RAIL WHEEL INTERACTION

SILABHADRA DAS

ASSISTANT. PROFESSOR(WMT)

IRIMEE JAMALPUR

RAIL WHEEL INTERACTION

- **Running of a railway vehicle over a length of track produces dynamic forces both on the vehicle and on the track**
- **The interaction affects both track and railway vehicle – *rail wheel interaction***
- **It is a complex non-linear phenomenon**

EFFECT OF VEHICLE ON TRACK

- **DETERIORATION OF TRACK GEOMETRY**
- **TRACK COMPONENT WEAR & DAMAGE**
- **NOISE**

EFFECT OF TRACK ON VEHICLE

- **SAFETY**
- **RIDING COMFORT**
- **COMPONENT WEAR & DAMAGE**

NEED FOR UNDERSTANDING

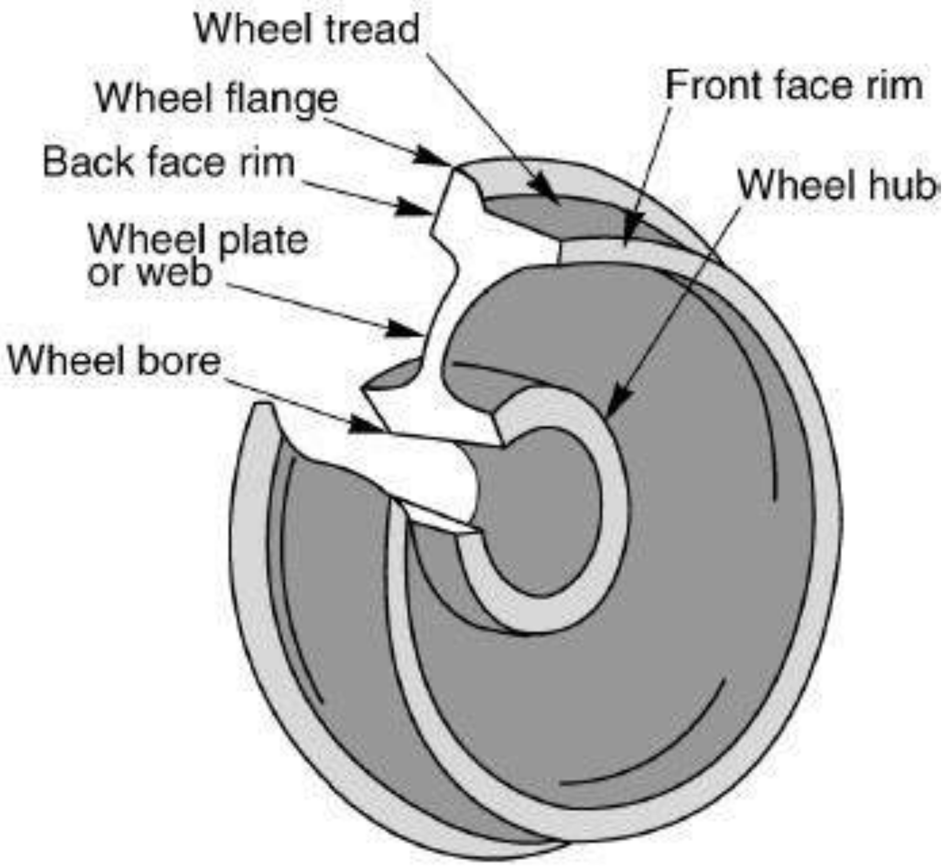
- REDUCE SAFETY RISK
- IMPROVE RIDING COMFORT
- REDUCE DETERIORATION OF TRACK GEOMETRY
- MINIMISE WEAR
- REDUCE NOISE AND VIBRATIONS IN VEHICLE

UNDERSTANDING RAIL -WHEEL INTERACTION

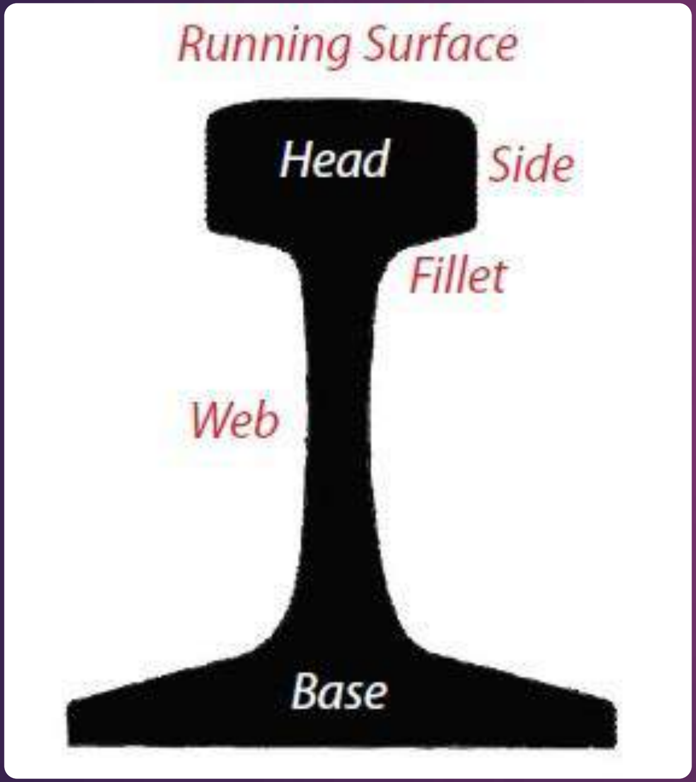
- DERAILMENT BY FLANGE MOUNTING
- WHEEL CONICITY AND GAUGE PLAY
- WHEEL OFF-LOADING
- CYCLIC TRACK IRREGULARITIES-RESONANCE & DAMPING
- CRITICAL SPEED
- TRACK / VEHICLE TWIST

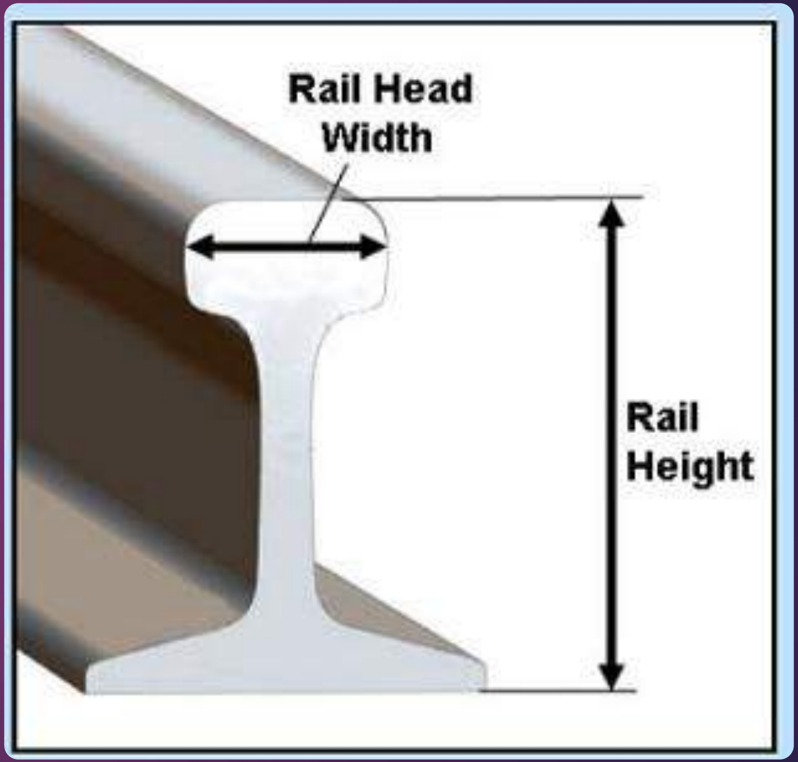
WHEEL

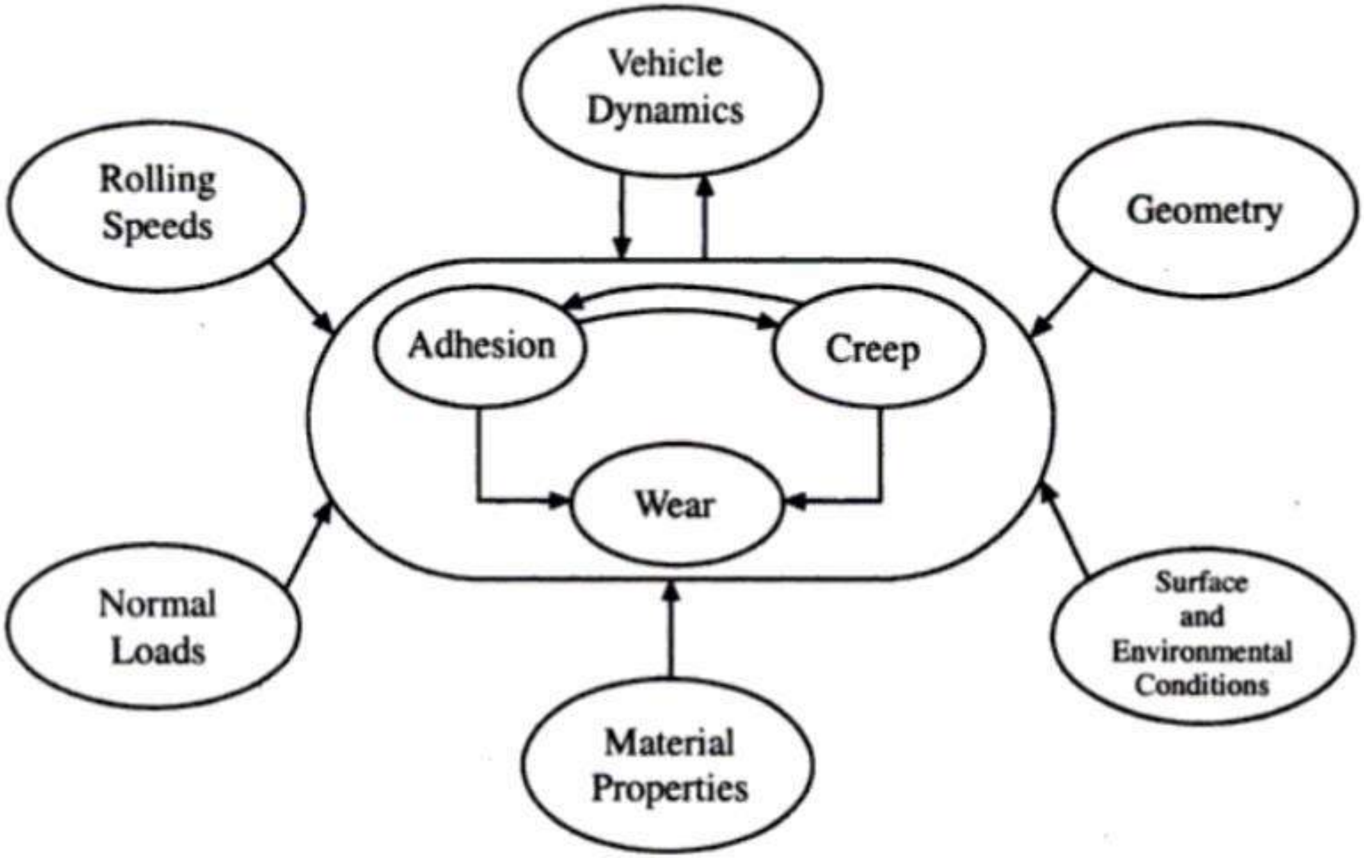
Wheel


Wheel tread
Wheel flange
Back face rim
Wheel plate
or web
Wheel bore
Front face rim
Wheel hub

RAIL


Running Surface
Head
Side
Fillet
Web
Base


Rail Head Width
Rail Height


Vehicle Dynamics
Rolling Speeds
Geometry
Adhesion
Creep
Wear
Normal Loads
Surface and Environmental Conditions
Material Properties

Rail wheel contact creepage

Creep occurs when two rigid bodies are pressed against each other and allowed to roll.

The contact surface thus created will be elliptical as per Hertz static theory.

Creepage is used to account for the deviations of velocities from pure rolling conditions.

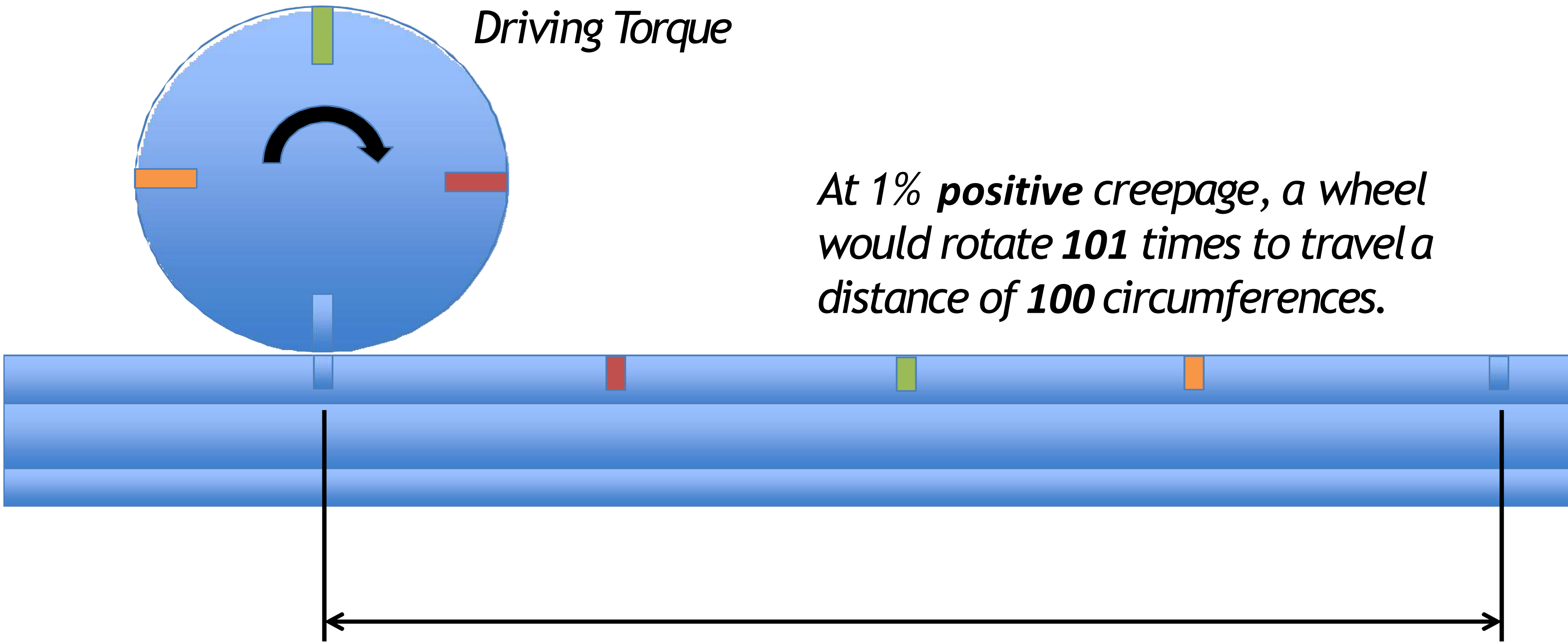
- *Longitudinal creepage,*
- *Lateral creepage*
- *Spin creepage*

Longitudinal creepage

$$\xi_x = \frac{\text{actural forward velocity} - \text{pure rolling forward velocity}}{\text{pure rolling forward velocity}}$$

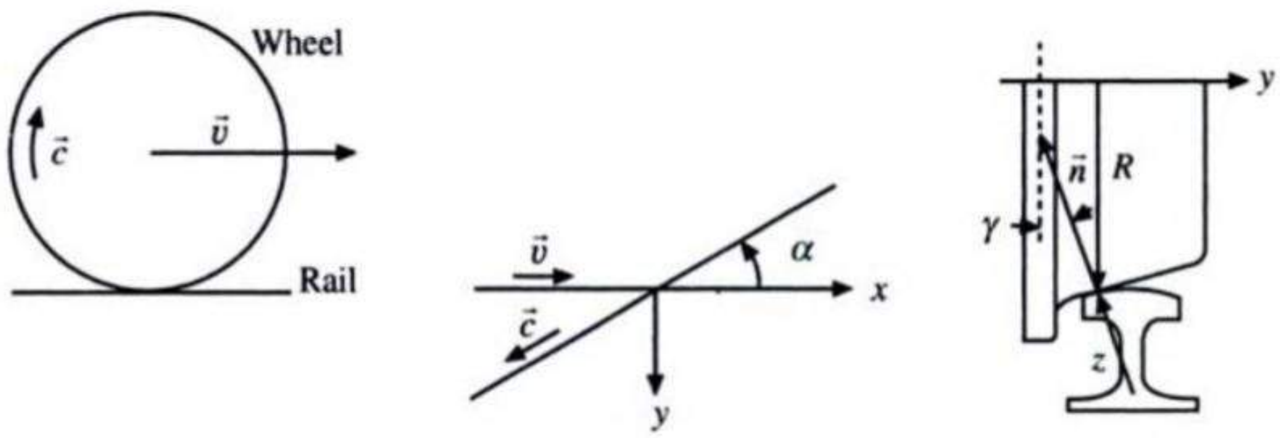
- Longitudinal Creepage can be calculated as: $\dfrac{R\omega - V}{V}$

Positive (Longitudinal) Creepage



*At 1% **positive** creepage, a wheel would rotate **101** times to travel a distance of **100** circumferences.*

Lateral creepage and spin creepage

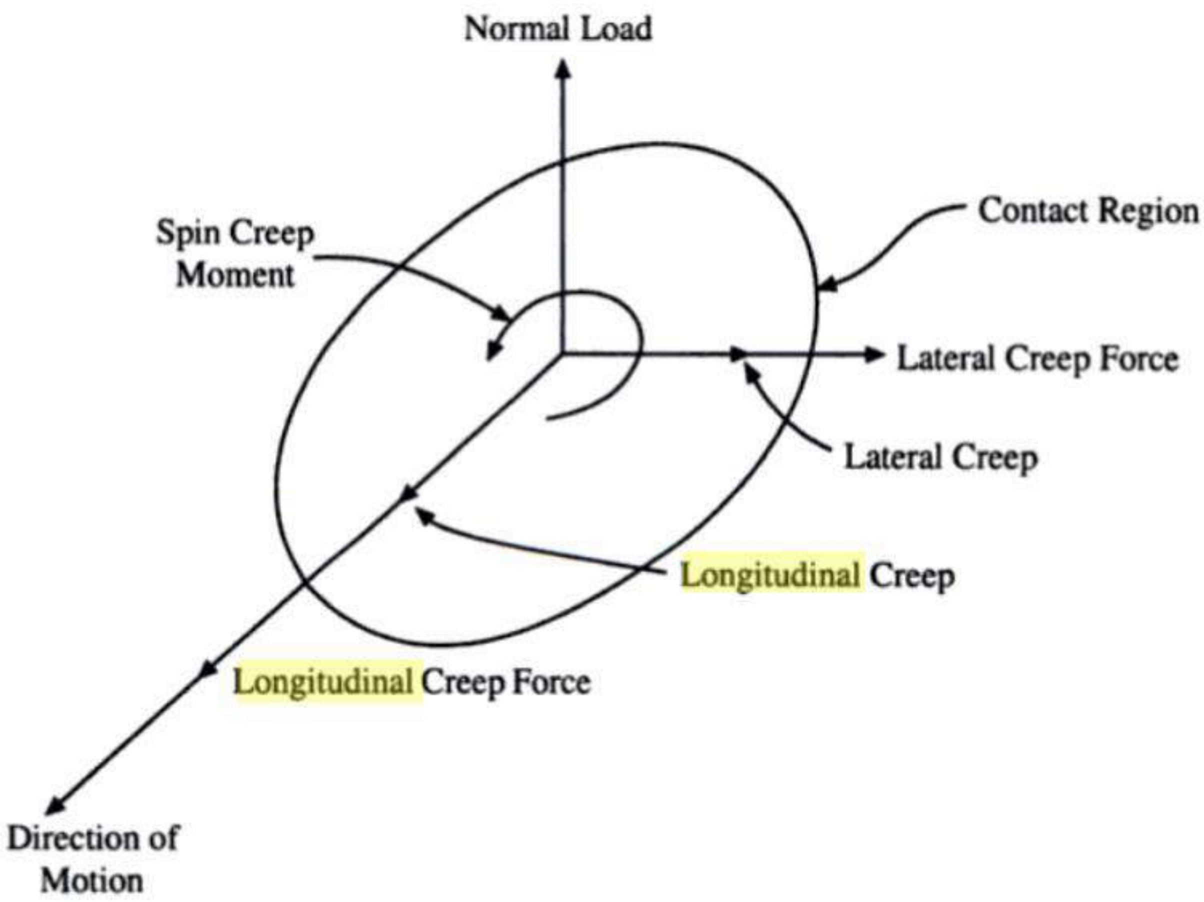


$$\xi_y = \alpha$$

Lateral creep

$$\xi_{sp} = R \sin \gamma / |\mathbf{c}| \gamma$$

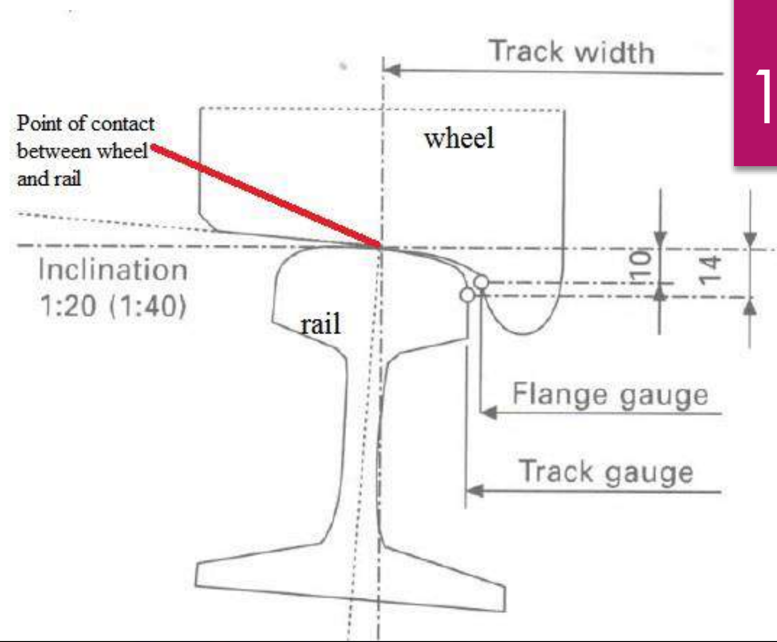
Spin creep

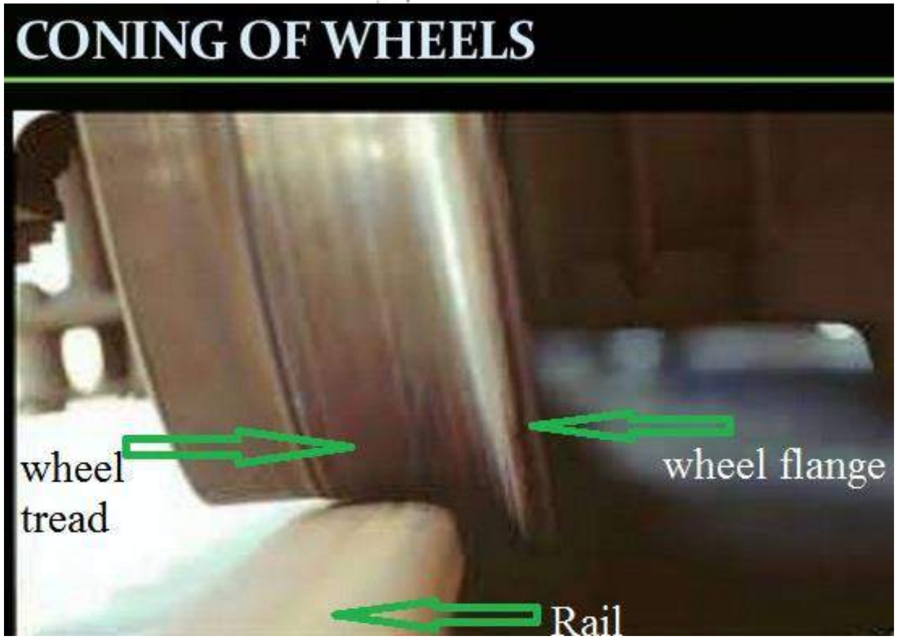

Normal Load
Spin Creep Moment
Contact Region
Lateral Creep Force
Lateral Creep
Longitudinal Creep
Longitudinal Creep Force
Direction of Motion

- Motion of a rail vehicle on track is a complex phenomenon. A large number of factors are at play, having bearing on safety and stability of the movement. These factors are related to track, vehicle and dynamic interaction between them.
- Because of various reasons e.g. wheel tread conicity, track irregularities, elastic characteristics of the track, suspension characteristics of the rolling stock, vehicle loading characteristics, vehicle operation characteristics etc. the wheel set travels along the track exerting a variety of oscillations.

- Normally, a wheel set has a minimum of two and a maximum of three points of contact with the rails. Two of these points are between the wheel tread and rail table top on each of the rails.
- The third point is located between the flange and the radius of the gauge face of the rail and appears whenever one of the flanges is in action.

An understanding of what happens at the rail-wheel interface will lead obviously to a better appreciation of the manner in which vehicle and track defects and operating features contribute to derailment proneness.



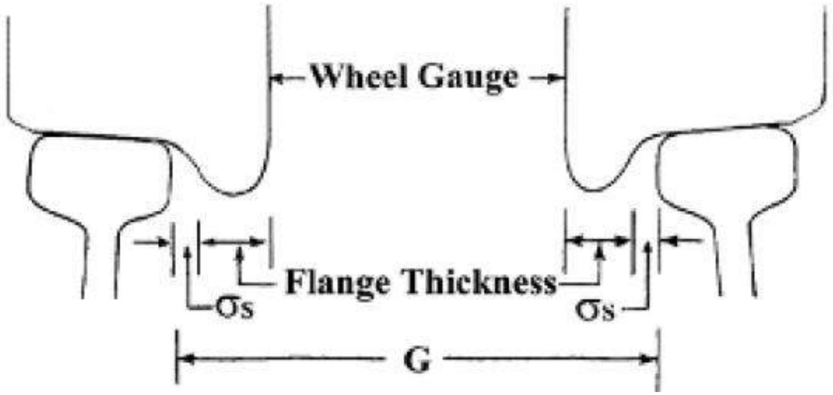


The standard play on BG and MG on Indian Railways is 19 mm.

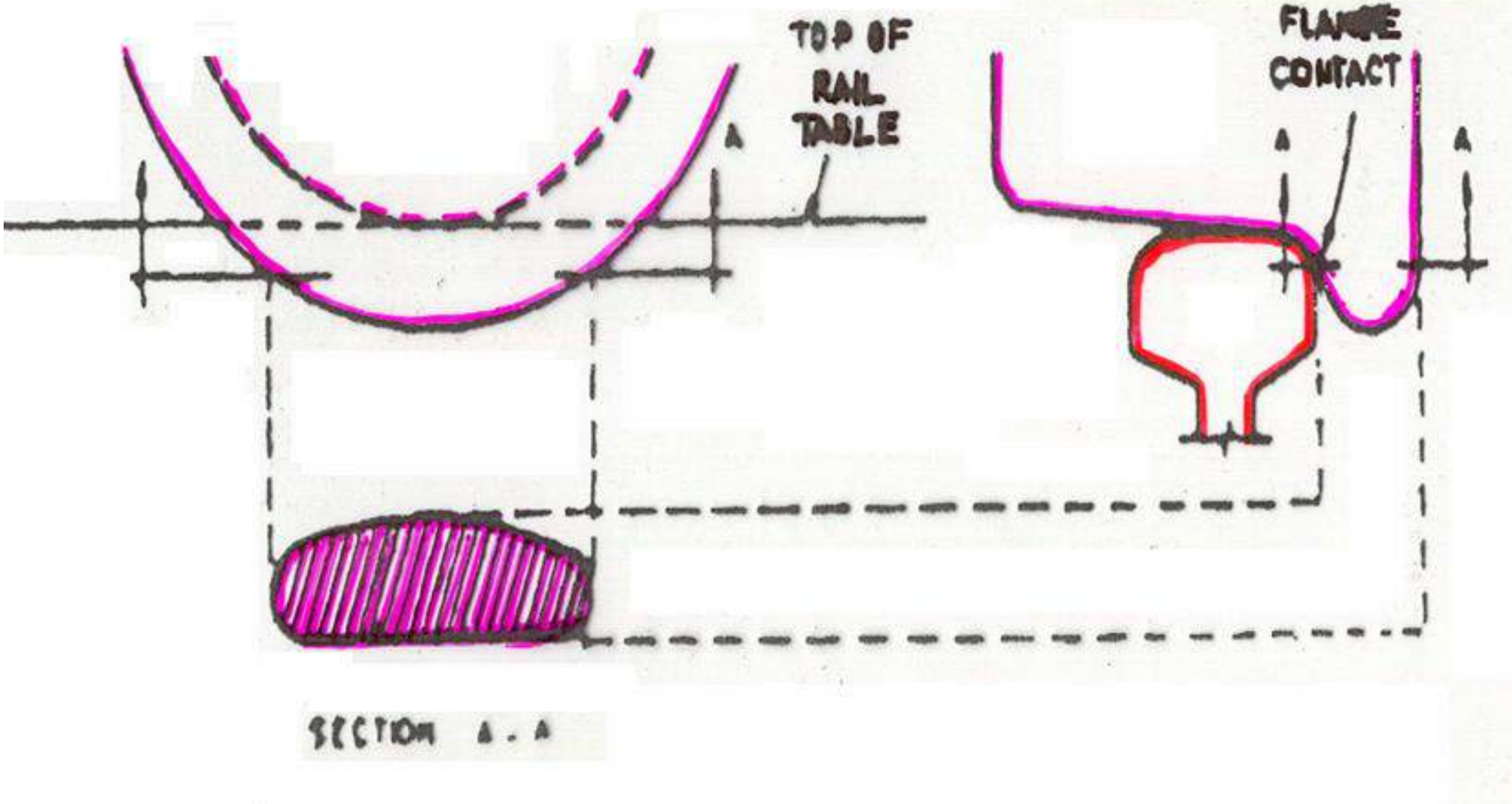
To avoid undue strain on vehicle components during movement, there have to be some longitudinal and lateral clearances at the axle-box level and also a play between the bearing and journal

Due to availability of such play and clearances the wheel-set is able to trail angular to the rails.

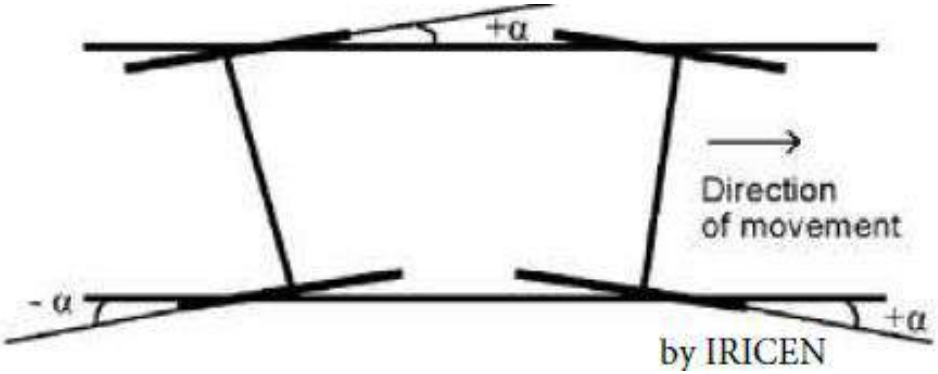
Thus the wheel-set rarely runs exactly parallel to the rails but moves with varying degrees of angularity.

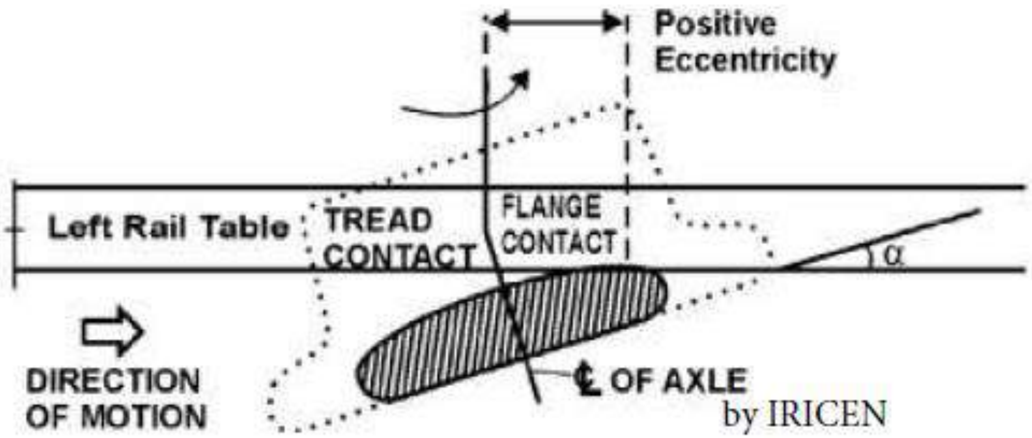


SECTIONAL PLAN OF WHEEL FLANGE AT LEVEL OF FLANGE TO RAIL CONTACT

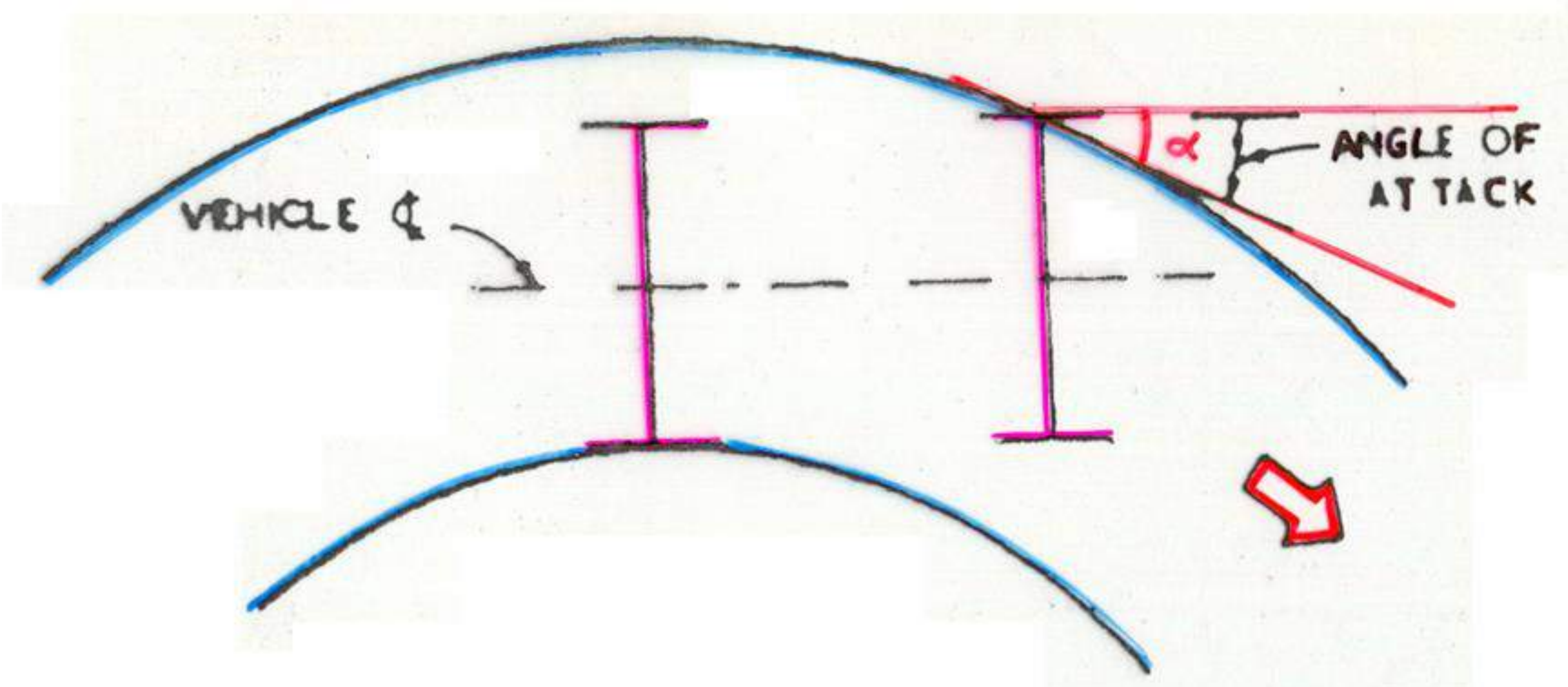


ANGULARITY OR ANGLE OF ATTACK



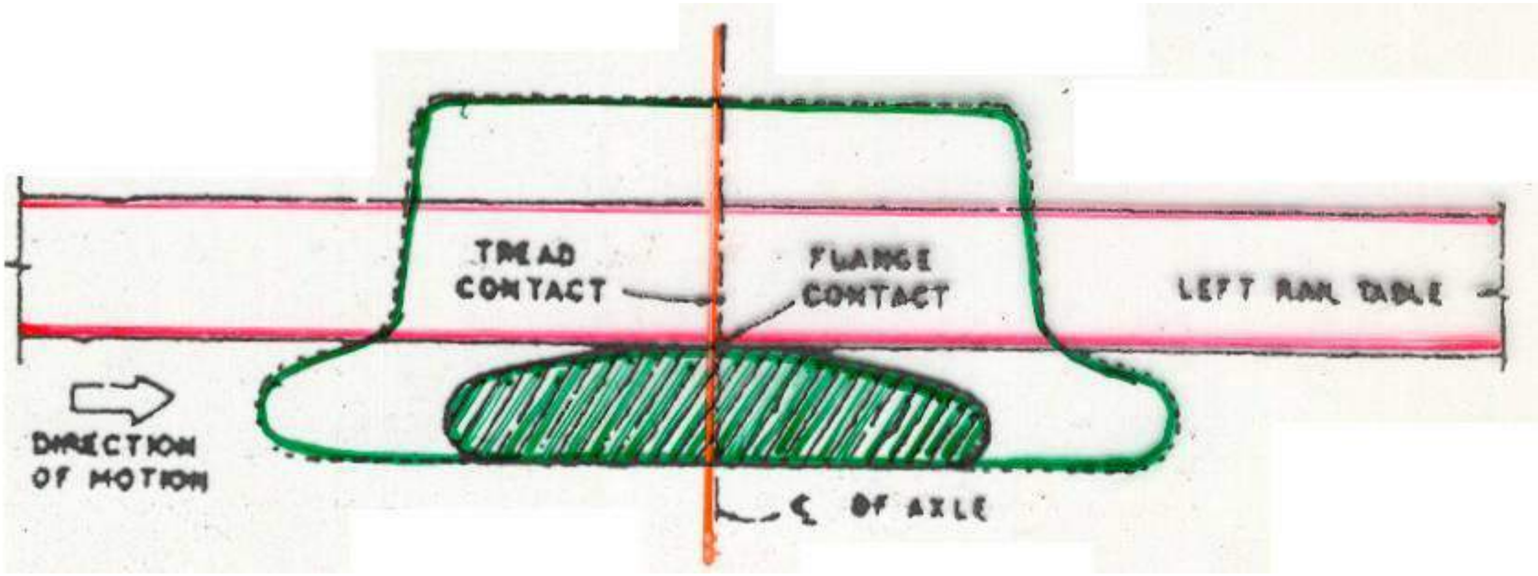


DESIGNED ANGULARITY WHILE NEGOTIATING CURVE

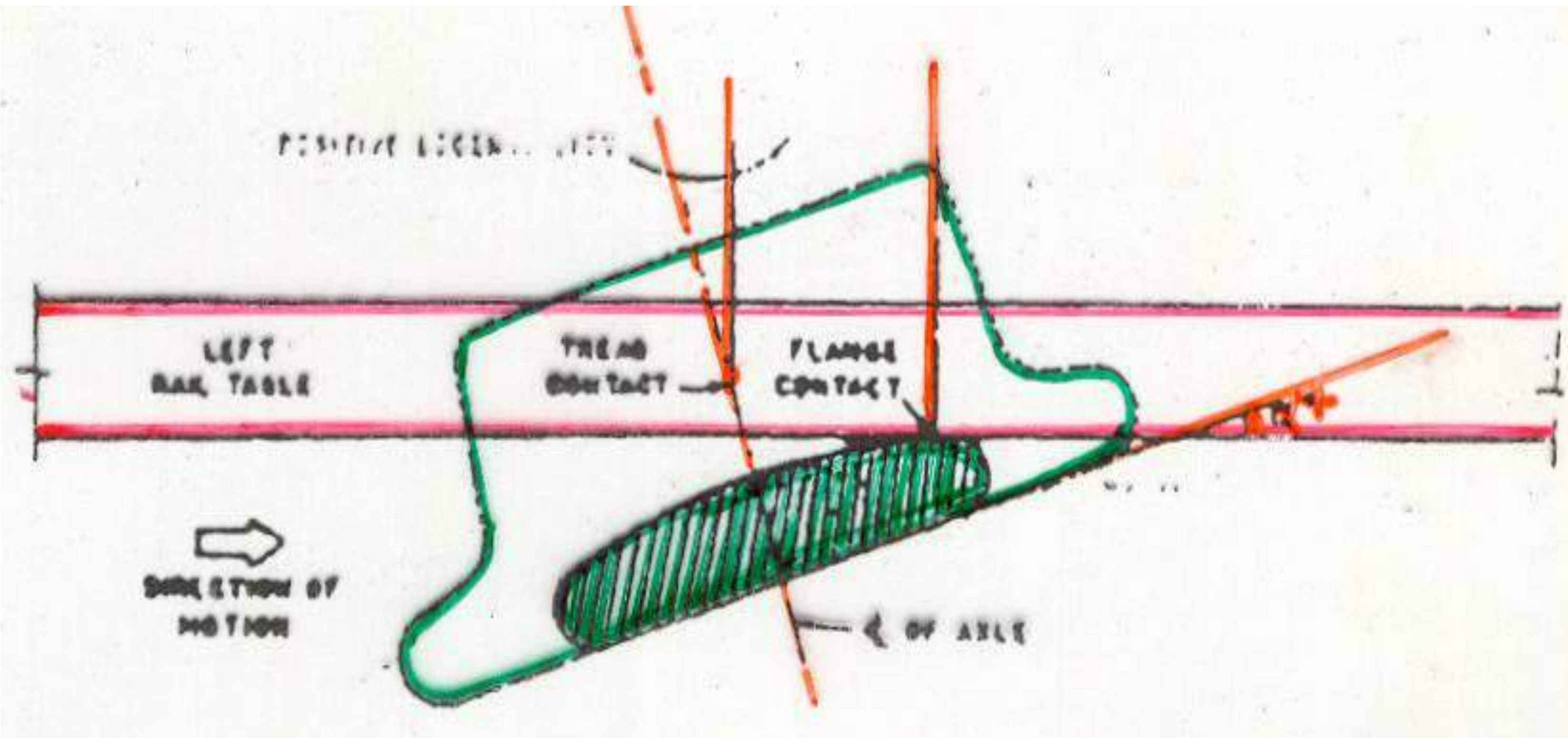


PLAY HELPS THE WHEEL NEGOTIATE CURVE

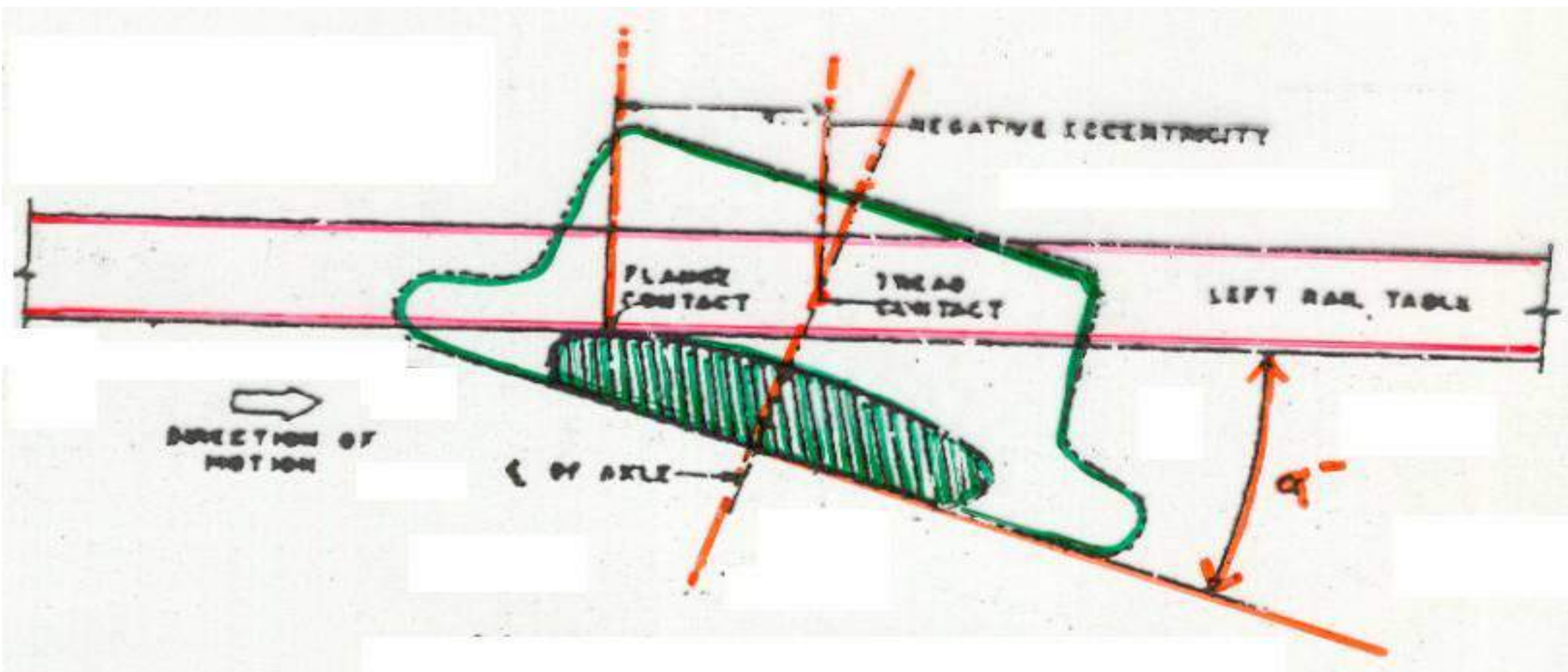
ZERO ANGULARITY (PLAN)



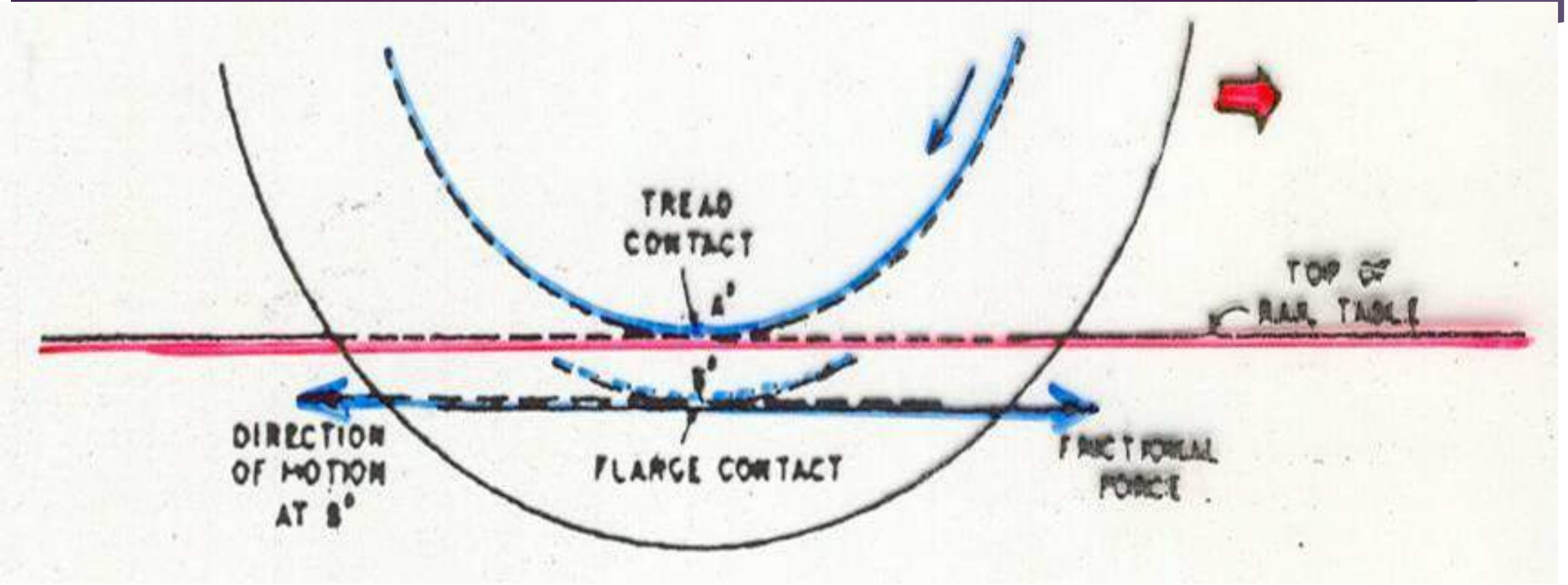
POSITIVE ANGULARITY (PLAN)



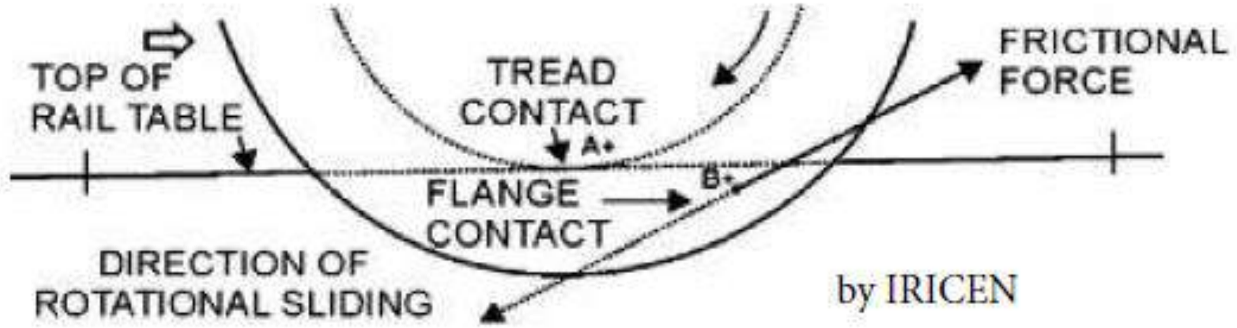
NEGATIVE ANGULARITY (PLAN)



ZERO ANGULARITY (ELEVATION)

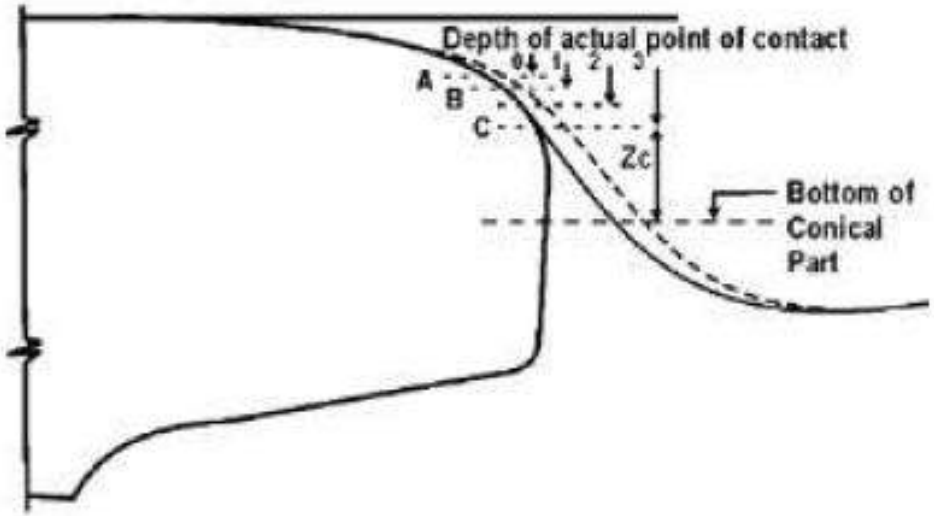


POSITIVE ANGULARITY (ELEVATION

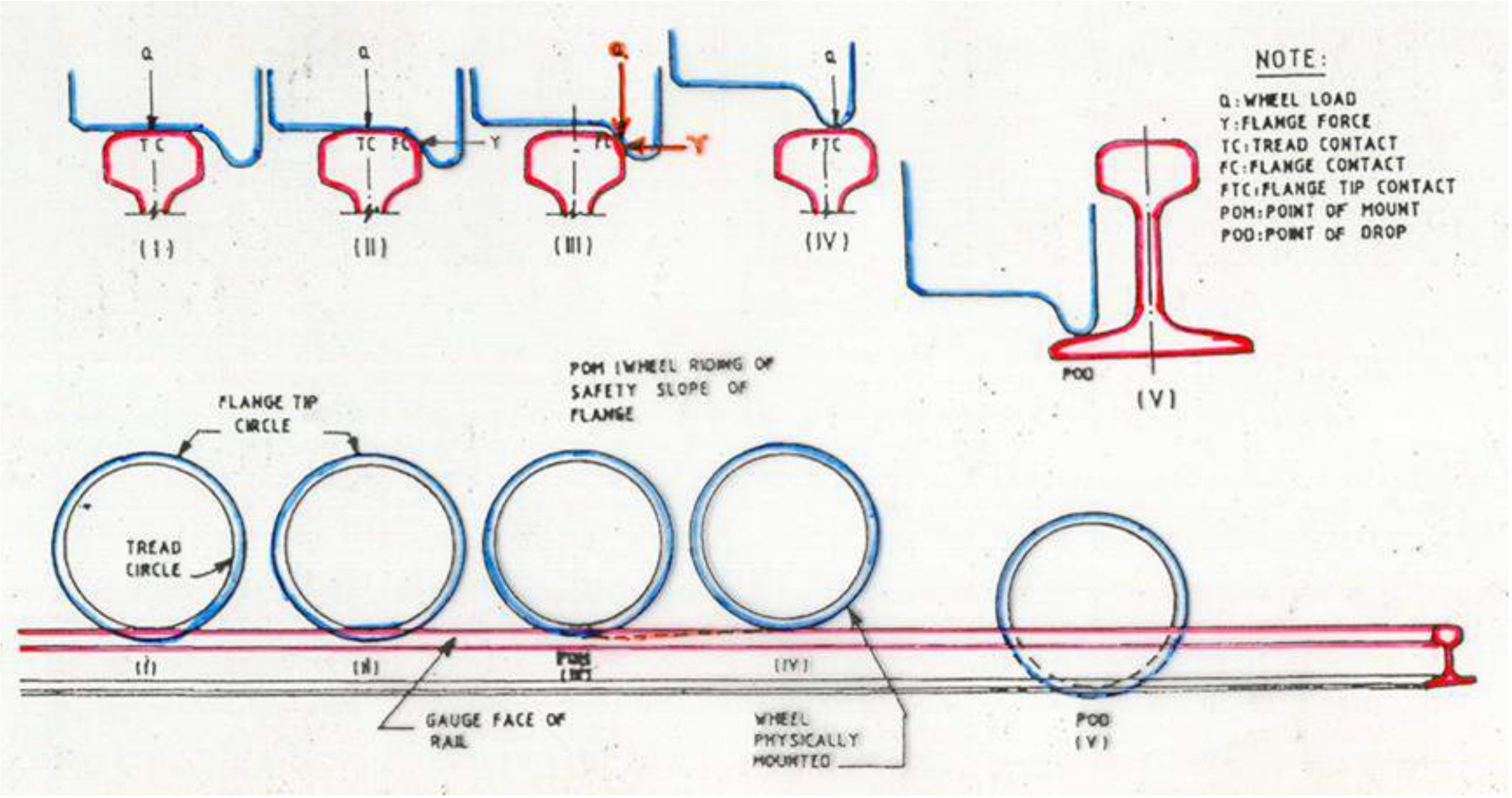


Safety Depth

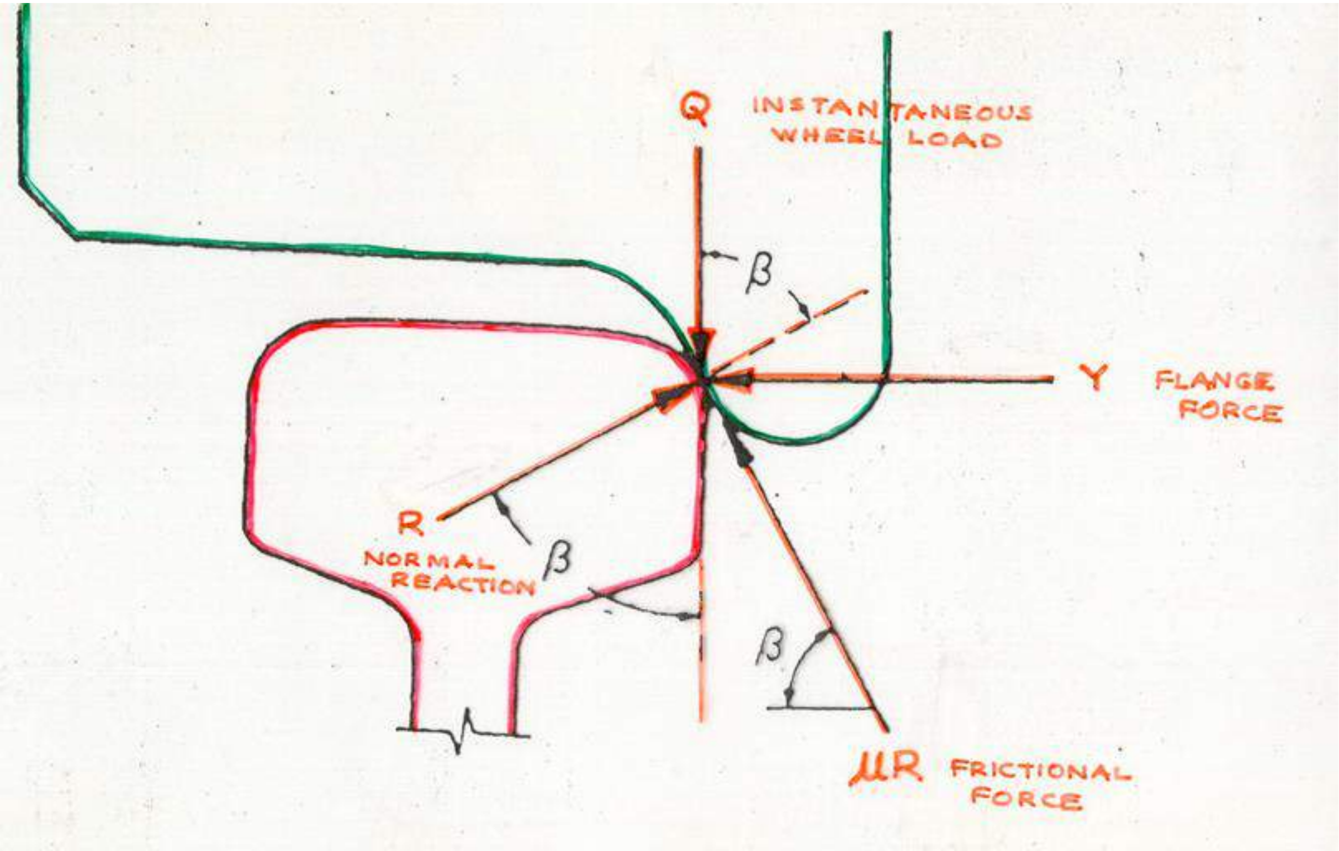
Safety depth is the amount 'Zc' a wheel can lift off the rail table before inviting certain derailment. It is the vertical distance between the position of the point of actual contact between flange and rail gauge face of an oblique wheel corresponding to the position of two point contact (contact both at rail table top and gauge face) , and the position of the point on the bottom of the conical part of flange, lying vertically below.



THE PROCESS OF FLANGE CLIMBING DERAILMENT



FORCES AT RAIL-WHEEL CONTACT AT MOMENT OF DERAILMENT



β - Flange angle

FORCES AT RAIL-WHEEL CONTACT AT MOMENT OF DERAILMENT

- **Resolving Along Flange Slope**

  R= Q cos β + Y sin β…. 1.

For safety against derailment

- Derailing forces > stabling forces
- Y cos β + μR > Q sin β
- Substituting R from equation 1

  ⇒ Y cos β + μ (Q cos β + Y sin β) > Q sin β

  ⇒ Y (cos β + μ sin β) > Q (sin β - μ cos β)

$$\Rightarrow \quad \frac{Y}{Q} \ngtr \frac{(\sin\beta - \mu\cos\beta)}{(\cos\beta + \mu\sin\beta)}$$

Nadal's Equation (1908)

$$\frac{Y}{Q} \ngtr \frac{\tan\beta - \mu}{1 + \mu\tan\beta}$$

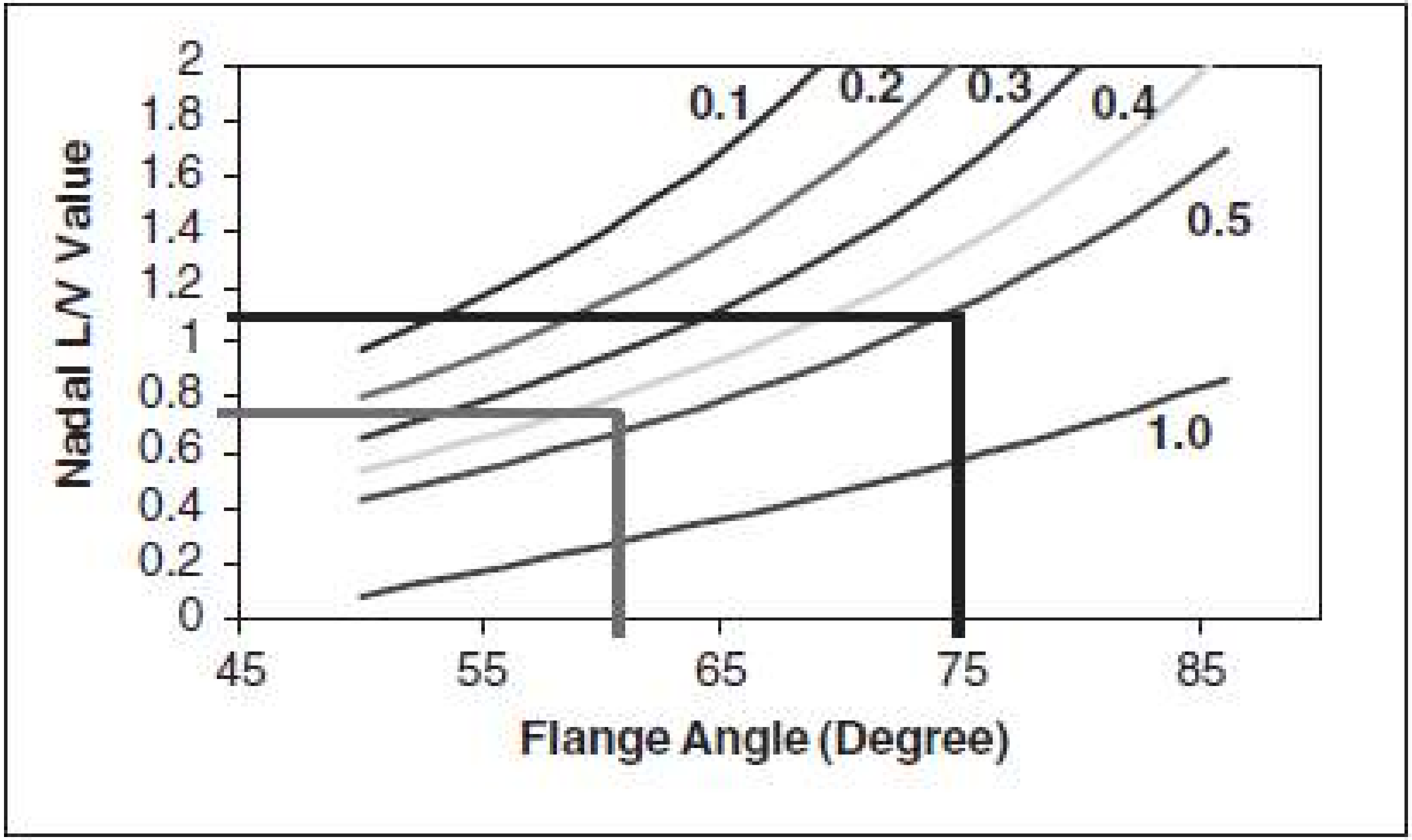
For Safety: LHS has to be small. RHS has to be large

Y $\rightarrow$ Low

Q $\rightarrow$ High

μ $\rightarrow$ Low

Y/Q ratio is also called L/V ratio (lateral/vertical)



Nadal L/V Value
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
45
55
65
75
85
Flange Angle (Degree)
0.1
0.2
0.3
0.4
0.5
1.0

FACTORS AFFECTING SAFETY

Flange angle

- **β = 90º would indicate higher safety.**
- **However, with slight angularity, flange contact shifts to near tip.**
- **Safety depth for flange reduces resulting into increase in derailment proneness**

FACTORS AFFECTING SAFETY

<u>Flange angle</u>

- **ANGULARITY is inherent feature of vehicle movement. If the vehicle has greater angularity, β should be less for greater safety depth of flange tip.**
- **However, there is a limit to it, as this criterion runs opposite to that indicated by Nadal's formula.**

FACTORS AFFECTING SAFETY

Flange angle

- **On I.R., for most of rolling stock β = 68º 12’ (flange slope 2.5:1)**
- **For diesel and electric locos, the outer wheels encounter greater angularity for negotiation of curves and turnouts. For uniformity, same β adopted for all wheels.**
- **β kept as 70^0 on locos upto 110 kmph**
- **β kept as 60^0 on locos beyond 110 kmph**

FACTORS AFFECTING SAFETY

Flange angle

- With wear β increases, but results in greater biting action, hence, increase in μ.
- Larger **β** causes the eccentricity to increase and the safety depth to reduce with even minute values of angularity. Thus, whatever advantage is indicated with increase in value of **β** in Nadal´s formula, safety is more or less off-set by the adverse effects of such increase.

FACTORS AFFECTING SAFETY

OTHER FACTORS INFLUENCING NADAL'S FORMULA

- **μ INCREASES WITH INCREASED ANGULARITY, α (PROF. HEUMANN)**

α	μ
0.0	0.0
0.02	0.27

(acting upwards for positive angularity)

FACTORS AFFECTING SAFETY

OTHER FACTORS INFLUENCING NADAL'S FORMULA

- **Greater eccentricity (positive angularity) increases derailment proneness as flange safety depth reduces.**
- **Persistent Angular Running**
- **As positive angularity increases derailment proneness, persistent angularity leads to greater chances of derailment.**

DEFECTS/FEATURES AFFECTING μ

1. **Rusted rail lying on cess, emergency x-over**
2. **Newly turned wheel – tool marks**
3. **Sanding of rails (on steep gradient, curves)**
4. **Sharp flange (radius of flange tip < 5mm) increases biting action**

DEFECTS/FEATURES CAUSING INCREASED ANGLE OF ATTACK

- **Excessive slack gauge**
- **Thin flange (<16mm at 13mm from flange tip for BG or MG)**
- **Excessive clearance between horn cheek and axle box groove**
- **Sharp curves and turnouts**
- **Outer axles of multi axle rigid wheel base subject to greater angularity, compared to inner wheel**

DEFECT/FEATURES CAUSING PERSISTENT ANGULAR RUNNING

- **DIFFERENCE IN WHEEL DIA MEASURED ON SAME AXLE**
- **INCORRECT CENTRALISATION & ADJUSTMENT OF BRAKE RIGGING AND BRAKE BLOCKS**
- **WEAR IN BRAKE GEARS**
- **HOT AXLE**
  - **HIGHER COEFFICIENT OF FRICTION**
  - **DIFFERENT BEARING PRESSURES**

- **Not possible to know values of Q, Y, μ, α and eccentricity at instant of derailment.**
- **Calculations by NADAL's formula not to be attempted.**
- **Qualitative analysis by studying magnitude of defects in track/vehicle and relative extent to which they contribute to derailment proneness, should be done.**

STABILITY ANALYSIS

Q & Y – Instantaneous values, measurement by MEASURING WHEEL

- Hy = Horizontal force measured at axle box level by placing a load cell between the axle end and the axle-box adapter
- Q = (Vertical) spring deflection x spring constant measured by measuring the spring deflections (by means of LVDTs viz. linear variable differential transducers), which, when multiplied by the spring constant (spring constant is load per unit deflection of the spring), gives the force Q.

STABILITY ANALYSIS

$$\frac{Y}{Q} \ngtr \frac{\tan\beta - \mu}{1 + \mu \tan\beta}$$

Dry Rail 0.33
Wet Rail 0.25
Lubricated Rail 0.13
Rusted Rail 0.6

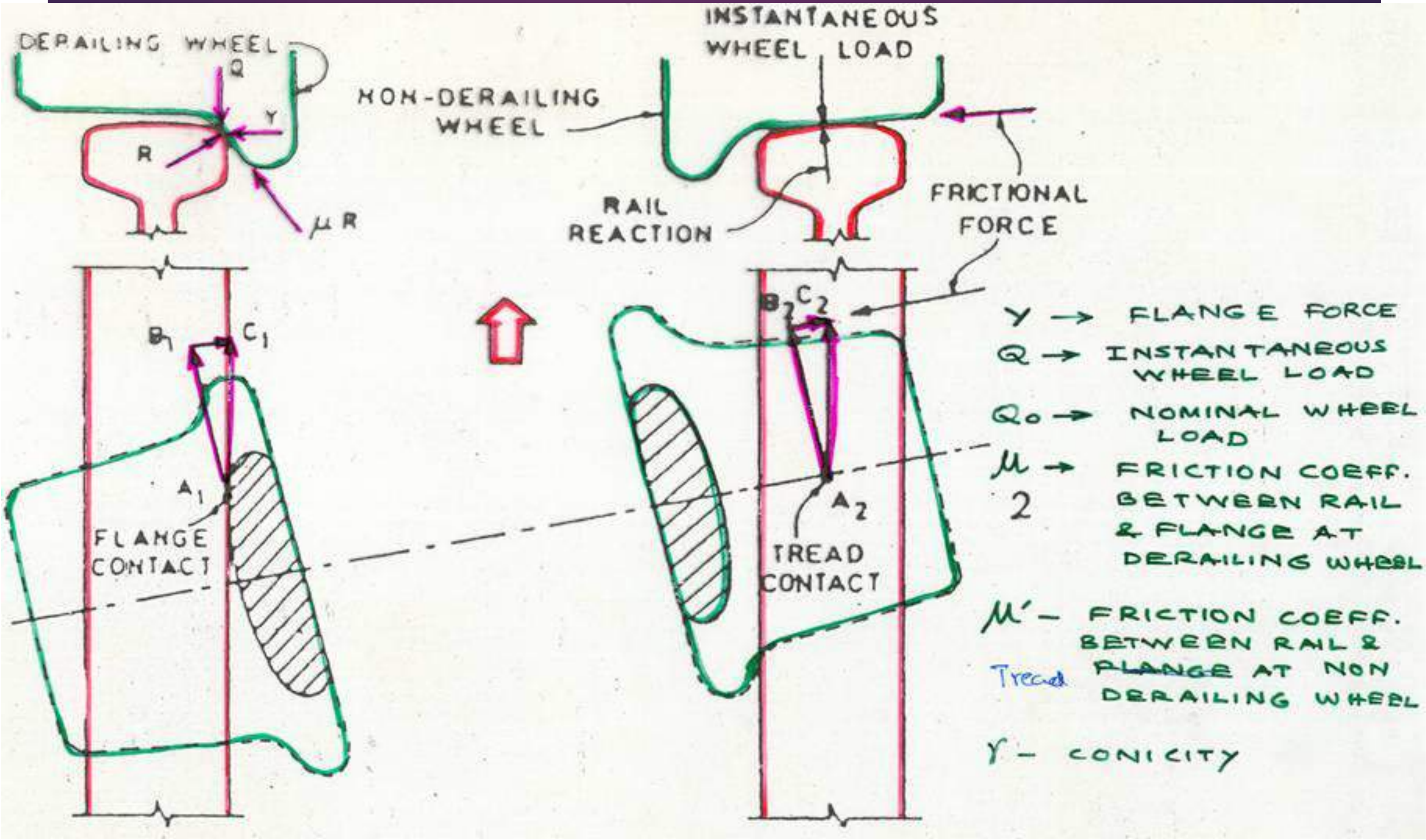
<u>for β=68º, μ=0.25</u>

RHS works out to 1.4, rounded off to 1.0 after considering factor of safety

- **On I.R. Hy/Q measurement done over period of 0.05 sec.**
- **Ratio of flange force to instantaneous wheel load should be less than 1.**

It is one of the <u>criteria for assessing stability of Rolling Stock</u>

DIRECTION OF SLIDING FRICTION AT TREAD OF NON-DERAILING WHEEL



CHARTET'S FORMULA

$$\frac{Y}{Q} \rhd K_1 - K_2 \frac{Qo}{Q}$$

$$K_1 = \frac{\tan\beta - \mu}{1 + \mu\tan\beta} + \mu' + \gamma$$

$$\mu' = \sqrt{2}\mu$$

$K_2 = 2(\mu' + \gamma)$

γ = Angle of coning of wheel $\gamma = 1/20 = 0.05$

$\mu = 0.25$ $K_1 = 2$ $K_2 \approx 0.7$

$$\frac{y}{Q} \ngtr 2 - 0.7\frac{Qo}{Q}$$

$$\Rightarrow \; Y \ngtr 2Q - 0.7Q_o$$

$$\Rightarrow \; 2Q \nless Y + 0.7Q_o$$

As $Y \to 0$ (at low speeds) $2Q \nless 0.7Q_o$

$$\Rightarrow Q \nless 0.35Q_o$$

Instantaneous Wheel Load Q should not drop below 35% of nominal wheel load $Q_{o.}$(65% off-loading)

For safety, the Q limited to 60 % of Qo .(40% off-loading)

QUESTION

- Tare weight of a WACCN (LHB 3 AC) coach is 45.5 t. Maximum payload is 6.5 t.

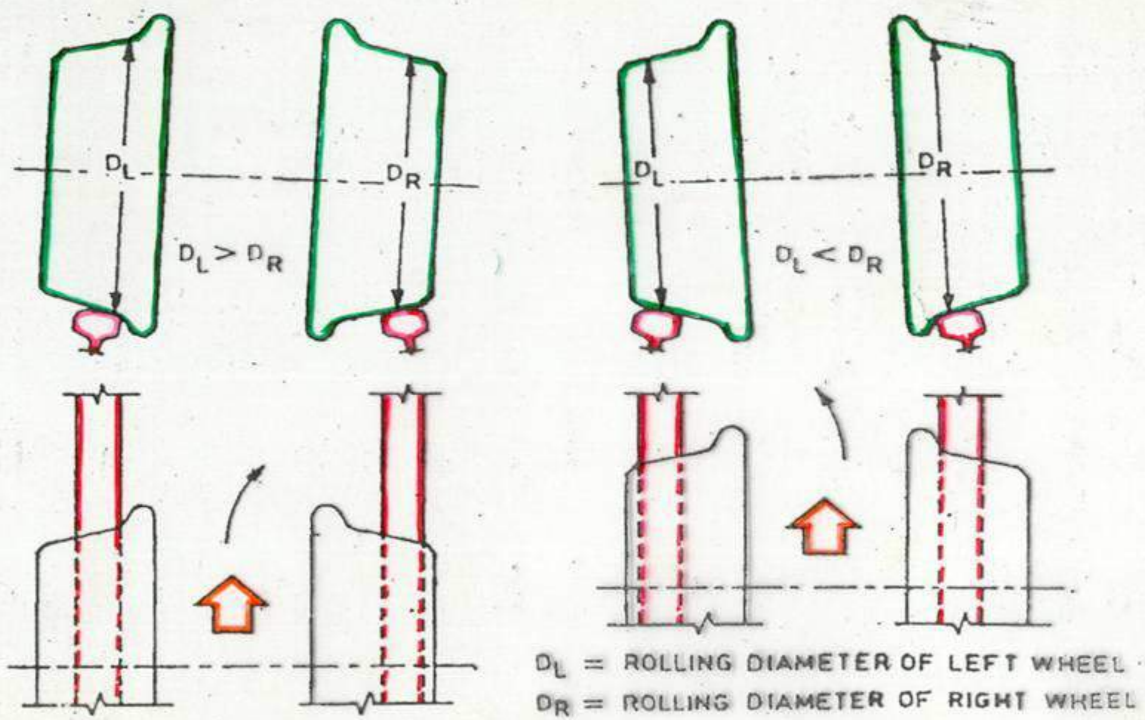
(a) What is the minimum instantaneous load below which chances of offloading/derailment substantially increases?
(b) What is the maximum flange force beyond which chances of climbing/derailment substantially increases?

(a) **3.9 t**

(b) **39 kN**

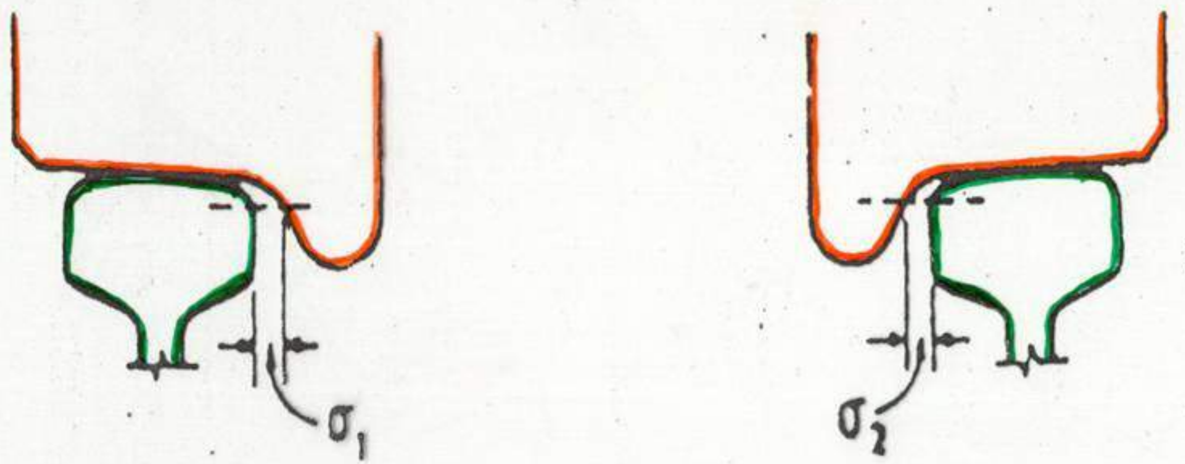
- **Normally, it is the consist of train, and not an individual rolling stock, which runs on track.**
- **Features of this consist of train, such as their coupling arrangement, system of traction and braking etc., and the operating features would have a very prominent effect on rail wheel interaction.**

SELF CENTRALIZING CONED WHEELS



Wheelset guidance by tread conicity through change in rolling diameters.

$$\boxed{\sigma_s = \sigma_1 + \sigma_2}$$



Play between wheelset and track

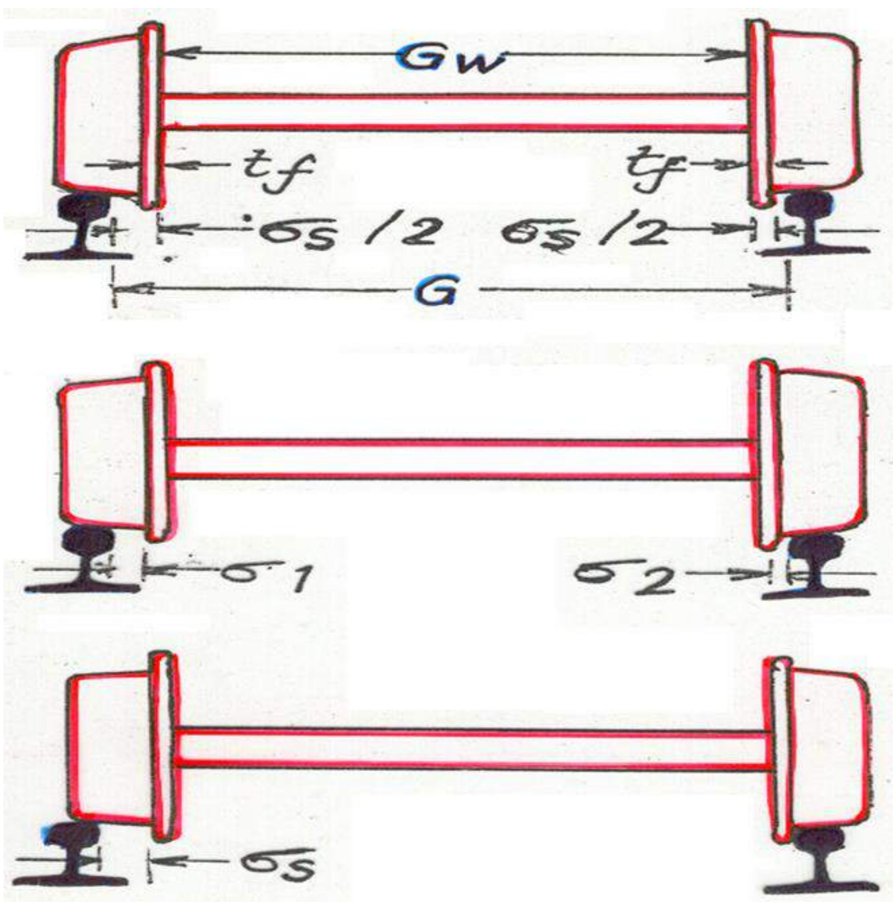
PLAY BETWEEN WHEEL SET AND RAILS

- **$G = G_w + 2\ t_f + \sigma_s$**
- **G is track gauge 1676 mm (BG)**
- **G_w is wheel gauge 1600 mm (BG)**
- **t_f is flange thickness –**

  28.5 mm new; 16mm worn out
- **σ_s is standard play**

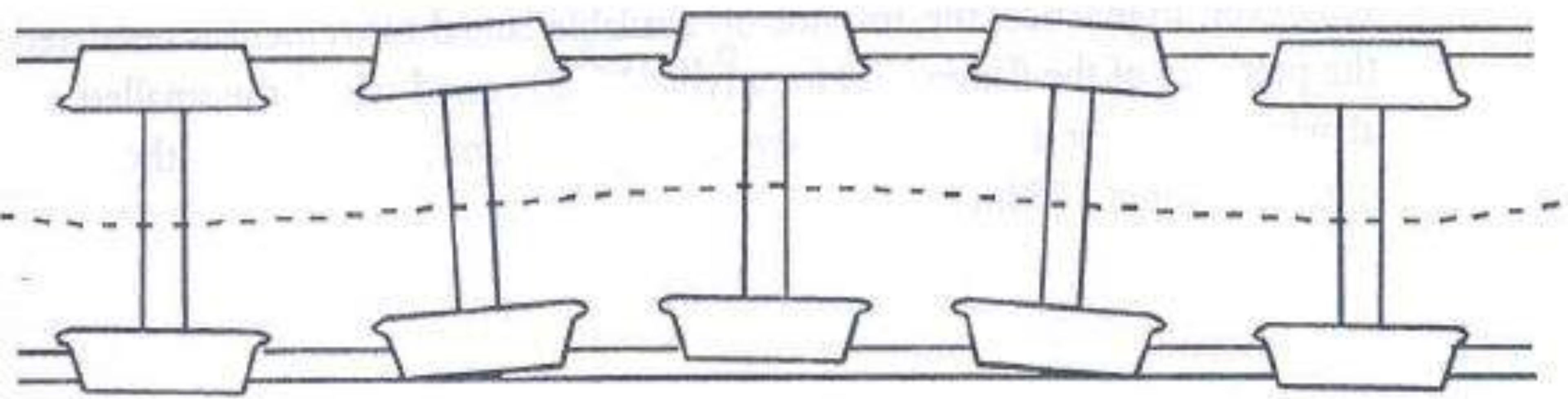
  = 19mm for new wheel

  = 44mm for worn out wheel

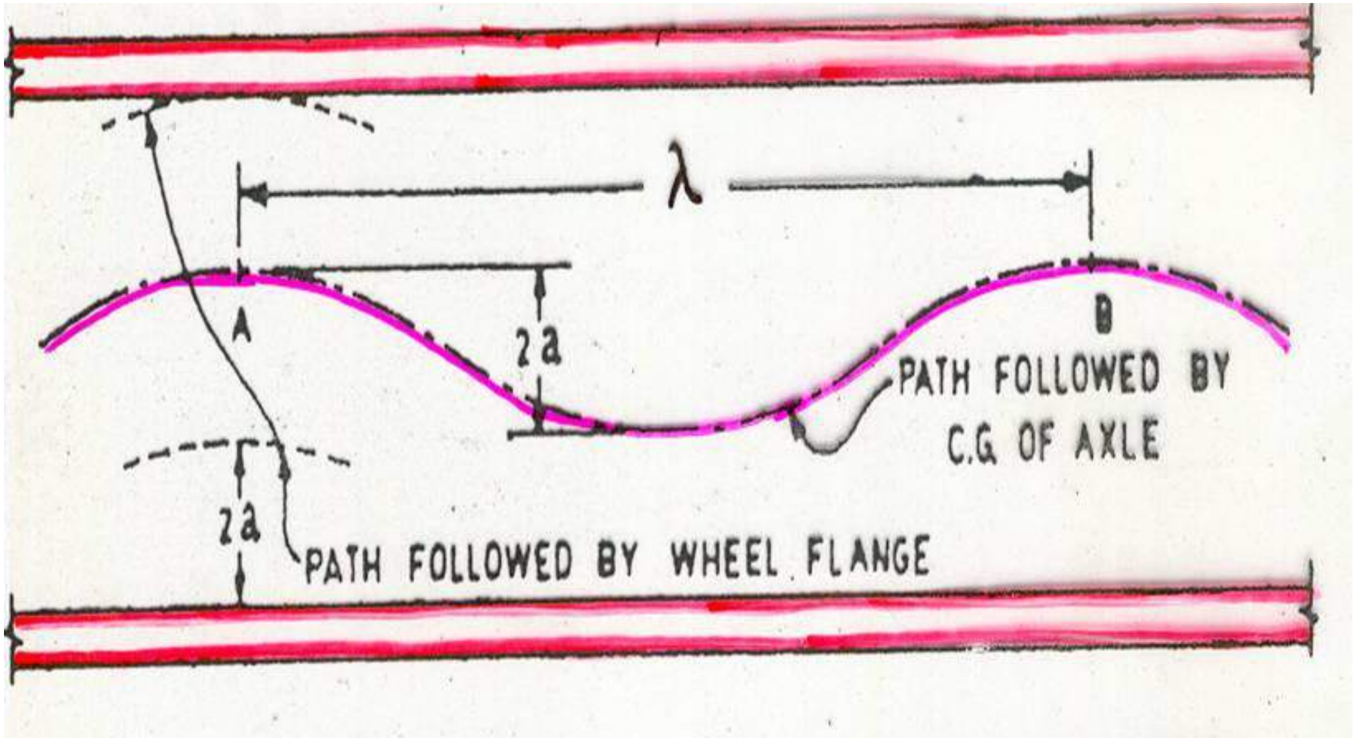


- Mean Position
- Typical (Asymmetrical) Position
- Extreme Position

Sinusoidal motion of wheelset



SINUSOIDAL MOTION OF VEHICLE



Sinusoidal motion of centre of gravity of coned wheelset.

EFFECT OF PLAY

Lateral Displacement Y = a sin wt

a $\rightarrow$ amplitude = σ/2 = Play/2

Lateral velocity = aw cos wt

Lateral Acceleration = -aw^2 sin wt

Max acc = -aw^2

Angular Velocity w = $2\pi f = \dfrac{2\pi v}{\lambda}$

KLINGEL'S FORMULA (1883)

Wavelength λ_0 of a Single wheel

$$\lambda_0 = 2\pi\sqrt{\frac{rG}{2\gamma}}$$

G = Dynamic Gauge

r = Dynamic Wheel Radius

γ = Conicity

$\lambda_0 \,\alpha\, \frac{1}{\sqrt{\gamma}}$ **;Frequency** $\alpha \sqrt{\gamma}$

•With increase γ, λ_0 reduces, f increases – oscillations increase – instability

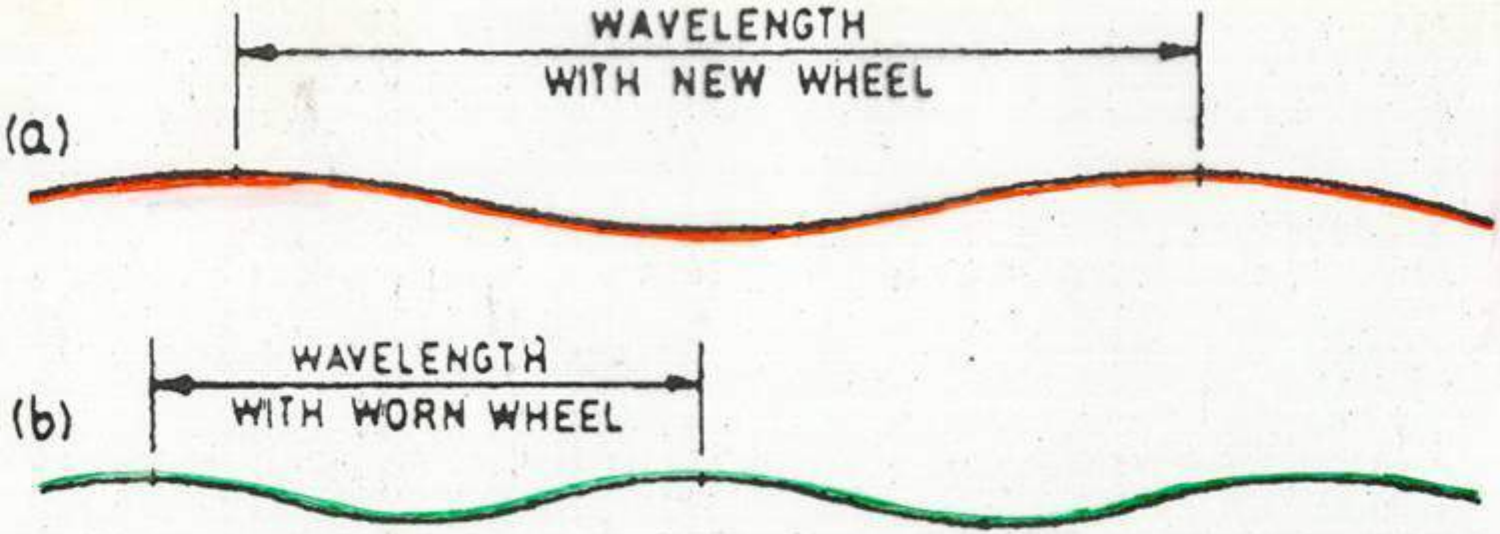
•For high speed γ – low 1 in 40 on high speed routes

•Worn out wheel γ increases – increasing instability

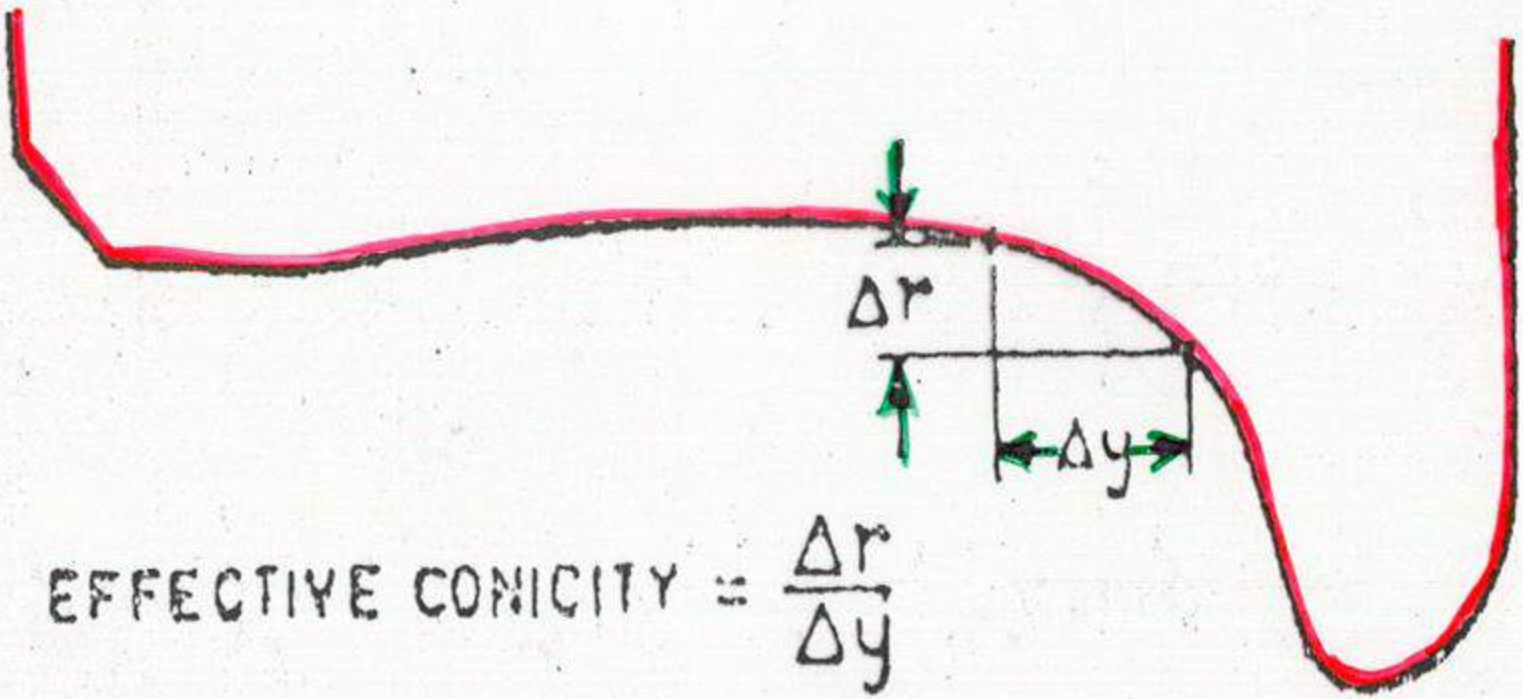
For wheel set (MULTIPLE RIGID WHEELS)

$$\lambda = \lambda o \sqrt{1 + \left(\frac{l}{G}\right)^2}$$

l= Rigid wheel base



Sinusoidal motion (a) with new wheel, (b) with worn wheel (i.e. with increased conicity γ).



Effective conicity.

$$acc = a.\frac{4\pi^2 v^2}{\lambda^2}$$

$$acc\,\alpha\,\frac{1}{\lambda^2}\,\alpha\gamma$$

- As conicity increases Lateral Acceleration Increases
- acc α a α σ/2 play
- As play increases Lateral Acceleration Increases

CONCLUSIONS

- **EXCESSIVE OSCILLATIONS DUE TO**
  - Slack Gauge
  - Thin Flange
  - Increased Play in bearing & Journal
  - Excessive Lateral and Longitudinal Clearances
- Increased Derailment Proneness

CRITICAL SPEED

- As speed of vehicle increases two types of hunting movements occur

1. Primary hunting – occurs at low speeds, affects ride comfort and can be controlled by damping measures.
2. Secondary hunting – occurs at higher speed, bogie oscillations increases, greater flange forces

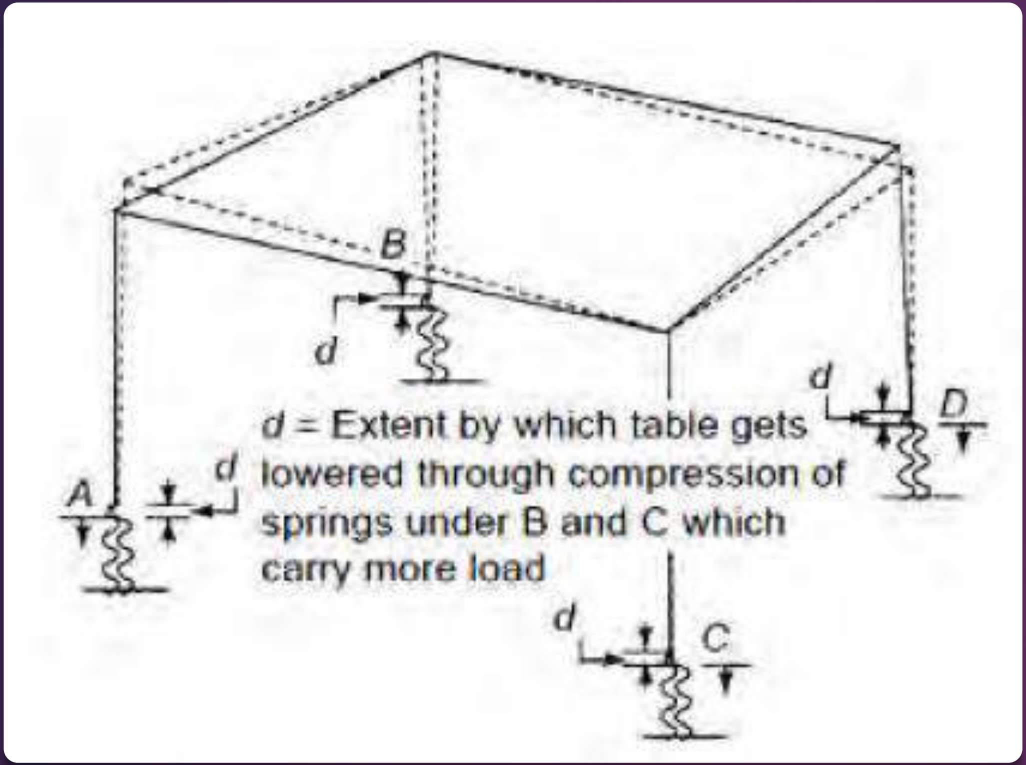
- Speed at the Boundary Condition between Stable & Unstable Condition when excessive flanging starts to occur is called critical speed.
- Depends on Many Factors

  Most Important - Conicity

  Inversely Proportional to Conicity
- Speed for which Rolling Stock is Cleared for Service Normally 10 To 15% Less than Critical Speed at which Vehicle Tested

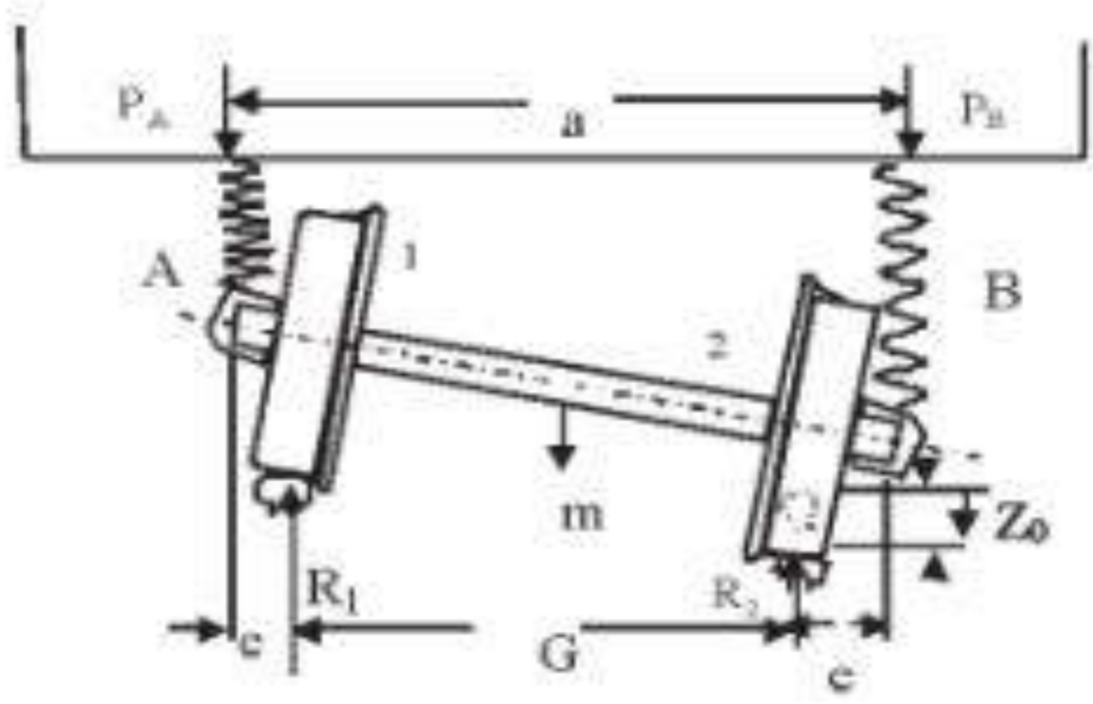
FACTORS AFFECTING CRITICAL SPEED

- Vehicle Wheel Profile
- Rail Head Profile Inclination & Gauge
- Rail Wheel Coefficient of Friction
- Axle Load and Distribution of Vehicle Mass
- Design and Condition of Vehicle Suspension



EFFECT OF TWIST ON VEHICLE

WHEEL OFF-LOADING DUE TO TRACK DEFFECT



A SITUATION IS CONSIDERED WHERE WHEEL 2 IS DEPRESSED BY z_0 TO MAKE WHEEL LOAD ZERO (R_2=0)

WHEEL OFF-LOADING DUE TO TRACK DEFECT

- a = Distance between Centers of Springs
- P_A = Load Reaction in Spring A
- P_B = Load Reaction in Spring B
- G = Dynamic Gauge
- R_1 = Rail Reaction under Wheel –1
- R_2 = Rail Reaction under Wheel-2

e = Amount of Overhang of Spring Centre beyond the Wheel Rail Contact Point.

T= Axle Load of Vehicle

EFFECT OF TRACK AND VEHICLE TWIST

- Track twist that will completely off load the wheel

  $Zo = f\ T\ (G/a)^2$

- This equation is given by Kereszty

This is the track twist required to fully off-load the wheel . As indicated earlier ,movement becomes unstable beyond 65% offloading, hence safety limit for depression will theoretically be 0.65 Z_0

Practically after consideration of factor of safety it should be 0.40 Z_0

EFFECT OF STIFFNESS OF SPRINGS

- Larger ‘f’ i.e. Deflection per Unit Load
- Better from Off Loading Point of View
- Indicates Softer Springs are Better
- From practical considerations, e.g. buffer heights etc; too soft a spring cannot be provided. There is an optimum value for specific deflection of springs in a particular rolling stock.

LOADED / EMPTY CONDITION OF VEHICLE

- Larger the ‘T’ , better the stability
- An empty vehicle is Less Stable while Negotiating a Track Twist

EFFECT OF OVERHANG OF SPRING

- G/a RATIO - should be Large
- Overhang should be Less

THANKS !!