GEOMETRIC DESIGN OF RAILWAY

Introduction:

Geometric design of a railway track discusses all those parameters which affect the geometry of the track. These parameters are as follows:

1. Gradients in the track
2. Curvature of the track: radius or degree of the curve, cant or super elevation on curves
3. Alignment of the track

Necessity of Geometric Design:

The need for proper geometric design of a track arises because of the following considerations:

- To ensure the smooth and safe running of trains
- To achieve maximum speeds
- To carry heavy axle loads
- To avoid accidents and derailments due to a defective permanent way
- To ensure that the track requires least maintenance
- For good aesthetics

Gradients:

Gradients are provided to negotiate the rise or fall in the level of the railway track. A rising gradient is one in which the track rises in the direction of movement of traffic and in a downor falling gradient the track loses elevation the direction of movement of traffic.

Gradients are provided to meet the following objectives:

- To reach various stations at different elevations
- To follow the natural contours of the ground to the extent possible
- To reduce the cost of earthwork
- To drain off rain water.

Types of gradient:

1. Ruling gradient
2. Momentum gradient
3. Pusher gradient
4. Station yard gradient

Ruling Gradient:

- Ruling gradient is the maximum gradient to which the track may be laid in a particular section.
- It depends on the load of the train and additional power of the locomotive.
- The power of the locomotive to be put into service on the track also plays an important role in taking this decision, as the locomotive should have adequate power to haul the entire load over the ruling gradient at the maximum permissible speed.

In plain terrain: 1 in 150 to 1 in 250
In hilly terrain: 1 in 100 to 1 in 150

Momentum Gradient:

- The gradient which is steeper than ruling gradient and where the advantage of momentum is utilized is known as momentum gradient.
- A train gets momentum when moving in down gradient and this momentum can be utilized for up gradient. A train while coming down a gradient gains sufficient momentum. This momentum gives additional kinetic energy to the moving train which would help the train to rise a steeper gradient than the ruling gradient for a certain length of the track. This rising gradient is called momentum gradient. In such gradients no signals are provided to stop the train.

Pusher or Helper Gradient:

- Pusher gradient is the gradient where extra engine is required to push the train.
- These are steeper gradient than ruling gradient and are provided at certain places of mountains to avoid heavy cutting or to reduce the length of track.
- A pusher gradient of 1 in 37 on Western Ghats with B.G. track is provided.
- On Darjeeling Railway with N.G. track, a ruling gradient of 1 in 25 is provided.]

Station Yard Gradient:

- Station yard gradient is the minimum gradient provided in station yard for easy draining of rain water.
- In station yards, maximum limit of gradient is fixed as 1 in 400 and minimum gradient recommended is 1 in 1000 for easy drainage of rain water.

The gradients in station yards are quite flat due to the following reasons:

(a) It prevents standing vehicles from rolling and moving away from the yard due to the combined effect of gravity and strong winds.

(b) It reduces the additional resistive forces required to start a locomotive to the extent possible.

Grade compensation on curves:

Grade compensation on curves is the reduction in gradient on curved portion of a track. On curves extra pull is required to pull the train due to more tractive resistance. It is expressed as percentage per degree of curve. The grade compensation provided on Indian Railways is as follows:

a. On B.G. curves – 0.04 percent / degree or 70/R, whichever is minimum
b. On M.G. curves – 0.03 percent / degree or 52.5/R, whichever is minimum
c. On N.G. curves – 0.02 percent / degree or 35/R, whichever is minimum
   where R is the radius of the curve in metres.

Radius or Degree of Curve:

A curve is denned either by its radius or by its degree. The degree of a curve (D) is the angle subtended at its centre by a 30.5 m or 100 ft arc.

The value of the degree of the curve can be determined as indicated below.

- Circumference of a circle = $2\pi R$
- Angle subtended at the centre by a circle with this circumference = 360°
- Angle subtended at the centre by a 30.5 m arc, or
- Degree of curve = $360°/2\pi R \times 30.5$ = 1 750/R (approximately R is in meter)

In cases where the radius is very large, the arc of a circle is almost equal to the chord connecting the two ends of the arc.

The degree of the curve is thus given by the following formulae:

- $D = 1750/R$ (when R is in metres)
- D = 5730/ R (when R is in feet)

Maximum permissible degree of curves:

The maximum permissible degree of a curve on a track depends on various factors such as gauge, wheel base of the vehicle, maximum permissible super elevation, and other such allied factors. The maximum degree or the minimum radius of the curve permitted on Indian Railways for various gauges is given in Table below.

Gauge	On plain track		On turnouts	
	Max. Degree	Min. Radius	Max. Degree	Min. Radius
B.G	10	175	8	218
M.G	16	109	15	116
N.G	40	44	17	103

Superelevation:

Superelevation is the raised elevation of the outer rail above the inner rail at a horizontal curve. It is denoted by 'e'.
When a vehicle moves on curve it is subjected to a centrifugal force. The centrifugal force exerts a horizontal force on the outer rail and the weight on the outer rail increases. This horizontal force and uneven load on rails will cause derailment. This centrifugal force can be counteracted by introducing the centripetal force by raising the outer rail with respect to inner rail. This raising of outer rail with respect to inner rail is known as 'superelevation' or 'canting'.

Objects of Providing Superelevation:

The following are the objects of providing superelevation:

- To introduce centripetal force to counteract the centrifugal force to avoid derailment and reduce the side wear of rails.
- To distribute the wheel loads equally on the two rails. This reduces the top wear of rails and results in saving of maintenance cost.
- To ensure comfortable ride to passengers and safe movements of goods.

Analysis of Superelevation:

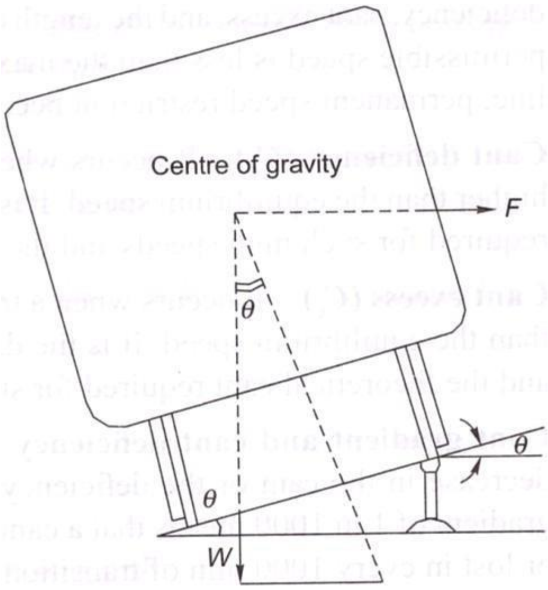
- A vehicle has a tendency to travel in a straight direction, which is tangential to the curve, even when it moves on a circular curve. As a result, the vehicle is subjected to a constant radial acceleration.
- Radial acceleration: $\mathbf{a = V^2/R}$,

  Where **V** is the velocity (metres per second) and **R** *is* the radius of curve (metres). This radial acceleration produces a centrifugal force which acts in a radial direction away from the centre.
- The value of the centrifugal force is given by the

  formula:Force = mass * acceleration,

  $$\mathbf{F = m \times (V^2/R) = (W/g) \times (V^2/R),}$$

  Where **F** *is* the centrifugal force (Kilo Newton), **W** *is* the weight of the vehicle (tonnes), **V** is the speed (m/s), **g** *is* the acceleration due to gravity (m/s2), and **R** is the radius of the curve in metres.
- To counteract the effect of the centrifugal force, the outer rail of the curve is elevated with respect to the inner rail by an amount equal to the *superelevation.*
- A state of equilibrium is reached when both the wheels exert equal pressure on the rails and the superelevation is enough to bring the resultant of the centrifugal force and the force exerted by the weight of the vehicle at right angles to the plane of the top surface of the rails. In this state of equilibrium, the difference in the heights of the outer and inner rails of the curve is known as *equilibrium superelevation.*



Equilibrium Superelevation:

- In Fig. above, if θ *is* the angle that the inclined plane makes with the horizontal line, then superelevation:
  - **tan θ** = Superelevation / Gauge = **e/ G**
  - **tan θ** = Centrifugal force/weight = **F/W**
- From these equations:
  - e/ G = F/W
  - e = f x G/W e

    = W/g x V^2/R x G/R

  $e = GV^2 / gR$

  Here, **e** *is* the equilibrium superelevation in metres, **G** is the gauge in metres, **V** *is* the velocity in metres per second, **g** is the acceleration due to gravity, and **R** *is* the radius of the curve in metres.
- In the metric system equilibrium superelevation is given by the formula:

  e = GV2 / 127R

  Where **e** is the superelevation in millimetres, **V** *is* the speed in km per hour, ***R*** *is* the radius of the curve in metres, and **G** is the dynamic gauge in millimetres, which is equal to the sum of the gauge and the width of the rail head in millimetres. This is equall to 1750 mm for BG tracks and 1058 mm for MG tracks.

Maximum value of Superelevation:

The maximum value of superelevation generally adopted on on many railways around the world is one-tenth to one-twelfth of the gauge. The values of maximum superelevation prescribed on Indian Railways are given in Table below.

Gauge	Limiting Value of Cant(mm)	
	Under normal conditions	With special permission
B.G	165	185
M.G	90	100
N.G	65	75

Cant Deficiency:

Cant deficiency is the difference between the actual cant provided and equilibrium cant necessary for the maximum permissible speed on a curve.
Cant deficiency should be as low as possible and is limited due to following reasons:

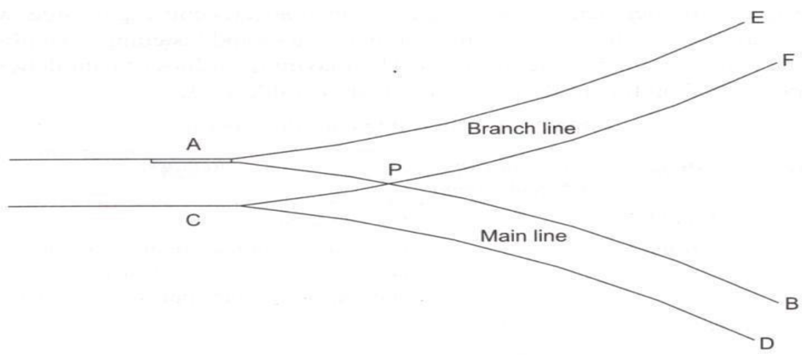
- Higher discomfort to passengers due to higher cant deficiency
- Higher cant deficiency results in higher unbalanced centrifugal force and hence extra pressure and lateral thrust on the outer rails, requiring strong track and more fastening for stability.
- Side wear and creep of outer rails of the track are more due to higher cant deficiency.

Limits of cant deficiency for different gauges on Indian Railways:

Gauge	Cant Deficiency(mm)	
	For speeds up to 100 km/hr	For speeds higher than 100 km/hr
B.G	76	100
M.G	51	Not specified
N.G	38	Not specified

Negative Superelevation:

When the main line lies on a curve and has a turnout of contrary flexure leading to a branch line, the superelevation necessary for the average speed of trains running over the main line curve cannot be provided. In **Fig**. below, AB, which is the outer rail of the main line curve, must he higher than CD. For the branch line, however CF should be higher than AE or point C should be higher than point A. These two contradictory conditions cannot be met within one layout. In such cases, the branch line curve has a negative superelevation and, therefore, speeds on both tracks must be restricted, particularly on the branch line.



(Fig: Negative superelevation)

The provision of negative superelevation for the branch line and the reduction in speed overthe main line can be calculated as follows:

(i) The equilibrium superelevation for the branch line curve is first calculated usingthe formula $\mathbf{e = GV^2 / 127R}$

(ii) The equilibrium superelevation e is reduced by the permissible cant deficiency C_d and the resultant superelevation to be provided is

$\mathbf{x = e - C_d}$

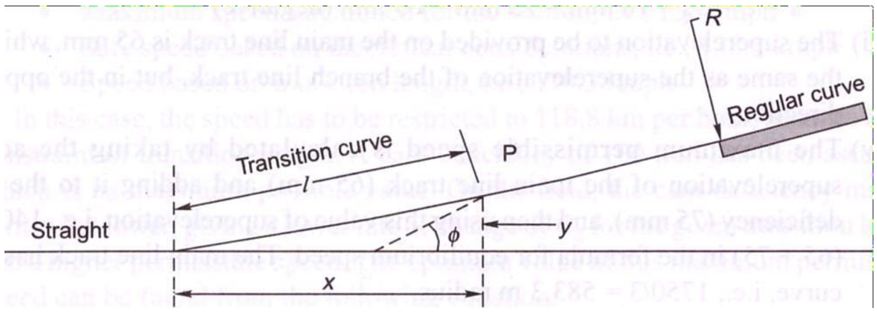
where x is the superelevation, e is the equilibrium superelevation, and C_d is 75 mm for BG and 50 mm for MG. The value of C_d is generally higher than that of e, and, therefore, x is normally negative. The branch line thus has a negative superelevation of x.

(iii) The maximum permissible speed on the main line, which has a superelevation of x, is then calculated by adding the allowable cant deficiency $\mathbf{(x + C_d)}$.

TRANSITION CURVES:

As soon as a train commences motion on a circular curve from a straight line track, it is subjected to a sudden centrifugal force, which not only causes discomfort to the passengers, but also distorts the track alignment and affects the stability of the rolling stock. In order to smoothen the shift from the straight line to the curve, transition curves are provided on eitherside of the circular curve so that the centrifugal force is built up gradually as the superelevation slowly runs out at a uniform rate (Fig. below). A transition curve is, therefore, the cure for an uncomfortable ride, in which the degree of the curvature and the gain of superelevation are uniform throughout its length, starting from zero at the tangent point to the specified value at the circular curve. The following are the objectives of a transition curve.

(a) To decrease the radius of the curvature gradually in a planned way from infinity at the straight line to the specified value of the radius of a circular curve in order to help the vehicle negotiate the curve smoothly.



(b) To provide a gradual increase of the superelevation starting from zero at the straight line to the desired superelevation at the circular curve.

(c) To ensure a gradual increase or decrease of centrifugal forces so as to enable the vehicles to negotiate a curve smoothly.

Requirements of an Ideal Transition Curve

The transition curve should satisfy the following conditions.

- It should be tangential to the straight line of the track, i.e., it should start from the straight part of the track with a zero curvature.
- It should join the circular curve tangentially, i.e., it should finally have the same curvature as that of the circular curve.
- Its curvature should increase at the same rate as the superelevation.
- The length of the transition curve should be adequate to attain the final superelevation, which increases gradually at a specified rate.

LENGTH OF TRANSITION CURVE

The length of the transition curve is length along the centre line of the track from its meeting point with the straight to that of the circular curve. This length is inserted at the junction half in the straight and half in the curve. Let, L = Length of transition curve in metres e = Actual cant or superelevation in cm. D = Cant deficiency for maximum speed in cm and V = Maximum speed in kmph.

Indian Railways specify that *greatest* of the following lengths should be taken as the length of the transition curve.

$L = 7.20\ e$

where e = actual superelevation in centimetres. This is based on Arbitrary gradient (1 in 720)

$L = 0.073\ D \times V_{max}$

The length of the transition curve prescribed on Indian Railways is the maximum of thefollowing three values:

$L = 0.008C_a \times V_m = C_a$

$\times V_m / 125L = 0.\ 008C_d$

$\times V_m = C_d \times V_m / 125L$

$= 0.72C_a$

Where L is the length of the curve in metres, $C_a$is the actual cant or superelevation in millimetres, and C_d is the cant deficiency in millimetres. Above first two equations are based ona rate of change of a cant or cant deficiency of 35 mm/sec. Third equation is based on a maximum cant gradient of 1 in a 720 or 1.4 mm/m.

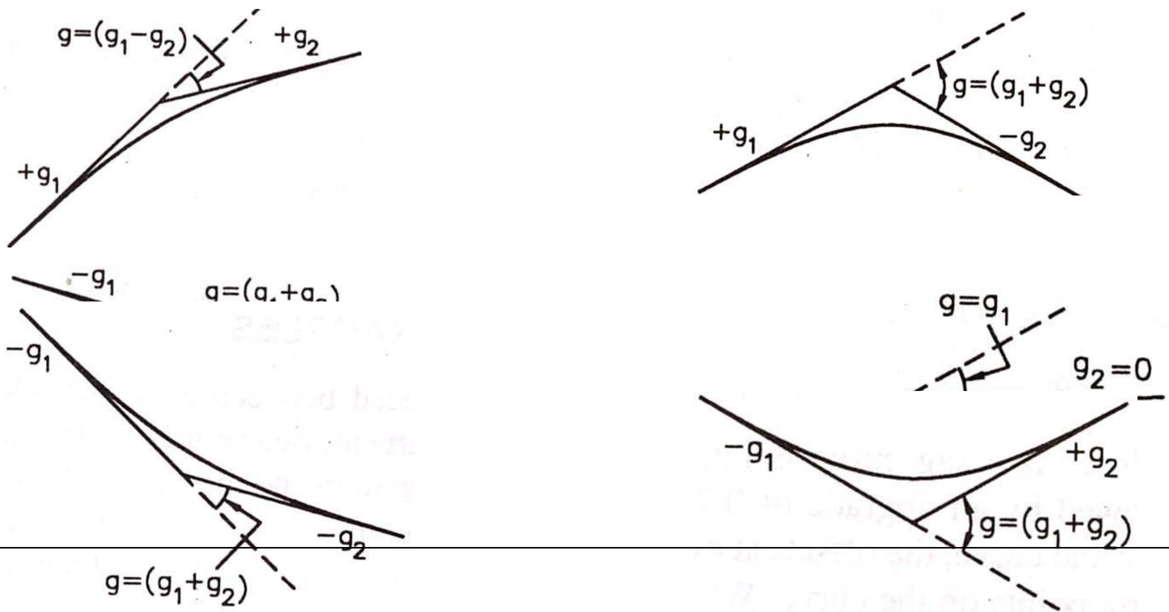
VERTICAL CURVES

They are of two types :

(i) Summit curves. (ii) Sag or Valley curves.

Whenever, there is a change in the gradient of the track, an angle is formed at the junction of the gradients. This vertical kink at the junction is smoothened by the use of curve, so that bad lurching is not experienced. The effects of change of gradient cause variation in the draw bar pullof the locomotive.

When a train climbs a certain upgrade at a uniform speed and passes over the summit of the curve, an acceleration begins to act upon it and makes the trains to move faster and increases the draw bar pull behind each vehicle, causing a variation in the tension in the couplings.



When a train passes over a sag, the front of the train ascends an up-grade while rear vehicles tendto compress the couplings and buffers, and when the whole train has passed the sag, the couplings are again in tension causing a jerk. Due to above reasons, it is essential to introduce a vertical curve at each sag and at each summit or apex.

A parabolic curve is set out, tangent to the two intersecting grades, with its apex at a level halfway between the points of intersection of the grade line and the average elevation of the two tangent points. The length of the vertical curve depends upon the algebraic difference in grade as shown in figure above and determined by the rate of change gradient of the line.

Widening of Gauge on Curves

There are several reasons for widening the gauge length in the case of a sharp curve.

- **Due to the loss of contact between wheel and rail in trailing position**
- **Due to the tendency of the inner wheels to slip in the backward direction. At the same time, the tendency of the outer wheels to skid in a forward direction.**
- **Due to the rigidity of the wheelbase, it is sometimes found on the curve that the rails are tilted outwards so that the actual gauge is more than the theoretical value.**
- **The centrifugal force which is acting in the outward direction tries to take the vehicle outward direction.**

  To overcome all the above reasons, some widening is required on the gauge on the curve.

The extra width of gauge (d) = $\frac{(B+L)^2 \times 125}{R}$

Where,

d = extra-wide of gauge on curve (in 'mm')
B = the rigid wheel base (in 'm')
L = Lap of flange (in 'm') = $2 \times \sqrt{(D+h)h}$
R = Radius of curve (in 'm')

D = Diameter of wheel (in 'm')
h = Depth of wheel flange below rail (in 'm')