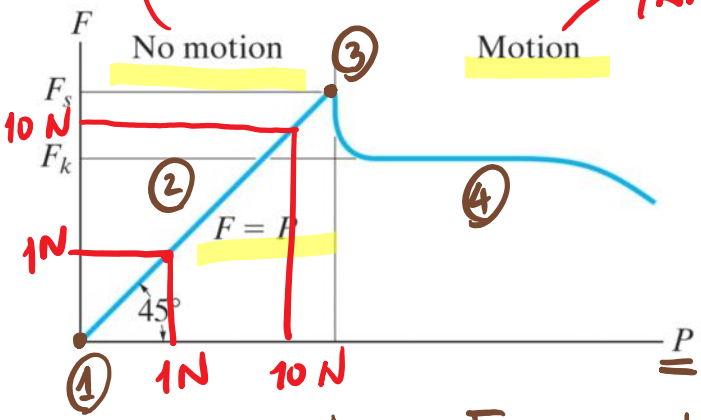

TAM 212

Table 8–1 Typical Values for μ_s	
Contact Materials	Coefficient of Static Friction (μ_s)
Metal on ice	0.03–0.05
Wood on wood	0.30–0.70
Leather on wood	0.20–0.50
Leather on metal	0.30–0.60
Aluminum on aluminum	1.10–1.70

Impending motion: $F_s = \mu_s N$

↑ coefficient of static friction

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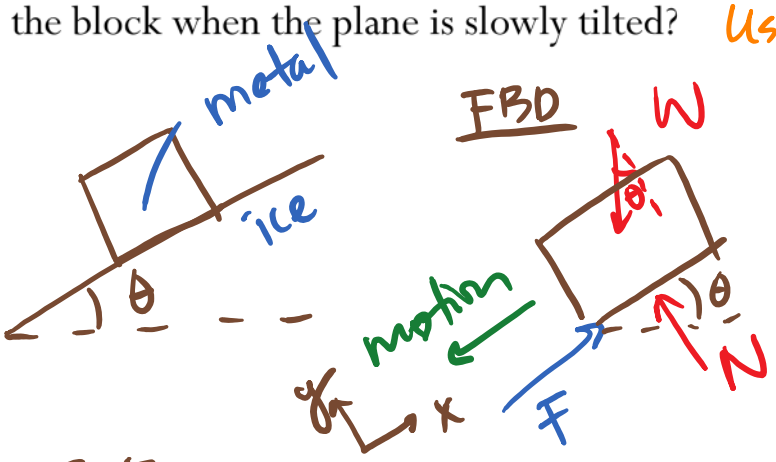
Determine μ_s Experimentally

A block with weight W is placed on an inclined plane. What will happen to the block when the plane is slowly tilted?

Use measured θ to find μ_s between the block and the ramp.



EoE

① $\Sigma F_x = F - W\sin\theta = 0$

② $\Sigma F_y = N - W\cos\theta = 0 \rightarrow W = \frac{N}{\cos\theta}$

② → ① $F - \left(\frac{N}{\cos\theta}\right)\sin\theta = 0 \rightarrow F = N\tan\theta = N\mu_s$

$N\mu_s$ ↑ maximum static friction equation.

$$\boxed{\mu_s = \tan\theta_s}$$

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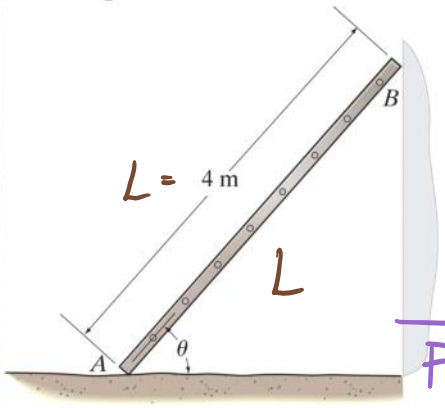
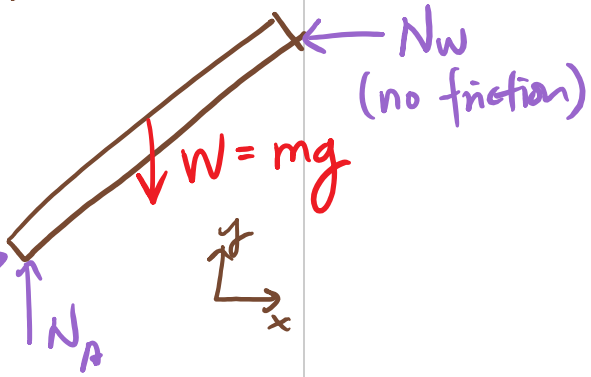
Example

A wooden ladder with a mass of 10 kg is leaning against a smooth wall on an icy ground. Can it maintain equilibrium if $\theta = 30°$?



FBD



From Table 8-1 earlier, μ_s between metal and ice: $\mu_s = 0.03 \sim 0.05$.

I. Find the friction force required to maintain equilibrium:

EoE: ① $\Sigma F_x = F - N_W = 0$

② $\Sigma F_y = N_A - W = 0 \rightarrow N_A = W$

③ $\Sigma M_A = W\left(\frac{L}{2}\right)\cos\theta - N_W(L\sin\theta) = 0$

$\rightarrow N_W = \frac{W(L/2)\cos\theta}{L\sin\theta} = \frac{W}{2}\cot\theta$

③ → ①: $F = N_W = \frac{W}{2}\cot\theta$ (friction force required for equilibrium)

II. Find the maximum static friction between the ladder and icy ground:

$F_s = \mu_s N_A = 0.03(W)$

III. Compare to see if friction required for equilibrium is less than maximum static friction:

$$F = \frac{W}{2}\cot\theta = 85\,N > F_s = 0.03W = 2.943\,N$$

→ Equilibrium cannot be maintained at $\theta = 30°$.

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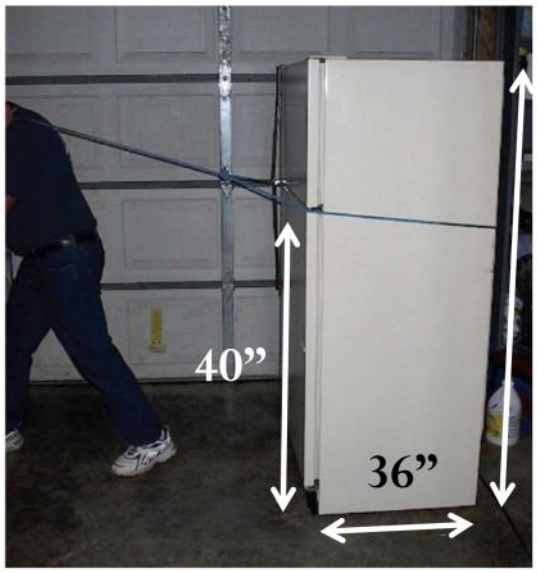

Given: Fridge weight = 250 lb and $\mu_s = 0.4$

Find: The maximum horizontal force P that can be applied at without causing movement of the crate.

It is observed that when the bed of the dump truck is raised to an angle of the vending machines will begin to slide off the bed. Determine the static coefficient of friction between a vending machine and the surface of the truck bed.