Roadway alignment

Topo/Terrain Classification:

1. Level terrain – gen curvature are considered
2. Rolling terrain – both grade and curvature are considered
3. Mountainous terrain – grade is most imp consideration

An ideal and most desirable roadway is one that follow existing natural alignment without making considerable adjustment in horizontal and vertical direction.

Alignment should be uniform and consistent to match with driver expectancy

Types of Alignment:

1. Horizontal alignment
2. Vertical alignment

Objective:

1. Comfort
2. Safety

Horizontal Alignment

Elements:
Straight section
Transition curve
Circular Curve
Superelevation
Sight distance
Offset of the roadside objects







Horizontal alignment

Straight sec or tangent of highway may need to be connected with circular curve with or without the provision of transition curves.

So, we need to design various **elements of curves as well as superelevation**.

Circular curve

- Simple curve
- Reverse curve
- Compound curve
- Spiral curve

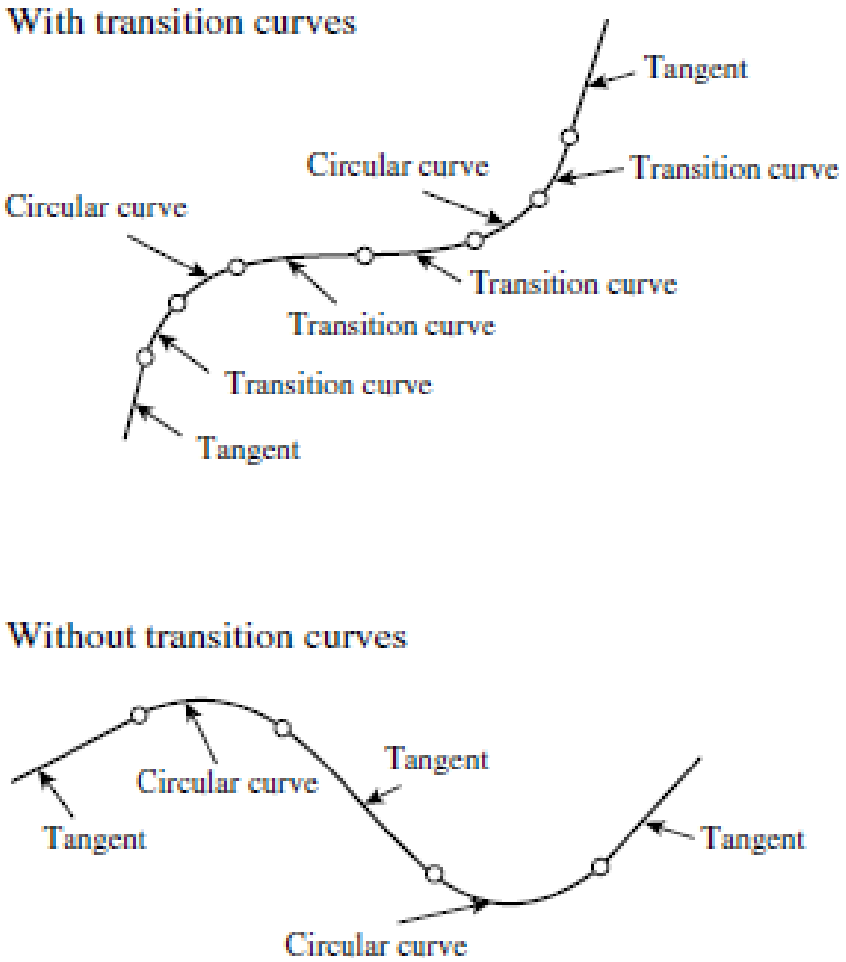
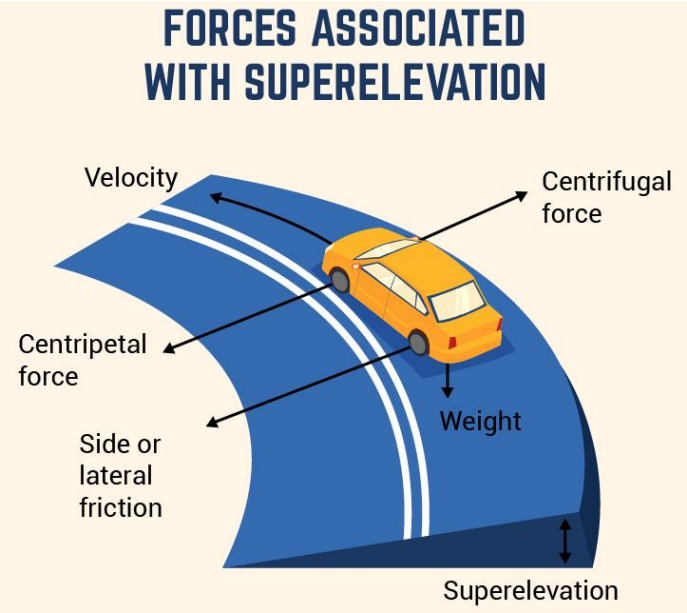


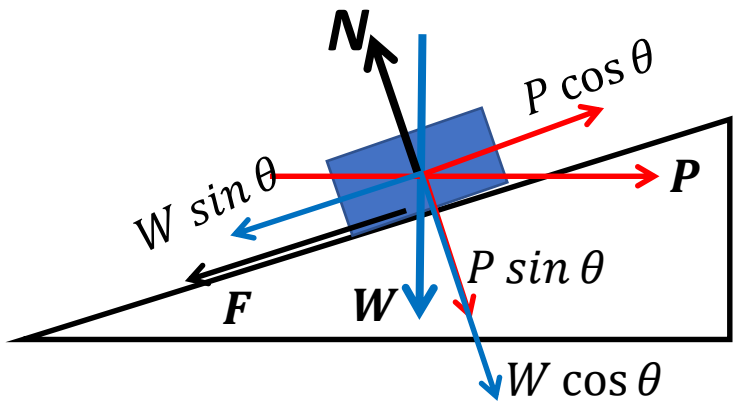
FIGURE 4.11
Horizontal alignments with and without transition curves.

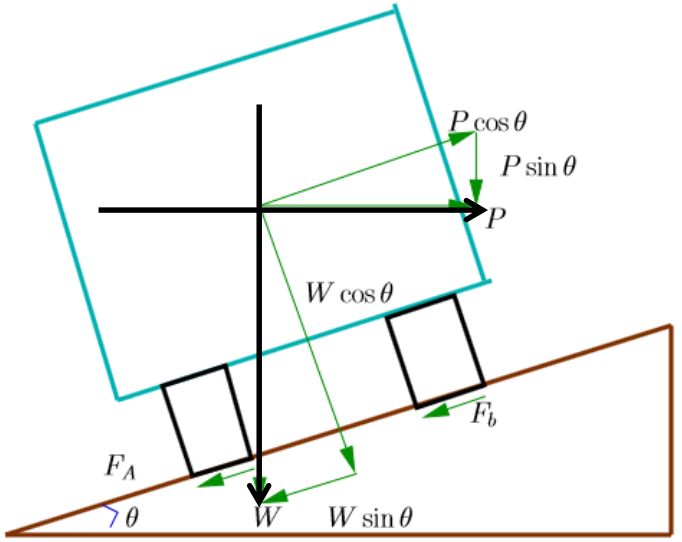
Why superelevation is provided

- To **counteract the effect of centrifugal force** acting on moving vehicle.
- To help a fast moving vehicles to **negotiate a curved path without overturning and skidding**.
- To ensure **smooth and safe movements** of passengers and goods on the road.
- To **prevent damaging effect on the road surface** due to improper distribution of load and thereby to reduce the maintenance cost of road on curve.



Analysis of Superelevation





W = Weight of the vehicle,
v = Speed of the vehicle in m/sec,
g = Acceleration due to gravity in m/sec²,
f = Coefficient of friction,
e = rate of superelevation (tanθ),
F = Frictional force resistance
P = Centrifugal force.

$\sum F_x = 0,\ P\cos\theta = W\sin\theta + F,\qquad P\cos\theta = W\sin\theta + F_A + F_B$

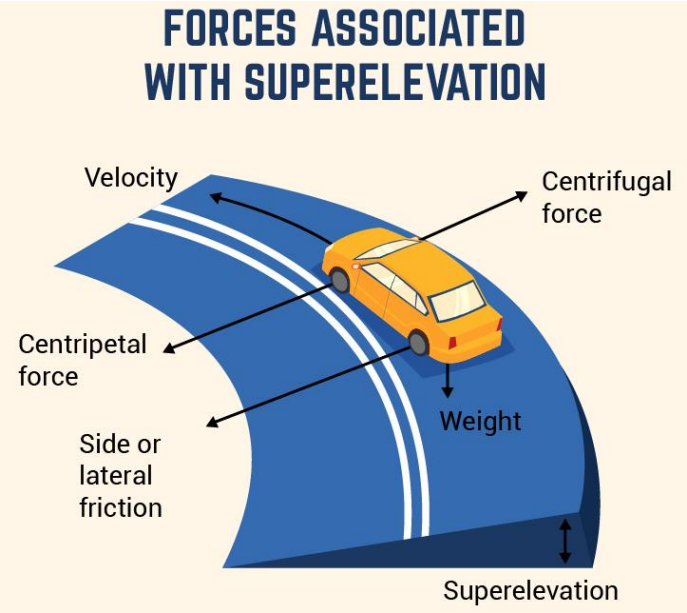
$\sum F_y = 0,\quad N = P\sin\theta + W\cos\theta \quad Again, F = F_A + F_B = fN = f(P\sin\theta + W\cos\theta)$

$Therefore, P\cos\theta = W\sin\theta + f(P\sin\theta + W\cos\theta)$

Or, $P = W\tan\theta + f(P\tan\theta + W)$ [dividing by $\cos\theta$]

Or, $\frac{P}{W} = \tan\theta + f(\frac{P}{W}\tan\theta + 1)$

Or, $\frac{P}{W}(1 - f\tan\theta) = \tan\theta + f \qquad or, \qquad \frac{P}{W} = \frac{\tan\theta + f}{(1 - f\tan\theta)}$

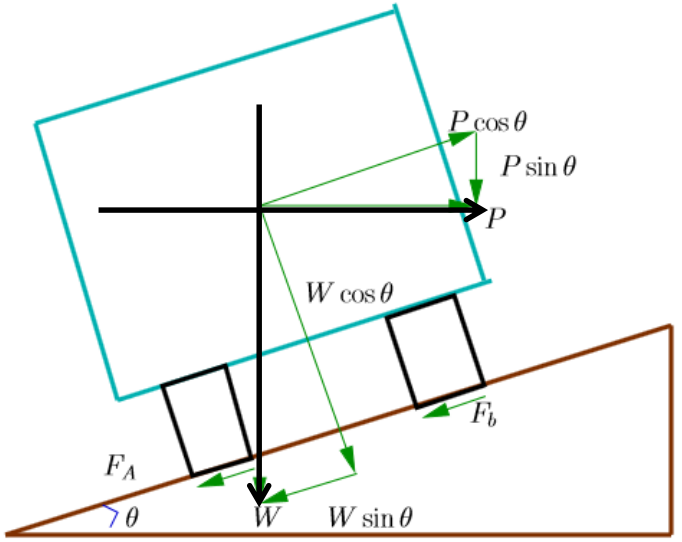


Analysis of Superelevation

$$or, \quad \frac{P}{W} = \frac{tan\,\theta + f}{(1 - f\,tan\,\theta)}$$

neglecting the value of $(1 - f\,tan\,\theta)$

$$tan\,\boldsymbol{\theta} + f = \frac{\boldsymbol{P}}{\boldsymbol{W}}$$



Again, if a vehicle of mass m, travelling at a constant speed v, along a curve of radius R, is subjected to a radial force (centrifugal force), $\boldsymbol{P = m\alpha = m\frac{v^2}{R} = \frac{W}{g}\frac{v^2}{R}}$, **or,** $\boldsymbol{\frac{P}{W} = \frac{v^2}{gR}}$

$tan\,\boldsymbol{\theta} + f = \boldsymbol{\frac{P}{W}}$ **and,** $\boldsymbol{\frac{P}{W} = \frac{v^2}{gR}}$ **Therefore,** $tan\,\boldsymbol{\theta} + f = \boldsymbol{\frac{v^2}{gR}}$

Thus, the centrifugal force is balanced by the sum of the effect of the super elevation and the effect of friction.

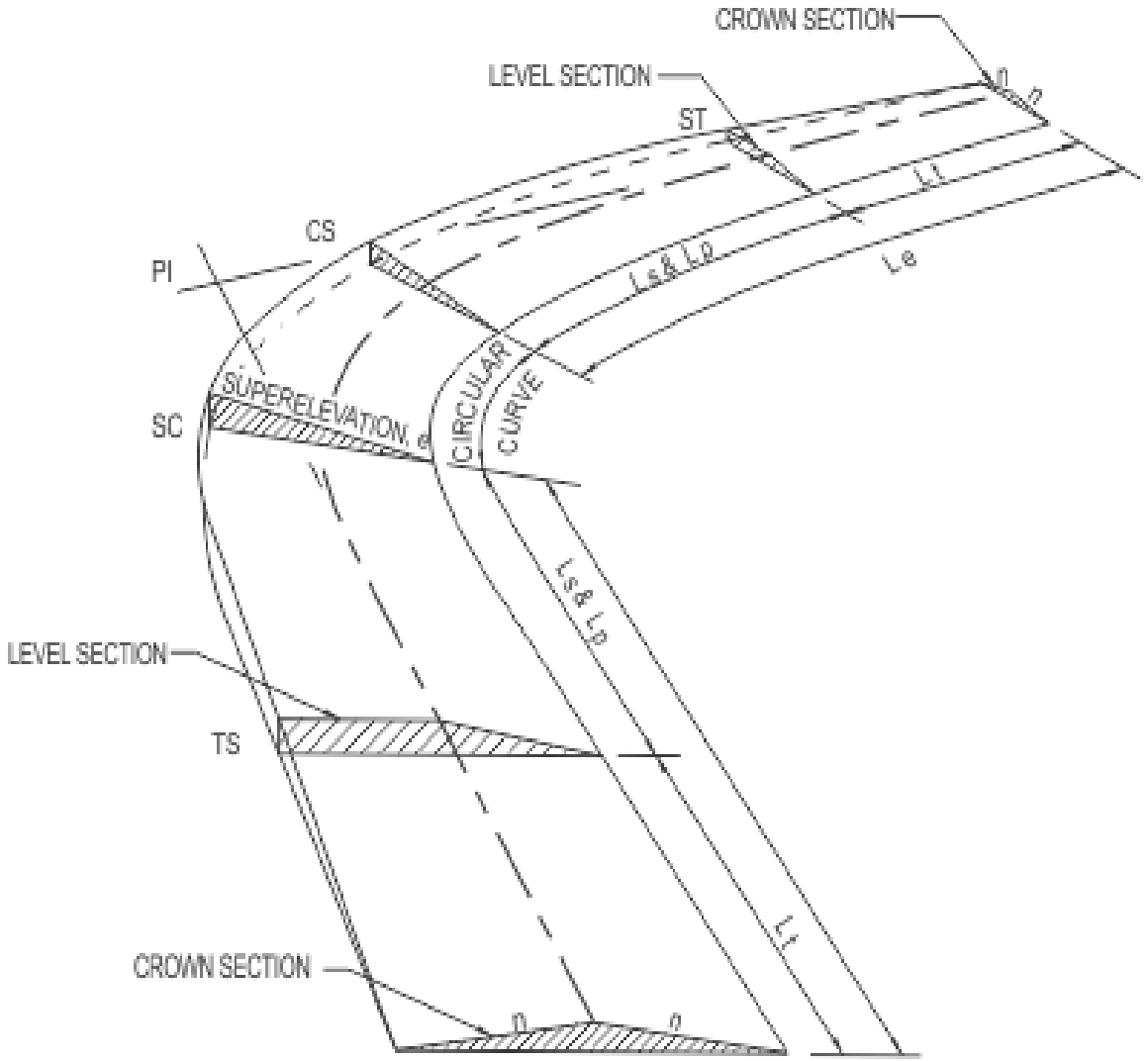
$\boldsymbol{e + f = \frac{v^2}{gR}}$ when the speed of vehicle is in **'m/s'**

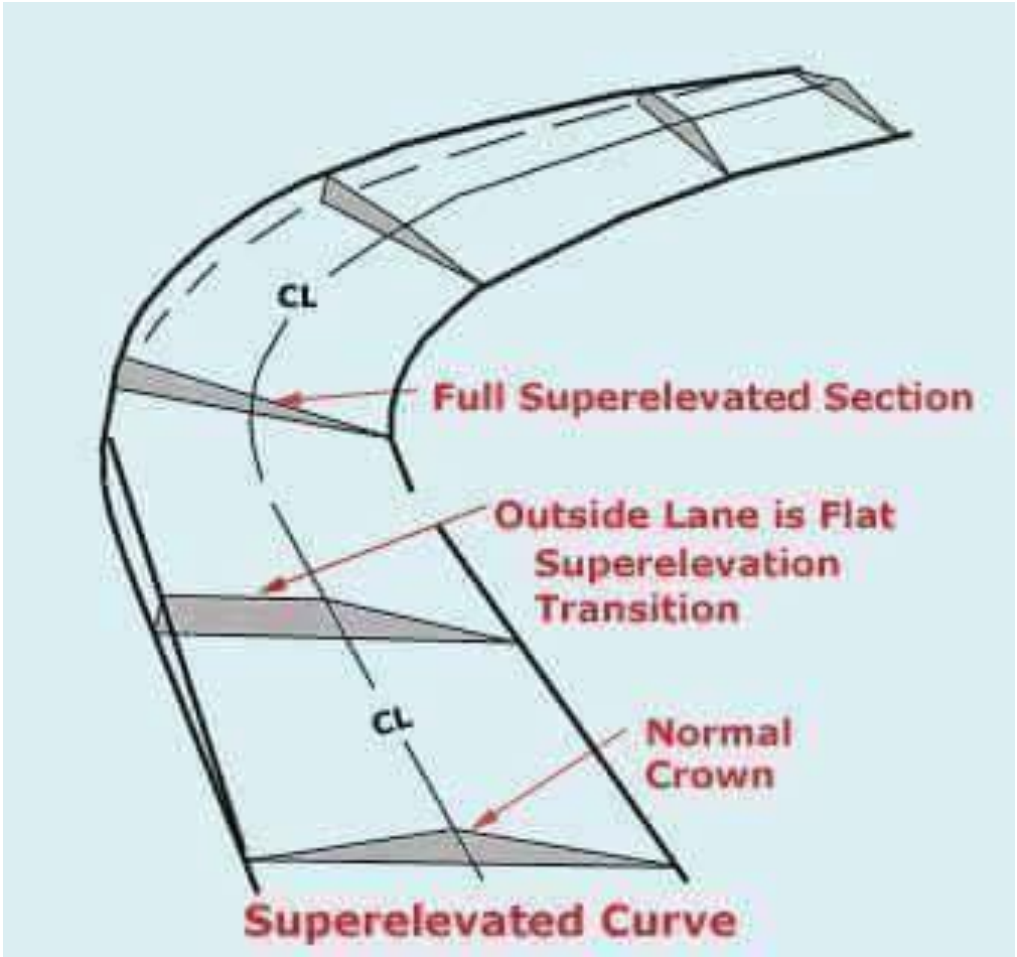
Or, $\boldsymbol{e + f = \frac{V^2}{127R}}$ when speed of vehicle is in **'kmph'**

$$\boldsymbol{e + f = \frac{v^2}{gR} = \frac{(\frac{v}{3.6})^2}{9.81R} = \frac{V^2}{127R}}$$

Superelevation Transition

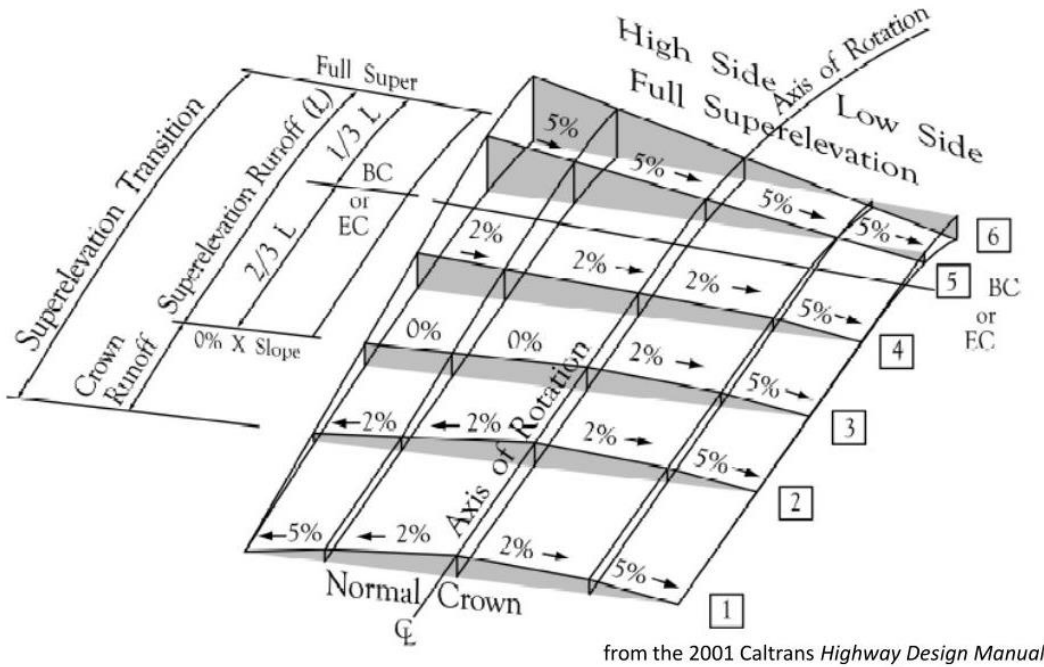
Transitions from crowned sections to superelevation sections should be gradual
Superelevation should be introduced and removed uniformly over the length of the curve



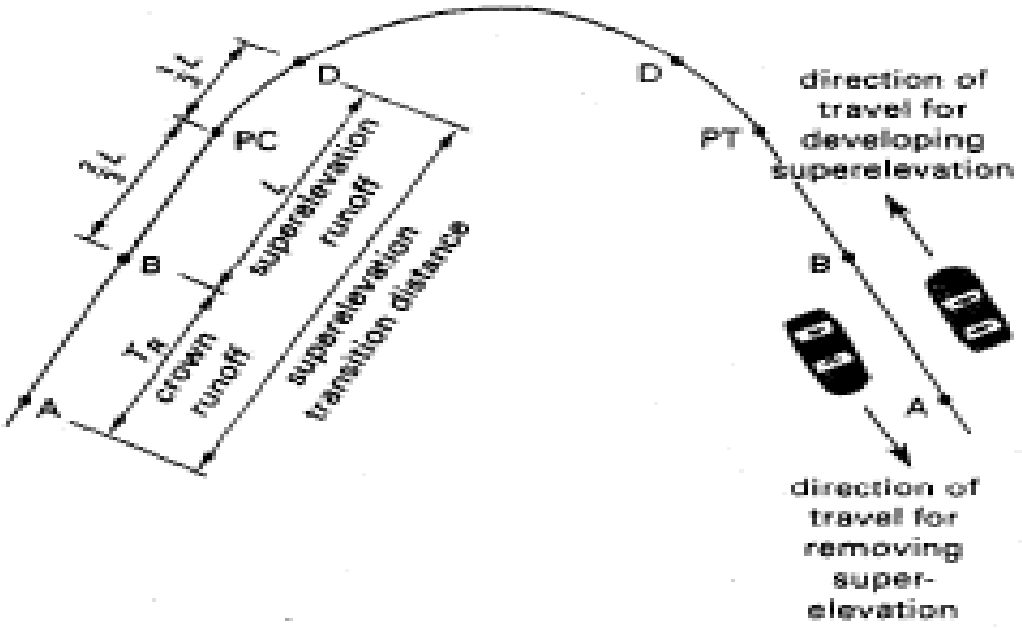


Superelevation Transition

Superelevation runoff: Dist. reqr for accomplishing the transition from a zero percent or flat sec to a fully super elevated sec

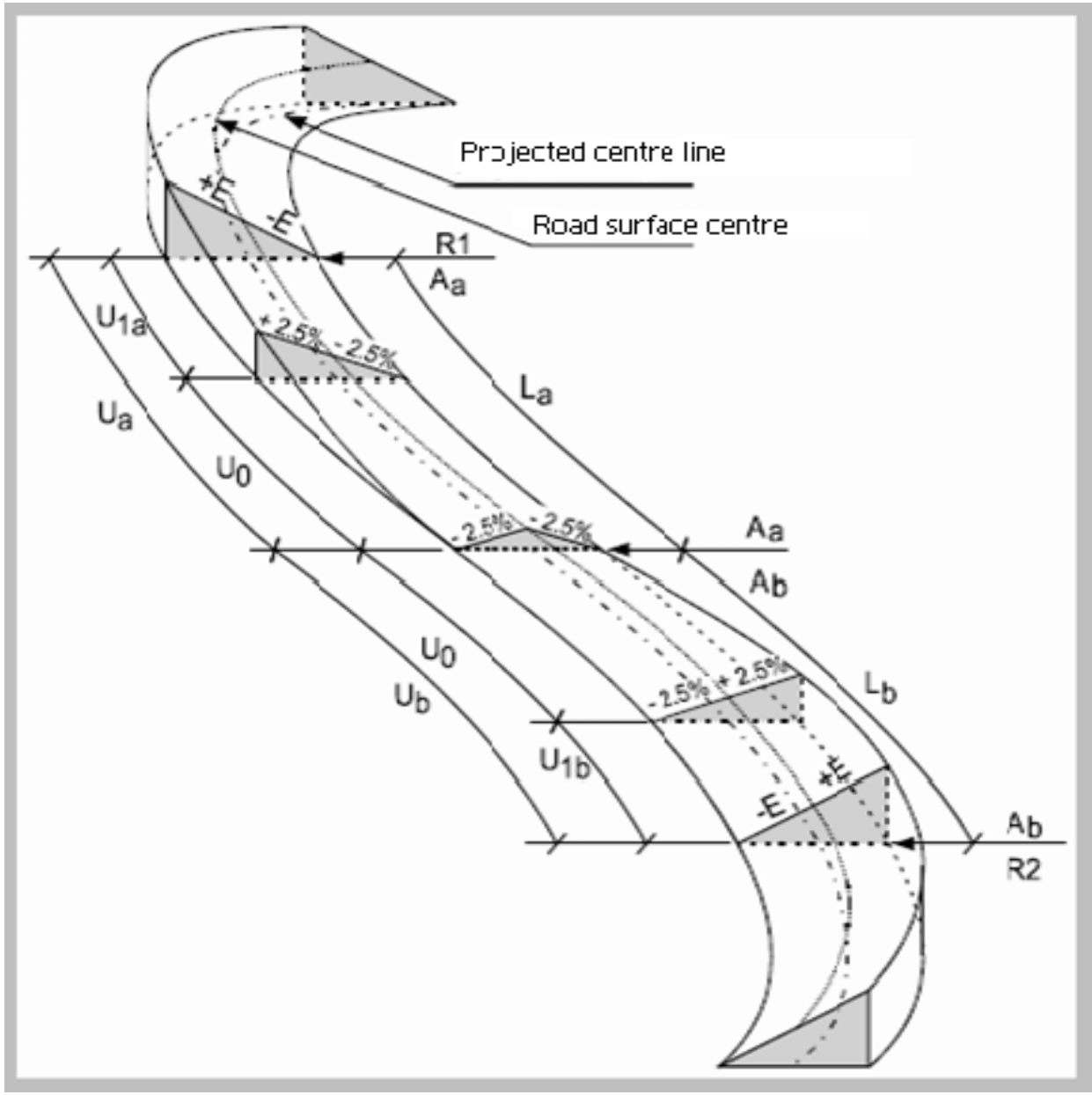


from the 2001 Caltrans *Highway Design Manual*



Tangent Runout: Dist. reqr for accomplishing the transition from adverse cross slope to flat sec or zero percent super elevated sec.

Super elevation Transition Distance



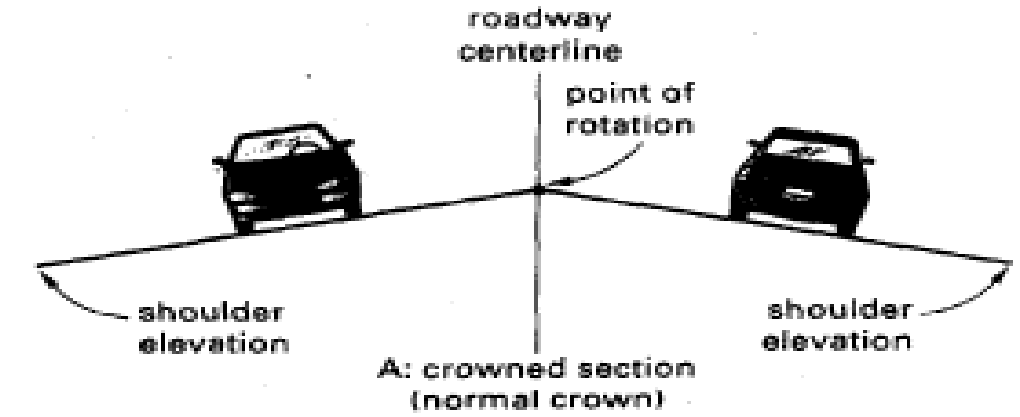
Method of attaining Superelevation

The transition from a tangent, normal crown sec to a curve superelevation sec must be accomplished without any appreciable reduction of speed and in such a manner as to ensure safety and comfort to the occupants.

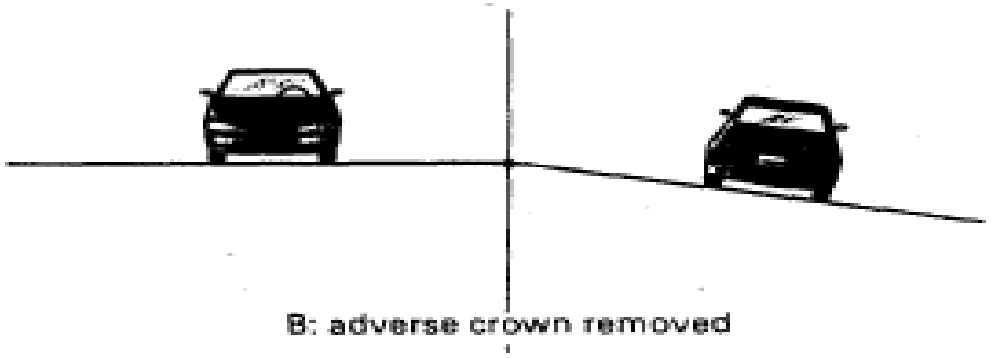
Superelevation is provided in two Steps:

1. Elimination of the crown of the cambered section.
2. Rotation of pavement to attain full superelevation

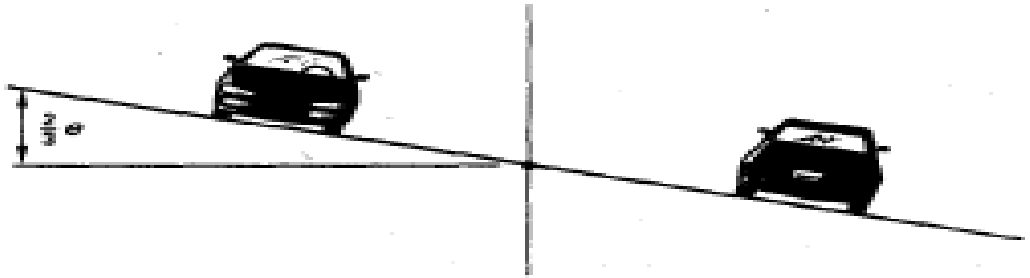
Method of attaining Superelevation



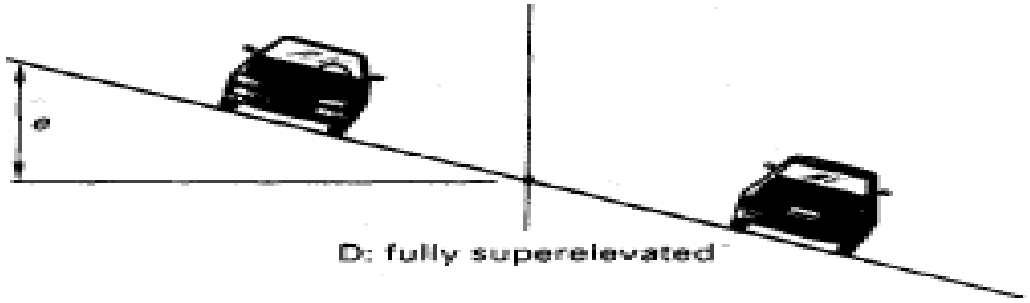
A: crowned section
(normal crown)



B: adverse crown removed



PC: 2/3 of superelevation developed



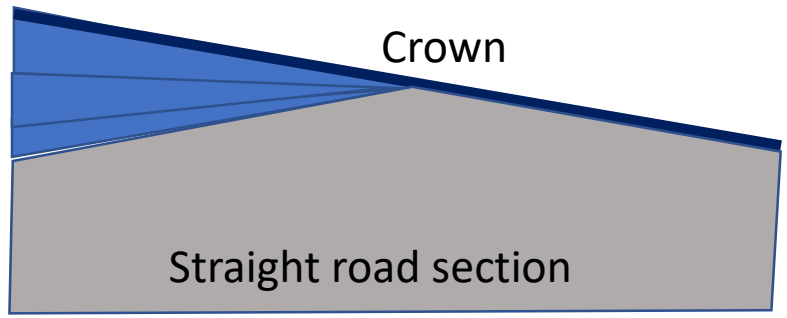
D: fully superelevated

Method of attaining Superelevation

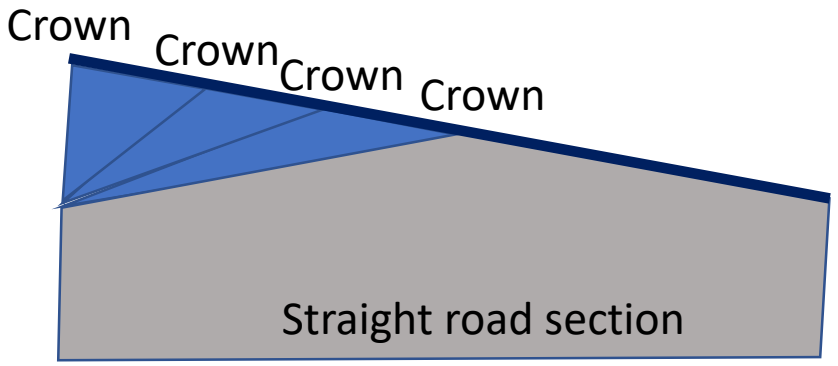
Step 1. Elimination of the Crown of the Cambered Section

In this method, the outer half of the camber is gradually decreased. This may be done by two methods

In the first method, the outer half of the camber is rotated about the crown at the desired rate such that the surface falls on the same plane as the inner half.



In the second method, the crown is progressively shifted outwards. This method is not usually adopted.



Method of attaining Superelevation

Step 2. Rotation of Pavement to attain full Superelevation

A. Revolving Pavement about the Center Line

In this method the surface of the road is **rotated about the center line of the carriageway, gradually lowering the inner edge and rising the upper edge**. The level of the **center line is kept constant**. This method is **widely used**.

B. Revolving Pavement about the Inner Edge

In this method, the surface of the road is **rotated about the inner edge, raising the center and outer edge, inner edge constant.**

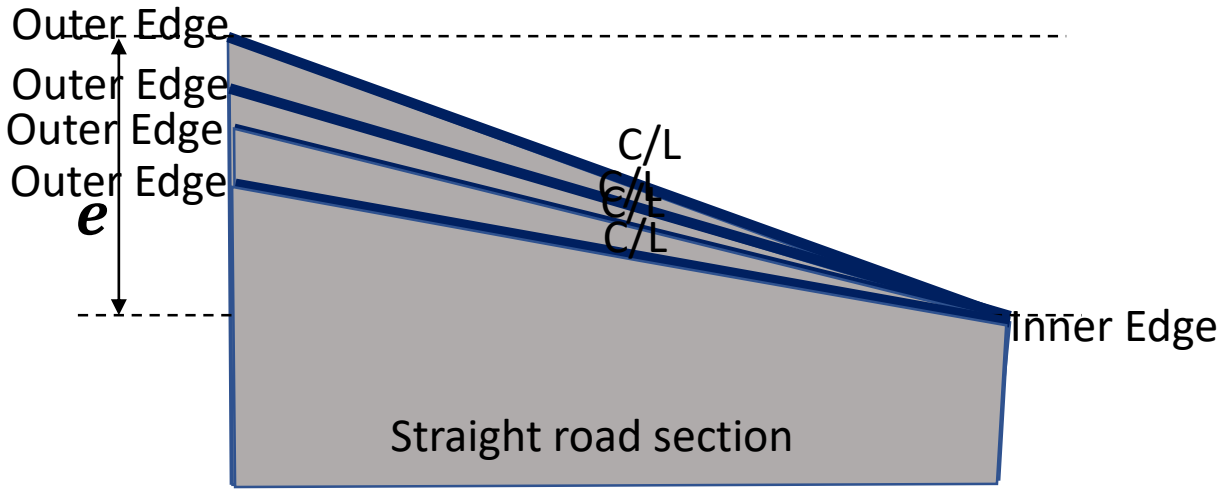
C. Revolving Pavement about the Outer Edge

In this method, the surface of the road is rotated about the outer edge **depressing center and inner edge**, **outer edge constant.**

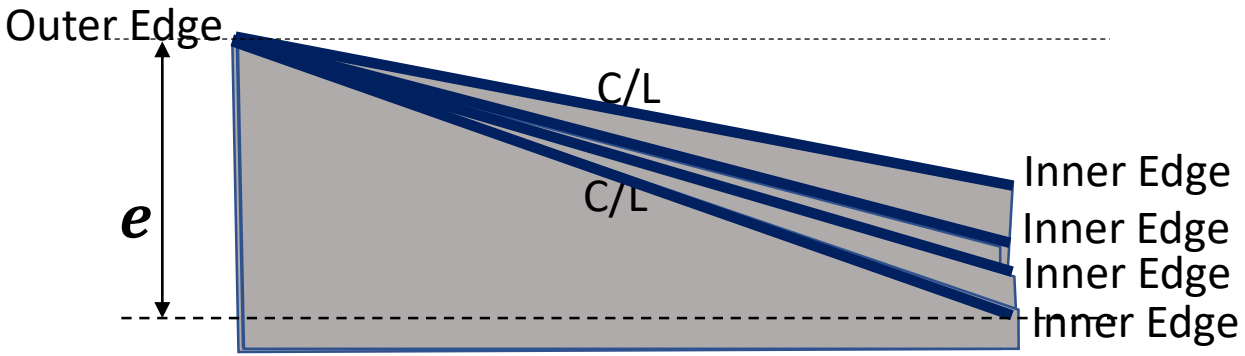
D. Revolving the straight cross slopes travelled way about the outer edge profile

Method of attaining Superelevation

Revolving Pavement about the Inner Edge

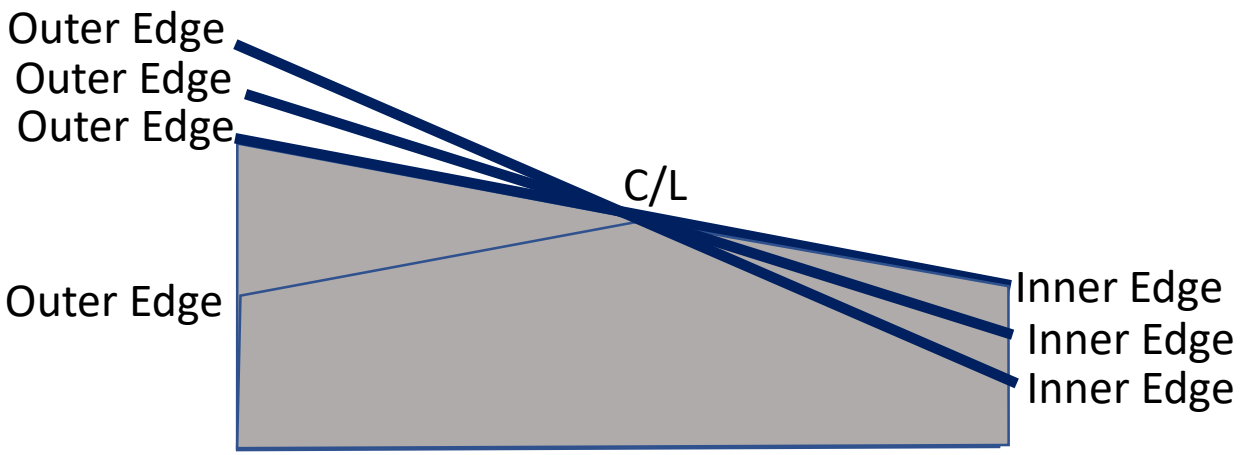


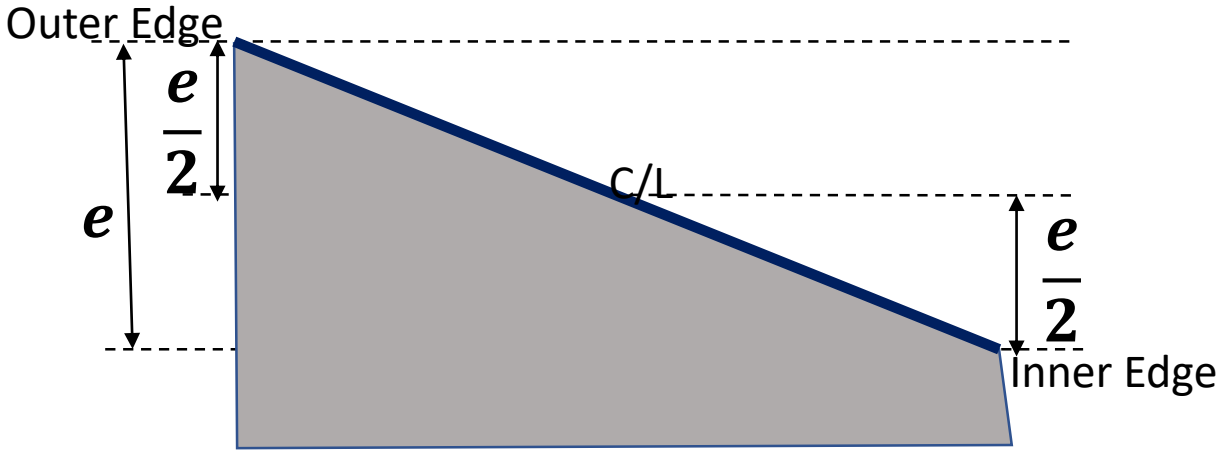
Revolving Pavement about the Outer Edge

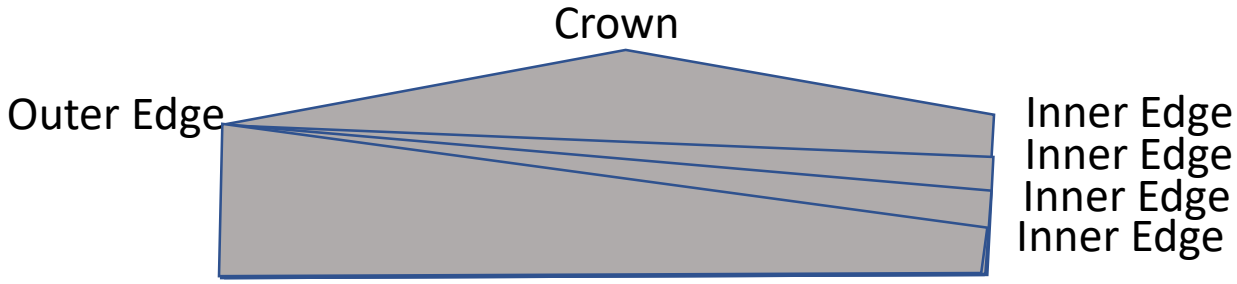


Method of attaining Superelevation

Revolving Pavement about the Center Line





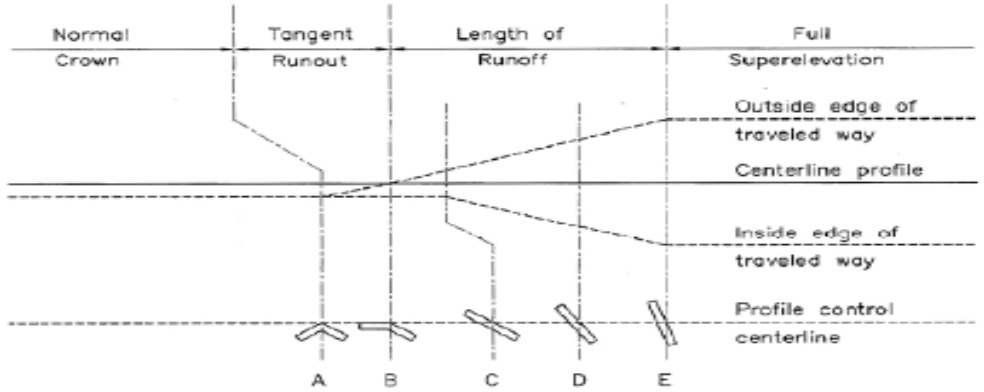


Method of attaining Superelevation

First Method: Most widely used

Change in elevation of the edge is made with less distortion
One-half of the change in elevation is made at each edge

1. Revolving a traveled way with normal cross slopes about the centerline



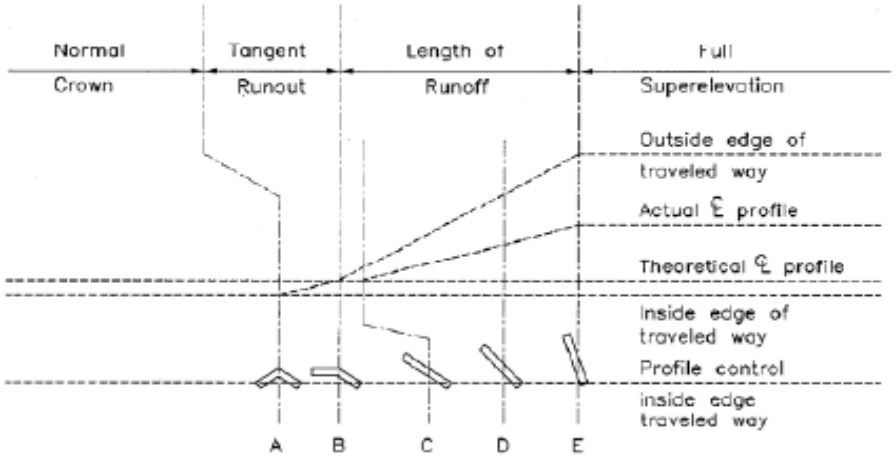
CROWNED
TRAVELED WAY REVOLVED ABOUT CENTERLINE

ASHTO 'Green Book', 2004

Second Method: Preferred when lower edge of profile is control for drainage

One-half of the change in elevation is made by raising the actual centerline profile with respect to the inside-edge profile and the other half by raising the outside-edge profile an equal amount with respect to the actual centerline profile

2. Revolving a traveled way with normal cross slopes about the inside edge profile



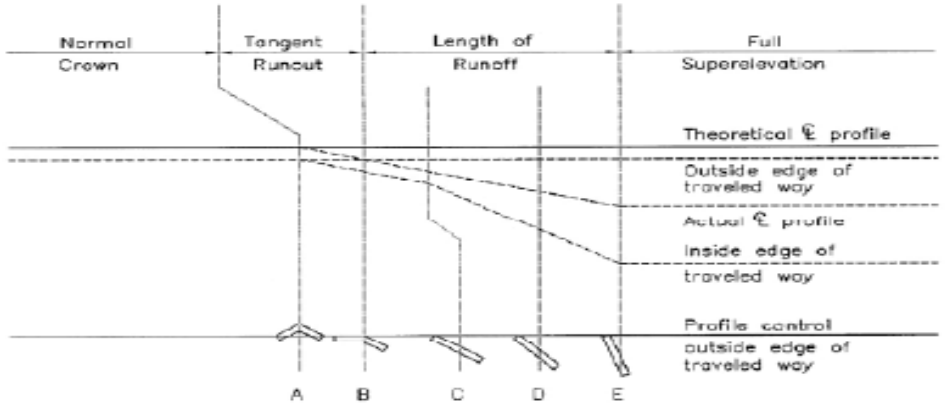
CROWNED
TRAVELED WAY REVOLVED ABOUT INSIDE EDGE

ASHTO 'Green Book', 2004

Method of attaining Superelevation

Third method
Similar to second method, except elevation change is accomplished below the out side edge profile

3. Revolving a traveled way with normal cross slopes about the outside edge profile



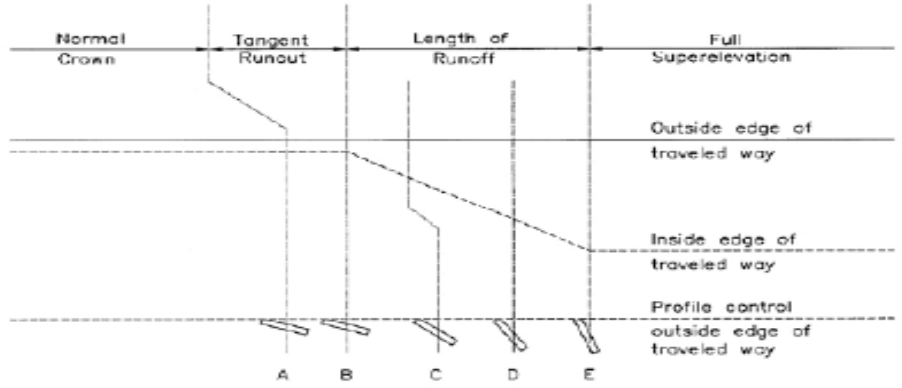
ASHTO 'Green Book', 2004

CROWNED

TRAVELED WAY REVOLVED ABOUT OUTSIDE EDGE

Fourth method
used for two-lane one-way roadways where axis of rotation coincides with the edge of traveled way adjacent to the highway median

4. Revolving a straight cross slope traveled way about the outside edge profile



ASHTO 'Green Book', 2004

STRAIGHT CROSS SLOPE

TRAVELED WAY REVOLVED ABOUT OUTSIDE EDGE

Super elevation Transition Distance

- Transition curve provides a gradual change from the tangent sec to the circular curve and vise versa.
- Radius of the transition curve/spiral curve varies from infinity at the tangent end to the radius of the circular arc at the end of the spiral
- The min length of the transition is

$L_s = 3.15\ \frac{V^3}{RC}$ **in FPS, L in ft, V in mph, R in ft, C is max rate of change in lateral acceleration (4ft/s³)**

$L_s = 0.0214\ \frac{V^3}{RC}$ **in MKS, L in m, V in km/hr, R in m, C is max rate of change in lateral acceleration (1.2m/s³)**

Properties of Simple Circular Curve

Length of the curve (PC to PT), $L = \frac{2\pi R\Delta}{360}$

Radius of Curve, $R = \frac{5729.58}{D}$

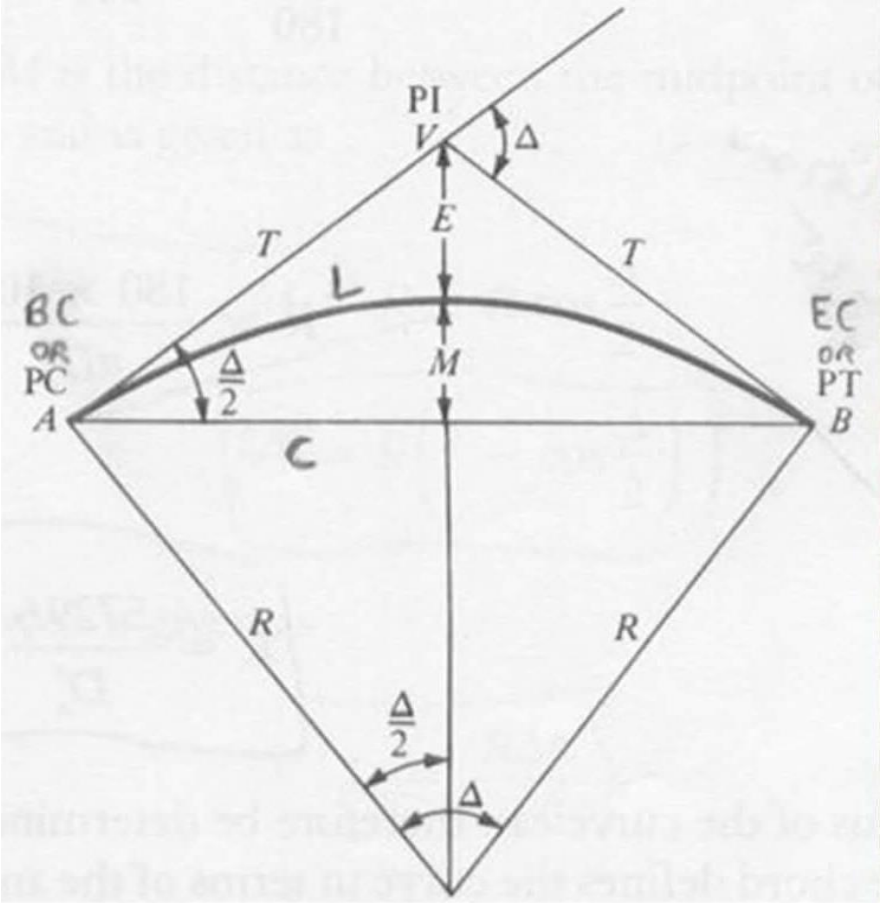
Length of Arc, $l = \frac{100\theta}{D}$

Middle ordinte, $M = R\left(1 - Cos\,\frac{\Delta}{2}\right)$

External distance, $E = R\left(\text{Sec}\,\frac{\Delta}{2} - 1\right)$

Chord length, $C = 2R\sin\frac{\Delta}{2}$

Tangent length, $T = R\,tan\frac{\Delta}{2}$



Maximum degree of curvature and Minimum Radius

Maximum degree of curvature or Minimum Radius is a limiting value of a curvature for given design speed and is determined from the max rate of superelevation and max allowable side friction factor.

$$R_{min} = \frac{v^2}{15(0.01e_{max}+f_{smax})}$$

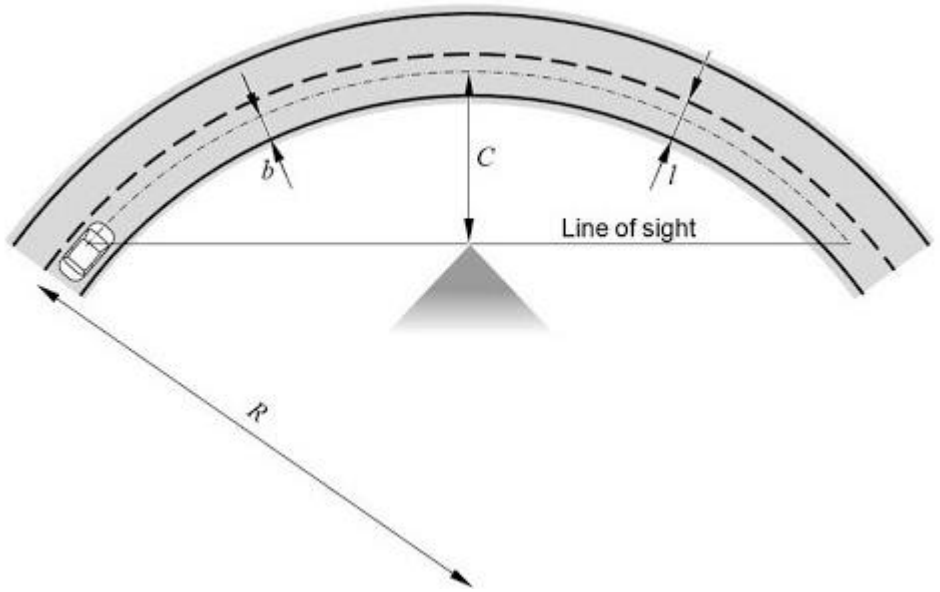
R = Radius of Curve (feet)

V = vehicle speed (mph)

e = tan α = rate of roadway superelevation

fs = coefficient of side friction

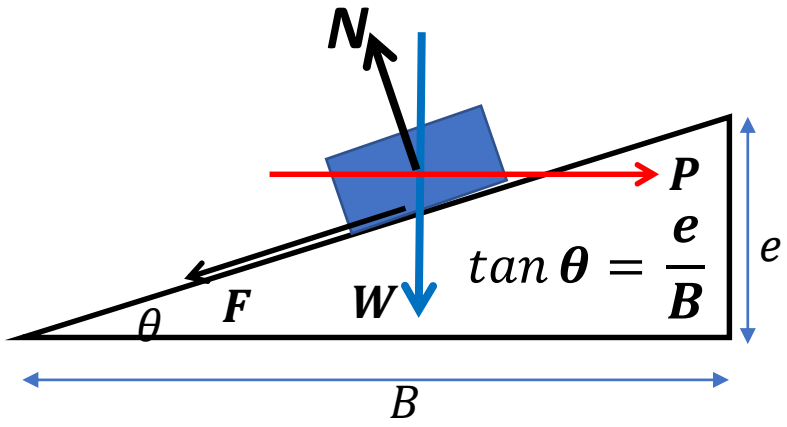
Offset of the Roadside Objects



Widening of Curves

As a veh turns, the rear wh of the veh follow the front wh on shorter radius, and this has the effect of increasing the veh width in relation to the lane width, hence need for additional pavement width. The amount of widening needed varies with

- the width of the pavement on the tangent
- the design speed
- the design veh
- the Horizontal curve radius



$tan\,\boldsymbol{\theta} + f = \dfrac{\boldsymbol{P}}{\boldsymbol{W}}$ and, $\dfrac{\boldsymbol{P}}{\boldsymbol{W}} = \dfrac{\boldsymbol{v^2}}{\boldsymbol{gR}}$ **Therefore,** $tan\,\boldsymbol{\theta} + f = \dfrac{\boldsymbol{v^2}}{\boldsymbol{gR}}$

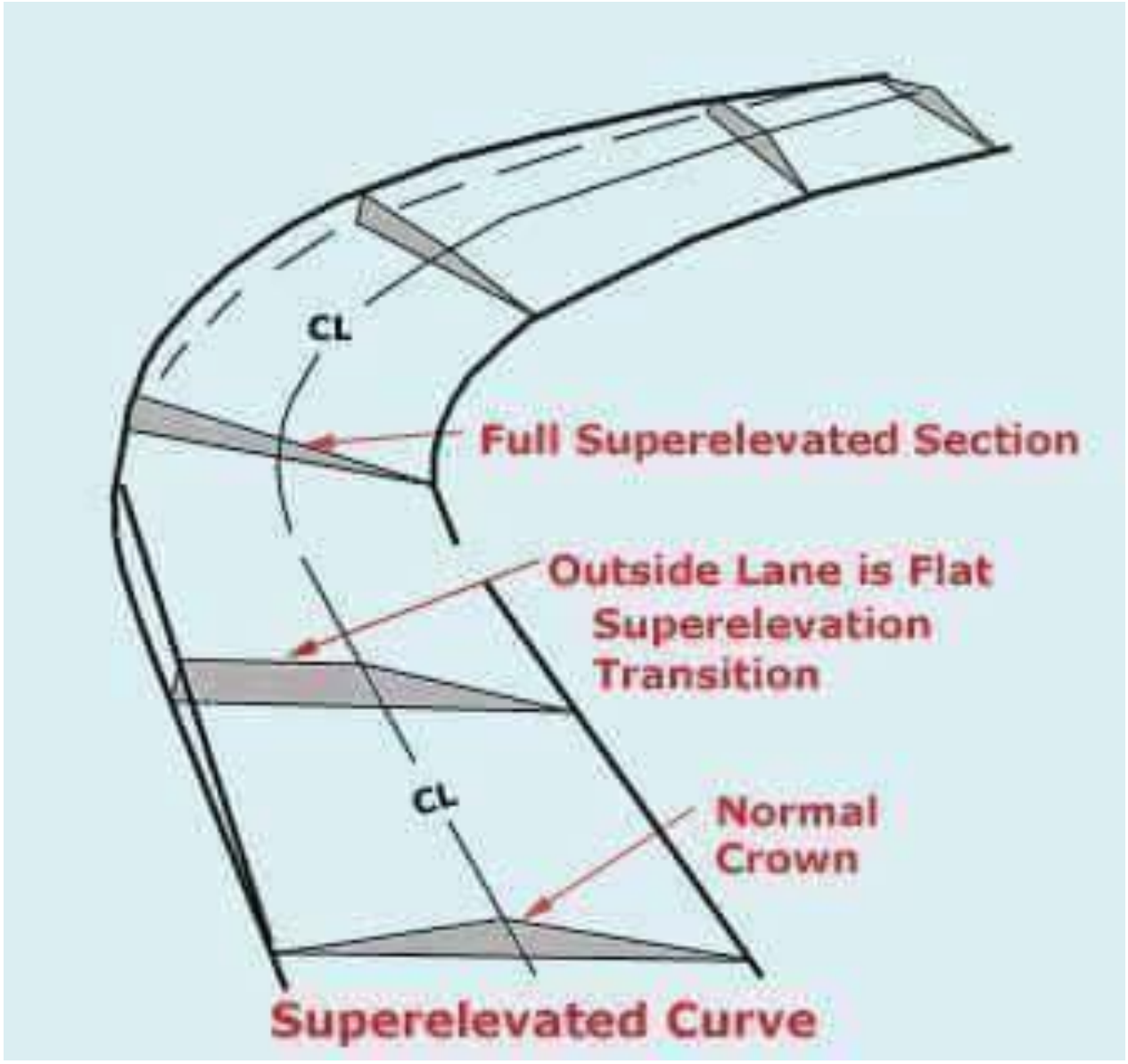
For balancing fully by super elevation, $\tan\boldsymbol{\theta} = \dfrac{\boldsymbol{v^2}}{\boldsymbol{gR}}$ **For balancing fully by friction,** $\boldsymbol{f} = \dfrac{\boldsymbol{v^2}}{\boldsymbol{gR}}$

Again, from roadway geometry, $tan\,\theta = \dfrac{e}{B}$ **(when, B road way width and e superelevation**

So, for roadway, $tan\,\boldsymbol{\theta} = \dfrac{\boldsymbol{e}}{\boldsymbol{B}} = \dfrac{\boldsymbol{v^2}}{\boldsymbol{gR}}$

and for railway, $tan\,\boldsymbol{\theta} = \dfrac{\boldsymbol{e}}{\boldsymbol{G}} = \dfrac{\boldsymbol{v^2}}{\boldsymbol{gR}}$ **when G is gauge of the railway**

Length of Transition Curve



Length of Transition Curve

Length should be such that the required s.e or cant is provided at a suitable rate.

1. By an arbitrary gradient
2. By the time rate
3. By the rate of change of radial acceleration

Method 1: By an arbitrary gradient

If gradient is 1 in n, then L=ne

Value of n varies from 300 to 1200

$L = ne = nB.\tan\theta = B.v^2/gR$ on road

$L = ne = nG.\tan\theta = G.v^2/gR$ on railways

Method 2: By the time rate

Let e is applied at an arbitrary time rate of r units per sec.

L=length of transition curve in m, v= speed of veh in m/sec, e amount of s.e.

Time taken by a veh to pass over a transition curve = t =L/v sec.

Super elevation attained in this time = t x r cm = r.L/v. So, e= r.L/v

Therefore, L = e.v/r meters

Length of Transition Curve

Method 3: By the rate of change of radial acceleration

In this method length of transition curve is decided on the basis of comfort of passengers. It is experienced that a rate of change of radial acceleration of 1 ft/sec (0.3 m/sec) will pass unnoticed.

If α is the rate of change of radial acceleration in m/sec and t is the time taken to travel over the transition curve having length L, Then acceleration attained in that time is = αt =αL/v sec.

But radial acceleration of a circular curve is v^2/R, so $v^2/R = \alpha L/v$

So $L = v^3/\alpha R$ where v is in m/sec

When α = 0.3 m/sec then $L = V^3/14R$ where V is in kmph

1. **By an arbitrary gradient, $L = ne = \frac{Bv^2}{gR}$**
2. **By the time rate, $L = e.\frac{v}{r}$**
3. **By the rate of change of radial acceleration, $L = \frac{v^3}{\alpha R}$, or $L = \frac{V^3}{14R}$**

Prob: A transition curve is required for a circular curve of 200m radius, the gauge being 1.5 m and max super elevation restricted to 15 cm. The transition is to be designed for a velocity such that no lateral pressure is imposed on the rails and the rate of gain of radial acceleration is 30 cm/sec^3. calculate the required length of the transition curve and the design speed.

$$\tan\theta = \frac{e}{G} = \frac{v^2}{gR}$$

$$\frac{15}{150} = \frac{v^2}{9.81 \times 200}$$

Thus v = 14 m/sec

$$L = \frac{v^3}{\alpha R} = \frac{14^3}{0.3 \times 200} = 46 \text{ m}$$

Prob: A Road bend which deflects 80° is to be designed for a max speed of 100 km per hr, a max centrifugal ratio of ¼ and a max rate of change of acceleration of 30 cm/sec^3. the curve consisting of a circular arc combined with two cubic spirals. Calculate

(a) radius of circular arc,
(b) the requisite length of transition,
(c) the total length of composite curve
(d) The chainage of the beginning and the end of transition curve and of the junctions of the transition curves with the circular arc if the chainage of the P.I is 42862m.

Prob: Calculate the super elevation required for road of 7 m wide on a curve of 250 m radius for permissible speed of 80 kmph. Let the coefficient of friction be 0.15.

$$e + f = \frac{V^2}{127R}$$

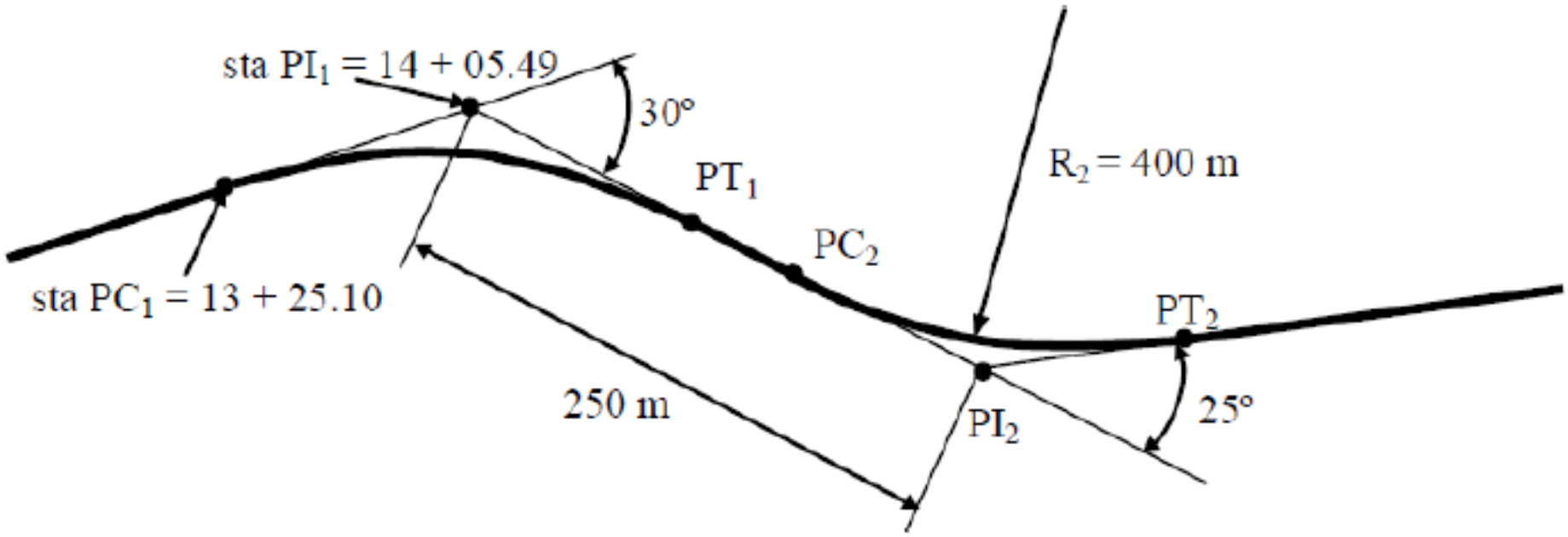
$$e + 0.15 = \frac{80^2}{127 \times 250} = 0.201$$

$$e + 0.15 = 0.201 - 0.15 = 0.051 \; per \; m \; of \; carraigeway$$

$$So, Superelevation = 0.051 \times 7 = 0.357 \; m$$
$$= 35.7 \; cm \; above \; the \; inner \; edge \; of \; the \; roadaigeway$$

Prob: a) For the horizontal alignment shown below, compute the stations of PT_1 and PC_2, and a point P that on curve 1 and is located 30.52 m before PT_1.

b) If the design speed is 80 km/h and the road is designed so that the superelevation for curve 1 is 0.058 (5.8 percent), determine the side friction demands on curve 1 for vehicles traveling at the design speed and at 10 km/h.



Maximum and Minimum superelevation

Maximum Superelevation

Maximum superelevation is provided to prevent the vehicle from being overturned. So, we can say, it is the maximum percentage of angle allowed for the road to prevent the vehicle from being overturned.
In plain and rolling terrain and in the snowbound area is 1 in 15 or 4° or 7 %.
On hill roads not bound by snow, a **maximum superelevation up to 10%** has been recommended by IRC.

Minimum Superelevation

The minimum super elevation is provided mainly for the drain of rainwater effectively.
The road surface should have a minimum **camber** to drain off rainwater. If the calculated superelevation is equal to or less than the camber of the road surface, then the minimum superelevation to be provided on the horizontal curve may be limited to the camber of the surface.
It is usually 2 to 4%.

Vertical Alignment

- The vertical alignment of a road consists of gradients (straight lines in a vertical plane) and vertical curves.
- A circular curve is used to connect horizontal straight stretches of road whereas vertical curves connect two gradients.
- When these two curves meet, they form either convex or concave. The former is called a summit curve, while the latter is called a valley curve.





Effect of gradient

- The effect of long steep gradient on the vehicular speed is considerable.
- This is **particularly important in roads where the proportion of heavy vehicles is significant**.
- Due to **restrictive sight distance at uphill gradients** the speed of traffic is often controlled by these heavy vehicles.
- As a result, not only the operating costs of the vehicles are increased, but also capacity of the roads will have to be reduced.
- Further, **due to high differential speed between heavy and light vehicles, and between uphill and downhill gradients, accidents abound in gradients**.

Vertical Alignment

- Change of grades from minus to plus should be placed in cuts and changes from a minus to plus grade should be planed in fills.
- **Max grade depends on design speed and topography**
- max grade ranges from 5 to 7 % depending on road way cl and surrounding topography.
- 5% for design speed of 70 mph
- **Min grade are governed by drainage condition**
- Whenever long sustained grades are used, the designer should not exceed the critical grade w/o provision of climbing lanes for slow mov veh. Critical grade vary from 1650 ft (for 3% grade) to 500 ft (for 8%).