Design of Braking System

Braking Fundamentals

* Energy of motion and frictional force

- Kinetic energy is the force that keeps the vehicle moving. This energy is provided by engine
- Kinetic energy is dissipated as heat by the brakes during application of brakes.
- The kinetic energy of vehicle during braking is given by

$$K.E = \frac{1}{2}\left(\frac{W}{g}\right)(U^2 - V^2) = \frac{1}{2} M (U^2 - V^2)$$

Where,

W → Vehicle gross weight

U → Initial velocity

V → Final Velocity

M → Mass of the Vehicle

- Thus, the kinetic energy doubles as the weight doubles, but it increases four times as speed doubles.

- The ability of a vehicle depends on the coefficient of friction between the contacting surface.

- Maximum useable coefficient of friction occurs between the tyre and road surface.

- Passenger car brakes have coefficient of friction 0.3 to 0.5.

- The amount of energy that can be absorbed by the brakes depends on the
  * Coefficient of friction of brake material
  * Brake diameter
  * Brake surface area
  * Shoe geometry
  * Pressure used to actuate the brake

- Stopping a car suddenly means very high friction, resulting in high brake temperature.

Brake balance :

* The braking of vehicle occurs at ground level, so affective braking force acts on the ground.

* Vehicle weight and kinetic energy of the vehicle act through center of gravity, which are above ground level.

* This causes the vehicle to pitch forward as the brakes are applied

* As a result of this action some of the vehicle weight is effectively transferred from rear to front wheel.

* Consequently front brake absorbs more kinetic energy than rear brake.

The maximum transfer of weight amounts to

$$W_t = \frac{\mu h}{b} W$$

When deceleration of the vehicle is considered then the weight transfer becomes.

$$W_t = \frac{\mu h}{b} \frac{f}{g} W$$

Where,

W_t → weight transferred

μ → coefficient of friction

h → height of CG from the ground

W → Vehicle gross weight

b → wheelbase

f → decleration of the vehicle

g → acceleration due to gravity

* Front brakes are designed to absorb this extra brake effort.

* With full braking it is desirable to have the front brakes lock up slightly ahead of the rear brakes.

* This causes the car to go straight ahead and do not spin out.

Stopping distance:

* Stopping distance is extremely important for emergency braking.

* It is based on deceleration rate and also it is affected by tyre deflection, air resistance, braking efforts and the Inertia of drive line

Distance travelled by the vehicle during application of brake can be obtained from the following equation of motion assuming braking efficiency as 100%

$$S = Ut - \frac{1}{2} f t^2 \text{ and } V^2 - U^2 = -2fs$$

If the vehicle comes to stand still due to application of brake, then V = 0

So, Stopping Distance $S = \frac{U^2}{2f}$

Brake fade

* After number of severe stops or after holding the brakes on a long down hill grade, a point is eventually reached when coefficient of friction drops so low that little braking effect is available
* This condition is called brake fade

Workdone in braking

The brake converts the kinetic energy possessed by the vehicle at any one time into heat energy by means of friction.

The kinetic energy possessed by vehicle is given by

$$KE = \frac{1}{2} M U^2$$

M → Mass of the vehicle

U → Speed of the vehicle.

The workdone in bringing the vehicle to rest is given by

$$W_D = FS$$

F → Average braking force

S → Distance travelled

While braking a moving vehicle to a stand still, the workdone must be equal to kinetic energy

$$K_E = W_D$$

$$\frac{1}{2} M U^2 = FS$$

Average Brake force, $$F = \frac{MU^2}{2S}$$

Scanned by TapScanner

Braking efficiency

* The braking force is the force of resistance applied to stop a vehicle or reduce its speed.

* Braking efficiency of a vehicle is defined as the braking force produced as a percentage of total weight of the vehicle.

$$\eta = \frac{\text{Braking Force}}{\text{Weight of Vehicle}} \times 100$$

* Braking efficiency of 100% is equal to a coefficient of friction of one.

$$\eta\ (100\%) = F/R = \mu = 1$$

* The braking efficiency can be derived from kinetic energy possed by vehicle and workdone in bringing vehicle to Standstill

$$\boxed{\eta = 0.4 \frac{v^2}{S}}$$

Tyre adhesion:

* The amount of the force applied on a shoe against a drum controls the resistance to rotation of a road wheel.

* Simultaneously the road surface has to drive the wheel around.

* This driving force attains its limit when the resistance offered by the brake equals the maximum frictional force generated between the tyre and road which is known as Adhesive force

Adhesive Force = Load on wheel X Coefficient of friction

* When limit is reached, the wheel starts skidding

* The adhesion between the tyre and road is the governing factor for minimum stopping distance.

* Road adhesion depends on
  - Types of road surface
  - Condition of surface [Eg: Wet, dry, Icy]
  - Design of tyre-tread, composition of tread materials and depth of tread

Braking of Vehicle

To bring the whole system in equilibrium the inertia force, which is also known as reverse effective force, is included with the system of forces actually existing

Let,

$W \rightarrow$ Weight of the vehicle

$R_f, R_R \rightarrow$ Total normal reaction between the ground and the front & rear wheel.

$\mu \rightarrow$ Coefficient of adhesion b/w tyres and road surface

$b \rightarrow$ Wheel base

$h \rightarrow$ height of CG from road surface.

$l \rightarrow$ perpendicular distance of CG from rear axle

$f \rightarrow$ Retardation force produced by braking force.

$(W/g) f \rightarrow$ Reverse effective force.

Brakes Applied to Rear Wheel

$$R_R = \frac{(b - l)\cos\theta}{b + \mu h} W$$

$$R_f = W\cos\theta - \frac{(b - l)\cos\theta}{b + \mu h} W$$

$$R_f = \frac{(l + \mu h)\cos\theta}{b + \mu h} W$$

Brakes Applied to front wheels

$$R_f = \frac{l\cos\theta}{b - \mu h} W$$

$$R_R = \frac{(b - l - \mu h)\cos\theta}{b - \mu h} W$$

Brakes Applied to all four wheels

$$R_F = \frac{(l + \mu h)\cos\theta}{b} W$$

$$R_R = \frac{(b - l - \mu h)\cos\theta}{b} W$$

Incase the vehicle moves on a level load, $\theta = 0$ and hence in above expression, the Values of $\sin\theta = 0$ and $\cos\theta = 1$