
CHAPTER SEVEN

ROUTE SURVEYING AND GEOMETRY OF HIGHWAY CURVES

7.0. Route Surveying

The **term Route Surveying** in a very general sense may be used for the surveys carried along the comparatively narrow strip of the territory for the location, design and construction of any of transportation route such as highway, railway, canal, sewers and so on.

Route surveying is conducted for the purpose of selecting the best route between two terminal OR end station, and to establish horizontal and vertical alignment of the selected route

Generally, Route Surveying includes all surveying & mapping activities (the field and office work) required to plan, design, and layout(construct) and any "Long and narrow" transportation facility.

Requirements of Highway alignment

The "shape" or geometry of any transportation route is called its **alignment**.

The basic requirements of an ideal alignment b/n two terminal station are that it should be:

- a) Short
 - b) Easy
 - c) Safe
 - d) Economical
- a) **Short:** It is desirable to have short alignment b/n two terminal stations. A straight alignment would be the shortest path.
- b) **Easy:** The alignment should be such that it is easy to construct and maintain the road with minimum problems.
- c) **Safe:** The alignment should be safe for construction and maintenance from the point of view of stability of natural slope, embankment & cut slope and also foundation drivers & passengers. /free of accident/.
- d) **Economical:** The road alignment could be considerate economical only if the total cost including initial cost, maintenance cost & vehicle operation cost is lowest.

Stage in Route Surveying

The survey may be completed in four stages:

- a) Map Study
- b) Reconnaissance
- c) Preliminary Survey

d) Final location and detail surveys

a) Map Study/Desk Study

If the topographic map of an area is available, it is possible to suggest the likely routes of the road. The main feature like rivers, hills, valleys etc. are also shown in these maps. By a careful study of such maps, it is possible to have an idea of several possible alternatives routes so that further details of these may be studied later at the site.

b) Reconnaissance or Site Visit

After the preliminary office work, a site visit must be made to the road. When potential route corridors have been identified from the desk study Analysis, then a reconnaissance survey is usually employed to verify interpretations, to help determine the preferred corridor, and to identify factors that will influence the feasibility design concept & cost companions.

A team consisting of the following personnel makes a site inspection visit:

- Highway Engineer
- Geotechnical Engineer (Soils & Materials Engineer)
- Surveying Engineer (Chief Surveyor)
- Hydrologist
- Environmentalist
- Sociologist
- Local administrative Personnel

Reconnaissance survey data can either be recorded on to topographical maps & aerial Photographs.

During the reconnaissance survey, the following information should be determined.

- ◆ Terrain classification
- ◆ Location of topographical constrains, such as cliffs, gorges, ravines, any other features not identified by the desk study
- ◆ Slope steepness
- ◆ Soil type
- ◆ Water sources, material sources & distribution

During the site inspection, the team should examine all alternatives. This information can be combined with the results of the desk study to determine the most appropriate alignment alternative.

c) Preliminary survey

The main objectives of the preliminary survey are:

- I. To survey the various alternatives alignments proposed after reconnaissance and to collect all the necessary physical information and details of topography, drainages soil.
- II. To compare the different proposals in view of the requirements of a good alignment.
- III. To estimate quantity of earthwork materials and other construction aspect and to work out the cost of alternative proposal.

d) Final location and detail survey

The alignment finalized at the design after the preliminary survey is to be first located on the field by establishing the centerline.

Survey teams can carry out the survey as follows:

- One team for the location of the control points
- One team to survey the center line & the longitudinal profile
- One team to survey the cross sections, and
- One team for the land acquisition survey

Geometry of Highway Curves

The design and construction of road progress include design of the curves. The initial design on the route is generally based on the series of connected straight lines. In the final design, a curve is provided at intersections if the straight line to affect the gradual change in the direction.

Geometric design referred to the design of the road using the concept of mathematical geometry for designing the road. The "shape" or geometry of any transportation route is called its **alignment**. This includes both its horizontal alignment (i.e. a plan view) and its vertical alignment (i.e., a profile view). The vertical alignment is also called the grade line.

The plan view should include:

- Bearing of the tangents
- Angle of intersection

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- Stationing
 - Geometric data for each horizontal curve
 - Topography adjacent to the center line
 - Existing structures affected by the project

The vertical alignment consists of straights (gradients) connected by vertical curves in a vertical plane.

The profile view should include:

- The existing ground surface
- Proposed route grade line
- Grades (slopes) of the tangents

7.1 Curves

Are geometrical figures that insert between two straight alignment intersections. This alignment intersection derived from certain directions and deflects to each other for some degree called ***deflection angle***. When the vehicle goes from the first straight to the second straight, the change in direction is so difficult for the vehicle to go up and turn. This becomes even more difficult in the case of the long rail. However, if these two lines joined by a curve, the change can comfortable and easily negotiable. **Curves are an area provided between intersections of the straight to negotiate the change in direction gradually.**

7.1.1 Types of curves

Based on their objectives two types curve are there:

- Horizontal curves
- Vertical curves

Horizontal curves

Curves provides on the horizontal plane to provide change in the direction. Horizontal curve is neither practicable nor feasible to have straight railways or high ways in a country. Their alignments require some changes in direction due to the nature of the terrain, cultural features or other unavoidable reasons such changes in direction cannot be at sharp corners but have to be gradual which necessitates the introduction of curves in between the straights. Curves are regular

bends horizontally provided in a line of communication like roads, railways and in canals to bring the gradual change of direction in horizontal plane to have a gradual change in direction is known as horizontal curves.

Horizontal curve has the following types

- a) simple circular curve
- b) reverse curve
- c) compound curve
- d) transition curve

a) simple circular curve

A curve, connecting two intersecting straight lines having a constant radius all through is known as a simple circular curve. It is tangential to the two straight lines at the joining ends.

In Figure. 2.1, T_1CT_2 is a simple circular curve of radius R , joining the two straight lines T_1I and T_2I intersecting at a point I .

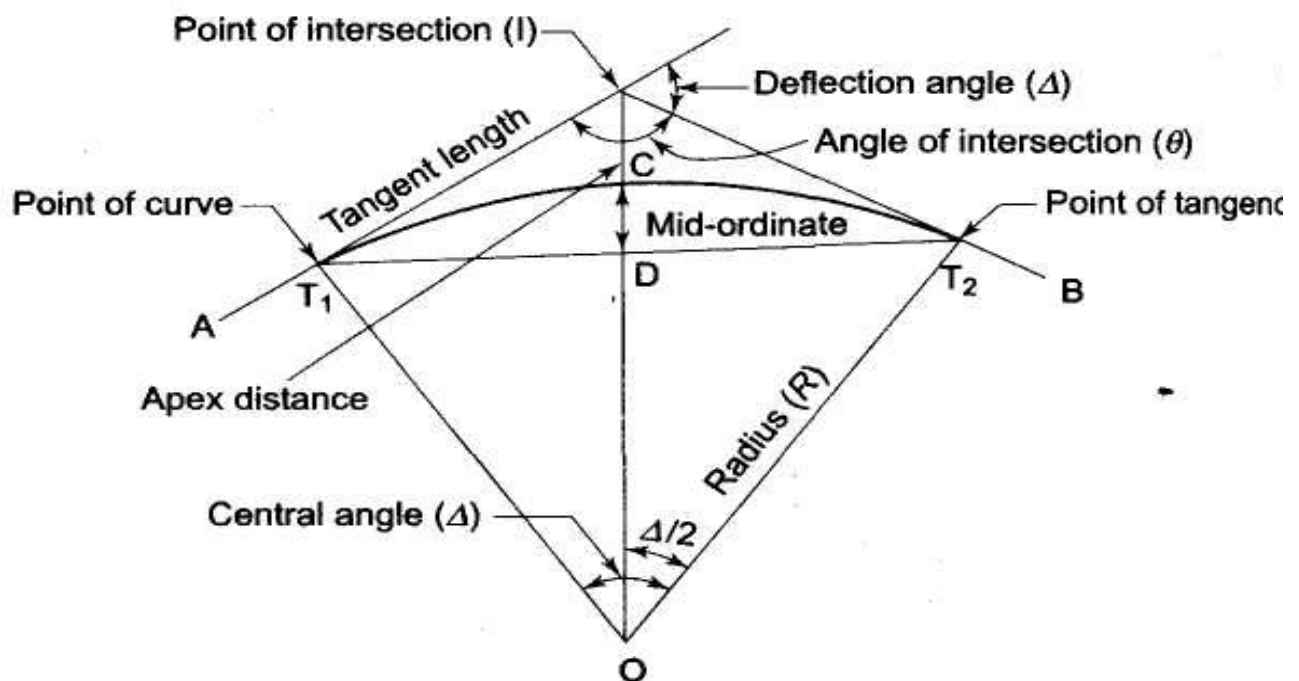


Figure 7.1: Simple Circular Curve

✚ Elements of Simple Circular Curve

T_1I and T_2I are the two intersecting straight lines joined by a simple circular curve T_1CT_2 of radius R , as shown in Figure 2.1. The point I is called the *point of intersection (P.I.)*. Δ the *deflection angle* is the external angle between the two intersecting straight lines. The internal angle, $\angle AIB$ (θ), is called the *angle of intersection*. The sum of these two angles, i.e. Δ and θ is 180° . O is the Centre of the circular curve. The point T_1 , where the circular curve begins is known as *point of curve (P.C.)*. The last point of the tangent, T_2 is known as *point of tangency (P.T.)*. IT_1 and IT_2 are known as *tangent lengths* and are always equal in length. The length T_1CT_2 is called the *total length of curve*. The middle point C of the curve is called *the apex* or *summit* of the curve. It lies on the bisector of the angle of intersection. The chord joining the point of curve and the point of tangency is known as *long chord*. The ordinate from the apex of the curve (C) to the mid-point (D) of the long chord is known as *mid-ordinate (CD)*. A chord of the curve between two consecutive regular stations (station at chain length) on it is called *normal chord* or *full chord*. Any other chord shorter in length than this, is called *sub-chord*. Usually, the first and the last chords of a curve are sub-chords. The distance between the point of intersection I and the apex of the curve (C), i.e. IC is known as *apex distance*. Angle T_1OT_2 subtended at the Centre of the curve (O) is known as *central angle*.

✚ Designation of Curve

The degree of a curve defines the sharpness or flatness of the curve that can be defined based on either an arc or a chord. According to the **arc definition**, the degree of a curve is defined as the central angle subtended by an arc of 30 or 20 m length (Fig. 2.2(a)). This definition is used primarily for highways. Notice that the larger the degree of curve the sharper the curve and the shorter the radius.

According to the **chord definition**, the degree of a curve is the central angle subtended by a chord of 30 or 20m length (Fig. 2.2(b)). The chord definition is used primarily for civilian railroad construction and is used by the military for both roads and railroads.

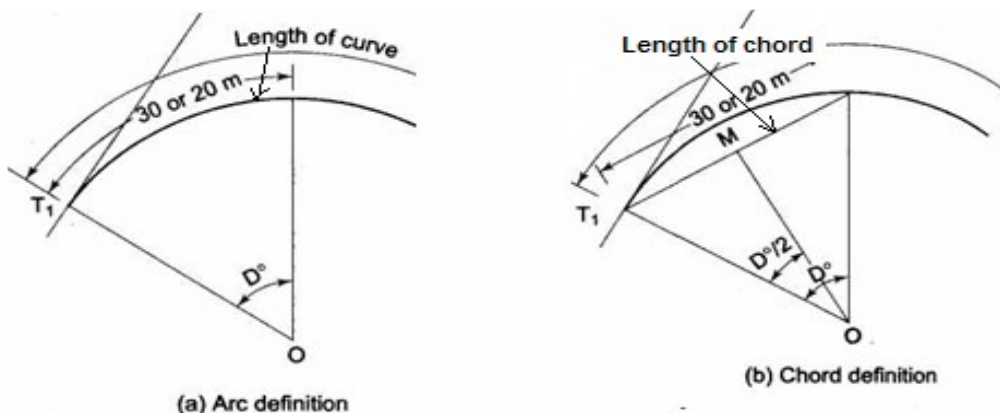


Figure 7.2: Arc definitions

▮ Relationship between Degree and Radius of Curve

Arc definition: If R is the radius of a curve and D is its degree for a 30m arc, then

$$\frac{\pi RD}{180^\circ} = 30$$

$$\text{or } R = \frac{30 \times 180^\circ}{D \times \pi}$$

$$\text{or } R = \frac{1718.9}{D} \approx \frac{1719}{D}$$

If D is the degree of curve for a 20 m arc, then

$$\frac{\pi RD}{180^\circ} = 20$$

$$\text{or } R = \frac{20 \times 180^\circ}{D \times \pi}$$

$$\text{or } R = \frac{1145.9}{D} \approx \frac{1146}{D}$$

Chord definition: For a 30m chord, from triangle T_1OM

$$\sin \frac{D}{2} = \frac{T_1M}{OT_1} = \frac{15}{R}$$

$$\text{or } R = \frac{15}{\sin \frac{D}{2}}$$

Since D is very small, therefore, $\sin \frac{D}{2} \approx \frac{D}{2}$. Hence,

$$R = \frac{15}{\left(\frac{D}{2}\right) \times \left(\frac{\pi}{180^\circ}\right)}$$

$$\begin{aligned} \text{or } R &= \frac{15 \times 2 \times 180^\circ}{D \times \pi} \\ \text{or } R &= \frac{1718.9}{D} \approx \frac{1719}{D} \end{aligned}$$

Similarly, for a 20 m chord, from triangle T_1OM

$$\begin{aligned} \sin \frac{D}{2} &= \frac{T_1M}{OT_1} = \frac{10}{R} \\ \text{or } R &= \frac{10}{\sin \frac{D}{2}} \end{aligned}$$

Since D is very small, therefore, $\sin \frac{D}{2} \approx \frac{D}{2}$. Hence,

$$\begin{aligned} R &= \frac{10}{\left(\frac{D}{2}\right) \times \left(\frac{\pi}{180^\circ}\right)} \\ \text{or } R &= \frac{10 \times 2 \times 180^\circ}{D \times \pi} \\ \text{or } R &= \frac{1145.9}{D} \approx \frac{1146}{D} \end{aligned}$$

Example: -

A circular curve has a 200 m radius and 65° deflection angle. What is its degree of curve?

(a) by arc definition?

(b) by chord definition?

Solution

(a) *Arc definition*

Assuming a 30 m chord length,

$$\begin{aligned} R \times D \times \frac{\pi}{180^\circ} &= 30 \\ \text{or } D &= \frac{30 \times 180^\circ}{R \times \pi} = \frac{30 \times 180^\circ}{200 \times \pi} = 8.595 \end{aligned}$$

(b) *Chord definition*

Assuming a 30 m chord length,

$$R = \frac{15}{\sin\left(\frac{D}{2}\right)} \quad (\text{but since } D \text{ is small, } \sin \frac{D}{2} \approx \frac{D}{2} \text{ radians})$$

Hence,

$$R = \frac{15}{\frac{D}{2} \times \frac{\pi}{180^\circ}}$$

or

$$D = \frac{15 \times 2 \times 180^\circ}{\pi \times 200} = 8.595$$

Formulas for elements of Simple Circular Curve

1. Length of the curve

Let the length of the curve T_1CT_2 be l and R be its radius. (fig.2.1)

Hence, $l = R \times \Delta$

$$l = \frac{R \Delta \pi}{180^\circ},$$

Where Δ is in degrees

2. Tangent length

$$T = IT_1 = IT_2 = R \times \tan\left(\frac{\Delta}{2}\right)$$

Tangent length,

3. Long chord length

Long chord length $L = T_1DT_2 = 2T_1D$

From triangle OT_1D

$$\sin\left(\frac{\Delta}{2}\right) = \frac{T_1D}{R}$$

$$T_1D = R \sin\left(\frac{\Delta}{2}\right)$$

Hence,

$$L = 2R \sin\left(\frac{\Delta}{2}\right)$$

4. Apex distance (External)

Apex distance, $IC = IO - CO$

$$IC = R \sec \frac{\Delta}{2} - R$$

$$IC = R \left(\sec \frac{\Delta}{2} - 1 \right)$$

5. **Mid-ordinate**

Mid-ordinate, $O_0 = CD = CO - DO$

$$O_0 = R - R \cos \frac{\Delta}{2}$$

$$O_0 = R \left(1 - \cos \frac{\Delta}{2} \right)$$

Therefore, mid-ordinate is also known as *versed sine of the curve*.

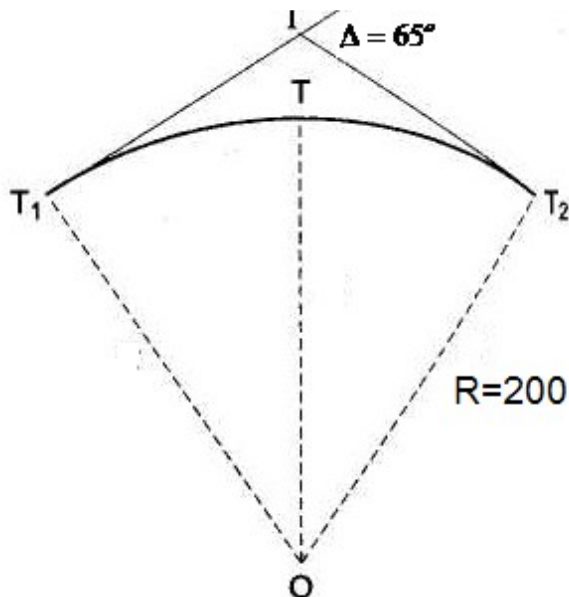
6. **P.C = Chainage on point of curvature** $P.C = P.I - T$

7. **P.T = Chainage on point of Tangency** $P.T = P.C + L$

Example: -

A circular curve has a 200 m radius and 65° deflection angle. Calculate the elements of simple circular curves from the given figure

- (i) length of curve,
- (ii) tangent length,
- (iii) length of long chord,
- (iv) apex distance,
- (v) mid-ordinate.



Solution

- (i) Length of the curve, $L = \frac{R\Delta\pi}{180^\circ} = \frac{200 \times 65^\circ \times \pi}{180^\circ} = 226.89 \text{ m}$
- (ii) Tangent length, $T = R \tan \frac{\Delta}{2} = 200 \tan \frac{65^\circ}{2} = 127.41 \text{ m}$
- (iii) Length of long chord, $L = 2 R \sin \frac{\Delta}{2} = 2 \times 200 \sin \frac{65^\circ}{2} = 214.92 \text{ m}$
- (iv) Apex distance $= R \left(\sec \frac{\Delta}{2} - 1 \right) = 200 \left(\sec \frac{65^\circ}{2} - 1 \right) = 37.13 \text{ m}$
- (v) Mid-ordinate $= R \left(1 - \cos \frac{\Delta}{2} \right) = 200 \left(1 - \cos \frac{65^\circ}{2} \right) = 31.32 \text{ m}$

Setting out of circular curves

Setting out a curve means locating various points at equal and convenient distances along the length of a curve. The methods of setting out curves can be mainly divided into two heads depending upon instruments used.

(1) **Linear methods.** In the linear methods, only a chain or tape is used. Linear methods are used when:

- (a) a high degree of accuracy is not required,
- (b) the curve is short.

(2) **Angular methods.** In angular method, an instrument such as a theodolite is used with or without a chain (or tape).

For the ease in calculations and setting out, it is essential that the pegs on the curve are at regular interval from the beginning to the end. Such interval is known as *peg interval* and the chord joining two such adjacent pegs is known as the *full chord or normal chord*. The length of the normal chord is generally taken equal to 100 ft in English units or 20 meters in metric units, so that angle subtended by the normal chord at the centre is equal.

Example: -Let the chainage of T_1 be 1545.5 m; let the length of curve be 540 m and let the peg interval be 20 m.

Determine:

- (i) the length of the first sub chord
- (ii) the number of full chords
- (iii) the length of the last sub-chord

Solution

To make the first point on the curve a full station, a multiple of 20 m next to the chainage of 1545.5 m, i.e. 1560 m, is selected. Therefore, length of the first sub-chord is $1560 - 1545.5 = 14.5$ m. The remaining length of the curve = $540 - 14.5 = 525.5$ m. Thus, the number of full chords = $525.5/20 = 26.275$ (26 + 5.5). Hence, The last sub-chord = 5.5 m.

Setting Out a Simple Circular Curve by Linear Methods.

The various linear methods of setting out a simple circular curve are

1. offsets from the long chord
2. perpendicular offsets from the tangent
3. radial offsets from the tangent
4. successive bisection of arcs

Offsets from Long Chord.

By assigning different values to x , the corresponding values of offsets O_x can be calculated. The calculated offsets can be laid from the long chord and points can be established in the field which when joined produce the required curve. What changes can you observe if you move from point M to tangent points (T_1, T_2)

Let it be required to set out a curve T_1CT_2 between the two intersecting straights T_1I and T_2I . R is the radius of the curve, O_0 the mid-ordinate, and O_x the offset at a point P at a distance x from the mid-point (M) of the long chord.

$$O_o = \text{Mid-ordinate} = R \left(1 - \cos \frac{\Delta}{2} \right) = 100 \left(1 - \cos \frac{60^\circ}{2} \right) = 13.40 \text{ m}$$

$$O_x = \sqrt{R^2 - x^2} - (R - O_o)$$

Let peg interval $x = 10 \text{ m}$

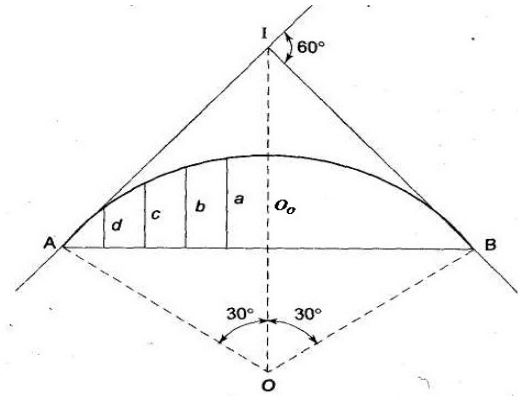
$$a = O_{10} = \sqrt{100^2 - 10^2} - (100 - 13.40) = 12.89 \text{ m}$$

Similarly, $b = O_{20} = \sqrt{100^2 - 20^2} - (100 - 13.40) = 11.38 \text{ m}$

$$c = O_{30} = \sqrt{100^2 - 30^2} - (100 - 13.40) = 8.79 \text{ m}$$

$$d = O_{40} = \sqrt{100^2 - 40^2} - (100 - 13.40) = 5.05 \text{ m}$$

and $A = O_{50} = \sqrt{100^2 - 50^2} - (100 - 13.40) = 0 \text{ m}$



b) Transition curve

It is a curve usually introduced between a simple circular curve and a straight, or between two simple circular curves. It is also known as an *easement curve*. A transition curve has a radius, gradually changing from a finite to infinite value or vice versa. It is widely used on highways and railways, since its radius increase or decreases in a very gradual manner. In Figure 2.20, T_1TD is the transition curve introduced between the simple circular curve $T_4DD'T_5$, and the straight T_1I .

Figure 2.20: Transition Curve

▮ Necessity of a transition curve

The effect of the centrifugal force may be neutralized if the outer edge of the track is raised. The raising of the outer edge of the track or the outer rail of the railways, is called *super-elevation* or *cant*. The amount of the super - elevation depends on the speed of the moving vehicles and the radius of the curve. In case of railways, the maximum super-elevation should not exceed 15 cm. Thus, it is evident that outer rail should be raised by 15 cm at the point of commencement, which is highly objectionable. The effect of the centrifugal force may be reduced and gradual increase of the super-elevation may be made by introducing a transition curve between the straight and the curve.

Introduction of transition curves has following advantages:

- It enables to introduce super-elevation in proportion to the rate of change of curvature.
- It avoids the danger of derailment at the point of commencement if full amount of super-elevation is suddenly applied at the point.
- It avoids over turning and side slipping of the moving vehicles.
- It eliminates discomforts caused to the passengers while negotiating a curve.

Super-elevation

When a vehicle moves from a straight to a curve, it is acted upon by centrifugal force in addition to its own weight. The centrifugal force acts through the centre of gravity horizontally away from the centre of the curve and tends to push the vehicle off the track. In order to balance this force, outer rail on railway or outer edge of highways, is raised above the inner one. The difference in the top levels of outer and inner rails is known as *super-elevation*, which depends upon the radius of the curve and the speed of the vehicles. As all the vehicles do not run with the same speed, the average of the fastest and slowest speeds of the vehicles is used for the purpose of calculation of the required amount of super elevation.

2. Vertical curves

Vertical curves are curves, in a vertical plane, used to join two intersecting grade lines. The reduced level of these curves change from point to point in a gradual and systematic manner. A vertical summit curve is provided when a rising grade (T_1I) joins a falling grade (T_2I), as shown

Figure 7.3 Vertical Curves

in Figure 7.3(a), and a vertical sag curve is provided when a falling grade (T_3I) joins a rising grade (T_4I), as shown in Figure 7.3 (b). Figure 2.28: Vertical Curves

Vertical curves are usually parabolic, and are classified as summit, and sag vertical curve.

A parabolic curve also provides the best riding qualities, as the rate of change in grade is uniform throughout along a parabola having its axis vertical *i.e.*, the rate of change of slope of a parabola is constant.

Length of vertical curves

The length of a vertical curve may be defined as the length from the point of commencement of the curve *i.e.*, the point of rising to the point of tangency of the curve *i.e.*, the point where curve meets horizontal straight again.

Let l_1 be the length of the curve from the point of commencement to summit; $g_1\%$ be the upgrade; r be the rate of change of grade,

Then,
$$l_1 = \frac{\text{percentage of up-grade}}{\text{rate of change of grade}} = \frac{g_1}{r}$$

Similarly, the length of the curve from the summit to the point of tangency

$$l_2 = \frac{\text{percentage of up-grade}}{\text{rate of change of grade}} = \frac{g_2}{r}$$

∴ Total length of the vertical curve
$$L = \frac{g_1}{r} + \frac{g_2}{r} \quad (a)$$

As upgrades are treated positive and downgrades negative, equation (a) may be written as

$$L = \frac{g_1 - (-g_2)}{r} \quad (b)$$

Hence, the length of the vertical curve may be obtained by dividing the algebraic difference of the grades by the rate of change of grade with due regard to the sign of each grade.