MODULE 4

SUSPENSION

SYLLABUS:

Suspension: - suspension geometry, terminology- Macpherson strut friction and spring offset - suspension roll centers: -roll centers, roll axis, roll center height, short swing and long arm suspension, transverse double wishbone, parallel trailing double arm and vertical pill strut suspension, Macpherson strut suspension, semi-trailing arm rear suspension, telescopic suspension.

High load beam axle leaf spring, sprung body roll stability. Rear axle beam suspension- body roll stability analysis: - body roll couple, body roll stiffness, body over turning couple

Body weight transfer, body direct weight transfer couple, body roll couple distribution, body roll weight transfer, lateral force distribution.

Anti-roll bars and roll stiffness: - anti roll bar function, operating principle, anti-roll bar action caused by the body rolling, single wheel lift -rubber spring bumper: -bump stop function and characteristics, axis inclination.

Rear suspension: - live rigid axle suspension, non-drive rear suspension- swing arm rear wheel drive independent suspension.

Low pivot split axle coil spring wheel drive independent suspension, trailing and semi trailing arm rear wheel drive independent suspension.

Transverse double link arm rear wheel drive independent suspension, De Dion axle rear wheel suspension - Hydrogen suspension, hydro-pneumatic automatic height correction suspension.

SUSPENSION GEOMETRY:

- The stability and effective handling of a vehicle depends upon the designer's selection of the optimum steering and suspension geometry which particularly includes the wheel camber, castor and kingpin inclination.
- It is essential for the suspension members to maintain these settings throughout their service life.
- Unfortunately, the pivoting and swiveling joints of the suspension system are subject to both wear and damage and therefore must be checked periodically.

SUSPENSION TERMINOLOGY:

- **Swivel joints or kingpins**: These are the points about which the steering wheel stub axles pivot.
- **Pivot center**: The point where the swivel ball joint axis or kingpin axis projects and intersects the ground.
- **Contact patch**: This is the flattened crown area of a tyre which contacts the ground.
- **Contact centres:** This is the tyre contact patch central point which is in contact with the ground.
- **Track**: This is the transverse distance between both steering wheel contact centres.

MACPHERSON STRUT FRICTION AND SPRING OFFSET:

- The MacPherson strut suffers from stickiness in the sliding motion of the strut, particularly under light load with an extended strut since the cylinder rod bearing and the damper piston will be closer together.
- Because the alignment of the strut depends upon these two sliding members, extending and reducing their distance will increase the side loading under these conditions.
- The problem of reducing friction between the inner and outer sliding members is largely overcome in two ways:

  1. By reducing the friction, particularly with any initial movement, using a condition which is known as stiction. This is achieved by facing the bearing surfaces with impregnated poly-tetra-fluoroethylene (PTFE) which gives the rubbing pairs an exceptionally low coefficient of friction.
  2. By eliminating the bending moment on the strut under normal straight ahead driving although there will be a bending moment under cornering condition.

- The tendency for the strut to bend arises because the wheel is offset sideways from the strut, causing the stub axle to act as a cantilever from the base of the strut to the wheel it supports, with the result the strut bends in a curve when extended or under heavy loads (Fig. 10.16)

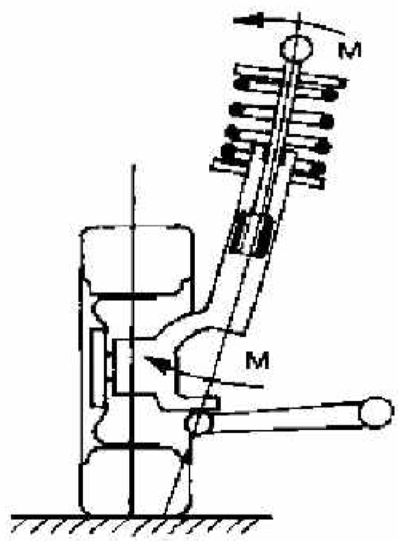


Fig. 10.16 Concentric coil spring and swivel pin axes permit bending moment reaction

- A simple solution which is commonly applied to reduce the bending moment on the strut is to angle the axis of the coil spring relative to the swivel joint axis causing the spring to apply a bending moment in the opposite sense to the vehicle load bending moment (Fig. 10.17).
- Under normal conditions this coil spring axis tilt is sufficient to neutralize the bending moment caused by the inclined strut and the stub axle offset.

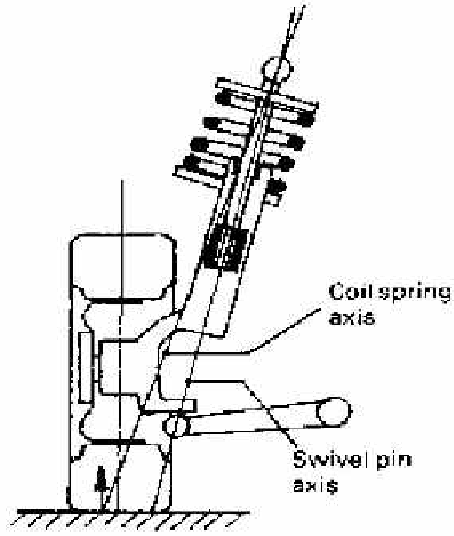


Fig. 10.17 Coil spring to swivel pin axis offset counteracts bending moment

SUSPENSION ROLL CENTERS:

ROLL CENTERS:

- The roll centre of a suspension system refers to that centre relative to the ground about which the body will instantaneously rotate. The actual position of the roll centre varies with the geometry of the suspension and the angle of roll.

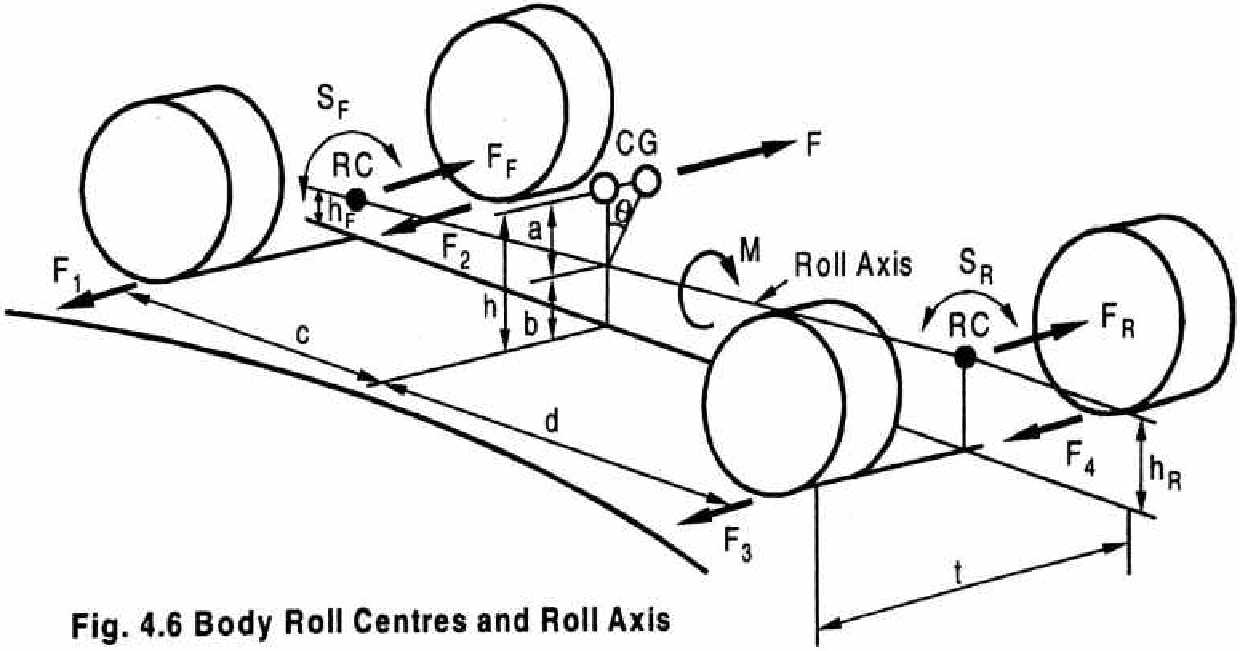


Fig. 4.6 Body Roll Centres and Roll Axis

ROLL AXIS:

- The roll axis is the line joining the roll centres of the front and the rear suspension.
- Roll centre height for the front and rear suspension will be quite different; usually the front suspension has a lower roll centre than that at the rear.
- The factors which determine the inclination of the roll axis will depend mainly on the centre of gravity height and weight distribution between front and rear axles of the vehicle.

SHORT SWING ARM SUSPENSION:

- When cornering, an overturning moment is generated which makes the body roll outwards from the centre of turn. The immediate response is that the inner and outer swing arm rise and dip respectively at their pivoted ends.

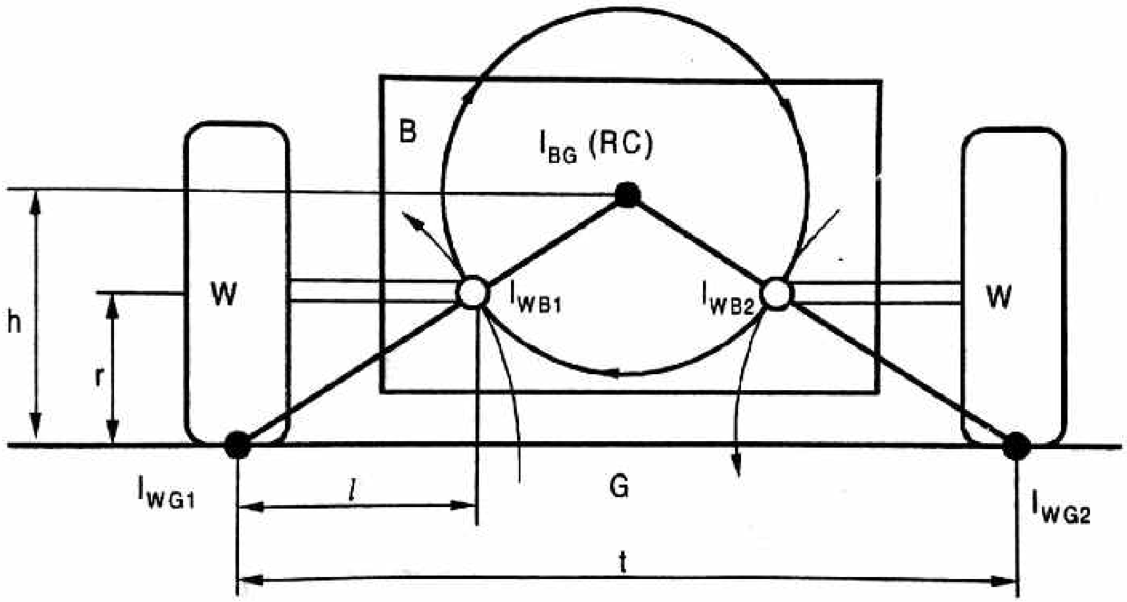


Fig. 4.7 Short Swing Axle

- The immediate response is that the inner and outer swing arm rise and dip respectively at their pivoted ends, so that the inner and outer wheels are compelled to tilt on their instantaneous tyre to ground centres, I_{WG1} and I_{WG2} in the opposite direction to the body roll.
- For effective body roll to take place there must be two movements within the suspension geometry:
  1. The swing arm pivot instantaneous centres I_{WB1} and I_{WB2} rotate about their instantaneous centres I_{WG1} and I_{WG2} in proportion to the amount of body roll.
  2. The swing arm pivot instantaneous centres I_{WB1} and I_{WB2} move on a circular path which has a centre derived by the intersecting projection lines drawn through the tyre to ground instantaneous centres I_{WG1} and I_{WG2}.

LONG SWING ARM SUSPENSION:

- The long swing arm suspension is very similar to the short swing arm arrangement previously described, but the arms extend to the opposite side of the body relative to its wheel it supports and therefore both arms overlap with each other.
- The roll centre is determined by joining the tyre contact centre and the swing arm pivot centre by a straight line for each half suspension.
- The point where these lines meet is the body roll centre and its distance above or below the ground is known as the roll centre height.
- Because the long swing arm suspension has a much longer arm than used on the short swing arm layout, the slope of the lines joining the tyre contact centre and swing arm pivot is not so steep. Therefore, the crossover point which determines the body roll centre height is lower for the long swing arm than for the short swing arm suspension.

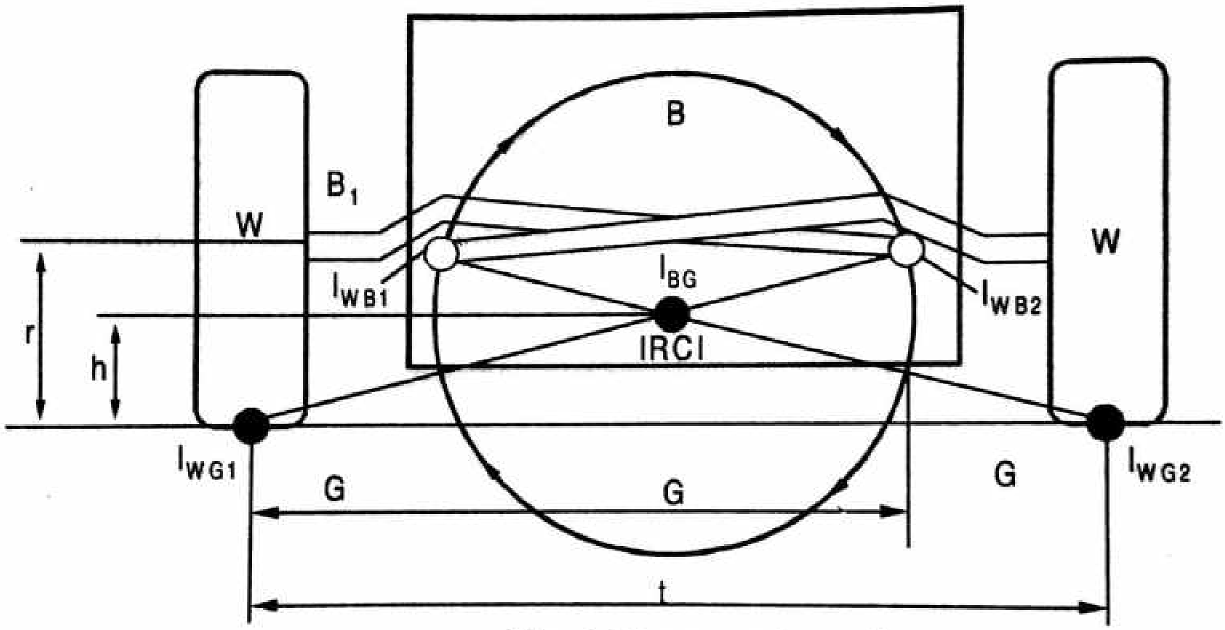


Fig. 4.8 Long swing axle

TRANSVERSE DOUBLE WISHBONE SUSPENSION:

- If lines are drawn through the upper and lower wishbone arms and extended until they meet either inwards (Fig. 10.20) or outwards (Fig. 10.21), their intersection point becomes a virtual instantaneous centre for an imaginary (virtual) triangular swing arm suspension.
- For **inwardly converging transverse** upper and lower wishbone arm suspension (Fig. 10.20) the body roll centre can be derived in two stages.
  1. Firstly, extend straight lines through the wishbone arms until they meet somewhere on the opposite side of the body at their virtual instantaneous centres I_{WB1} and I_{WB2}.
  2. Secondly, draw straight lines between the tyre contact centres I_{WG1} and I_{WG2} and the virtual centres I_{BW1} and I_{BW2} for each half suspension.

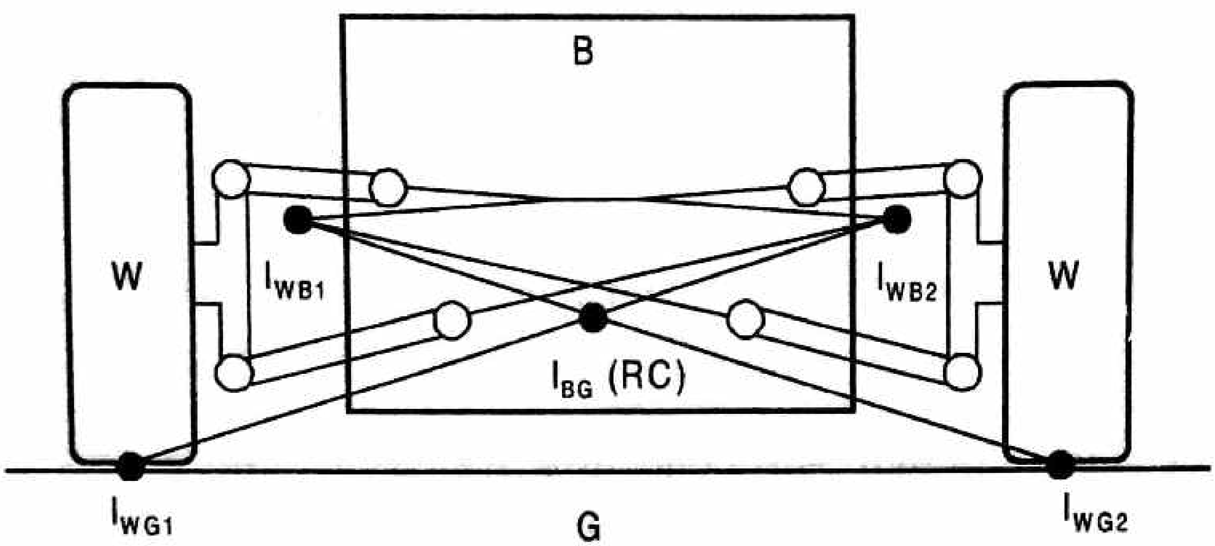


Fig. 4.9 Inward converging transverse double wishbone

- For **outward converging transverse** upper and lower wishbone arm suspension (Fig. 10.21) the body roll centre is found again by drawing two sets of lines.
- Firstly, project straight lines through the wishbone arms for each side of the vehicle until they meet somewhere on the outside of each wheel at their virtual instantaneous centres I_{WB1} and I_{WB2}.
- Next draw straight lines between the tyre contact centres I_{WG1} and I_{WG2} and the virtual centres $I_{WB1}$and I_{WB2} for each half suspension, and at the same time extend these lines until they intersect near the middle of the vehicle. This point therefore becomes the body roll centre I_{BG}.
- It can be seen that inclining the wishbone arms so that they either converge inward or outward produces a corresponding high and low roll centre height.

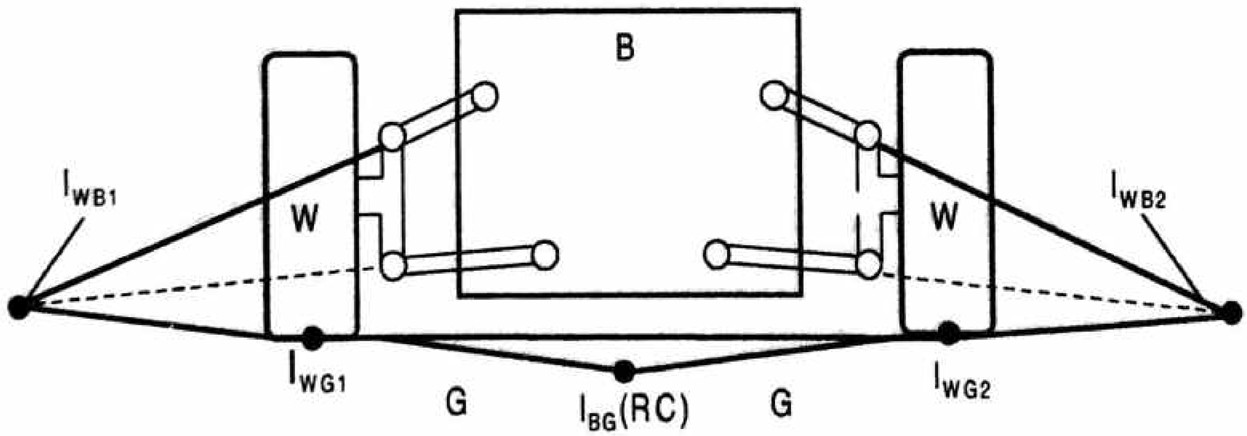


Fig. 4.10 Outward converging transverse double wishbone

- With **parallel transverse** upper and lower wishbone arms suspension (Fig. 10.22) lines drawn through the double wishbone arms would be parallel.
- They would never meet and so the virtual instantaneous centres I_{WB1} and I_{WB2} would tend to infinity.
- Under these circumstances, lines normally drawn between the tyre contact centres I_{WG1} and I_{WG2} and the virtual instantaneous centres I_{WB1} and I_{WB2} would slope similarly to the wishbone extended lines.
- Consequently, the downwardly inclined parallel wishbone suspension predicts the tyre contact centre to virtual centre extended lines which meet at the roll centre would meet just above ground level. Therefore, if the parallel wishbone arms were horizontally instead of downwardly inclined to the ground then the body roll centre would be at ground level.

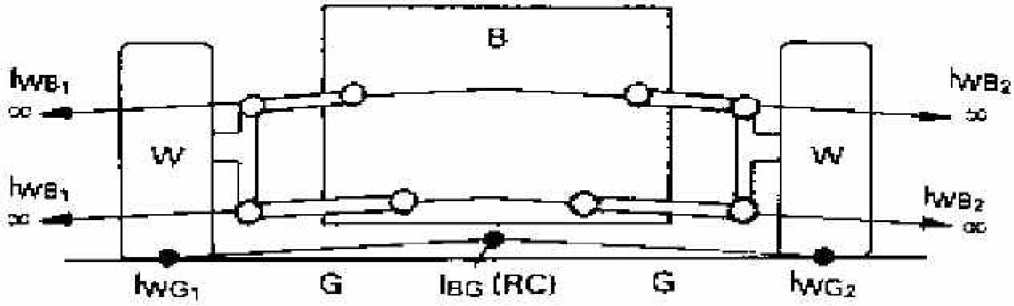


Fig. 10.22 Parallel transverse double wishbone

PARALLEL TRAILING DOUBLE ARM AND VERTICAL PILLAR STRUT SUSPENSION:

- In both examples of parallel double trailing arm (Fig. 10.23) and vertical pillar strut (Fig. 10.24) suspensions their construction geometry becomes similar to the parallel transverse double wishbone layout, due to both vertical stub axle members moving parallel to the body as they deflect up and down.
- Hence looking at the suspension from the front, neither the double trailing arms (Fig. 10.23) nor the sliding pillar (Fig. 10.24) layout has any trans verse swing tendency about some imaginary pivot. Lines drawn through the two trailing arm pivot axes or sliding pillar stub axle, which represent the principle construction points for determining the virtual swing arm centres, project to infinity.
- The tyre contact centre to virtual instantaneous centre joining lines projected towards the middle of the vehicle will therefore meet at ground level, thus setting the body roll centre position.
- Inclining the trailing arm pivot axes or the vertical sliding pillar axis enables the roll centre height to be varied proportionally.

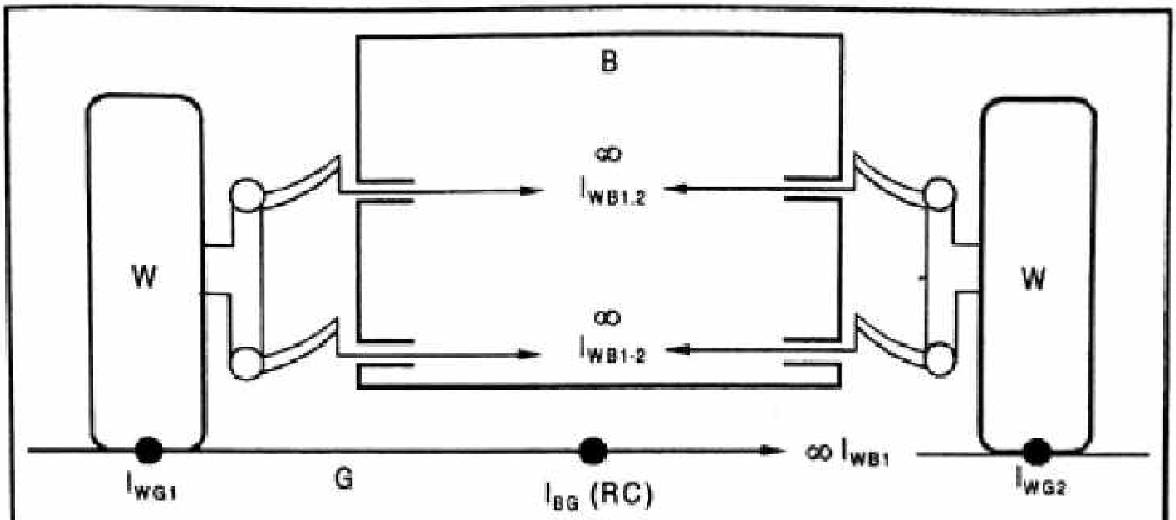


Fig. 4.11 Parallel trailing double arm

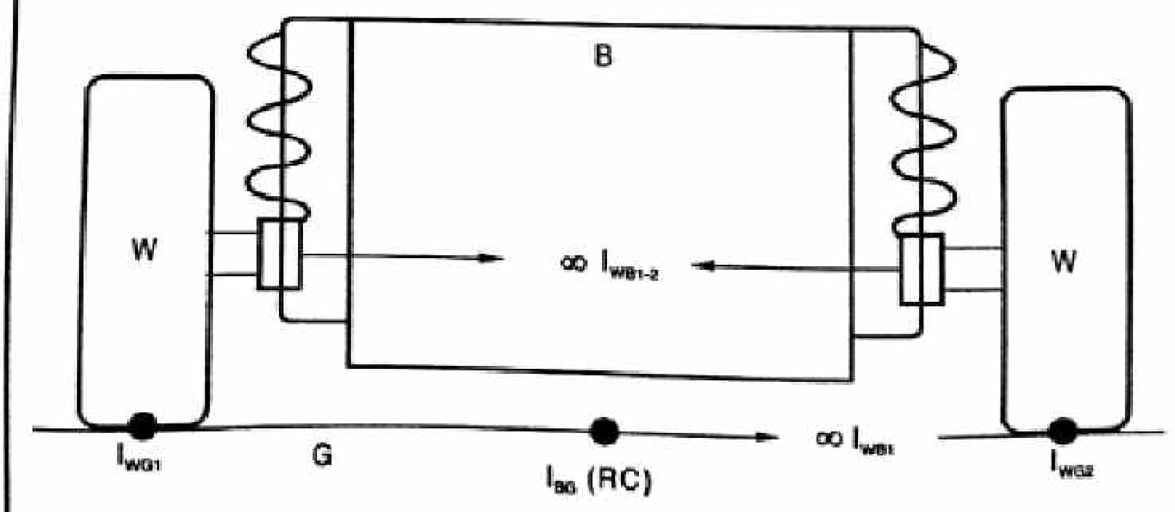


Fig. 4.12 Vertical pillar strut

MAC PHERSON TYPE SUSPENSION:

- In this most widely used layout, only lower wishbones are used.
- A strut containing shock absorber and the spring carries also the stub axle on which the wheel is mounted.
- The wishbone is hinged to the cross member and positions the wheel as well as resists accelerating, braking and-side forces.
- This system is simpler than double wishbone type and is also lighter, keeping the unsprung weight lower.
- Further, the camber also does not change when the wheel moves up and down. This type of suspension gives the maximum room in the engine compartment and is, therefore, commonly used on front wheel drive cars.

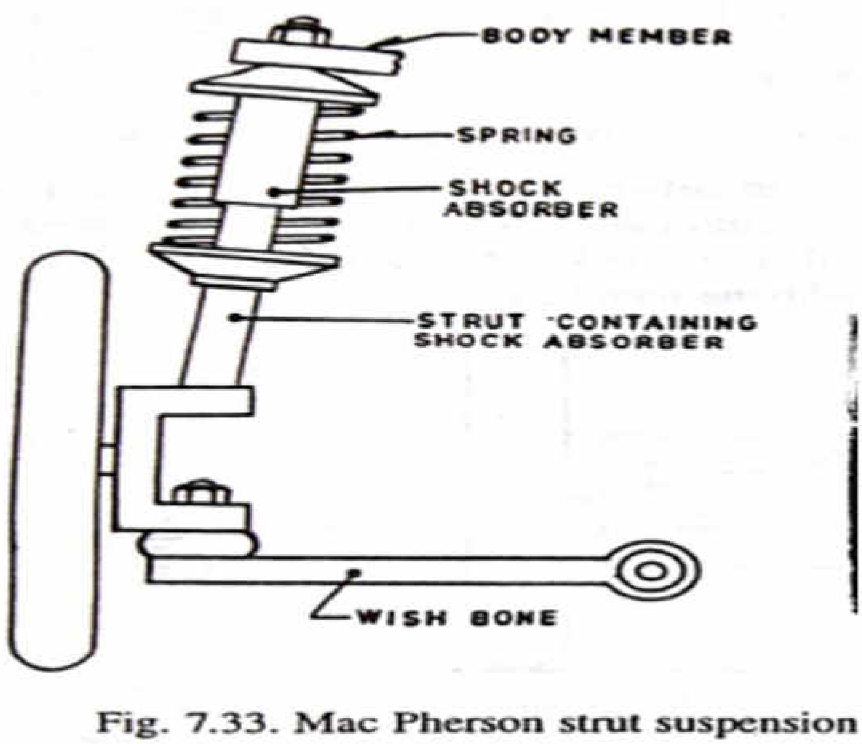
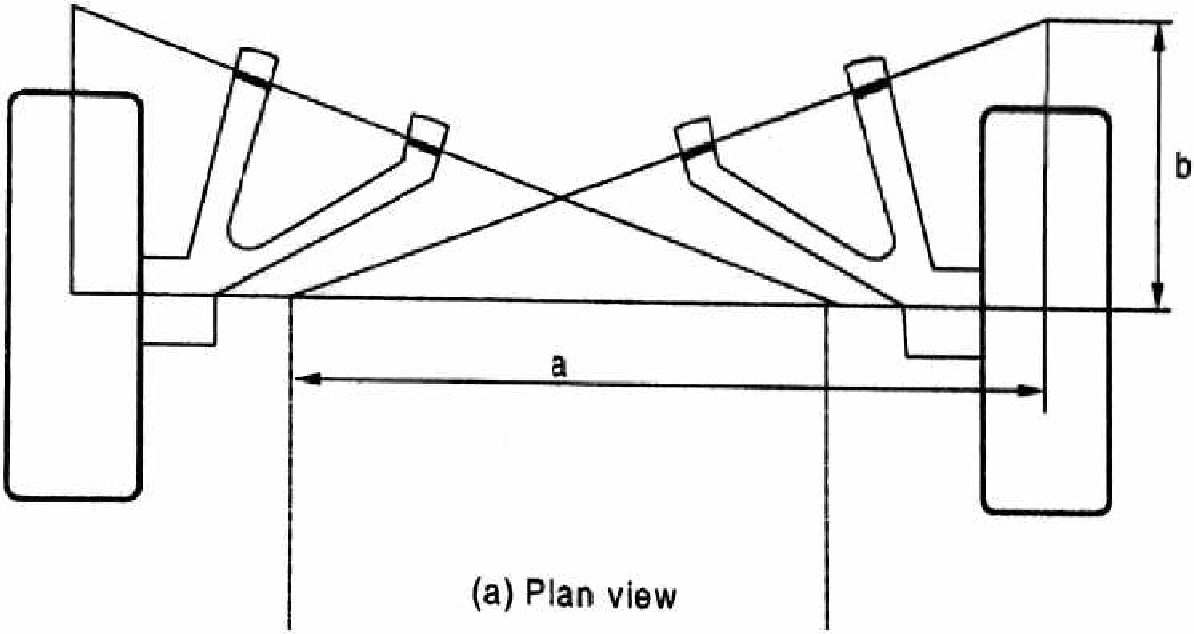


Fig. 7.33. Mac Pherson strut suspension

SEMI-TRAILING ARM SUSPENSION:



(a) Plan view

TELESCOPIC SUSPENSION:

- Suspensions are different in type, among them telescopic suspension is popular one.
- Almost every motorcycle uses telescopic forks for the front suspension.
- The forks are simply large hydraulic shock absorbers with internal coil spring. They allow front wheel to react to a limitation in road while separating the rest of motorcycle from that motion.

TELESCOPIC SHOCK ABSORBER:

- The telescopic shock absorber is shown in Fig. 4.15.
- The shock absorber lengthens and shortens as the wheels meet bump and pot holes.
- When this happen, a piston inside a cylinder of the shock absorber is moved up or down.
- The cylinder is filled with fluid.
- There are valve openings in the piston and also at bottom of cylinder tube.

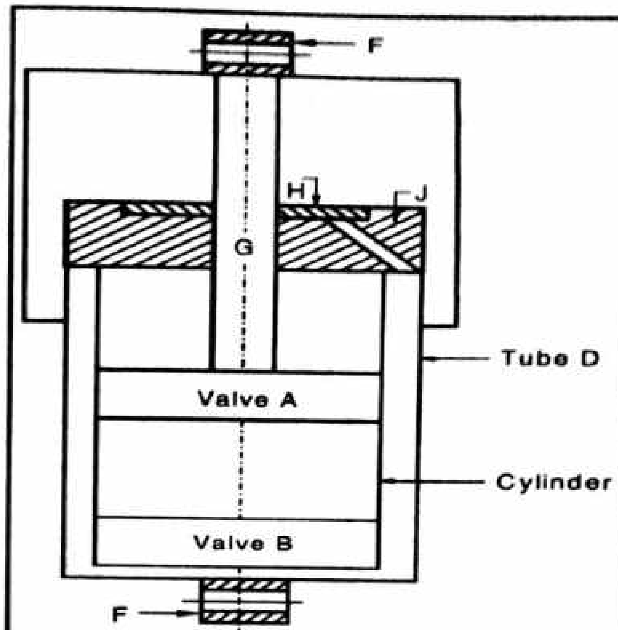


Fig. 4.15 - Telescopic Shock Absorber

- There is a reservoir tube full of the fluid.
- When the shock absorber is compressed, the fluid in the cylinder passes upwards through the restricted piston valves.
- At the same time, the fluid passes down through a small valve of the cylinder tube.
- By this arrangement, piston moves against the resistance of the fluid.
- Thus, the shock on the vehicle is absorbed by the fluid, in the shock absorber.
- In this way, telescopic shock absorber is useful in bikes.

Advantages of telescopic shock absorber:

- More resistance to shock
- Better durability
- No need for readjustment
- Instantaneous response to sudden shock.

BODY ROLL STABILITY ANALYSIS:

- When a vehicle moves on corner, the centrifugal force generated acts outwards through the center of gravity of the sprung mass, but the tyre to ground reaction, opposes it.
- Therefore, the vehicle will tend to overturn.
- An overturning movement is produced which transfers weight from the inner wheels to the outside wheels.
- The opposition to any body roll will be distributed between the front and rear suspension.

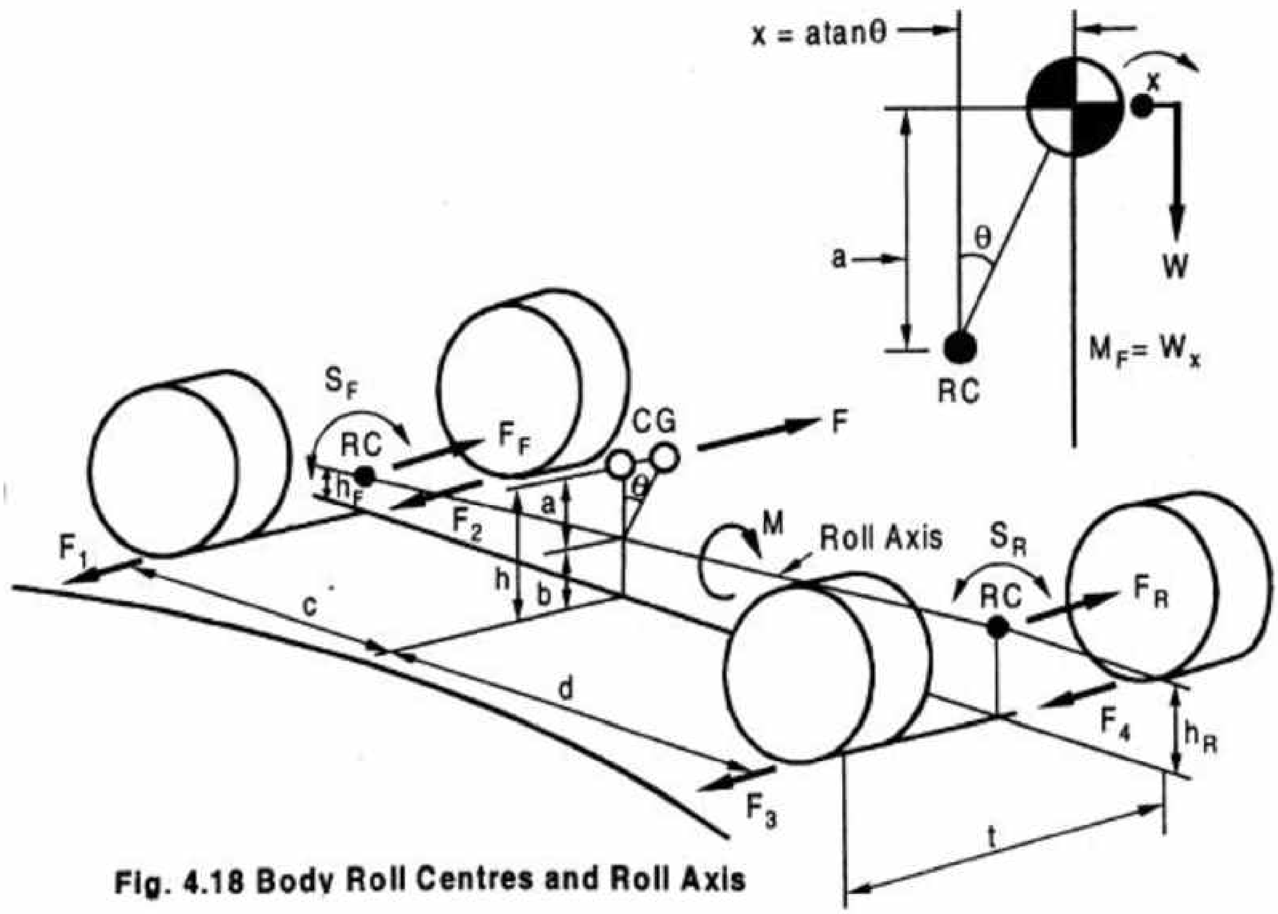


Fig. 4.18 Body Roll Centres and Roll Axis

Body roll couple

- From the **Fig. 4.18**, the body roll couple is obtained.
- The body roll couple (moment) μ has two components.

(i) Centrifugal moment about the roll centre $= Fa$ (Nm)

(ii) Transverse displacement moment $= Wa \tan\theta$ (Nm)

where F – Centrifugal side force

a – Distance between the centre of gravity and roll centre.

W – Unsprung weight

θ – Angle of body roll.

Therefore, total roll movement, $M = Fa + Wa\tan\theta$

$M = [F + W\tan\theta]\, a$ (Nm)

Body roll stiffness

It is defined as the roll couple produced per degree of body roll.

ie., Roll stiffness $= \dfrac{\text{Roll couple}}{\text{Roll angle}}$ (Nm/deg)

$$S = \frac{m}{\theta} \text{ (Nm/deg)}$$

where S – Roll stiffness (Nm/deg)

m – Roll couple (Nm)

θ – Angle of roll (deg)

The fraction of torsional stiffness for the front and rear suspension will be given:

$$S_F = \frac{S_F}{S_F + S_R}$$

$$S_R = \frac{S_R}{S_R + S_F}$$

where S_F – fraction of front torsional stiffness.

S_R – fraction of rear torsional stiffness.

Body over turning couple

When a vehicle is moving on a circular track, the centrifugal force F created acts through the body's centre of gravity (CG) at some height h

- It is opposed by the four tyre to ground reaction forces F_1, F_2, F_3 and F_4.
- The body overturning couple is shown in **Fig. 4.19.**

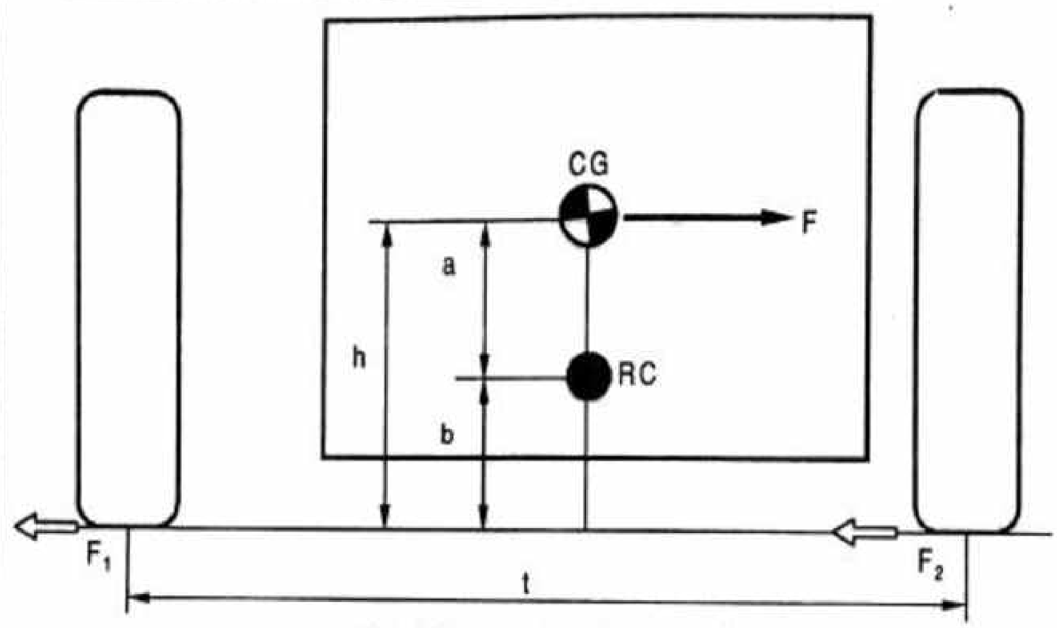


Fig. 4.19 Overturning couple

- Consequently, an over turning couple Fh is produced that transfers weight W from the inside wheels to the outer wheels, which are spaced the track width t apart.
- Thus, the overturning couple is equivalent to Wt ie., $Wt = Fh$

i.e., Weight transferred, $W = \frac{Fh}{t}$ in N

The centre of gravity height 'h' is obtained from two measurements:

- The distance between the ground and the body roll centre b.
- The distance between the roll centre and the centre of gravity a.

Therefore, Total body roll couple $Fh = F(a + b)$ in N

$$\mu = Fa + Fb \text{ in } N$$

Body roll weight transfer

- The overturning couple (Fa) is rotating about the roll centre that causes the body to roll. The body roll weight transfer is shown in **Fig. 4.20.**

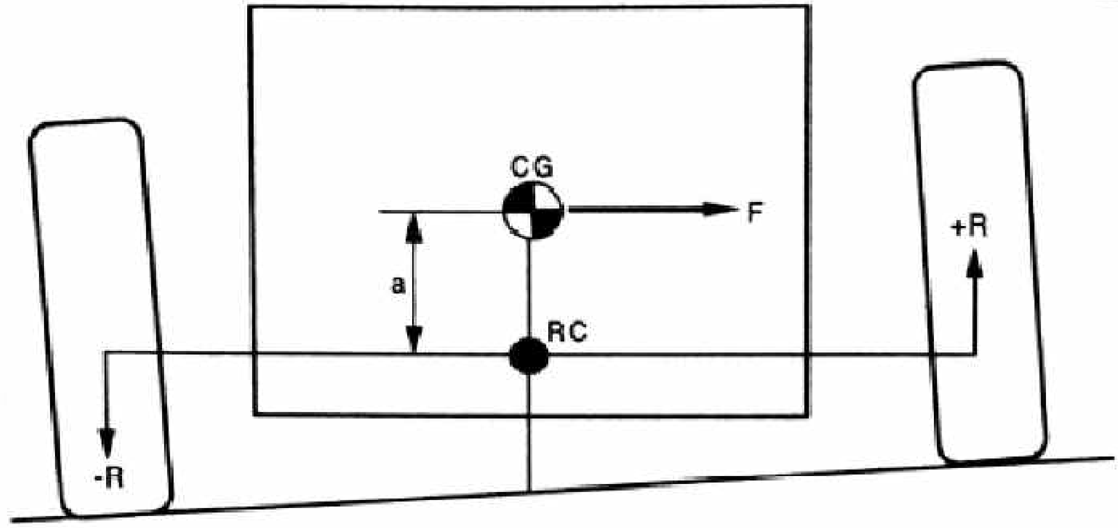


Fig. 4.20 Body Roll Weight Transfer

- This couple is opposed by a reaction couple, Rt

Therefore, $Rt = Fa$

$$\Rightarrow \quad R = \frac{Fa}{t} \text{ in } N$$

R – Vertical reaction force.

t – Wheel track width

- As the distance between the ground and the body roll centre known as the couple arm becomes smaller, the overturning couple and therefore the body roll will also be reduced in the same proportion.
- Therefore, if the couple arm is minimized to zero the reaction force R will approach zero.

Body direct weight transfer couple

- If the centrifugal force is acting through the roll centre axis instead of through the centre of gravity, a moment (*Fb*) about the ground would be produced. The body direct weight transfer is shown in **Fig. 4.21.**

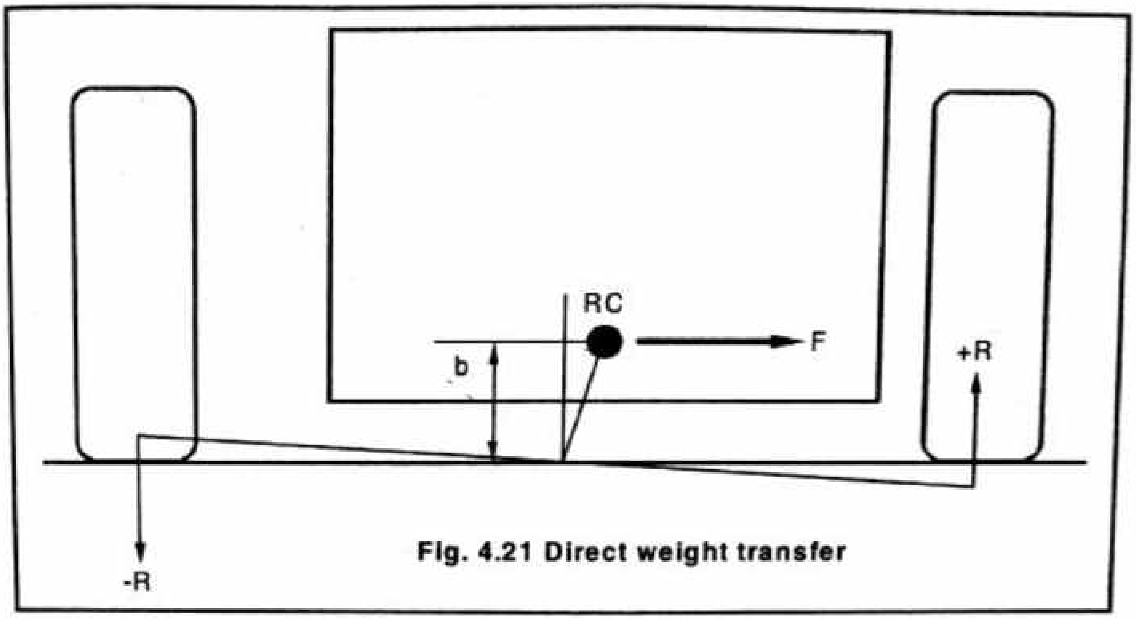


Fig. 4.21 Direct weight transfer

- Therefore, direct transfer of weight from the inner to the outer wheels occurs.
- The resisting moment *Rt* is equal but opposite in sense to moment *Fb*. Hence, $Rt = Fb$
- If two forces F_F and F_R are acting outwards from the front and rear roll centres, then the reaction forces will be,

$$R_F = \frac{F_F\, b_F}{t} \text{ in } N$$

$$R_R = \frac{F_R\, b_R}{t} \text{ in } N$$

where R, R_F and R_R – Total, front and rear vertical forces respectively.

- By reducing the body roll centre, correspondingly decreases the vertical reaction force *R*.

- By having roll centre at ground level, direct weight transfer couple is eliminated.
- If roll axis slopes from ground upwards from front to rear, all the direct weight transfer couple will be concentrated on the rear wheels.

Body roll couple distribution

- The body roll couple on the front and rear tyres is proportional to the front and rear suspension stiffness fraction.

i.e., Roll couple on front tyres is given as,

$$M_F = \frac{S_F}{S_F + S_R}(F + W\theta)\,a + F_F h_F \text{ (Nm)}$$

Similarly, Roll couple on rear tyres is given as,

$$M_R = \frac{S_R}{S_R + S_F}(F + W\theta)\,a + F_R h_R \text{ (Nm)}$$

(i) Body roll angle

It is defined as the roll couple per unit of roll stiffness.

$$\Rightarrow \text{Total roll angle } = \frac{\text{Roll couple}}{\text{Roll stiffness}} = \frac{\text{Nm}}{\text{Nm/Deg}}$$

$$\text{ie., Total roll angle } = \frac{M}{S_F + S_R} \text{ (Deg)}$$

Body roll weight transfer

It is defined as the ratio of roll couple to track width.

$$\text{Total roll weight transfer } = \frac{\text{Roll couple}}{\text{Track width}}\left(\frac{\text{Nm}}{\text{m}}\right)$$

$$W = m/t \text{ in N}$$

$$\text{Front suspension: } W_F = \frac{S_F}{S_F + S_R} \times \frac{m}{t} \text{ in N}$$

$$\text{Rear suspension: } W_R = \frac{S_R}{S_R + S_F} \times \frac{m}{t} \text{ in N}$$

where, W, W_F and W_R = Total, front and rear weight transfer respectively in N

t = Track width in m

Lateral force distribution

The total lateral resisting forces generated at all tyre to ground interfaces should be equal to the centrifugal force acting through the body's centre of gravity. The longitudinal weight distribution is shown in **Fig. 4.22.**

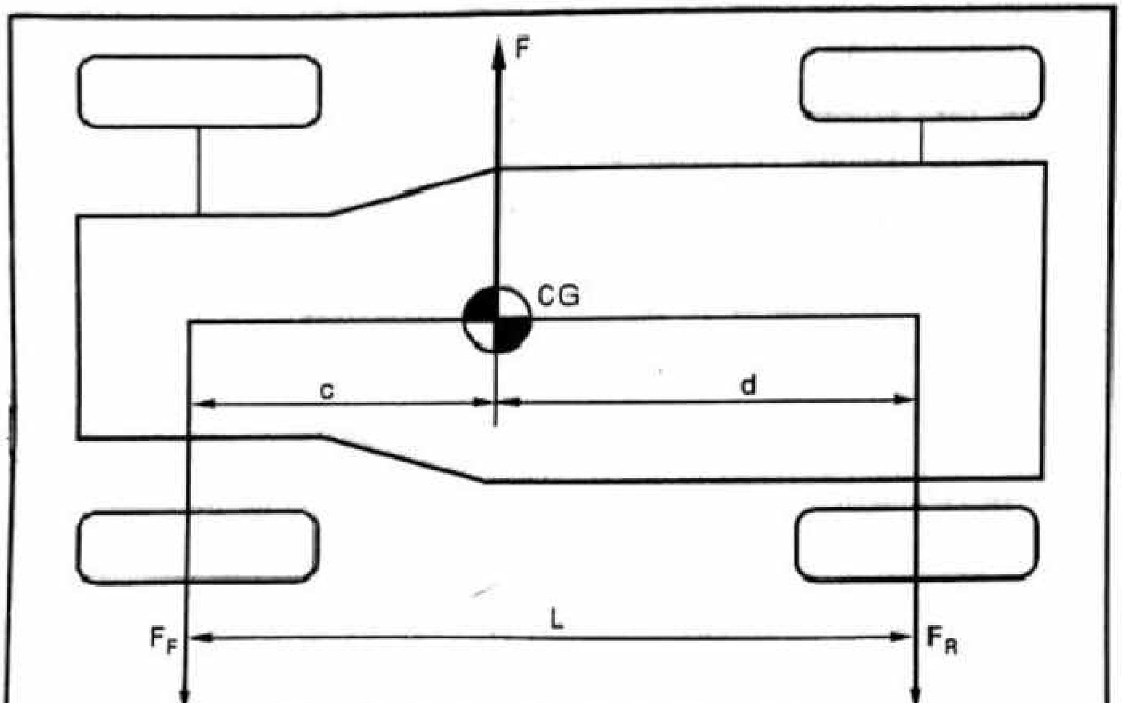


Fig. 4.22 Longitudinal Weight Distributions

From diagram,

F_F, F_R – Forces at front and rear wheels

- Thus, the amount of load and cornering force carried by either the front (a) rear tyres is proportional to the distance of centre of gravity from one (or) other axle.
- At the front half of the vehicle, slightly more weight is concentrated.
- Therefore, greater cornering forces and slip angles are generated at the front wheels compared to rear.

ANTI ROLL BARS AND ROLL STIFFNESS:

Anti-roll bar function:

- A torsion anti-roll bar is incorporated into the suspension of a vehicle with low rate soft springs. The anti-roll bar is shown in Fig. 4.23.
- It also provides a more comfortable ride under normal driving conditions.

- The anti-roll bar becomes effective if one wheel is raised higher than the other as the vehicle passes over a hump (speed breaker) in the road.
- When a pair of wheels supported on axle travel over bumpy road one (or) other wheel will lift and fall.
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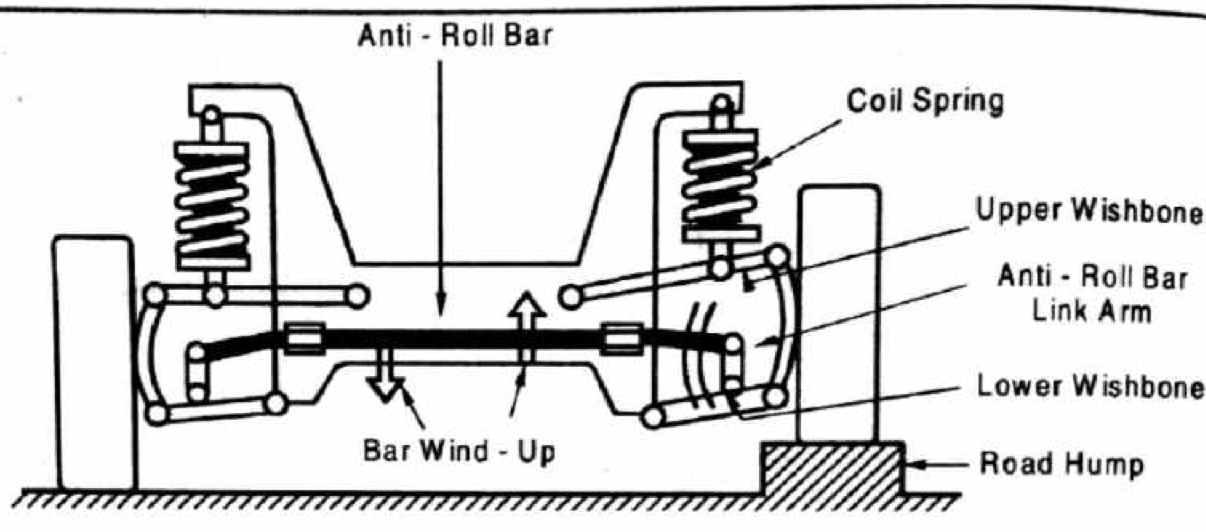


Fig. 4.23 - Transverse Double Wishbone Coil Spring Independent Suspension with Anti-Roll Bar

- If the springs are very hard, they have high spring rate while moving in bumpy road, more disturbance occurs.
- The soft spring with lower spring rate effectively reduces disturbance.
- But, in cornering, there is insufficient stiffness to resist overturning moment. Hence anti-roll bars are used. This also increases the vehicle's ride comfort.
- This is possible because the soft spring improve the suspension response on good straight roadway, with the help of anti-roll bar.
- The relationship of body roll and suspension spring and anti-roll bar stiffness is shown in Fig. 4.25.

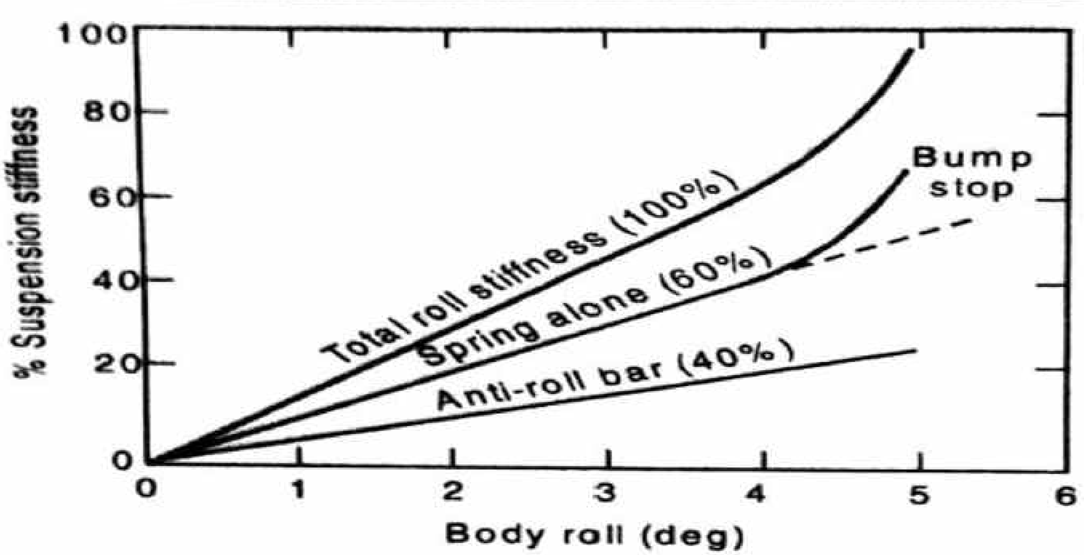


Fig. 4.25 Relationship of body roll and suspension spring and anti-roll bar stiffness

Anti-roll bar caused by the body rolling:

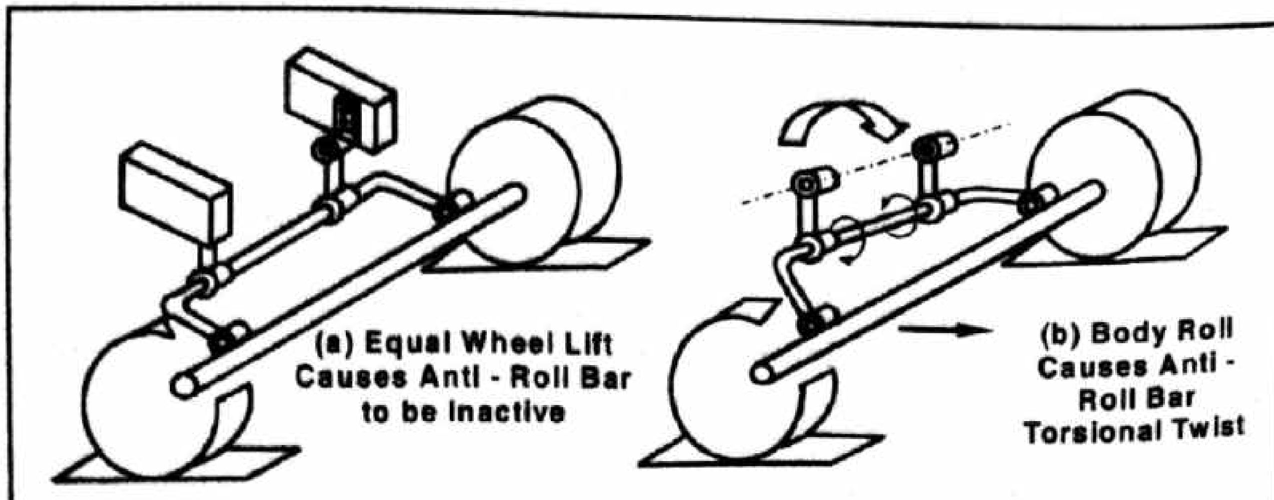
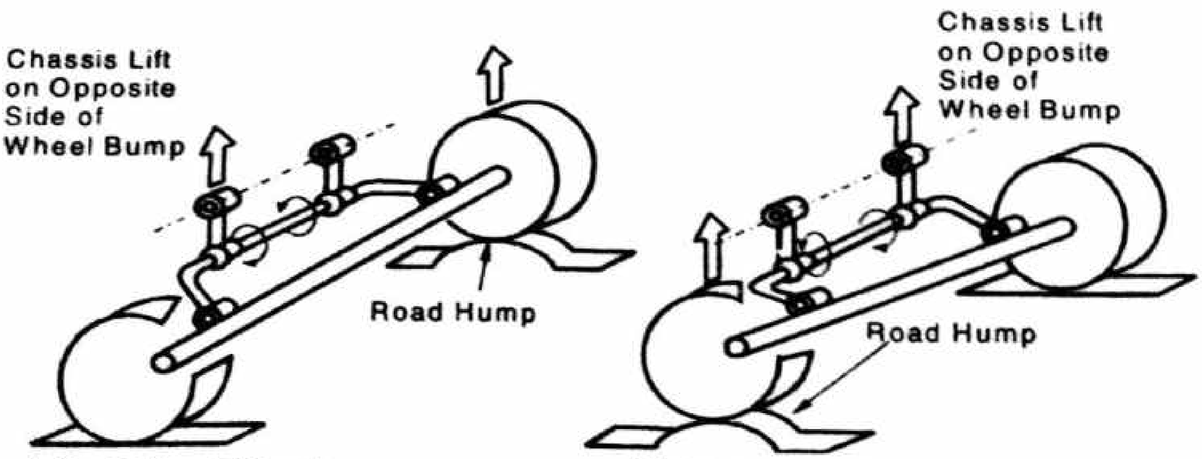


Fig. 4.26

- While cornering, the centrifugal force acting through the center of gravity of the sprung body generates an overturning moment, which will therefore tend to make the body roll. [Shown in Fig. 4.26].
- The rolling body will tilt the transverse span of the roll bar so that cranked arms on the outer wheel to the turn will be depressed down, whereas cranked arm on inside wheel to the turn will be rised.
- The consequence of misalignment of anti-roll bar arms, transmit torque from the inside wheel (which is subject to less load) to the outside wheel which is heavily loaded.

Anti-roll bar action caused by single wheel lift:



(a) Left Hand Wheel Lift Causing Anti-Roll Bar Torsional Twist

(b) Right Hand Wheel Lift Causing Anti-Roll Bar Torsional Twist

Fig. 4.27 Anti-Roll Bar Action

- If one of a pair of axle wheels lifts as it climbs over bump in road, the vertical deflection of the spring and wheel increases.
- It also rotates the anti-roll bar's cranked arm on that side, so that transverse span of the bar is twisted.

- The bar is therefore subjected to a torque which is proportional to its angle of rotation.
- The anti-roll bar action is shown in Fig.

REAR SUSPENSION:

- Commonly used rear suspension systems are:
    1. live rigid axle suspension
    2. Non-drive rear suspension
    3. swing arm rear wheel drive independent suspension.
    4. Low pivot split axle coil spring wheel drive independent suspension
    5. Trailing and semi trailing arm rear wheel drive independent suspension.
    6. Transverse double link arm rear wheel drive independent suspension
    7. De Dion axle rear wheel suspension

1. LIVE RIGID AXLE SUSPENSION:

- Live axle suspension geometry characteristics are given below;
    - Wheel camber is zero if the vehicle is stationary (or) moving in the road.
    - If the one-wheel travels over dip in the road, then the axle will tilt.
    - Wheel track remains constant under all driving condition.
    - In live axle, the unsprung weight is very high.
    - The live rigid axle is attached to the body by either leaf or coil springs.
- But the body weight distribution cannot be predicted. This will result in poor road holding and steering response.

2. NON-DRIVE REAR SUSPENSION:

- The non-drive rear axle is also called as dead axle.
- It does not have the drawback of large unsprung weight.
- It maintains both wheels parallel at all times.
- This suspension linkage is used to provide a vertically up and downward motion of the axle relative to the body.
- It also prevents longitudinal and lateral axle misalignment due to braking thrust, cross winds (or) centrifugal side force.

3. SWING ARM REAR WHEEL DRIVE INDEPENDENT SUSPENSION:

- In this suspension system, pair of triangular transverse swing arm members is situated on the either side of final drive. (Shown in Fig. 4.31)

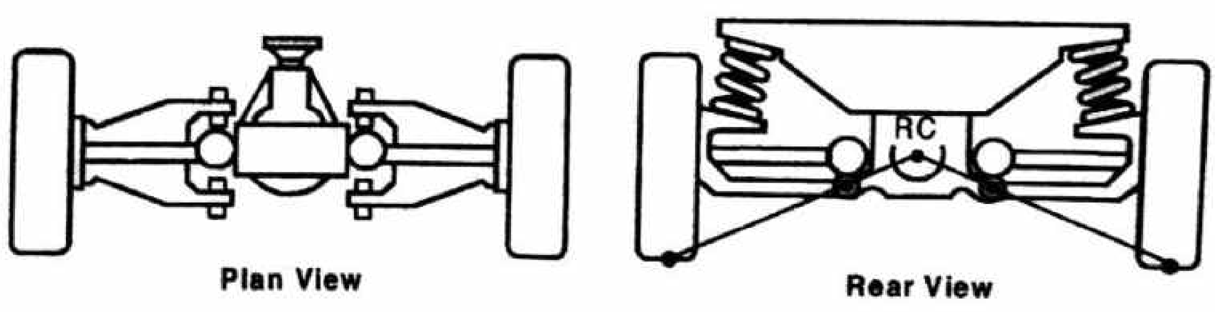


Fig. 4.31 Transverse swing arm coil spring rear wheel drive independent suspension

- Coil springs are located vertically on top of swing arm members near the outer ends.
- Each drive shaft has only one universal joint mounted inboard with its centre aligned with that of swing arm pivot axes.
- When the body rolls during cornering, the inner and outer wheels relative to turn become cambered negatively and positively respectively.
- With a change in static weight of the vehicle, both swing arms dip an equal amount that decreases the wheel track width.
- Both wheels will remain parallel at all times as there is no change in toe-in or toe-out.

4. LOW PIVOT SPLIT AXLE COIL SPRING WHEEL DRIVE INDEPENDENT SUSPENSION:

- The conventional swing arm type suspension is affected from three major limitations:
  - The swing arms were relatively short because the pivot had to be mounted on either side of the final drive housing.
  - The body roll centre of this suspension system is high.
  - When cornering, shoot swing arms are jacked up. With the load concentrated on the outside, the highly positively cambered wheel loses its ability to hold on the road.
- This type of suspension was developed to overcome the shortcomings of the relatively large change in wheel camber and the very high roll centre height. It is shown in Fig. 4.32

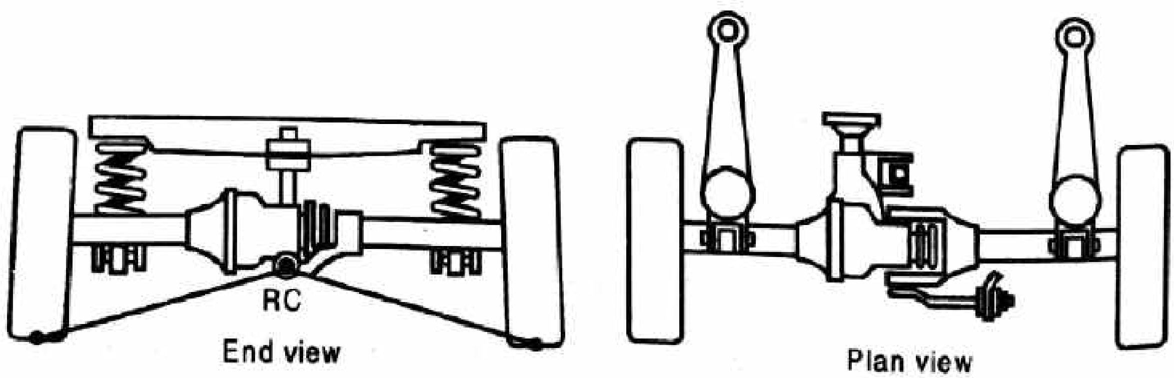


Fig. 4.32 Low pivot split axle coil spring rear wheel drive suspension

- With this modified swing axle arrangement, the axle is split into two, with the adjacent half axles hinged on a common pivot axis below the final drive housing.
- A vertical strut supports final drive assembly.
- The left-hand side half axle consists of a drive shaft, crown wheel and differential unit.
- A single universal joint is located inside the casing so that it aligns with the axle's pivot axis.
- The right-hand half axle consists of drive shaft and a rubber boot. The boot secures the final drive assembly from outside contamination, such as dirt and water.
- A horizontal arm forms a link between the pivot axis and body structure. It controls any lateral movement of the body relative to the axles.

5. TRAILING ARM REAR WHEEL DRIVE INDEPENDENT SUSPENSION:

- The independent trailing arm suspension consists of both the right- and left-hand arms, (shown in Fig. 4.33)
- They are hinged on axis at right angles to the vehicle center line.