DESIGN OF VERTICAL ALIGNMENT

INTRODUCTION

The natural ground or the topography may be level at some places, but may have slopesof varying magnitudes at other locations. While aligning a highway it is the common practice to follow the general topography or profile of the land, keeping in view the drainage and otherrequirements on each stretch. This is particularly with a view to minimise deep cuttings and very high embankments. Hence the vertical profile of a road would have level stretches as wellas slopes or grades.

In order to have smooth vehicle movements on the roads, the changes in the gradient should be smoothened out by the vertical curves. The vertical alignment is the elevation or profile of the centre line of the road. The vertical alignment consists of grades and vertical curves.

The vertical alignment of a highway influences

1) Vehicle Speed
2) Acceleration and Deceleration
3) Stopping Distance
4) Sight Distance
5) Comfort While Travelling at High Speeds
6) Vehicle Operation Cost.

Gradient

Gradient is the rate of rise or fall along the length of the road with respect to the horizontal. It is expressed as a ratio of 1 in x (1 vertical unit to x horizontal units). The gradientis also expressed as percentages such as n%, the slope being n vertical units to 100 horizontal units

Types of gradient

a) Ruling Gradient
b) Limiting Gradient
c) Exceptional Gradient
d) Minimum Gradient

Ruling gradient

The ruling gradient or the design gradient is the maximum gradient with which the designer attempts to design the vertical profile of the road. This depends on the terrain, lengthof the grade, speed, pulling power of the vehicle and the presence of the horizontal curve. In plain terrain, it may be possible to provide at gradients, but in hilly terrain it is not economicaland sometimes not possible also.

The IRC has recommended ruling gradient values of

a) 1 in 30 on plain and rolling terrain
b) 1 in 20 on mountainous terrain
c) 1 in 16.7 on steep terrain.

Limiting gradient

Where topography of a place compels adopting steeper gradient than the ruling gradient, 'limiting gradient' is used in view of enormous increase in cost in constructing roads with gentler gradients. However, the length of continuous grade line steeper than ruling gradient should be limited. On rolling terrain and on hill roads, it may be frequently necessaryto exceed ruling gradient and adopt limiting gradient, but care should be taken to separate suchstretches of steep gradients by providing either a level road or a road with easier grade.

Exceptional gradient

In some extra ordinary situations, it may be unavoidable to provide still steeper gradients than limiting gradient at least for short stretches and in such cases the steeper gradientup to 'exceptional gradient' may be provided. However, the exceptional gradient should be strictly limited only for short stretches not exceeding about 100 m at a stretch.

Minimum gradient

This is important only at locations where surface drainage is important. Camber will take care of the lateral drainage. But the longitudinal drainage along the side drains requires some slope for smooth flow of water.

The road with zero gradient passing through level land and open side drains are providedwith a gradient of 1 in 400.A minimum of 1 in 500 may be sufficient to drain water in concretedrains or gutter, on inferior surface of drains 1 in 200 or 0.5%, on kutcha open drains steeper slope up to 1 in 100 or 1 % may be provided

Gradient for roads in different terrains

Type of Terrain	**Ruling Gradient**	**Limiting Gradient**	**Exceptional Gradient**
Plain or Rolling	3.3 %, 1 in 30	5 %, 1 in 20	6.7 %, 1 in 15
Mountainous terrain and steep terrain having elevation more than 3000 m above the mean sea level	5 %, 1 in 20	6 %, 1 in 16.7	7 %, 1 in 14.3
Steep terrain up to 3000 m height above mean sea level	6 %, 1 in 16.7	7 %, 1 in 14.3	8 %, 1 in 12.5

Grade Compensation on Horizontal Curve

When sharp horizontal curve is to be introduced on a road which has already the maximum permissible gradient, then the gradient should be decreased to compensate for the loss of tractive effort due to curve. This reduction in gradient at the horizontal curve is called Grade compensation or compensation in gradiebt at the horizontal curve, which is intended tooff-set the extra tractive effort involved at the curve. This is calculated from the below equation

$$\text{Grade Compensation \%} = \frac{30+R}{R}$$

The max value of grade compensation is limited to 75/R, where R is the radius of the circular curve in m

As per IRC the grade compensation is not necessary for gradients flatter than 4.0 %, and therefore when applying grade compensation correction, the gradients need not be eased beyond 4 %.

The compensated gradient = Ruling Gradient – Grade Compensation

Vertical Curves

Due to changes in grade in the vertical alignment of highway, it is necessary to introduce vertical curve at the intersections of different grades to smoothen out the vertical profile and thus ease off the changes in gradients for the fast moving vehicles.

The vertical curves used in highway may be classified into two categories:

(a) Summit curves or crest curves with convexity upwards

(b) Valley curves or sag curves with concavity upwards

Summit curves

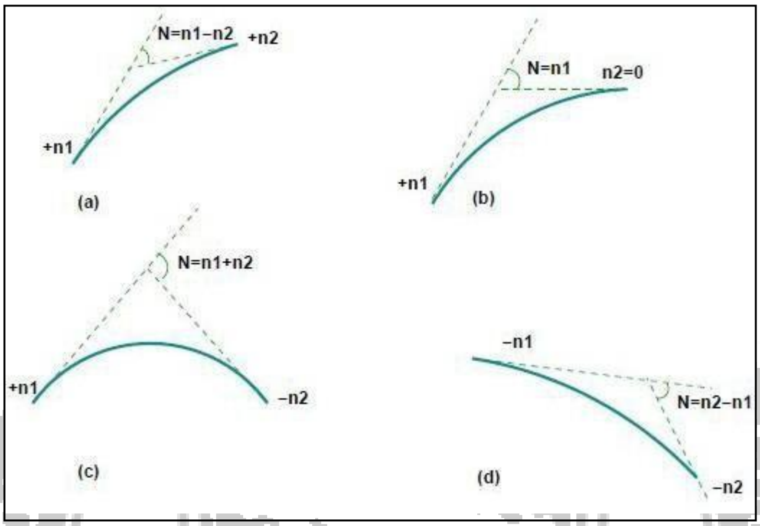
Summit curves with convexity upwards are formed in any one of the cases as given below

a) When a positive gradient meets another positive gradient

b) When positive gradient meets a at gradient

c) When an ascending gradient meets a descending gradient.

d) When a descending gradient meets another descending gradient



The deviation angle, N between the two intersecting gradients is equal to the algebraic difference between them. Among all the cases, the deviation angle will be maximum when anascending gradient, (+ n1) meets with a descending gradient, (- n2).

Therefore, deviation angle, N= n1 - (- n2) = (n1 + n2)

When a fast moving vehicle travels along a summit curve, the centrifugal force will actupwards, against gravity and hence a part of the self-weight of the vehicle is relieved resultingin reduction in pressure on the tyres and on the suspension springs of the vehicle suspensions.So there is no problem of discomfort to passengers on summit curves, particularly because thedeviation angles on roads are quite small. Also if the summit curve is designed to have adequate sight distance, the length of the summit curve would be long enough to ease the shock due to change in gradients.

Type of Summit Curve

Many curve forms can be used with satisfactory results; the common practice has beento use parabolic curves in summit curves. This is primarily because of the ease with it can be laid out as well as allowing a comfortable transition from one gradient to another.

LENGTH OF THE SUMMIT CURVE

The important design aspect of the summit curve is the determination of the length of the curve which is parabolic. As noted earlier, the length of the curve is guided by the sight distance consideration.

Length of the summit curve for SSD

a) When L > SSD

The equation for length L of the parabolic curve is given by

$$L = \frac{NS^2}{(\sqrt{2H} + \sqrt{2h})^2}$$

As per IRC

$$L = \frac{NS^2}{4.4}$$

a) When L < SSD

The equation for length L of the parabolic curve is given by

$$L = 2S - \frac{(\sqrt{2H} + \sqrt{2h})^2}{N}$$

As per IRC

$$L = 2S - \frac{4.4}{N}$$

The minimum radius of parabolic summit curve is given by R/N

Length of the summit curve for OSD or ISD

a) When L > OSD or ISD

The equation for length L of the parabolic curve is given by

$$L = \frac{NS^2}{8H}$$

As per IRC

$$L = \frac{NS^2}{9.6}$$

S – OSD or ISD, m

a) When L < OSD or ISD

The equation for length L of the parabolic curve is given by

$$L = 2S - \frac{8H}{N}$$

As per IRC

$$L = 2S - \frac{9.6}{N}$$

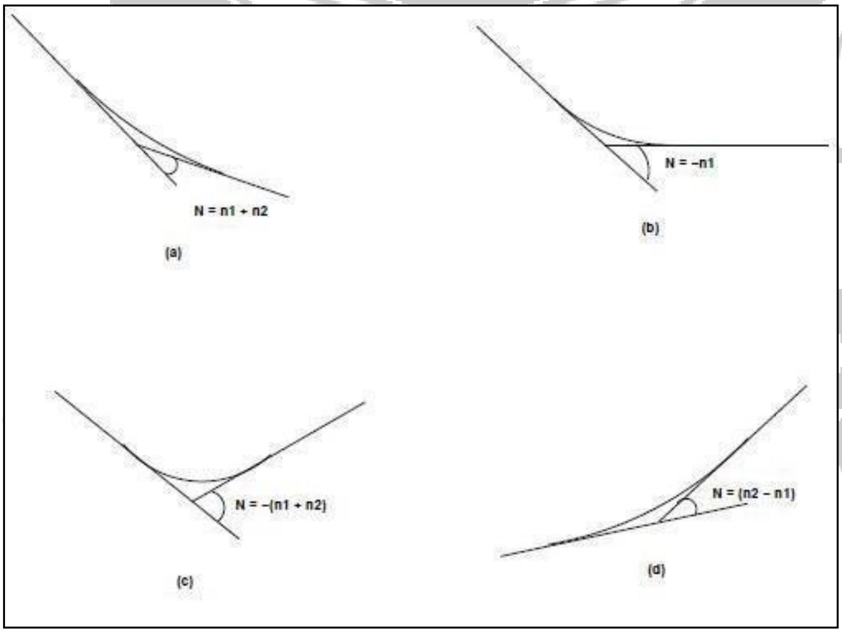
Valley curve

Valley curve or sag curves are vertical curves with convexity downwards. The deviationangle, N between the two intersecting gradients is equal to the algebraic difference between them. Among all the cases, the deviation angle will be maximum when a descending gradient,(- n1) meets with an ascending gradient, (+ n2).

Therefore, deviation angle, N= - n1 - (+ n2) = - (n1 + n2)

They are formed when two gradients meet as illustrated in figure below in any of the following four ways:

1) When a descending gradient meets another descending gradient
2) When a descending gradient meets a at gradient
3) When a descending gradient meets an ascendinggradient
4) When an ascending gradient meets another ascending gradient



Length of the valley curve

The length of the valley transition curve is designed to fulfil two criteria

a) Allowable rate change of centrifugal acceleration

b) The required HSD for night driving

Length of transition curve for Comfort condition

The equation for length L of the parabolic curve is given by

$$L = 2\left|\frac{Nv^3}{C}\right|^{\frac{1}{2}} = 0.38(NV^3)^{\frac{1}{2}}$$

Where

L – Total length of valley curve = 2Ls

N – Deviation angle, equal to algebraic difference in grades, radians, or tangent of deviation angle

C – the allowable rate of change of centrifugal acceleration, the value of C may be taken as 0.6m/sec^3

v – Design speed in m/s

V – design speed in kmph

The minimum radius of cubic parabolic valley curve is given by $R = \frac{Ls}{N} = \frac{L}{2N}$

Length of the summit curve for OSD or ISD

a) **When L > OSD or ISD**

If the valley curve is assumed to be parabolic shape, with equation y = a x ^{2}, where a = N/2L

The equation for length L of the parabolic curve is given by

$$h_1 + S\tan\alpha = a\,S^2 = \frac{NS^2}{2L}$$

Where

h1 – the average height of head light = 0.75m

α - 1°, the beam angle

$$L = \frac{NS^2}{(1.5 + 0.035S)}$$

L – Total length of valley curve, m

S – OSD or ISD, m

N - Deviation angle = (n1 + n2), with slopes – n1 and + n2

a) When L < OSD or ISD

The equation for length L of the parabolic curve is given by

$$h_1 + S\tan a = (S - \frac{L}{2})\,N$$

Where

h1 – the average height of head light = 0.75m

α - 1°, the beam angle

$$L = 2S - \frac{(1.5 + 0.035S)}{N}$$