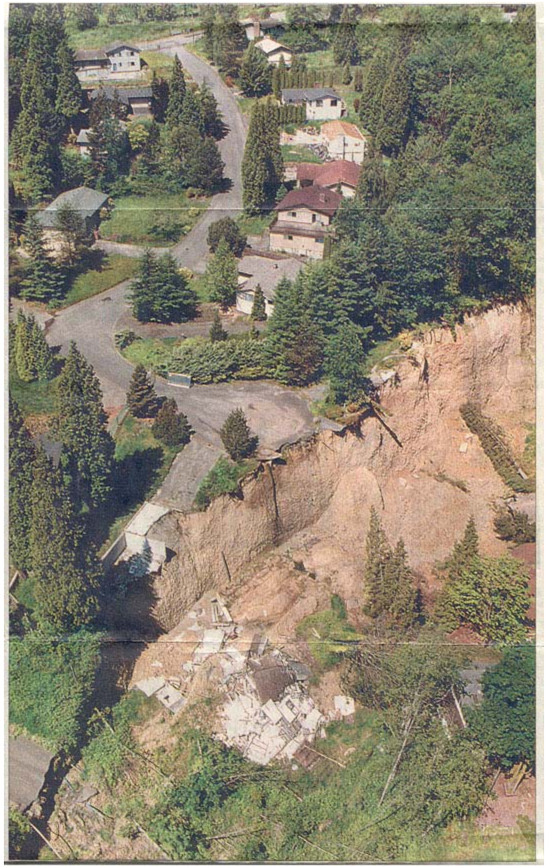
Lecture 12: Slope Stability

Key Questions

1. How do “friction” and “cohesion” work together to stabilize slopes?
2. What is trying to “pull” slope material down?
3. How does the slope angle play a role in slope stability?
4. What is the “factor of safety” equation?

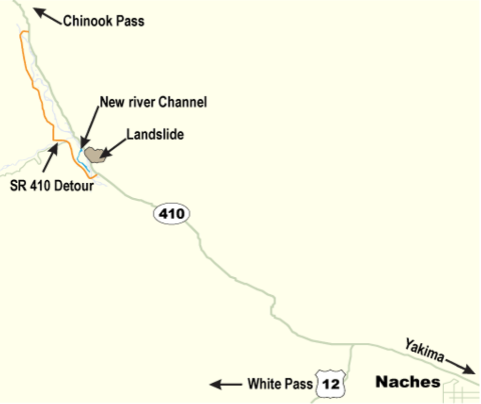
Kelso, WA Landslide



http://www.nwgeoscience.com/kelso/photos/index.html

Decemeber 2007 storm event near Chehalis

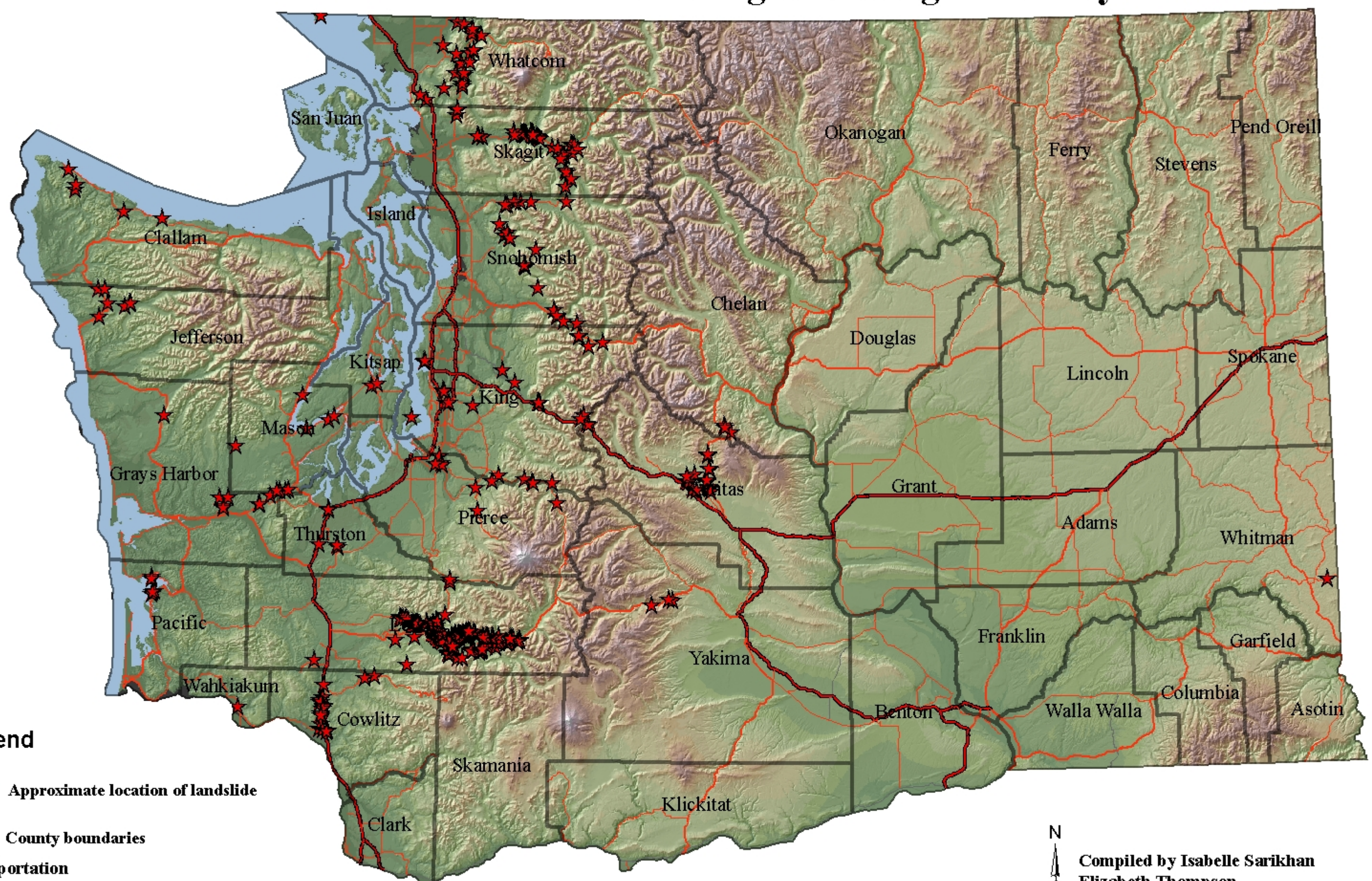
Naches Landslide in October 2009



A massive landslide that closed a section of State Route 410, destroyed at least two homes, blocked and changed the flow of the Naches River (10/11/2009)

WASHINGTON STATE DEPARTMENT OF
Natural Resources

January 2009 Storm Event
Landslide Locations
Division of Geology and Earth Resources
Washington Geological Survey



Legend

★ **Approximate location of landslide**

County boundaries

Transportation

Interstate

U.S.

State

Local

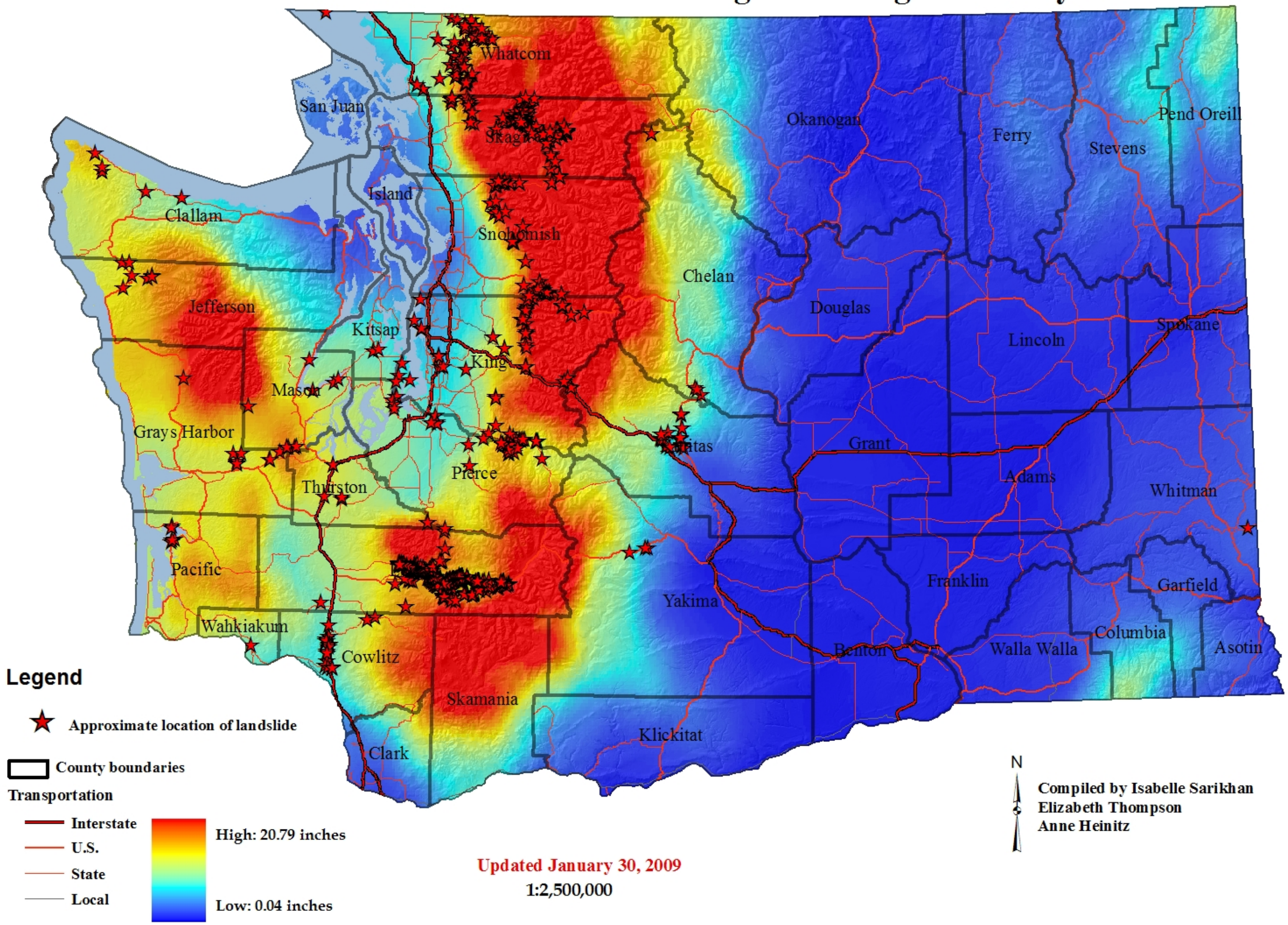
N

Compiled by Isabelle Sarikhan
Elizabeth Thompson
Anne Heinitz

Updated January 16, 2009 at 4:00pm

WASHINGTON STATE DEPARTMENT OF
Natural Resources
Peter Goldmark - Commissioner of Public Lands

January 2009 Storm Event
January 6-9th Precipitation Totals
Division of Geology and Earth Resources
Washington Geological Survey

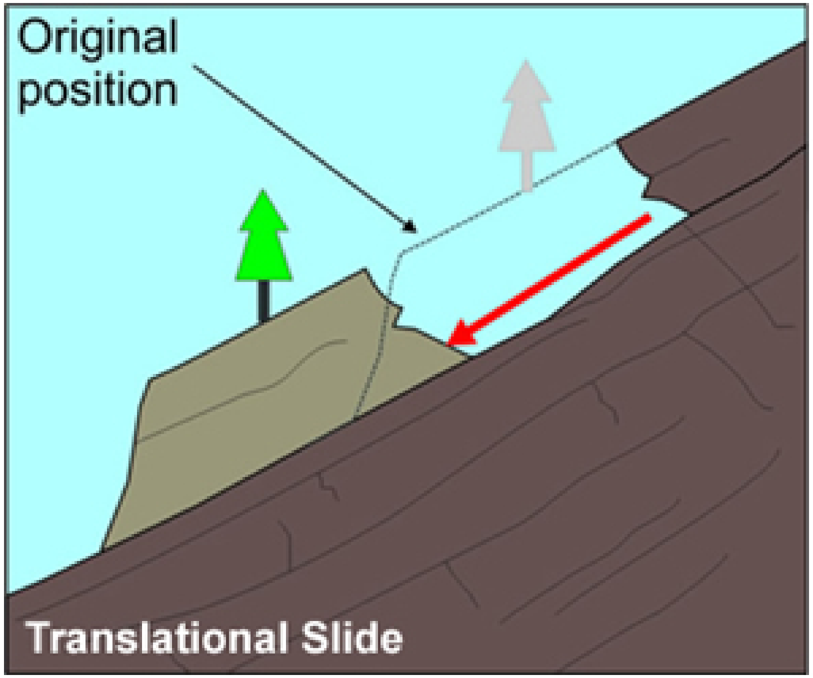


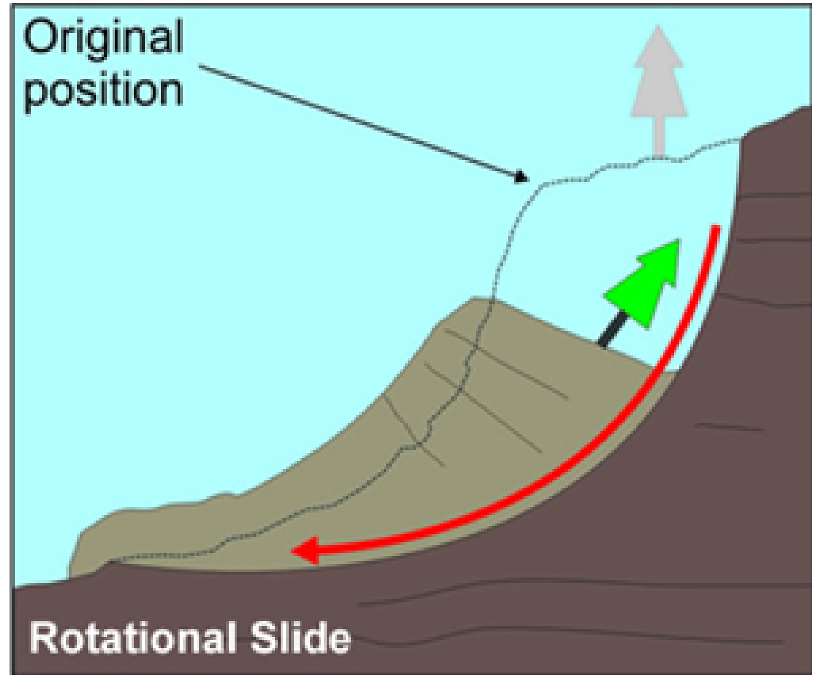
Updated January 30, 2009
1:2,500,000

Slope stability is controlled by

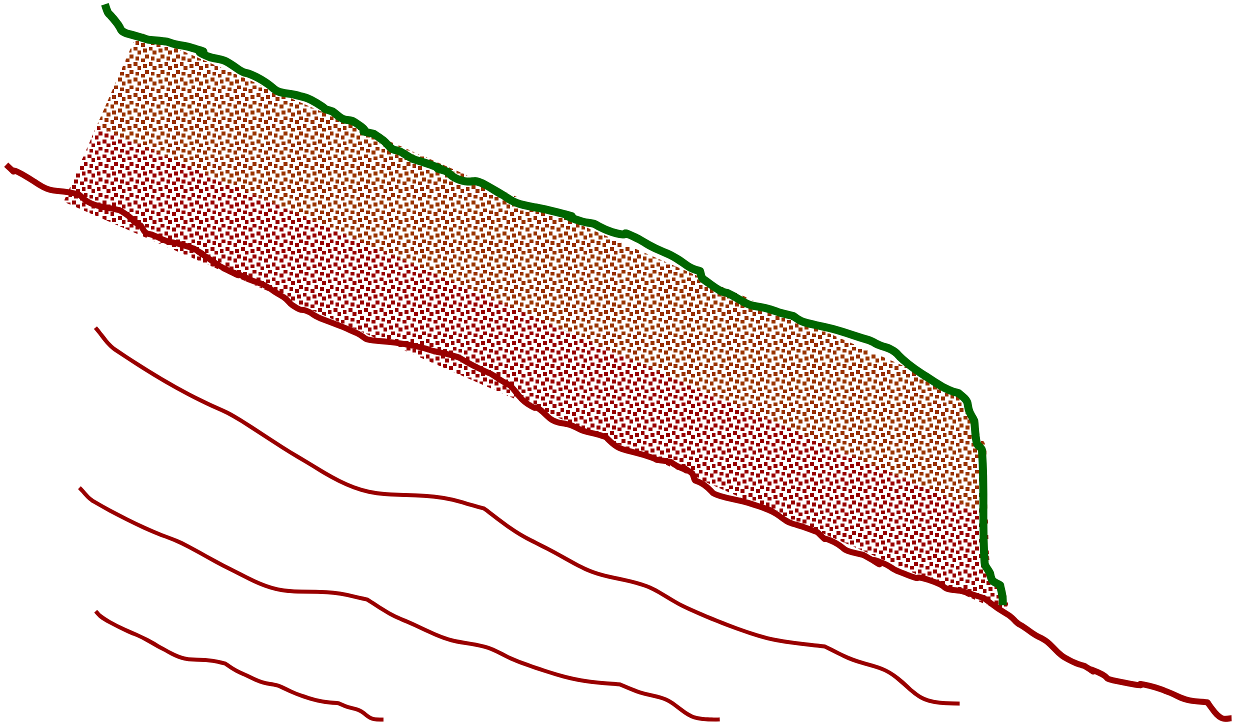
Tons of earth and vegetation washed away from clear-cut hillsides into Stillman Creek, a tributary of the south fork of the Chehalis River.

- relief
- material strength
- soil water content
- vegetation

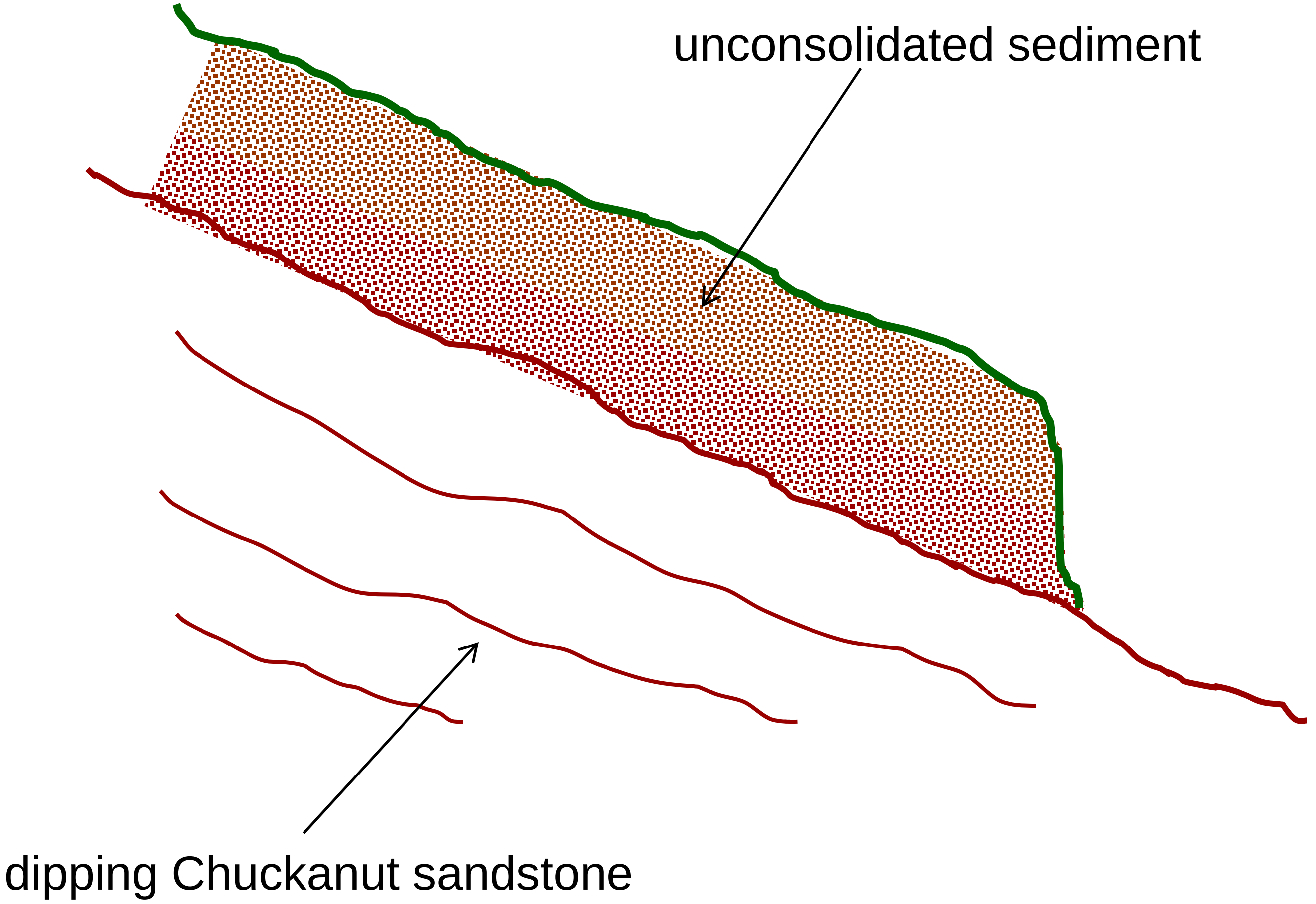

Original
position
Translational Slide


Original
position
Rotational Slide

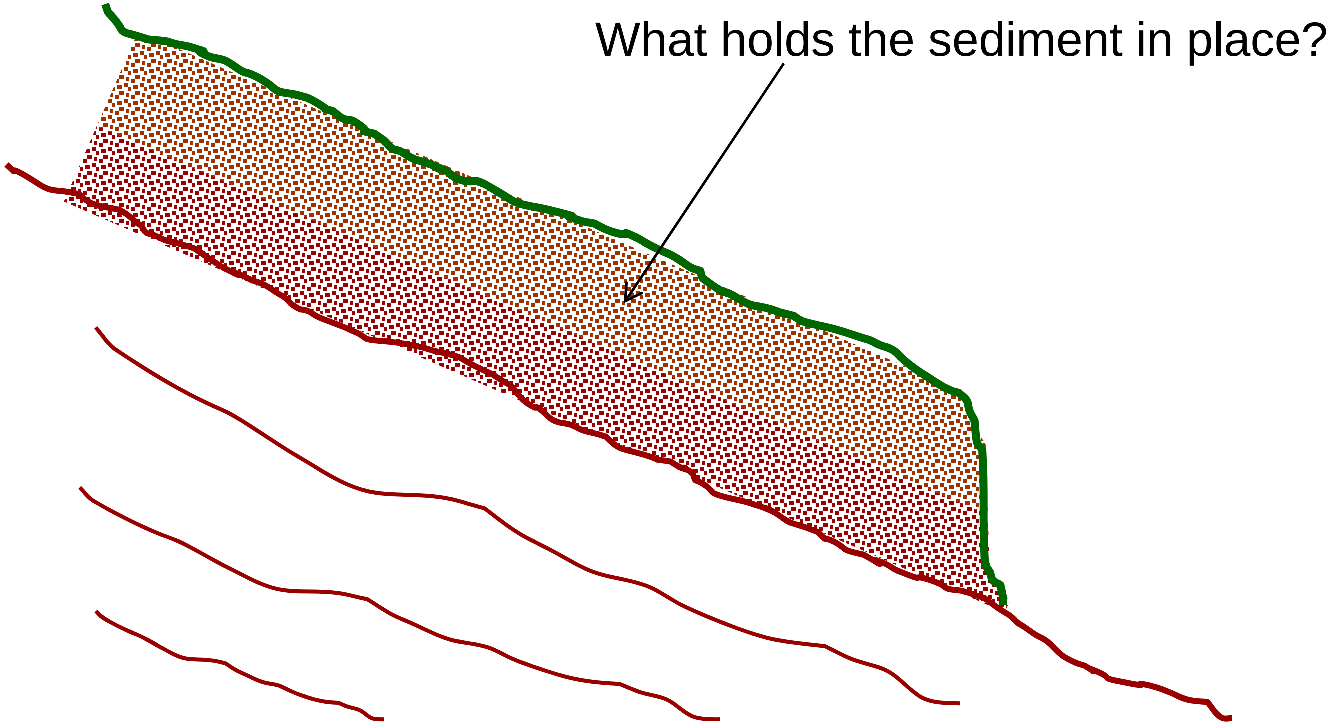
Slope mechanics and material strength



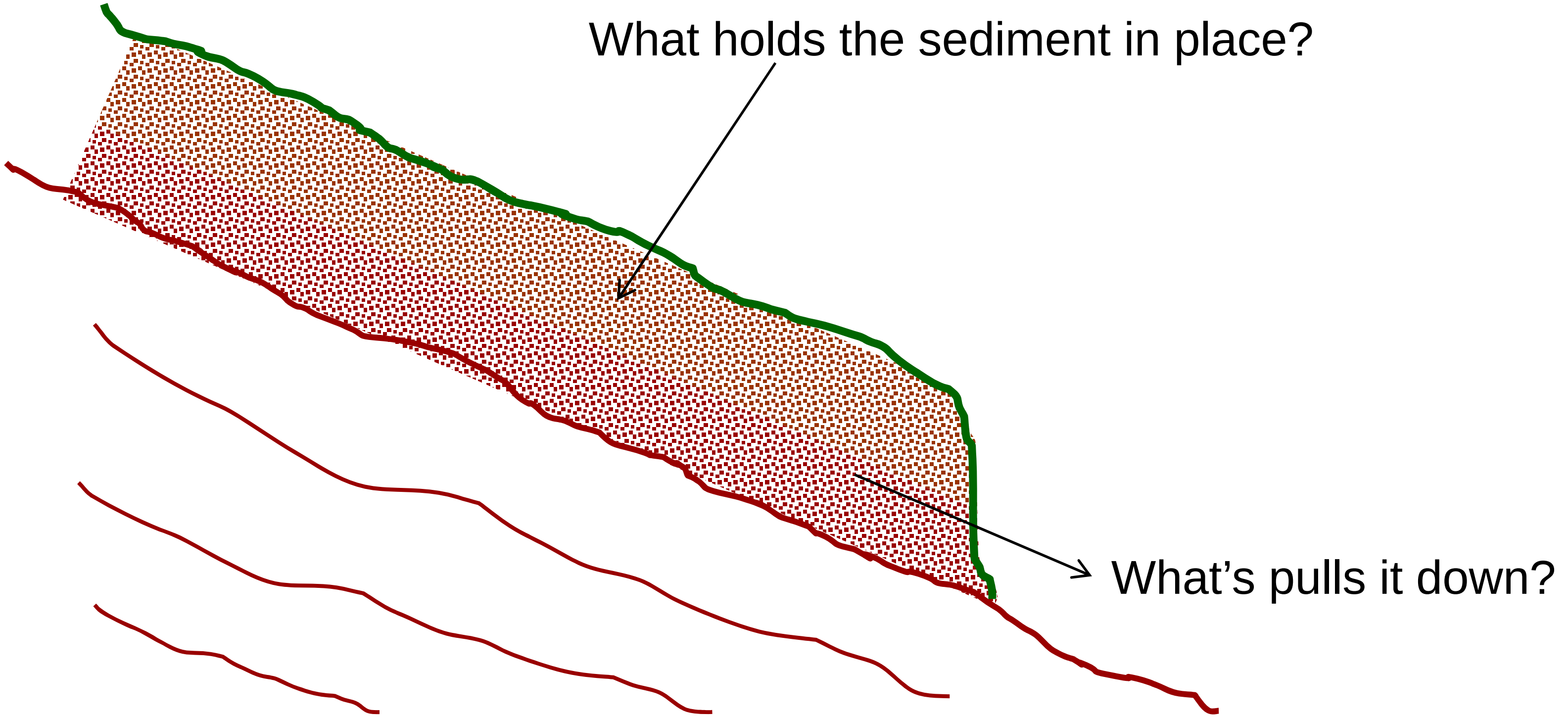
Arboretum



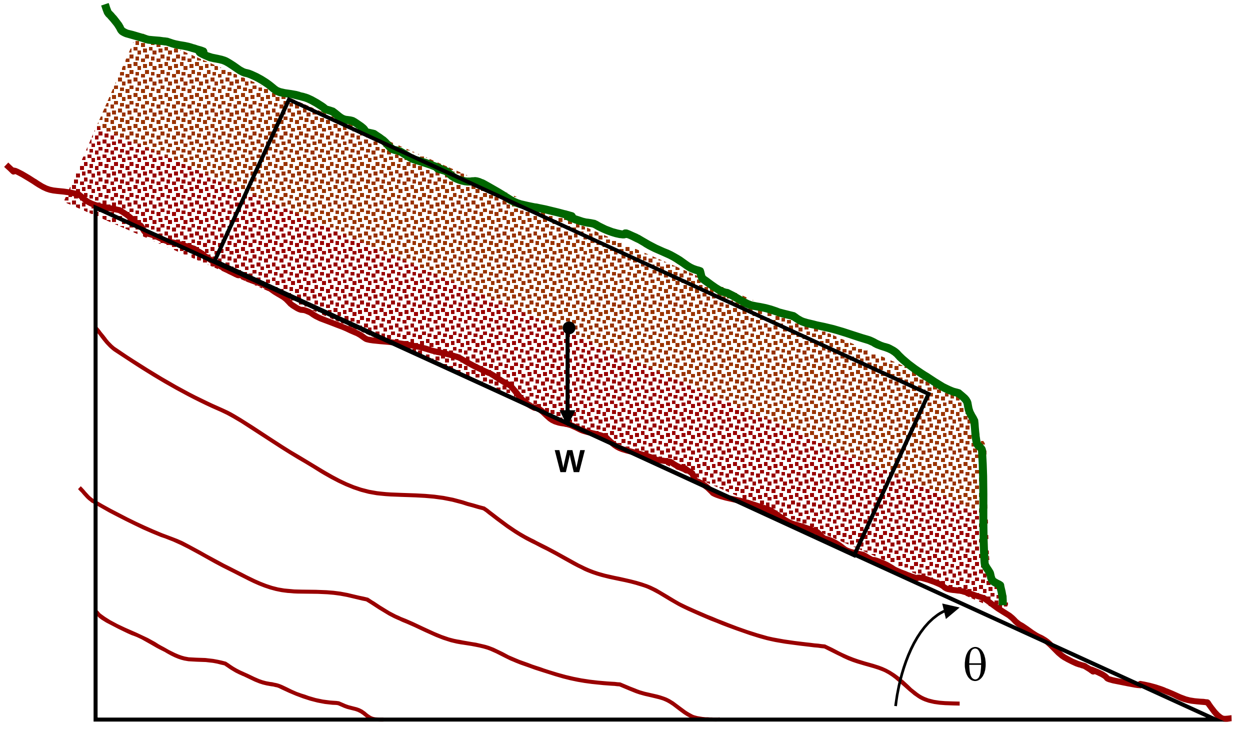
Arboretum



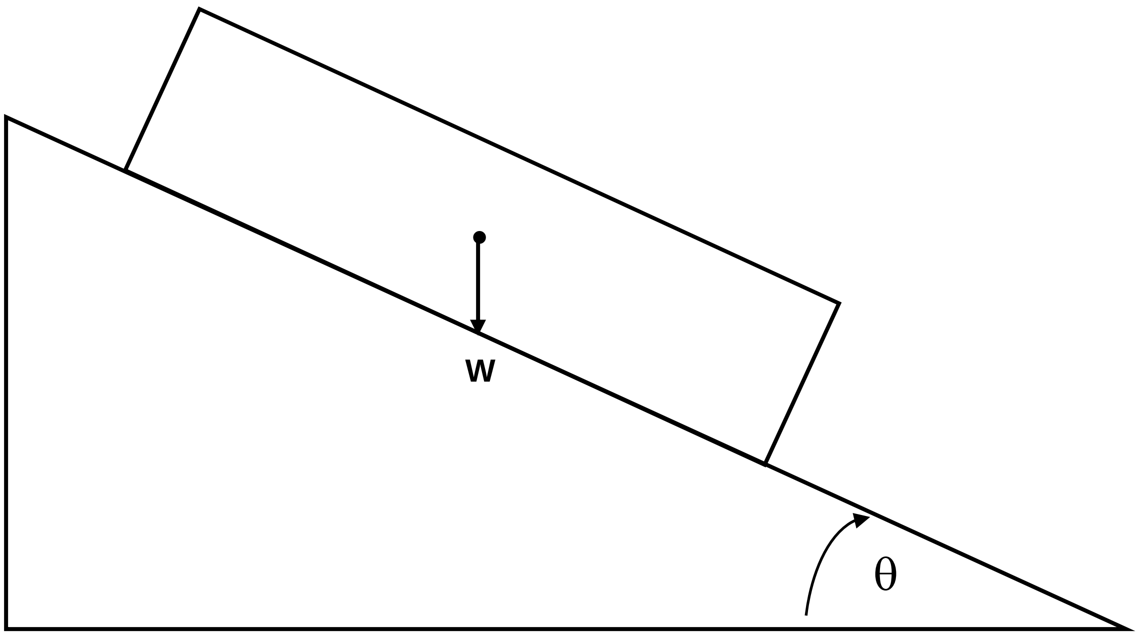
Arboretum

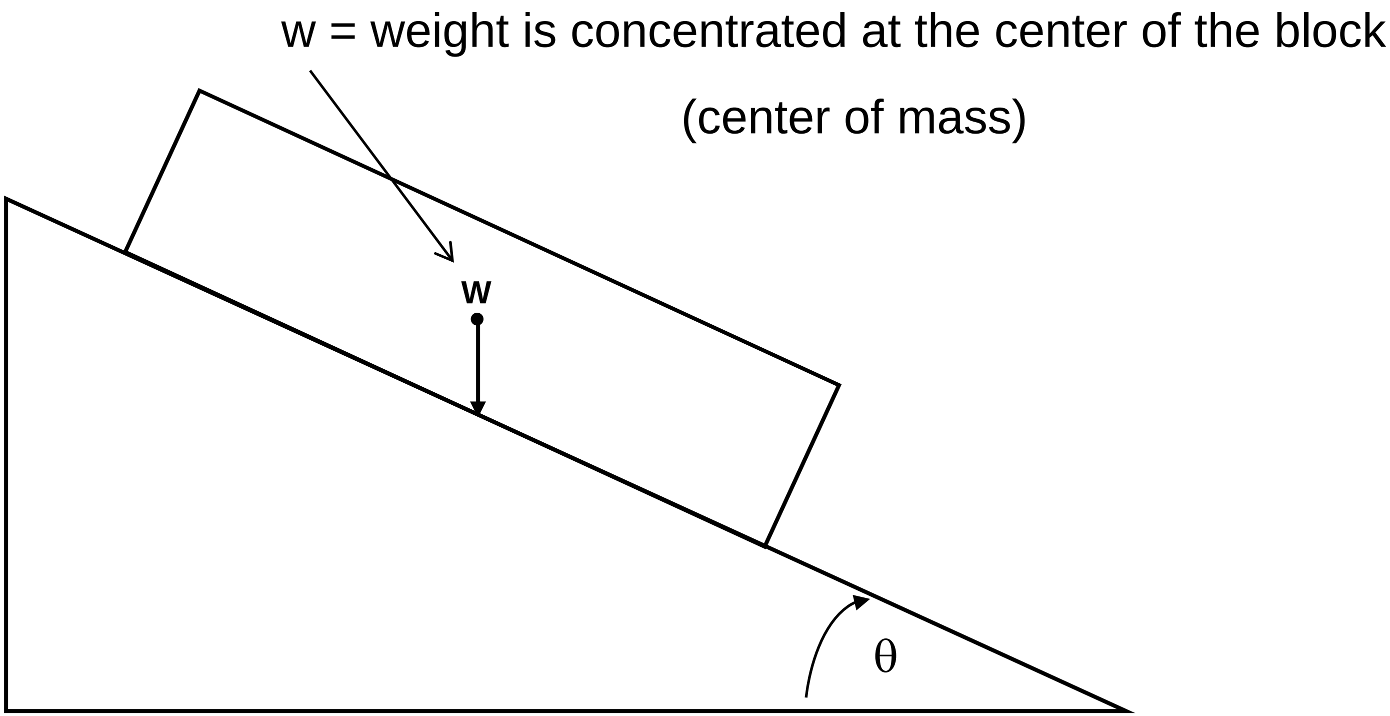


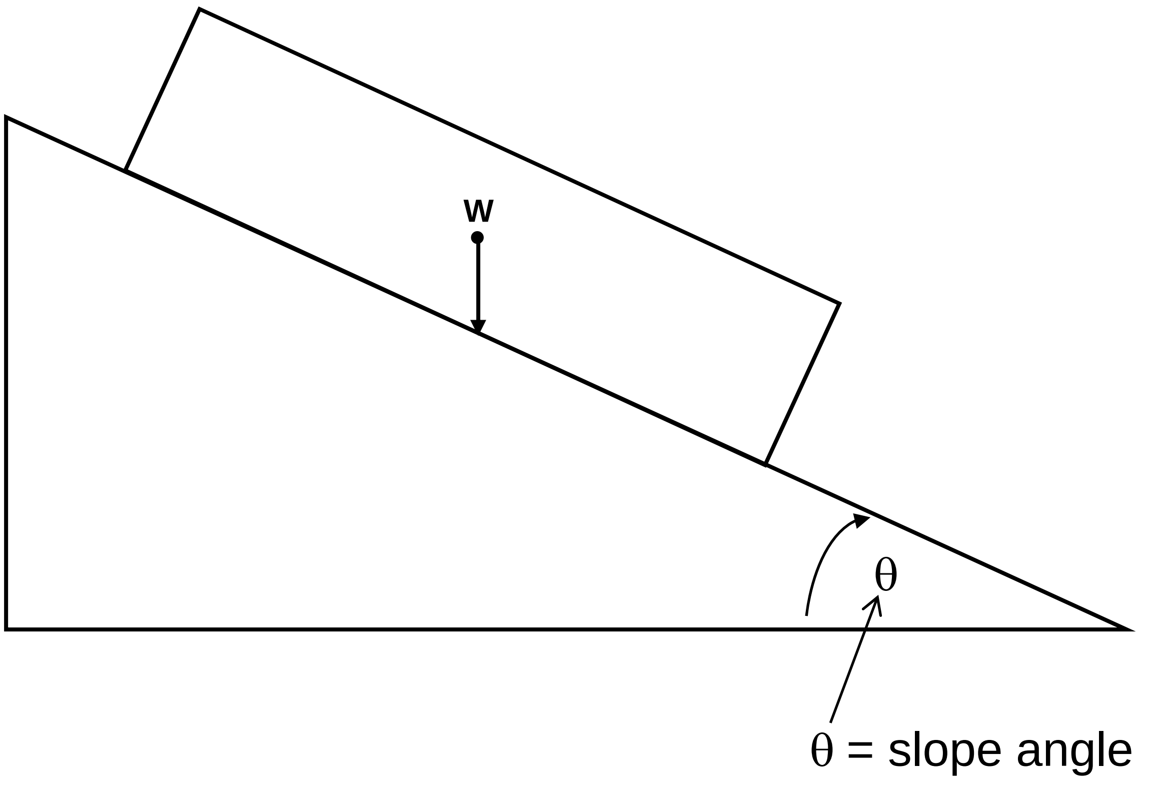
Conceptual Model

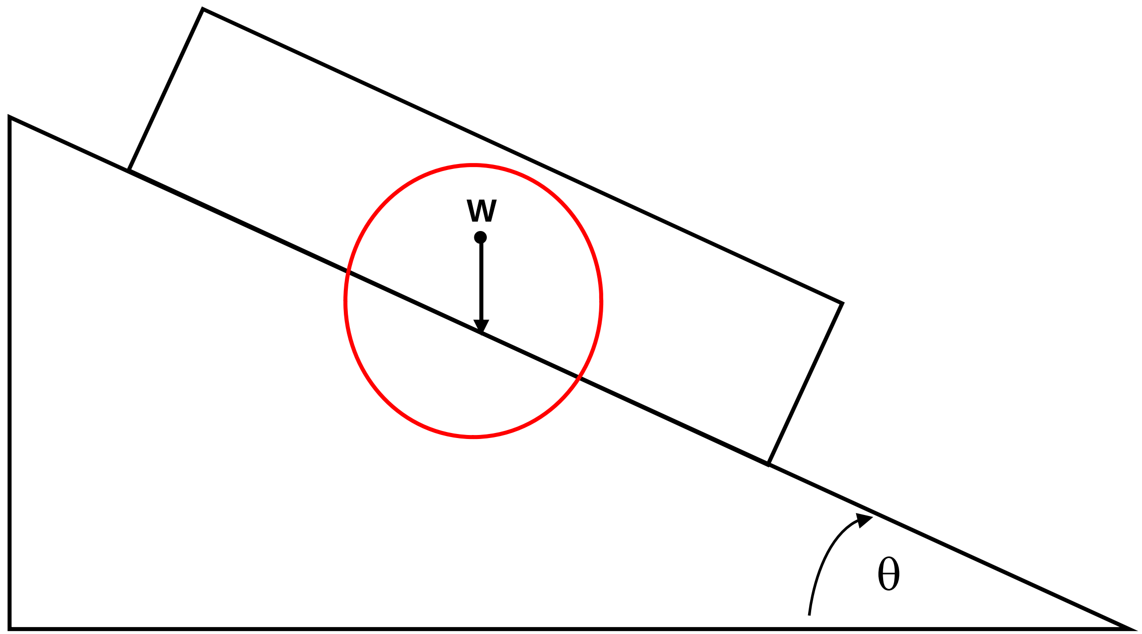


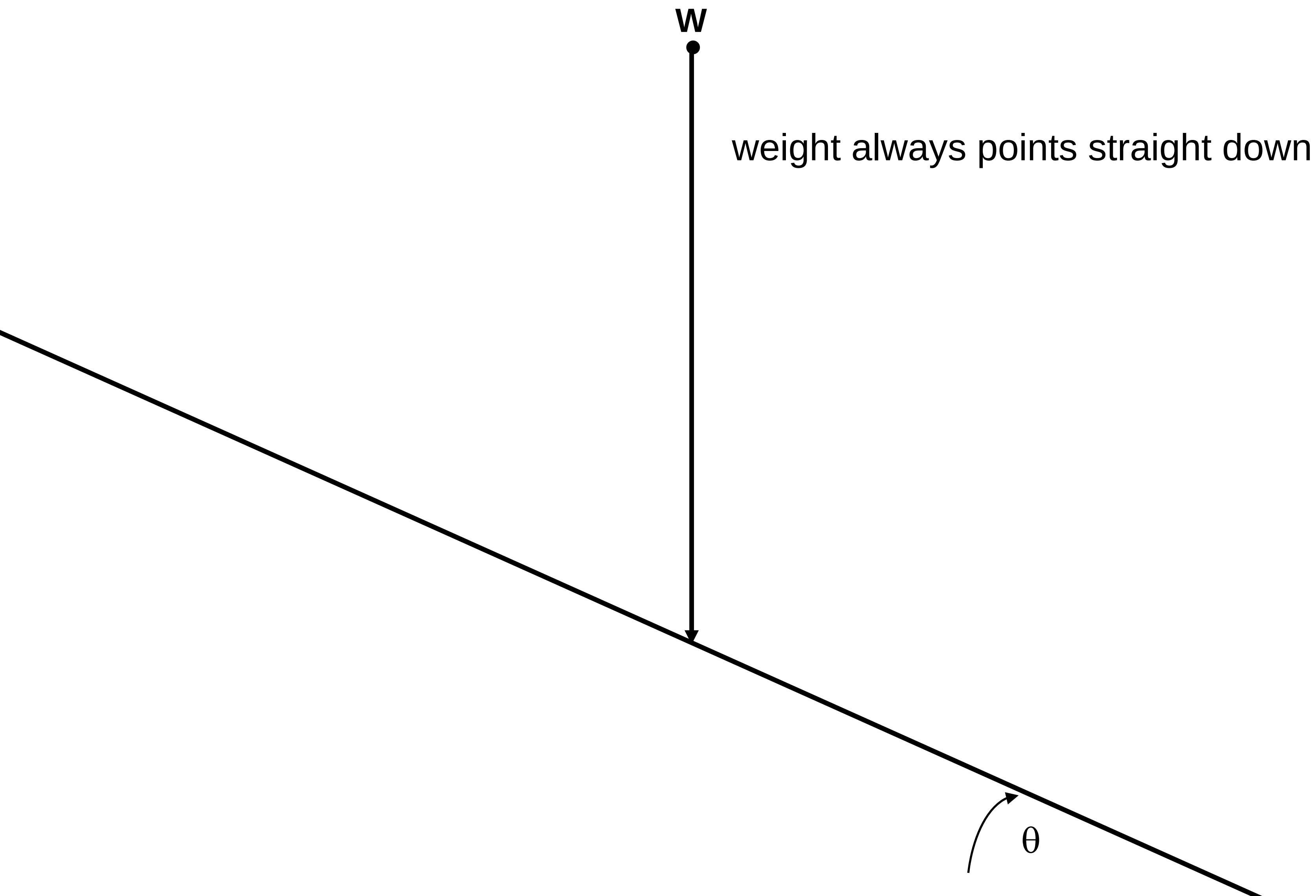
Conceptual Model

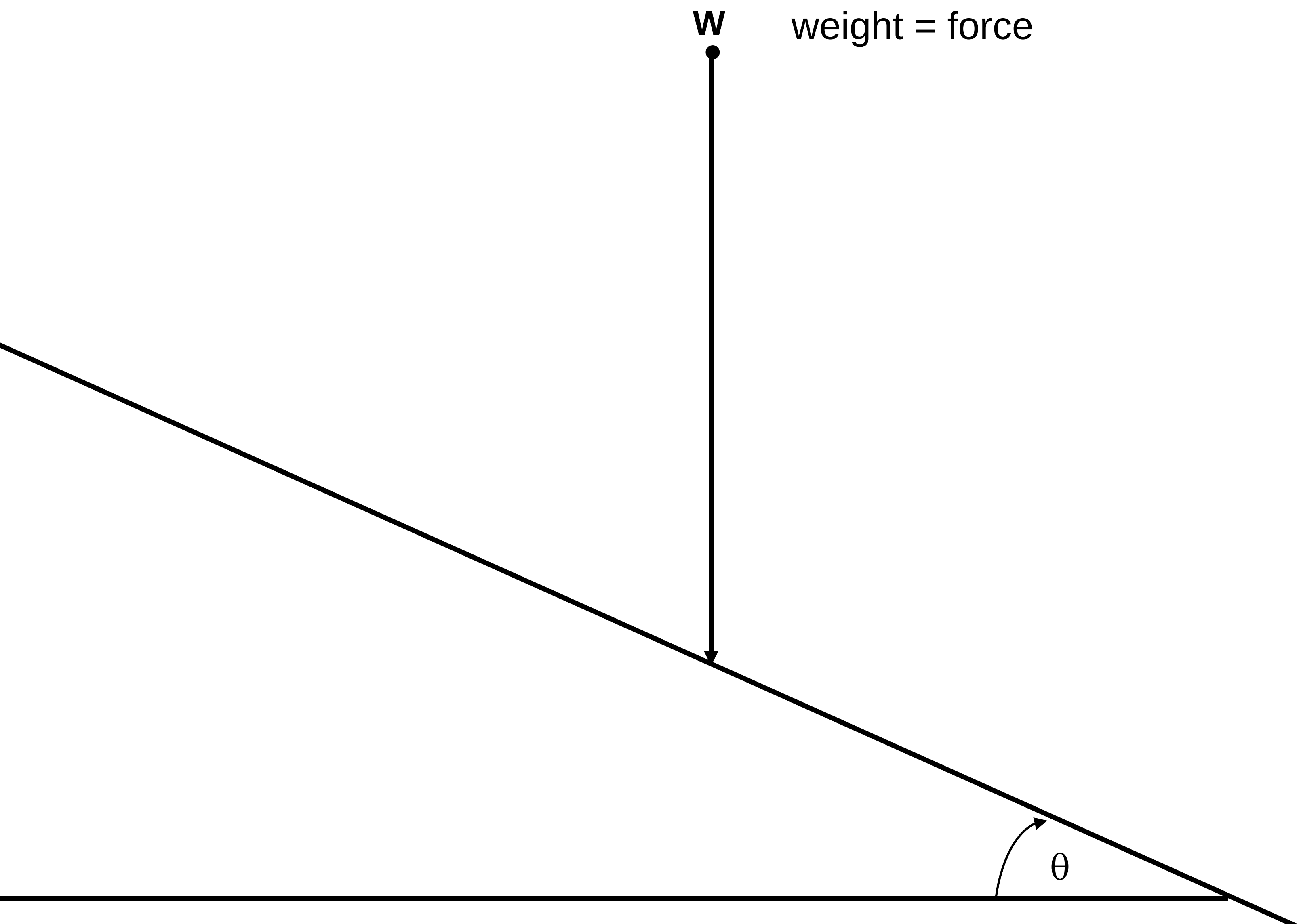


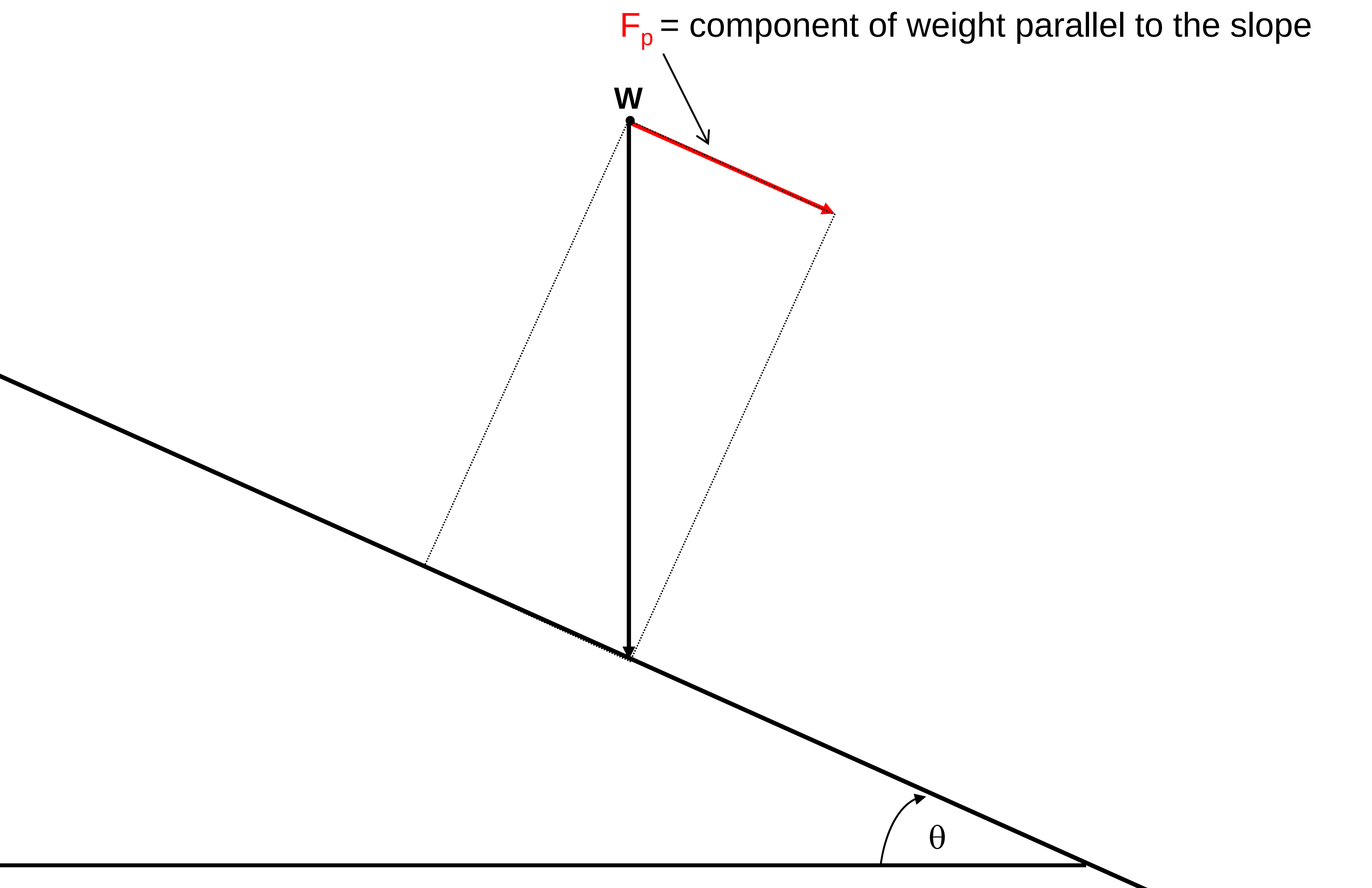

w = weight is concentrated at the center of the block
(center of mass)
w
θ

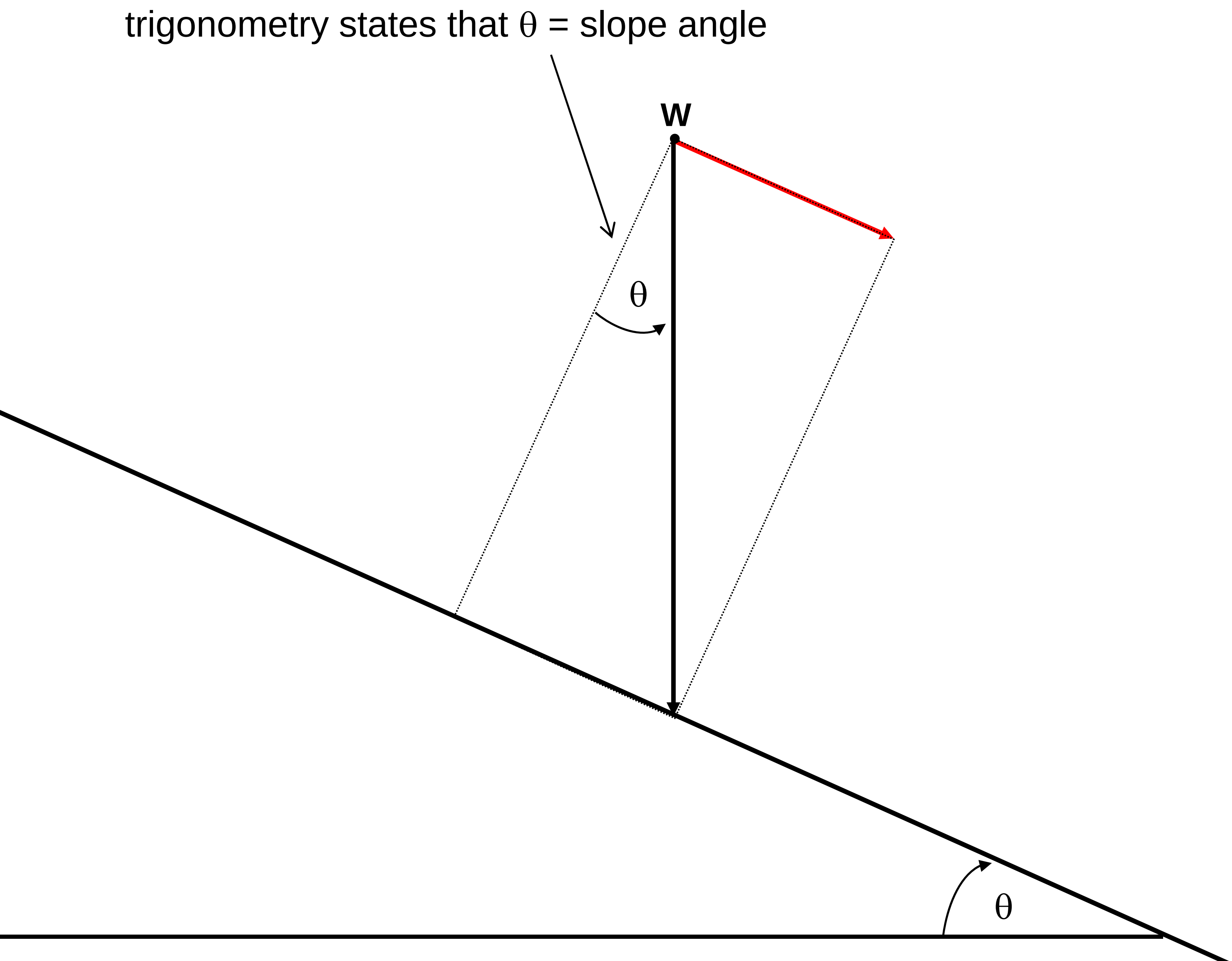

W
θ
θ = slope angle

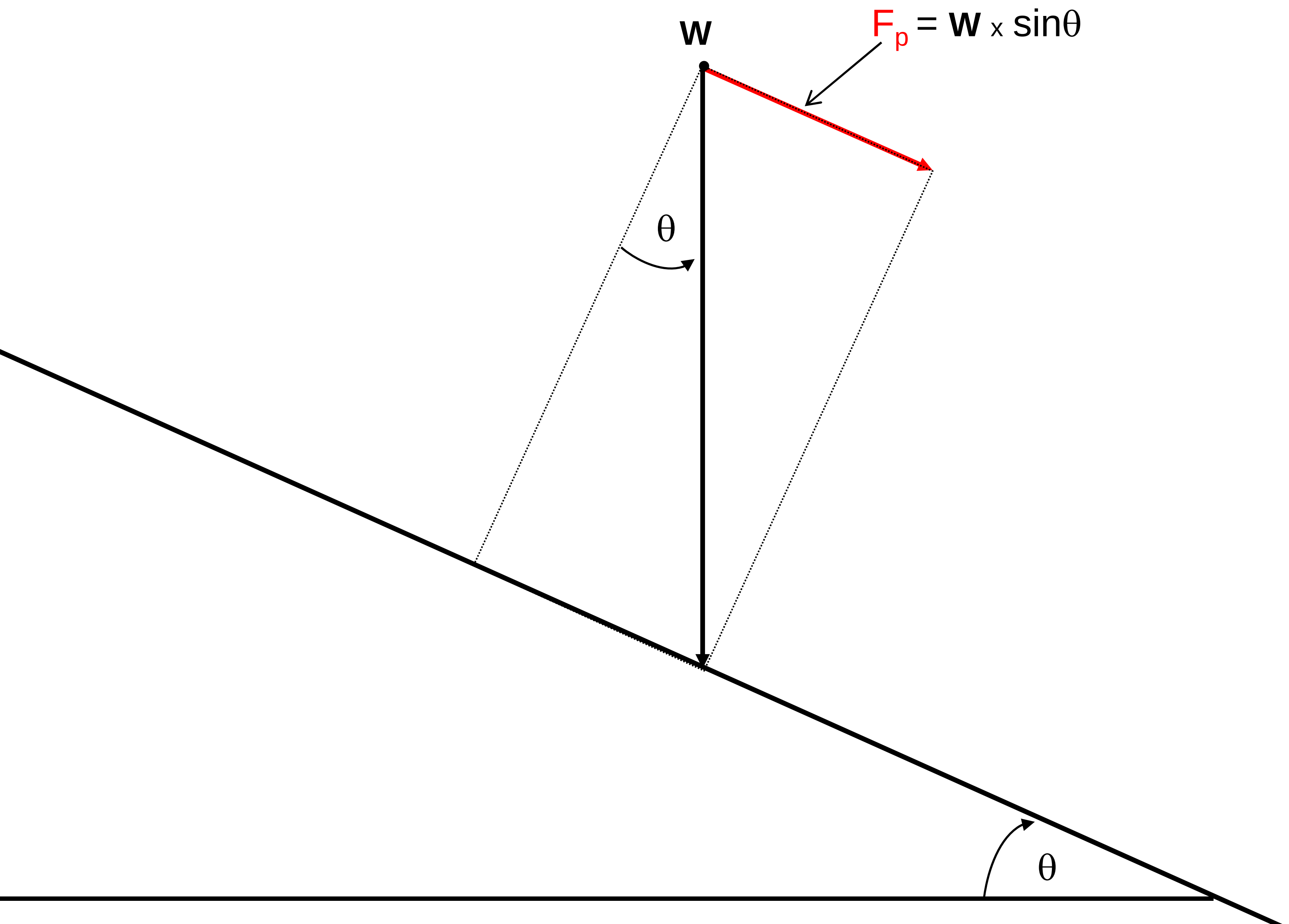

W
θ


W
weight always points straight down
θ

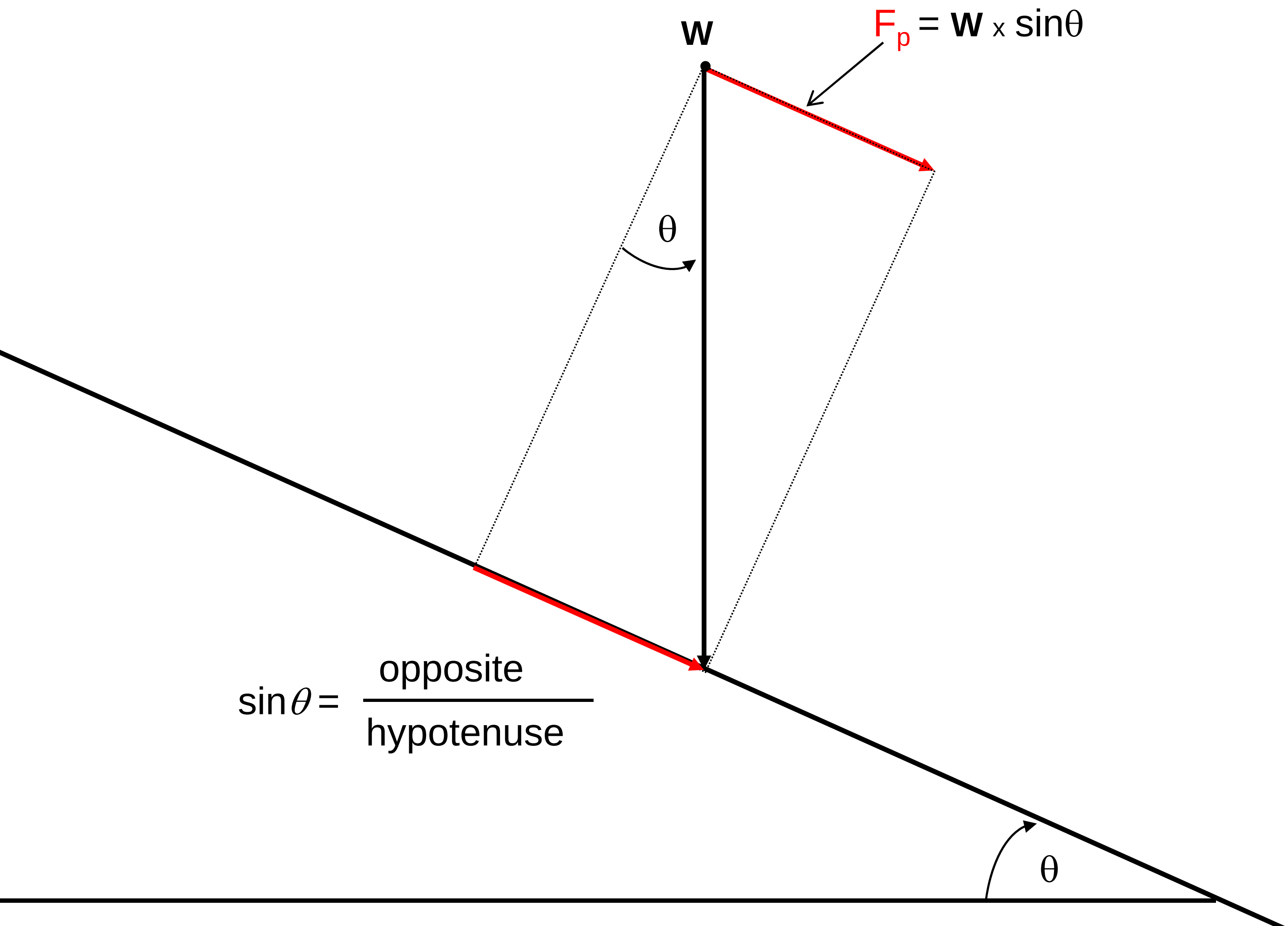

W
weight = force
θ


F_p = component of weight parallel to the slope
W
θ

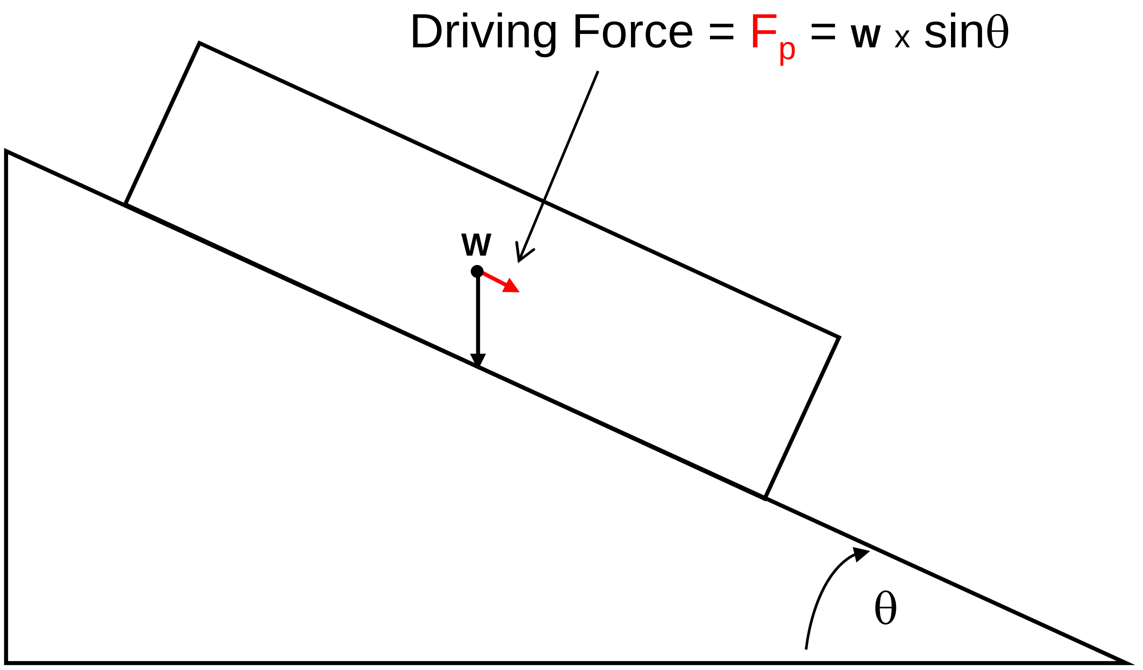

trigonometry states that θ = slope angle
W
θ
θ

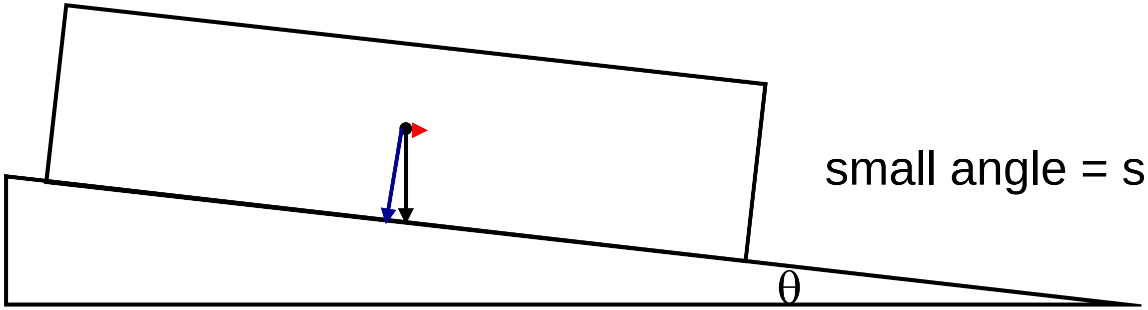


W
Fp = W x sinθ
θ
θ

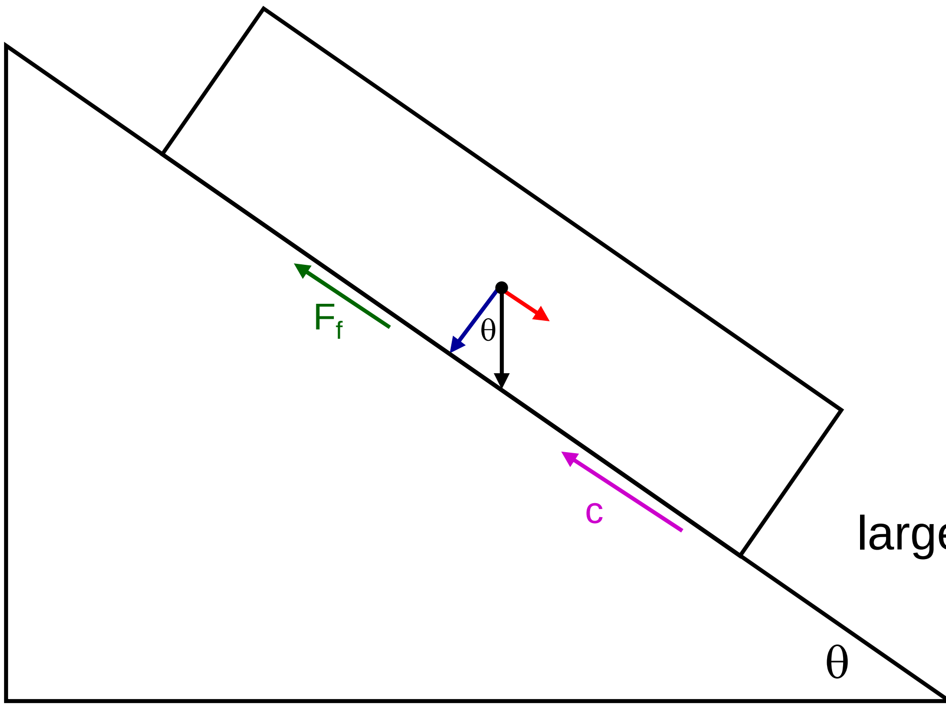

W
Fp = W x sinθ
θ
θ
sinθ = opposite / hypotenuse

The force parallel to the inclined plane F_p is what "pulls' it down the slope



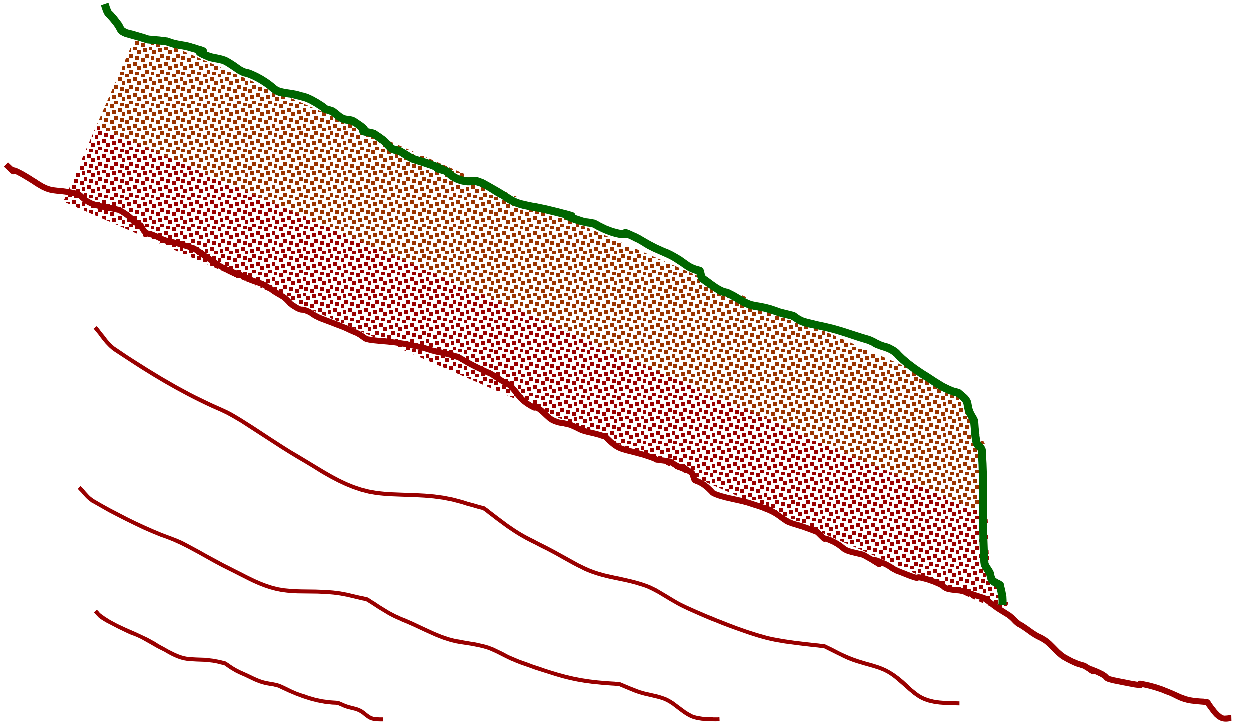


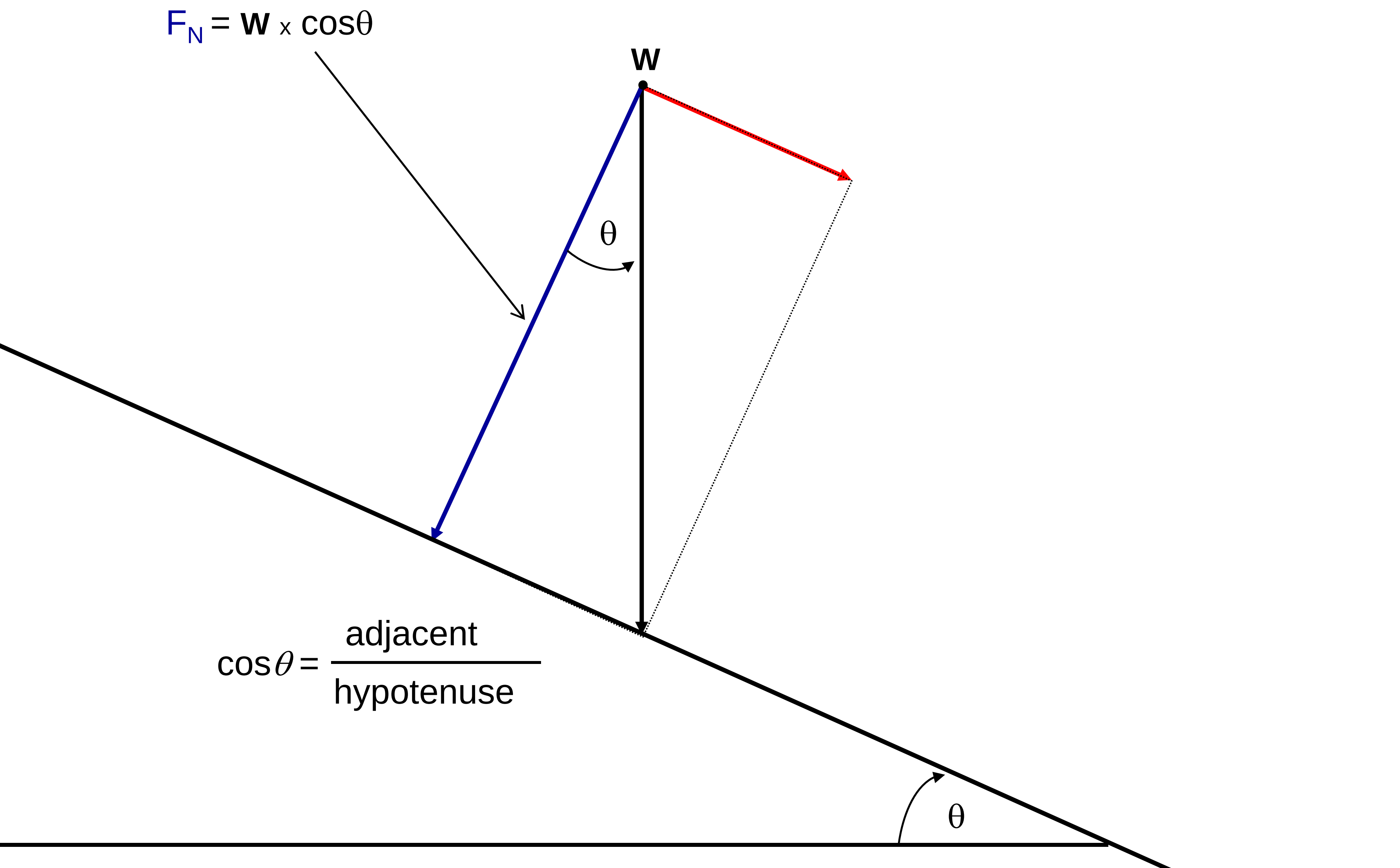
small angle = small pulling force F_p



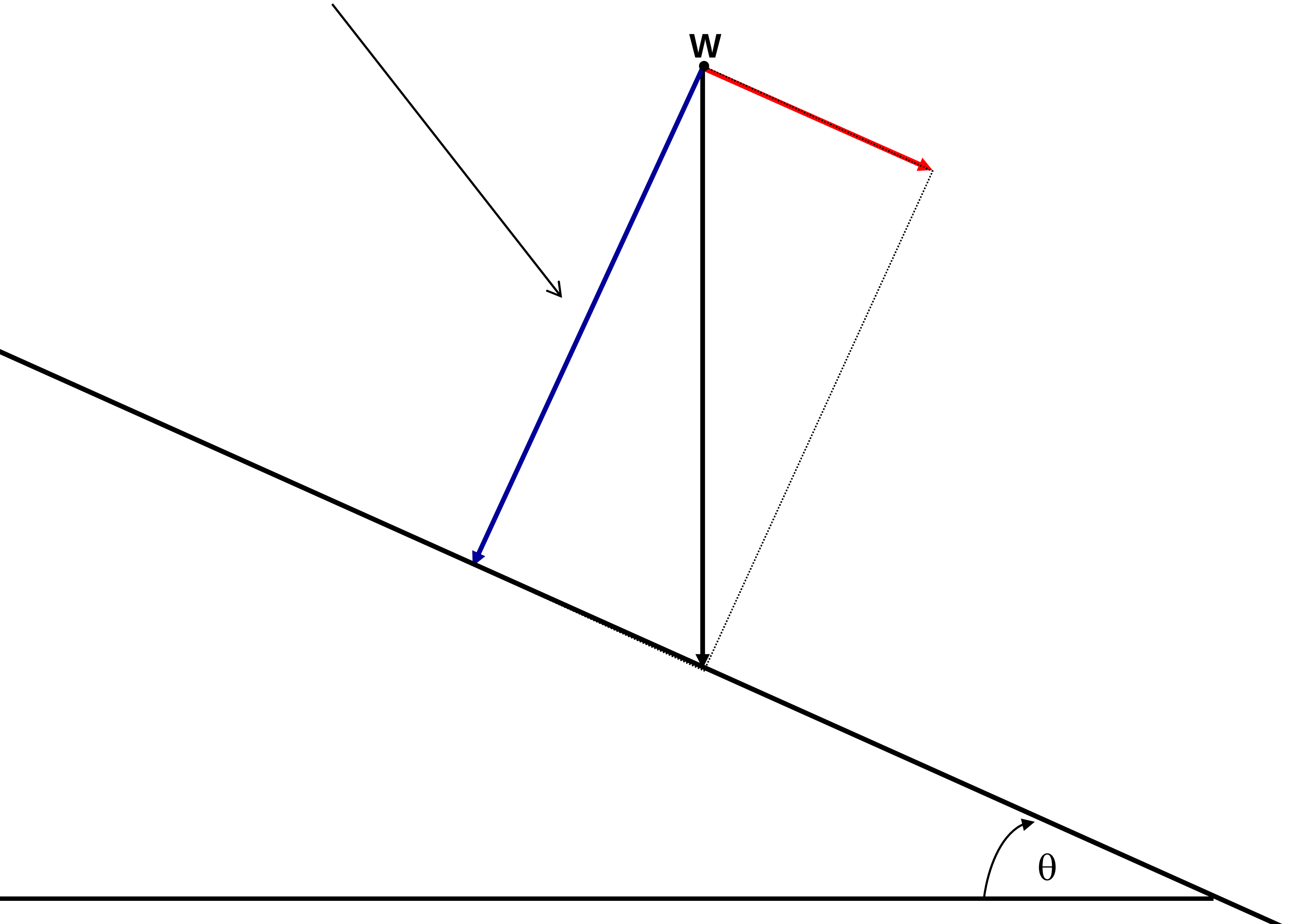
large angle = large pulling force F_p

Slope mechanics and material strength

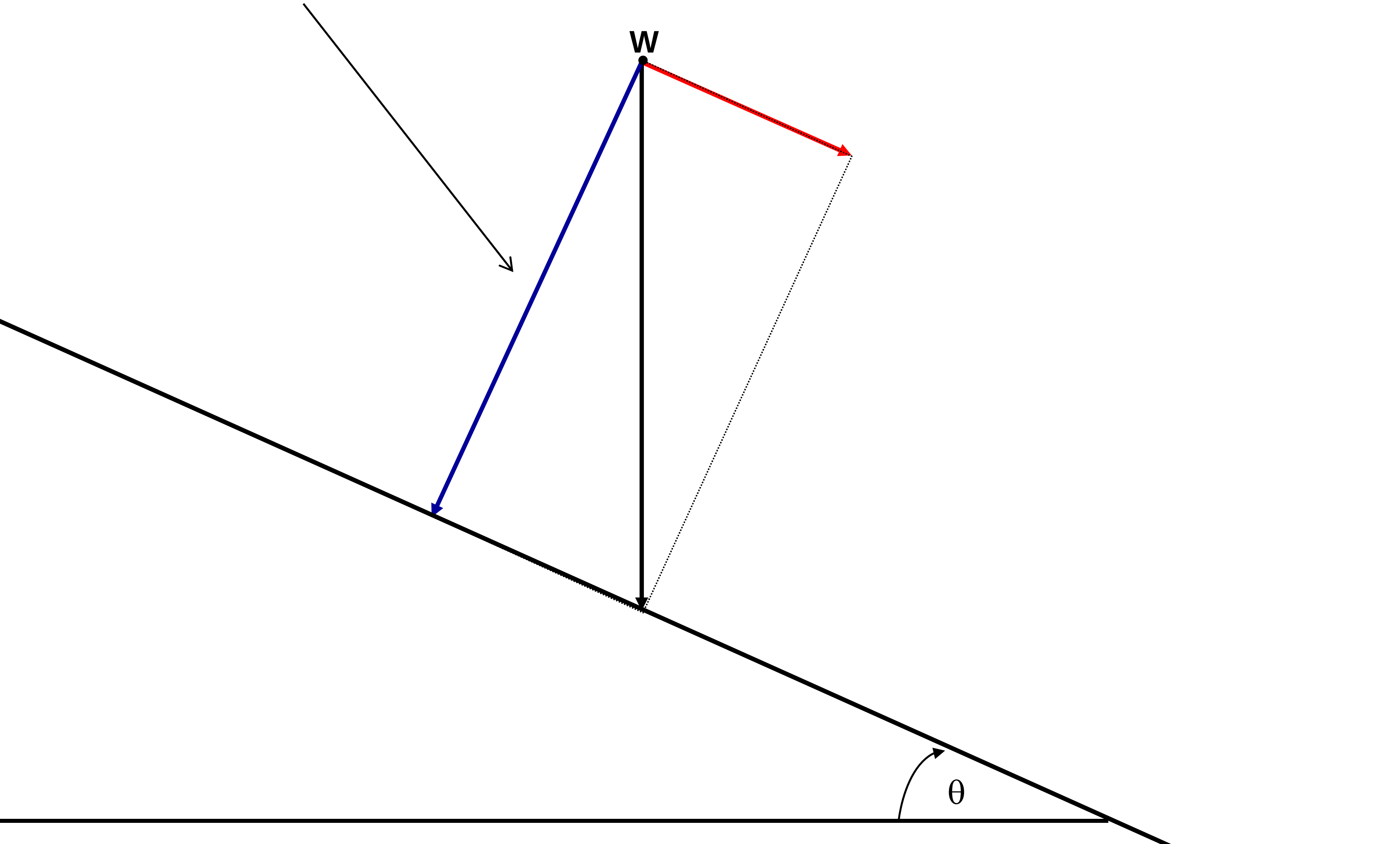



$F_N = \mathbf{W} \times \cos\theta$
W
θ
$\cos\theta = \frac{\text{adjacent}}{\text{hypotenuse}}$
θ

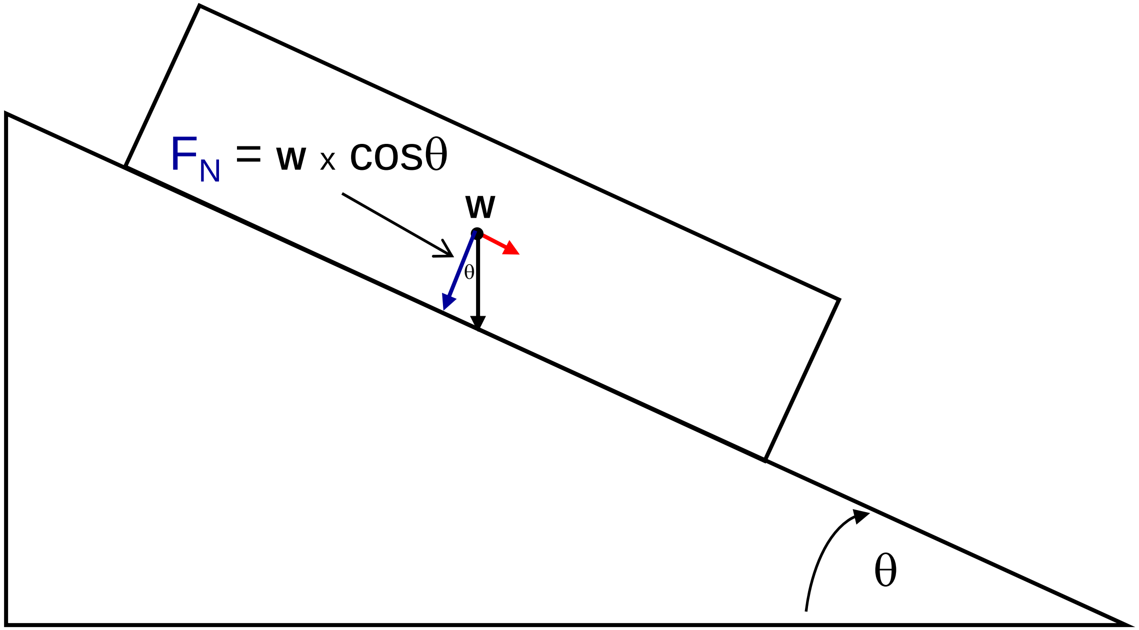
F_N = component of weight “normal” or perpendicular to the slope



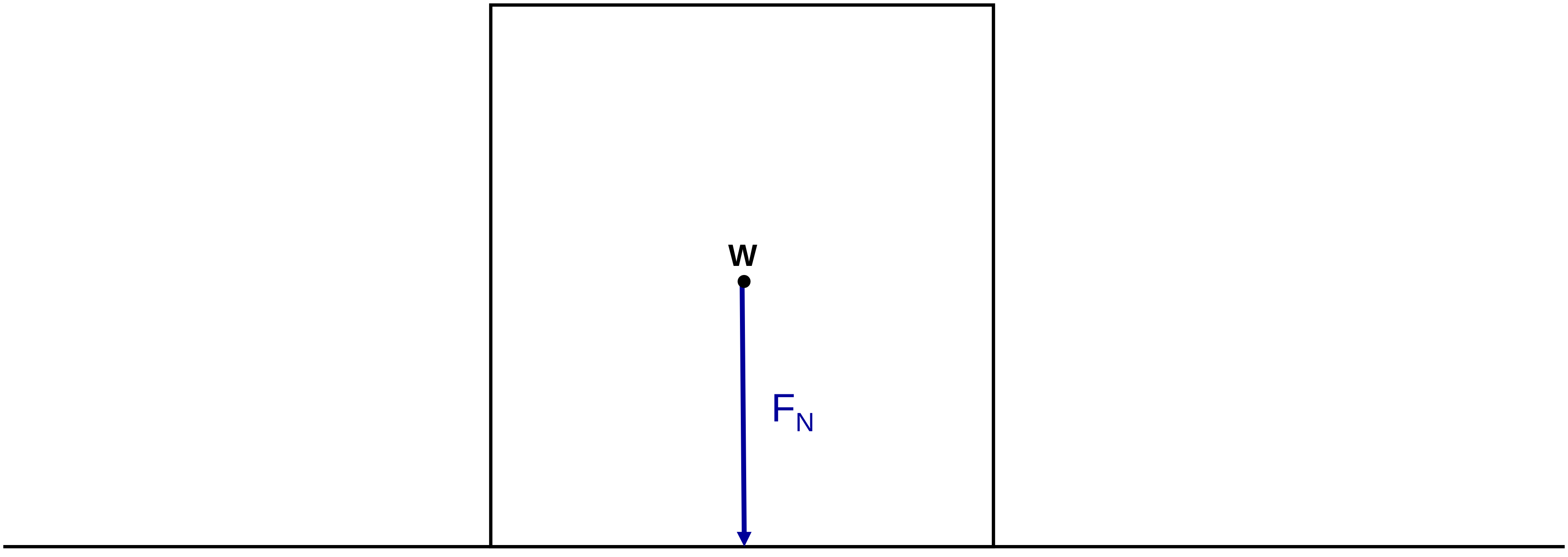
F_N = component of weight “normal” or perpendicular to the slope

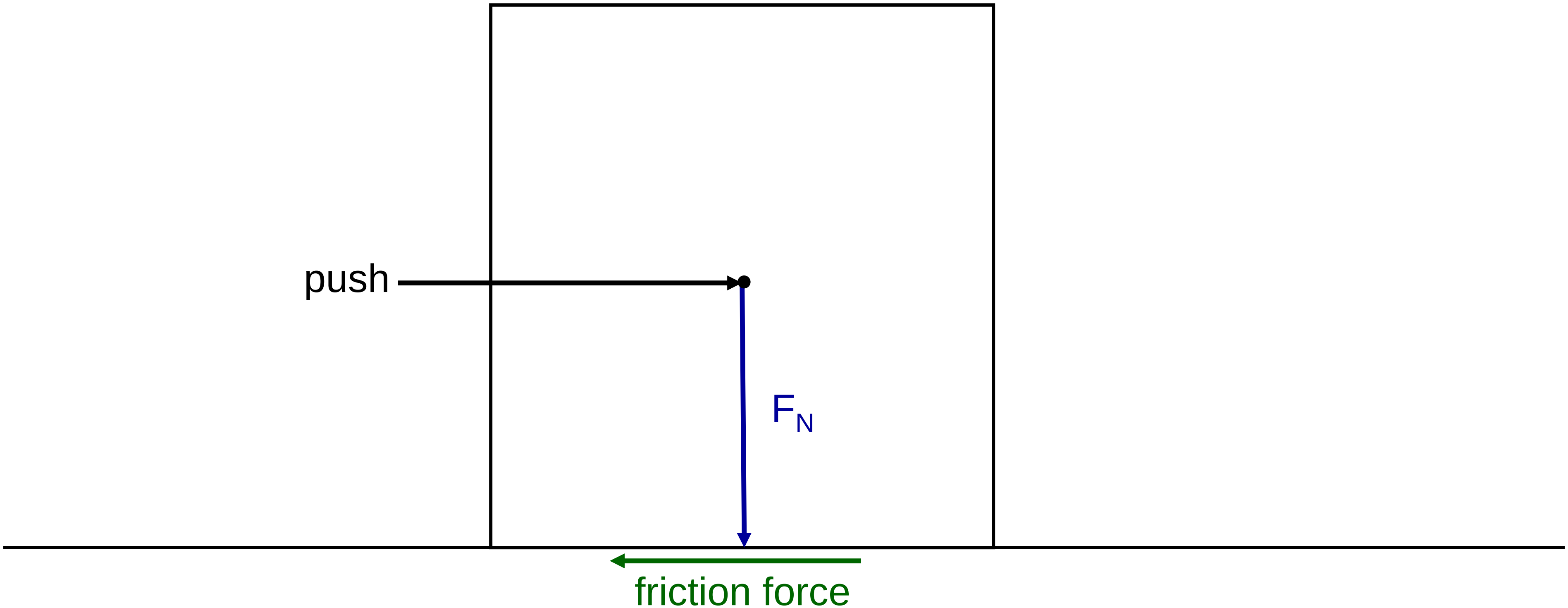


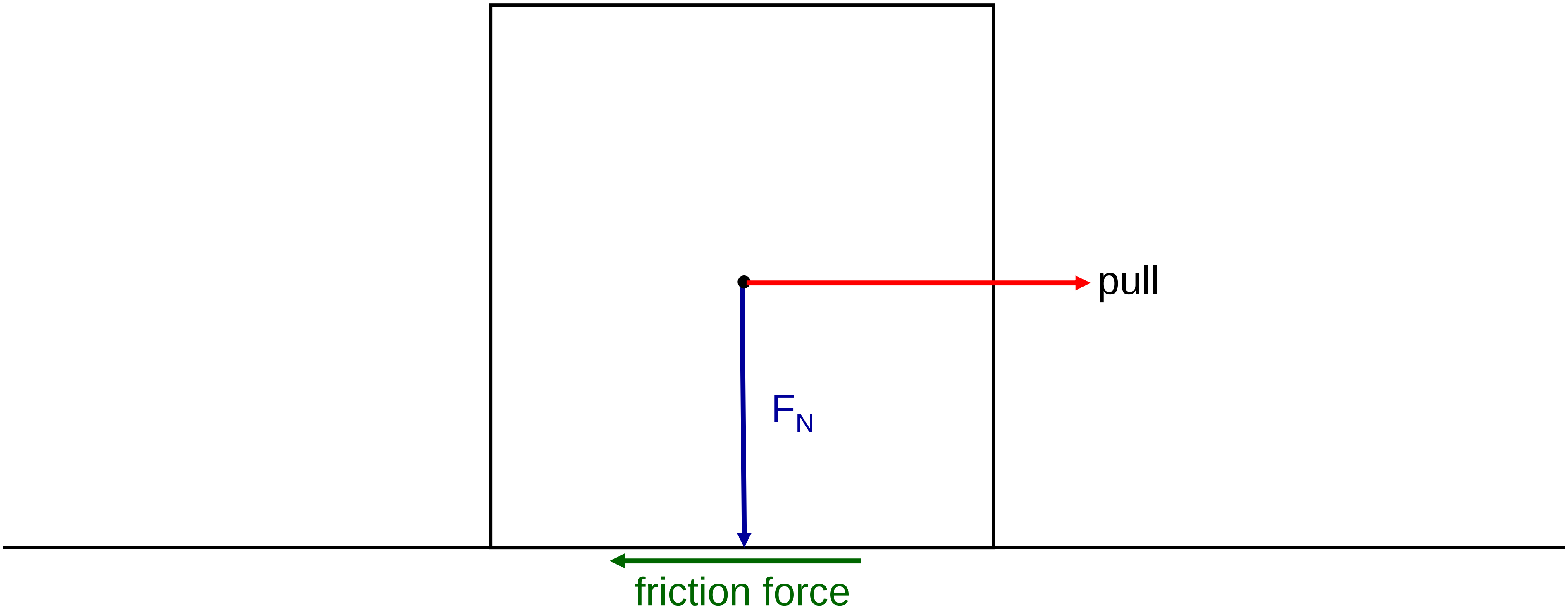
The “normal” force F_N is what contributes to a force the “resists” movement down the slope (i.e., it in part controls the material strength)



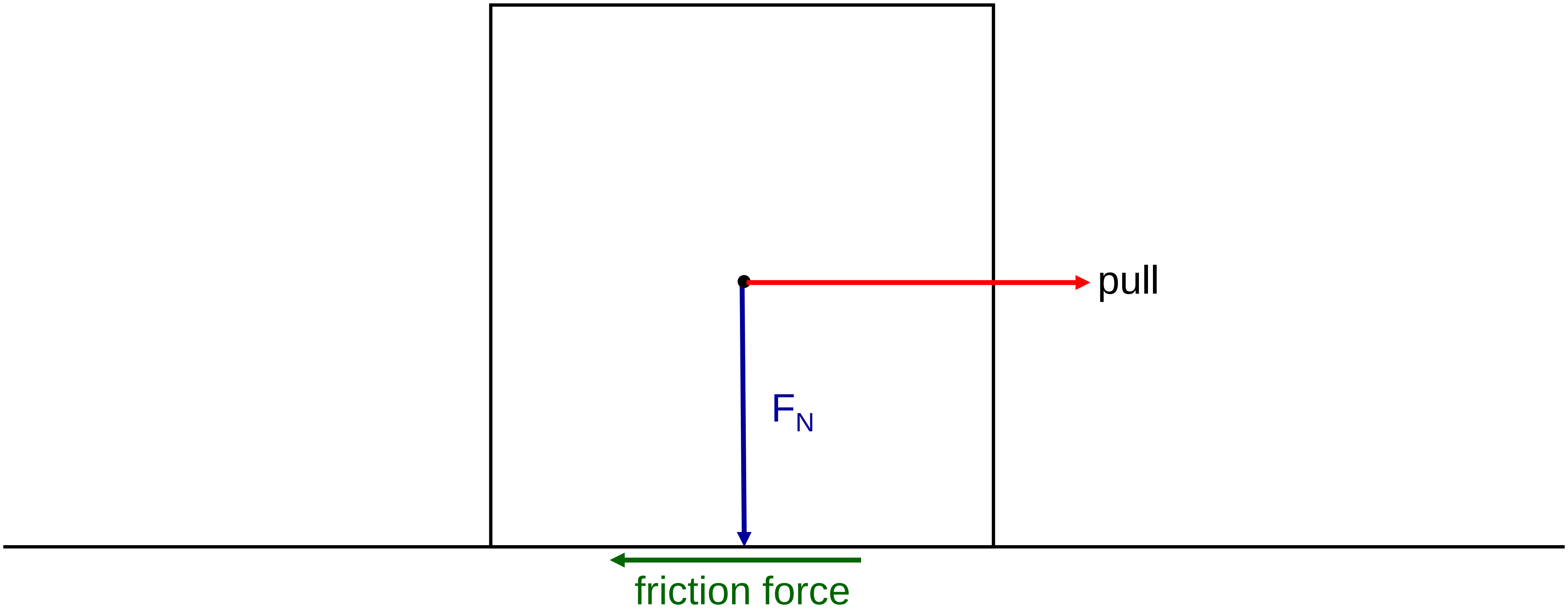
When the block is horizontal ($\theta = 0$) then $F_N = \mathbf{w}$



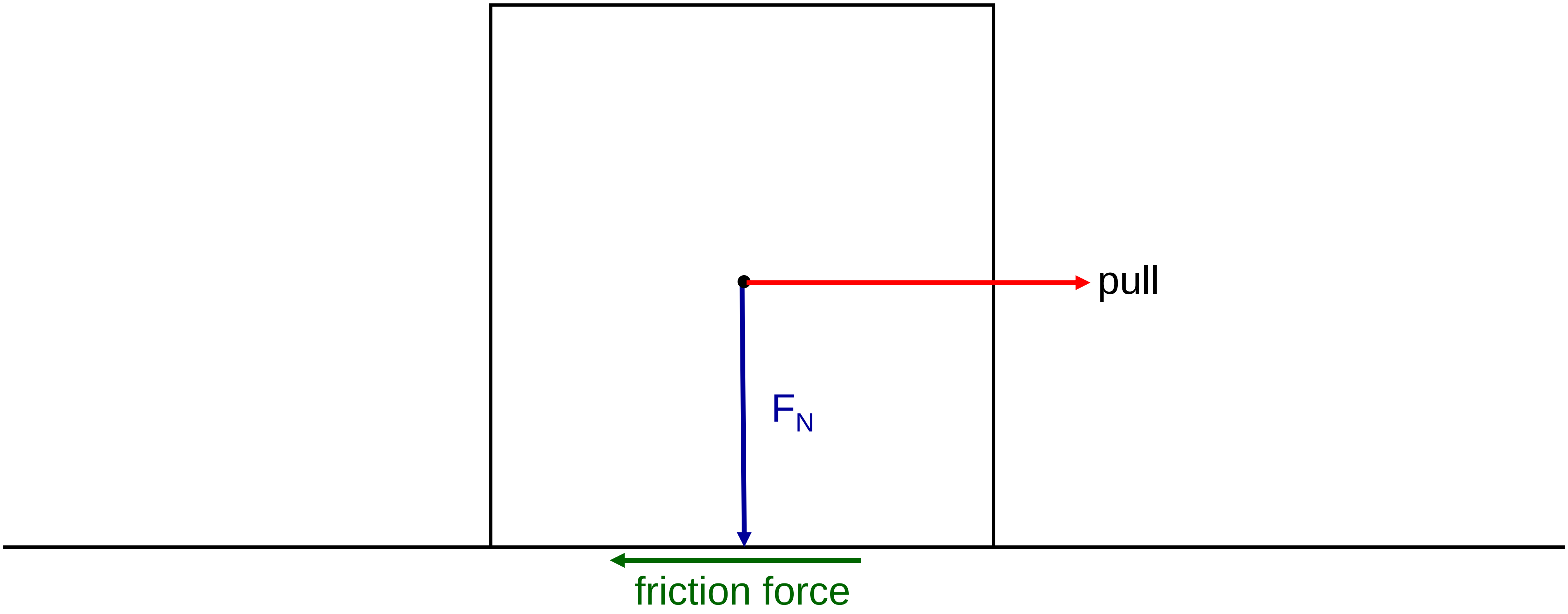

push
F_N
friction force


pull
F_N
friction force

F_f = friction force = F_N x coefficient of friction



The coefficient of friction quantifies the degree of roughness between the two surfaces (bottom of the block and the horizontal surface)

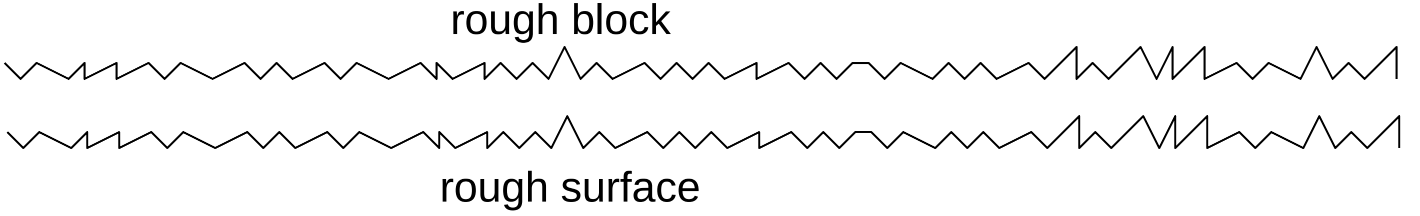


low coefficient of friction

smooth block

smooth surface

high coefficient of friction



The coefficient of friction changes with geologic material

Clay = 0.1 to 0.3

Sand = 0.4 to 0.8

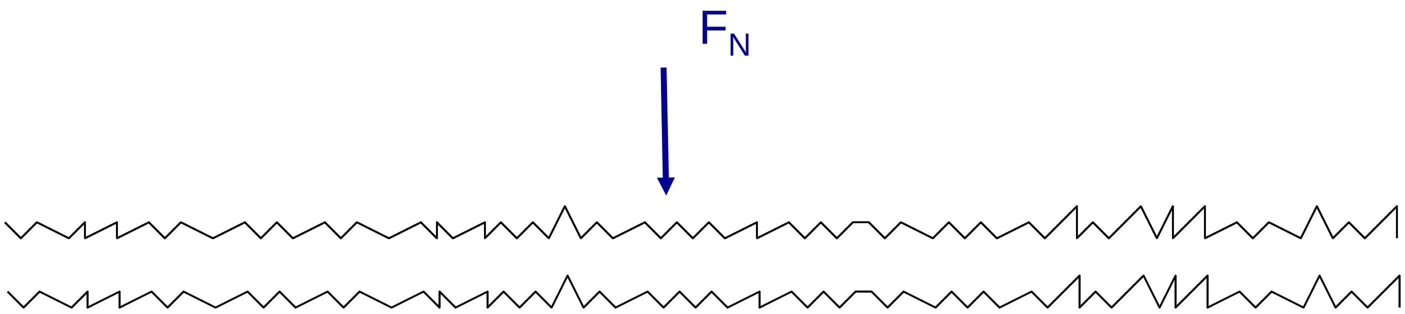
Broken rock = 0.5 to 0.9

Note: the Greek symbol μ (mu) is usually used for coefficient of friction

The coefficient of friction is also controlled by

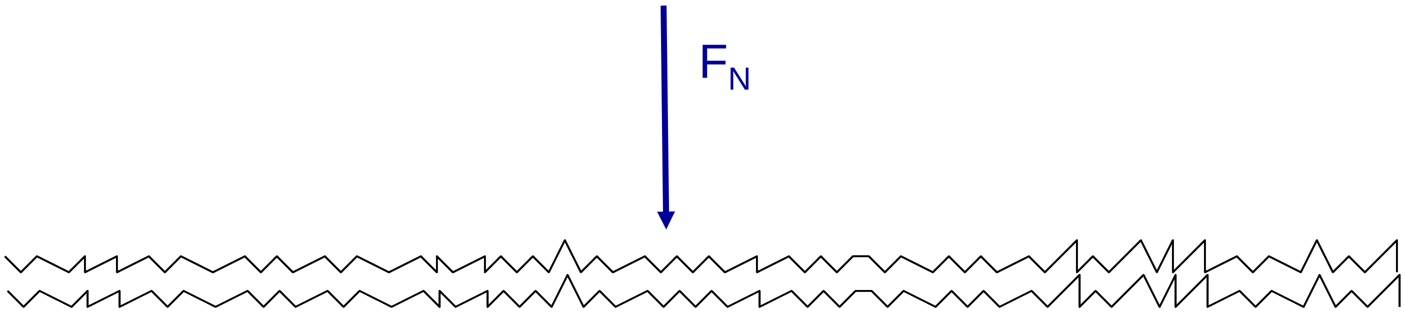
- mineralogy (quarts is strong, olivine is not)
- grain shape (angular versus rounded)
- packing arrangement (loose versus tight packing)

The magnitude of F_N increases the interlocking of the two surface because the force “pushes” the imperfections together making it harder for the block to slide—this increase the friction force



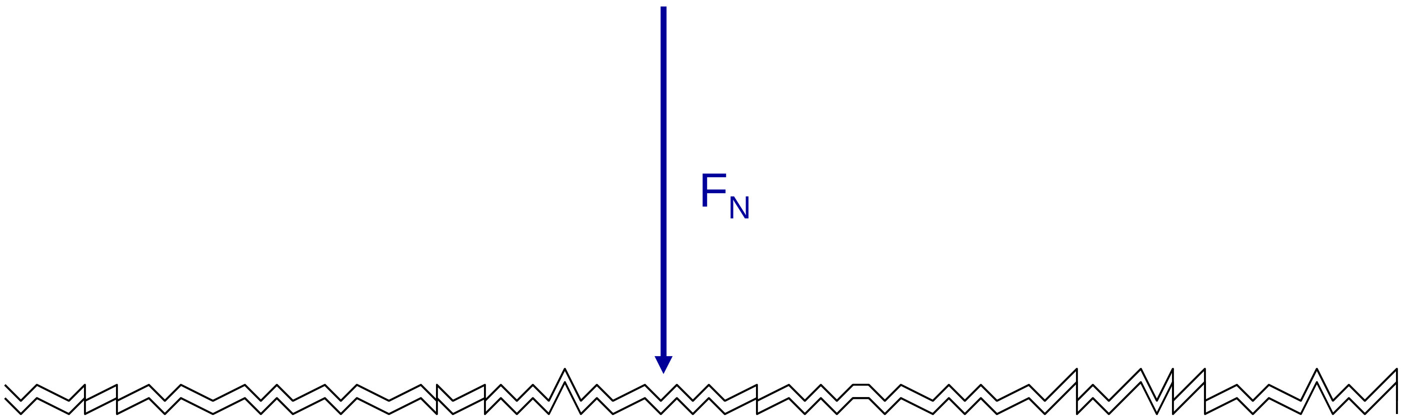
F_f = friction force = $F_N \times \mu$

The magnitude of F_N increases the interlocking of the two surface because the force “pushes” the imperfections together making it harder for the block to slide

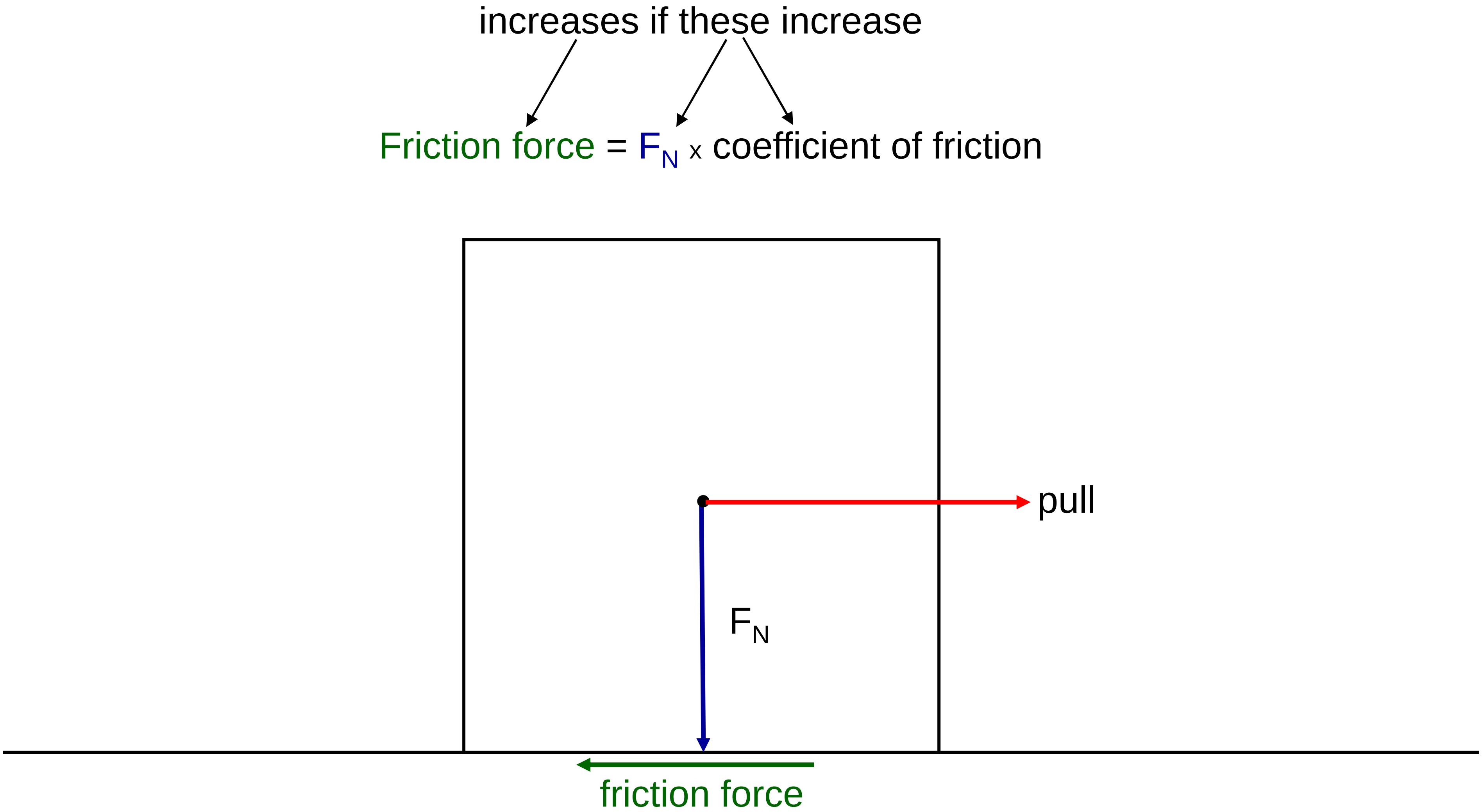


$\uparrow F_f$ = friction force = $\uparrow F_N \times \mu$

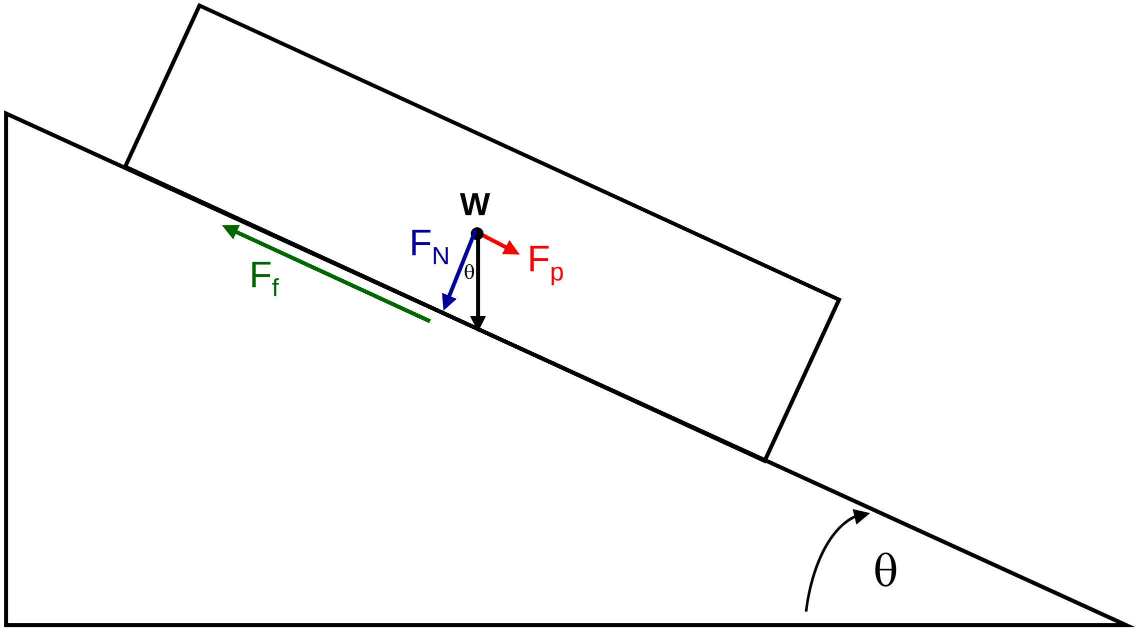
The magnitude of F_N increases the interlocking of the two surface because the force “pushes” the imperfections together making it harder for the block to slide

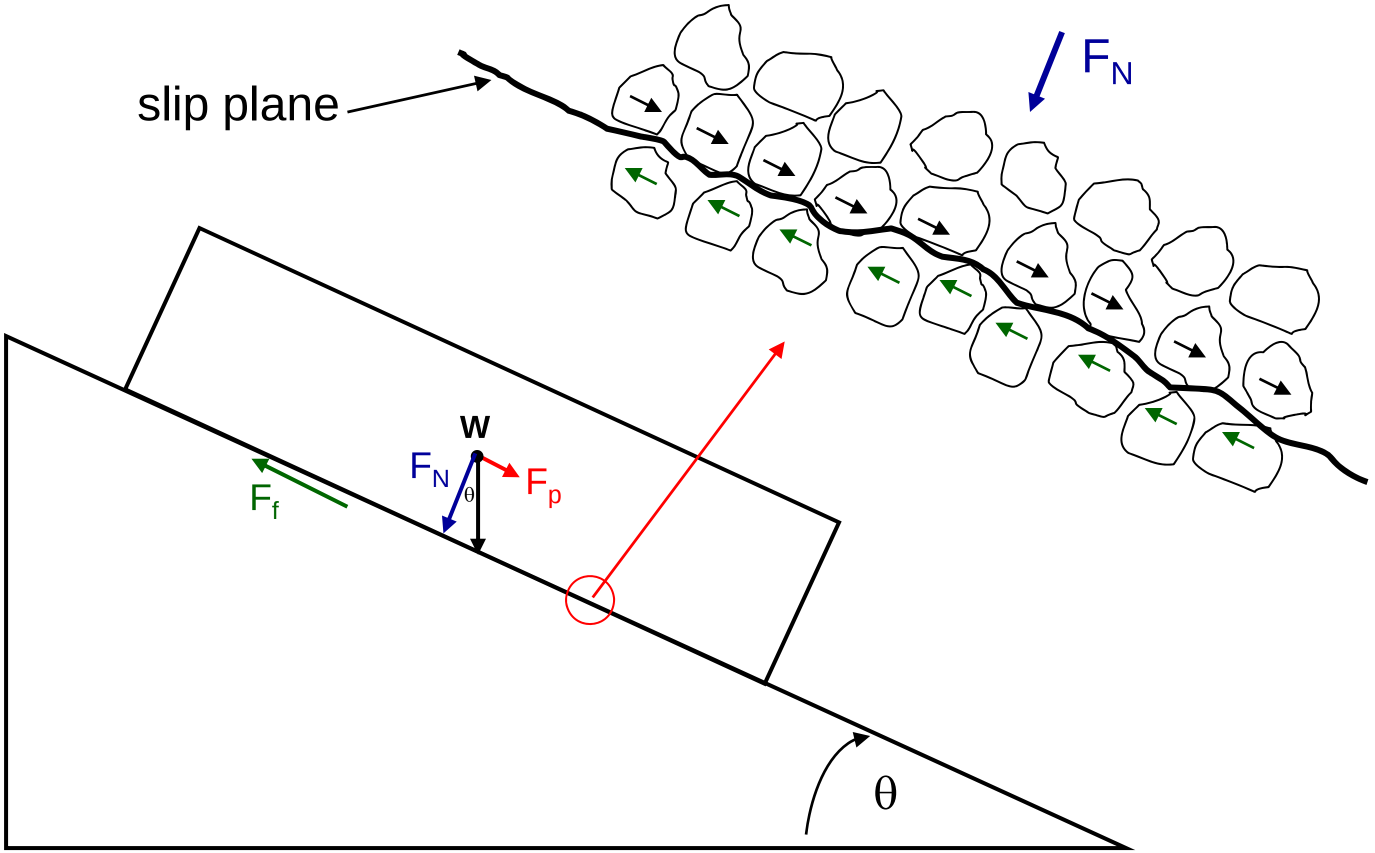


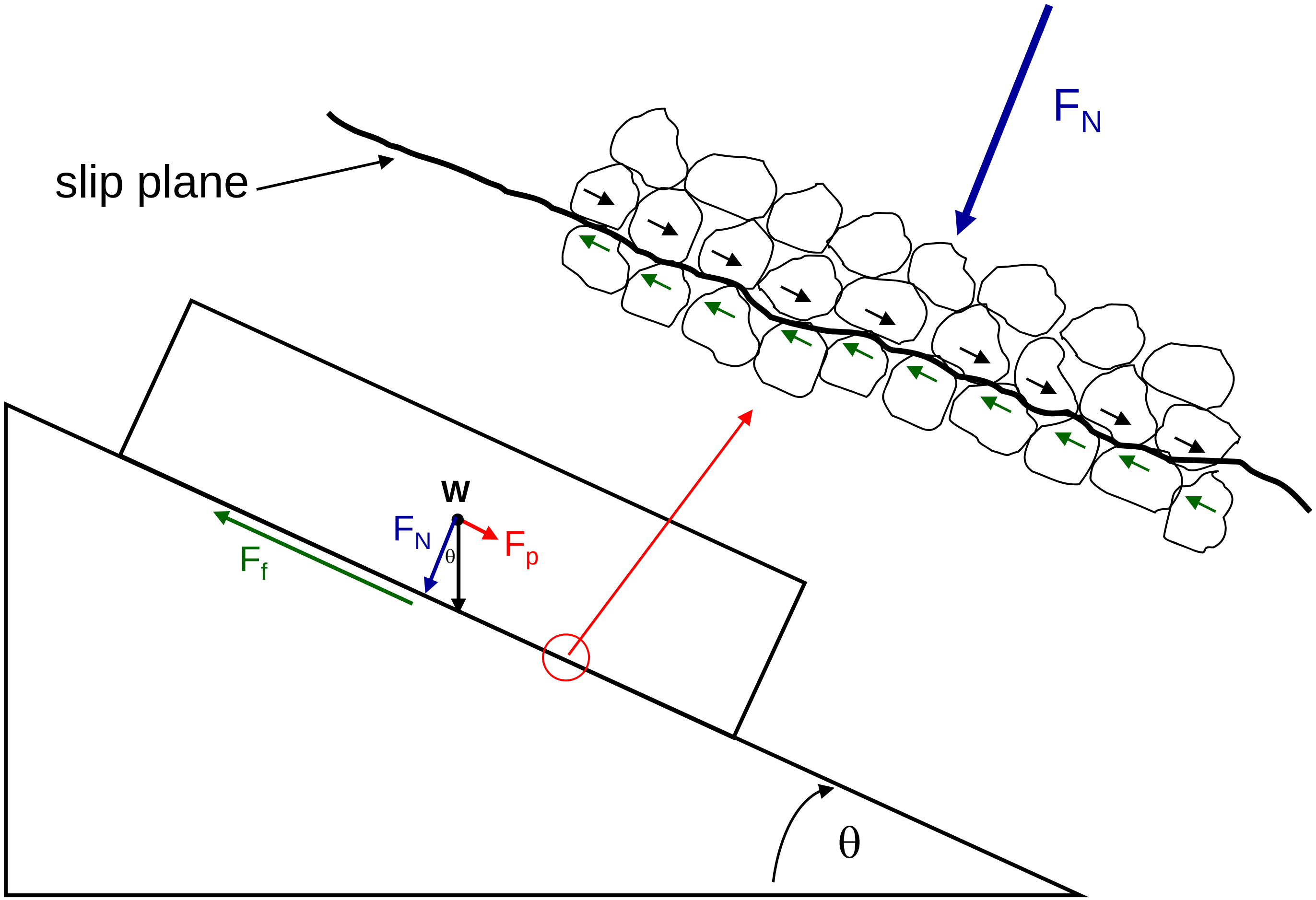
↑ F_f = friction force = ↑ $F_N \times \mu$


increases if these increase
Friction force = F_N x coefficient of friction
pull
F_N
friction force

Mechanical friction keeps the block from sliding

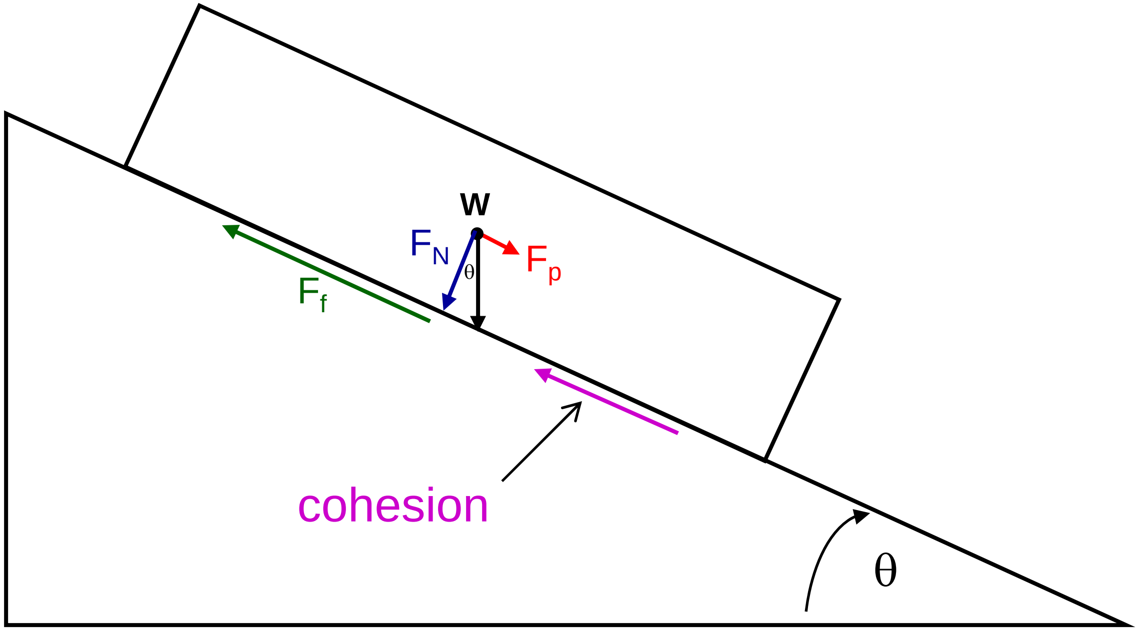



slip plane
F_N
W
F_N
θ
F_p
F_f
θ



F_N
slip plane
W
F_N
θ
F_p
F_f
θ

Molecular cohesion between the grains also contributes to the material strength and keeps the block from sliding

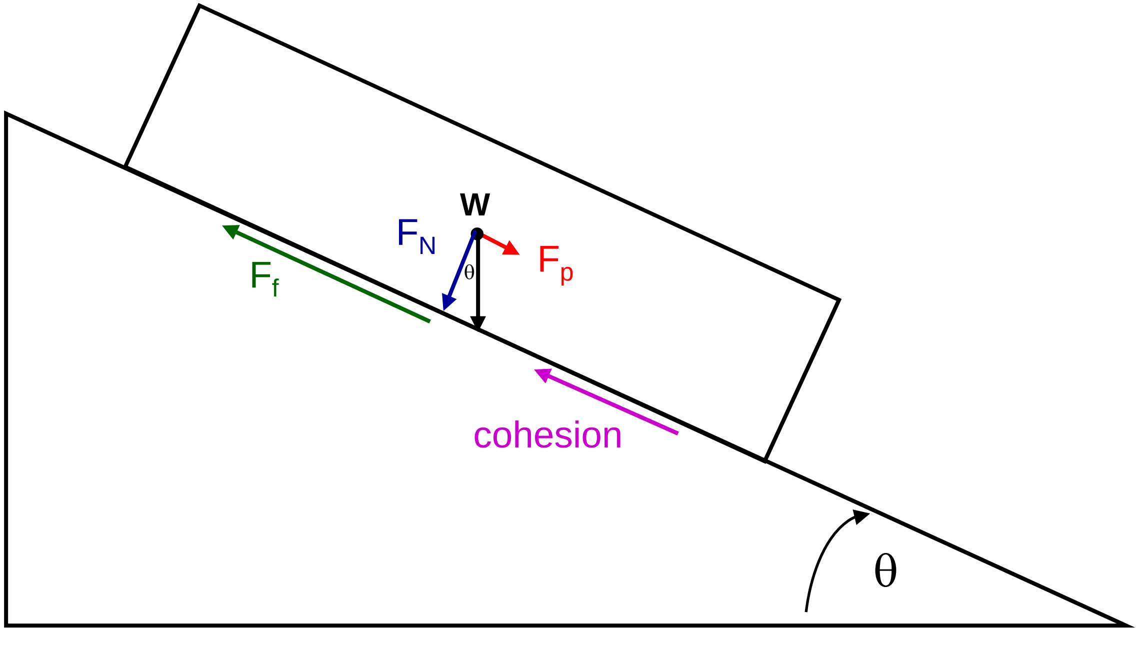


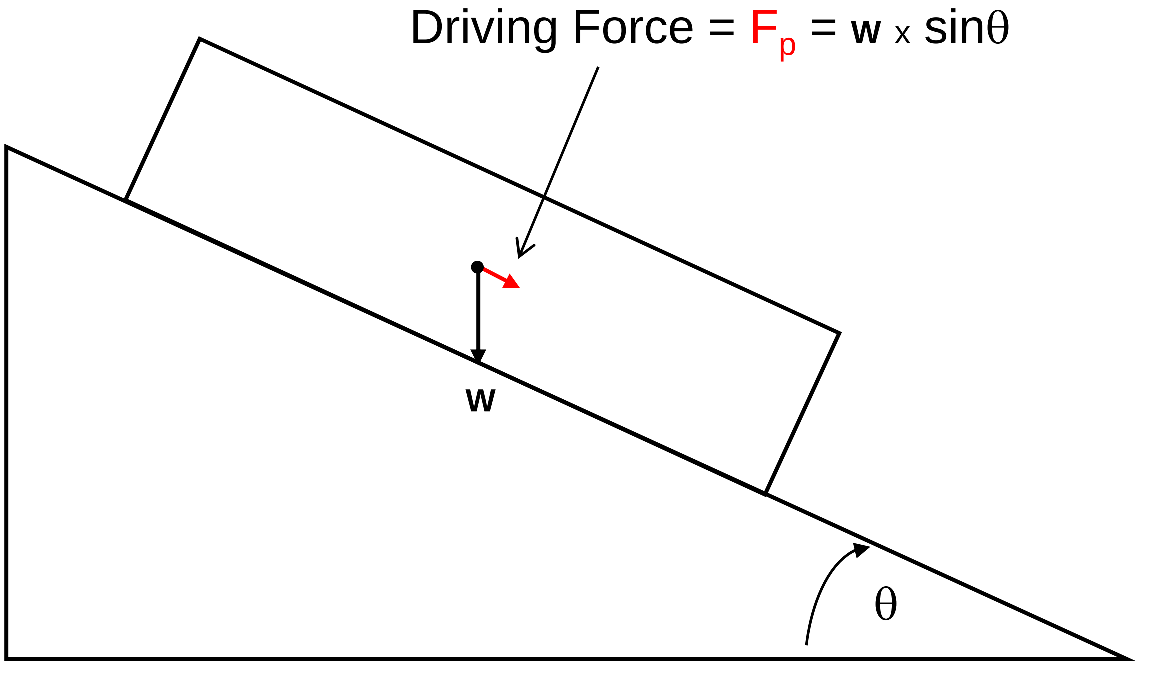
Moist sand has strength

The strength is created by “molecular” forces of attraction between the sand – water – air

Calcite and silica cements that bind minerals together is another form of molecular cohesion

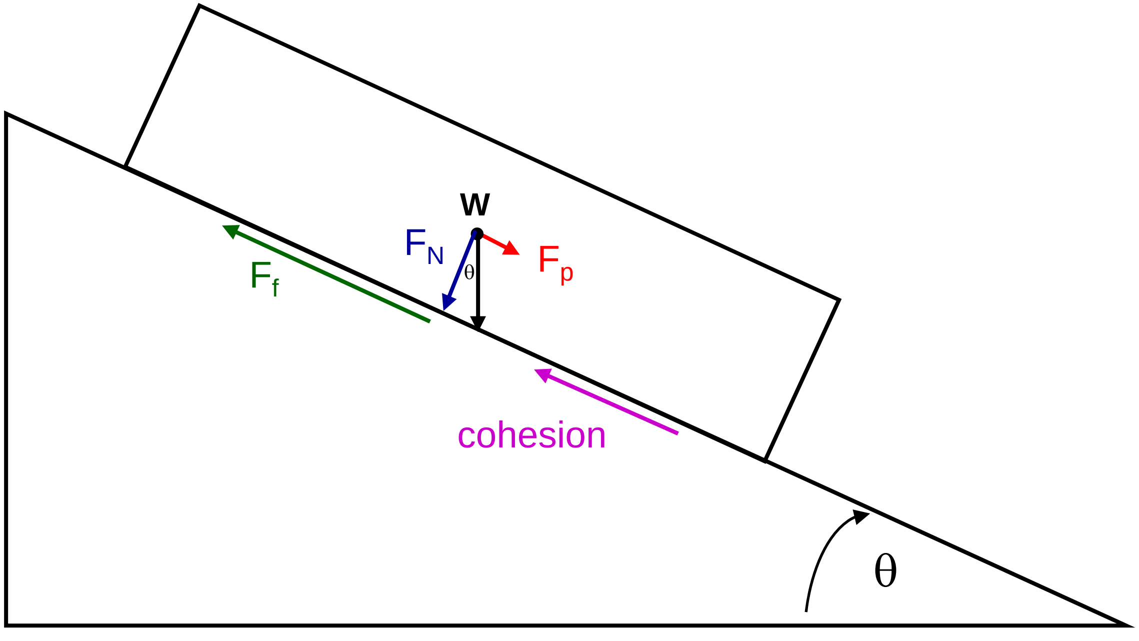
The stability of slopes is analyzed by comparing the magnitude of the “driving” forces to the “resisting” forces



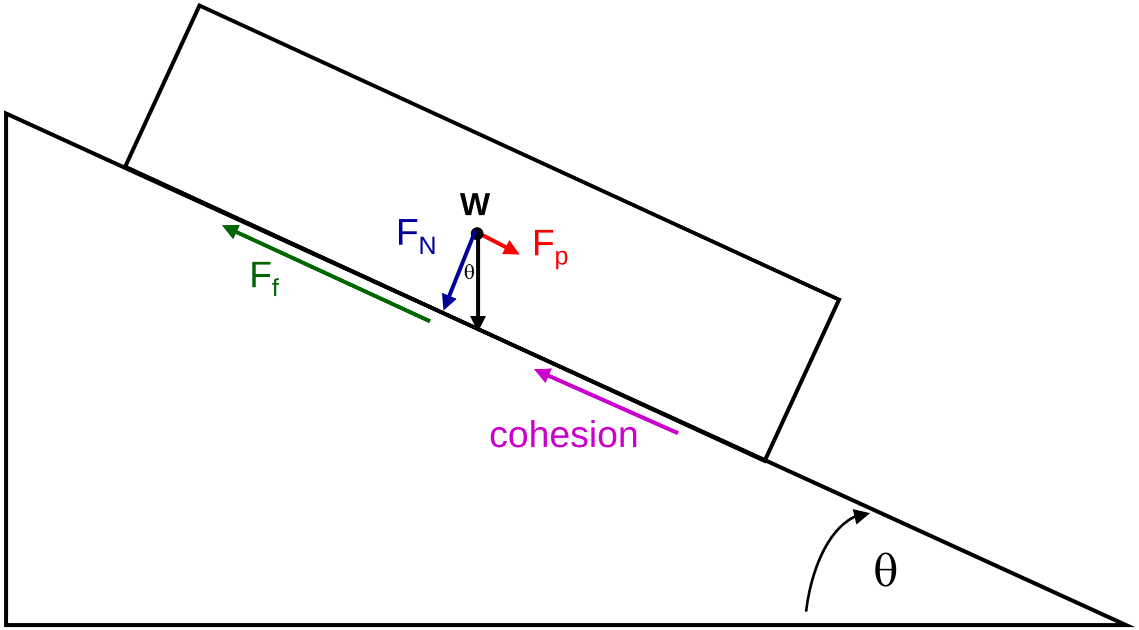


Driving Force = Fp = w x sinθ
w
θ

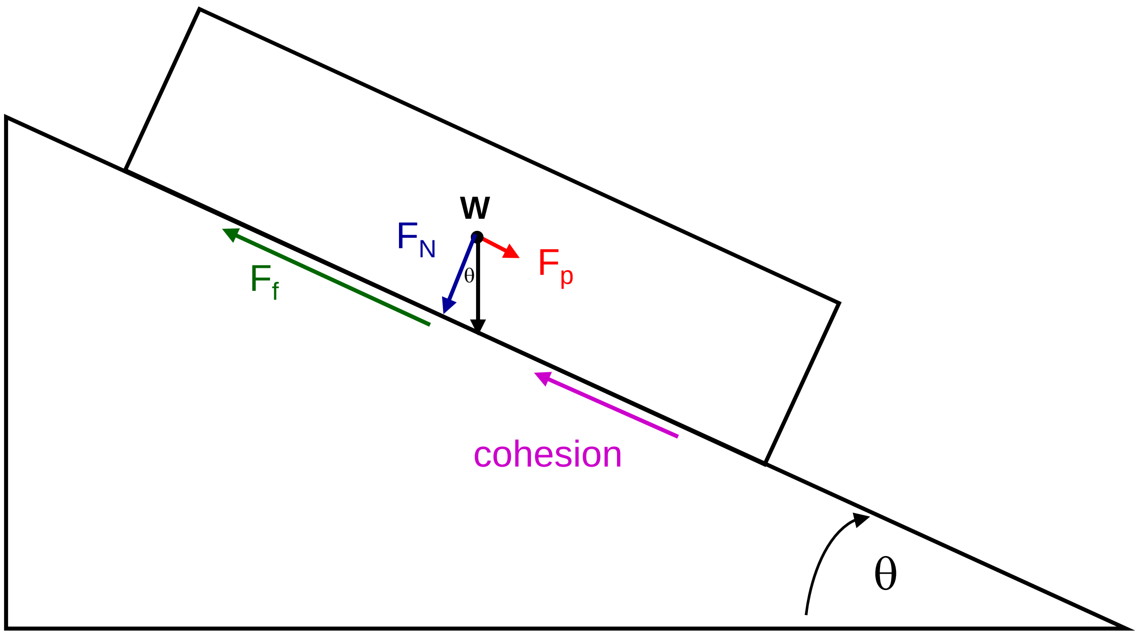
Resisting forces = friction + cohesion



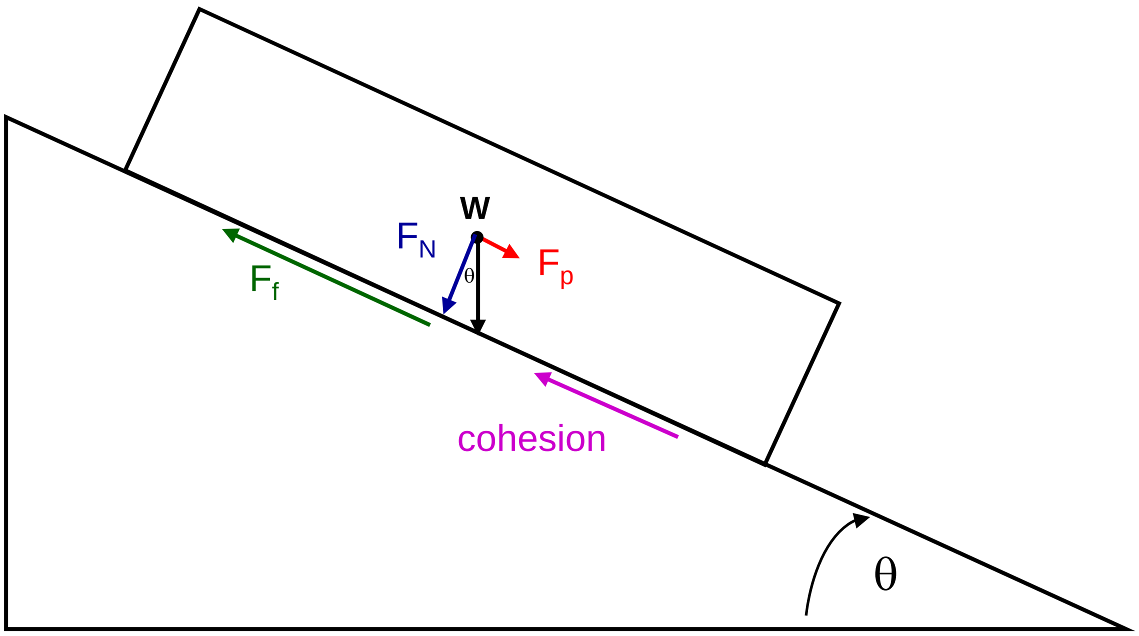
$$\text{Factor of Safety} = \frac{\text{resisting force}}{\text{driving force}}$$



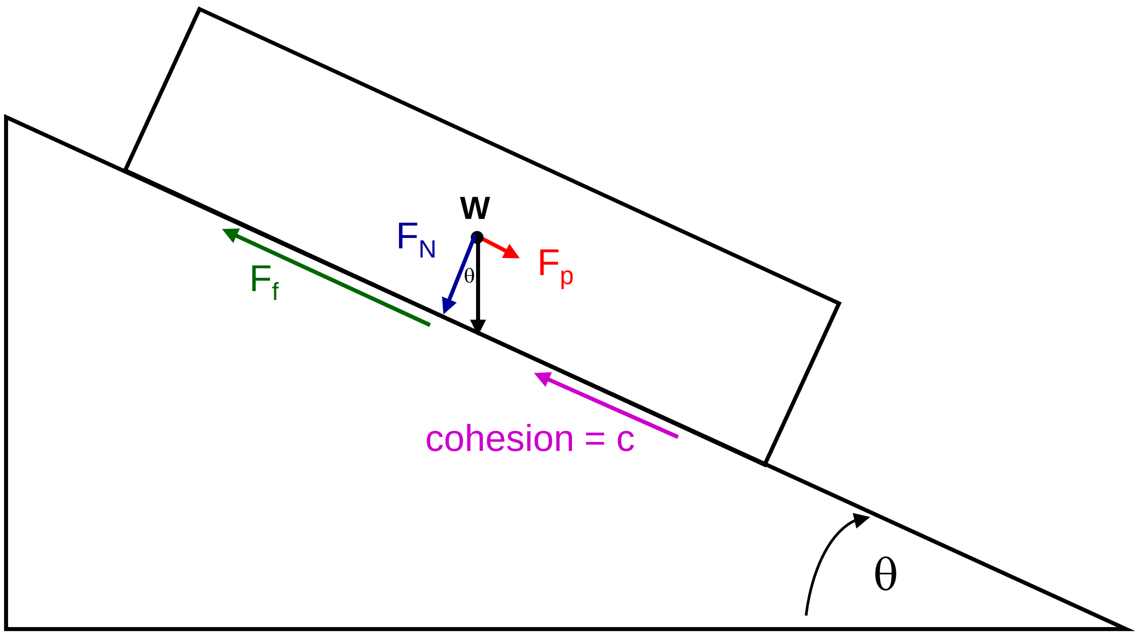
$$\text{Factor of Safety} = \frac{\text{friction} + \text{cohesion}}{F_p}$$



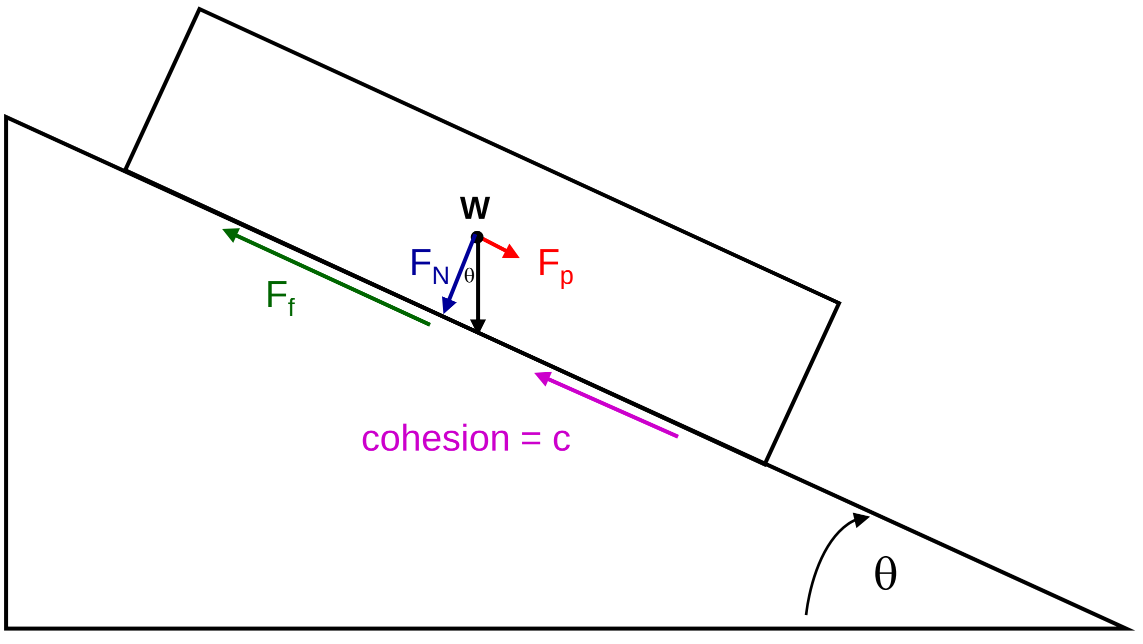
$$\text{Factor safety} = \frac{\text{resisting force}}{\text{driving force}}$$



$$\text{Factor safety} = \frac{F_f + c}{F_p}$$

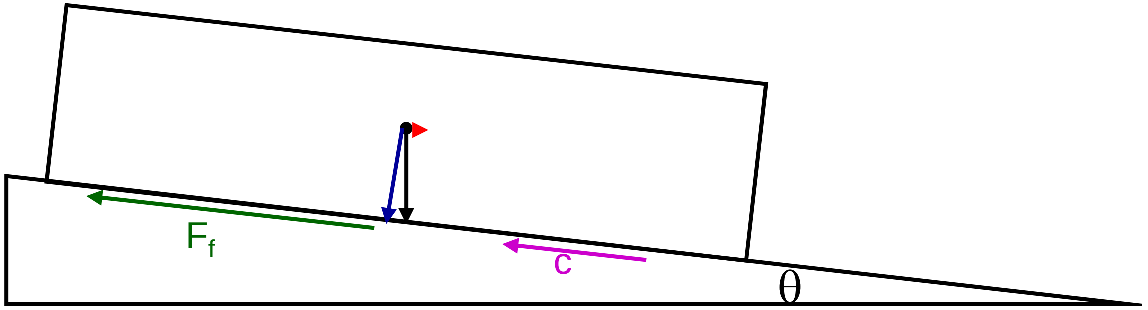


$$\text{Factor safety} = \frac{W \times \cos\theta \times \mu + c}{W \times \sin\theta}$$



At low slope angles "θ" F_p is small and F_N and hence F_f are larger

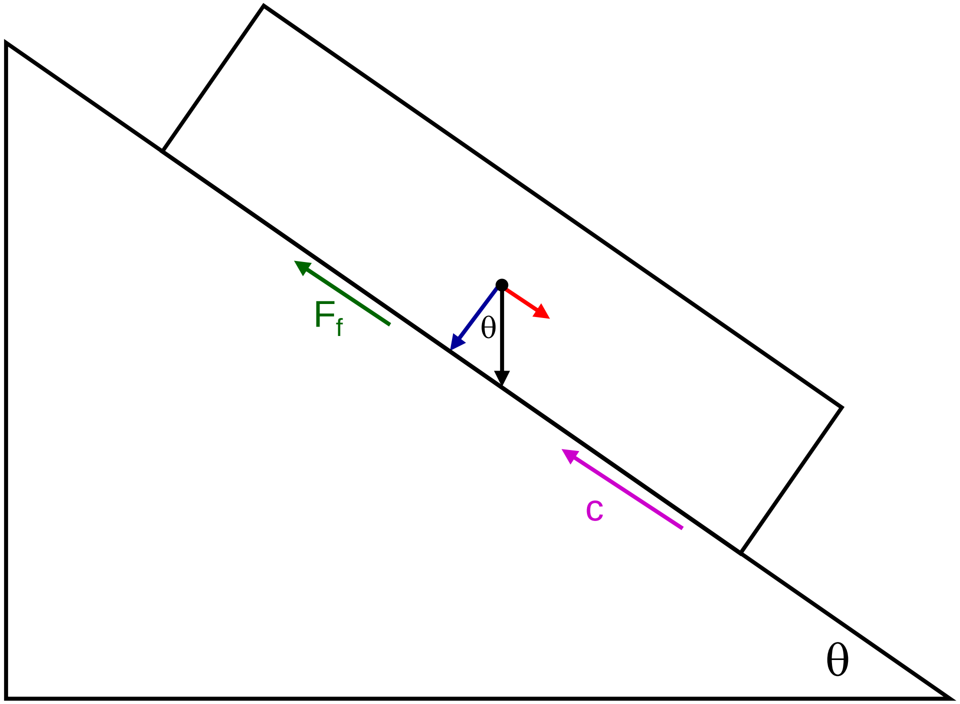
$$\text{Factor safety} = \frac{\uparrow F_f + c}{\downarrow F_p} = FS \gg 1$$



$$\text{Factor safety} = \frac{W \times \cos\theta \times \mu + c}{W \times \sin\theta} = FS \gg 1$$

At high slope angles "θ" F_p is large and F_N and hence F_f are smaller

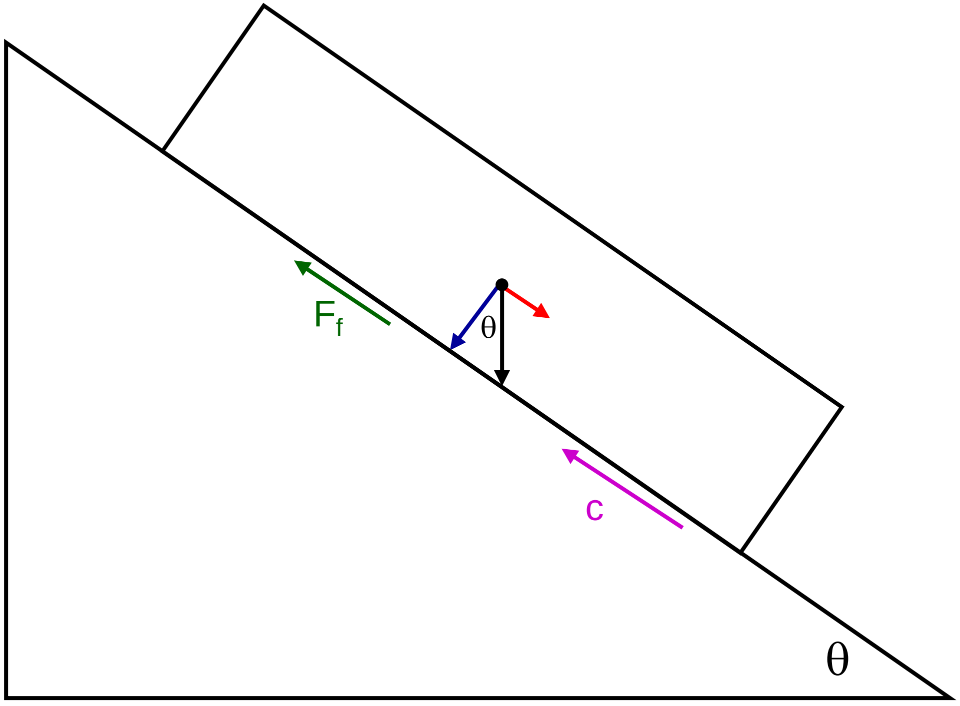
$$\text{Factor safety} = \frac{\downarrow F_f + c}{\uparrow F_p} = FS < 1$$



$$\text{Factor safety} = \frac{W \times \cos\theta \times \mu + c}{W \times \sin\theta} = FS < 1$$

$$\text{Factor safety} = \frac{\text{resisting forces}}{\text{driving forces}} = FS < 1$$

The slope fails if FS is less than “1”



Thirteen homes had to be evacuated in Burien near Shorewood Drive SW and 131st Street when a hillside gave way and sent a wall of mud on homes and the street below.

Crews work to clear Westlake Avenue North after heavy rains caused a mud slide. (December 03, 2007)

A car rests beneath a section of Golden Gardens Drive NW, which collapsed early this morning during heavy rains. (December 03, 2007)