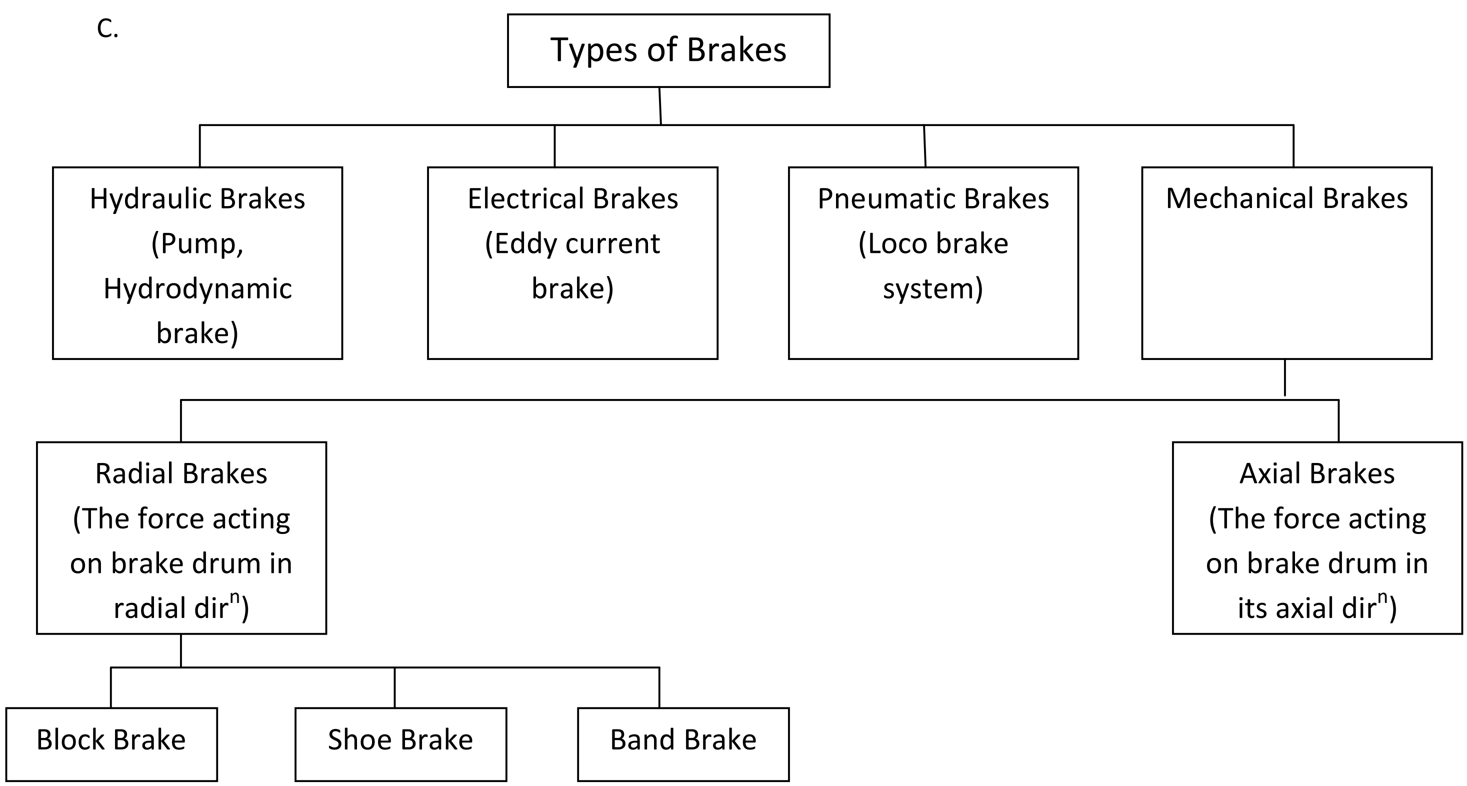
BRAKES

A. The capacity of brakes depends upon the following factors:
   a) The unit pressure between the braking surface.
   b) The coefficient of friction between the braking surface.
   c) The peripheral velocity of the brake drum.
   d) The projected area of the friction surface.
   e) The ability of the brake to dissipate heat equivalent to the energy being absorbed.

Note: One major function difference between clutch & brake is that a clutch is used to keep the driving & the driven member moving together, whereas the brake are used to stop a moving member or to control its speed.

B. Materials for brake lining: The materials used for brake lining should have the following characteristic
   a) It should have high co-efficient of friction with minimum fading, i.e, the co-efficient of friction should remain constant with change in temperature.
   b) It should have low wear rate.
   c) It should have high heat resistance
   d) It should have high heat dissipation capacity.
   e) It should have adequate mechanical strength.
   f) It should not get affected by moisture & oil.

C.



D. **Single block or shoe brake:** A single block or shoe brake as shown in Gif.(1) & fig.(2). It consists of a shoe of a softer material from the rim of wheel. This type of brake is commonly used in railway trains 7 trams.

The friction between the blocks:

CASE-I

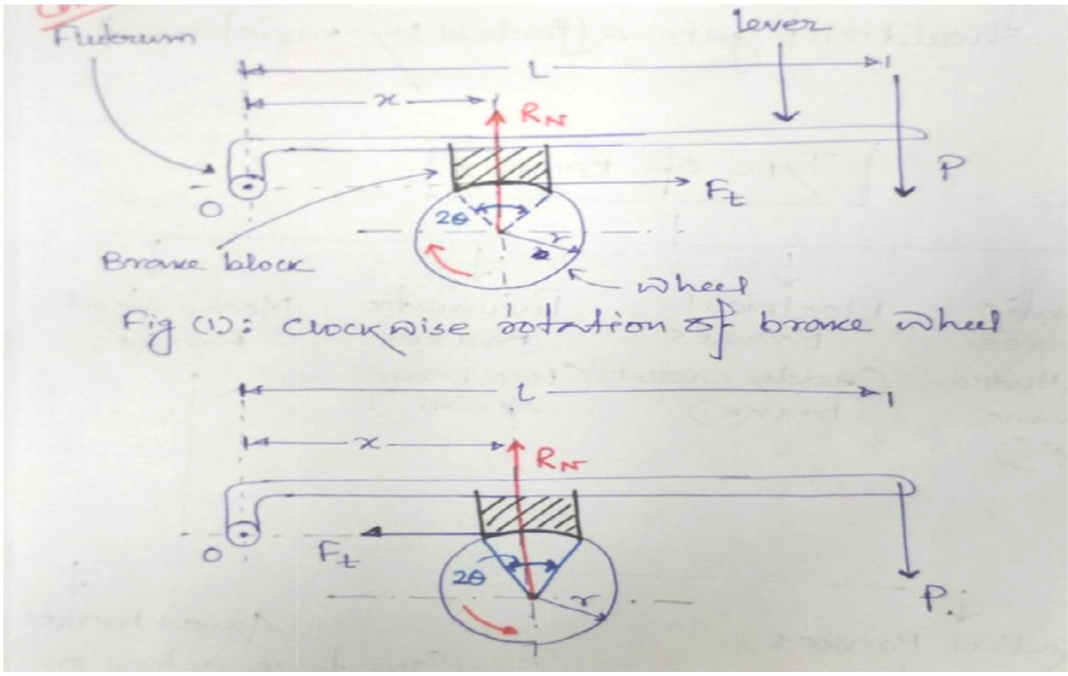


Fig.(2) Anti-clock wise rotation of brake wheel.

The wheel causes a tangential braking force to act on wheel, which retard the motion of wheel. The block is pressed on the wheel by a force applied to one end of the lever to which the block is rigidly fixed. The other end of the lever is pivoted on a fixed fulcrum O.

Let, P= Force applied at the end of lever

R_N= Normal force pressing the brake block on the wheel

R= Radius of wheel

2θ= Angle of contacts surface of the block

μ= Co-efficient of friction

Ft= Tangential braking force or the friction force acting at the contact surface of the block & Wheel

T_B= Braking torque on wheel

Let us consider that if 2θ= Angle of contacts is <60° then the normal pressure is uniform. As per the laws of friction forces,

F_t X R_N

=> $F_t = \mu R_N$ ---- (1)

Braking torque, $T_B = F_t$ X $r = \mu R_N r$ ----(2)

Now as per fig.(1) & fig.(2), the line of action of the tangential force is going through the fulcrum O.
Consider in this case that brake wheel rotating clockwise as fig.(1)
Taking moment about point O

$+\curvearrowright \Sigma\mu_O = P \text{ X } L - R_N \text{ X } x = 0$

=> $R_N = \frac{P \, X \, L}{x}$

∴ Putting the value of R_N in Equ. (1) & (2)

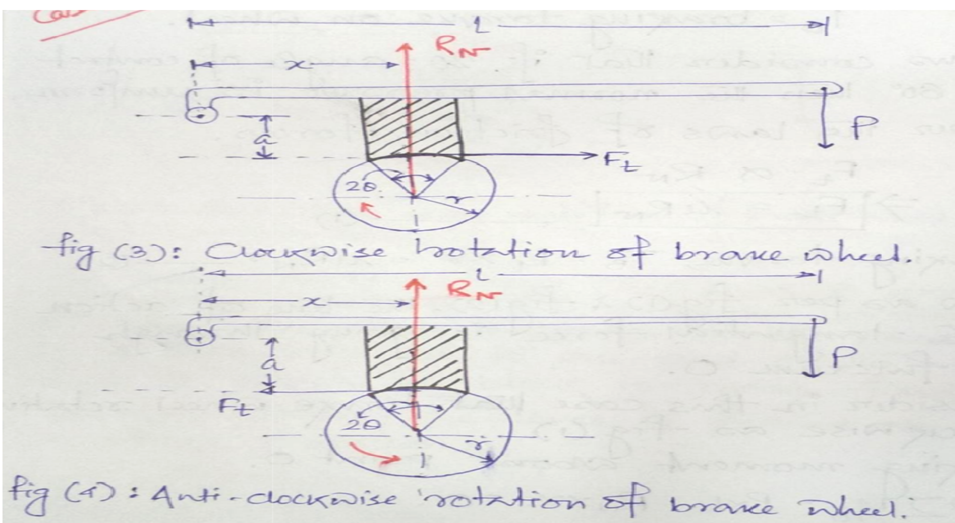
$T_B = \mu.R_N.r$

=> $T_B = \mu.\frac{P \, X \, L}{x}.r$ ----(3)

=> $F_t = \mu.\frac{P \, X \, L}{x}$ ----(4)

Also when the brake wheel rotates anti clockwise like fig.(2), all equ^n. (1) to (4) will be applicable.

CASE-II



When the line of action of tangential braking fore (F_t) passes through a distance "a" below the fulcrum & the brake wheel rotates clockwise, then taking moment about point O.

$+\curvearrowright \Sigma\mu_O = P \text{ X } L - R_N \text{ X } x - F_t \text{ X } a = 0$

=> R_N X $x + \mu R_N a$ [∴ $F_t = \mu R_N$]

=> $R_N = \frac{P \, X \, L}{x - \mu a}$ -----(5)

∴ Braking torque $Tb = \mu.R_N.r$

=> $T_B = \frac{\mu.(P.L).r}{x - \mu a}$ -----(6)

Again when the brake wheel rotates anti clockwise fig.(4)

Taking the moment about point O.

$+\circlearrowright\ \Sigma\mu_O = P \times L - R_N \times x + F_t \times a = 0$

$\Rightarrow R_N \times x - \mu R_N a = P \times L$

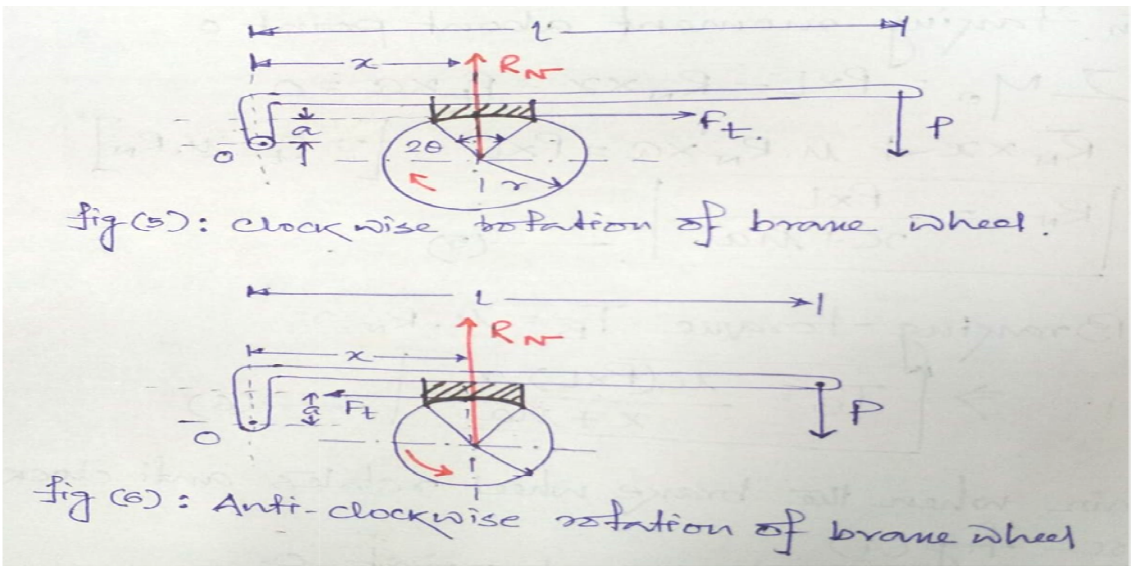
$\Rightarrow R_N (x - \mu a) = P \times L$

$\Rightarrow R_N = \frac{P \times L}{x - \mu a}$ -----(7)

Braking torque:

$T_B = \frac{\mu.P.L.r}{x - \mu a}$ -----(8)

CASE-III



distance "a" above the fulcrum "O" and the brake wheel rotates clockwise as shown in fig.(5) then for equilibrium, taking moment about point O, we get

$+\circlearrowright\ \Sigma\mu_O = P \times L - R_N \times x + F_t \times a = 0$

$\Rightarrow R_N \times x = P \times L + \mu R_N a$

$\Rightarrow R_N (x - \mu a) = P \times L$

$\Rightarrow R_N = \frac{P \times L}{x - \mu a}$ -----(9)

$\therefore$ In this case braking torque

$T_B = \mu.R_N.r = \frac{\mu.P.L.r}{x - \mu a}$ -----(10)

When the wheel is rotating anticlock wise then for equilibrium, taking moment about point "o" (fig. 6)

+$\curvearrowright$ $\Sigma\mu_O = P \times L - R_N \times x - F_t \times a = 0$

$\Rightarrow R_N (x + \mu a) = P \times L$

$\Rightarrow R_N = \frac{P \times L}{x - \mu a}$ ----(11)

$\therefore$ Braking torque TB = $\frac{\mu.P.L.r}{x - \mu a}$ ------(12)

E. **Pivot block or shoe brake:** When angle of contact $(2\theta) > 60^O$, then the unit pressure normal to the surface of contact is less at the ends than at the centre. In such cases, the block or shoe is pivoted to the lever as the fig. below, instead of being rigidly.

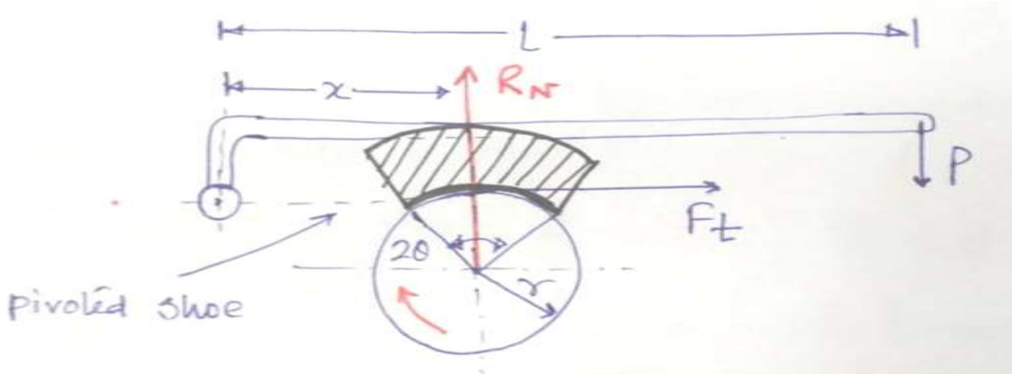


Fig (7): Pivoted block or shoe brake

Attached to the lever. This gives uniform wear of the brake lining in the dir^n. Of the applied forced. In this case, the braking torque is given by:

$T_B = F_t \times r = \mu \times R_N \times r$

Where µ = Equivalent co-efficient of friction

$= \frac{4\mu Sin}{2\theta + sin2\theta}$

The process of calculating R_N is similar to the earlier process for clock-wise and anticlockwise and anticlockwise dir^n.

F. **Double block or shoe brake:** When a single block rake is applied to a rolling wheel, an additional load is thrown on the shaft bearing due to the normal force (R_N). This produces bending of the shaft. In order to overcome this problem, a double shoe or brake is being applied. It consists of two brake block applied at the opposite ends of a diameter of the wheel, while eliminate or reduce the unbalanced force on the shaft.

This type of brake is generally used on electric cranes.

In a double block brake, the braking action is doubled by the use of two blocks and these blocks may be operated practically by the same force which will operate one.

In case of double block or shoe brake, the braking torque is given by,

$$TB = (F_{t1} + F_{t2}) \text{ X } r \quad \text{----(13)}$$

As per the fig. (8) let us consider the double brake shoe.

P= spring force necessary to set the brake

R_{N1} & F_{t1} = Normal reaction & braking force on the right hand side shoe.

R_{N2} & F_{t2} = corresponding value on the left hand side of brake assembly.

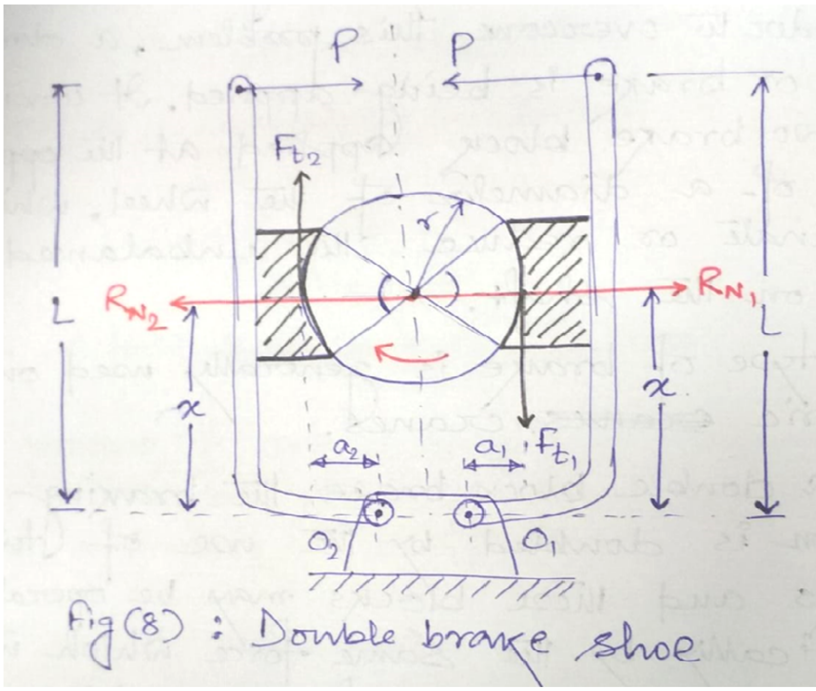


Fig (8) : Double brake shoe

Let us consider the angle of contact (2θ) is greater than 60^{O}

$\therefore \mu = \frac{4\mu.\sin\theta}{2\theta+\sin 2\theta}$

Where μ = equivalent co-efficient of friction

μ = Actual co-efficient of friction

Now taking moment about fulcrum O_1

$+\curvearrowright \Sigma\mu_O = -P \text{ X } L + R_{N1} \text{ X } x - F_{t1} \text{ X } a_1 = 0$

$\Rightarrow R_N \text{ X } x + \mu.R_{N1}.a_1 = P \text{ X } L$

$\Rightarrow R_N (x + \mu a_1) = P \text{ X } L$

$\Rightarrow R_N = \frac{P \text{ X } L}{x-\mu a1}$

$\therefore F_{t1} = \mu \text{ X } R_{N1} = \frac{\mu 1.P.L}{x-\mu a1}$ ------(14)

Again taking moment about O_2

$+\curvearrowright \Sigma\mu_{O2} = -P \text{ X } L - R_{N2} \text{ X } x - F_{t2} \text{ X } a_2 = 0$

$\Rightarrow R_N \text{ X } x - \mu.R_{N2}.a_2 = P \text{ X } L$

$\Rightarrow R_{N2} (x + \mu a_2) = P \text{ X } L$

$\Rightarrow R_{N2} = \frac{P \text{ X } L}{x-\mu a2}$

$\therefore F_{t2} = \mu \times R_{N2} = \frac{\mu 1.P.L}{x - \mu a2}$ ------(15)

Putting the value of f_{t1} & f_{t2} is equ^n (13) we get:

$$T_B = (F_{t1} + F_{t2}) \times r$$

$$\Rightarrow T_B = \mu PL \left(\frac{1}{x+\mu a1} + \frac{1}{x-\mu a2}\right) \times r$$

Now as the fig. is symmetrical, we can consider, $a_1=a_2=a$, as the applied forces are also in equal.

$$\therefore T_B = \mu PL \left(\frac{1}{x+\mu a1} + \frac{1}{x-\mu a2}\right) \times r$$

$$\Rightarrow T_B = \mu PL \left(\frac{1x-\mu a + x+\mu a}{(x+\mu a)(x-\mu a)}\right) \times r$$

$$\Rightarrow T_B = \frac{\mu PL \times 2x \times r}{x2-(\mu a)2}$$

$$\therefore TB = \frac{2.\mu xr.PL}{x2-(\mu a)2} \quad \text{-----(15)}$$

G. Simple band brake:

A band break consists of a flexible band of leather, one or more ropes, or a steel lined with frictional material, which embraces a part of the circumference of the drum. A simple band brake, as shown in fig. below, one end is attached to a fixed pin or fulcrum of the lever while the other end is attached to the lever at a distance "b" from the lever.

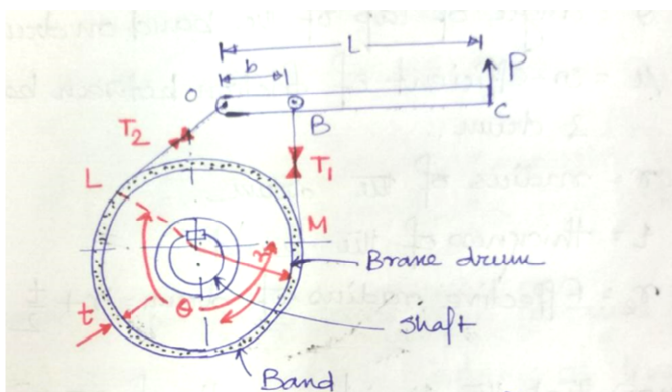


fig (9) : Clockwise rotation of drum

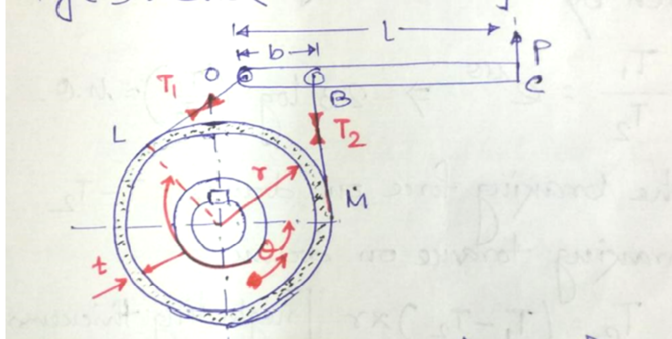


fig (10) : Anti-clockwise rotation of drum

Now let us consider a force P is applied at the end of the lever at point C. The lever turns about the fulcrum pin O and tightens the band on the drum & hence the brake gets applied. The friction between the band & the drum provides the braking force.

Let, T1 = Tension in the tight side of band

T2 = tension in the slack side of band

θ = Angle of lap of the band on drum

μ = Co-efficient of friction between band & drum

r = Radius of the drum

r_e = Effective radius of drum = $r+\frac{t}{2}$

We know that the limiting ratio of the tension is given by

$$\frac{T1}{T2} = e^{\mu\boldsymbol{\theta}} => 2.3\log\left(\frac{T1}{T2}\right) = \mu\boldsymbol{\theta}$$

And the braking force on drum = T_1-T_2

∴ Braking torque on drum

$T_B = (T_1-T_2) X r$ [neglecting thickness of band]

$= (T_1-T_2) X r_e$ [considering thickness of band] -------(16)

Now considering the equilibrium of the lever OBC. It may be noted that when the drum rotates in the clockwise direction, as shown in fig.(9), the end of the band attached to the fulcrum O will be slack and it is T_2 and end of the band attached with B will be tight side with tension T_1.

On the other hand if the drum rotates in anti clockwise dir^n. Then opposite of the above phenomenon will occur.

Now taking moment about fulcrum O, we have

P X L = T_1 X b (for clockwise rotation of drum)

P X L = T_2 X b (for anti clockwise rotation of drum)

Where L= length of lever from fulcrum (OC)

B= Perpendicular distance of line of action of T_1 or T_2 from fulcrum.

H. Braking of a vehicle:

In a four wheeled moving vehicle, the brakes may be applied to:

1. Rear wheels only
2. Front wheels only
3. All the four wheels

This is a case of dynamics, where we require to determine the retardation of the vehicle when brakes are applied.

a) Now let us consider a vehicle moving upward and braking being done rear wheels, as shown in the fig.

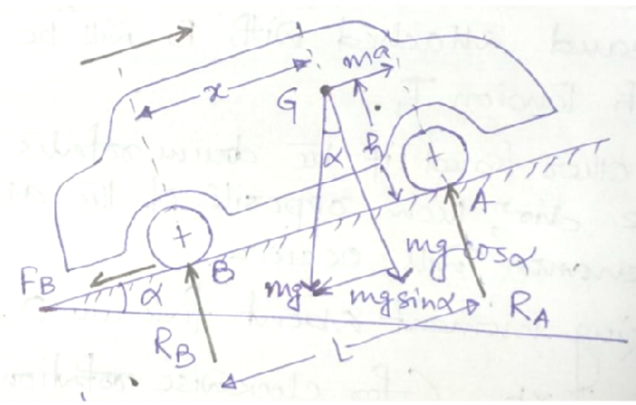


Fig.(11): Motion of vehicle up the inclined plane & brakes are applied to rear wheel only.

Let, α = Angle of inclination of the plane with horizontal surface
m = Mass of the vehicle in Kg.
h = Height of the center of gravity of the vehicle from the road surface in meter
x = Perpendicular distance of C.G from the rear axle in meter
L = Wheel base in meter
R_A = Reaction force of front wheel
R_B = Reaction force of rear wheel
μ = Co-efficient of friction between types and road surface
a = Retardation of vehicle in m/s^2

A the braking being applied at rear wheel, thus braking force will get initiated at the rear wheel & it will act in the opposite dir^n of the motion of vehicle

Let, F_B = Total braking force acting downward along the road surface

$F_B = \mu RB$ ----(a)

From equilibrium of forces consider all forces parallel to the working plane,

$$F_B + mgSin\alpha - ma = 0$$

$$\Rightarrow F_B + mgSin\alpha = ma \quad \text{-----(b)}$$

Now taking equilibrium of forces in the perpendicular dir^n. Of working plane,

$$R_A + R_B - mgCos\alpha = 0$$

$$R_A + R_B = mgCos \quad \text{-----(c)}$$

Now taking moment about point G

$+\curvearrowright M_G = -F_B \times h - R_B \times x + R_A (L-x) = 0$

$\Rightarrow F_B \times h + R_B \times x = R_A (L-x)$

$\Rightarrow \mu.R_B.h + R_B \times x = (mg.Cos\alpha - R_B)(L-x)$

$\Rightarrow \mu.R_B.h + R_B x = (mg.Cos\alpha)(L-x) - R_B(L-x)$

$\Rightarrow \mu.R_B.h + R_B x + R(L-x) = (L-x)(mg.Cos\alpha)$

$\Rightarrow R_B(L+\mu h) = (L-x)(mg.Cos\alpha)$

$\Rightarrow R_B = \frac{(L-x)\mathrm{m}gCos\alpha}{L+Mh}$ ----(d)

$\therefore$ $R_A = \frac{(L-x)\text{m}gCos}{L+\mu h}$ + mgCos$\boldsymbol{\alpha}$

$\therefore$ $R_A = \frac{\text{m}gC \quad (x+\mu h)}{L+\mu h}$ ----(e)

Again from eqn. (b) we get

$A = F_B + mgSin\boldsymbol{\alpha} / m$

=> $a = F_B/m + gSin\boldsymbol{\alpha}$

=> $a = \mu R_B/m + gSin\boldsymbol{\alpha}$

=> $a = \frac{\mu(L-x)gCos\alpha}{L+\mu h} + gSin\boldsymbol{\alpha}$ ---(7)

Notes:

1. When the vehicle moves on a level track, then $\boldsymbol{\alpha} = 0$

   $\boxed{R_A = \frac{\text{m}g(L-x)}{L+\mu h}}$ / $\boxed{R_B = \frac{\text{m}g(x-\mu h)}{L+\mu h}}$

   And $a = \frac{\text{m}g(L-x)}{L+\mu h}$

2. When the vehicle moving downward, then equ. (b) becomes

   $F_B - mgSin\boldsymbol{\alpha} = ma$

   $\therefore$ $a = F_B / m - gSin\boldsymbol{\alpha} = \frac{mgcos\alpha(L-x)}{L+\mu h} - gSin\boldsymbol{\alpha}$

b) **When the brakes are applied to front wheels:** Now let us consider a case where brake is applied to front wheels only while the vehicle is moving upward on an inclined plane.

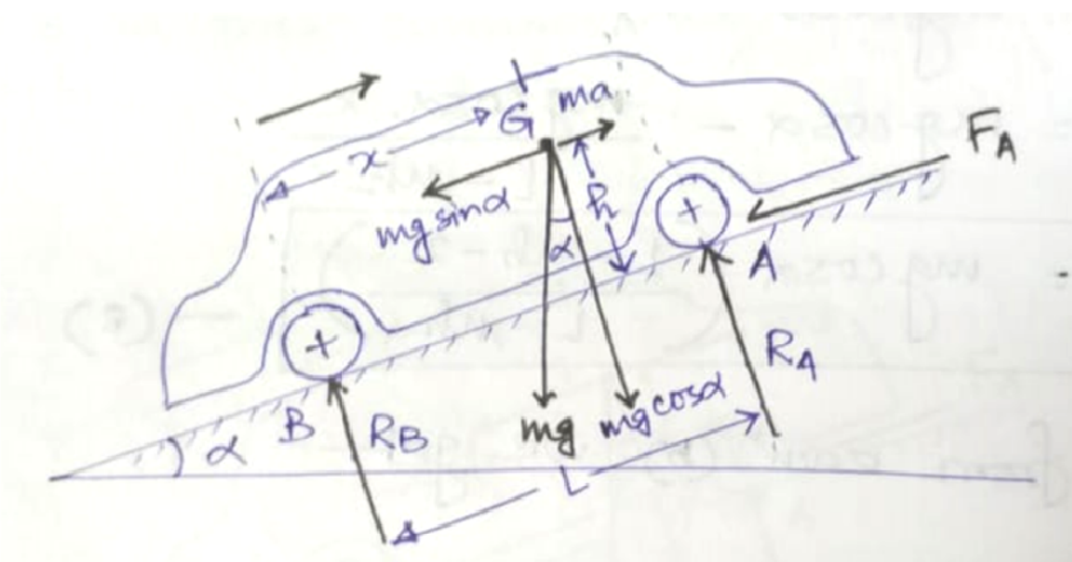


Fig. (12): Motion of vehicle up the inclined plane and brakes are applied to front wheels only.

Let F_A = Total braking force acting at the front wheels due to the application of brakes.

$F_A = \mu R_A$ ----(a)

Taking equilibrium of forces parallel to the inclined plane

$F_A + mg.\sin\boldsymbol{\alpha} = ma$ ----(b)

Again taking equilibrium of forces perpendicular to inclined plane

$R_A + R_B = mg.\cos\boldsymbol{\alpha}$ ----(c)

Again taking moment about point G.

$F_A \text{ X } h + R_B \text{ X } x = R_A (L-x)$

=> $\mu.R_A \text{ X } h\ (mg.\cos\boldsymbol{\alpha} - R_A)x = R_A (L-x)$ [from eqn^n (a) &(b)]

=> $\mu h.R_A + mg.\cos\boldsymbol{\alpha} - \cancel{R_A.x} = R_A.L - \cancel{R_A.x}$

=> $R_A (L- \mu h) = mg.\cos\boldsymbol{\alpha}.x$

=> $R_A = \frac{mg.\cos\alpha.x}{L-\mu h}$ ------- (d)

Putting the value of R_A in eqn^n we get

$R_B = mg.\cos\boldsymbol{\alpha} - R_A$

=> $R_B = mg.\cos\boldsymbol{\alpha} - \frac{mg.\cos\ .x}{L-\mu h}$

=> $R_B = mg.\cos\boldsymbol{\alpha} - \frac{L-\mu h-x}{L-\mu h}$ -----(e)

Again from eqn^n (b) we get

$F_A / m + g.\sin\boldsymbol{\alpha} = a$

=> $a = \mu R_A/m + g.\text{sign}\boldsymbol{\alpha}$

=> $a = \frac{mg.\cos\alpha.x}{L-\mu h} + g.\text{sign}\boldsymbol{\alpha}$ ----(f)

Note: 1. When the vehicle moving on level track then $\boldsymbol{\alpha}$ = O

$\therefore R_A = \frac{mgx}{L-\mu h}$ / $R_B = \frac{mg(L-\mu h-x)}{L-\mu h}$

$A = \frac{mgx}{L-\mu h}$

2. When the vehicle is moving downward, then eqn^n (b) becomes

$F_A - mg.\sin\boldsymbol{\alpha} = ma$

$\therefore a = F_A / m - g.\sin\boldsymbol{\alpha}$

$= \mu R_A / m - g.\text{sign}\boldsymbol{\alpha}$

$= \frac{mg.\cos\alpha.x}{L-\mu h} - g.\text{sing}\boldsymbol{\alpha}$

c) **When brakes are applied to all four wheels:** This is the most common way of braking the vehicle.

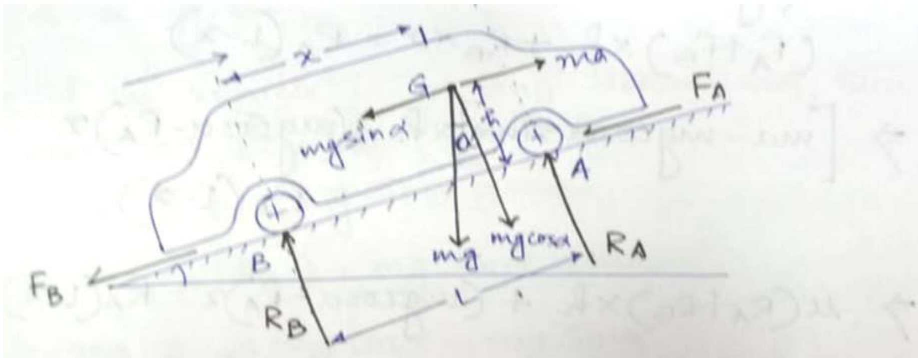


Fig. (13): Motion of vehicle up the inclined plane and brakes are applied to all the four wheels.

Let, F_A = Braking force provided by the front wheel

$= \mu.R_A$

F_B = Braking force provided by rear wheel

$= \mu.R_B$

A little consideration will show that when the brakes are applied to all the four wheels, the brake distance will be the least. It is due to this reason that the brakes are applied in all the four wheels.

Now considering the equilibrium of forces & resolving the forces parallel to the plane.

$$F_A + R_B + mg.\sin\boldsymbol{\alpha} = ma \quad \text{----(a)}$$

$$= \mu\,(R_A = R_B) = ma - mg.\text{sign}\boldsymbol{\alpha}$$

Resolving the forces perpendicular to the plane.

$$R_A + R_B = mg.\cos\boldsymbol{\alpha} \quad \text{------(b)}$$

Taking moment about point G

$$\Rightarrow [ma - mg.\text{sing}\boldsymbol{\alpha}] \times h + (mg.\cos\boldsymbol{\alpha} - R_A).x = R_A\,(L-x)$$

$$\Rightarrow \mu(R_A + R_B) \times h + (mg.\cos\boldsymbol{\alpha} - R_A).x = R_A\,(L-x)$$

$$\Rightarrow \mu.mg.\cos\boldsymbol{\alpha}.h + mg.\cos\boldsymbol{\alpha}.x - \cancel{R_A.x} = R_A.L - \cancel{R_A.x}$$

$$\Rightarrow R_A.L = mg.\cos\boldsymbol{\alpha}(x + mh)$$

$$\Rightarrow \frac{mg.\cos\alpha(x + \mathbf{mh})}{L} \quad \text{------(C)}$$

$$\therefore R_B = mg.\cos\boldsymbol{\alpha} - R_A$$

$$\Rightarrow R_B = mg.\cos\boldsymbol{\alpha}\,[1 - \frac{(x + mh)}{L}] \quad \text{-----(d)}$$

Now from the eqn^n (a)

$$Ma = \mu(R_A + R_B) + mg.\sin\boldsymbol{\alpha}$$

$$\Rightarrow A = \mu.g.\cos\boldsymbol{\alpha} + g.\sin\boldsymbol{\alpha}$$

$$\Rightarrow A = g.(\mu.\cos\boldsymbol{\alpha} + \sin\boldsymbol{\alpha}) \quad \text{----(e)}$$

Note: 1. When the vehicle moves on a level track, i.e. $\boldsymbol{\alpha} = 0$

Then, $R_A = \frac{mg(\mu h + x)}{L}$, $R_B = mg.\frac{(L - \mu h - x)}{L}$

2. If the vehicle is moving downward, then eqn^n (a) becomes

$$F_A + F_B - mg.\sin\boldsymbol{\alpha} = ma$$

$$\Rightarrow \mu(R_A + R_B) - mg.\sin\boldsymbol{\alpha} = ma$$

$$\Rightarrow ma = \mu mg.\cos\boldsymbol{\alpha} - mg.\sin\boldsymbol{\alpha}$$

$$\Rightarrow a = g\,(\mu\cos\boldsymbol{\alpha} - \sin\boldsymbol{\alpha})$$