Applied Mechanics
Chapter 5
Friction
Lecture 7 (week 7)

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Learning Objectives

- Understand the fundamental Laws of Friction.
- Differentiate between Static and Dynamic Coefficients of Friction.
- Calculate the Angle of Friction and its significance.
- Analyze real-world engineering examples demonstrating the practical usage of friction.
- Apply the principles of friction to solve engineering problems.
- Demonstrate proficiency in calculating friction-related parameters in structures, such as Tension Friction grip bolts.

5. Friction

Friction

When one body slides or tends to slide over another, resistance is always offered to its motion in the tangential direction. This tangential resistive force is termed as frictional force or force of friction.

Types of friction

a) Static friction: The frictional force experienced by a body at rest. In fact, it is the frictional force acting on body which tends to move.

b) Dynamic friction: The frictional force experienced by a body at motion.

Dynamic friction

- Sliding friction
  - Occurs when body slides on another body
- Rolling friction
  - Occurs when one body rolls over another body

Examples of engineering usage of friction

- In manufacturing industry
- Application of friction in nut bolt system
- Vehicle movement system and Braking System
- In mechanism of vehicle engine and Conveyor belt
- Clutches and transmission
- Rock climbing equipment

Effect of friction

- It causes undesirable effects like tear and wear of mechanical parts in machines.
- Overall efficiency of machines is reduced.
- Without friction we cannot do things in our daily lives as we do.
- We can't walk, can't drive a vehicle, cannot hold the pen etc.

Friction cannot be avoided in machines; it should be noted that it could be reduced by application of lubricants.

Advantages of friction

- It helps the motion of vehicles by gripping
- Vehicle braking system is the application of friction.
- It can convert mechanical energy into heat and light etc.
- It helps us for efficient working in many activities.
- Friction helps to transmit power from bent system and clutches.
- We can write, walking running without slipping.

Disadvantages of friction

- Sometimes produce unnecessary sound at unmanaged system.
- Friction reduces the life of machine parts.
- It reduces the efficiency of work due to energy dissipation.
- Causes unnecessary wear and tear at the machinery parts.
- opposes the motion so greater energy is required to overcome.

5.1 Laws of Friction

Coulomb's laws of Dry Friction

1. Laws of static friction

- Frictional force always acts such as to oppose the tendency of one surface to slide relative to the other. It acts tangential to the surface in contact.
- The magnitude of frictional force is equal to the force applied to move the body up to impending motion condition.
- The maximum force of friction is independent of the area of contact.
- Force of friction depends on the nature of surface in contact.
- The magnitude of limiting static friction is proportional to the normal reaction between the two sliding surfaces.

i.e. $F_{smax} \alpha N$

$F_{smax} = \mu_S N$ $\therefore \mu s = \frac{F_{smax}}{N}$ [μ_s is called coefficient of static friction

2. Laws of dynamic or kinetic friction

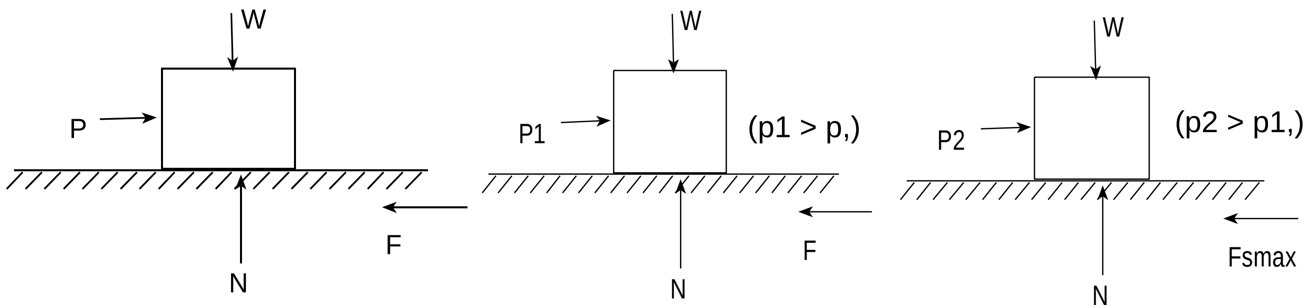
- Frictional force always acts in opposite direction to the direction of motion of body.
- For low relative velocities between sliding bodies, frictional force is independent to the relative speed with which the surfaces move each other.
- The ratio of kinetic friction (F_k) to the normal reaction (R) is always constant.

  $\frac{F_K}{N}$ $=\mu_k$ (constant) [i.e. $F_k \alpha N$]

  μ_k is called coefficient of kinetic friction.

[Note: *Frictional force is equal to $\mu_s N$ is applicable only at the point of impending motion. If the body does not move under the action of external forces, then the frictional force developed is less than the maximum value of static friction. Once motion has started the frictional force is equal to kinetic friction which is less than the maximum static friction.*

Limiting friction and impending motion



(p> 0, but very small)
No motion but in equilibrium

No motion but in equilibrium

point of impending motion.

If p is gradually increased to P_1 the F also increases.

Hence the maximum or limiting value of frictional force which acts on the body it just starts to slide is called limiting static friction and is denoted by $F_{s, max}$.

When the applied force becomes equal to maximum frictional force, the body just comes into motion. This stage of motion is called impending motion.

5.1.1 Variation of frictional force with respect to external applied force

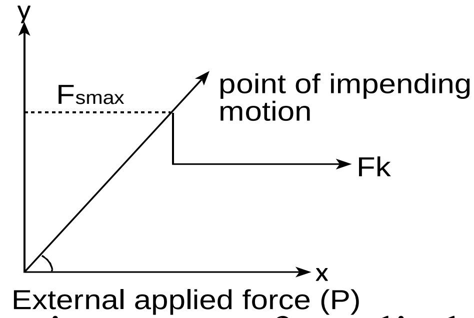


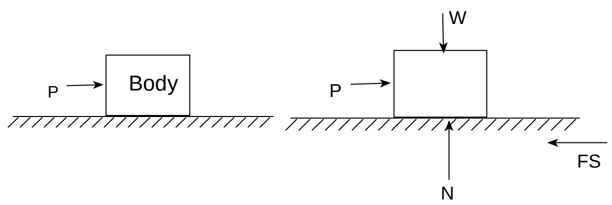
Figure shows that the increase of frictional force as increase of applied force in the same ratio up to point of impending motion. Beyond the point of impending motion, the frictional force drops to force of kinetic friction (F_k) and it almost constant. Depending upon the value of frictional force developed between the contact surfaces, we come across three different conditions.[1]

1. When $F < F_{s,max}$ no motion occurs.
2. If $F = F_{s,max}$ motion impends
3. If $F > F_{s,max}$ body under motion.

5.1.2 Illustration of coefficient of static friction is greater than coefficient of kinetic friction.

The ratio of the frictional force to the normal reaction is called coefficient of friction i.e. [$\mu = \frac{F}{R}$] We know, frictional force is maximum at the statge of impending motion.

Let us consider a body having wt. w is experienced by a maximum Frictional force Fs at the impending motion condition



we know [$\mu s = \frac{F_s}{N}$] in static condition

In equilibrium

$P - F_s = 0$

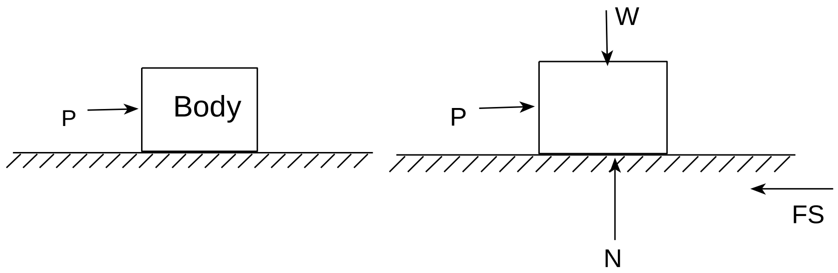
$P - \mu_s N = 0$

So, $\mu_s = \frac{P}{N}$ – i)

When motion starts F_{max} falls to some value less than F_{max} called F_k. If μ_k is coefficient of kinetic friction

Applying equilibrium condition,

For Motion



$$P - F_k = ma$$

$$P - \mu_k N = ma$$

$$\text{So, } \mu_k = \frac{P\text{-}ma}{N} \quad - \text{ii)}$$

We know,

Acceleration is greater than O so, we can conclude that coefficient of static friction μ_s is greater that coefficient kinetic friction (μ_k)

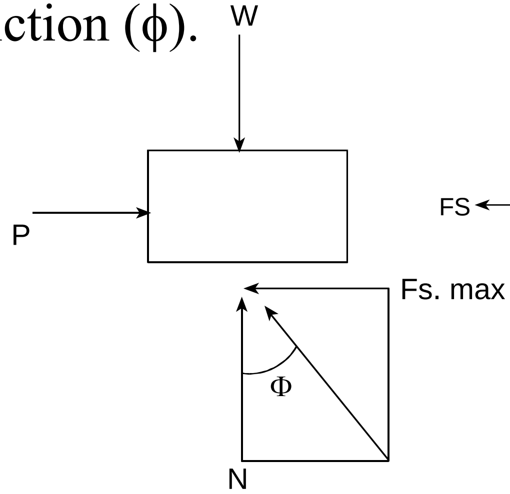
[i.e. $\mu_s > \mu_k$]

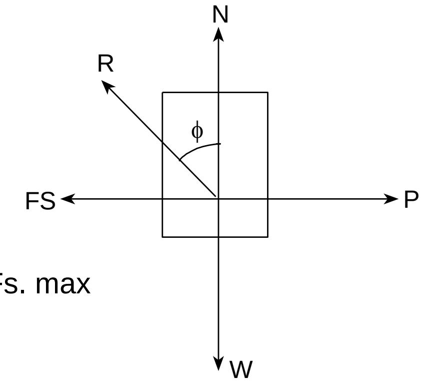
Normal Reaction

The force exerted by a surface on an object in contact with it which prevents the object from passing through the surface.

Angle of friction

An angle made by resultant of normal reaction and limiting frictional force with normal reaction is known as angle of friction (ϕ).





From the geometry of triangle

$$\tan\phi = \frac{F_{smax}}{N}$$

$$F_{s,max} = \mu_s N$$

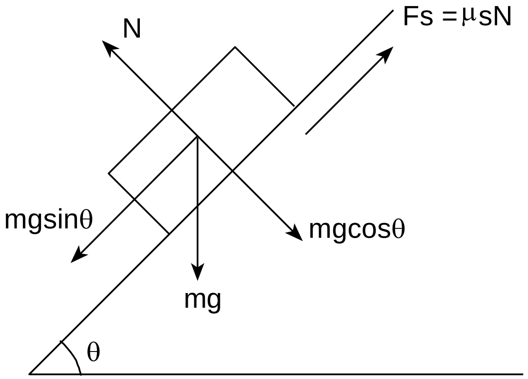
So, $[\tan\phi = \mu_s]$

Thus, the tangent of the angle of static friction is equals to the coefficient of static friction.

Angle of repose (θ)

The angle of inclination with horizontal for which the body on the inclined surface is in the verge of motion without application of any external force and verge of motion means just starts to move.

At equilibrium



$F_s = mg\sin\theta$ .... (1)

$N = mg\cos\theta$ .... (2)

From (1) and (2)

$\text{Tan}\ \theta = \frac{F_S}{N} = \mu_s$

$\text{Tan}\ \theta = \mu_s$

Also, we have, $\text{Tan}\ \phi = \mu_s$ So, $\tan\theta = \tan\phi$ $\therefore\ \theta = \phi$

[Angle of repose = angle of friction]

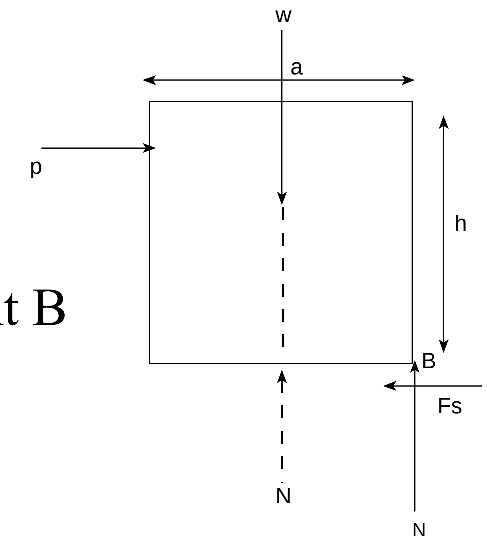
Tipping and sliding of a block

As the magnitude of applied force P increases frictional force F also increases and the normal reaction N moves towards the right end of the block, so that the couple formed by P and F is balanced by the couple formed by W and N. we know Couple formed by P and F tends to overturn the block.

Let us consider h is the height of the applied force from the base.

The produced couple of P and F is = $(p \times h = F_s \times h)$

$$ph = \mu_s N \times h$$



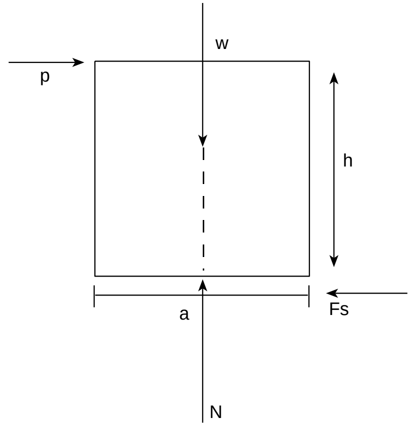
When frictional force F increases from 0 to $F_{s,max}$,

the point of application of normal reaction moves to point B

So, couple formed by W and N is $= w \times \frac{a}{2} = N \times \frac{a}{2}$

If there is no tipping both couples are in balanced so,
The condition for no tipping is

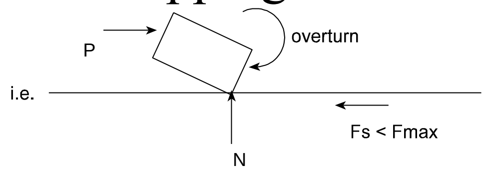
$$\mu_s N h = N \times \frac{a}{2} \qquad \text{or, } [\therefore\ h = \frac{a}{2\mu_s}]$$

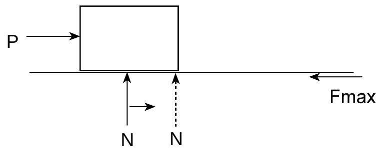


$$\text{or } [\therefore\ h \leq \frac{a}{2\mu_s}]$$

If normal reaction N reaches point B before frictional force reaches F_{max} the block will tip (overturn) about 'B' before it starts sliding which is called tipping of block.

- When the applied force P in increasing in such a way that frictional force F reaches to $F_{s,max}$ before Normal reaction reaches at the end point B, the block starts to slide along the surface of contact which is known as sliding of body.

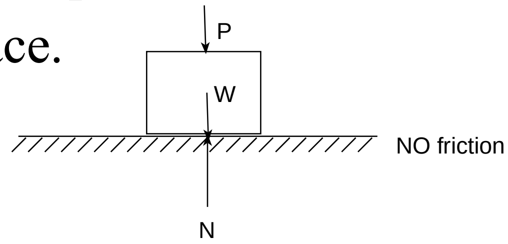




5.1.3 Illustration of condition of no friction, no motion, impending motion and motion

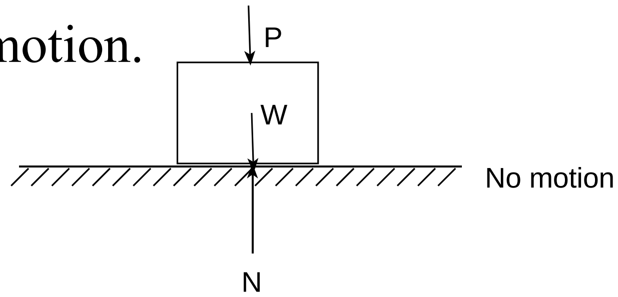
Condition of no friction

- If the force is applied normal to the surface, then the object exerts only normal reaction from that surface. And there is no motion produce from that applied forces, hence no frictional force occurs at the surface.



Condition of no motion

- If the applied force is not greater than the produced frictional forces. Then the object is in rest condition and if applied force is equals to frictional force, then the object tends to move but not in motion.

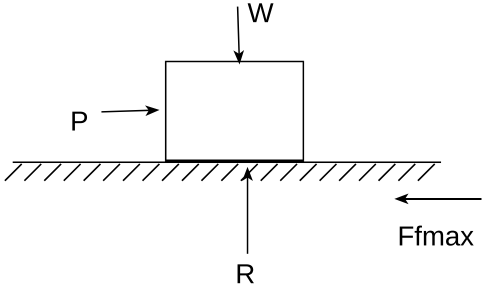


$[P = F_f)$

Condition of impending motion

- The applied force is such that the body is about to slide it means at the stage of impending motion.

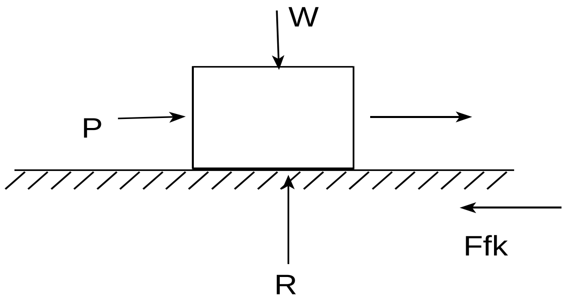
  $[P = F_{f,max}]$



Condition of motion

If the applied force is greater than the maximum frictional force after that stage the force creates motion of object.

Frictional force, $F_{fk} = \mu_k N$



5.1.4 High tension friction grip bolt

It is a structural bolt having high strength which have been tightened such as to induce tension in the shank of bolt structure. Because of the high frictional resistance, the interface between the steel member cannot move.

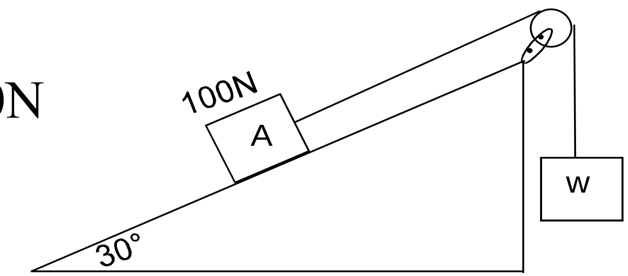
Friction Grip Principle

The effectiveness of HTFG bolts relies on the principle of friction grip. When properly tightened, the friction between the bolt and the connected members resists external forces, such as tension, compression, or shear.

The clamping force generated by the friction grip ensures that the structural connection remains stable and can withstand various loads and environmental conditions.[2]

5.2 Calculation involving friction

Q. A block 'A' of weight 100N rests on a inclined plane and another weight W is attached to the first weight through a string as shown in figure if the coefficient of friction between the block and plane is 0.3. Determine the maximum value of 'W' so that equilibrium can exist.[1]



Solution: Given, weight of block (A) (W_A) = 100N

Coefficient of friction (μ_s) = 0.3

At 1st Draw the F.B.D of the system.

Here, block tends to move upward because maximum value of 'W' i.e. motion creates by weights of 'w' block.

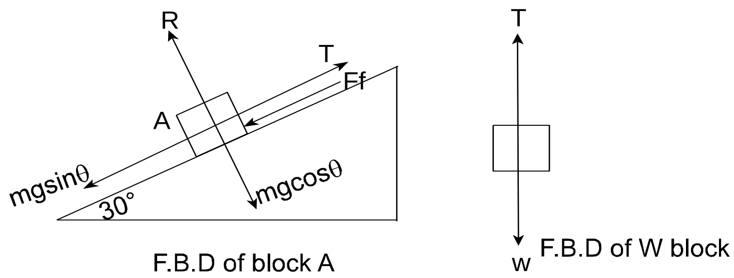
Now, applying condition of equilibrium perpendicular to the inclined plane,

i.e. ($\nwarrow$+) (ΣFy) = o

$$R - mg\cos\theta = 0$$

$$R - 100 \cos 30° = 0$$

$$[R = 86.60N]$$



Applying condition of equilibrium parallel to the inclined surface

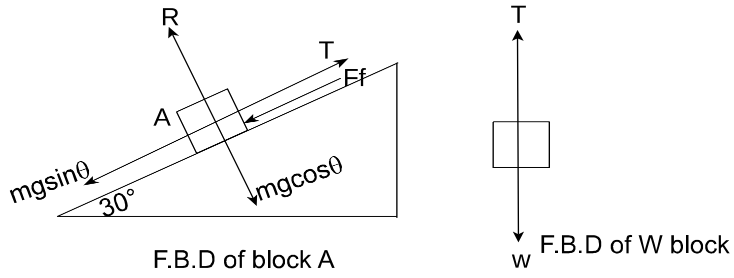
i.e. $\Sigma Fx (\nearrow +) = 0$

$T - mg\sin\theta - F_f = 0$

$T - 100 \sin 30° - \mu \times R = 0$

$T - 100 \sin 30° - 0.3 \times 86.60 = 0$

$[T = 75.98N]$



For another block using equilibrium vertically

$(+\uparrow)\ \Sigma Fy = 0$

$T - W = 0$

$[W = 75.98N]$

Hence, the maximum value of 'W' so that equilibrium can exist is 75.98N

References

[1] Kumar, D. (2019). *Engineering Mechanics.* New delhi: S.K Kataria and Sons.

[2] Neupane, P. a. (2024). *A Text book of Engineering Mechanics.* Bhotahity Kathmandu: Heritage Publisher and Distributors PVT .LTD.

Thank You!!!