



# Unit III

## *Wheels, Tyres and Braking Systems*

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## ❖ Syllabus:

- Basic requirements of wheels and tyres, Types of road wheels, Construction of wheel assembly, wheel balancing, Tyre construction, material, types, tubeless, cross ply radial type, tyre sizes and designation, Aspect ratio, tyre trade pattern, tyre valve, Tyre inflation pressure, safety precautions in tyres, Tyre rotation and matching, Types of Tyre wear and their causes, Selection of tyres under different applications, tyre retreading hot and cold, factors affecting tyre performance.
- Function and requirements of braking system, Types of brakes, Elementary theory of shoe brake, drum brake arrangement, disc brake arrangement, self energizing, brake friction material. brake linkages, hydraulic brake system and components, hydraulic brake fluids, air brakes, vacuum servo assisted brake, engine exhaust brake, parking brakes, dual power brake system, regenerative brake system, fail-safe brake, anti – lock brakes, anti skid brakes, brake efficiency and testing, weight transfer, braking ratio.



## ❖ **Basic requirements of wheels:**

1. It should be balanced both statically as well as dynamically.
2. It should be lightest possible so that the un-sprung weight is least.
3. It should be possible to remove or mount the wheel easily.
4. Its material should not weaken with weathering and age. In case, the material is susceptible to corrosion, it must be given suitable protective treatment.
5. The wheel along with the tyre has to take the vehicle load, provide a cushioning effect and cope with the steering control.
6. Must be of maximum strength to take the weight road shocks, driving torque and must be able to compensate all sorts of load varying in magnitude and direction.
7. Must be strong enough to resist local deformation or when it hits a road kerb or any other obstacle.



- The automobile wheels support **the total weight**, resist **the strains** created during **turning** and **transmit the driving torque** for **propelling** and **breaking torque** for **retarding**.
- The wheels must have **well balanced construction** particularly for running at high speeds.
- **Unbalanced wheel assemblies** cause **excessive vibration**, which **accelerates tyre and king-pin wear**.





## ❖ Types:

1. Pressed Steel Disc wheels
2. The wire wheels
3. The light alloy wheels



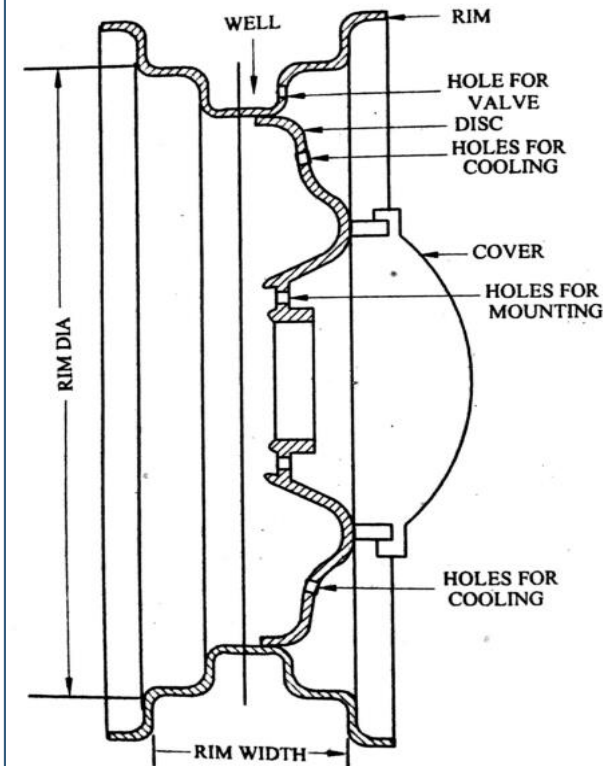
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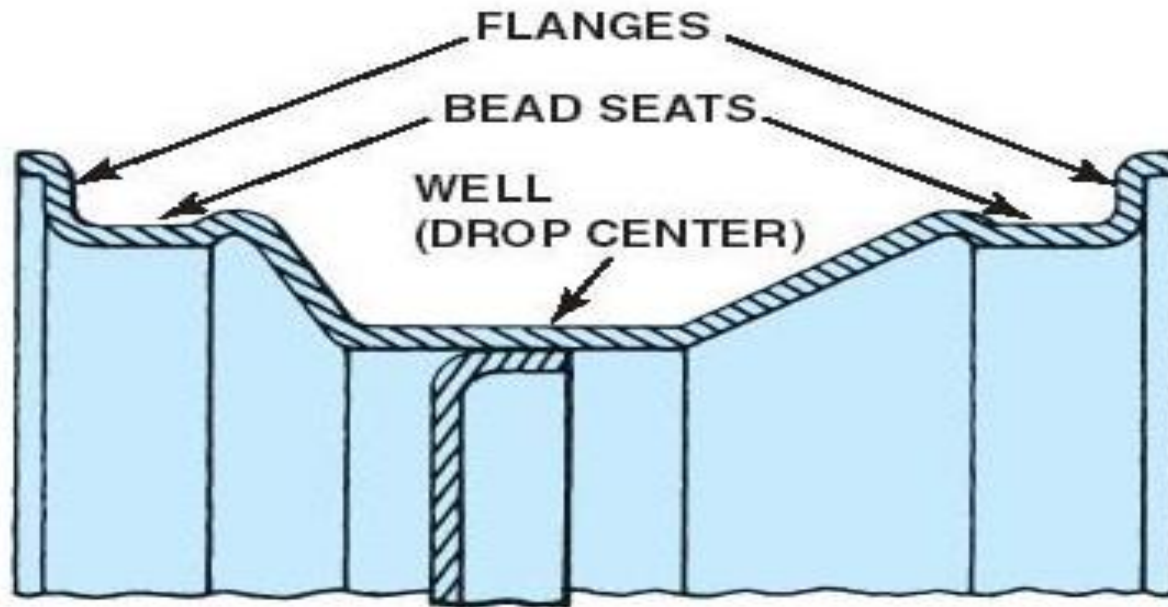
## ❖ Pressed Steel Disc wheels:

- The pressed steel wheels are used by over 90% manufacturers worldwide because of its **simplicity, robust construction, lower manufacturing cost and ease in cleaning.**
- They require negligible maintenance and are easy to produce. Mostly these are made of steel.
- This types of wheel consists of two parts, a steel rim which is generally well based to receive the tyre and pressed steel disc.
- The rim and disc may be **integral, permanently attached or attachable** depending upon design.
- A typical steel disc wheel is shown in figure in which pressed steel disc is welded to rim.





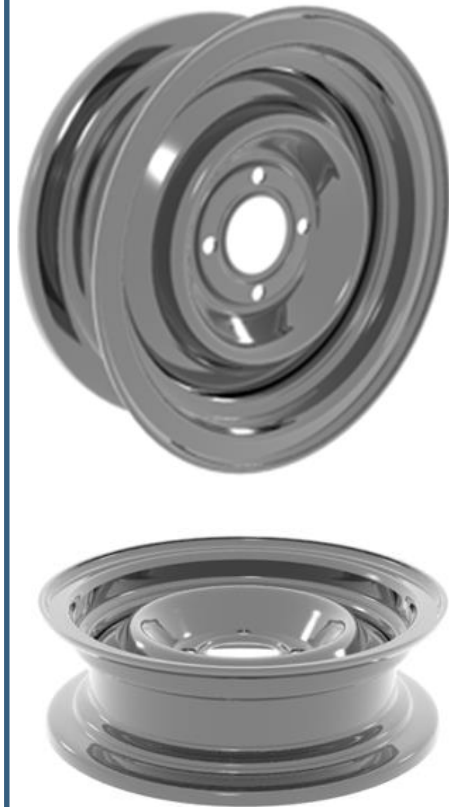
## WHEEL RIM CONTOUR



**FIGURE 20-29** The wheel rim well provides a space for the tire to fit during mounting; the bead seat provides a tire-to-wheel sealing surface; the flange holds the beads in place.



- The rim profile, indicated by letters, J, K, JJ, JK or B in the specification, is designed to comply with the tyre bead profile.
- When the bead of the tyre is resting in the well, it is possible to pass the tyre over the opposite edge of the rim.
- Without the well it would not be possible to mount or remove the tyre from the wheel.
- The seat of the rim where the tyre rests usually has a 5 degree or 15 degree taper so that as the tyre is inflated, the beads are forced up the taper to give wedge fit.
- A steel disc performs the functions of the spokes. The wheel is fitted on the axle by bolting to a flange attached to the later.





- Some slots are generally provided in the wheel disc to allow the air to the inner side for better cooling of the brake drum inside.
- Since these holes tend to weaken the disc, the holes in modern wheels are swaged which means that some portion of the disc around each hole is turned inwards smoothly.
- This more than compensates for the loss of strength due to holes.
- A separate cover is also provided on the wheel disc. A hole in the rim serves to accommodate tube valve.
- The disc has a number of equal-spaced shallow elongated slots immediately under the base of the rim well which improves brake cooling and decreases the transfer of heat from the brake-drum to the tyre due to passage of air through the slots.





- The disc is fixed to the axle-hub by a number of studs and nuts with conical or spherical seating.
- The rim for the car wheel is cold rolled from flat steel strip and the rims for heavier commercial vehicle are hot rolled to the section from steel bars.
- The steel strip is cut to the required length and then rolled into a circle before the ends are butt-welded.
- The circular steel strip then undergoes a series of rolling operations to obtain a complete rim.
- The rim is then expanded to size and the valve hole is punched.

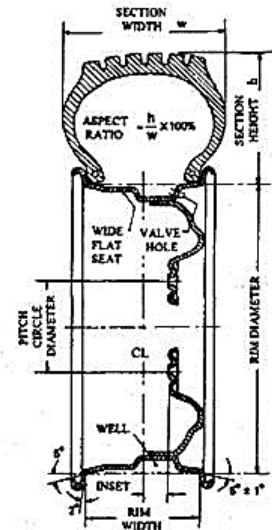
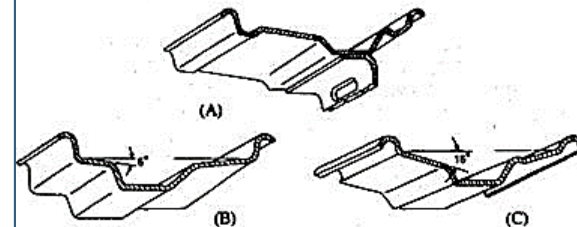


Fig. 23.1. Car well-base disc-type wheel.





## ❖ Car Well-base Rims

- Wheel rims are designed to minimize dislodging of the tyre, when subjected to heavy cornering (Fig. A).
- Originally the rim was tapered from the rim flange to the edge of the well so that the pressure acting over a short length of the bead would force back the tyre bead into the well.
- This can happen due to the interaction of the cornering side-force acting on the wheel and the reaction of the tyre and the road.
- This is prevented in the flat-ledge rim profile due to the provision of a parallel flat ledge between the outer taper adjacent to the flange and the edge of the well.
- In a close-fitting tyre bead this can happen only due to the pressure acting all the way round the bead.
- Another approach for improving the bead rim seal and joint is to form a hump slightly in front the shorter taper next to the rim flange .
- Once the bead sits over the short taper portion adjacent to the rim flange, it is very difficult for it to climb over the hump, back into the rim well.

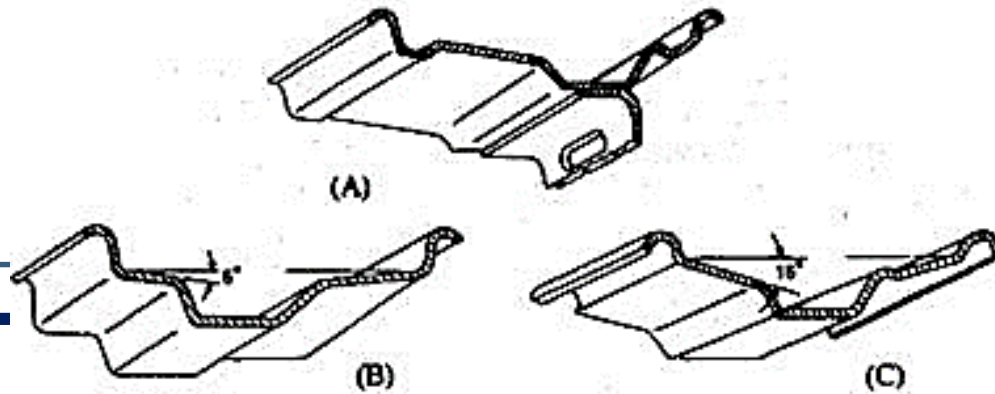


### ❖ Van 5 Degrees Seat-angle Well-base Rim.

- These rims (Fig. B) have high wall flanges, which protect the tyre beads and walls from damage due to external interference. Generally both tubed and tubeless tyres are fitted on these rims. However large stiff tyres cannot be mounted over these flanges, and hence these rims are only used for vans and small commercial vehicles.

### ❖ U-type Drop-centre 15 Degrees Taper Rim.

- Tubeless tyres and large section tyres with relatively flexible beads are used for vans, buses, and medium sized trucks. These tyres use a single-piece well-base wheel rim, having relatively shallow flanges at the edge of 15 degrees taper bead-seats (Fig. C). This profile of the rim provides a good joint and sound seal between the tyre bead and the rim taper.

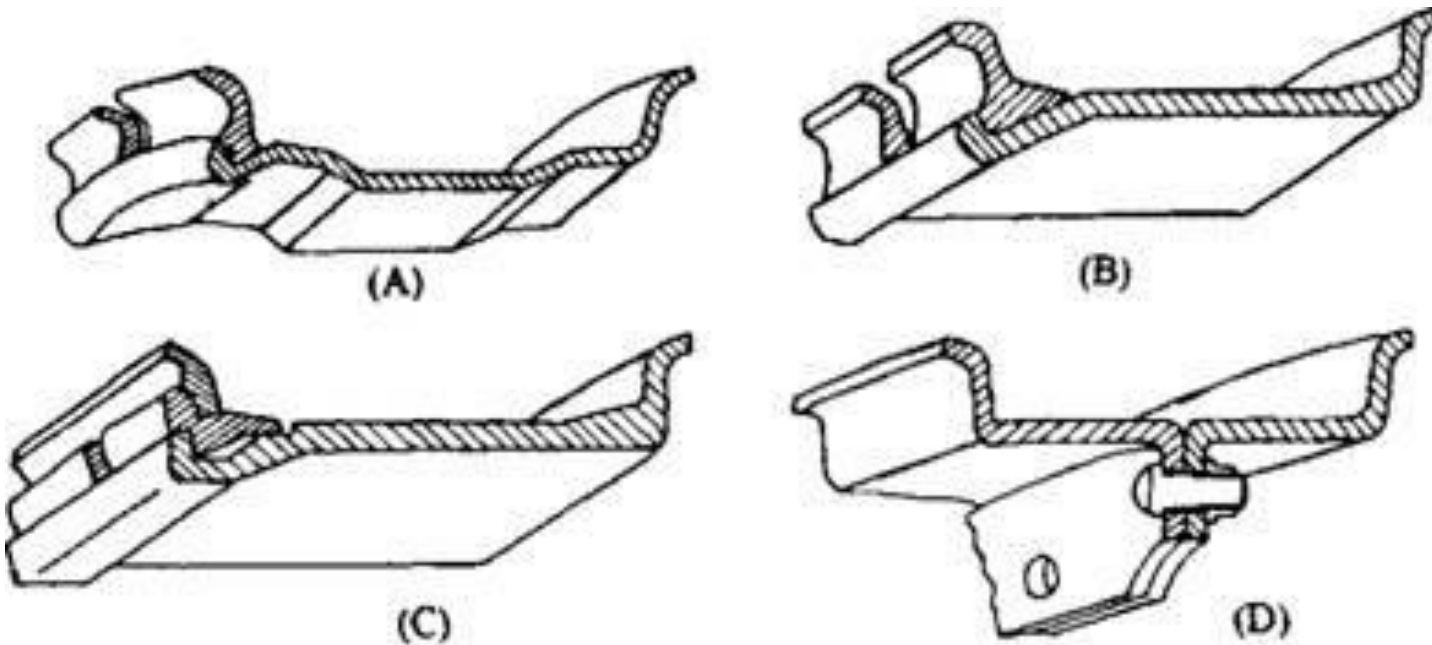






## ❖ Detachable-rim Wheels

- Large tyres for commercial vehicles use more plies in the casing and are therefore relatively bulkier in the bead region.
- The rims for these tyres have one removable side-flange, which allows the wheel tyres to slide into position, and then the flange can be replaced and locked in place.

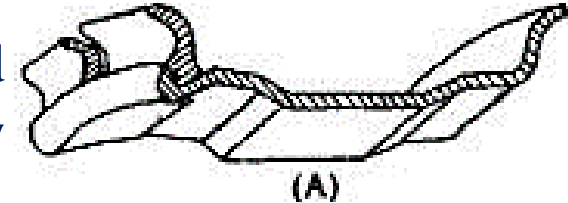






## ❖ Semi-drop-centre Two-piece Rim

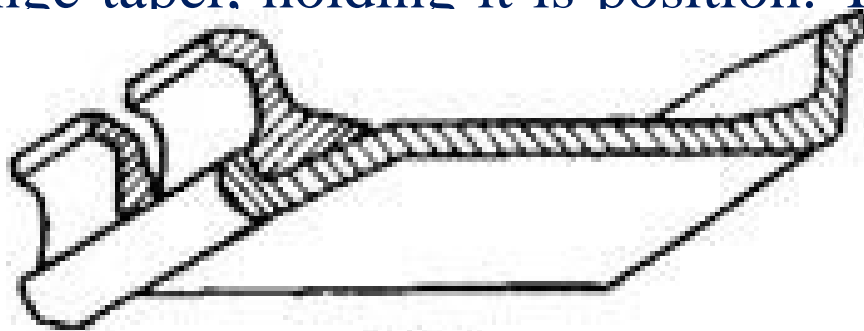
- This type of rim (Fig. A) has inner and outer tapered tyre-bead-seating surfaces separated by a shallow central or near central well.
- The inner flange can be removed for fitting a tyre. In this design, the well depth only permits the tyre beads to pass over the top of the outer bead-seat taper.
- The outer flange is detachable and is sprung into a continuous groove formed along the outer edge of the rim base so that it is retained in its working position.
- This rim forms an intermediate class between the well-base and wide-base rims. It accommodates heavier beads, which are too rigid for fitting on the full well-base type. This rim is used on light trucks.





## ❖ Wide-base Two-piece Rim

- This rim (Fig.B) is made up of one fixed flange integral with the rim base and one split detachable flange.
- The rim uses 5 degrees taper seats for tyre beads, the one on the detachable flange side being integral with the flange.
- The outer detachable flange is sprung into a continuous groove formed along the outer edge of the rim base to retain the flange in its working position. During inflation of the tyre the bead sits over the detachable-flange taper, holding it in position. This rim is used mainly on medium

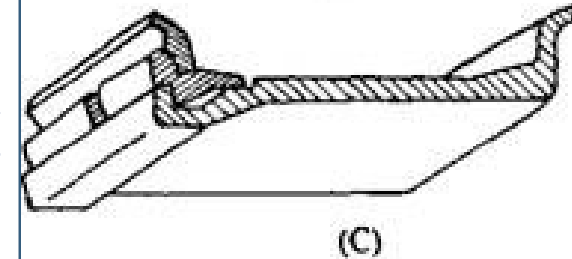


(B)



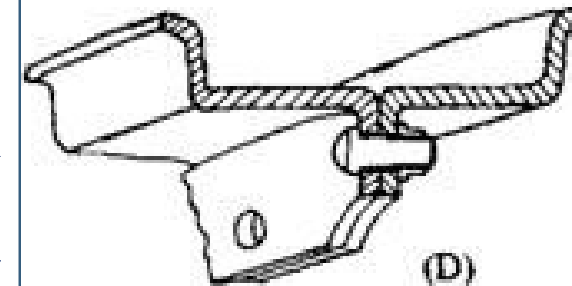
## ❖ Wide-base Three-piece Rim

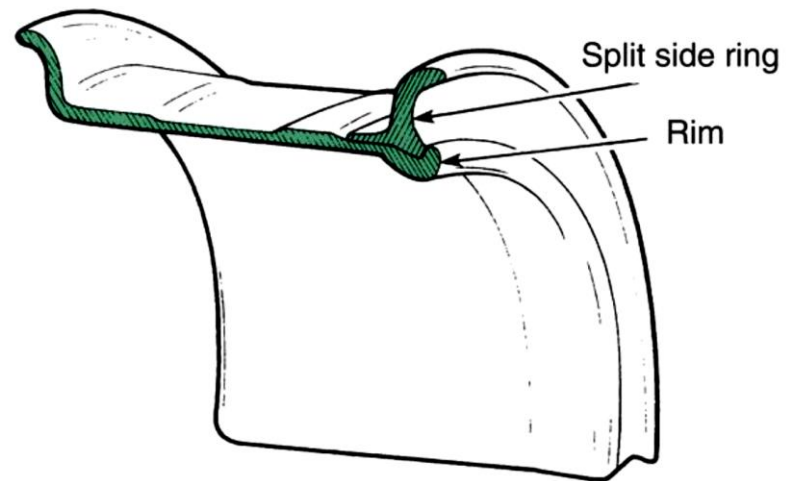
- This type of rim (Fig.C) contains one fixed flange integral with the rim base, one detachable endless flange, and a separate flange-retaining split lock-ring. The rim uses 5 degrees taper seats for tyre-bead location, the one on the detachable-flange side usually being on an extension of the spring lock-ring.
- During inflation of the tyre the bead sits over the extension of the spring lock-ring, holding it in position. This rim is used on large commercial vehicles.



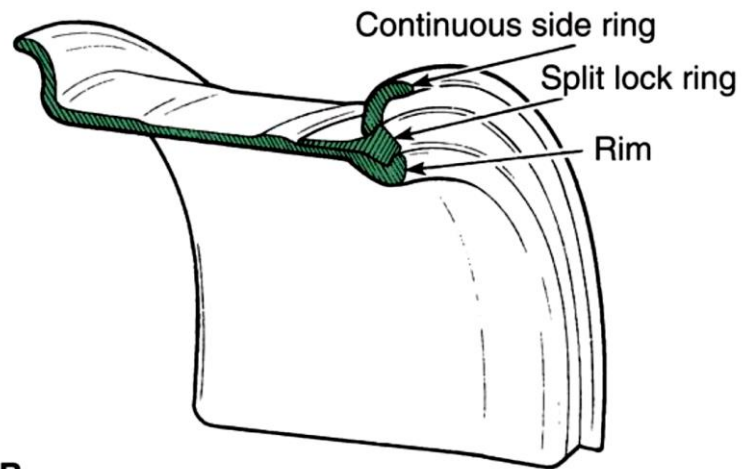
## ❖ Divided Flat-base Rim.

- This type (Fig.D) of rim is integral with the wheel itself. For fitting or removal of the tyre the two halves of the wheel are divided by dismantling the outer ring of bolts, which hold the wheel halves together. These rims are used primarily for large military trucks.



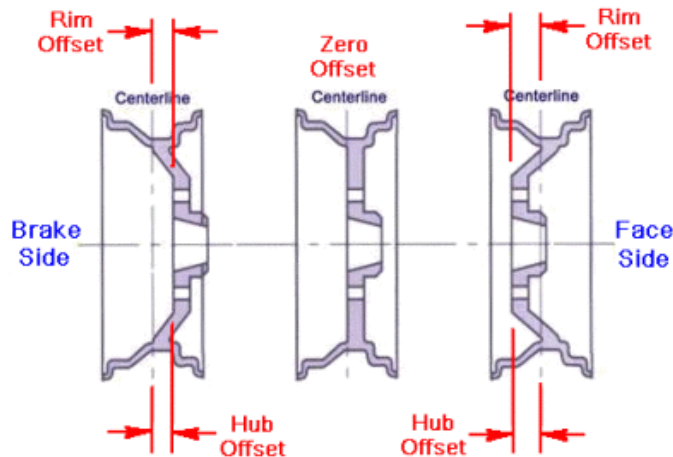
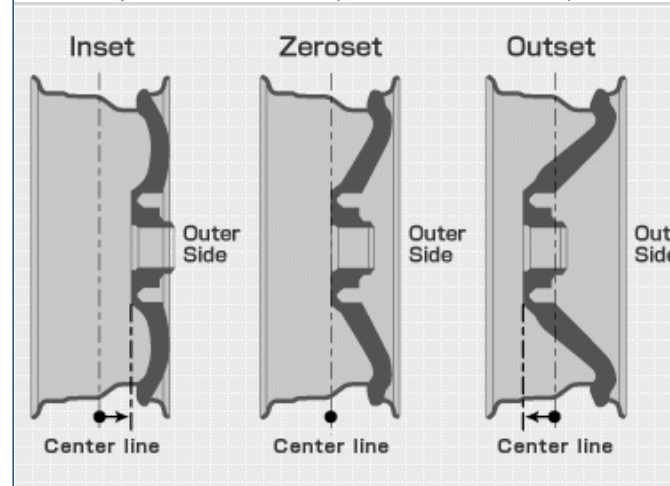
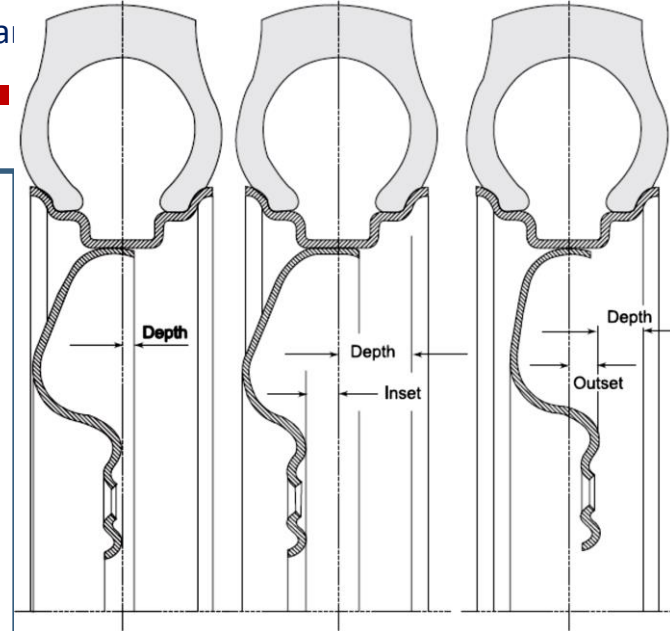


**A**



**B**

- A wheel may be **inset**, **zeroset** or **outset**, depending upon the position of the rim in relation to attachment face of the disc.
- In the **inset wheel**, the center line of the rim is located outboard of the attachment of the face of the disc.
- A **zeroset wheel** is the one in which the centerline of the rim coincides with the attachment face of the disc.
- In the **outset wheel**, the center line of the rim is located inboard of the attachment of the face of the disc.

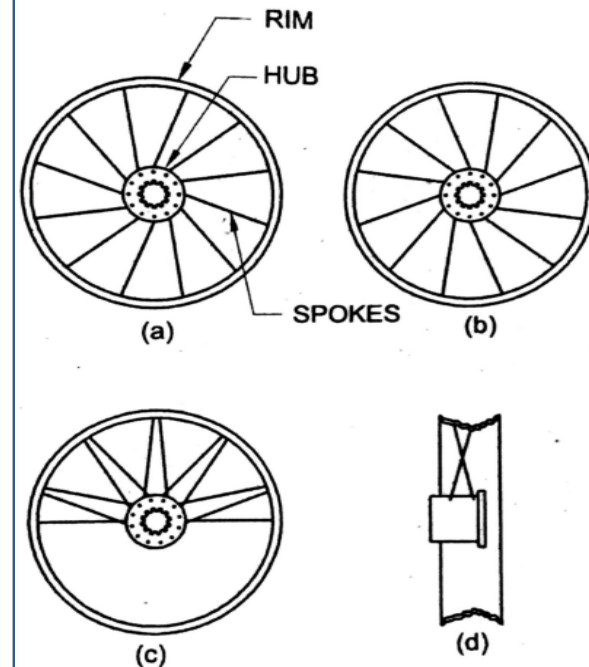






## ❖ Spoke or Wire Wheels:

- Oldest in design but remained in use largely because of light weight and strong construction but costly.
- Unlike the disc wheel the wire wheel has a separate hub which attached to the rim through a number of wire spokes.
- Each spoke is individually hooked at one end of the hub while other end is pushed through a hole in the rim, where a tapered nut is screwed down pulling the spoke tight.
- If a spoke is too loose or too tight, the rim would distort.
- The spokes carry the weight, transmit the driving and braking torques and withstand the side forces while cornering, in tension.







- Spokes are long, thin wires and as such these cannot take any compressive or bending stresses. All types of loads are sustained by the spokes in tension.
- The spokes are mounted in a complicated criss-cross fashion in all the three planes.
- The component of vehicle weight in direction of spokes above the hub is sustained by these spokes in tension (fig. c).
- Similarly, the driving and braking torques are taken up by the spokes in the desired direction as shown in fig. a and b.
- Thus it is seen that the spokes have to be mounted on the wheel in a complicated manner.
- The initial tension of the spokes can be adjusted by means of tapered nuts which also serve to secure the spokes to the rim



## ❑ Advantages:

- Light in weight
- High strength
- Provides better cooling of brake drum
- Very easy to change the wheel when required because only one nut has to be removed.

## ❑ Disadvantages:

- ✓ Can not sustain compressive and bending stresses
- ✓ Expensive due to their intricate construction
- ✓ Can not be used with tubeless tyre



## ❖ Alloy Wheels

- These wheels are manufactured as a single-piece rim and disc. Car wheels are generally cast or extruded, but truck wheels are forged. Magnesium and aluminum alloys are most commonly used for reduction in weight.
- **Magnesium alloy produces a saving of weight of 30% over aluminum alloys and 50% over steel for similar strength.**
- Magnesium alloys exhibit very good fatigue properties and excellent resilience, due to which they are capable of resisting vibrational and shock loading better than both aluminum alloy and steel.
- However they are highly susceptible to corrosion and therefore must be provided with a protective surface coating.
- Although aluminum alloys have relatively less fatigue properties but their corrosion characteristic is also less and they can be readily cast or forged.



- The section thickness for the rim and disc are required to be greater with light alloys than with steel.
- Even though it is a disadvantage to machine the wheel rim and the stud hole flange after casting or forging operation, but this produces close-tolerance wheels.
- Also most **light alloys are better conductors of heat than steel**, so that they transfer any heat generated by the tyre or brake more quickly to the wheel-disc for dissipation to the air stream.
- Light-alloy wheels are more expensive to manufacture than pressed-steel wheels. Aluminum-alloy wheels are cheaper than magnesium alloy wheels. Light-alloy wheels are used for better appearance and lighter weight.
- Usually an **aluminum alloy is preferred for passenger cars and trucks**, and a **magnesium alloy for sports and racing cars**. The wheel-rim profile used for both light alloy wheels and steel rims is similar.



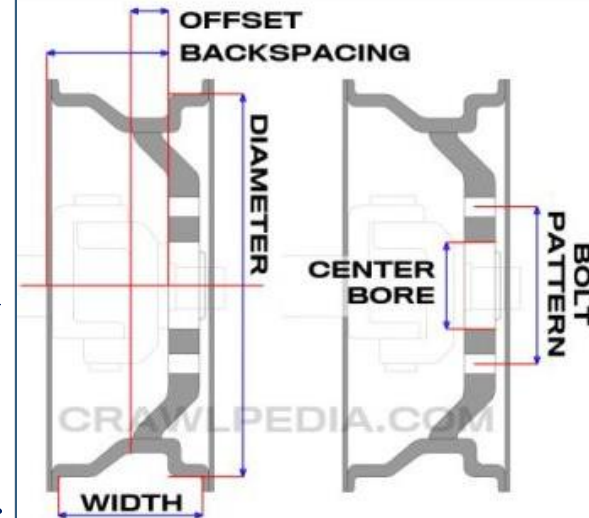
- Wider rims and radial ribs, also acts as angled spokes to provide strength and air circulation.
- Construction avoids any sharp lines and angles to improve strength.
- Heavier sections can be used to improve the stiffness of the wheel and result in better stress distribution.
- Rims with **larger area can be used**, results in the use of **wider tyres with less diameter**, an absolute advantage in **racing car since the lower centre of gravity** and wider tyres result in **better road grip** particularly **during cornering**.





## ❖ Wheel Dimensions:

- Wheel Size:** Wheels are sized according to their diameter and width measured from the tire mounting surfaces, usually in inches. A wheel with a 17" diameter and 8.5" width would be listed as a 17 x 8.5" wheel.
- Backspacing:** The distance from the back of the wheel to the wheel mounting surface is called backspacing. This measurement determines how far out from the axle the wheel will sit and is a critical dimension for proper wheel fitting. Backspacing is often abbreviated as "BS" and measured in inches.



**FIGURE 20-28** The size of the wheel is usually cast or stamped into the wheel. This wheel is 5 1/2 in. wide. The letters JJ refer to the contours of the seat area of the wheel.

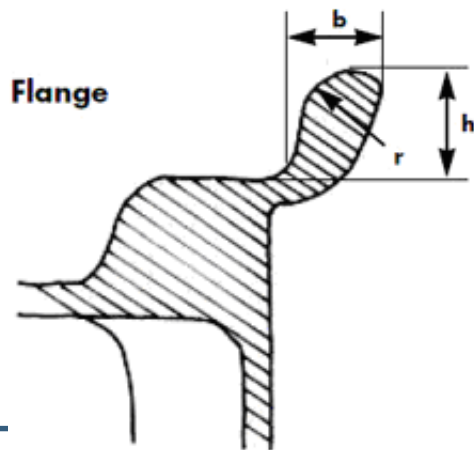




- **Offset:** Offset is similar to backspacing in that it determines how far out from the axle the wheel will sit. It is measured in millimeters from the centerline of the wheel to the wheel mounting surface. A negative offset wheel sits outward while a positive offset wheel sits further inward. Offset is also sometimes listed as ET with ET45 being a 45mm offset.
- **Center Bore:** The size of the hole in the center of a wheel is known as the center bore. It is measured in millimeters and is often abbreviated as "CB".
- **Lug-Centric:** Wheels that place the weight of the vehicle on the lug nuts are called lug-centric and require a center bore that is simply large enough to clear the axle hub. Lug-centric wheels require tapered or ball style lug nuts



- Hub-Centric:** Wheels that support the weight of the vehicle on the axle hub flange are hub-centric and require a center bore that offers an exact fit. Hub-centric wheels normally use flange style lug nut.
- Bolt Pattern:** The quantity and pattern in which the wheel's lug nut holes are laid out is referred to as the wheel's bolt pattern. The pattern is measured in inches or millimeters and is displayed as the number of lugs times the diameter of the circle. A wheel with 5 lugs on a 5.5" circle has a 5 x 5.5" bolt pattern.

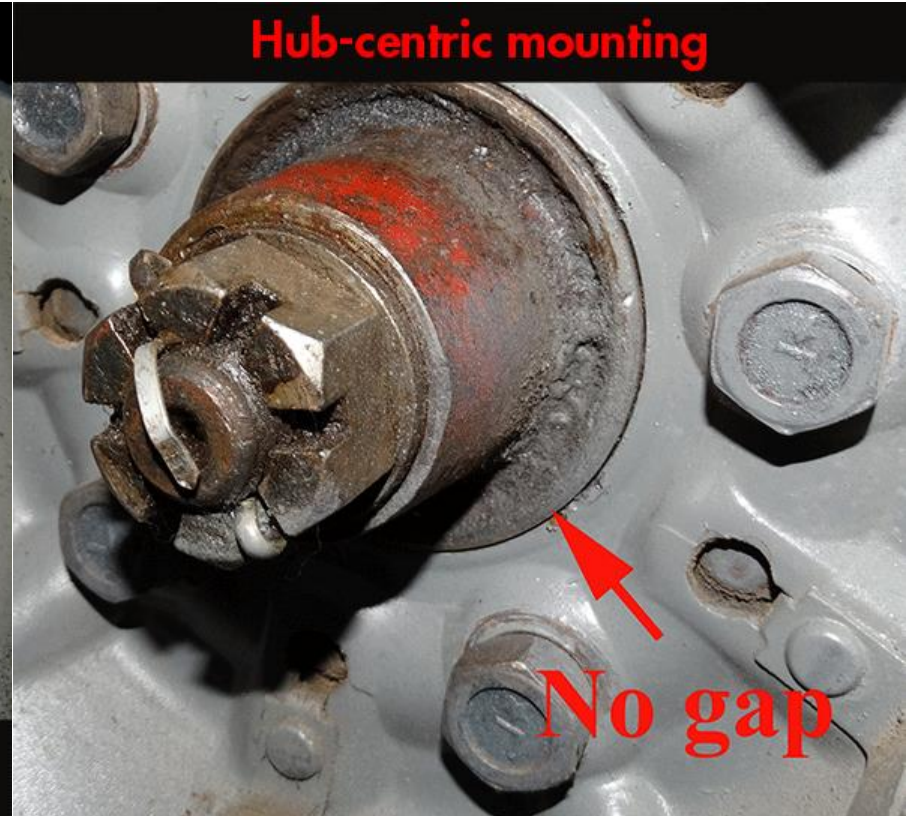


Dimension

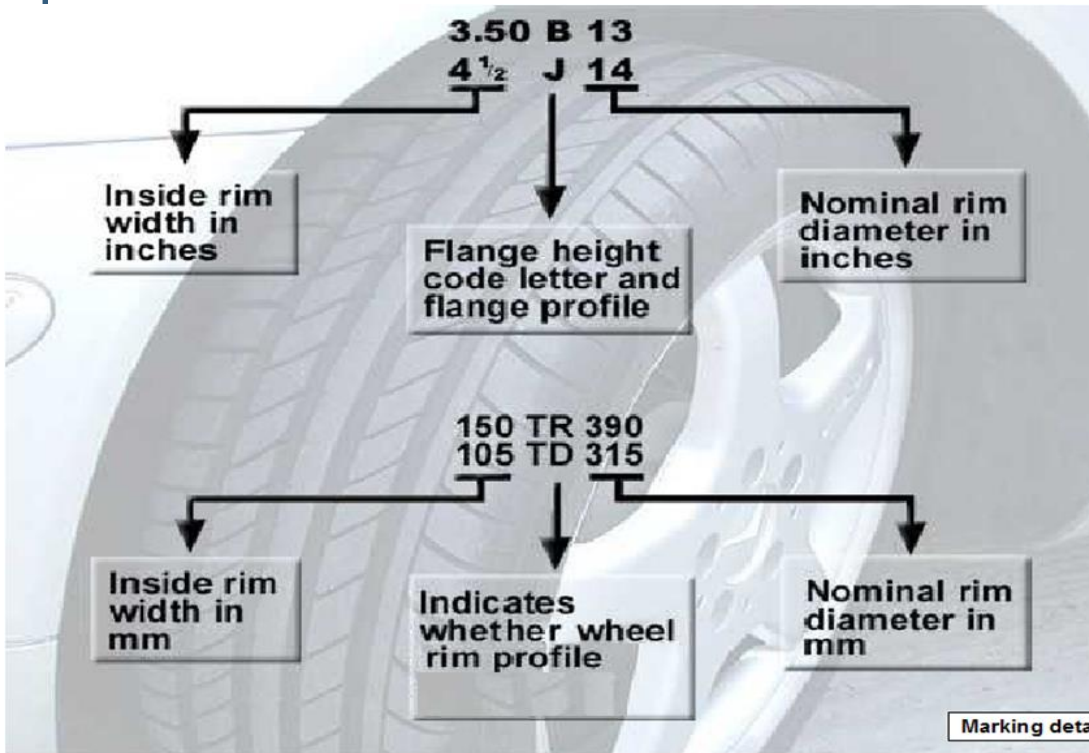
Symbol	Unit : mm		
	h	b	r
B	14.0 +1.0, -0.5	10.0	7.5
J	17.5 +1.0, -0.5	13.0	9.5
JJ	18.0 +0.7, -0.7	13.0	13.0

tolerance









**FIGURE 20-13** A typical door placard used on a General Motors vehicle indicating the recommended tire inflation. Note that the information also includes the tire size and speed rating of the tire as well as the recommended wheel size.



## ❖ Wheel Balancing:

- For smooth rotation of the wheel and tyre assembly without causing its own vibrations, the wheel assembly must be in a state of dynamic balance.
- Factors responsible for an imbalance of the mass distribution around the wheel are as follows
  - Tyre molding may not be fitted concentric on the wheel rim.
  - Wheel with lateral run out or buckled wheel rim.
  - Tyre walls, crown tread thickness may be non-uniform around the carcass as a result of manufacturing defect.
  - Wheel lock may produce excessive tread wear during braking over a relatively small region of the tyre.
  - Side wall may scrape the curb causing excessive wear on one side of the tyre.
  - Over or under inflation of tyre may cause uneven wear across the tread
  - Incorrect assembly of tyre on wheel relative to valve.





- Single or combination of above factors may cause uneven mass concentration (or lack of mass) about the wheel, so that one segment of the wheel and tyre becomes lighter and consequently the portion diametrically opposite to it becomes heavier.
- When the **heavier regions of the wheel and tyre assembly revolve** cause **centrifugal force**, which exerts an outward rotating pull on the support axis (the axle or stub axle) and bearings.
- The **magnitude of this outward pull** is directly **proportional to the cut of balance mass, the square of the wheel rotational speed**, and **inversely proportional to the radius** at which the mass is concentrated from its axis of rotation.



i.e. Centrifugal force ( $F$ ) =  $\frac{m V^2}{R}$  (N)

where  $F$  = centrifugal force (N)

$m$  = out of balance mass (kg)

$V$  = linear wheel speed (m/s)

$R$  = radius at which mass is concentrated  
from the axis of rotation (m)

- Example. If a 100 g of rubber tread has been removed from a portion of the tyre tread 250 mm from the center of rotation, and when the wheel has reached a speed of 160 km/h then find, (a) **angular speed of wheel in revolution per minute**, and (b) **centrifugal force**.



Linear speed of wheel  $V = \frac{160 \times 10^3}{60}$

$$= 2666.666 \text{ m/min}$$

or  $V = \frac{2666.666}{60}$

$$= 44.444 \text{ m/s}$$

a) Angular speed of wheel  $N = \frac{V}{\pi D}$

$$= \frac{2666.666}{\pi 0.5}$$

$$= 1697.65 \text{ rev/min}$$

b) Centrifugal force  $F = \frac{m V^2}{R}$

$$= \frac{0.1 (44.444)^2}{0.25}$$

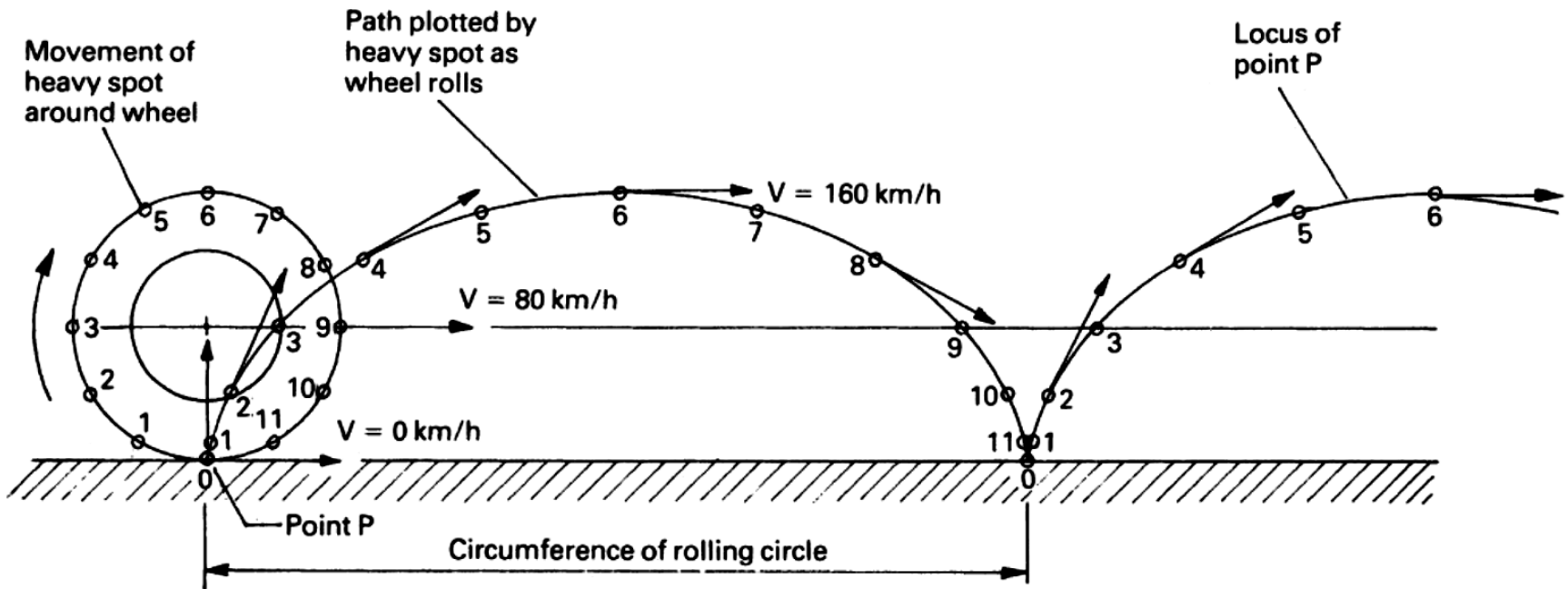
$$= 790.1 \text{ N}$$

- This example demonstrates that when a vehicle with a typical wheel size for a car is travelling at a speed of **160 km/h**, a **100g imbalance** of the tyre produces a radial outward pull on the wheel axis of **790 N**.
- A heavy spot on the tyre **when revolving accelerates from zero to a maximum velocity for half a revolution and then decelerates to zero velocity** in the second half of the revolution. As this spot has mass and its **velocity changes, a varying force acts on it in a tangential direction.**



- Consequently as the wheel moves forwards, the direction of the inertia pull caused by this heavy spot constantly changes.
- The greatest reaction experienced on the wheel occurs for a short time when the heavy spot decelerates downwards to ground level, momentarily stops, changes its direction and accelerates upwards.
- **Therefore, at the end of each cycle and the beginning of the next there is a tendency to push down and then lift up the tyre from the ground.**
- Although this effect may be **insignificant at vary low speeds of the vehicle**, but as the **speed increases the magnitude of the accelerating force rises**, which **produces the periodic bump and bounce or jerking response** of the tyre. The balancing of rotating masses can be considered in two stages.
- Firstly the static balance in one plane of revolution, and secondly the dynamic balance in more than one plane of revolution.





**Fig. 8.50** Cyclic movement of a heavy spot on wheel relative to the road

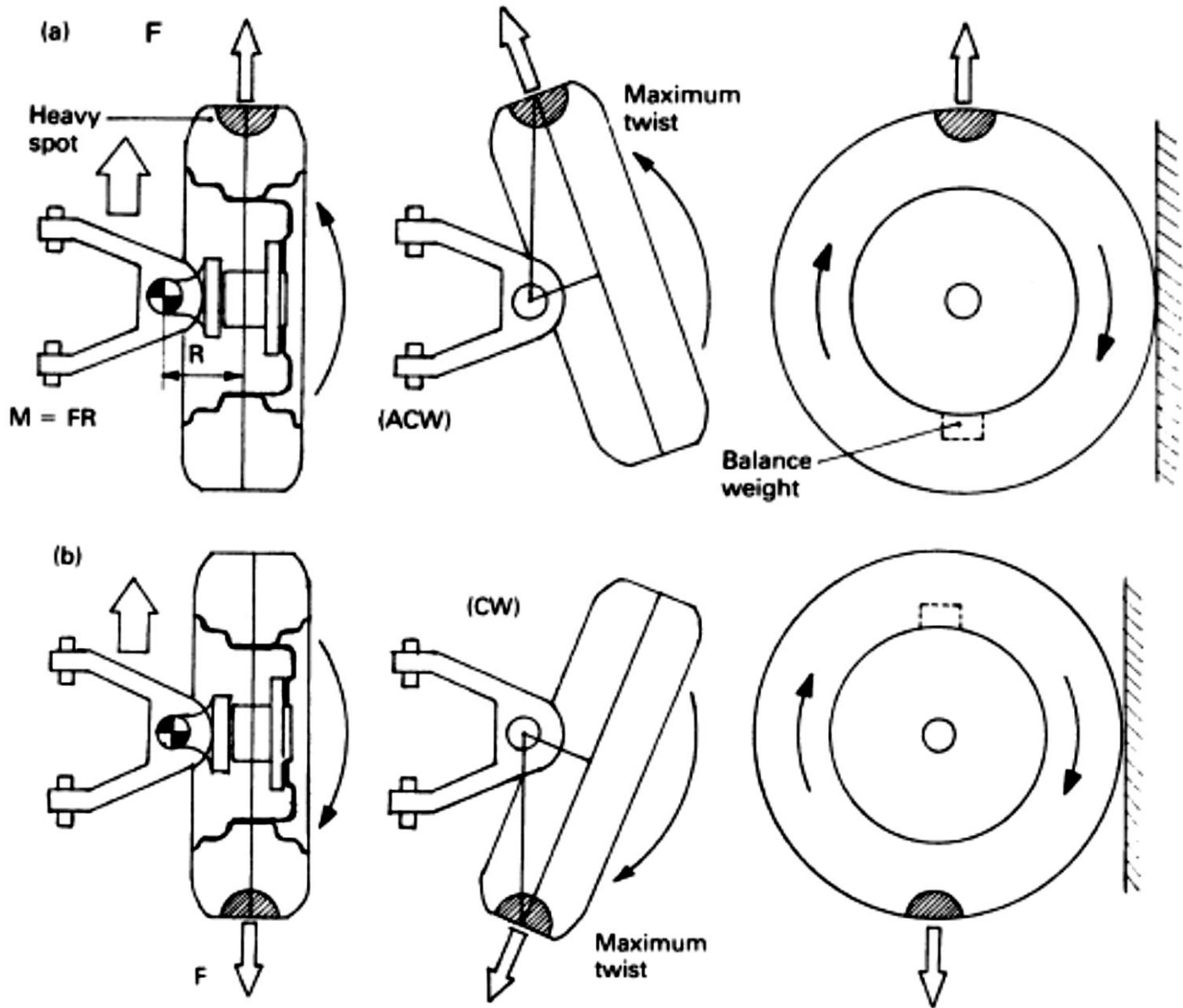


## ❖ Static Balance

- The static wheel imbalance is best understood by mounting a wheel and tyre assembly on the hub of a wheel balancing machine.
- **The assembly is then spun around by hand and released. The wheel spins a few times depending upon the momentum gained, before it stops momentarily and then starts to oscillate to and fro with decreasing amplitude until it comes to rest.**
- If the lowest point of the tyre is marked with a chalk and is now turned in one direction to certain angle and then released, it immediately commences a to and fro oscillatory motion, until coming to rest with the chalk mark at the lowest point.
- This illustrates that the heaviest part of the wheel assembly always gravitates to the lowest position. A small magnetic weight, equivalent to the out of balance mass, is placed on the wheel rim diametrically opposite the heavy side of the wheel.



- Now if the wheel is rotated to any other position, it remains at rest in that position. However, if there is still a slight movement of the wheel on its own, then the magnetic weight attached is too small, or if the wheel oscillates faster than before the weight is too large.
- This process of either adding or reducing the amount of weight placed opposite the heavy side of wheel and then moving the wheel round about a quarter of a turn to observe if the wheel tries to rotate on its own is a simple and effective technique used to check and correct any wheel imbalance on one plane.
- Once the correct balancing weight has been obtained, the magnetic weight is replaced with a clip-in weight of similar mass. With experience this trial and error method of statically balancing the wheel can be quick.



Plan view of wheel and suspension

Anticlockwise and clockwise twist due to imbalance  
 Automotive Chassis and Transmission

Side view of wheel



- As a statically unbalanced wheel and tyre, rotates on a fixed circular path around its axis (Fig. above), the heavy side of the wheel pulls radially outwards due to the centrifugal force.
- In case if the swivel pins and the centre of the unbalanced mass are offset to each other and if the heavy spot is in the horizontal plane pointing towards the front of the vehicle, then a moment of force is produced ( $M = FR$ ), which tends to twist the stub axle and wheel assembly anticlockwise about the swivel pins (Fig. A).
- As the wheel rolls forward a further half turn, the heavy spot now faces towards the rear so that the stub axle and wheel assembly tries to swivel in the opposite direction (clockwise) (Fig. B).
- Therefore with a statically unbalanced tyre, the stub axle twists about its pivot every time the heavier side of the wheel completes half a revolution between the extreme points in the horizontal plane.



- The **oscillations thus produced** are transmitted in the form of **shocks to the steering wheel.**
- The **frequency and magnitude** of this **shock increases with rise of vehicles speed.**
- When the swivel pin or king pin has excessive wear, the stub axle tends to move vertically up or down on its supporting joints.
- This may convey vibrations to the body through the suspension, which can be critical if allowed to resonate with possibly the unsprung or sprung parts of the vehicle.



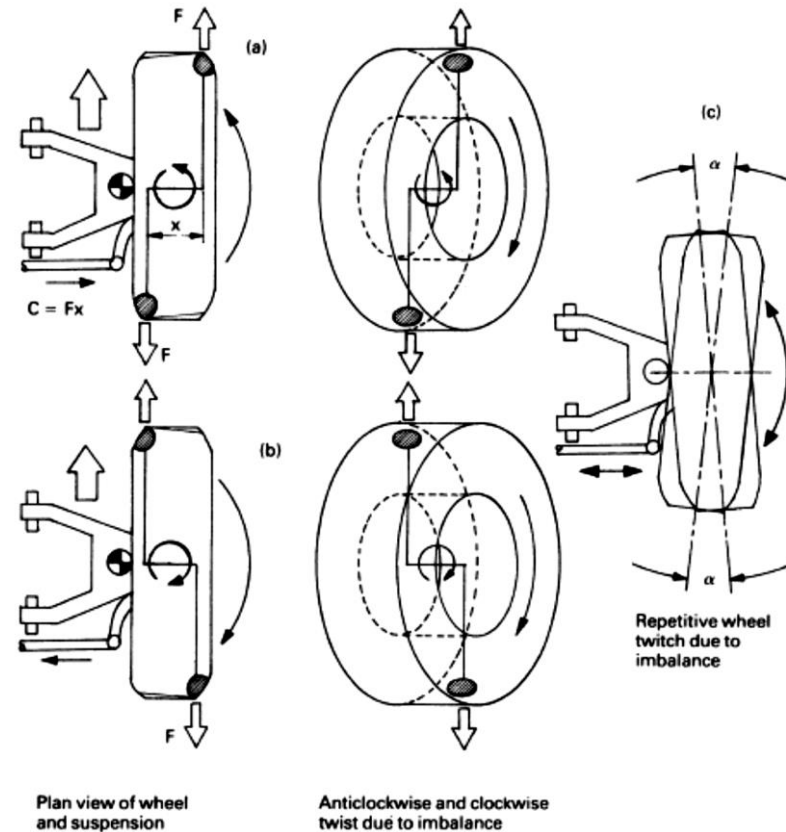


## ❖ Dynamic Balancing

- If a driven drum is made to engage the tread of the tyre so that the wheel is spun through a speed range then the wheel is likely to develop a **violent wobble**, which peaks at some point and then decreases as the wheel speed rises.
- The balance weight may be placed correctly opposite the heavy spot of the tyre, but on the wheel rim may be in a different rotational plane to that of the original out of balance mass. Consequently the tyre heavy spots pull outwards in one plane while the balance weight of the wheel rim pulls radially outwards in a second plane. As a result a rocking couple is produced, which causes the wheel to wobble.



- The magnitude of this couple is proportional to the product of centrifugal force acting through one of the masses and the distance between the opposing forces ( $C = Fx$ ).
- Figure A, B and C illustrates the effects of the offset statically balanced masses. When the heavy spot and balancing weight are horizontal (Fig. A) the mass on the outside of the wheel points in the forward direction of the vehicle and the mass on the inside of the wheel points towards the rear so that the wheel tends to twist in an anti-clockwise direction about the swivel pins.

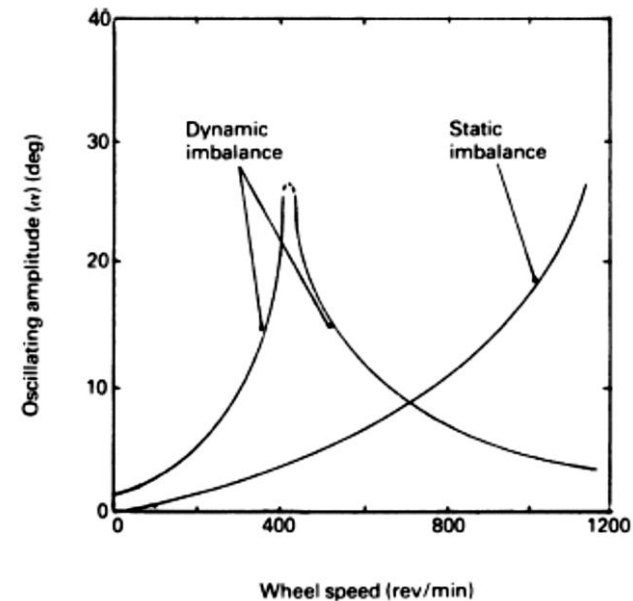




- If the wheel is rotated further through 180 degrees, the weights again are horizontal but this time the weights have interchanged their positions. Therefore, the direction of the unbalanced rocking couple is now changed to a clockwise one.
- The wheel, thus, rocks in both a clockwise and anticlockwise direction during its every revolution causing the steering wheel to jerk from side to side (Fig. C).
- It may be noted that when the masses move to a vertical position relative to the ground, the swivel pins constrain the rocking couple so that no movement occurs unless the swivel ball joints or king pins are excessively worn.



- The magnitude of wheel twitching about the swivel pins steadily increases with rise in wheel speed with static unbalanced wheels.
- In case of dynamic imbalance, the magnitude of wheel twitching increases to a maximum and then decreases with further increase of wheel speed (Fig.8.53).
- Therefore a dynamic unbalanced wheel can be driven on road without noticing any appreciable instability at speeds, which fall on either side of the critical period of oscillation(maximum amplitude).
- However, if the wheel is driven within the narrow critical speed range violent wheel wobble results.



**Fig. 8.53** Relationship of wheel speed and oscillating amplitude for both static and dynamic imbalance



- Any looseness in the swivel pins or steering linkage ball joints with unbalanced tyres promotes **excessive wheel twitch or wobble**, causing not only the steering wheel vibrations, but also heavy tyre tread scrub and wear.



## ❖ Tyres: (Functional requirements)

1. It should Support the vehicle load
2. It should provide cushion against shocks
3. It must transmit driving and braking forces to the road
4. It should provide cornering power for smooth steering
5. It must be strong enough to carry all loads and resist damage
6. It must have a long lifetime and run smoothly.
7. Must meet all the requirement of all weather conditions and on all surfaces without overheating.
8. It must provide good road grip for traction, cornering, accelerating and braking.





## ❖ Desirable Tyre Properties

### 1. Non Skidding

- This is one of the most important tyre properties. The tread pattern on tyre must be suitably designed to permit least amount of skidding even on wet road.

### 2. Uniform Wear

- To maintain the non-skidding property, it is very essential that the wear on the tyre tread must be uniform.

### 3. Load- Carrying

- The tyre is subjected to alternating stresses during each revolution of the wheel. The tyre material and design must be able to ensure that the tyre is able to sustain these stresses.



## 4. Cushioning

- The tyre should be able to absorb small high frequency vibrations set up by the road surface and thus provide cushioning.

## 5. Power consumption

- The automotive tyre does absorb some power which is due to friction between tread rubber and road surface and also due to hysteresis loss on account of the tyre being continuously flexed and released. This power comes from the engine fuel and should be the least possible.

## 6. Tyre noise

- The tyre noise may be in the form of definite pattern sing, a sequel or a loud road. In all these cases, it is desirable that the noise should be minimum.

## 7. Balancing

- This is very important consideration. The tyre being a rotating part of the automobile, it must be balanced statically as well as dynamically. The absence of balance gives rise to peculiar oscillations called wheel tramp and wheel wobble.



## ❖ Tyre Materials:

- A tyre is mainly made of “rubber” and cords. Rubber in this context means the rubber compound to be exact. The compound is made by mixing polymer, reinforcement material, softener and various chemicals.
- The main polymers used for tyre are as follows:
  1. Natural Rubber (NR)
  2. Chloroprene (Neoprene) Rubber (CR).
  3. Styrene Butadiene Rubber (SBR)
  4. Butadiene Rubber (BR)
  5. Isoprene Rubber (IR)
  6. Ethylene Propylene Rubber (EPR)
  7. Isobutene-isoprene (butyl) Rubber (IIR).



## 1. Natural Rubber:

- NR is made from latex taken from rubber trees, mainly grown in southeast Asia. Although there are now various kinds of synthetic rubber available, NR is still used extensively in tyre manufacturing.
- Natural rubber provides **good wear resistance** and **excellent tear resistance**.
- It also offers **good road holding** on dry roads but provides only a **moderate grip on wet surfaces**. Additionally it has **low heat build-up**, but this merit is contrasted by **high gas permeability**.
- Also the resistance offered by this material for **aging and ozone deterioration** is only fair. The side walls and treads have been made from natural rubbers but nowadays it is normally blended with other synthetic rubbers to exploit their desirable properties by minimizing their shortcomings.



## 2. Chloroprene (Neoprene) Rubber (CR).

- This synthetic rubber was one of the earliest to compete with natural rubber and is made from **acetylene and hydrochloric acid**.
- This rubber compound has **good wear and tear resistance with a reasonable road surface grip**.
- A major limitation is its **inability to bond with the carcass fabric** due to which a natural rubber film is provided between the cords and the Neoprene covering.
- Neoprene rubber provides moderately **low gas permeability and does not indicate signs of weathering or aging throughout** the service life of the tyre.
- If blended with natural rubber it becomes suitable for side wall covering.



### 3. Styrene-butadiene Rubber (SBR).

- It is probably the most widely used synthetic rubber for the manufacturing of the tyre. This rubber compounds are made from styrene (a liquid) and butadiene (a gas).
- Styrene-butadiene rubber (SBR) forms a very strong bond to fabrics and it provides a very good resistance to wear, but exhibits poor tear resistance compared to natural rubber.
- One remarkable feature of this rubber is its high degree of energy absorption or high hysteresis and low resilience, which allow exceptional grip characteristic, especially on wet surfaces.
- Because of the high heat build up, this rubber is used only for the tyre tread while the side walls are normally made from low hysteresis compounds, which provide greater rebound response and run cooler.





- Blending SBR and NR provides the best properties of both synthetic and natural rubber to be utilized so that only one rubber compound is used for some types of car tyres.
- The high hysteresis characteristic of SBR is partially achieved by adding an extra high styrene content and a large proportion of oil, the overall effects being to increase the rubber plastic properties and to lower its resilience (i.e. reduce its rebound response)



## 4. Butadiene Rubber:

- This compound provides **very high wear resistance** and a **high resilience i.e. a low hysteresis level**.
- It is **exceptionally stable with temperature changes**. When blended with SBR in the correct proportions, its wet road holding ability reduces slightly but considerably improves its ability to resist wear.
- Due to its high resilience (large rebound response), the road holding in wet weather becomes relatively poor.
- For its application in tyres it is normally mixed with SBR in the proportion of 15 to 50%. It is, however, expensive to produce.



## 5. Isoprene Rubber

- This rubber exhibits very similar characteristics as natural rubber, however provides **improved wear and specifically tear resistance**.
- It has an additional advantage of an **extremely low heat build up with normal tyre flexing**.
- This rubber material is **blended** with **natural rubber** and **styrene-butadiene rubber** to produce tyre treads with **very high abrasion resistance**.
- This material is highly suitable for **heavy duty application** such as track tyres where **high temperatures and driving on rough terrains** are a problem.



## 6. Ethylene Propylene Rubber (EPR).

- This rubber provides the major advantage of mixing it with large amounts of cheap carbon black and oil without losing its rubbery properties.
- Depending upon the compound composition it **gives excellent abrasive ageing and ozone resistance** with varying road holding qualities in wet weather. It has also **varying skid resistance** on ice.
- A great disadvantage with this rubber compound is that it bonds **poorly to cord fabric**.
- Therefore, rubber compounds containing EPR have not proved to be successful as a material for tyre till date.



## 7. Isobutene-isoprene (butyl) Rubber (IIR).

- This kind of rubber has exceptionally low permeability to gas. In practice it retains air in tubes ten times longer than the natural rubber, so that it has been extensively used for tyre inner tubes and for inner linings of tubeless tyres.
- Unfortunately it does not blend with SBR and NR unless it is chlorinated. Its resistance to wear is good and it has a high hysteresis level so that it becomes more plastic like than rubber to distortion.
- It provides good road grip for both dry and wet conditions. Its desirable properties are generally improved when mixed with carbon black. Due to its high hysteresis it does not readily give out energy to the surroundings so that tyre treads made from this material do not generate noise in the form of squeal.



Two examples of typical rubber compositions suitable for tyre treads are:

a) High styrene butadiene rubber	31%
Oil extended butadiene rubber	31%
Carbon black	30%
Oil	6%
Sulphur	2%
b) Styrene butadiene rubber	45%
Natural rubber	15%
Carbon black	30%
Oil	8%
Sulphur	2%





# COMPONENTS



Carbon black adds strength and abrasion resistance, while protecting rubber against UV light.



During curing, sulphur links rubber molecules together, adding strength, and giving the rubber resistance to both heat and cold.



Zinc stearate

Small amounts of zinc stearate and waxes help control curing rate, prevent oxidation and make rubber easier to process.



Accelerators are used to control the cure rate, so different types of rubber can cure fully – in same amount of time.



Antioxidants and antiozonants are added to rubber to fight degradation by oxygen and ozone, which can shorten the life of tyres.



## ❖ **Classification of Tyres:**

### ■ **On basis of Construction**

1. Conventional (Inner Tube) Tyre
2. Tubeless Tyre

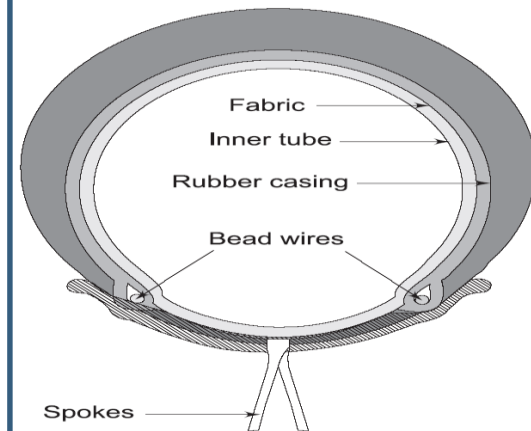
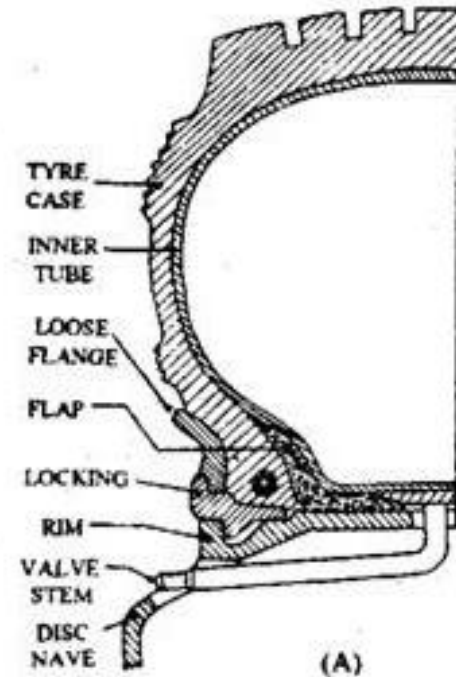
### ■ **On basis of Carcass or Skelton**

1. Cross Ply Tyre
2. Radial Ply Tyre
3. Belted-Bias Tyre



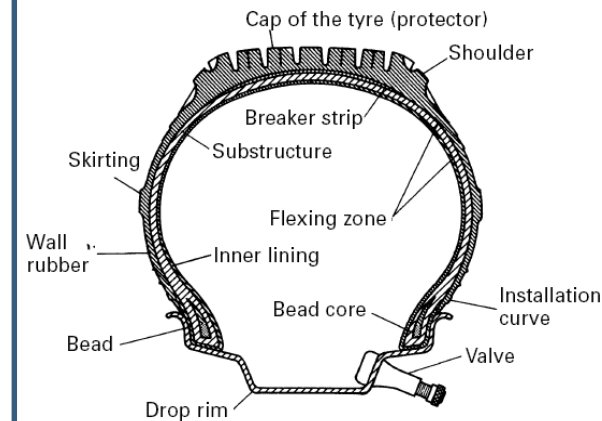
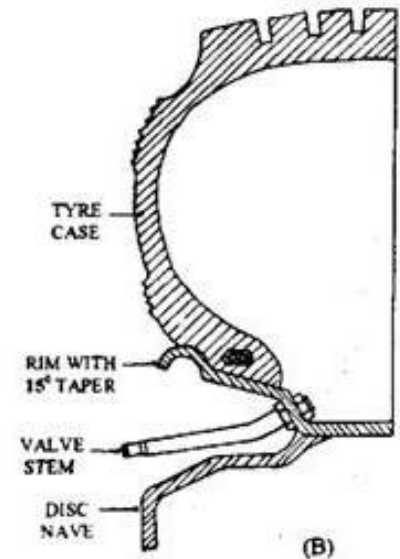
## ❖ Conventional (Inner Tube) Tyre

- The inner tube of a tyre is a flexible tube container, which when inflated with compressed air expands until it bursts unless the expansion is restrained by the tyre, acting as a casing.
- The inner tube (Fig. A) then takes the shape of the tyre cover, which protect it and contains this trapped pressurized air over long periods.
- The tube is manufactured from extruded rubber sheets, which are shaped on a former and cured (vulcanized) in a steam-heated mould to the cover shape.
- The tube is constructed to about 10% undersize. To provide an outlet or inlet to the tube interior, a valve stem is sealed to the inside circumference during vulcanization.



## ❖ Tubeless Tyre:

- The tubeless tyre (Fig.B) constitutes an outer cover and instead of the inner tube an unstretched rubber lining is bonded to the inside of the cover wall.
- The rubber lining continues under the beads dredges of the cover to join up with the outer side-wall rubber.
- The bead portion of the tyre makes an effective air-tight seal between the tyre and the rim.
- The taper rim seats on each side of the weft base and adjacent to the rim flanges, and assists initial sealing between the bead and the wheel rim during inflation of the tyre.





- Car and commercial vehicle rims have taper angles of  $5^\circ$  and  $15^\circ$  respectively.
- In this layout, the tyre valve is generally positioned in a hole formed in the well base of the rim.
- Car valves are sealed by rubber grommets, whereas commercial vehicle valves have all-metal threaded system and is secured to the rim by nuts.



## ❖ Merits of Tubeless over Tubed Tyres

Following are the benefits of using tubeless tyres over tubed tyres.

- **Air Retention:** In the tubeless tyre, the inner lining does not stretch unlike ordinary inner tubes, and the cover wall itself resists air passage, therefore air loss is very much slower. The tyre bead and the rim also provide seal between them so that no leakage of air around the tyre rim is allowed.
- **Safety:** The tubed tyres can suddenly puncture without warning. With a tubeless tyre, if a tyre is ruptured a slow loss of air takes place giving enough time to take care of the problem.
- **Ride Comfort:** The tubeless tyre is lighter than the inner tube and tyre, giving less unsprung-mass reaction on the vehicle's suspension system, which reduces wheel bounce.



- **Tyre Cooling:** When there is no inner tube, the heat generated in the compressed air is dissipated to atmosphere directly through the metal rim. The inner tube being relatively poor conductor of heat, a greater temperature builds up in tubed tyres.
- **Wheel Assembly Balance:** A commercial-vehicle tubeless tyre does not incorporate a tube flap, loose flange, and lock-ring. In this case the tyre bead fits concentric to the taper wheel rim. This layout provides a better balanced assembly.
- **Assembly of Tyre to Wheel:** There is no chance of the inner tube being nipped or punctured during assembly as only the cover has to be fitted over the wheel rim. Also there is no danger of loose components flying off during inflation of tubeless tyre due to distortion or carelessness.





## ❖ Tyre Construction

- The carcass, beads, side walls, and tread are the major components of a tyre cover.
- **Carcass.** This is a horseshoe-shaped inner lining of the tyre and is made up of a number of layers of textile cord piles. The carcass forms the backbone of the tyre construction and the tread, bead, and walls all are moulded on to these cord piles.
- **Bead.** This forms the inner edge of the tyre, and locates and centralizes the cover on to the wheel rim. It has the rigidity and strength required to support the carcass. To achieve this endless wire core is moulded circumferentially through the bead.
- **Side Wall.** This constitutes the outside rubber covering of the carcass between the bead and the tyre tread. The amount of protection provided to the carcass and the stiffness of the tyre during deflection depends on the thickness of side wall.





- **Tread.** This forms the part of the tyre, which contacts the road surface when the wheel rolls. It is a rubber compound and its pattern design considerably influences the tyre's gripping, road-holding ability and working life.
- Many textile cords are crisscrossed and embedded to provide strength to the cross-ply tyre in the rubber. These cords are arranged in layers, usually referred to as plies, which perform two jobs.
- Firstly they have to make the walls strong enough to contain the air pressure and yet leave them as supple as possible for deflection. Secondly they have to support the tread.
- These two requirements conflict each other because to obtain sufficient bracing of the tread, the ply must be reasonably stiff, which then means that the walls has to be rigid.
- Radial plies perform only one job that is to make the wall of the tyre strong enough to contain the air pressure. They do not support the tread.



- So they do not require to be criss-crossed, instead are laid readily following the natural profile of the tyre.
- This provides a supple but strong wall, which is desirable. To support the tread, a layer of rayon or steel cords forming a belt is placed underneath it.
- The sole purpose of this belt is to brace the whole of the tread firmly flat down and open on to the road.
- The greatest difference in tyres lies in the cord material and the way it is put into the tyre. The cross-bias cord angle runs from 30 to 40 degrees.
- This provides a cross-cord side wall, which gives required strength to transfer acceleration and braking torque. The tyres have gone from four-ply to two-ply construction.



- The strength of the ply is the result of the weight of the cord rather than the number of plies. Two-ply tyres are as strong as four ply tyres, because the tyre cord denier is larger than used in four ply tyres.
- Two-ply tyres run cooler, are more flexible to absorb shock from road irregularities, and apply greater self aligning torque to the steering system after a turn.
- Bias-ply allows the tyre to squirm as it moves through the tyre foot print or contact patch. The tread is pushed together as it goes into the foot print. This stores energy in the rubber.
- As it comes out of the foot print, the tyre rapidly expands and goes beyond the neutral point into a stretched position.
- Closing and opening of the tread as it moves through the contact patches is one of the major causes of normal tyre wear.



- In belted tyres the tread stability and reduction of squirm results in upto 100% improvement in tyre running compared to bias-ply tyres.
- By holding the tread shape, belted tyres run cooler, improve fuel consumption, improve traction, and double blow-out resistance when compared to bias-ply tyres.
- Belted tyres do not flex as easily as bias-cord tyres, so that more road shock is transfer into the wheels and suspension system in this tyre, and hence the wheel spindles, knuckles, and suspension system are required to be stronger.
- Radial-ply belted tyres have been built having radial ply cord angles run from 88 to 90 degrees and the belt cords run from 12 to 20 degrees.
- The radial cord provides a soft side wall, which produces a softer ride than belted bias tyres.

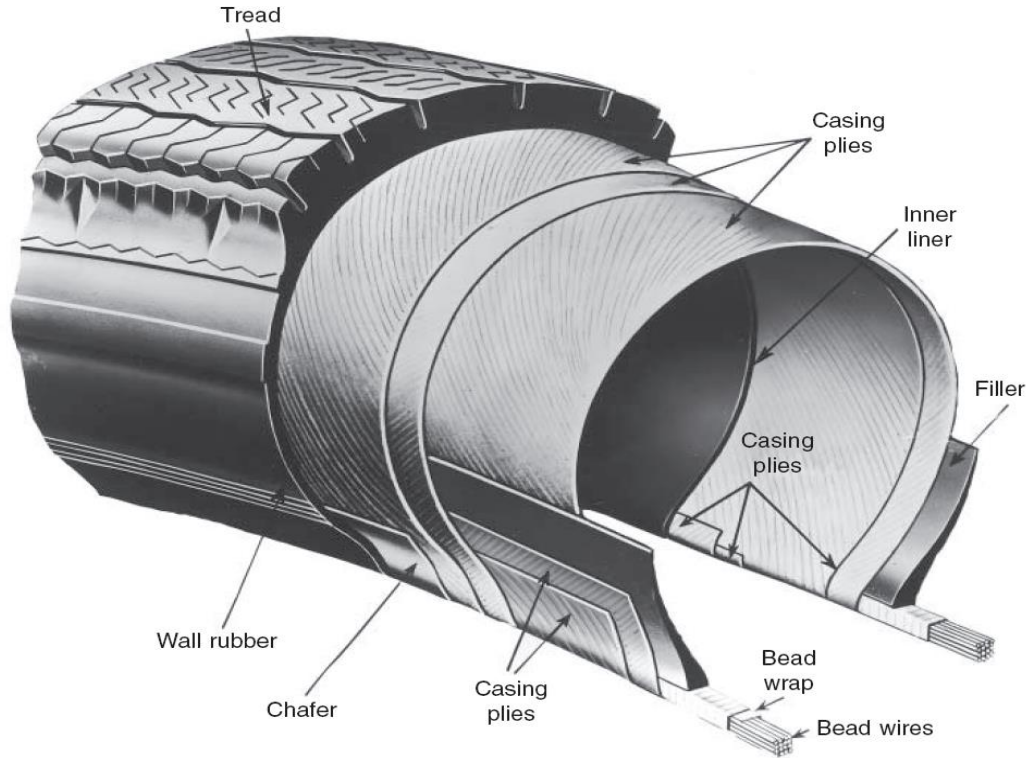


- The belt (steel wires, Fiberglass, or rayon) around the radial cords holds the tread shape through the contact patch or foot prints.
- Radial belted tyres, as a result of a lower slip angle, provide more cornering power and less wear than bias belted tyres.
- These tyres produce a harsh ride at low speed, require a high steering effort, especially when parking and are expensive.
- The steel-belted radial tyre has less tread flexing so it rolls easier, thereby improving fuel consumption.
- With the radial belted tyres, loss of tyre-to-road adhesion occurs suddenly, with little warning, especially on wet surfaces.





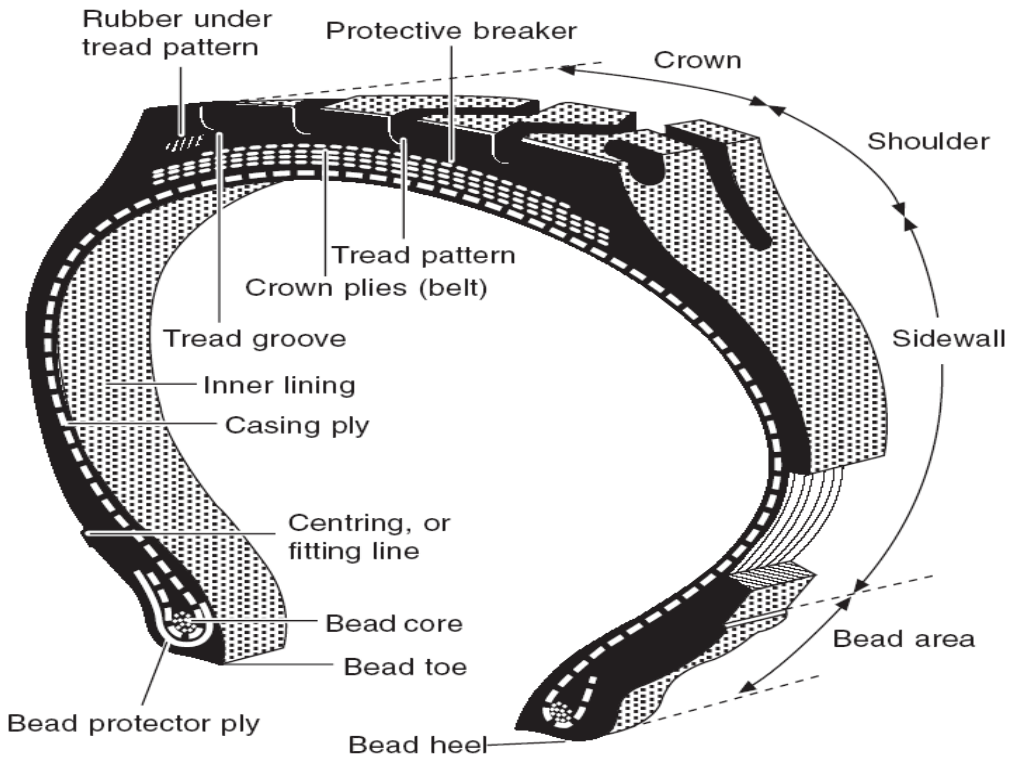
## ❖ Cross Or Bias Ply Tyre:





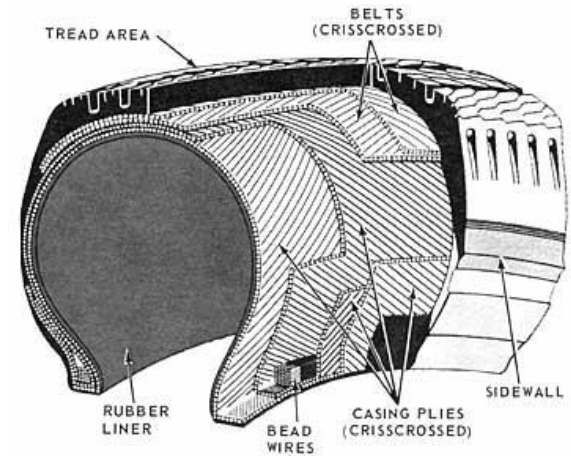
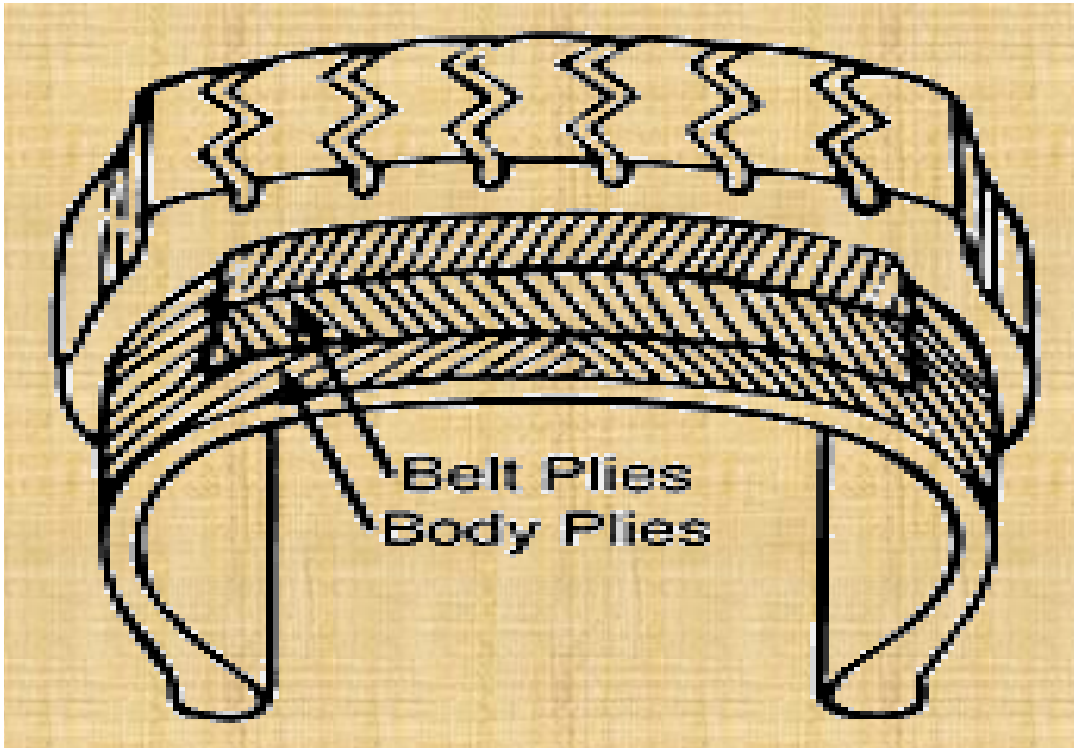


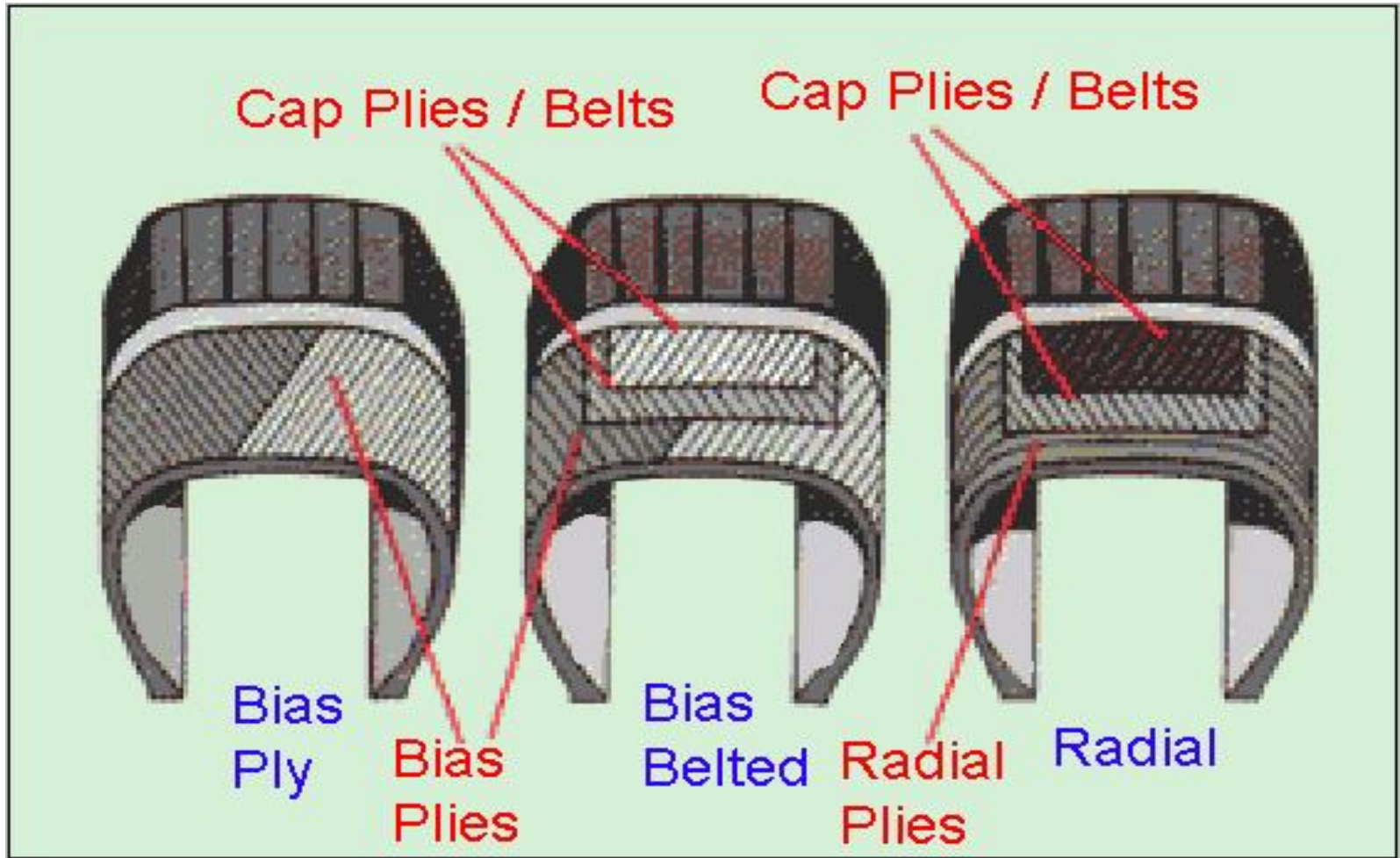
## ❖ Radial Ply Tyre:





## ❖ Belted Bias Ply Tyre:



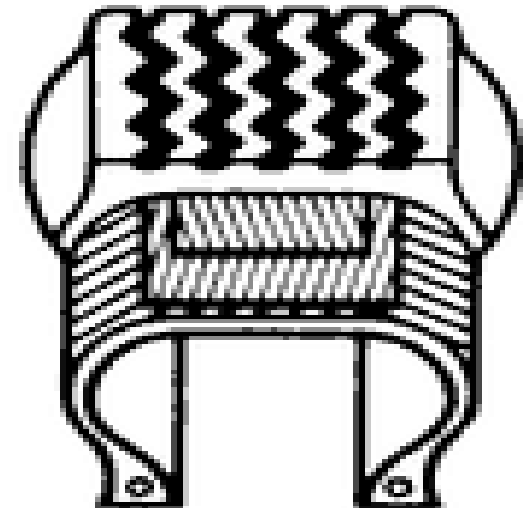
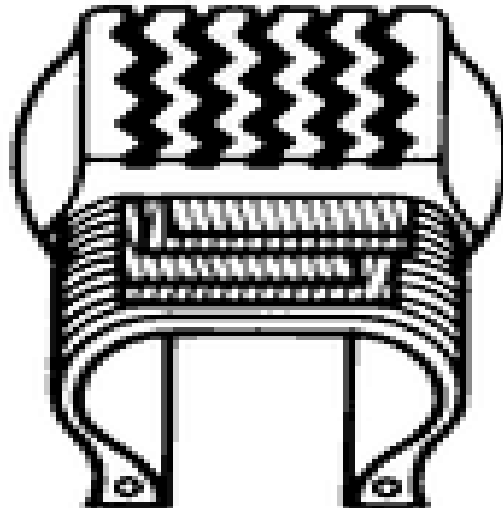
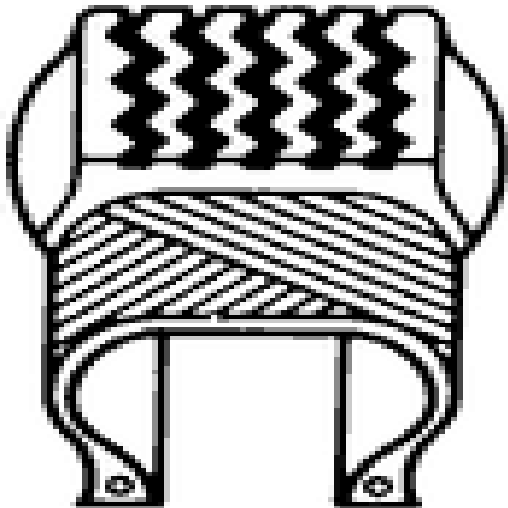


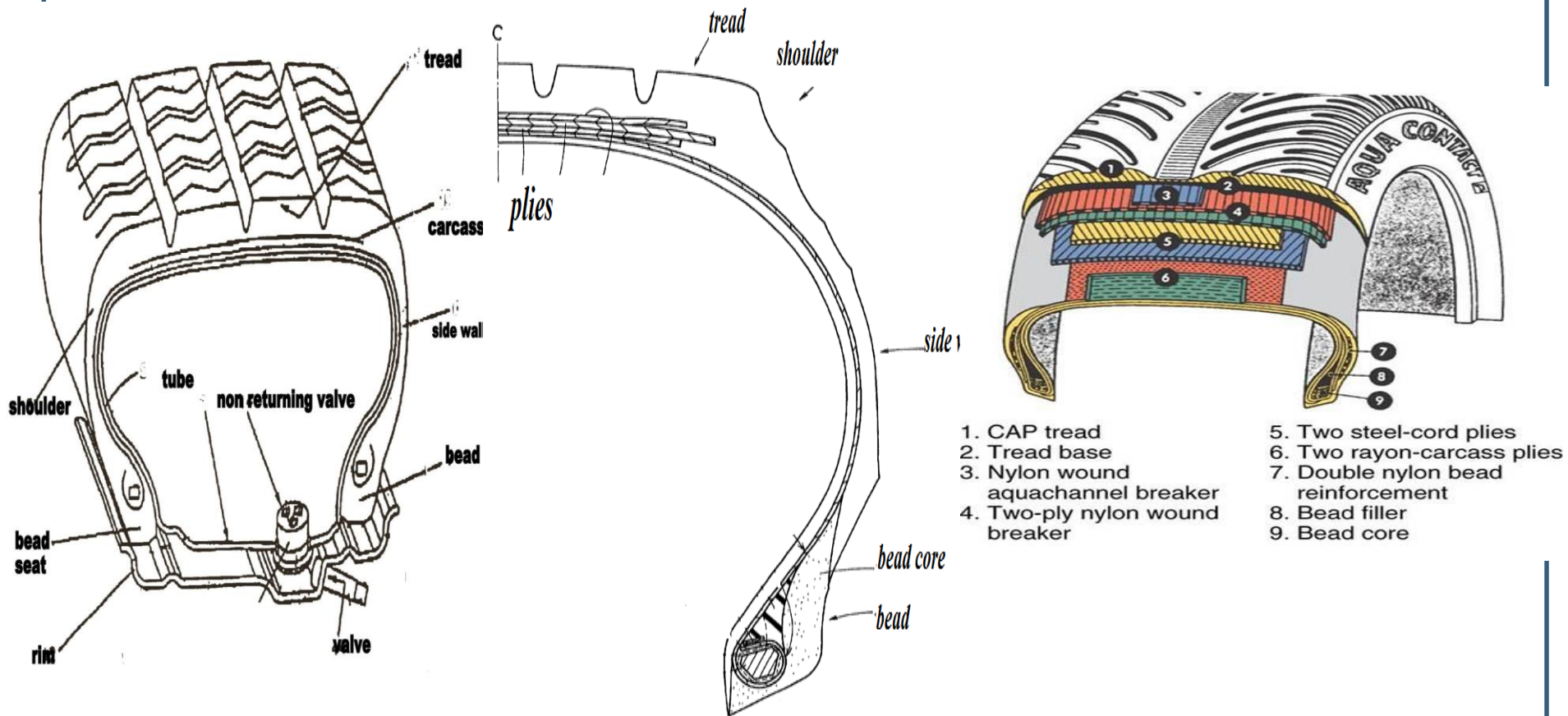


**BIAS PLY**

**RADIAL**

**BELTED BIAS**

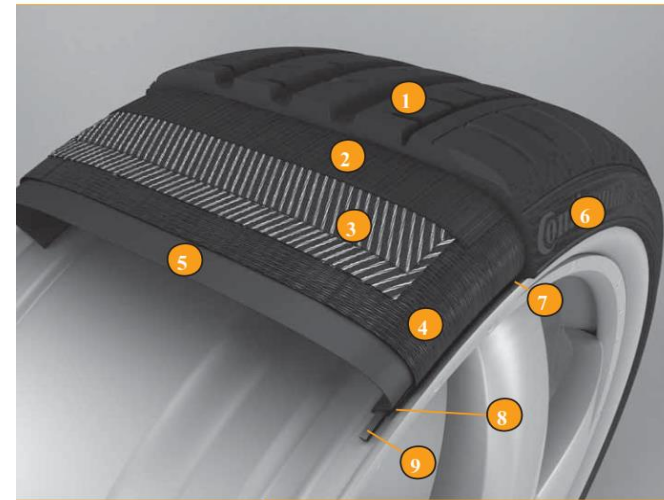








- 1 Tread – high mileage good road grip and water expulsion**
- 2 Jointless cap plies – enable high speeds**
- 3 Steel-cord belt plies – optimise directional stability and rolling resistance**
- 4 Textile cord ply – controls internal pressure and maintains the tyre's shape**
- 5 Inner liner – makes the tyre airtight**
- 6 Side wall – protects from external damage**
- 7 Bead reinforcement – promotes directional stability and precise steering response**
- 8 Bead apex – promotes directional stability, steering performance and comfort level**
- 9 Bead core – ensures firm seating on the rim**





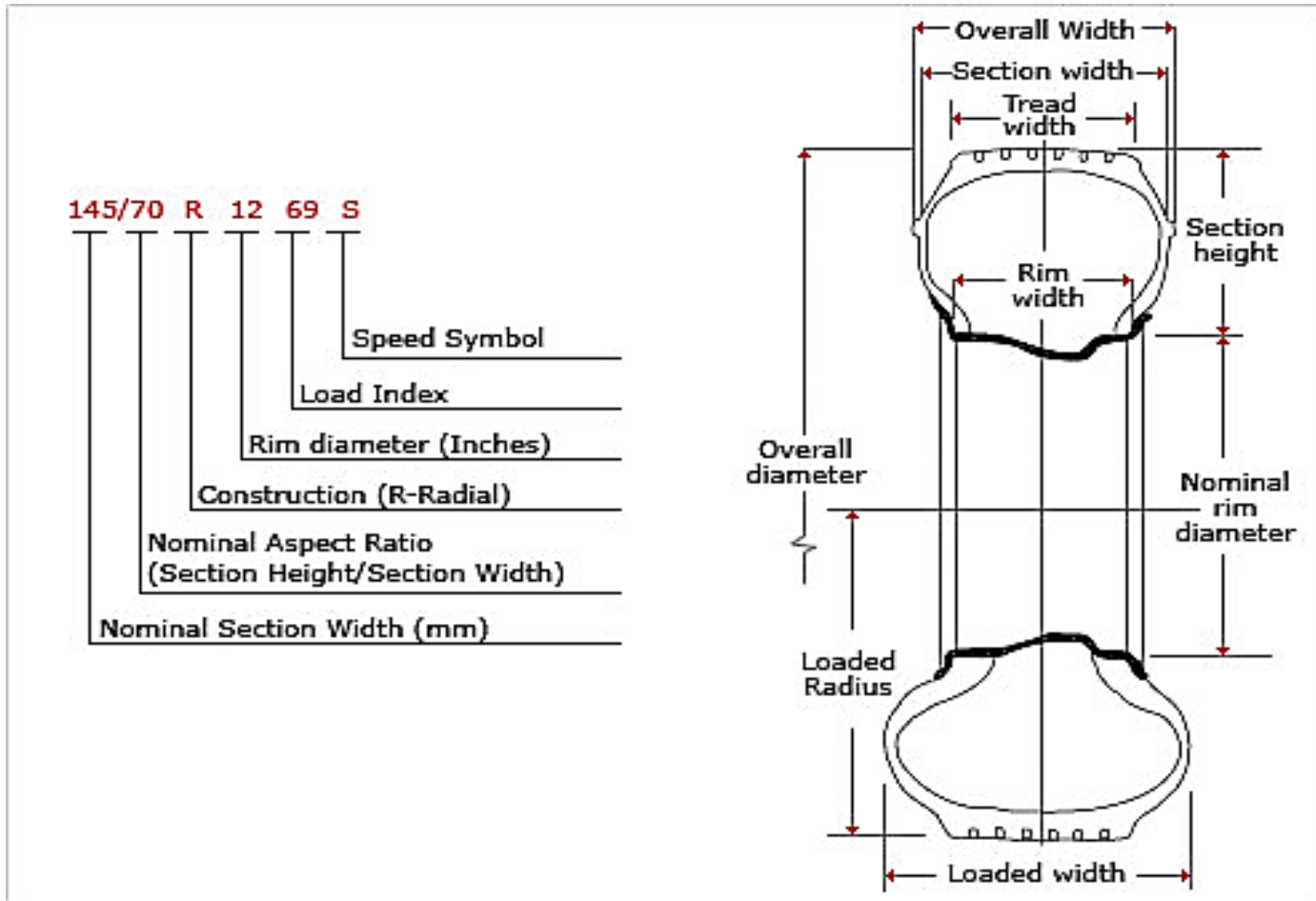
## ❖ Advantages of radial ply Tyres:-

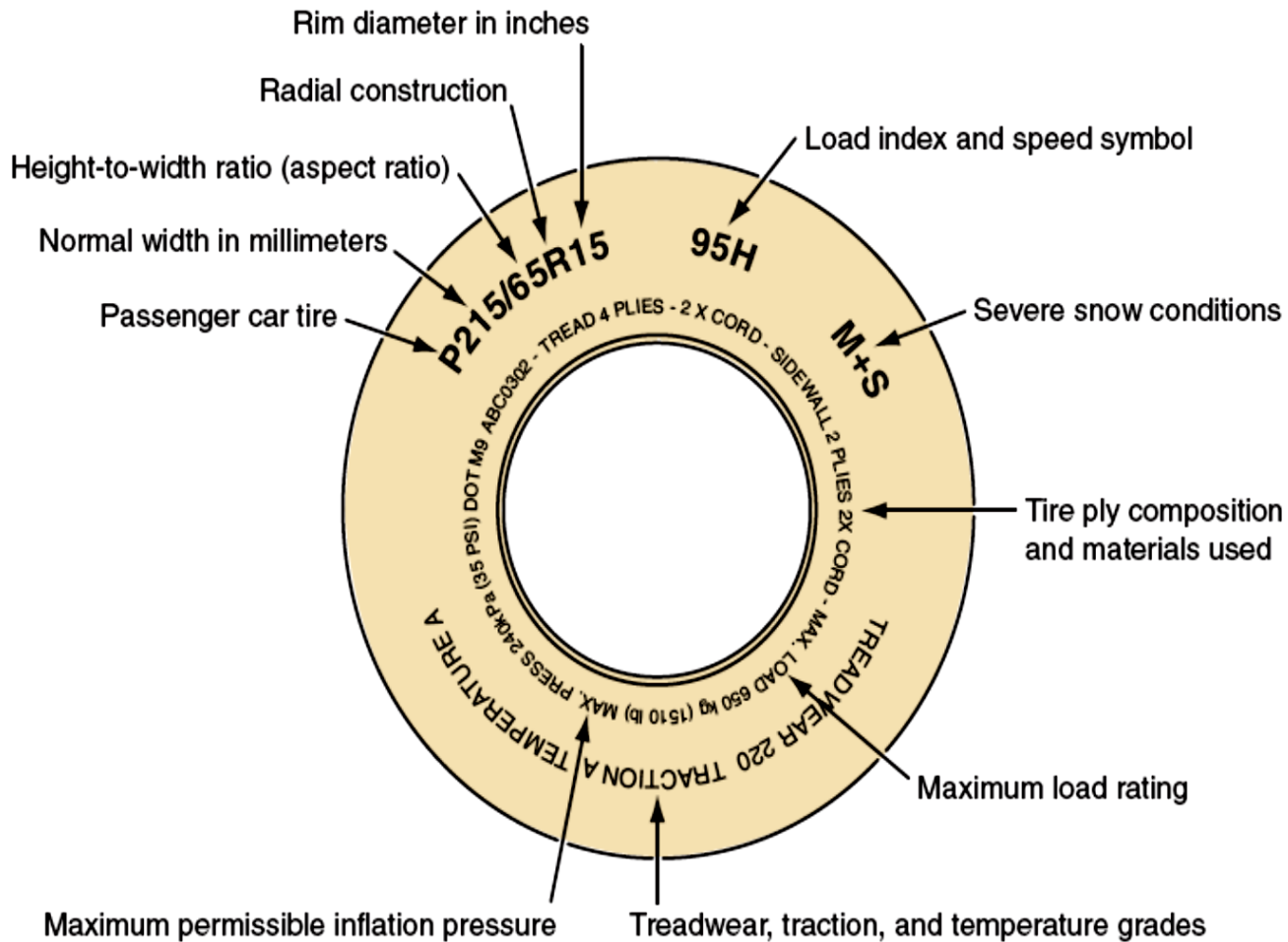
- The side walls can be bend readily ,its shock absorbing capacity is 25% more than bias ply or cross ply.
- The breaker strips of radial Tyres act independently of the wall plies unlike in cross ply where there is no breaker strip.
- Lower rolling resistance and hysteresis loss leads to less fuel consumption.
- Longer tread life because of less heat build in Tyre.
- Breaking efficiency on wet roads is better because of greater sidewall flexibility and tread stiffness.
- Smaller slip angles and higher cornering power which results in Better steering characteristics.
- While taking turns it has less tendency to distort and lift off the road from one side.
- Larger resistance to punctures ,cuts and impacts in the tread area.



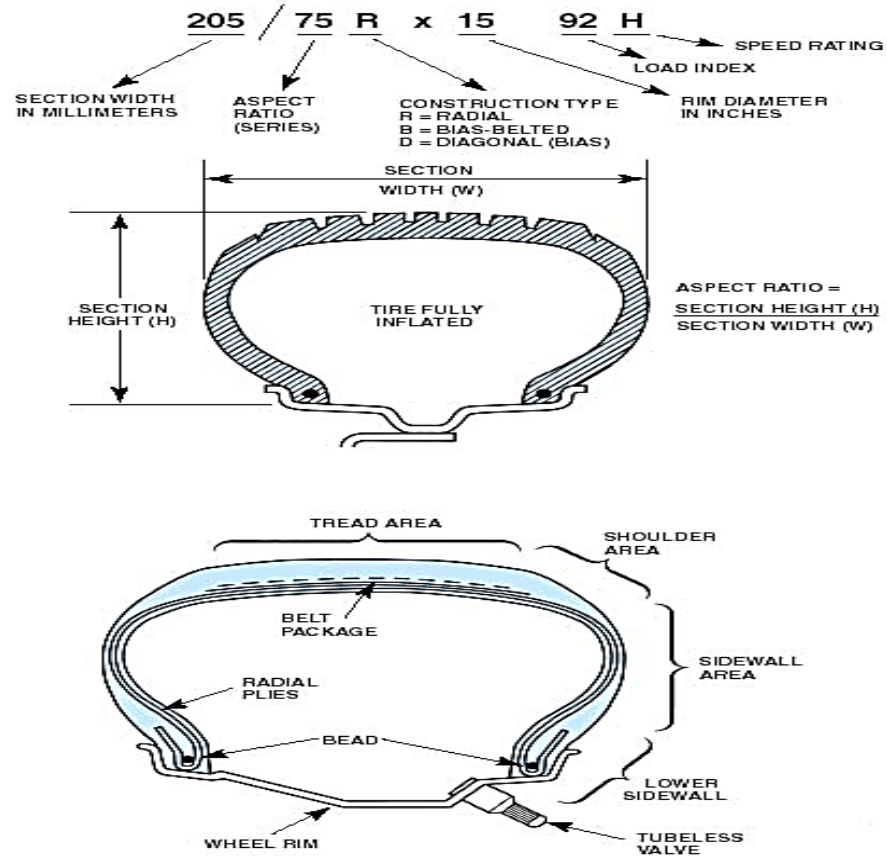


## ❖ Tyre sizes and designation:





**Figure 61.11** Information found on (a typical passenger) tire sidewall.



**FIGURE 3-10** Cross-sectional view of a typical tire showing the terminology.

**P-Metric Designation**

**P205/75HR x 15**  
 P passenger vehicle  
 205 cross-sectional width in mm  
 75 aspect ratio

**Service Description**

**205/75R x 15 92H**  
 205 cross-sectional width in mm  
 75 aspect ratio  
 R radial construction

H speed rating  
 (130 mph/210 km/h)  
 R radial construction  
 15 rim diameter in inches

15 rim diameter in inches  
 92 load index  
 H speed rating (130 mph/  
 210 km/h)



- Some tires use letters at the end of the tire size (suffixes) to indicate special applications including the following.

LT = light truck

ML = mining and logging

MH = mobile home

ST = special trailer

TR = truck

- **Service Description**

P205/75R x 15 92H

205 cross-sectional width in mm

75 aspect ratio

R radial construction

15 rim diameter in inches

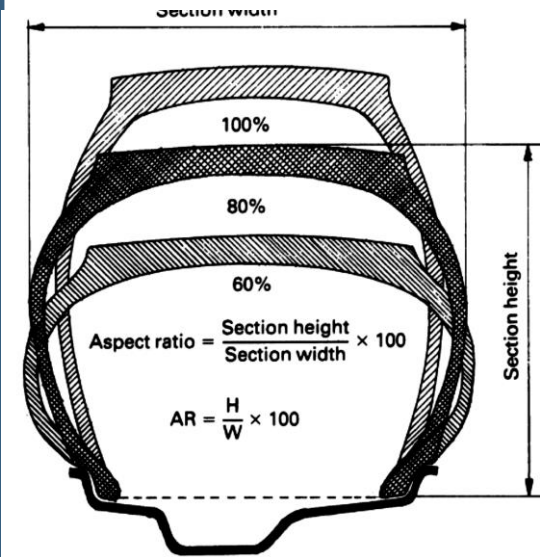
92 load index

H speed rating (130 mph/210 km/h)



## ❖ Aspect Ratio:

- A tyre carcass profile considerably influences its rolling and handling characteristics. The tyre's cross-sectional configuration determines its suitability for better performance under various applications.
- The aspect ratio of tyre may be defined as the ratio of the tyre cross-sectional height (the distance between the tip of the tread to the bead seat) to that of the section width (the outermost distance between the tyre walls) (Fig.).
- This ratio is constant for a particular tyre and is used for predicting the suitability of a tyre for an application



$$\text{Aspect ratio} = \frac{\text{Section height}}{\text{Section width}} \times 100$$



- A tyre with a large or small aspect ratio is known respectively as a high or low aspect ratio profile tyre. Until about 1934 aspect ratios of 100% were used. With a better understanding and improvement in tyre construction lower aspect ratio tyres become available.
- Due to lowering the aspect ratio the tyre side wall height is reduced so that the vertical and lateral stiffness of the tyre increases, thereby establishing a shorter and wider contact patch.
- A short and wider contact patch,
  - (a) increases the load carrying capability of the tyre ;
  - (b) generates larger cornering forces so that vehicles are able to travel faster on bends;
  - (c) decreases the pneumatic trail so that the self-aligning torque correspondingly reduces and becomes more consistent; and
  - (d) under certain driving conditions, reduces the slip angles generated by the tyre when subjected to side forces.



- Consequently the tread distortion reduces and as a result scuffing and wear decrease. Water drainage at speed becomes difficult with wider tyre contact patches, particularly in the mid tread region.
- Therefore it is more critical to design the tread pattern with low profile tyre on wet” roads, in case the tyre holding is to match with the higher aspect ratio tyres.
- The increase in vertical and lateral stiffnesses causes the following,
  - (a) Due to an increase in vertical stiffness and a reduction in tyre deflection, less energy is dissipated by the tyre casing thereby reducing the resistance. This also causes the tyre to run continuously at high speeds at lower temperatures, which increases the tyre’s life.





- (a) The increased lateral stiffness of a low profile tyre increases the sensitivity to camber variations and quicken the response to steering changes.
- (b) The increased vertical stiffness of the tyre reduces static deflection of the tyre under load, due to which more road vibrations are transmitted through the tyre.
- This provides a harsher ride reducing ride comfort unless the body is further isolated from the suspension. The availability of lower aspect ratio tyres over the years was as follows : 1950s — 95%, 1962-88%, 1965-80% and about 1968-70%. Since then for special applications even lower aspect ratios of 65%, 60%, 55% and even 50% have become available



## ❖ Load Index/Rating

- How much weight a tire can safely support at a specified air pressure
- Amount of load determined by area of tire and air pressure in it
- Vehicle's gross weight rating (GVW or GVWR) includes weight of vehicle, passengers, luggage
  - Curb weight – weight of vehicle without people
- DOT symbol indicates the tire meets DOT safety standards





Load Index	Pounds	Kilograms	Load Index	Pounds	Kilograms
71	761	345	91	1356	615
72	783	355	92	1389	630
73	805	365	93	1433	650
74	827	375	94	1477	670
75	853	387	95	1521	690
76	882	400	96	1565	710
77	908	412	97	1609	730
78	937	425	98	1653	750
79	963	437	99	1709	775
80	992	450	100	1764	800
81	1019	462	101	1819	825
82	1047	475	102	1874	850
83	1074	487	103	1929	875
84	1102	500	104	1984	900
85	1135	515	105	2039	925
86	1168	530	106	2094	950
87	1201	545	107	2149	975
88	1235	560	108	2205	1000
89	1279	580	109	2271	1030
90	1323	600	110	2337	1060



## ❖ Ply Rating

<b>PLY RATING</b>	<b>LOAD RANGE</b>	<b>PLY RATING</b>	<b>LOAD RANGE</b>
<b>2</b>	<b>A</b>	<b>14</b>	<b>G</b>
<b>4</b>	<b>B</b>	<b>16</b>	<b>H</b>
<b>6</b>	<b>C</b>	<b>18</b>	<b>J</b>
<b>8</b>	<b>D</b>	<b>20</b>	<b>L</b>
<b>10</b>	<b>E</b>	<b>22</b>	<b>M</b>
<b>12</b>	<b>F</b>	<b>24</b>	<b>N</b>



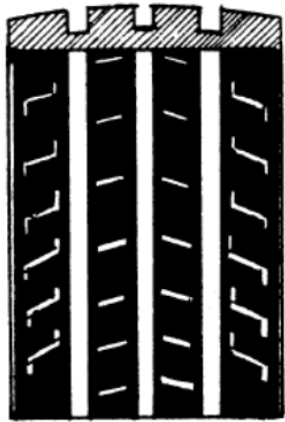
## ❖ Speed Rating

Letter	Maximum Rated Speed
L	120 km/h (75 mph)
M	130 km/h (81 mph)
N	140 km/h (87 mph)
P	150 km/h (93 mph)
Q	160 km/h (99 mph)
R	170 km/h (106 mph)
S	180 km/h (112 mph)
T	190 km/h (118 mph)
U	200 km/h (124 mph)
H	210 km/h (130 mph)
V	240 km/h (149 mph)
W	270 km/h (168 mph)
Y	300 km/h (185 mph)
Z	Open-ended*

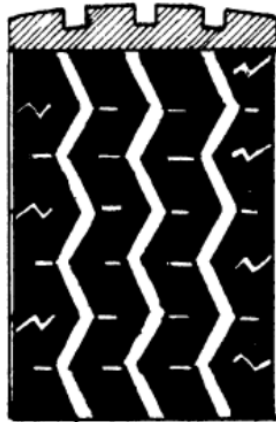
\*The exact speed rating for a particular Z-rated tire is determined by the tire manufacturer and may vary according to size. For example, not all Brand X Z-rated tires are rated at 170 mph, even though one size may be capable of these speeds.



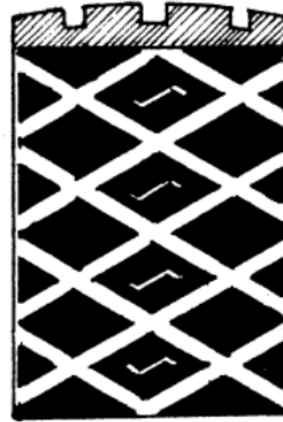
## ■ Tyre Tread Pattern



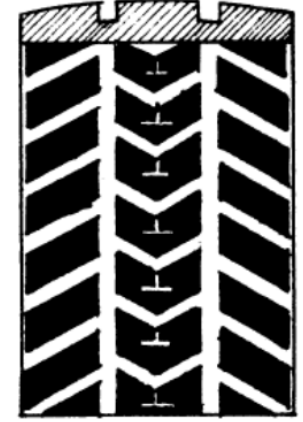
(a) Circumferential straight grooves and ribs with multiple sipes



(b) Circumferential zig-zag grooves and ribs with multiple sipes



(c) Diagonal grooves with diamond shaped blocks and central sipes



(d) Diagonal bars with central vee blocks and sipes



## ❖ Performance Tyre:

- Performance tires tend to be designed for use at higher speeds. They often have a softer rubber compound for improved traction, especially on high speed cornering.







## ❖ All-terrain tyres

- All-terrain tires are typically used on SUVs and light trucks. These tires often have stiffer sidewalls for greater resistance against puncture when traveling off-road, the tread pattern offers wider spacing than all-season tires to evacuate mud from the tread.





## ❖ Mud tyres

- Mud terrain tires are characterized by large, chunky tread patterns designed to bite into muddy surfaces and provide grip. The large open design also allows mud to clear more quickly from between the lugs.





## ❖ Winter tyres

- Winter tires are designed to provide improved performance under winter conditions compared to tires made for use in summer. The rubber compound used in the tread of the tire is usually softer than that used in tires for summer conditions, so providing better grip on ice and snow.





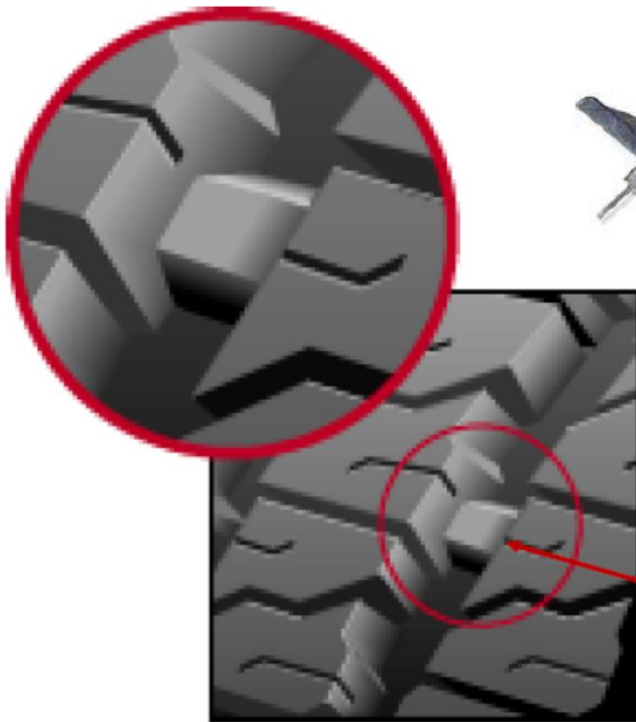
## ❖ All-weather tyres

- These are an attempt to make a tire that will be a compromise between a tire developed for use on dry and wet roads during summer, and a tire developed for use under winter conditions, when there is snow and ice on the road. However, the type of rubber and the tread pattern best suited for use under summer conditions cannot, for technical reasons, give good performance on snow and ice. The all-weather tire is therefore a poor compromise, and is neither a good summer tire, nor a good winter tire.





## Tread Wear Markings



Wear Measuring tool



Coin method

Tread wear indicator





## ❖ Tyre Valve

- Passenger car valve stems usually rubber
  - Designed for pressures less than 62 psi
- Spring loaded valve core screwed into valve stem
- Some have a gasket to prevent air loss past valve core
- Short stem used when there is a hub cap
- Long stem accommodates full wheel covers

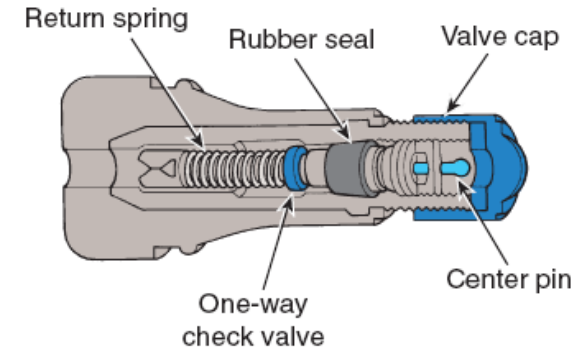
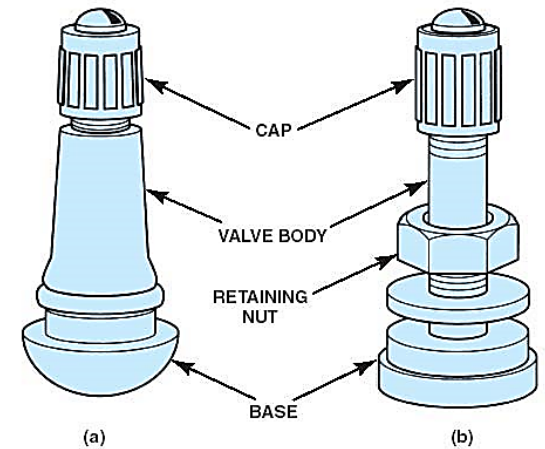


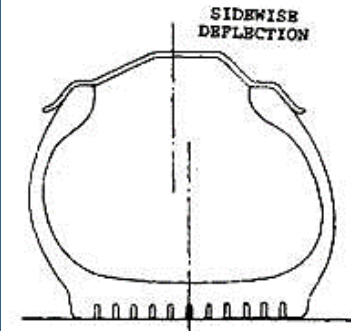
Figure 61.40 Parts of a rubber valve stem.



**FIGURE 20-37** (a) A rubber snap-in style tire valve assembly. (b) A metal clamp-type tire valve assembly used on most high-pressure (over 60 psi) tire applications such as is found on many trucks, RVs, and trailers. The internal Schrader valve threads into the valve itself and can be replaced individually, but most experts recommend replacing the entire valve assembly every time the tires are replaced to help prevent air loss.

## ❖ Tyre Inflation Pressure:

- The tyre is designed to match the rim to maintain a tight air seal, which keeps air pressure in the tyre. The width of the wheel rim in relation to the size of the tyre is important.
- Engine acceleration torque tries to turn the rim inside of the tyre, and the friction between the bead and rim keeps this away from happening. This type of force also occurs during braking, but in the reverse direction.
- During a turn, the tyre is deflected sideways as illustrated in Fig. This force tends to loosen the bead from the rim on one side of the tyre. The tyre bead must be sufficiently secured to hold contact with the rim.







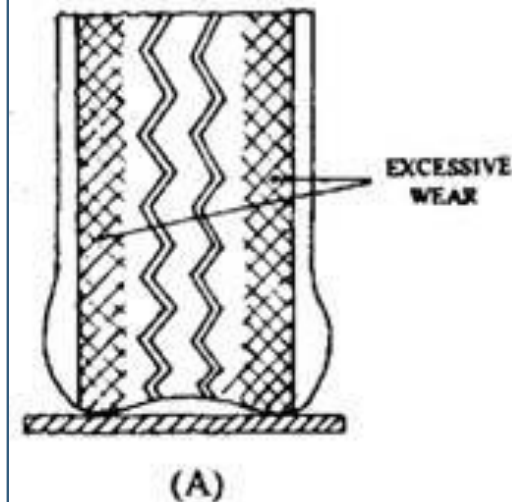
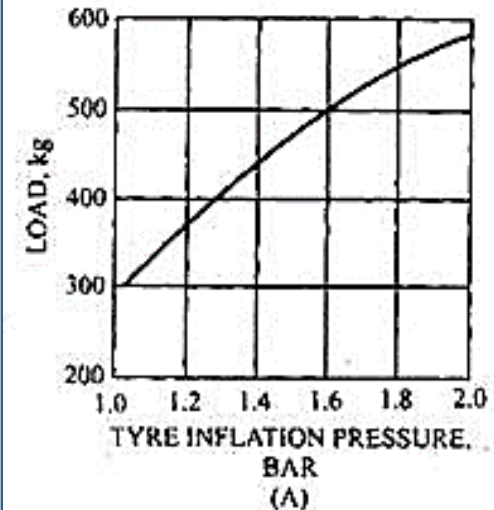
- Centrifugal force, at high vehicle speeds, increases the tyre diameter, which tries to throw the bead from the rim. The bead wire holds the bead diameter, so that it remains in contact with the rim.
- Belted tyres keep the tread from expanding at high speeds, which stabilizes the tread and minimizes heat built up. Tyres flex as they rotate while carrying vehicle load.
- This flexing distorts the tyre, especially when the tyre assumes a side load while going ground a curve. Distortion, a natural reaction of a tyre, allows the tyre of absorb road shock and to flex through the contact patch without skidding as the vehicle takes a turn.



- Heat build-up in the tyre due to natural tyre flexing stabilizes at a safe temperature during its normal operation within its load range.
- Temperatures above 394 K result in the loss of tyre strength, the rubber-to-cord bond separates, and the air escapes, often as a blow out, and in some cases they start to burn.
- The simplest method to reduce heat is to slow the vehicle speed, which decreases flexing per minute and provides more cooling time between flexing.
- Tyre inflation pressures are recommended to have the best compromise for load carrying capacity, vehicle handling, and tyre life. The inflation pressures are usually related to the expected wheel load.



- Increased inflation pressure supports the tyre casing more, due to which its load-carrying capacity increases (Graph. A). The factors on which the load-carrying capacity depends are the carcass ply-cord material, the resilience of the tread grip, the bounce absorption (i.e. the cushioning qualities), uniform wear, and expected life.
- Under-inflation of tyres increases the tyre-wall deflection at the base of the wheel resulting in a continuous flexing of the tyre walls thereby generating heat and reducing the fatigue life of the casing (Fig. A).

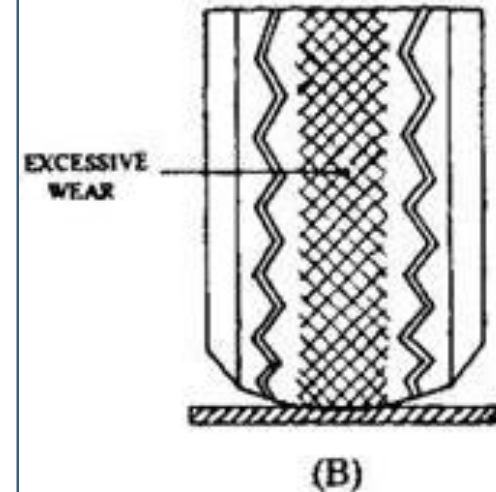




- Under-inflation reduces tyre life, because excessive distortion of tyre walls results in their cracking and in cord breakage. Heat generated from friction between cord layers inside tyre helps the breakdown to occur. The other adverse effects besides reduces tyre life may result from under inflation are as follows:
  - (a) Lack of directional stability of the vehicle.
  - (b) Increased, rolling resistance and therefore, increased fuel consumption.
  - (c) Tread wear is uneven.
  - (d) In a severe case, a tyre may creep on its rim and with a conventional tube may rip the valve out.



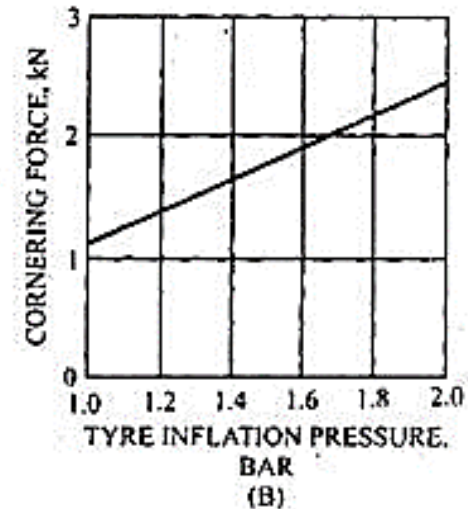
- **Over-inflated tyres** (Fig. B), on the other hand, over-stress the cord plies and rubber covering due to which they cannot take the repeated impacts to which the tyre is subjected.
- A prolonged journey with overloaded over-inflated tyres would eventually cause failure of the walls. Also with over-inflated tyres, the cushioning is less and the ride is harder. The over-inflation causes the following problems.
  - (a) Tyre cushioning properties are reduced.
  - (b) Greater chance of fracture and cutting, as casing and tread are subjected to greater tension. Impact resistance is reduced.
  - (c) Tread wear is confined to a smaller section of tread.
  - (d) Road holding properties are reduced.





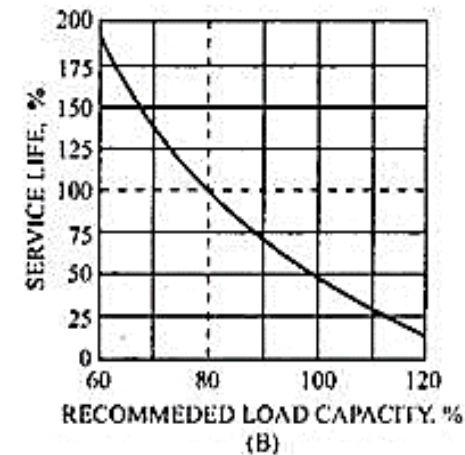
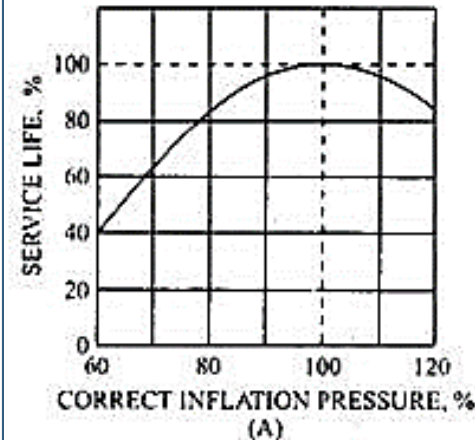
## ❖ Vehicle Handling:

- The cornering force on the tyre when negotiating a bend is proportional to the tyre inflation pressure within given limits (Fig. B).
- The slip angle for a given cornering force reduces as the air pressure increases. The proportion of inflation pressure between the front and rear wheels can influence the under-steer and over-steer characteristics of a vehicle.
- If the tyre pressures are raised at the front and lowered at the rear, the vehicle is expected to over-steer. Conversely if the pressure is reduced at the front and increased at the rear, the vehicle tends to under-steer.



## ❖ Tyre Life:

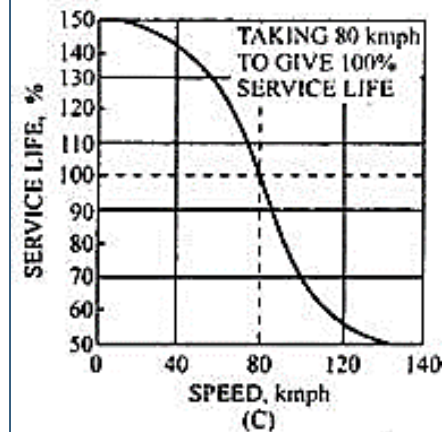
- Tyre life depends upon inflation pressure, wheel load, and vehicle speed. The correct tyre pressure minimizes the distortion and straining of the tyre case.
- Low inflation pressure rapidly wears the outer edges of the tread, and high inflation pressure causes to wear the centre of the tread crown (Fig. A ).
- Overloading the tyre reduces tyre life because it highly stresses the carcass structure, distort the tread-pattern blocks and increase their scrubbing action, and overheat the tyre (Fig. B).







- At higher wheel speed, the rate of flexing and the rise in carcass temperature shorten tyre life. Also, at high speed the wheels do not closely follow the road surface contour due to which the tread is in a constant state of scuffing as it contacts and leaves the ground (Fig. C).
- The tread wear increases with speed due to the following reasons,
  - (a) Operating temperature is increased because of more deflections per minute. The resistance of the tread rubber to abrasive wears decreases as temperature rises.
  - (b) Acceleration and braking tend to be fiercer.
  - (c) Tyre slip and distortion when rounding bends and corners are increased.
  - (d) Minor road irregularities produce more bounce and scuffing wear than would be the case at low speeds.



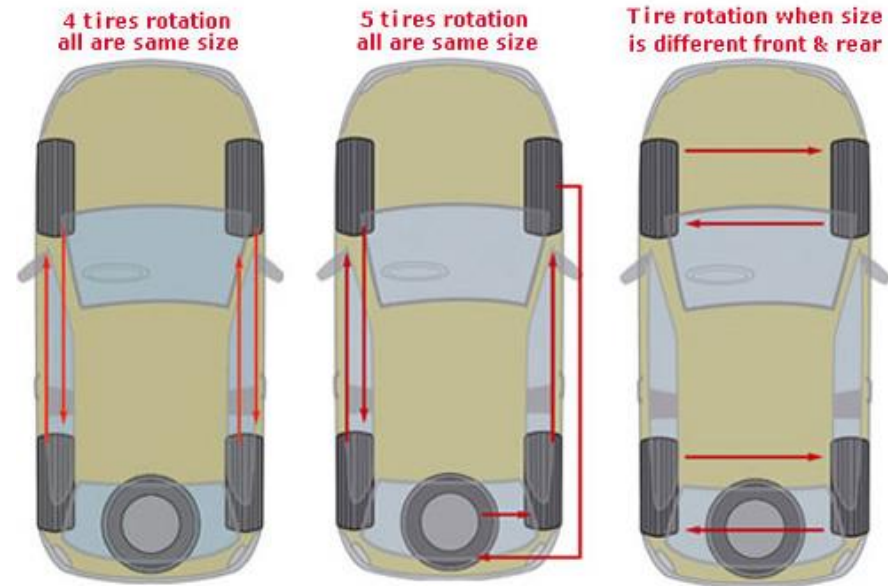
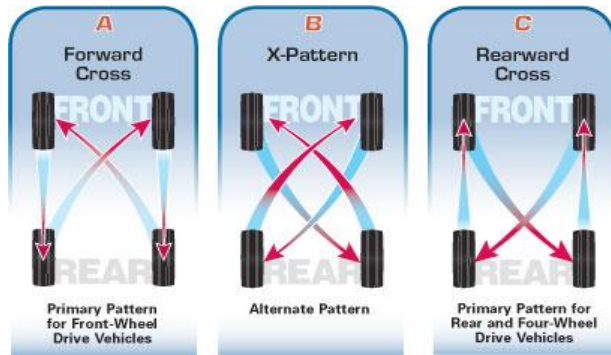
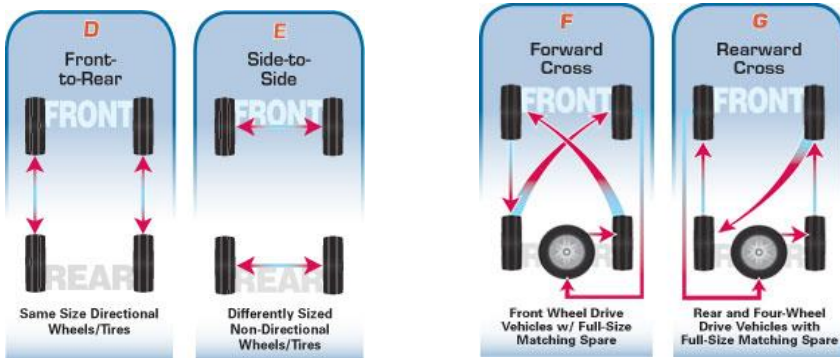


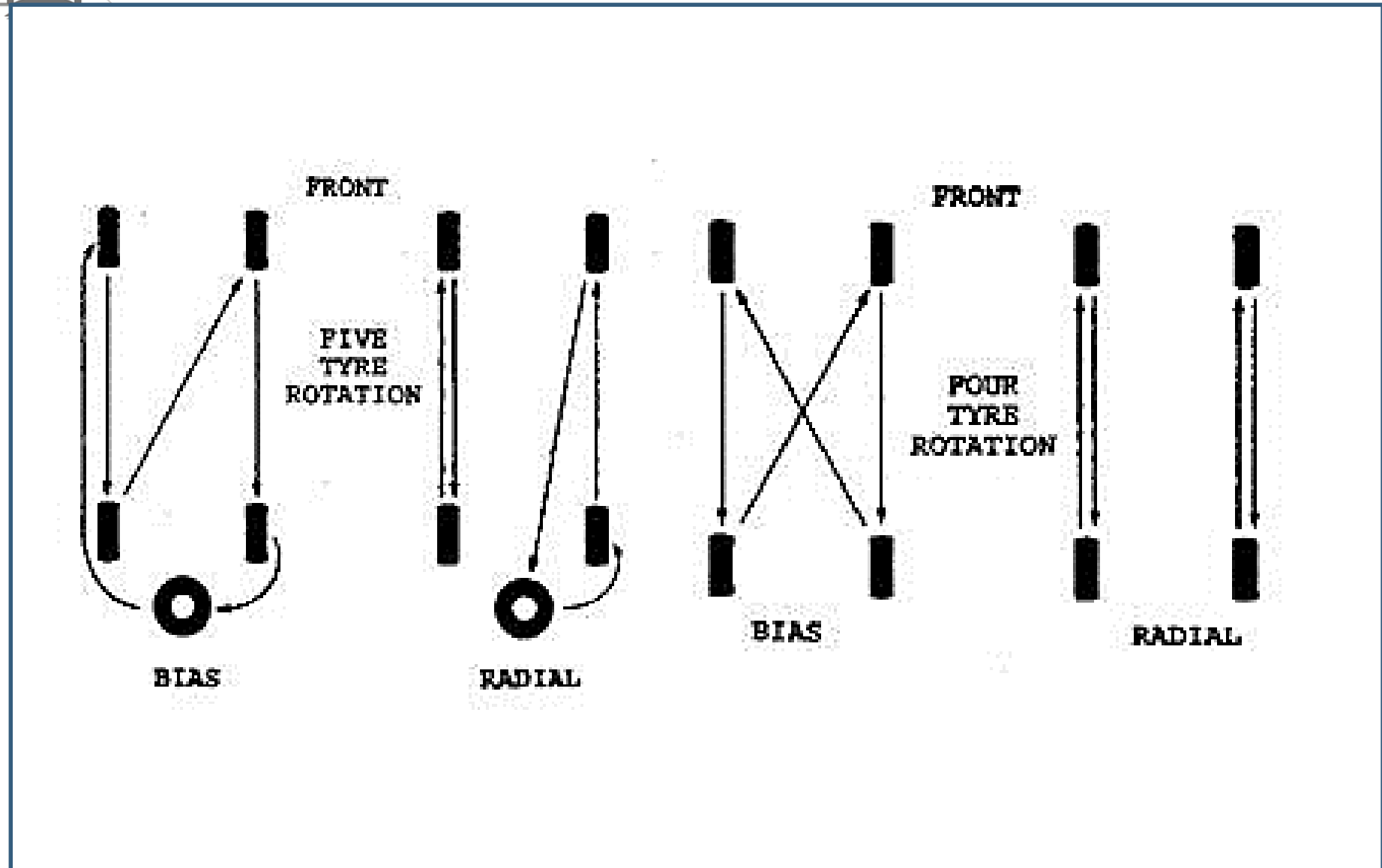
- Figure below illustrates the tread contact with road under under-inflation, over-inflation and proper inflation conditions.
- Normal tyre tread wear is rated at 96.5 kmph. Lower speeds improve tyre life while higher speeds reduce it. The 88.5 kmph speed limit improves tyre life. Tyre life on a set of tyres can be extended by rotating the tyre and wheel position after each 800 km run. This can be doubled for radial tyres.





# ❖ Tyre Rotation:



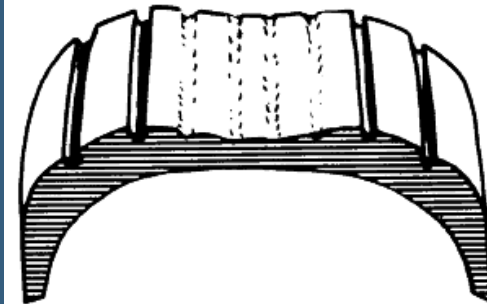




## ❖ Tyre Wear Pattern:

### 1. Over Inflation

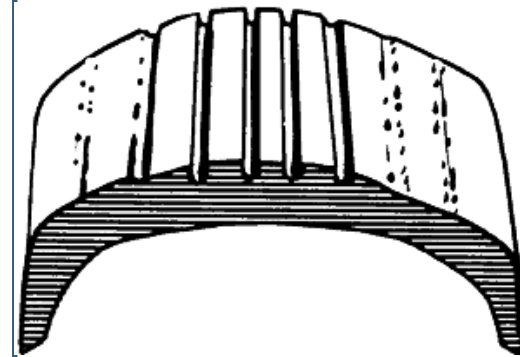
- Excessive wear at the center of the tread indicates that the air pressure in the tire is consistently too high. The tire is riding on the center of the tread and wearing it prematurely.
- Many times, the "eyeball" method of inflation (pumping the tires up until there is no bulge at the bottom) is at fault; tire inflation pressure should always be checked with a reliable tire gauge.
- Occasionally, this wear pattern can result from outrageously wide tires on narrow rims. The cure for this is to replace either the tires or the wheels.





## 2. Under Inflation

- This type of wear usually results from consistent **under inflation**. When a tire is under inflated, there is too much contact with the road by the outer treads, which wear prematurely.
- Tire pressure should be checked with a reliable pressure gauge. When this type of wear occurs, and the tire pressure is known to be consistently correct, a bent or worn steering component or the need for wheel alignment could be indicated.
- **Bent steering or idler arms** cause incorrect toe-in and abnormal handling characteristics on turns.

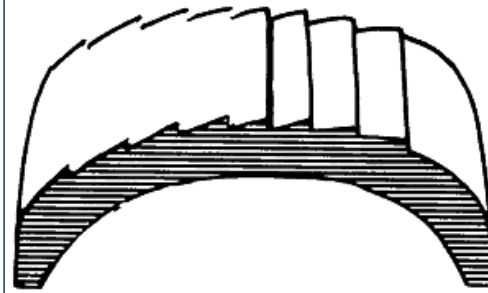






### 3. Feathering

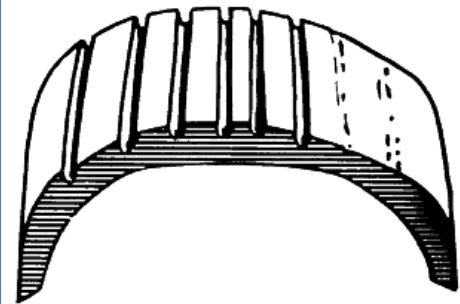
- Feathering is a condition when the edge of each tread rib develops a slightly rounded edge on one side and a sharp edge on the other. By running your hand over the tire, you can usually feel the sharper edges before you'll be able to see them.
- The most common cause of feathering is **incorrect toe-in setting**, which can be cured by having it set correctly. Occasionally toe-in will be set correctly and this wear pattern still occurs.
- This is usually due to deteriorated bushings in the front suspension, causing the wheel alignment to shift as the car moves down the road.





## 4. One Side Wear

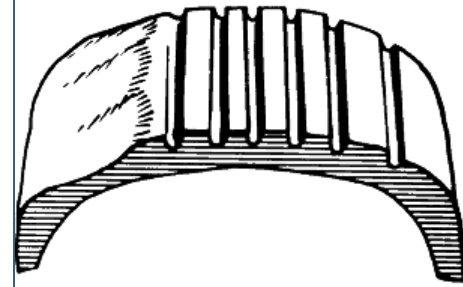
- When an inner or outer rib wears faster than the rest of the tire, the **need for wheel alignment** is indicated. There is **excessive camber** in the front suspension, causing the wheel to lean too much to the inside or outside and putting too much load on one side of the tire.
- The car may simply need the wheels aligned, but misalignment could be due to **sagging springs, worn ball joints, or worn control arm bushings**. Because load has a great affect on alignment, be sure the car is loaded the way it's normally driven when you have the wheels aligned; this is particularly important with independent rear suspension cars.





## 5. Cupping

- Cups or scalloped dips appearing around the edge of the tread on one side or the other, almost always **indicate worn (sometimes bent) suspension parts**. Adjustment of wheel alignment alone will seldom cure the problem. Any worn component that connects the wheel to the car (ball joint, wheel bearing, shock absorber, springs, bushings, etc.) can cause this condition. Worn components should be replaced with new ones.
- The worn tire should be balanced and possibly moved to a different location on the car. Occasionally, wheels that are **out of balance** will wear like this, but wheel imbalance usually shows up as bald spots between the outside edges and center of the tread.





## 6. Toe wear/Camber wear:

- Excessive wear on the inner or outer edge of the tire, known as “toe wear” or, in more extreme cases, as “camber wear,” suggests something may be wrong with the wheel alignment.



Toe Wear



Camber Wear



Cupping Wear



Center Wear



Outer Edge Wear



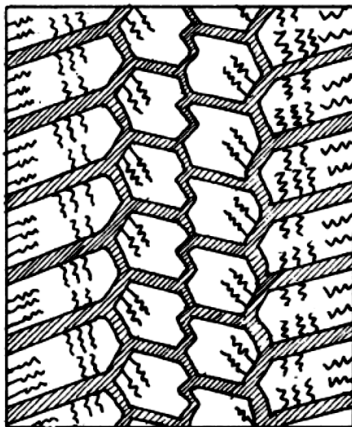
Patchy Wear



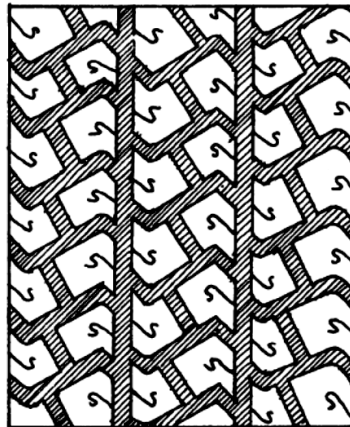
## ❖ Selection of tyres under different applications

### 1. Normal Car Tyres.

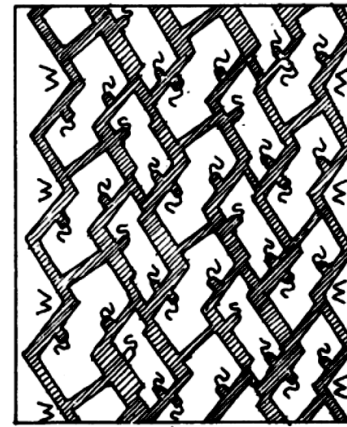
- General duty car tyres, which effectively operate at all speeds use tread blocks arranged in an oblique fashion with a network of surrounding drainage grooves so that both circumferential and lateral water release (Fig. A, B and C) are provided.



(a) Car moderate speed radial



(b) Car high speed radial



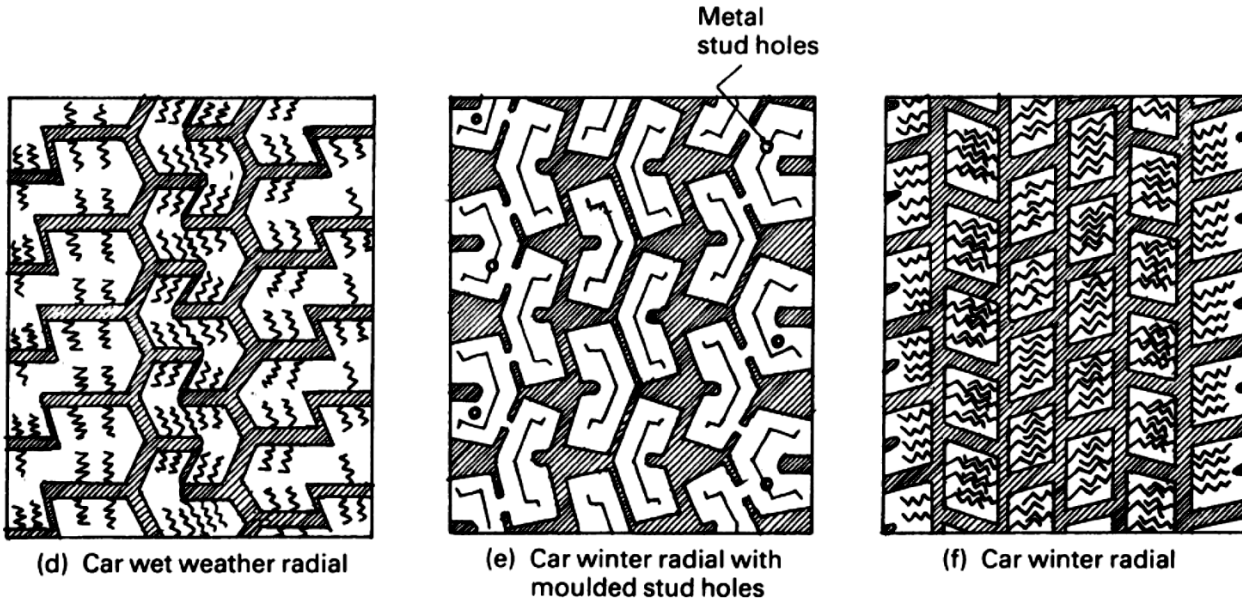
(c) Car very high speed radial





## 2. Wet Weather Car Tyres.

- These car tyres are usually similar to the general duty car tyre except that the tread grooves are made wider to allow easier water dispersion and to provide better exposure of the tread blocks to snow and soft ice without damaging much the tread (Fig. D, E and F).

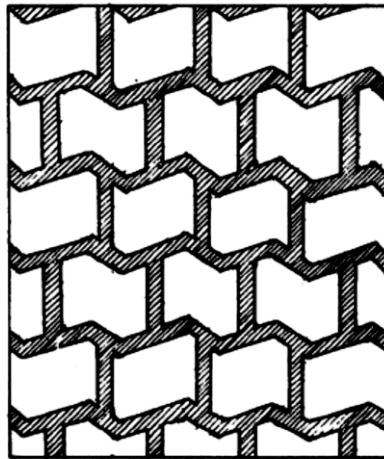




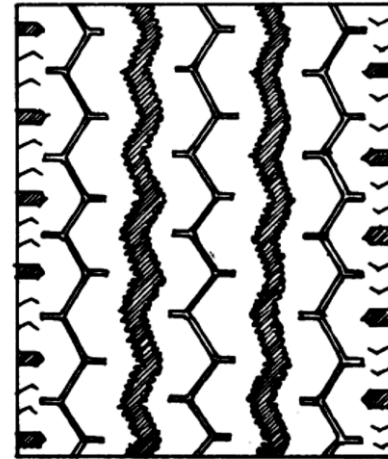


### 3. Truck Tyres.

- Truck tyres designed for steered axles normally use circumferential zigzag ribs and grooves (Fig. G and H) so that very good lateral reaction on curved tracks is available. On the other hand, the drive axle tyre is designed so that tread blocks have adequate grooving for optimum traction grip under both dry and wet conditions. Some of these tyres also incorporate provision for insertion of metal studs for severe winter hard packed snow and ice conditions.



(g) Light vehicle off/on road winter tread



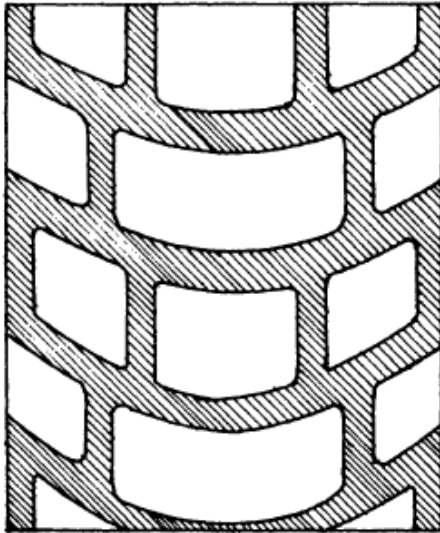
(h) Truck steer axle tread



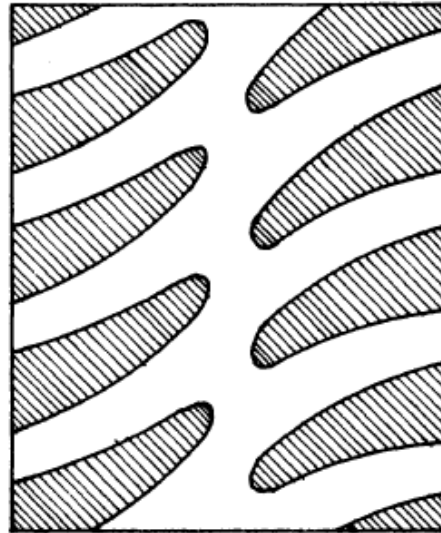
## 4. Off / On Road Vehicles.

- Off/on road vehicle tyres normally use a much simpler bold block treads with a relatively large surrounding groove.
- This arrangement permits each individual block to react independently with the ground causing biting and exerting traction on soil, which may be hard on the surface but soft underneath without break-up of the top layer, so that the tyre is prevented from digging in.
- The tread pattern blocks are also designed sufficiently small to operate on hard road surface without causing excessive ride harshness at moderate speeds.
- Truck and Tractor off Road and Cross-country Tyres. Truck or tractor tyres for off road operation generally use slightly curved rectangular blocks separated with wide grooves, which provide a strong flexible casing as well as present a deliberately penetrating grip.

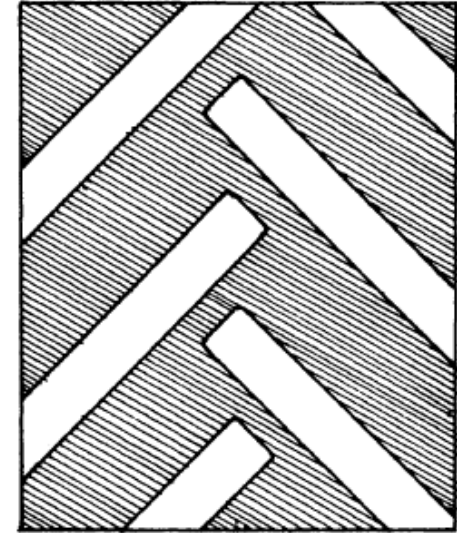
- Cross-country tyres, for operating on soft soil, have diagonal bars either merging into a common central rib or arranged with separate overlapping diagonal bars to provide exceptionally good traction on muddy soil, snow and soft ice (Figs. J, K and L)



(j) Truck rough ground tyre



(k) Truck cross-country tyre



(l) Tractor cross-country tyre



## ❖ Factors affecting tyre performance

### 1. Inflation Pressure:

- The science and the technology that has gone into producing even the best quality of tyre will go waste if the tyres are not inflated to the recommended pressure – Pressure commensurate to the load carried. The best performance of tyres can only be achieved when the tyre is inflated to the designated pressure based on the load per tyre.
- “Under inflation” or “Over inflation” on the tyre tend to impact tyre life, vehicle handling and safety. There are two factors with weight distribution of the vehicle. One is contact patch and other linked to the tyre wear. This results in heat buildup/tyre temperature and thus loss of tyre life, premature tyre removals, increased rolling resistance and fuel consumption.



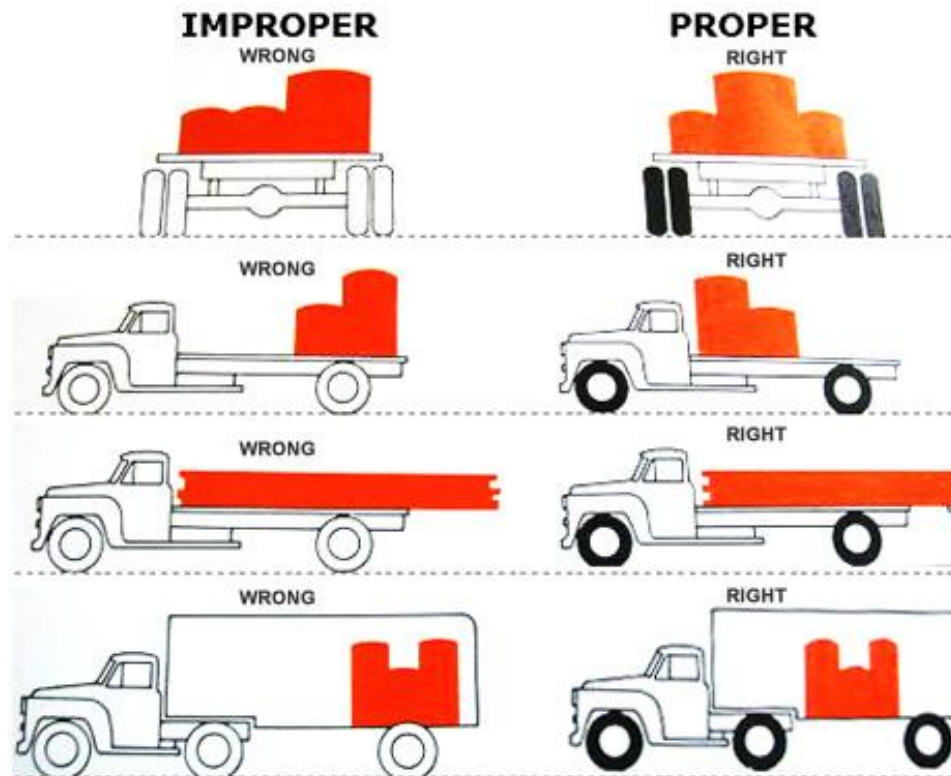


- “Under Inflation” is more common than Over inflation. Tyre users are not always conscious about maintaining or matching tyre pressure to the loads carried.
- In pneumatic tyre the “Air carries the load”. The best tyre performance and lower tyre CPKM are obtained by maintaining correct tyre inflation pressure.
- It is important to remember that the total weight (GVW) carried may not exceed the registered laden weight (RLW) or vehicle passing weight, but one side of the truck or one axle may be severely overloaded due to improper distribution of the load in the pay load platform or loading area.
- Improper load distribution overloads the tyre(s). This condition combines with high speed , long hauls and load transfers result in tyres wearing fast and premature removal of tyres



## 2. Loads and Loading practices

- It is important to remember that even one trip of the truck, with improper load distribution may cause irreversible damage to the tyres.







### 3. Speed

- Excessive high speeds results in increased tyre running temperature. As the rubber gets heated up its modulus (stiffness) gets reduced.
- Rubber being a good non conductor of heat the residual heat is retained causing increased tyre wear and separation of components.

### 4. Wheel Alignment

- A vehicle is said to be properly align when all the steering and suspension components and set as per the vehicle manufacturer and when the tyre wheel assembly are running straight and true.
- Proper alignment is necessary for perfect vehicle control, uniform and even tyre wear and safety.
- Recommended to get the vehicle alignment checked and corrected as per vehicle owner's manual as soon as tyre are wearing unevenly or ride handling problems(vibrations, pulling to one side etc).



## 5. Wheel Balancing

- A wheel which is not properly balanced may setup vibrations which can affect steering control. Wheels, tyres and tubes are usually checked for balance before leaving factory.
- This balance is achieved by positioning weights on the wheel to counterbalance heavy spots on the tyre wheel assembly.
- Properly balanced tyres are important for driving comfort and long tyre life.
- Tyres should be balanced when they are mounted on the wheels for the first time or when they are removed for repair or periodically as per vehicle manufacturer's recommendations.



## 6. Tyre Rotation

- Rotation of tyre in a vehicle is recommended for a uniform tyre tread wear on all wheel position to achieve optimum tyre life.
- It is preferred to rotate tyres as per vehicle manufacturers recommendation or in case of any uneven tyre wear noticed.
- It is suggested to check wheel alignment, wheel balance and suspension before the tyres are rotated. Rotation patterns /pictures to be incorporated.



## Tyre Rotation pattern for normal wear (Tyre rotation only)

Four Tyre Rotation Pattern			Five Tyre Rotation Pattern		
Front Wheel Drive (FF)	Rear Wheel Drive (FR)	Four Wheel Drive (4WD)	Front Wheel Drive (FF)	Rear Wheel Drive (FR)	Four Wheel Drive (4WD)

## Tyre Rotation pattern for one side wear (Tyre rotation after changing the tyre side)

	Four Tyre Rotation Pattern			Five Tyre Rotation Pattern			Procedure
	Front Wheel Drive (FF)	Rear Wheel Drive (FR)	Four Wheel Drive (4WD)	Front Wheel Drive (FF)	Rear Wheel Drive (FR)	Four Wheel Drive (4WD)	
<b>Before Rotation</b>							<p>If one side shoulder wear is found on outer or inner shoulder, remove the tyre from the rim and change side of the tyre, after that do the tyre rotation.</p>
<b>After Rotation</b>							



## 7. Road Conditions:

- Vehicle /tyre operating conditions which significantly influence tyre life both in terms of new tyre life and structural durability.
  - Rough/abbrasive road surface
  - Paved road
  - Straight road
  - Broken up roads
  - Hilly windings roads
  - Unmade country roads





## 8. Driving habits

- Careful driving habits will ensure optimum tyre life, unavoidable damages besides avoiding serious road accidents. Some of the habits which cause serious damages to tyre and road accidents are:
  - Over speeding
  - Speeding over pot holes, stone etc.
  - Quick starts and sudden stops
  - Riding over road divider and other obstacles
  - Sharp turns at high speeds
  - Hitting the road, curbs, objects etc.
  - Running on improperly inflated tyres



## 9. Seasonal Effects

- Climatic and whether conditions in our country varies widely from region to region. Dry and extremely hot during summer, extreme cold during winter and rains during monsoon.
- This variation in climatic conditions influence tyre life in terms of mileage and structural durability.

## 10. Do's and Don'ts

- Tyre Pressure checks including the spare tyre must be done regularly at least once in two weeks.
- Tyre pressure should be checked using an accurate pressure gauge.
- Tyre pressure should be checked when tyres are cold.
- Under inflation and over inflation will cause rapid tread wear and premature tyre failures.
- Tyre pressure should always be maintained as per the vehicle manufacturers recommendations, mentioned at information placard, at door, owners manual.

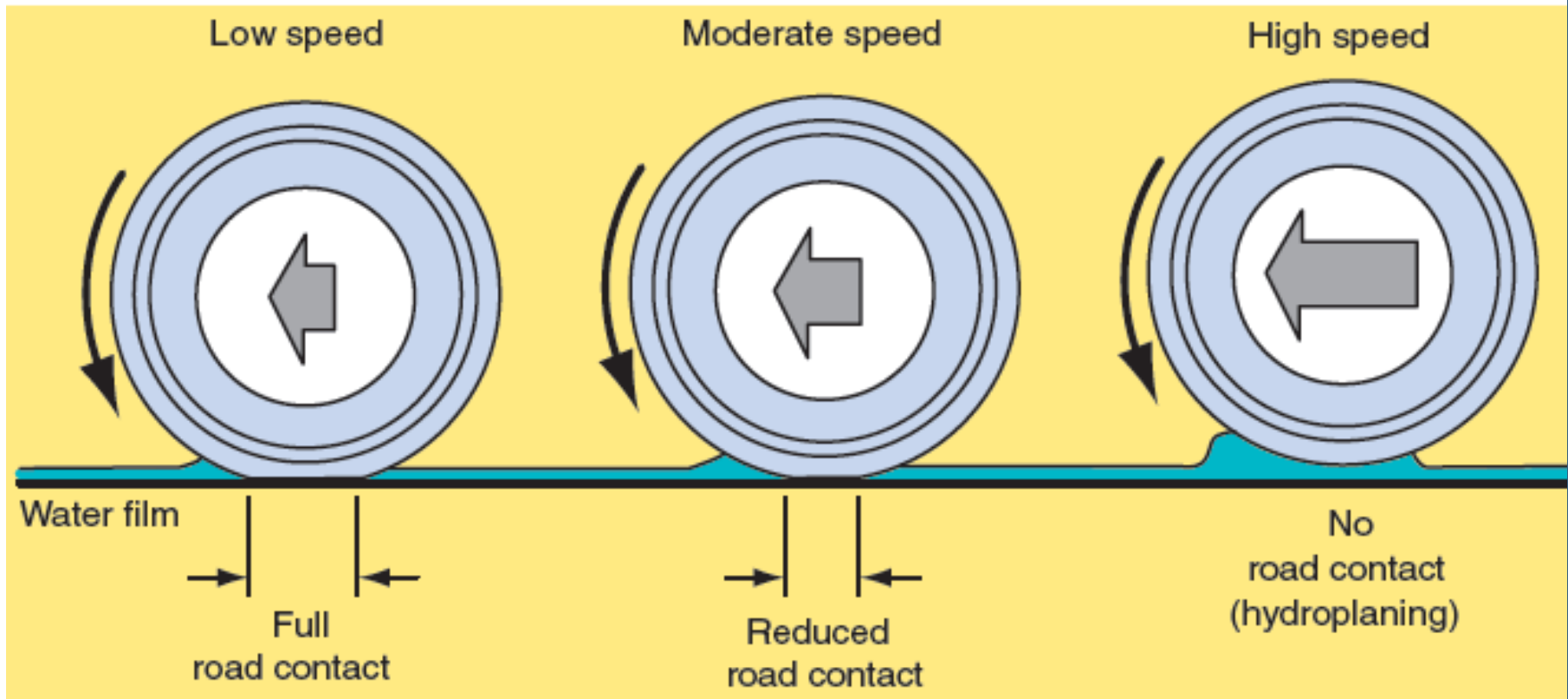


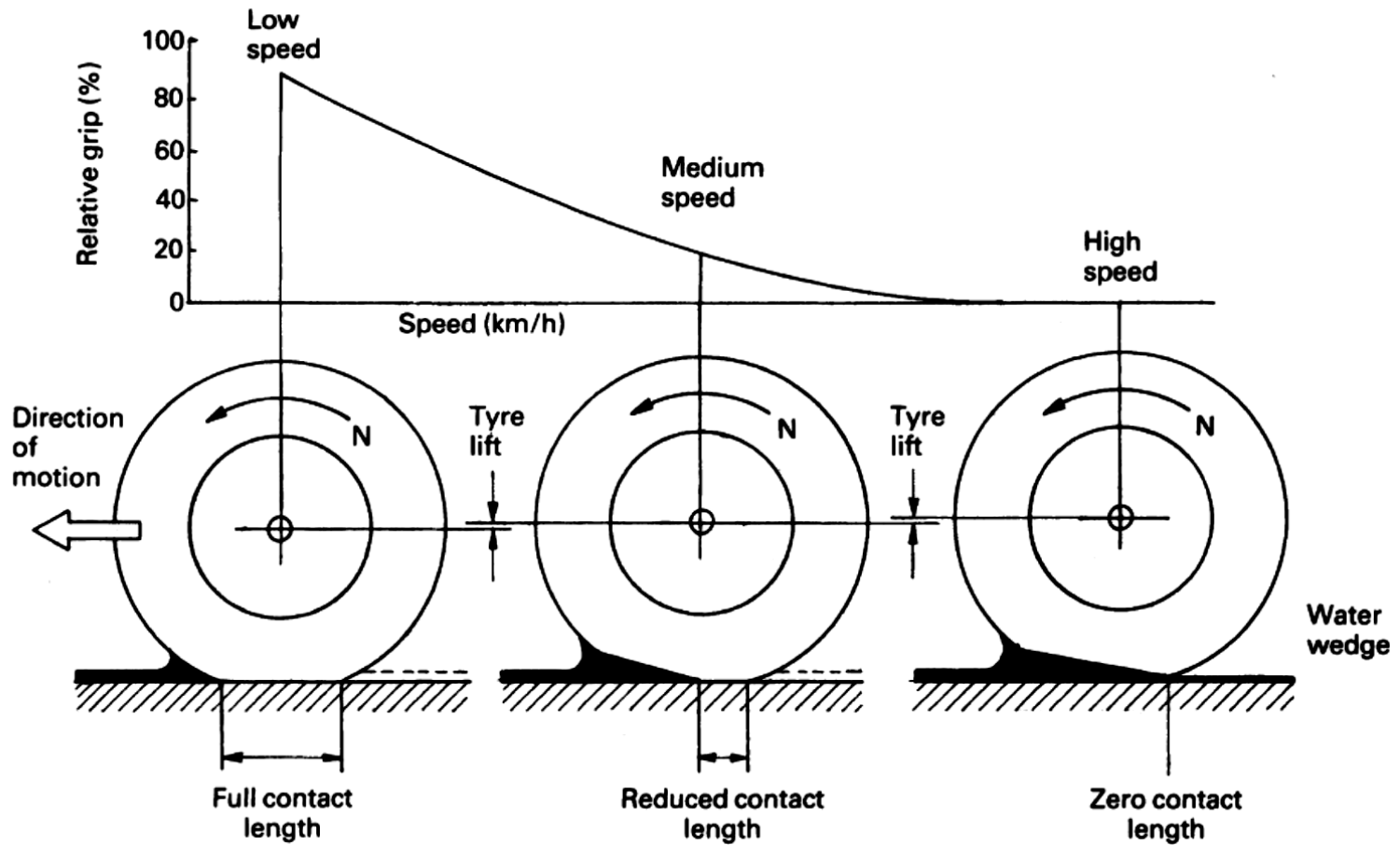
## ❖ Aquaplaning (Hydroplaning)

- Direction or speed change relies on friction between the tyres and the road surface.
- Grooves of a rubber tyre are designed to disperse water from under the tyre, providing high friction even in wet conditions.
- Aquaplaning occurs when a tyre encounters more water than it can dissipate
- Steering appears light as if we are driving with wheels in air
- Water pressure in front of the wheel makes a wedge of water under the leading edge of the tyre, causing it to lift from the road.
- This loss of traction causes the wheels to slip and prevents the vehicle from responding to steering, braking or accelerating. As a result, the vehicle can go out of control, start to skid or spin.
- Risk of aquaplaning increases with the depth of standing water
- If multiple tyres aquaplane, the vehicle loses directional control and slide until it either collides with an obstacle, or slows down so that friction is regained.



- Tyre tread wear: Worn tyres will aquaplane more easily due to lack of tread depth.
- Tyre inflation pressure: Under inflation enhances aquaplaning
- Tyre tread aspect ratio: Longer and thinner the contact patch, less likely a tyre is of aquaplaning. (Small diameter and wide tyres are more prone to aquaplaning)
- Vehicle weight: More weight on a properly inflated tyre increases the contact patch. Weight can have the opposite effect if the tyre is underinflated.
- Vehicle type: Combination vehicles like semi-trailers are more likely to experience uneven aquaplaning caused by uneven weight distribution **SOLUTION:** If aquaplaning is encountered (steering feels disconnected), **DO NOT** brake, accelerate, or steer the vehicle. Allow the speed to reduce on its own







## ❖ Braking System:

- The function of the braking system is to retard the speed of the moving vehicle or bring it to rest in a shortest possible distance whenever required.
- The vehicle can be held on an inclined surface against the pull of gravity by the application of brake. Brakes are **mechanical devices for increasing the frictional resistance that retards the turning motion of the vehicle wheels.**
- It absorbs either kinetic energy or potential energy or both while remaining in action and this absorbed energy appears in the form of heat.
- While moving down a steep gradient the vehicle is controlled by the application of brakes. In this case brakes remain in action for a longer period making it imperative to dissipate the braking heat to atmosphere as rapidly as possible





- Automobiles are fitted with two brakes; **the service or foot brake and the emergency or hand brake.** The foot brake is used to control the speed of the vehicle and to stop it, when and where desired, by the application of force on the brake pedal.
- The hand brake, applied by a lever, is used to keep the vehicle from moving when parked. **Hand brakes are called emergency brakes** because **they are applied when the service brake fails.**
- Virtually all vehicles are now equipment with 4-wheel brakes. The front brakes must operate without interfering with the steering action.
- The brakes must be capable of decelerating a vehicle at a faster rate than the engine is able to accelerate it. Normally brakes have to **absorb three times the amount of engine horsepower** energy in its equivalent form.



## ❖ **Functions of Braking System**

- To stop the vehicle safely in shortest possible distance in case of emergency.
- To control the vehicle when it is descending along the hills.
- To keep the vehicle in desired position after bringing in at rest.



## ❖ Requirements of Braking System

1. Brakes must be strong enough to stop vehicle with in a minimum distance in an emergency.
2. Brakes must have good anti-fade characteristics i.e. their effectiveness should not decrease with prolonged application. This requirement demands cooling of brakes should be very efficient.
3. The retardation should be smooth and free from jerk or shudder.
4. Not to be affected by water, heat, road grit and dust etc.
5. Permit the operator to retain control of the vehicle must not skid when brakes are applied
6. Adequate durability with economical maintenance and adjustment
7. High reliability and highest degree of safety on road




## ❖ **Brake Force Required to Stop the Vehicle :**

- A vehicle with a 100 hp engine require about 60 sec to accelerate the vehicle from 0 to 100 kmph. If the same vehicle is required to be stopped from 100kmph to 0 kmph in not more than 6 sec then brakes must do the same amount of work as engine did but in one tenth of the time. This means brakes must develop 1000 hp to stop the vehicle .
- **If the weight of the vehicle is doubled then brake power must be doubled.**
- **If the speed of the vehicle is doubled then stopping power must be four times.**
- **If both weight and speed is doubled then brake power must be increased 8 times.**

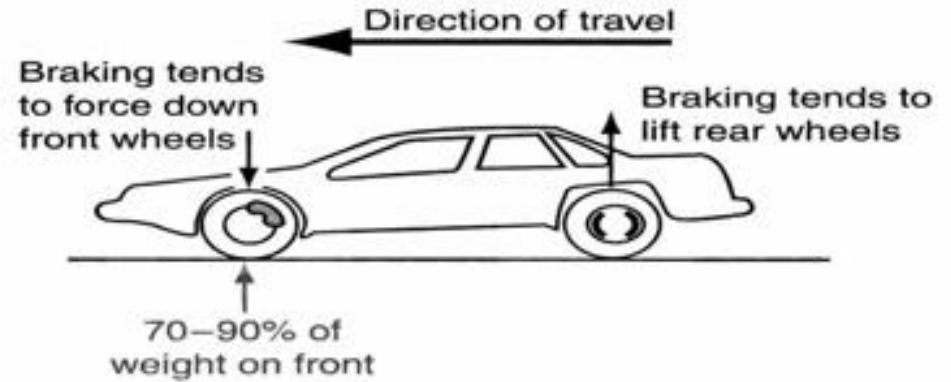


2,000 pounds  = 60,200 foot pounds of energy  
30 mph →

4,000 pounds  = 120,400 foot pounds of energy  
30 mph →

2,000 pounds  = 60,200 foot pounds of energy  
30 mph →

2,000 pounds  = 240,802 foot pounds of energy  
60 mph →





## ❖ Capacity of a Brake :

- Unit pressure between the braking surfaces.
- Coefficient of friction between the braking surfaces.
- Projected area of the braking surfaces.
- Peripheral velocity of the brake drum.
- Ability of the brake to dissipate heat equivalent to the energy being absorbed



## ❖ Braking Fundamentals

- Kinetic energy is the force that keeps the vehicle moving. This energy is provided by the engine in order to accelerate the vehicle from a standstill to desired speed. Kinetic energy is dissipated as heat by the brakes during application of breaks (Fig.). The kinetic energy of a vehicle during braking is given by

$$KE = (1/2) (W/g) (U^2 - V^2) = (1/2) M (U^2 - V^2)$$

where,  $W$  = vehicle gross weight, N

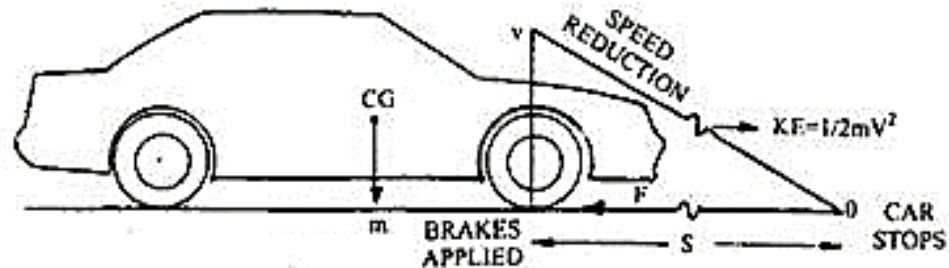
$U$  = initial velocity, m/s

$V$  = final velocity, m/s

$M$  = Mass of the vehicle, kg

$g$  = acceleration due to gravity,  $m/s^2$

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







## ❖ Coefficient of Friction.

- Frictional force opposes the motion of the vehicle. Consequently it consumes power and produces heat. Frictional force occurs between the sliding tire and the road surface when wheel rotation is locked by brakes.
- The ability of a vehicle to stop depends on the coefficient of friction between the contacting surfaces. 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 upon the **coefficient of friction of the brake materials, brake diameter, brake surface area, shoe geometry, and the pressure used to actuate the brake**. Stopping a car suddenly means very high friction, resulting in high brake temperature.



$$F_R = \mu R$$

- The value of Coefficient of friction depends on several factors:
  - Road surface condition.
  - Tyre tread pattern.
  - Inflation pressure (Correct, over or under –inflated.)
  - Material of road surface.



## ❖ Brake Balance

- The braking of a vehicle occurs at ground level, so effective 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 the rear wheels to the front wheels. Consequently, the front brakes must absorb more kinetic energy than the rear brakes. 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,

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

where  $W_t$  = weight transferred, N

$\mu$  = coefficient of friction

$h$  = height of C.G. from the ground, m

$W$  = vehicle gross weight, N

$b$  = wheel base, m

$f$  = deceleration of the vehicle,  $m/s^2$

$g$  = acceleration due to gravity,  $m/s^2$



- This weight is added to the static weight on the front wheels and subtracted from the static weight on the rear wheels.
- The front wheel static weight is normally 55% of the vehicle weight. Front brakes are designed to absorb this extra brake effort by selecting shoe-drum or shoe-disc, combination type, brake size, lining coefficient of friction, wheel cylinder size and differential hydraulic actuating pressures.
- 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 to not spin out.



- Example.** A vehicle has its wheel base equal to 3 times the height of its CG above the ground. If the vehicle is braked on all four wheels over a road whose adhesion factor is 0.6, determine the weight transferred from the rear to front wheels.

**Solution. Given,**  $b = 3h$

$$\mu = 0.6$$

**For four wheels braking,**  $f = \mu g$

**Therefore weight transfer to front wheel amounts to**

$$W_t = \frac{\mu h}{b} \cdot \frac{f}{g} \cdot W = \frac{0.6h}{3h} \cdot \frac{\mu g}{g} \cdot W = \frac{0.6 \times 0.6}{3} W = 0.12 W$$

**Therefore, % of weight transfer =  $(W_t/W) \times 100 = 12\%$  Ans.**



## ❖ Stopping Distance

- Stopping distance is extremely important for emergency braking. The stopping distance is based on the deceleration rate.
- Also, it is affected by the tyre deflection, air resistance, braking efforts and the inertia of the driveline.
- Distance travelled by the vehicle during application of brake can be obtained from the following equations of motion assuming the brake efficiency as 100%.

$$S = Ut - (1/2)ft^2 \text{ and } V^2 - U^2 = -2fS$$

where,  $S$  = distance moved by vehicle, m

$U$  = initial velocity of vehicle, m/s

$V$  = final velocity of vehicle, m/s

$t$  = duration of application of brake, s

$f$  = deceleration of the vehicle,  $m/s^2$



- If the vehicle comes to stand still due to application of brake, the final velocity,  $V = 0$  in the above equations, then stopping distance,  $S$  is given by the relations,  $S = U^2 / 2f$ .
- The stopping distance remains same with the same tyre and road conditions, when the wheels are locked and skidding, regardless of the weight, number of wheels or vehicle load.
- Maximum braking force occurs when the wheels are braked just before the locking point or point of impending skid. Non-skid brake systems are designed to operate at or below this point. Any changes in load on a wheel changes the point of impending skid.





- **Example.** Calculate the minimum stopping distances for a vehicle travelling at 60 km/hr with a deceleration equal to the acceleration due to gravity.

**Solution.**

$$S = \frac{U^2}{2f}$$

$$U = 60 \text{ km/hr} = \frac{60}{3.6} \text{ m/s}$$

$$f = 9.81 \text{ m/s}^2$$

Therefore,

$$S = \left[ \frac{60}{3.6} \right]^2 \frac{1}{2 \times 9.81} = \frac{60 \times 60}{3.6 \times 3.6 \times 2 \times 9.81} = 14.4 \text{ m Ans.}$$



## ❖ Brake Fade

- Since brake lining material is a poor conductor of heat, most of the heat goes into the brake drum or disc during braking. Under severe use, brake drums may reach **590 K temperatures**.
- The coefficient of friction between the drum and lining is much lower at these high temperatures so that additional pedal pressure is required. After a number of severe stops or after holding the brakes on a long down hill grade, a point is eventually reached when the **coefficient of friction drops so low that little braking effect is available**. This condition is called **brake fade**.
- In drum brakes, the lining covers a large portion of the internal drum surface so that a little cooling space is available. Therefore, drum brakes are more susceptible to fade than disc brakes. As the vehicle moves, cooling air is directed around the drum and disc to remove brake heat.



- **The maximum brake torque that can be absorbed by the lining or pad depends on the size and type of brake, gross vehicle weight, axle loading, the front to rear braking ratio and maximum attainable speed.**
- **The drum and disc expansion due to brake temperature is another factor for brake fade. The diameter of the drum increases as it gets hot. The shoe no longer matches the drum and hence lining-to-drum contact surface becomes smaller.**
- **The same stopping force requires higher pedal pressure and this in turn increases the temperature on the smaller contact surface.**
- **Continued braking increases the problem until the braking becomes ineffective, regardless of the pedal force.**



- On the other hand, expansion of **disc has little effect on braking** because **the pads apply braking force on the side of the disc** and hence **braking surface area remains constant**. Leading shoes are more susceptible to fade than trailing shoes.
- Fade-resistant drum brakes must limit brake shoe arc to 110 degrees and power absorption to 28370 kW/m\* of lining. The power absorbed by the brakes during a stop can be calculated as,

$$P = \frac{KE}{1000 t}$$

where,  $P$  = power absorbed, kW

$KE$  = kinetic energy, Nm or J

$t$  = time, s



## ❖ Brake Torque

- **The braking torque is the twisting action caused by the drum or disc on the shoes or caliper anchors during the application of brakes.**
- **The amount of torque is determined by the effective axle height and stopping force between the tyre and road surface.**
- **Brake torque on the front wheels is absorbed by the knuckle and suspension control arm. In rear, it is absorbed by the axle housing and the leaf spring or control arm.**
- **Braking torque during an emergency stop is much higher than accelerating torque at full throttle. Brake supporting and anchoring members must, therefore, have sufficient strength to withstand these high braking loads.**



## ❖ Brake Safety.

- All automobiles are equipped with an emergency brake that would operate independently from the service brakes.
- Safety standard require the emergency brake to hold the automobile on a 30% slope indefinitely after the brake has been applied until the operator releases it.



## ❖ Work Done in Braking

- The kinetic energy possessed by a moving vehicle depends on the weight and speed of the vehicle. This energy must be partially or totally dissipated when the vehicle is slowed down or brought to a standstill. 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 the vehicle is given by the equation,  $K_E = (1/2) MU^2$

where  $K_E$  = kinetic energy of vehicle,

$M$  = mass of vehicle, kg

$U$  = speed of vehicle, m/s.

The work done in bringing the vehicle to rest is given by  $W_D = FS$

where  $W_D$  = work done, J

$F$  = average braking force, N

$S$  = distance traveled, m

When braking a moving vehicle to a standstill, the work done by the brake drums must equal the initial kinetic energy possessed by the vehicle so that

$$K_E = W_D$$

or 
$$FS = (1/2) MU^2.$$

Therefore, average brake force, 
$$F = \frac{MU^2}{2S}, N$$





- **Example.** A car of mass 800 kg is travelling at 36 kmph. Determine (a) the kinetic energy it possesses, and (b) the average braking force to bring it to rest in 20 meters.

**Solution.**

(a) 
$$U = \frac{36 \times 1000}{60 \times 60} = 10 \text{ m/s}$$

Kinetic energy =  $(1/2) MU^2 = (1/2) \times 800 \times 10^2 = 40 \text{ kJ. Ans.}$

(b) Work done to stop car = change in vehicle's kinetic energy

$$FS = (1/2) MU^2$$

$$20 F = 40000$$

$$F = \frac{40000}{20} = 2000 \text{ N} = 2 \text{ kN. Ans.}$$



## ❖ Braking Efficiency

- The force applied during braking of a vehicle opposes the motion of the wheels, as a result reduces the vehicle speed or brings it to a standstill. Therefore the braking force is the force of resistance applied to stop a vehicle or reduce its speed. The braking efficiency of a vehicle is defined as the braking force produced as a percentage of the total weight of the vehicle. Thus,

$$\text{Braking efficiency, } \eta = \frac{\text{Braking force}}{\text{Weight of vehicle}} \times 100.$$

- The braking efficiency is generally less than 100% because of insufficient road adhesion, the vehicle is on a down gradient or ineffective brake system. The brake efficiency is similar to the coefficient of friction, which is the ratio of the frictional force to the normal load between the rubbing surfaces.



$$\text{Coefficient of friction} = \frac{\text{Friction force}}{\text{Normal load}}$$

or 
$$\mu = \frac{F}{R}$$

Therefore, 
$$\eta = \frac{F}{R} = \mu$$

where,  $\mu$  = coefficient of friction

$\eta$  = brake efficiency

$F$  = friction force, N

$R$  = normal load, N

Thus a braking efficiency of 100% is equal to a coefficient of friction of one.

i.e. 
$$\eta (100\%) = \frac{F}{R} = \mu = 1.$$

The brake efficiency can be derived from the kinetic energy possessed by the vehicle and the work done in bringing the vehicle to standstill.

Let

- $F$  = Braking force, N
- $\mu$  = coefficient of friction
- $W$  = vehicle weight, N
- $U$  = initial braking speed, m/s
- $M$  = vehicle mass, kg
- $S$  = stopping distance, m
- $\eta$  = brake efficiency.



Then equating work and kinetic energy,  $FS = (1/2) MU^2$

But 
$$M = \frac{W}{g}$$

Hence 
$$FS = \frac{WU^2}{2g}$$

or 
$$S = \frac{WU^2}{2Fg}$$

But 
$$\frac{F}{W} = \mu = \eta.$$

Thus, stopping distance, 
$$S = \frac{U^2}{2g \eta}$$

Therefore, braking efficiency, 
$$\eta = \frac{U^2}{2gS} \times 100$$

To convert m/s to kmph,

$$U \text{ (m/s)} = \frac{1000}{60 \times 60} U = 0.28 U \text{ (km/h)}$$

Hence 
$$\eta = \frac{(0.28 U)^2}{2 \times 9.81 S} \times 100 = 0.4 \frac{U^2}{S} \%$$



- **Example.** Determine the braking efficiency of a vehicle if the brakes bring the vehicle to rest from 60 kmph in a distance of 15 meters.

**Solution.**

$$\eta = \frac{0.4 U^2}{S} = \frac{0.4 \times 60^2}{15} = 96\%. \text{ Ans.}$$



## ❖ 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 the adhesive force. This force can be determined from the expression :

$$\text{Adhesive force} = \text{Load on wheel} \times \text{Coefficient of friction}$$

- When the limit is reached, the wheel starts to skid, and any extra force on the brake shoe does not increase in the rate of slowing down the vehicle, no matter how good is the braking system. This means that the adhesion between the tyre and road is the governing factor for the minimum stopping distance.



- Road adhesion depends on :
  - Type of road surface.
  - Conditions of surface e.g. wet, dry, icy, greasy, etc.
  - Designs of tire tread, composition of tread material and depth of tread.
- The stopping distance of a wheel is greatly affected by the interaction of the rotating tyre tread and the road surface. The relationship between the decelerating force and the vertical load on a wheel is known as the adhesion factor. This factor is very similar to the coefficient of friction, that occurs when one surface slides over the other. In the **ideal situation of braking, the wheel should always rotate right up to the point of stopping to obtain the greatest retarding resistance.**





- Typical adhesion factors for various road surfaces are presented in Table.

**Table 28.1. Adhesion factors for various road surfaces.**

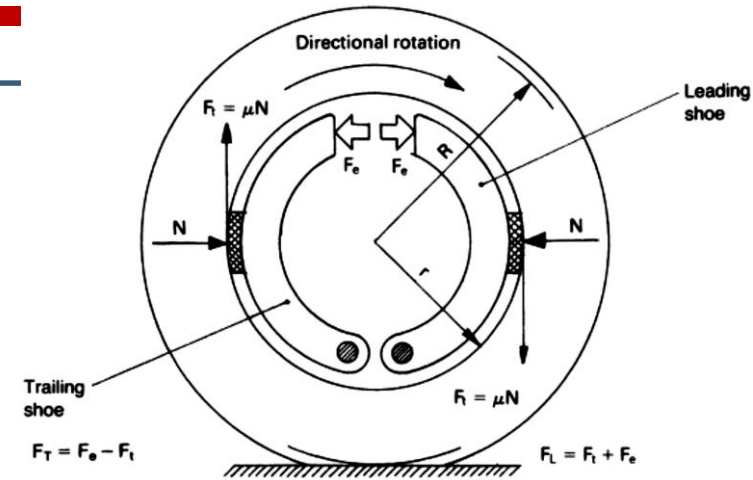
No.	Road Surface	Adhesion Factor
1	Concrete, coarse asphalt dry	0.8
2	Tarmac, gritted bitumen dry	0.6
3	Concrete, coarse asphalt wet	0.5
4	Tarmac wet	0.4
5	Gritted bitumen tarmac wet	0.3
6	Gritted bitumen tarmac greasy	0.25
7	Gritted bitumen, snow compressed dry	0.2
8	Gritted bitumen, snow compressed wet	0.15
9	Ice wet	0.1

- It is a common thinking that the shortest stopping distance is achieved when the wheel is locked to produce a skid. This idea is incorrect because experiments have confirmed that the force required to ‘unstick’ a tyre is greater than the force required to skid it over the surface. A wheel held on the verge of skidding not only provides the shortest distance, but also allows the driver to maintain directional control of the vehicle.



## ❖ Self-energization Brake

- When the drum is rotating clockwise and the upper tips of the shoes are pushed apart by the expander force  $F_e$ , a normal inward reaction force  $N$  will be provided by the drum which resists any shoe expansion.
- As a result of the drum sliding over the shoe lining, a tangential frictional force  $F_t = \mu N$  will be generated between each pair of the rubbing surfaces.
- The friction force or drag on the right hand shoe tends to move in the same direction as its shoe tip force  $F_e$  producing it and accordingly helps to drag the shoe onto the drum, thereby effectively raising the shoe tip force above the that of the original expander force.



**Fig. 11.2** Drum and shoe layout



- The increase in shoe tip force above that of the input expander force is described as positive servo, and shoes which provide this self-energizing or servo action are known as leading shoes.
- i.e.  $F_L = F_e + F_t$   
where  $F_L$  = leading shoe tip resultant force
- Likewise considering the left hand shoe the frictional force or drag  $F_t$  tends to oppose and cancel out some of the shoe tip force  $F_e$  producing it.
- This causes the effective shoe tip force to be less than the expander input force. The resultant reduction in shoe tip force below that the initial input tip force is described as negative servo and shoe arrangements which have this de-energizing property are known as trailing shoes.
- i.e  $F_T = F_e - F_t$



- **The magnitude of the self-energizing action is greatly influenced by the rubbing surface temperature, dampness, wetness, coefficient of friction and speed of drum rotation.**
- Changing the direction of rotation of the drum causes the original leading and trailing shoes to reverse their energizing properties, so that the leading and trailing shoes now become trailing and leading shoes respectively.



## ❖ Classification of Brakes

### 1. By method of power

- a) Mechanical brakes
- b) Hydraulic brakes
- c) Air brakes
- d) Vacuum brakes
- e) Power assisted hydraulic brakes
- f) Magnetic brakes
- g) Electrical brakes

### 2. By method of application:

- a) Service or foot brakes
- b) Parking or hand brakes



### **3. By method of operation:**

- a) Manual
- b) Servo
- c) Power operation

### **4. By method of Braking contact**

- a. Internal Expanding Brakes
- b. External Contracting Brakes

### **5. By Method of Applying Brake force:**

- a. Single Acting Brakes.
- b. Double Acting Brakes.



## ❖ Mechanical Brakes:

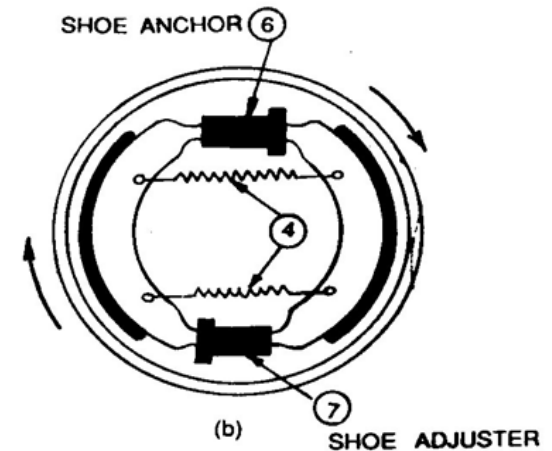
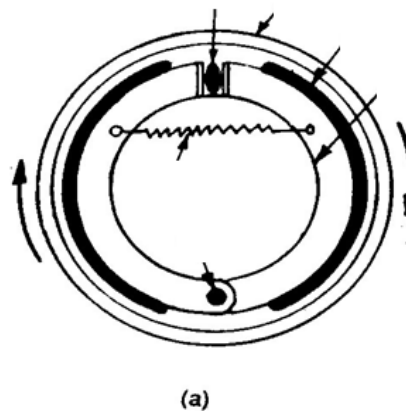
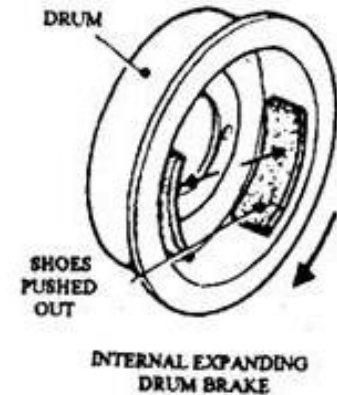
- The two main types of mechanical brake are drum brake and disc brake.
  - In both types a fixed (non-rotating) shoe or pad rubs against a moving drum or disc.
  - To increase the friction between the rubbing surfaces, a special friction material is attached to the fixed part.
  - Earlier this friction material had a high content of asbestos, but its dust is injurious to health so that a safe asbestos free friction material is nowadays used.
1. Drum Brakes (Internal Expanding or External Contracting)
  2. Disc Brakes



## ❖ Drum Brakes:

The main components of drum brakes are

1. Brake drum
2. Back plate
3. Brake shoes
4. Brake Liners
5. Retaining Springs
6. Cam
7. Brake Linkages

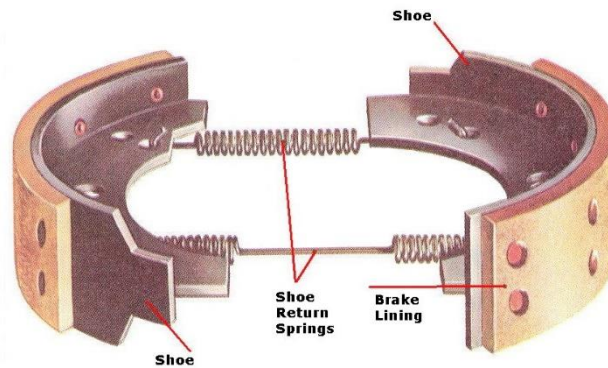
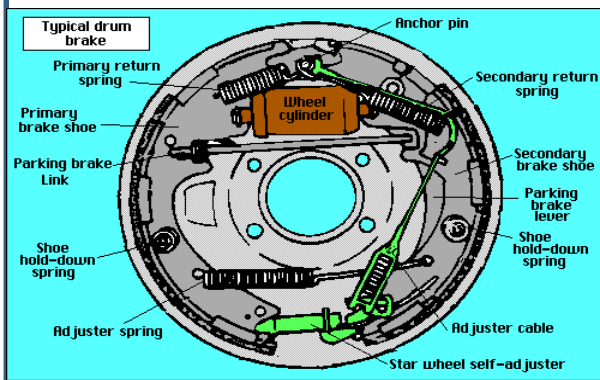




- This internal expanding type of brake contains two shoes that are attached to a back-plate and are fixed to a stub axle or axle tube.
- A friction lining is riveted or bonded to the outer face of the shoe. A drive is fitted at one end of the shoe so that the shoe expands when the brake pedal is applied. In a simple brake a cam is used as a shoe expander, but modern systems for cars use hydraulically operated pistons for shoe expansion.
- The shoe anchor is rigidly attached to the back-plate and takes the form of a large pin that passes through the shoes, or housing. The shoes butt against the anchor. Springs pull the brake shoes on the back-plate and also return the shoes to the 'off position after the brake has been applied.
- In some layouts separate springs execute the retention and return functions.



- The inner cylindrical surface of the cast iron drum is made smooth on to which the brake linings rub. The drum is generally fixed to the hub flange using counter-sunk screws and secured by the wheel nuts.
- It is necessary to adjust excessive clearance due to wear of the friction facing, so that they are always positioned very close to the drum. This is carried out either manually adjusting the brakes periodically, or having an automatic adjuster that continually sets the shoes.





## ❖ Brake Layouts

- There are two types of drum brakes, such as externally contracting and internally expanding.
- The internal expanding type, along with a drum, is commonly used in braking systems of vehicles. The drum brakes, used with light vehicles, are hydraulically operated.
- These brakes are commonly used for the rear wheels to complement a disc system at the front. This disc/drum layout permits the front wheels to undertake more braking effort.
- In addition, the compatibility of a mechanical hand-brake with a drum brake makes this type an obvious option for rear brakes.
- **Various shoe arrangements in use include :**
  - Leading and trailing shoe (L&T)
  - Two leading shoe (2LS)
  - Duo-servo.



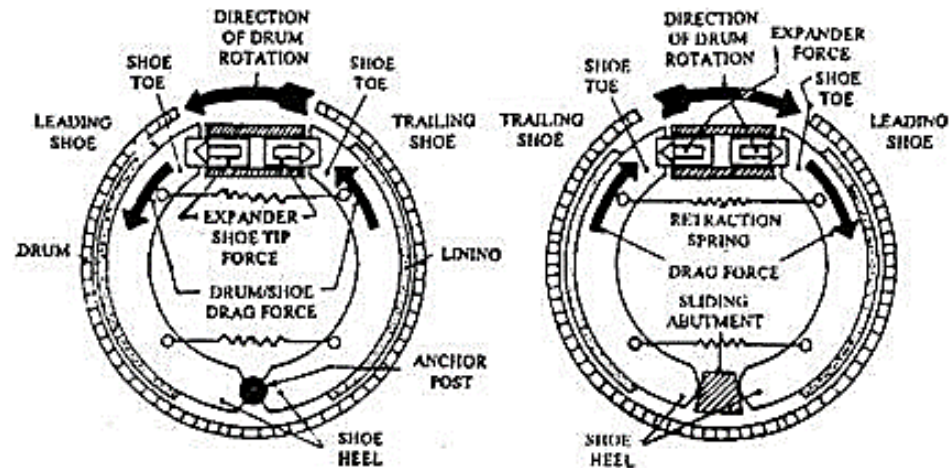
## ❖ Leading and Trailing Shoe (L&T)

- The layout of a leading and trailing shoe brake is presented in Fig. below. This arrangement uses a pair of shoes pivoted at a common anchor point. The free ends of both shoes are radially forced against the inside surface of the brake-drum using a double piston/cylinder expander.
- When the brake is applied with the vehicle stationary, hydraulic pressure pushes each shoe outwards and an equal force is applied by each shoe to the drum. But this applied force does not remain equal when the vehicle is moving (Fig. A below).
- The drag of the moving drum on the friction linings causes one shoe to be applied hard and the other to be pushed towards the 'off position'.





- The shoe that does more work is called the leading shoe, and the other shoe is called the trailing shoe. The rate of lining wear of leading shoe is higher as it does more work than the trailing shoe.
- Therefore, leading shoe reaches its wear limit well before the trailing shoe, unless a thicker lining is used. If the direction of the drum is reversed, the leading shoe, however, is converted into a trailing shoe.
- The unequal wear pattern can be taken up by the floating pistons in the wheel cylinder in some layouts as shown in Fig. A. Otherwise, some provision is incorporated to adjust the brake shoes so that they are always centralized with respect to the drum





## ❖ Two Leading Shoe Brake (2LS)

- The 2LS system was in use for front brakes of vehicles before the adoption of the disc system. Each shoe of the 2LS arrangement uses its own expander; therefore both shoes can have self-servo action (Fig.28.17).
- An interlinking pipe fitted behind the back-plate provides an equal hydraulic pressure to each single-acting cylinder.
- Since the cylinder housings act as shoe anchors for the floating shoes, the cylinders are rigidly fixed to the back-plate.

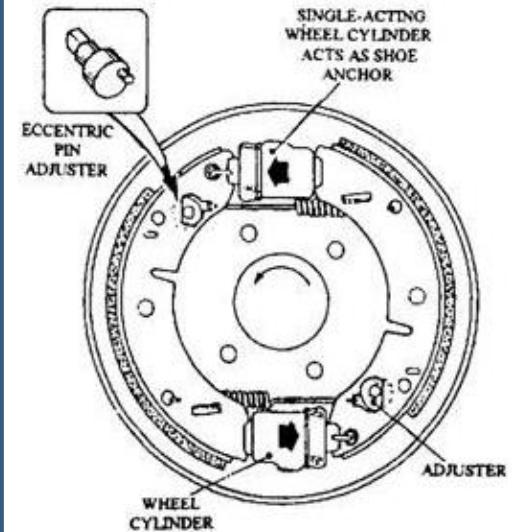
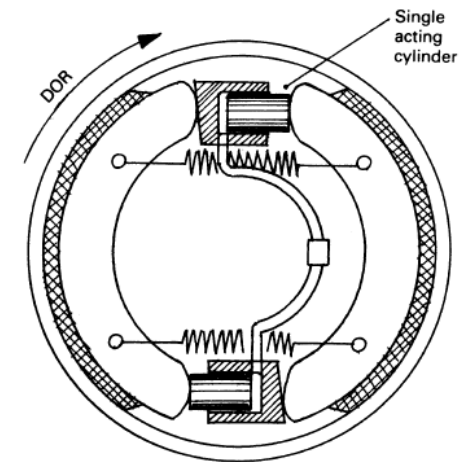


Fig. 28.17. Two leading shoe brake.



(b) Two leading shoes





## ❖ **2LS brake offers the following advantages over L&T shoe brakes:**

- **Even lining wear-** Because both shoes perform an equal amount of work, the brake runs cooler needing relatively less adjustment and has a long life.
- **Equal self-servo action-** Two effective shoes provide a more powerful and stable brake.
- **Greater resistance to fade-** Since both the shoes share the braking equally, the self-servo action on this shoe can be reduced so that a more progressive braking action, which is less sensitive to heat, is achieved.
- **One disadvantage** of the 2LS type is that unless a special double-acting linkage is incorporated, **both shoes change to trailing shoes during backward** movement of the car.
- To compensate for this problem L&T type brakes are used as rear brakes.



## ❖ Duo-servo Brake

- This brake arrangement is also known as the self-energizing brake. Although this is a very powerful brake, its effectiveness reduces severely with the decrease in the friction value.
- A hydraulically operated duo-servo brake is shown in Fig. 28.18. The principle of operation is based on the utilization of drum energy to considerably boost the force applied on the brakes by the driver.
- When the leading shoe is pushed to contact the forward-moving drum, it rotates partially with the drum due to the frictional force.



- This shoe movement, produced by this self-wrapping action, is conveyed through a floating adjuster to the trailing shoe so that the shoe is brought into contact with the drum.
- The force applied by the expander is supplemented by the self-energizing action of both shoes.
- To minimize the delay in application of the self-energization action, the trailing shoe is held on the anchor pin by a stronger return spring so that the expander only moves the leading shoe.
- In this arrangement, the leading shoe is called the primary shoe, because this shoe is made to contact the drum before the secondary shoe..

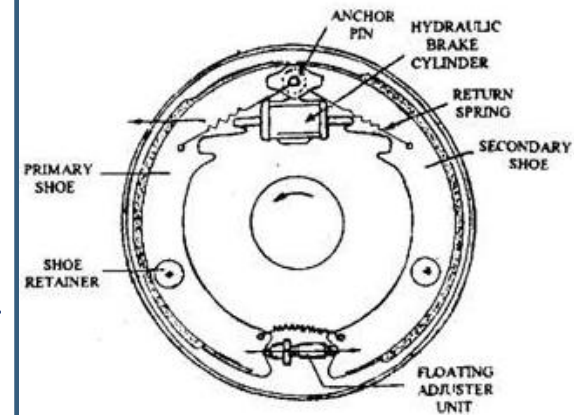
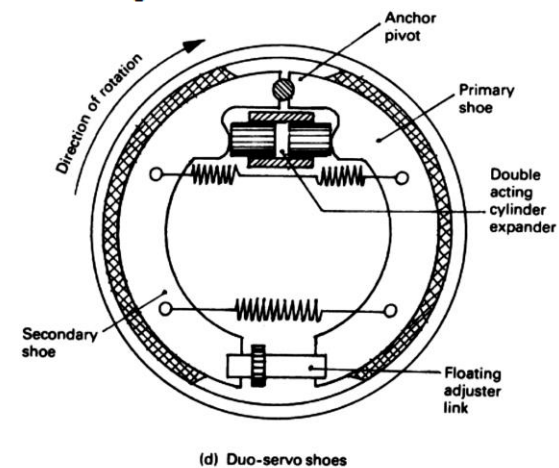


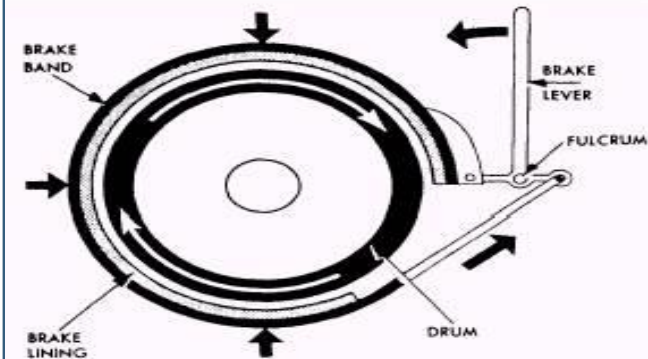
Fig. 28.18. Duo-servo brake.





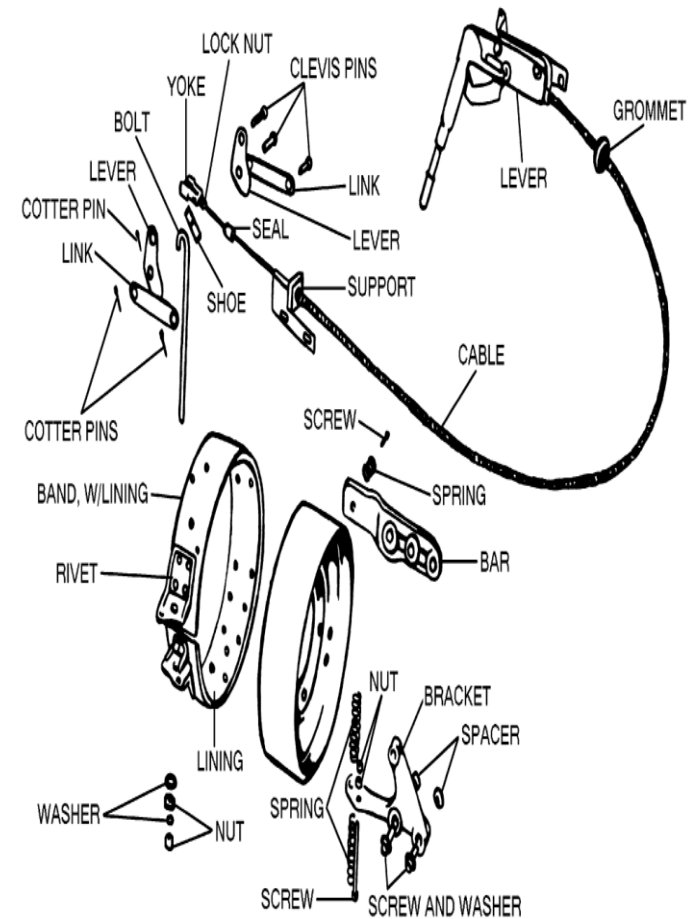
## ❖ External contracting brake drum

- In external contracting brake drum has brake drum is used for only parking purpose. This system consist of Drum, brake & lining, operating lever with adjusting lever and push rod with returning spring.
- External braking system is model braking system used to operate in floor mills, various types of electrical components. the following various types of parts is applied on brake drum.





- The working system of external braking system, when push rod is operated by hand or foot operated lever, then the lined brake drum is fitted around the drum is tightened to lock or slow down the drum.
- When the brake is released the return springs bring the band brake back to its initial position.
- The system remains air opened; therefore dirt is being accumulated between the rubbing surfaces, which reduces the efficiency.



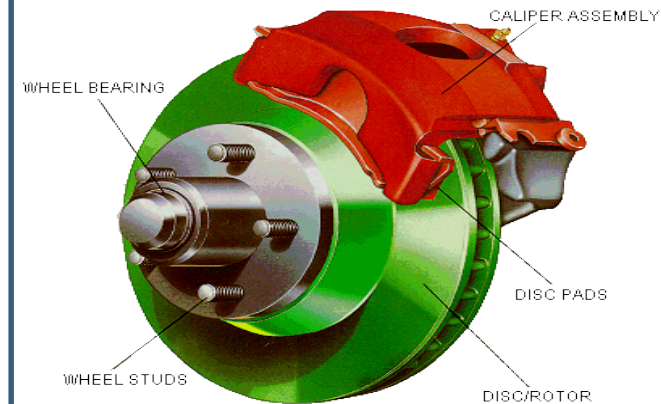
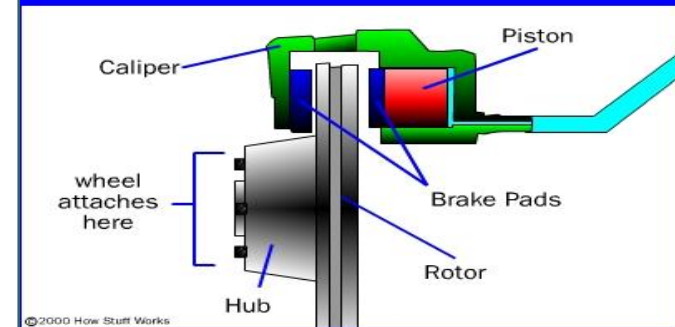




## ❖ Disc Brakes

- One problem with drum brakes is fade and to minimize this problem the disc brake was developed.
- It uses an exposed disc that is attached to the hub flange. The two friction pads are pressed on to this disc to provide braking action.
- The pads are actuated by hydraulic pistons placed in cylinders formed in a caliper, which is secured to a fixed part of the axle.
- The hydraulic pressure forces the friction pads against the rotating cast iron disc.

### How a Disc Brake Works





- Consequently, the disc motion is retarded and heat generated from the energy of motion is conducted to the disc.
- Since a large part of the disc is exposed to the air, heat is easily dissipated, so that the brake can be used continuously for long periods before serious fade occurs.
- In this layout the friction pads move at a right angle to the disc, so that any drop in the friction value does not affect the force applied to the pad.
- For the application of a disc brake, a greater pedal pressure is necessary to produce a given retardation than that required for a drum brake.
- Adjustment of pad wear is automatic on a disc brake. In this brake system the pads can also be inspected easily and in the absence of corrosion, the pads can be renewed easily





## ❖ Principle of the Disc Brake

- The disc brake consists of a circular plate disc mounted on to and rotated by the wheel hub and a bridge member, termed as the caliper. The caliper straddles the disc and is attached to the suspension carrier, stub axle or axle casing (Fig.)
- The caliper incorporates a pair of pistons and friction pads, which clamp the rotating disc during the application of the brakes. Consequently reduction of speed, proportional to the hydraulic pressure acting on each piston produced by the pedal effort, occurs.
- The normal clamping thrust,  $N$ , on each side of the disc (Fig.below) produces a frictional force,  $F = \mu N$ , at the interfaces of disc and pad on both sides of the disc.



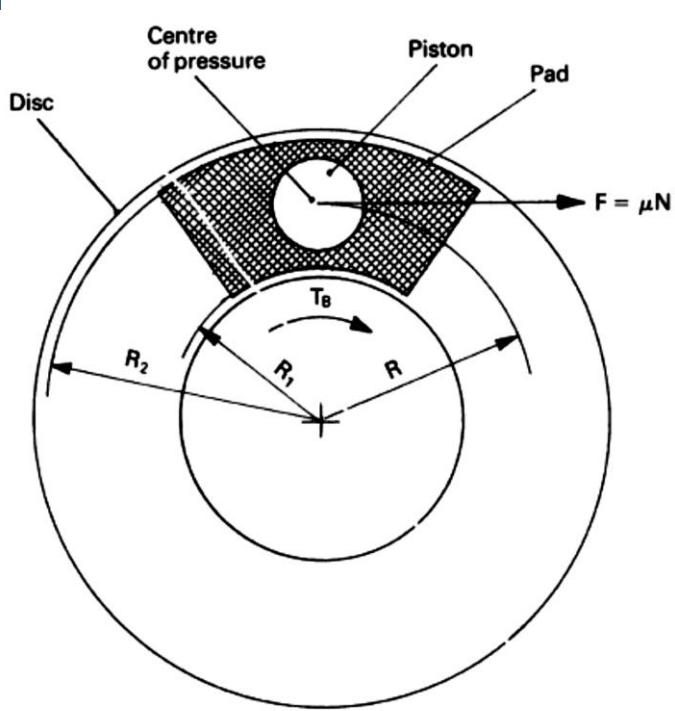
- If the resultant frictional force acts through the centre of the friction pad then the mean distance between the centre of pad pressure and the centre of the disc becomes

$$\frac{R_2 + R_1}{2} = R$$

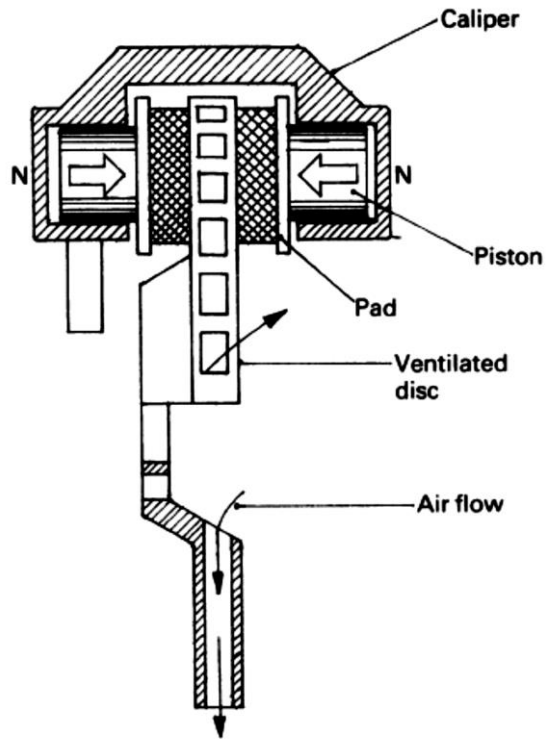
where,  $R_1$  and  $R_2$  are the inner and outer diameter of the pad respectively.

- Accordingly, the frictional braking torque (Fig. A) is doubled due to the action of frictional force,  $N$  on both sides of the disc and depends upon the distance the pad is located from the disc centre of rotation.
- Therefore, the braking torque,

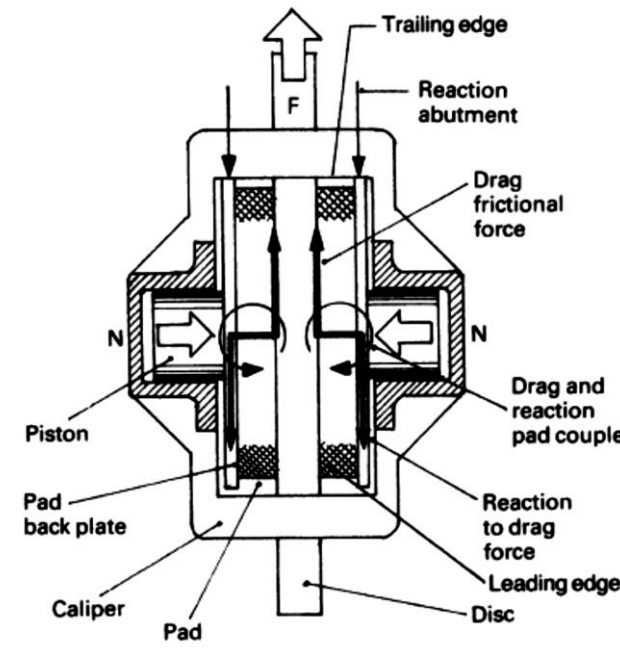
$$T_B = 2 \mu N \left( \frac{R_2 + R_1}{2} \right) = 2\mu NR, \text{ Nm.}$$



(a) Front view



(b) End view



(c) Plan view



## ❖ Disc Brake Pad Alignment

- During the application of brake, the pads are pressed against the disc with uniform pressure. However a slight tilt tendency exists between the leading and trailing pad edges due to frictional pad drag. Additionally the rate of wear from the inner to the outer pad edges is not uniform.
- The thickness of the pad provides a small offset between the pad/disc interface and the pad's back plate reaction abutment within the caliper (Fig. b above).
- This produces a couple, which presses the pad harder against the disc at its leading edge compared to the trailing edge. Consequently this effect causes a very small self-energizing servo action, due to which the wear rate at the leading edge is relatively higher than that at the trailing edge.



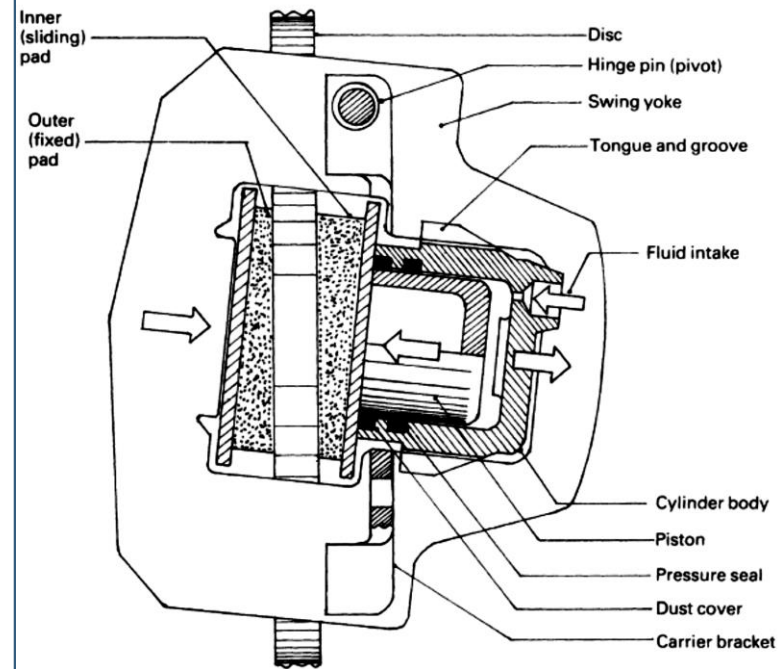
- As the disc sweeps across the pad face, the circular distance it covers in one revolution increases proportionately from the inner to the outer edges of pad (Fig. A above).
- Consequently the rubbing speed, and hence the work done increases from the inner to the outer edges, due to which the pad temperature and wear per unit area rises with the increase in the radial distance from the disc centre.



## ❖ Disc Brake Pad Support Arrangements

### 1. Swing Yoke Type Brake Caliper

- This disc brake caliper is a single cylinder unit and is of light weight. The caliper unit uses a rigid yoke of steel pressing, a cylinder assembly, two pads and a carrier bracket bolted to the suspension hub carrier.
- A tongue and groove joint rigidly secure the cylinder to one side of the yoke frame while the yoke itself pivots at one end on its supporting carrier bracket.
- The disc is mounted on the transmission drive shaft hub which provides the drive to the disc. The lining pads are supported on either side of the disc in the yoke frame (Fig. 11.19)



**Fig. 11.19** Swing yoke type brake caliper



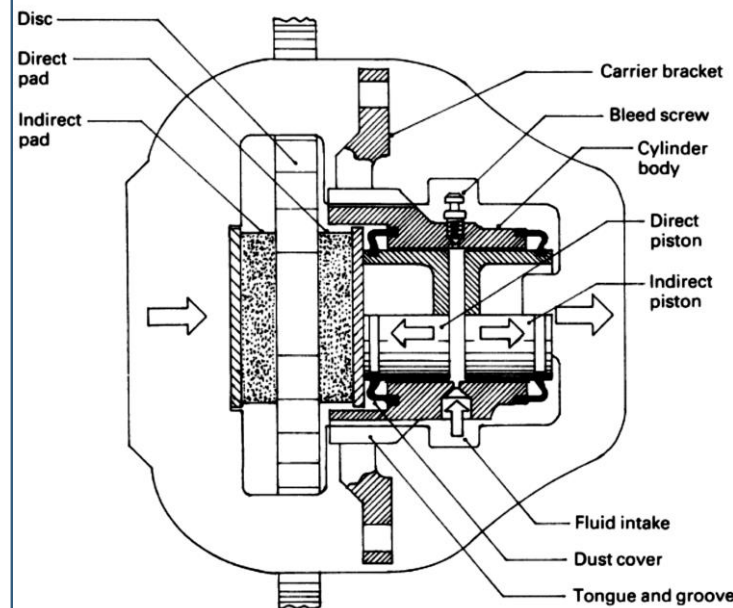
- During operation of the foot brake, hydraulic pressure pushes the piston and inboard pad against their adjacent disc face.
- At the same time, the hydraulic reaction moves the cylinder in the opposite direction so that the outboard pad and cylinder body are bridged.
- Then the yoke pivots, forcing the outboard pad against the disc face opposite to that of the inboard pad. As the pads wear the yoke moves through an arc about its pivot.
- The lining pads are tapered in shape to compensate for this tilt. The operating clearance between the pads and disc is maintained roughly constant by the inherent distortional stretch and retraction of the pressure seals as the hydraulic pressure is increased and reduced respectively.





## 2. Sliding Yoke Type Brake Caliper

- In this type of caliper unit the cylinder body is rigidly fixed to the suspension hub carrier. The yoke slides between parallel grooves formed in the cylinder casting (Fig.11.20 ).
- Application of the foot brake causes hydraulic pressure to push the pistons apart.
- The direct piston forces the direct pad against the disc whereas the indirect piston forces the yoke to slide in the cylinder in the opposite direction until the indirect pad contacts the outstanding disc face.



**Fig. 11.20** Sliding yoke type brake caliper



- Further increase in pressure provides an equal but opposing force which sandwiches the disc between the friction pads.
- The rubber seals distort due to pressure increase as the pistons move apart. As the hydraulic pressure collapses the seals retract and withdraw the pistons and pads from the disc surface.
- Yoke rattle between the cylinder and yoke frame is minimized by incorporating either a wire or leaf spring between the sliding joints.

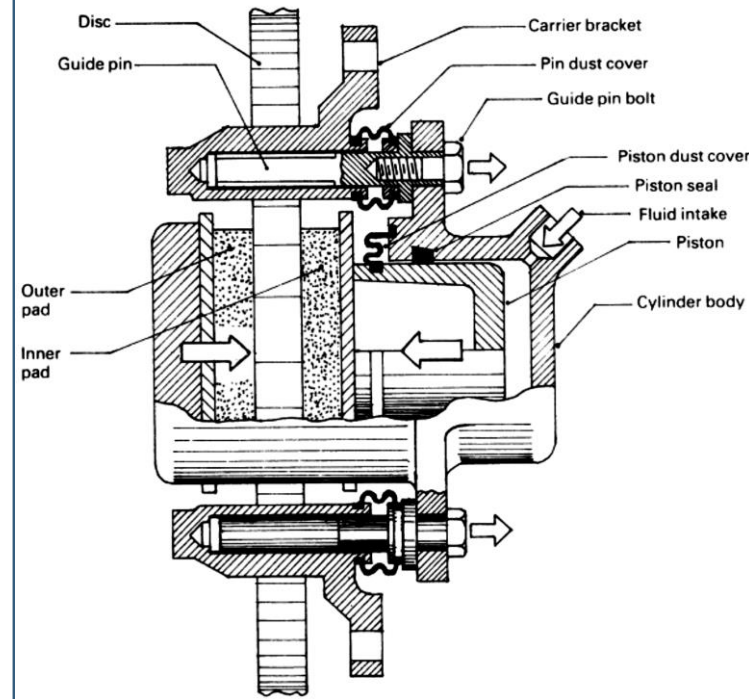


### 3. Sliding Pin Type Brake Caliper.

- This type of disc brake caliper unit incorporates a disc, a carrier bracket, a cylinder caliper bridges, piston and seals, friction pads and a pair of support guide pins (Fig. 11.21 ).
- The carrier bracket is bolted onto the suspension hub carrier. It supports the cylinder caliper bridge and absorbs the brake torque reaction. The cylinder caliper bridge is mounted on a pair of guide pins that slide in holes in the carrier bracket.
- The guide pins only support and guide the bridge. These are sealed against dirt and moisture by dust covers. The frictional drag of the pads is absorbed by the carrier bracket. The application of the foot brake generates hydraulic pressure that pushes the piston and cylinder apart.
- The inboard pad moves up to the inner disc face. In contrast, the cylinder and bridge react in the opposite direction until the outboard pad touches the outside disc face. Further increase of hydraulic pressure imposes equal but opposing forces against the disc faces via the pads.



- Similar to all other types of caliper units, in slide pin type also, the brake caliper pad to disc free clearance is provided by the pressure seals.
- The pressure seals are fitted inside recesses in the cylinder wall. They grip the piston when hydraulic pressure forces the piston outwards, getting distorted in the process.
- When the foot brake is released the pressure is withdrawn from the piston crown and the strain energy of the elastic rubber pulls back the piston so that the pressure seal is restored to its original shape.



**Fig. 11.21** Slide pin type brake caliper

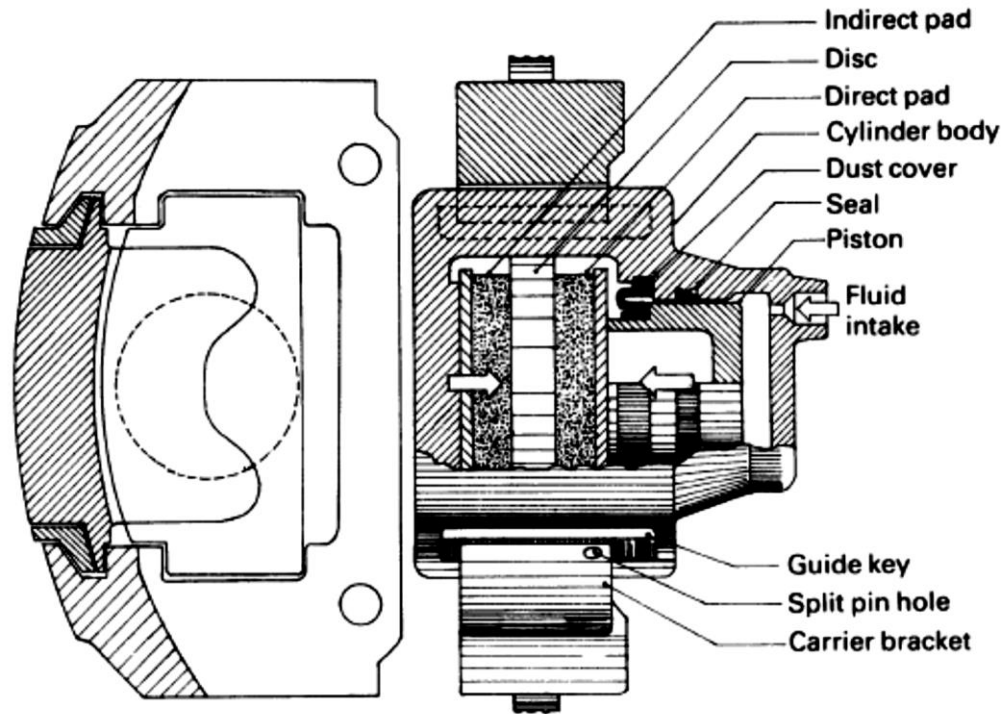


## 4. Sliding Cylinder Body Type Brake Caliper.

- This type of brake caliper unit uses a carrier bracket bolted to the suspension hub carrier and a single piston cylinder bridge caliper.
- The caliper straddles the disc and slides laterally on guide keys located in wedge-shaped grooves formed in the carrier bracket (Fig. 11.22).
- The hydraulic pressure, generated due to the application of the foot brake, pushes the piston along with the direct acting pad onto the inside disc face.
- The cylinder body caliper bridge is pushed in the opposite direction, so that it reacts and slides in its guide groove at right angles to the disc.
- This causes the indirect pad to contact the outside disc face, equalizing the forces acting on both sides of the disc.



- A pad to disc face working clearance is provided as in the other units by the retraction of the pressure seal, after the hydraulic pressure collapses.
- Anti-rattle springs are incorporated alongside each of the two-edge-shaped grooves to avoid vibration and noise caused by the relative movements between the bridge caliper and carrier bracket sliding joint.



**Fig. 11.22** Slide cylinder body brake caliper





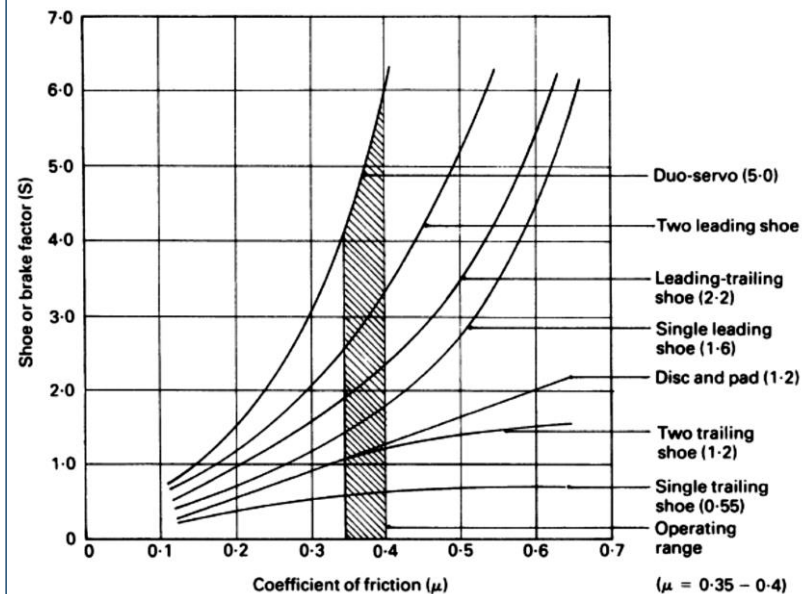
## ❖ A comparison of Shoe Factors and Shoe Stability

- Different brake shoe arrangements and the disc brake are compared on a basis of shoe factor,  $S$ , or output torque against the variation of rubbing coefficient of friction (Fig. 28.13).
- The coefficient of friction, however, for most linings and pads ranges between 0.35 and 0.45. The shoe factor in increasing order is roughly as presented in Table for the normal working range of the co-efficient of friction.
- The figures in the table indicate that the torque output (shoe factor) for a single or two trailing shoes is only approximately one-third of the single or two leading shoe brake.





- The combination of a leading and trailing shoe performs at about twice that of the two trailing shoe, or roughly two-thirds of the two leading shoe layout (Fig. 28.13).
- The disc and pad perform a very similar to the two trailing shoe layout, but with higher coefficients of friction its shoe factor rises at a faster rate than that of the two trailing shoe brake.
- The duo servo shoe arrangement exhibits a superior shoe factor relative to all other layouts.



**Fig. 28.13.** Relationship of shoe or brake factors and coefficient of friction for different shoe layouts and the disc brake.



- The lining or pad stability is the ability of the shoes or pads to maintain approximately the same shoe factor for a small change in the coefficient of friction, possibly because of wetness or an increase in temperature of the friction material.
- The stability changes in the reverse order as presented in Table. In general, brakes with very high shoe factors are unstable and produce a relatively large change in shoe factor (output torque) for a small increase or decrease in the coefficient of friction between the rubbing surfaces.
- Arrangements with low shoe factors tend to produce a consistent output torque for a considerable variation in the coefficient of friction. Since the shoe layouts with high shoe factors are unstable, the front brakes of most vehicles are either two leading shoes or disc and pads, and at the rear a leading and trailing shoe system.
- Additional assistance of vacuum or hydraulic servo or full power air operation is opted. A combined leading and trailing shoe brake thus provides a relatively high leading shoe factor but with only a moderate degree of stability, whereas a trailing shoe produces a very low shoe factor with very high stability.



- Leading and trailing shoe brakes are still selected on the rear wheels because they easily accommodate the handbrake mechanism and produce an extra self-energizing effect when the handbrake is applied. Since this is not possible in the case of the disc and pad brake, it requires a considerably greater clamping force to achieve wheel lock condition.

**Table 28.2. Shoe factor, relative braking power and stability for various brake layouts.**

Type of brake	Shoe factor	Relative braking power	Stability
Single trailing shoe	0.55	Very low	Very high
Two trailing shoes	1.15	Very low	Very high
Disc and pad	1.2	Low	High
Single leading shoe	1.6	High	Low
Leading and trailing shoes	2.2	Moderate	Moderate
Two leading shoes	3.0	High	Low
Duo servo shoes	5.0	Very high	Very low



## ❖ Comparison between Drum Brake and Disc Brake

	Description	Drum brake	Disc brake
1	Life of friction material	Reasonable (about 1500 km)	Reasonable (about 2500 km)
2	Visibility of wear from outside	Not possible	Can be seen at a glance
3	Heat dissipation	Inferior	Better
4	Replacement of friction materials	Troublesome and time taking	Easy and rapid
5	Weight	Bulky	Lighter
6	Cooling	Very slow	Efficient
7	Water and dust collection	Accumulates	Self cleaning
8	Braking effect	Generally inconsistent	Consistent



## ❖ Comparison between Drum Brake and Disc Brake

	Description	Drum brake	Disc brake
9	Temperature effect	Severe	Unaffected
10	Self energizing action	Exists	absent
11	Brake pedal efforts	Higher	Proportional to retardation
12	Behavior of hydraulic system in released state	Some pressure always exists	No hydraulic pressure on piston
13	Force needed to apply brake	Comparatively less	More, since brakes are not self energizing
14	Nature of wear	Non uniform	Uniform
15	Shape of friction lining	Curved	Straight



## ❖ Properties of Friction Lining and Pad Materials

### 1. Friction Level

- The coefficient of friction should be sufficiently high to limit brake pedal effort.
- It should not be so high that it causes grab, or in the extreme cases lock or sprag.
- In such a situation rotation of the drum becomes impossible. The friction material must be compatible with the degree of self-energization (Fig. 28.32).
- The average coefficient of friction of modern friction materials is **between 0.3 and 0.5**.

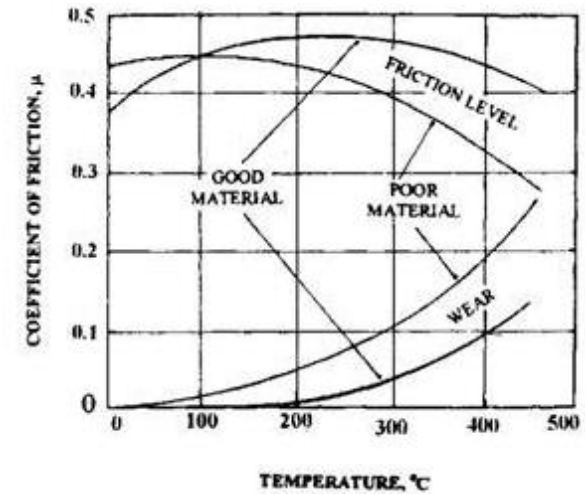


Fig. 28.32. Effect of temperature on the coefficient



## 2. Resistance to Heat Fade

- This property allows a lining or pad material to **retain its coefficient of friction with an increase in rubbing temperature** of the drum and shoes or disc and pads.
- A **decrease in the coefficient of friction requires greater brake pedal effort** and results in poor braking response. The changes in the coefficient of friction as a consequence of rising working temperatures are also partly caused by the additional **curing of the pad due to chemical changes in the binder resin** (Fig. 28.32).
- A **progressive reduction in the frictional level in the higher temperature range may be acceptable**. A rapid decrease in the coefficient of friction severely reduces the braking power capability specifically when the vehicle experiences long descents or continuous stop-start travel.





### 3. Recovery from Fade

- This is the ability of a friction material to **return to its original friction level after cooling** once brake lining or pad temperature fade has occurred.
- A good quality material restores its frictional characteristics on cooling, even after repeatedly subjected to severe heating. In case of **an inferior material, the poor recovery is principally due to chemical breakdown** in the ingredients.
- The friction level may be **permanently altered causing hardening, cracking, flaking, and charring or even burning of the linings or pads**. If the thermoplastic binder resins are used with the lining or pads a deposit may form on the rubbing surfaces, which may change the friction properties of the material (Fig. 28.32).



## 4. Resistance to Wear

- The life of a friction material, for both lining and pad, **depends to a great extent upon the rubbing speed and pressure** because they are responsible for material wear.
- The wear is also **greatly influenced by the working temperature**. At the upper limits of the lining or pad temperature range, the material structure is weakened, resulting in a higher wear rate (Fig. 28.32).



## 5. Resistance to Rubbing Speed

- Practically, the **coefficient of friction** between two rubbing surfaces slightly **reduces with the increase of speed**, specifically **at the higher operating temperature** range although it should be independent of speed.
- But a low quality friction material may exhibit a high friction level at low rubbing speeds and may cause judder and grab as the vehicle tends to stop.
- It may also suffer from a relatively rapid decrease in the friction level as the rubbing speed increases (Fig. 28.33).

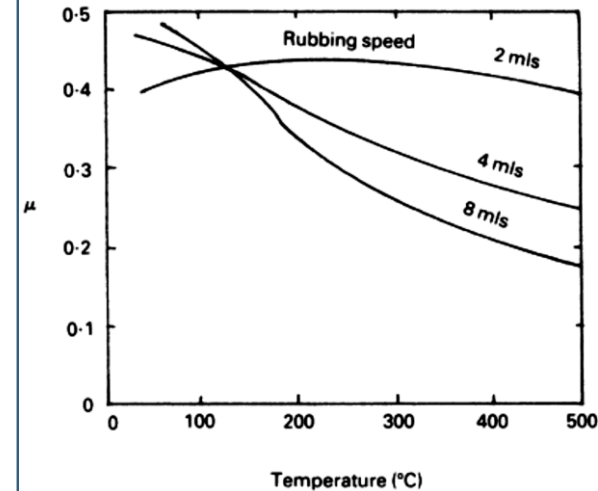


Fig. 28.33. Effects of rubbing speed on the level of friction over the temperature range.



## 6. Resistance to the Intensity of Pressure.

- As per the laws of friction, the coefficient of friction should be independent of the pressure holding the rubbing surface together.
- But present friction materials are generally compounds, which are held together with resin binders; as a result pressure between the rubbing surfaces reduces friction level to some extent.
- A pressure-stable lining produces deceleration proportional to the pedal effort. But a pressure-sensitive material requires a relatively greater pedal force to produce a given braking effort.
- Disc brakes operate better at high rubbing pressures, whereas at similar pressures shoe linings exhibit inferior performance (Fig. 28.34).

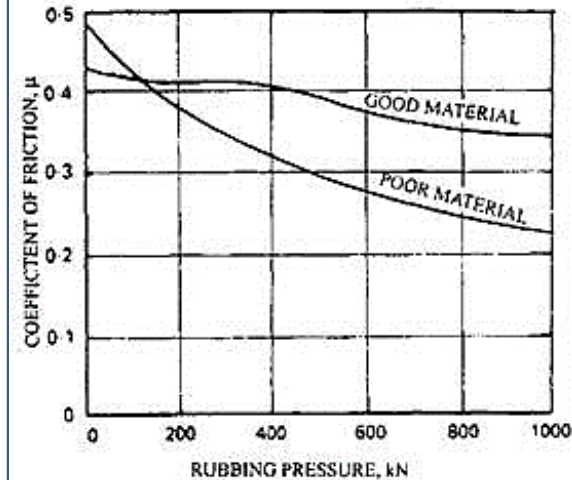


Fig. 28.34. Effect of rubbing pressure on the coefficient of friction.



## 7. Resistance to Water Contamination.

- Principally all friction materials to some extent are **affected by water contamination**.
- Therefore, a safe margin of friction level should be available for operation with wet conditions.
- Good quality friction materials should **recover quickly and progressively to their original friction level during the drying out process**. A poor quality material may either recover **very slowly** or may have **over-recovery** characteristic.
- Over-recovery tendency causes brake-grab and even wheel-lock under certain driving conditions (Fig. 28.35).

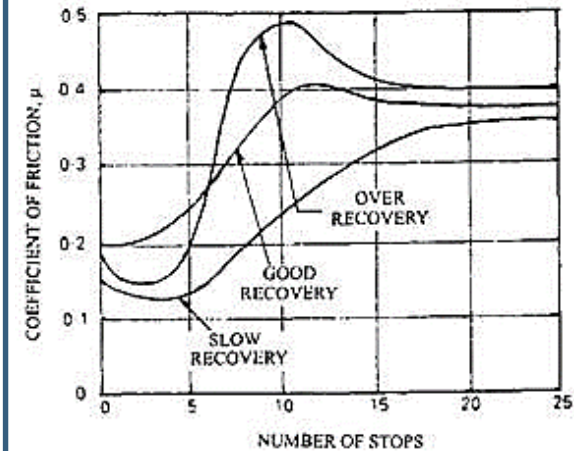


Fig. 28.35. Effects of water contamination on the materials friction recovery over a period of vehicle stops.



## 8. Resistance to Moisture Sensitivity.

- **Atmospheric dampness, humidity or dew** may increase the friction level for the first few applications.
- They may develop the **brakes noise and cause brake-grab for a short time**. Moisture-sensitive friction materials should not be used with brakes having high self-energizing characteristics.



## ❖ Friction Materials

- These materials generally have merits as well as limitations. **Sintered metals have a long life but exhibit a relatively low coefficient of friction.**
- **Ceramics mixed with metals are very rigid**, but have **much higher coefficient of friction** (due to which they are made in sections).
- They are **very harsh on the drums and discs**, resulting in much **higher wear rates** than asbestos-based materials.
- Friction materials have been produced containing much less asbestos and much softer metal, such as brass and zinc inserts or aluminium granules.
- Non-asbestos materials are now available containing **DuPont's Kevlar**, a high strength aramid fiber.





- Some non-asbestos materials suffer from a **drastic reduction in the coefficient of friction during operation in winter temperatures.**
- Such materials may not have adequate coefficient of friction for holding overnight parking brake.



## ❖ **Materials Used for Brake Friction Lining/Pads**

- Asbestos
- Semi-Metallic
- Non-Asbestos Organics
- Low Steel
- Carbon
- Exact composition of each manufacturer's pads is a closely guarded secret



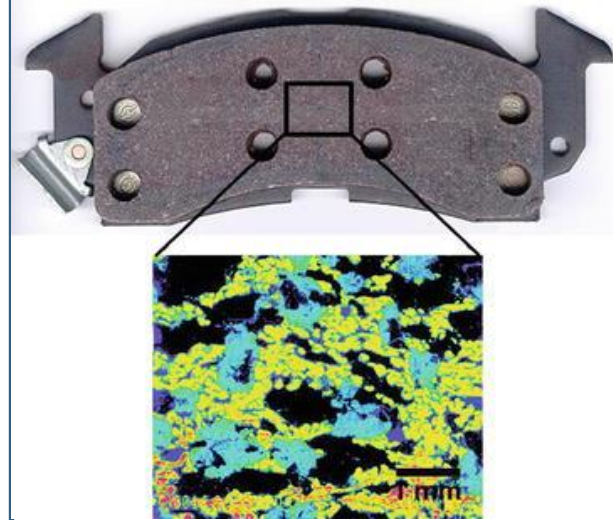
## *1. Asbestos organic type:*

- Asbestos-based organic friction materials were widely used prior to mid-1970 due to its high friction effectiveness, thermal stability, and reinforcing capability.
- They normally contained 30–40 wt.% of organic ingredients, several property modifiers, and asbestos. The friction materials based on asbestos, however, were **banned in 1989** after asbestos was declared a **carcinogen** (Nolan and Langer 1987).
- Currently, asbestos is not permitted to be used for automotive components in the US, EU, and most of the developed countries.



## 2. *Semi-metallic type:*

- This material was introduced in the 1960s and eventually made up approximately 90% of the passenger and light truck market in the 1980s.
- It normally contains more than **50 wt.% of iron powder and steel fibers** bound by a **phenolic resin** (Fig.).
- This type of friction material shows high aggressiveness against gray iron discs while it offers stable friction and improved fade resistance. It has been used **for heavy-duty operations.**





### 3. *Nonasbestos organic (NAO) type:*

- NAO-type friction materials were developed to replace asbestos-based friction materials by using nonasbestos fibers and other property modifiers. The **asbestos substitutes comprise various inorganic fibers of glass, mineral, ceramic, steel, copper, brass, and organic materials.**
- Platy materials such as **mica, vermiculate, and porous metals** are also used as an asbestos substitute. No single fiber can replace asbestos, and a mix of several reinforcing fibers is used to meet various performance and processing-related requirements.
- In general, commercial NAO friction materials are divided into two different types: **non-steel** (Fig. 3) and **low-steel type friction materials** (Fig. 4), depending on the existence of the steel fiber (low steel type normally contains less than 10 wt.%) in the friction material, which increases friction effectiveness but often aggravates disc (or drum) wear.

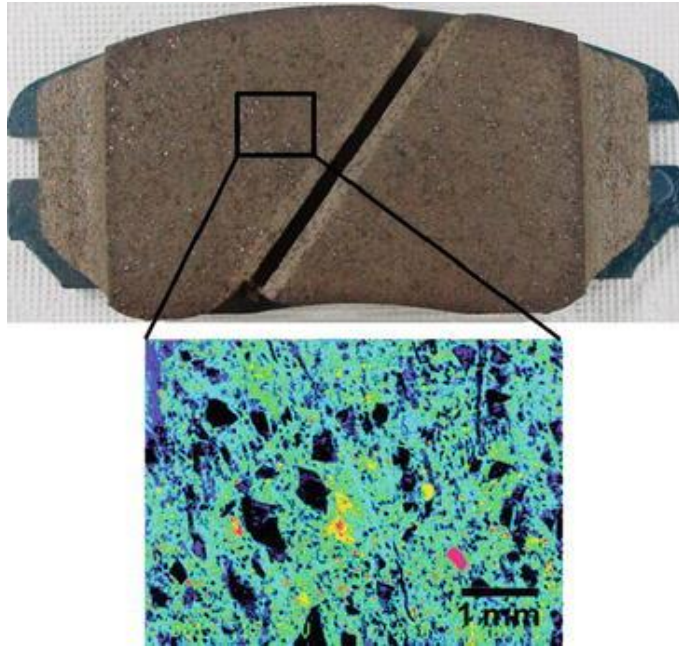


Fig. 3

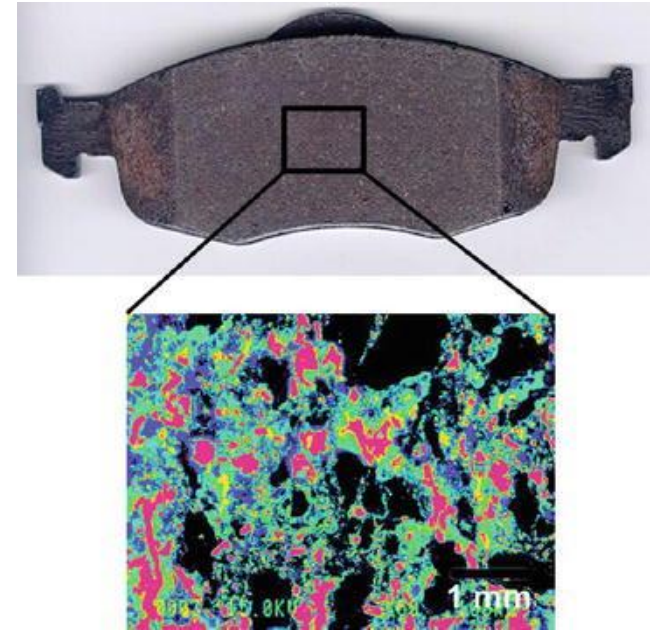


Fig.4



#### *4. Sintered metallic type:*

- This material was **developed for high-speed trains and aircraft brakes**, which **require thermal stability at extreme braking conditions**.
- It normally contains **ceramic materials in a metallic matrix** based on iron or copper.

#### *5. Carbon composite type:*

- This is a carbon fiber–reinforced carbon matrix composite and developed **mainly for aircraft and racecar brakes** as a substitute for heavy sintered metallic friction materials.
- Due to its excellent **thermal stability and relatively high heat capacity**, its application has been **expanded to high-end passenger cars**.





## ❖ Brake Friction Materials Ingredients

**Brake Friction Materials, Table 1** Typical ingredients used for brake friction materials

Group	Type/role	Ingredients
Binders	Straight	Phenolic resin, polyimide, resol, COPNA resin
	Modified	Aralkyl modified, boron-modified, cashew modified, silicon-modified, phosphor-modified, acryl-modified, epoxy-modified, rubber modified phenolic resin
Reinforcements	Fibrous	Aramid pulp, steel fiber, bronze fiber, <sup>a</sup> copper fiber, <sup>a</sup> brass fiber, <sup>a</sup> stainless fiber, rock wool, glass fiber, ceramic fiber, potassium titanate (whisker), <sup>a</sup> sepiolite, <sup>a</sup> basalt fiber, cellulose fiber, carbon fiber, acrylic fiber
	Non-fibrous	Mica, vermiculite, potassium titanate (plate), copper powder, <sup>a</sup> iron powder, woolastonite
Property modifiers	Lubricants	Graphite, MoS <sub>2</sub> , CaF <sub>2</sub> , ZnS, Sb <sub>2</sub> S <sub>3</sub> , <sup>a</sup> Sb <sub>2</sub> O <sub>5</sub> , <sup>a</sup> WS <sub>2</sub> , CuS, Na <sub>3</sub> AlF <sub>6</sub> , cokes
	Abrasives	ZrSiO <sub>4</sub> , quartz, Al <sub>2</sub> O <sub>3</sub> , MgO, ZrO <sub>2</sub> , zeolite, Fe <sub>3</sub> O <sub>4</sub> , SiC, ZnO, chromite
	Miscellaneous modifiers	Ca(OH) <sub>2</sub> , cashew, rubber powder, cork, Al, Cu powder, <sup>a</sup> bronze powder, <sup>a</sup> cut copper, <sup>a</sup> Zn powder, Sn powder
	Space fillers	BaSO <sub>4</sub> , CaCO <sub>3</sub>

<sup>a</sup>Materials with potential health hazards or environmental issues

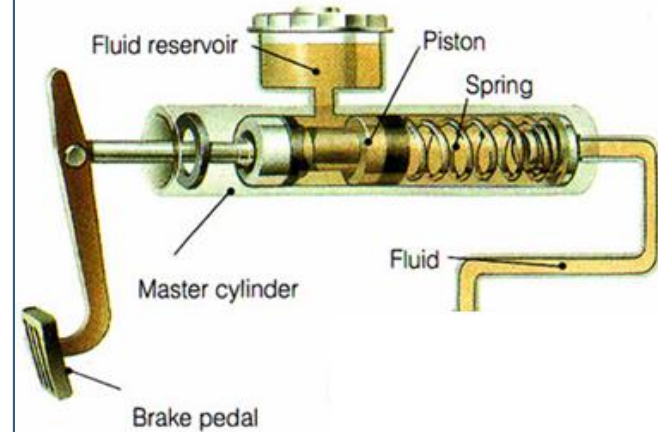


## ❖ Hydraulic Brakes:

- The hydraulic brake is an arrangement of braking mechanism which uses brake fluid, to transfer pressure from the controlling unit, which is usually near the operator of the vehicle, to the actual brake mechanism, which is usually at or near the wheel of the vehicle.

## ❖ History:

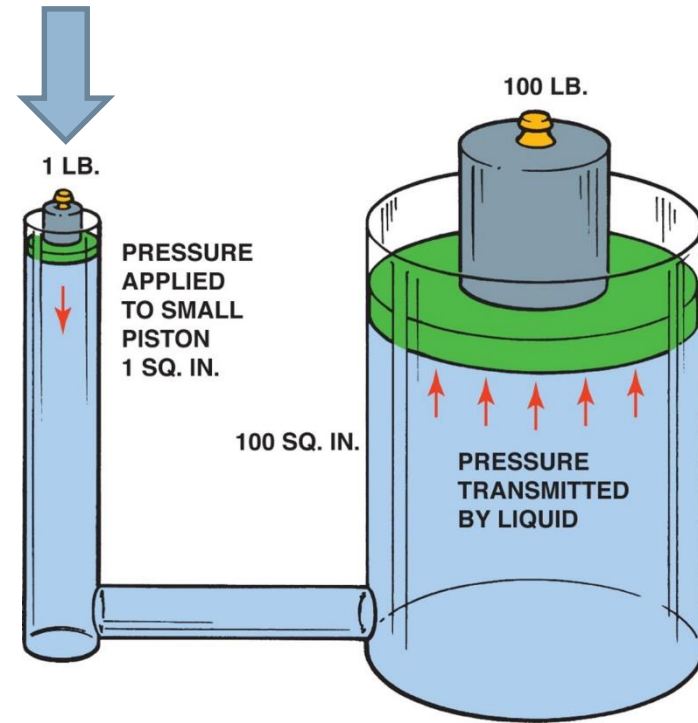
- In 1918 Malcolm Lockheed developed a hydraulic brake system.

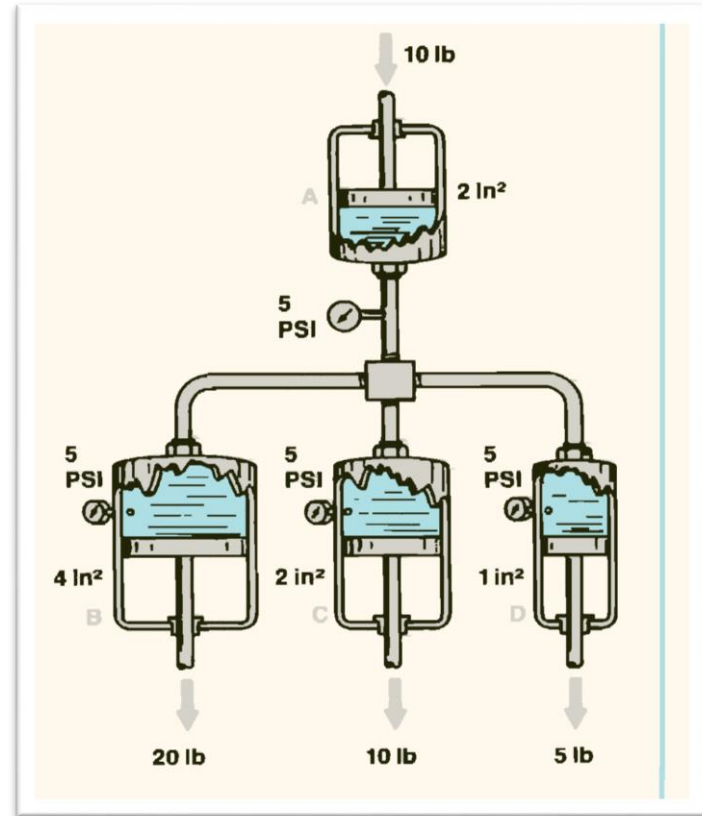
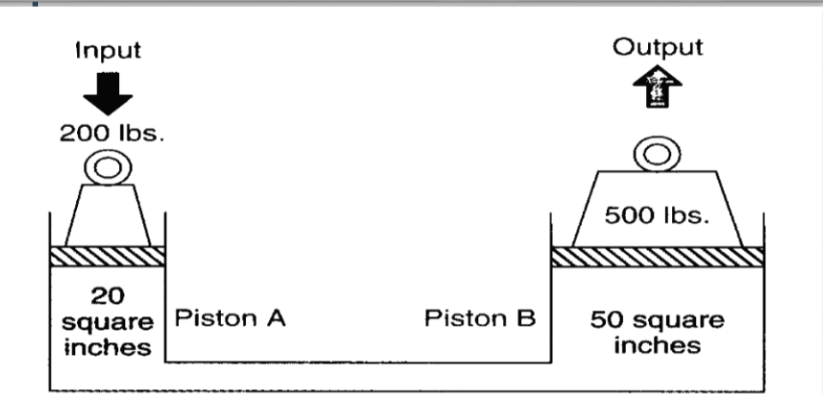
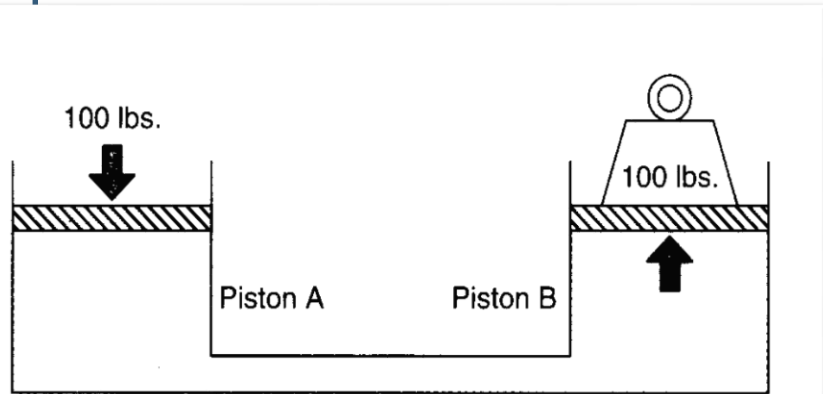




## ❖ Working Principle

- Hydraulic brakes work on the principle of Pascal's law which states that "pressure at a point in a fluid is equal in all directions in space".
- According to this law when pressure is applied on a fluid it travels equally in all directions so that uniform braking action is applied on all four wheels.







## ❖ Hydraulic Braking System

- A hydraulic braking system transmits brake-pedal force to the wheel brakes through pressurized fluid, converting the fluid pressure into useful work of braking at the wheels.
- A simple, single-line hydraulic layout used to operate a drum and disc brake system is illustrated in Fig. 28.36. The brake pedal relays the driver's foot effort to the master-cylinder piston, which compresses the brake fluid.
- This fluid pressure is equally transmitted throughout the fluid to the front disc-caliper pistons and to the rear wheel-cylinder pistons. As per the regulations a separate mechanical parking brake must be incorporated with at least two wheels.
- This provision also allows the driver to stop the vehicle in the event of failure of the hydraulic brake system.

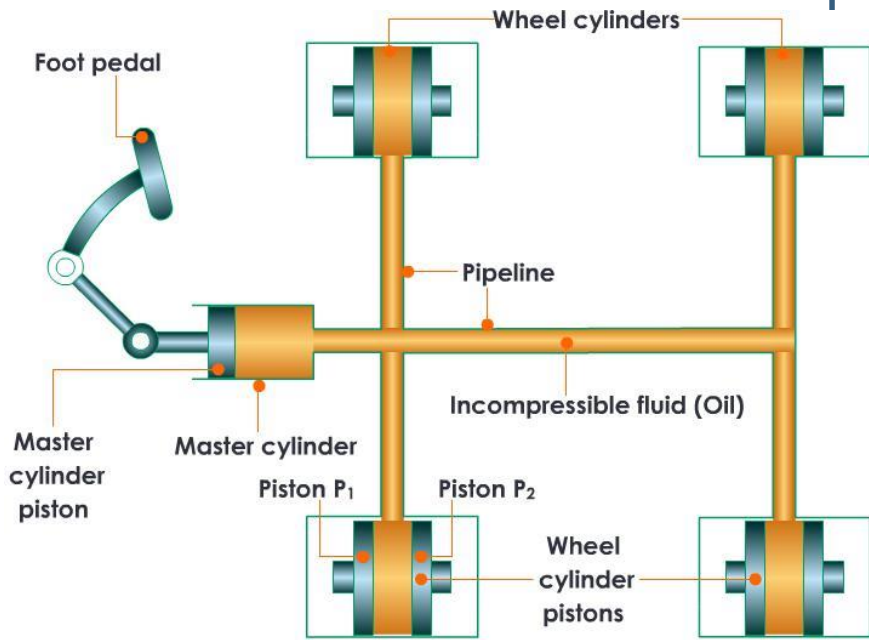
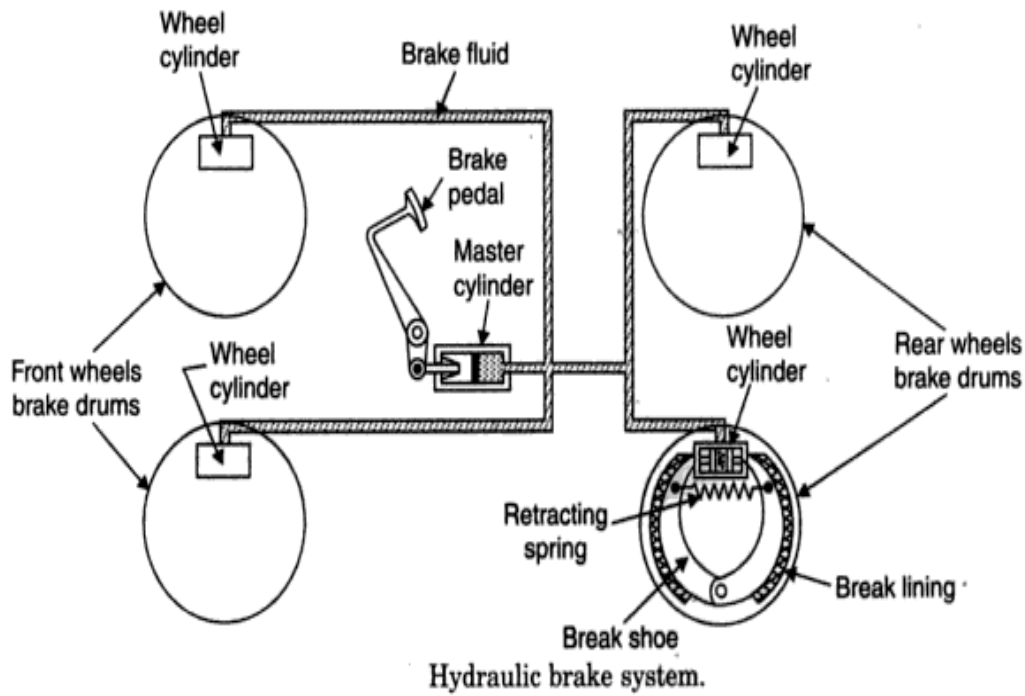


- In a hydraulic braking system the braking force is directly proportional to the ratio of the master-cylinder cross-sectional area to the disc or drum-brake wheel-cylinder cross-sectional areas.
- Therefore these cylinder diameters are appropriately chosen to produce the desired braking effect.
- The **wheel-cylinder cross-sectional areas of the front and rear disc-and drum-brakes** respectively may be chosen **to produce the best front-to-rear braking ratio**. Hydraulic fluid is incompressible provided there is no trapped air in the system.
- If air is present in the braking circuit, the foot-brake movement becomes spongy. In a hydraulic system the internal friction exists only between the cylinder pistons and seals.
- The friction is caused by the fluid pressure squeezing the seal lips against the cylinder walls as the piston moves along its stroke



- A hydraulic braking system is suitable only for intermittent braking applications, and a separate mechanical linkage must be incorporated for parking brakes.
- The hydraulic system offers the following **advantages over the mechanical layout**,
  - i. This provides **equal braking effort on all wheels**.
  - ii. This requires **relatively less braking effort to deliver the same output**.
  - iii. This is a fully compensated system so that **each brake receives its full share of the pedal effort**.
  - iv. The **efficiency** of the hydraulic system is **greater than that of the mechanical** layout.
  - v. This system is suitable for **vehicles having independent suspension**.
  - vi. It is easy to alter thrust on shoe because the force exerted on a piston depends on the piston area. The larger the area, the greater the thrust on the trailing shoe, so a larger piston can be used.

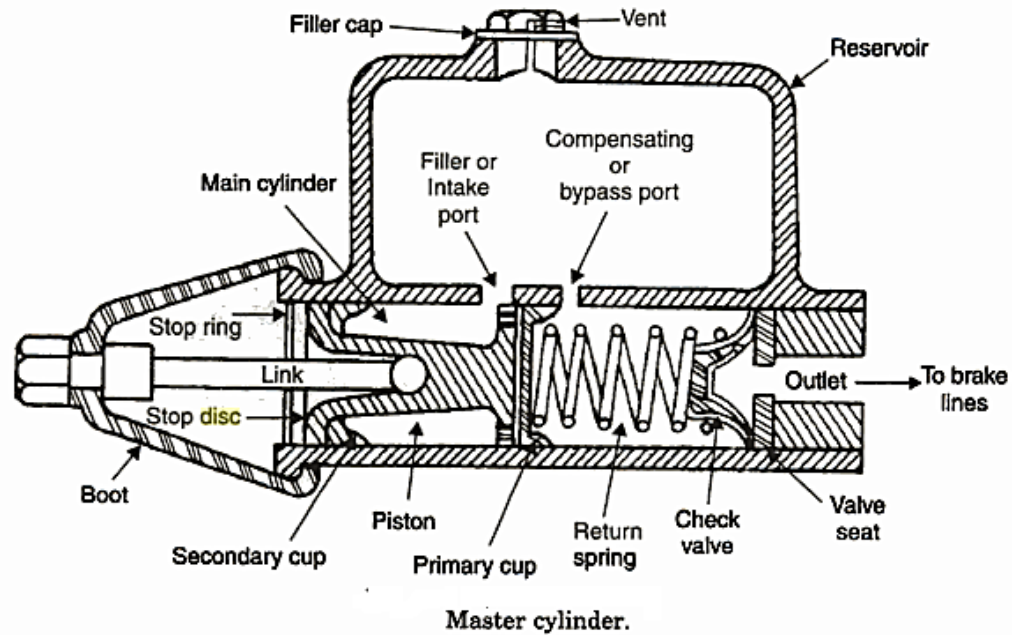






## ❖ HBS Components:

### 1. Master Cylinder





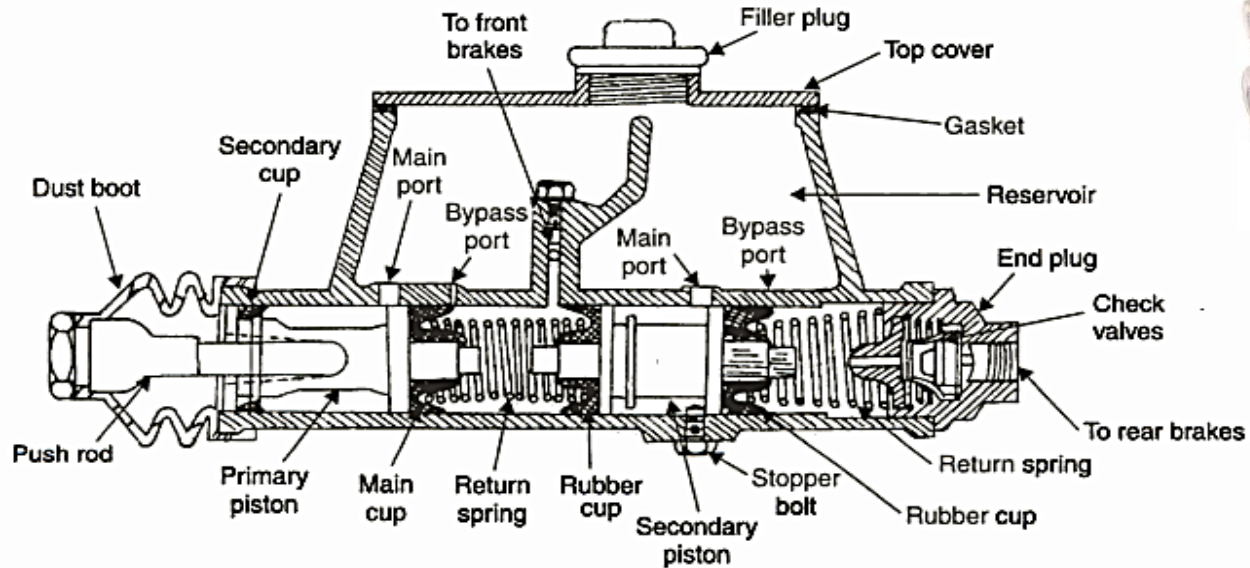
- The Master Cylinder is the heart of the hydraulic brake system.
- It consists of two main chambers.
- The fluid reservoir which contains the fluid to supply to the brake system, and the compression chamber in which the piston operates.
- The reservoir supplies fluid to the brake system through two ports.
- The larger port is called the filler or intake part and is connected to the hollow portion of the piston between the primary and secondary cups which act as piston seals.
- The smaller port is called the relief, bypass or compensating port which connects the reservoir directly with the cylinder and lines when the piston is in the released position.



- When the brake pedal is depressed, the master cylinder piston moves forward to force the liquid under pressure into the system.
- The relief port is sealed out of the system.
- The liquid pressure is conducted to the wheel cylinders, where it forces the wheel cylinder pistons out wards.
- These pistons force the brake shoes out against the brake drums.
- When brake pedal is released, the return spring quickly forces the master cylinder piston back against the piston stop.
- Because the fluid in the lines returns rather slowly, a vacuum tends to form in the cylinder in front of the piston.
- This causes the primary cup to collapse to allow the liquid to flow from the reservoir through the filter port past the piston to fill the vacuum.



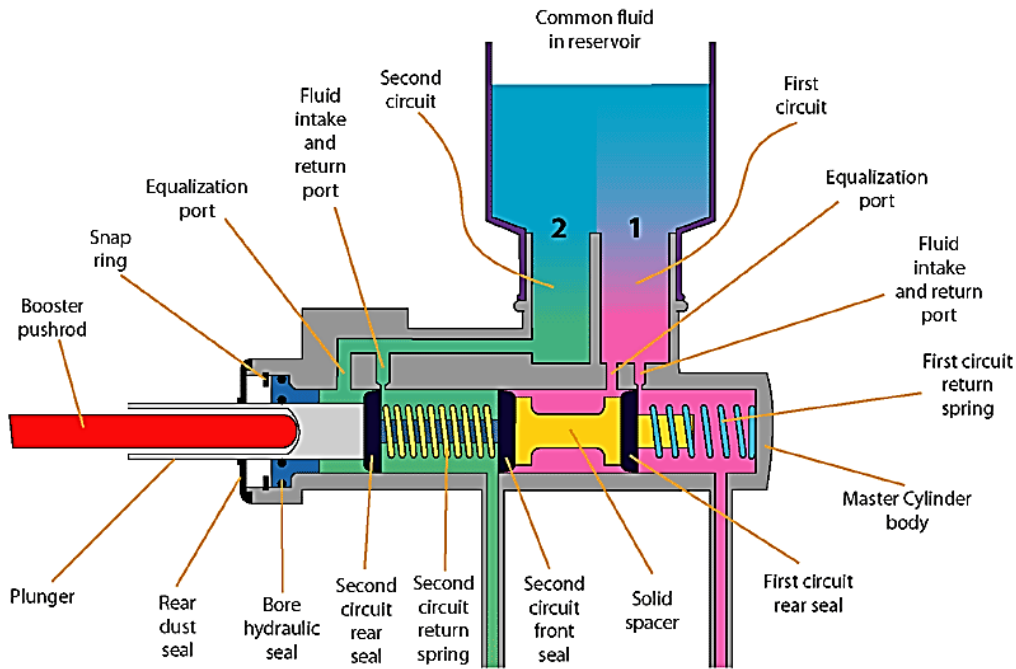
## ❖ Tandem Master Cylinder:



Tandem master cylinder (Sectional view).







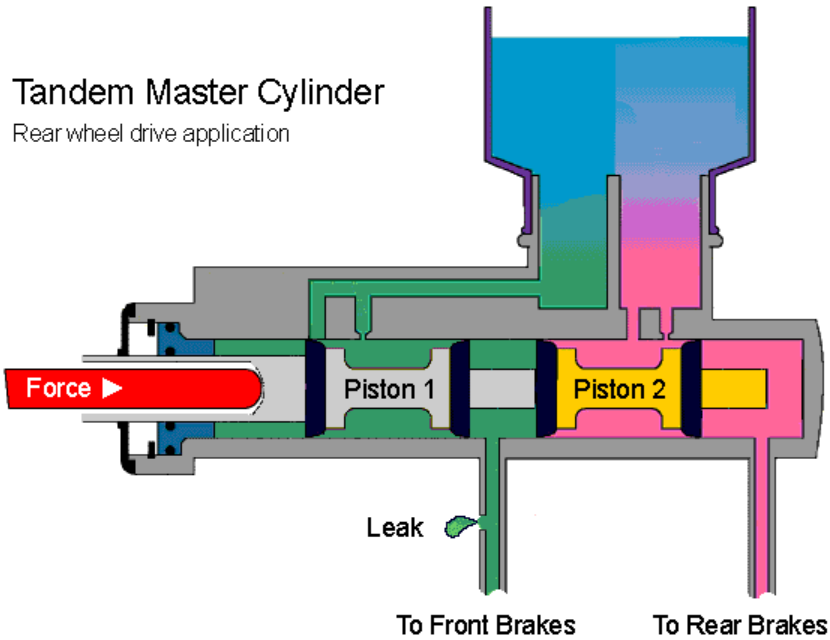


- A tandem master cylinder is characterized by two pistons operating in series within a common bore, as shown in the two illustrations below.
- In rear-wheel drive applications the piston that's located closer to the pedal (labeled "Piston 1") applies the vehicle's front brakes.
- In normal operation, fluid displaced and pressurized by Piston 1 also causes movement of a second piston ("Piston 2"). Piston 2 applies the vehicle's rear brakes.
- The following two illustrations show how a tandem master cylinder isolates leaks in the front and rear brake plumbing respectively. (In both illustrations, the pedal has already been depressed to the point of brake application.)

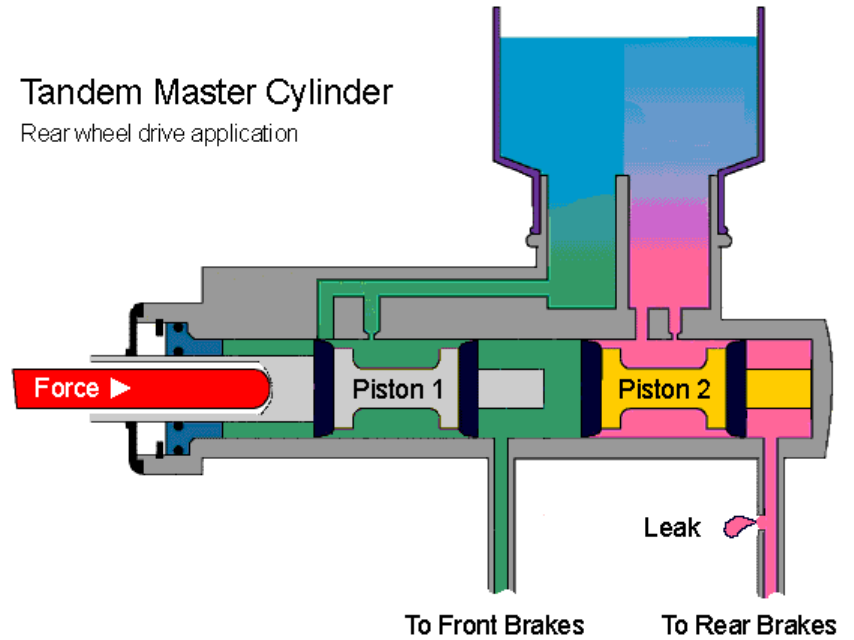




Tandem Master Cylinder  
Rear wheel drive application



Tandem Master Cylinder  
Rear wheel drive application





- The following two illustrations show how a tandem master cylinder isolates leaks in the front and rear brake plumbing respectively. (In both illustrations, the pedal has already been depressed to the point of brake application.)
- As shown in Illustration 1, if a leak develops in the front brake system, Piston 1 will move forward until it contacts Piston 2.
- Force from the brake pedal will be transmitted mechanically through Piston 1 to Piston 2.
- Although overall braking performance will be severely compromised, the rear brakes will still be functional provided sufficient pedal travel is available. The pedal will need to travel further than normal to fully engage the rear brakes.



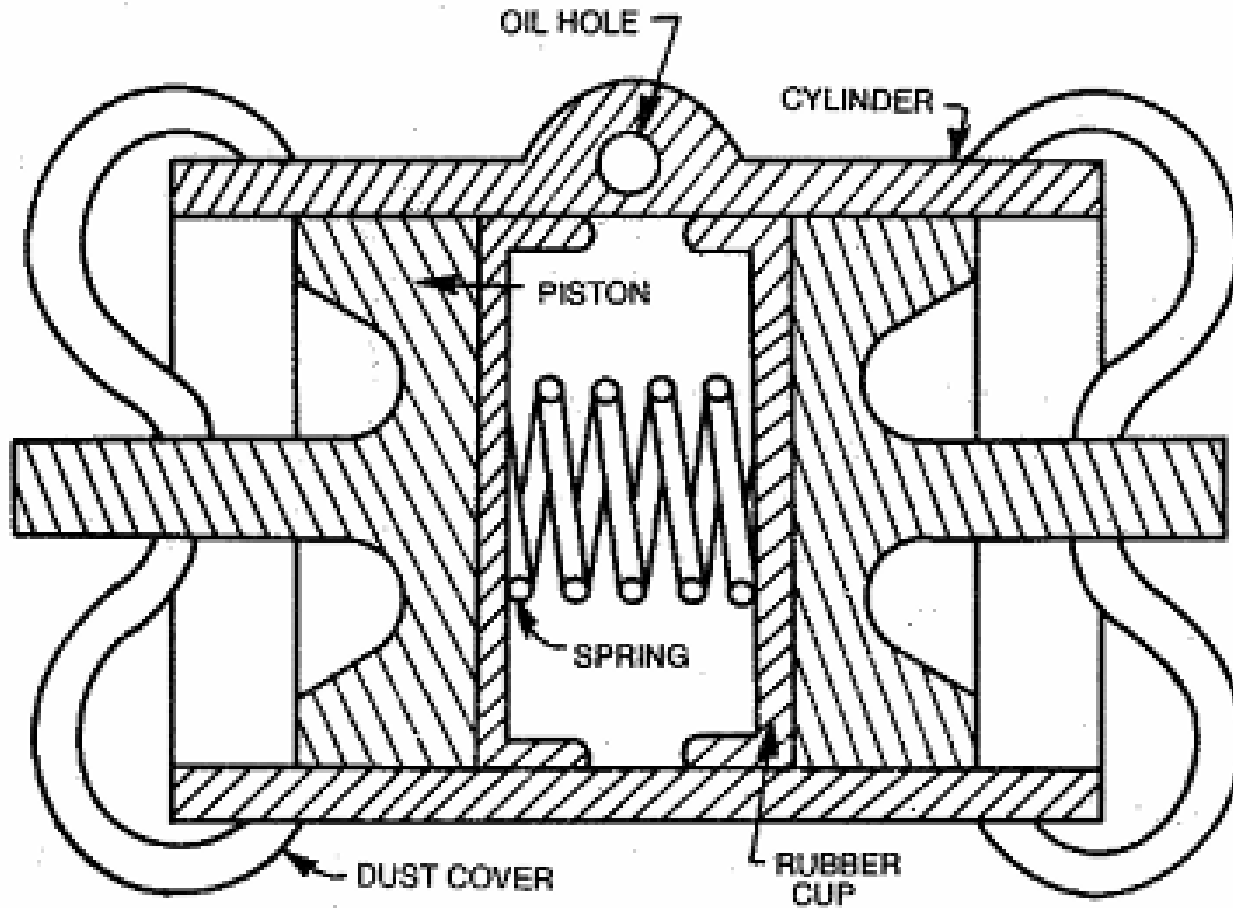
- Also, it should be appreciated that trying to stop quickly with just the rear brakes is very tricky because the rear tires will easily reach the point of lock-up.
- As the car is slowing, weight transfers forward and the rear wheels lose some of their much needed traction.
- If a leak develops in the rear brake system, Piston 2 will move forward until it contacts the closed end of the master cylinder housing.
- Once Piston 2 becomes stationary, pressurization of fluid between the two pistons will apply the front brakes.
- Although overall braking performance will be significantly compromised, the front brakes will still be functional provided sufficient pedal travel is available.



- The pedal will need to travel further than normal to fully engage the front brakes. (Frankly, some inattentive or inexperienced drivers have been known to continue driving with non-functional rear brakes, despite longer pedal travel and longer stopping distances. For this reason, newer cars are fitted with brake failure warning lights.)



## ❖ Wheel Cylinder:





- Wheel cylinder is the second important Part in the hydraulic brake system.
- It consists of two pistons which can move in opposite directions by the fluid pressure.
- It is rigidly mounted on the brake shield or backing plate.
- The boots protect the cylinders from foreign substances.
- Bleeder valves are provided in the cylinder to permit air and liquid to be pumped out of the system during of the bleeding operation .
- Piston cup fits tightly in the cylinder against each piston and seal the mechanism against leakage of the brake fluid.
- A Spring serves to hold the cups against the piston when the pressure is decreased.



- When the brakes are applied the brake fluid enters the cylinder from a brake line connection inlet between the two pistons.
- It causes to force out the two pistons in opposite directions.
- This motion is transmitted to the brake shoe.
- Directly or through links force them against the brake drum, thus applying the brake.