

**CHAPTER TWO****2. ROUTE SURVEYING****2.1 Introduction**

A Route Survey is conducted for locating and constructing transportation or communication lines that continue across country for some distance, such as highways, railroads, open conduit systems, pipelines, and power lines. Generally, the preliminary survey for this type of work takes the form of a topographic survey.

The position or the layout of centerline of the highway on the ground is called *alignment*. A road should be aligned very carefully as improper aligning would result in one or more of the following disadvantages.

- a. Increase in the cost of construction
- b. Increase in the maintenance cost
- c. Increase in the vehicles operation cost
- d. Increase in the rate of accident.

Requirements of Highway Alignment

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

- 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.

Factors Controlling Alignment

In order to suggest the possible route of a road the topographic and photographic maps of the areas should be available with good contour intervals showing the main features like rivers, hills, valleys, churches, mosques, national parks etc. For the alignment to be shortest it should be straight between the terminal stations. This is not always possible due to various practical difficulties such as intermediate obstruction and topography. A shortest route may have very



steep gradient and hence not easy for vehicle operation. Similarly there may be construction and maintenance problem along a route, which may otherwise, be short and easy. Roads are often deviated from the shortest route in order to cater for intermediate places of higher importance or obligatory points.

The various factors, which control the highway alignment, in general are:

- | | | |
|----------------------|----------------------------|--------------------------|
| 1. Cost | 4. Geometric design factor | 6. Drainage |
| 2. Obligatory points | 5. Stability | 7. Environmental factors |
| 3. Traffic | | |

Stages 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/Desk Study

It is important when the distance between two points is large. If the topographic map of the 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 Survey

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.

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.

Responsibilities of surveyor during reconnaissance;

- Selecting alternative routes
- Matching up aerial photos to a strip of mosaic
- Finding control points (BMs) available for the project.

Purposes of reconnaissance

- ✚ Find whether there is any satisfactory line between the proposed route
- ✚ Establish the best line
- ✚ Determine approximately the maximum grade to be used
- ✚ Report the type of geological formation and the cost of construction
- ✚ Take note of the existing resources of the area, its manufacturers, mines, agricultural or natural products and the capabilities of improvement and development of the area resulting from the introduction of the roadway.



C. Preliminary Survey

It is detailed survey of a strip of territory through which the proposed line is expected to run. And it is made of the best several lines investigated previously on the reconnaissance survey. It differs greatly in method and precision. Invariably, however, there is at least one traverse which serves as a frame work for the topographical details. When there are two or more routes under consideration, a preliminary survey of each may be made and from the study of the maps and other data thus obtained, the final selection of the route is determined.

Instruments for preliminary survey are;

Transit	Compass	Engineer's Level	Hand Level
Leveling Staff	Chains and Tapes	Sub tense Bar	Rods, Pegs and etc.

On small projects, preliminary survey is done by one party. On big projects the survey work is done by three parties under the general supervision of the locating engineer. These parties are;

1. Transit party
2. Level party and
3. Topographic /cross-section party.

Role of the surveyor is to collect data in the selected route that determine the desired speed.

Preliminary survey serves the following purposes:

- Fix accurately the maximum grade for use in Location survey
- Determine the best line
- Provide a map as basis
- Make a close estimate of the cost of work
- Secure, in certain cases, legal rights by filing plans

D. Location/Detailed Survey

It is the ground location of proposed route marked on the map or final fitting of the line to ground. It includes setting stakes along the tangents and the curves of the route centerline or and often along an offset line as well. Curves are used to connect the straight lines or tangents



and the alignments of the route. Horizontal alignment of the route can be laid out on the ground after the curve computations have been made and appropriate field notes are prepared.

Purposes of location survey;

- ✓ To make minor improvements on the line as may appear desirable on the ground.
- ✓ To fix up the final grades along the route.

Responsibilities of the surveyor during location survey;

- ✓ Progress staking of centerline and collect topographic data and locate property corners within the route boundaries or right-of-way (ROW).
- ✓ Obtaining profile and cross-section data for final design for preparation of engineering drawings and final estimate of earth work quantities.

E. Construction Surveying

The purpose of construction survey is to re-establish points, lines, and grades on the ground during construction. It also consists in staking out various details such as culverts and bridges.

Surveying operations for construction purpose are;

- Retracing of centerline shown on the plan and referencing certain points on the curves.
- Checking BMs and running centerline levels over the retraced line.
- Staking pegs at all reduced levels.
- Setting slope stakes and grade stakes.
- Setting stakes for complete layout of bridges and culverts.
- Setting out curves.
- Final cost estimate etc.

2.1 HORIZONTAL CURVES

When a highway changes horizontal direction, making the point where it changes direction a point of intersection between two straight lines is not feasible. The change in direction would be too abrupt for the safety of modern, high-speed vehicles. It is therefore necessary to interpose a



curve between the straight lines. The straight lines of a road are called *tangents* because the lines are tangent to the curves used to change direction.

The smaller the radius of a circular curve, the sharper the curve. For modern, high-speed highways, the curves must be flat, rather than sharp. The principal consideration in the design of a curve is the selection of the length of the radius or the degree of curvature. This selection is based on such considerations as the design speed of the highway and the sight distance as limited by headlights or obstructions (see Fig. 1).

The horizontal curve may be a simple circular curve or a compound curve. For a smooth transition between straight and a curve, a transition or easement curve is provided. The vertical curves are used to provide a smooth change in direction taking place in the vertical plane due to change of grade.

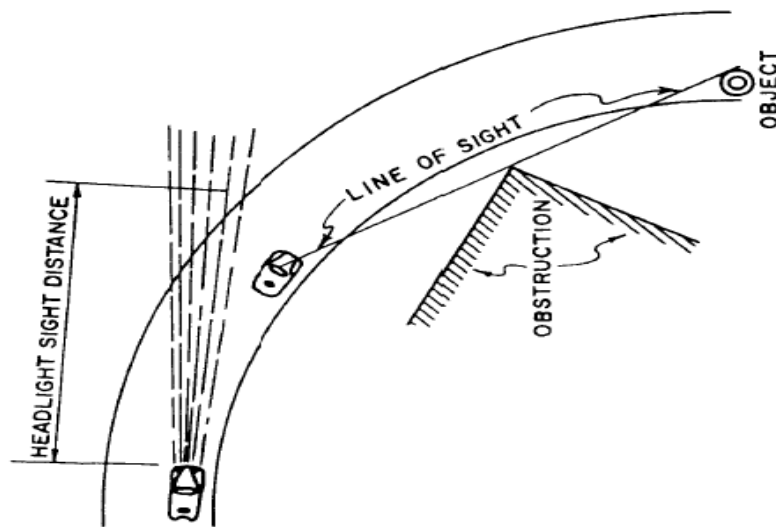


Figure 1 Line of sight.

2.1.1 Types of Horizontal Curves

There are four types of horizontal curves. They are described as follows:

A. Simple. The simple curve is an arc of a circle (view A, fig. 2). The radius of the circle determines the sharpness or flatness of the curve.

B. Compound. Frequently, the terrain will require the use of the compound curve. This curve normally consists of two simple curves joined together and curving in the same direction (view B, fig. 2).



C. Reverse. A reverse curve consists of two simple curves joined together, but curving in opposite direction. For safety reasons, the use of this curve should be avoided when possible (view C, fig. 2).

D. Spiral. The spiral is a curve that has a varying radius. It is used on railroads and most modern highways. Its purpose is to provide a transition from the tangent to a simple curve or between simple curves in a compound curve (view D, fig. 2).

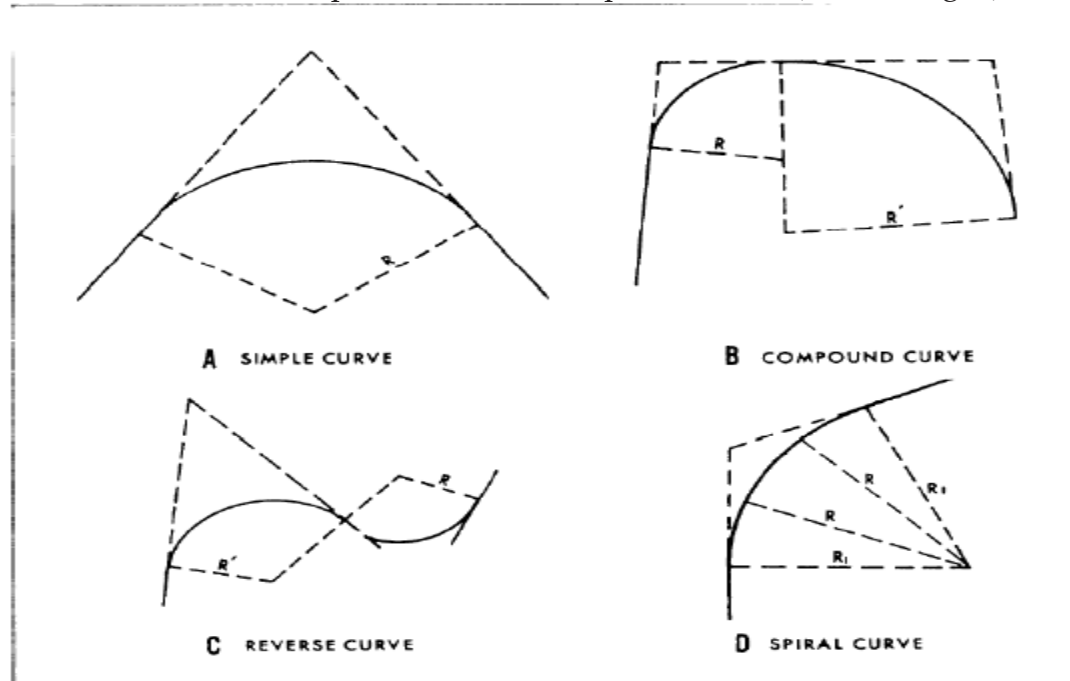


Figure 2.—Horizontal curves.

(A) Horizontal Curve or Circular Curves of Constant Radius.

Elements of a Circular Curve and Notations

Fig. below shows a simple circular curve of radius R with its Centre at O . A curve has the following elements:

Back tangent: The tangent AT_1 at the point of commencement T_1 of the curve is the back tangent.

Forward tangent: The tangent T_2B at the end point T_2 of the curve is the forward tangent.

Point of intersection (P.I.): The point I where the back tangent when produced forward and forward tangent when produced backward meet, is called the point of intersection.

Intersection angle: The angle ϕ between the back tangent AT_1 and the forward tangent T_2B at I is called the intersection angle.

Deflection angle of the curve: The angle Δ through which the forward tangent deflects is called deflection angle of the curve. It may be either to the left or the right.

Point of commencement (P.C.): The point T_1 where the curve commences is called the point of commencement of the curve. It is also called **point of the curvature**.

Point of tangency (P.T.): The point T_2 where the curve joins the forward tangent is called point of tangency.

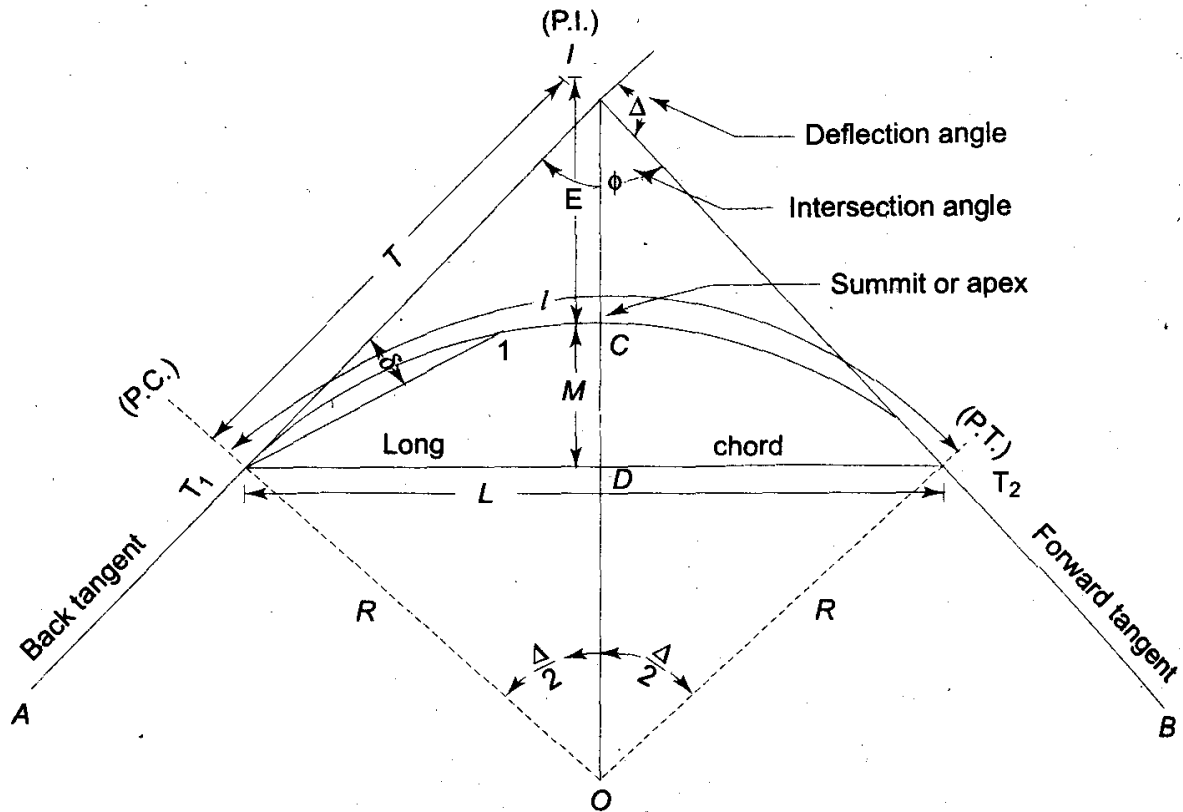


Figure 3 Elements of a Circular Curve

Deflection angle to any point on the curve: The deflection angle α to any point 1 on the curve is the angle at P.C. between the back tangent and the chord T₁ 1 from P.C. to the point on the curve.

Tangent distance (T): It is the distances between P.C. to P.I. Or (**PI** to **PT**.)

External distance (E): It is the distance from the midpoint of the curve to P.I. It is also known as the apex distance.

Length of curve (l): It is the total length of the curve from P.C. to P.T.

Long chord (L): It is the chord joining P.C. and P.T.

Mid-ordinate (M): It is the ordinate from the midpoint of the long chord to the midpoint of the curve. It is also called the versine of the curve.

Normal Chord (C): A chord between two successive regular pegs on the curve is called a normal chord.

Sub-chord (C): When the chord is shorter than the normal chord, it is called a sub-chord. These generally occur at the beginning and end of the curve. These will be designated by C_f and C_l , respectively.

Right-hand curve: If the curve deflects to the right of the direction of the progress of survey it is called the right-hand curve.

Left-hand curve: If the curve deflects to the left of the direction of the progress of survey, it is called the left-hand curve.



The equations that are used to compute the parts of simple curve are:

- Tangent length, $T = R \tan (\Delta/2)$
- Arc length (length of the circle joining the straights), $\ell = (\pi R \Delta)/180$
- Length of long chord, $L = 2R \sin(\Delta/2)$
- External distance (i.e. the distance from intersection point to the midpoint of the arc length)
 $E = R [1/\cos(\Delta/2) - 1]$
- Middle ordinate, $M = R [1 - \cos(\Delta/2)]$

Where R is the radius of the curve

STATIONING ALONG A ROUTE

One of the goals of route design is to establish the stations of the entire PC (i.e. point of curvature) and the PT (i.e. the point of tangency) since the final stationing along the route runs continuously along the tangents and curves. Stations indicate the true centerline distances from the beginning point of the project. The expressions for stationing along the simple curve are:

$$\text{Station PC} = \text{Station PI} - T$$

$$\text{Station PT} = \text{station PC} + \ell$$

Relationship between the Radius and Degree of a curve Based on fixed length of an arc

Let D° be the angle subtended by an arc of 30 m length of a circle whose radius is R .

The total circumference of the circle = $2\pi R$

Therefore 30 m arc of the circumference makes an angle

$$\begin{aligned} D^\circ &= \frac{360^\circ}{2\pi R} \times 30 \\ &= \frac{10800}{2\pi R} \text{degrees} \\ \frac{1718.9}{R} &= D^\circ \text{ (By definition)} \end{aligned}$$

Examples*****!!!

2.1.2 Setting out of Simple Circular Curves

A simple circular curve may be set out on the ground by any one of the following methods.

1. Offsets from the tangents
2. Offsets from the long chord.
3. Deflection angles from the point of commencement and normal chords.
4. Deflection angles from the point of commencement and point of tangency using two theodolites.

Methods 1 and 2 are known as **linear methods** whereas the other two methods are known as **angular methods**.

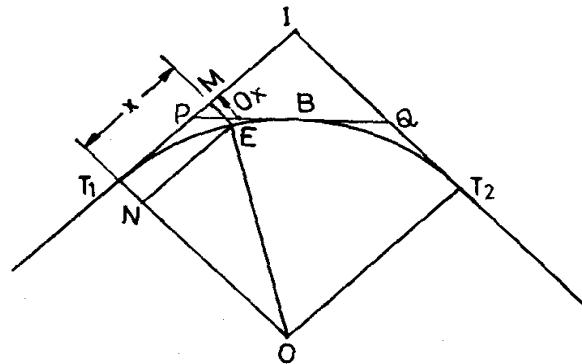
1. Offsets from the Tangents

Limitation of the Method: This method can be used conveniently if the deflection angle and radius of the curve are comparatively small.

The offsets from the tangents may be either, perpendicular or radial



a. Perpendicular Offsets



Let any point **M** on the back tangent of a curve of radius **R** is at a distance of **x** from **T1**. Length of the offset **ME** to the curve perpendicular to the tangent **T1I** is **Ox**.

Construction: Draw **EN** perpendicular to **OT1**.

Now

$$OE^2 = NE^2 + NO^2$$

$$R^2 = x^2 + (R - Ox)^2$$

$$(R - Ox)^2 = R^2 - x^2$$

$$\boxed{} = R^2 - x^2$$

$$Ox = R - \sqrt{R^2 - x^2} \quad (\text{Exact})$$

Note: The following points may be noted.

1. One half of the curve may be conveniently set out from the back tangent **T1I**. The other half of the curve is to be set out from the forward tangent **T2I**
2. If the curve is long, the offsets will also be long. In such cases it is advisable to set the middle third of the curve by calculating offsets from a tangent at the midpoint **B** of the curve.

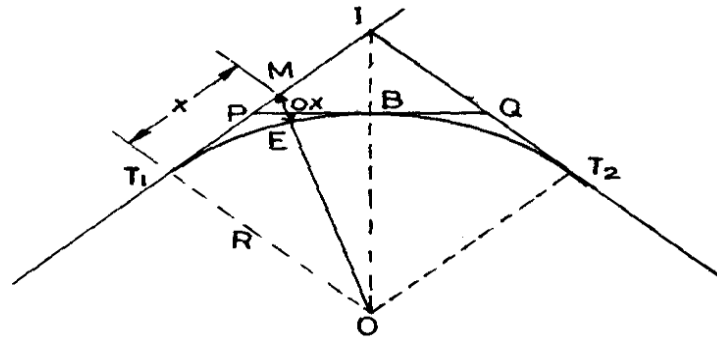
Field Operations: Before setting out a curve of radius say 250 m, a table of offsets corresponding to a number of points on the tangents may be made in as shown below.

S. N.	X (metres)	Ox (metres)
1	10	0.20
2	20	0.80
3	30	1.80
4	40	3.20
5	50	5.00

Procedure: From the point of commencement **T1**, measure distances **x1**, **x2**, and **x3**, etc., along the tangent **T1I**. Erect perpendiculars equal in lengths of the offsets corresponding to distances **x1**, **x2**, **x3**, etc., with the help of 3-4-5 method.



b. Radial offsets



Let **M** be any point on the tangent at a distance **x** from the point of commencement **T₁**. **Ox** is the radial offset from **M** to the curve. **R** be the radius of the Curve with **O** as its centre.

$$\text{Now, } (R + Ox)^2 = R^2 + x^2$$

$$R + Ox = \sqrt{R^2 + x^2}$$

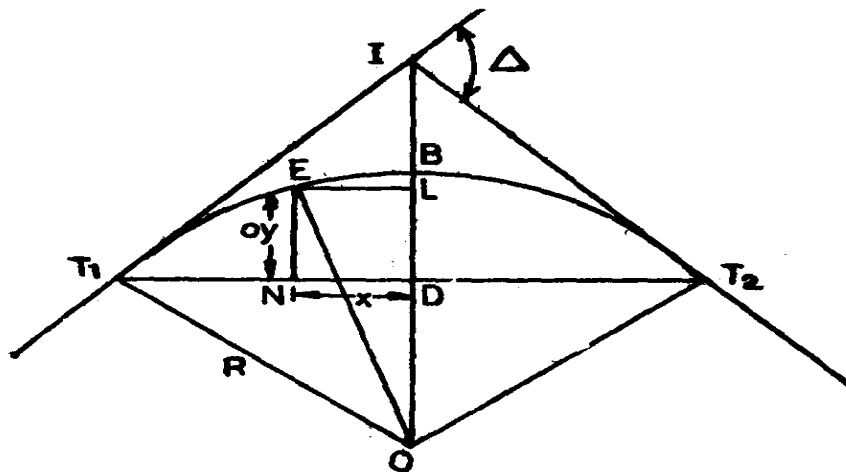
$$Ox = \sqrt{R^2 + x^2} - R$$

Field Operation: Following steps are followed.

1. Fix ranging rods at **T₁**, **I**, **T₂** and **O**.
2. Measure a distance **x** along **T₁I** and fix a point **M**.
3. From **M** measure a distance equal to the calculated offset length along the line joining the point **M** and the centre of the curve **O**.
4. Similarly, locate other points on the first half of the curve.
5. The other half of the curve is similarly set out from the forward **T₂I**.

2. Offsets from the Long Chord

Let **T₁** and **T₂** be the points of commencement and tangency of the curve. Radius of the curve is **R** having **O** as centre.





Construction: Join T_1T_2 . Divide T_1T_2 at D . Join ID which intersect the curve at B . The maximum length of the offset from the long chord T_1T_2 is BD , whose value may be calculated as under.

From ΔT_1DO ,

$$T_1O^2 = T_1D^2 + OD^2$$

$$R^2 = (L/2)^2 + (OB - BD)^2$$

Where L is the length of the long chord

$$R^2 = (L/2)^2 + (R - Ox)^2$$

$$(R - Ox)^2 = R^2 - (L/2)^2$$

$$(R - Ox) = \sqrt{R^2 - (L/2)^2}$$

$$Ox = R - \sqrt{R^2 - (L/2)^2}$$

To find the ordinate Oy at any point N at a distance x from midpoint D , draw EL perpendicular to BD .

Now, $Oy = EN = LD = LO - OD$

$$Oy = LO - (R - Ox) **$$

From ΔELO .

$$LO = \sqrt{OE^2 - EL^2}$$

$$= \sqrt{R^2 - x^2}$$

Substituting the value of LO in $**$ above

$$Oy = \sqrt{R^2 - x^2} - (R - Ox)$$

Where Ox is the ordinate at the mid-point of the long chord.

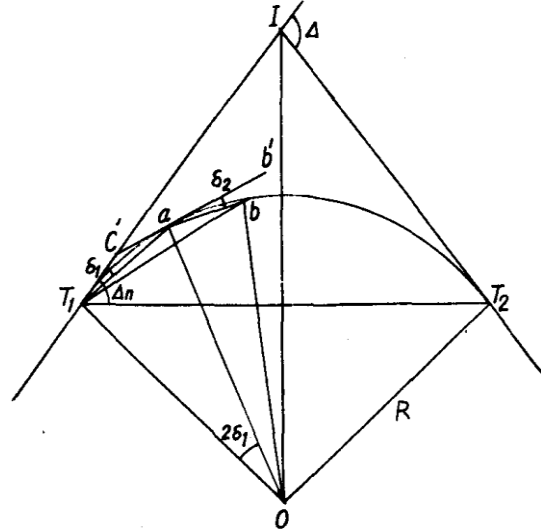
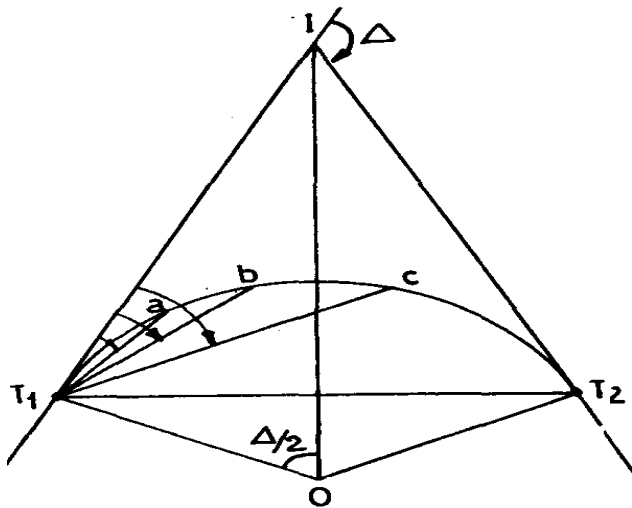
Field Operations: To set out a circular curve with offsets from the long chord, the following steps are followed.

1. Erect ranging rods at T_1 , D and T_2 .
2. Divide the long chord T_1T_2 in equal parts of suitable length.
3. Calculate the lengths of the offsets corresponding to distances from the mid-point of the chord.
4. Erect perpendiculars with the help of a 3-4-5 method and measure the calculated offset lengths.

3. Deflection Angles from the Point of Commencement and Normal Chords (Tape and Theodolite (Rankanics) Method)

The angle between the back tangent and the chord joining the point of commencement of the curve and other point on the curve is generally known deflection angle.

In the Figure below angles IT_1a , IT_1b , IT_1c , etc. are deflection angles of the chords T_1a , T_1b , T_1c , etc. These deflection angles are not to be confused with the angle of deflection of the curve. The latter being the total which the forward tangent of the curve deflects with respect to the back tangent.



Derivation of the formula

Assumption: When the radius of the curve is large, the small arc of the circle approximates to its chord, i.e. the arc **T1a** is very nearly equal to chord **T1a**.

Let the deflection angle for the chord **T1a** be δ_1 , angle **OT1a** = $90^\circ - \delta_1$ = angle **OaT1**

Therefore Angle subtended by the arc **T1a** at the centre **O** = $180^\circ - 2(90^\circ - \delta_1) = 2\delta_1$,

Draw a tangent **b'c'** at **a** and let angle **b'ab** be δ_2 .

Now, angle **aT1b** = angle **b'ab** = δ_2 .

Therefore Total deflection angle **IT1b** for chord **T1b** = Angle **IT1a** + Angle **aT1b**

Or angle **IT1b** = $\delta_1 + \delta_2$.

Similarly, values of deflection angles for remaining chords may calculate.

In general practice, the first and last sub-chords are not equal. These are designated as **C1** and **C2** whereas normal chords are designated by **C**.

$$\text{The length of the arc } C_1 = \frac{2\pi R \times 2\delta_1}{360^\circ}$$

$$\begin{aligned} \delta_1 &= \frac{360^\circ}{4\pi R} \cdot C_1 \text{ degrees} = \frac{90^\circ \times C_1}{\pi R} \text{ degrees} \\ &= \frac{90 \times 60 \times C_1}{\pi \times R} \text{ minutes} \end{aligned}$$

$$\delta_1 = 1718.9 \frac{C_1}{R} \text{ minutes}$$

..

And, for normal chords,

$$\delta = 1718.9 \frac{C}{R} \text{ minutes.}$$



For sub chord of length C_2 ,

$$\delta_2 = 1718.9 \frac{C_2}{R} \text{ minutes.}$$

If $\delta_1, \delta_2, \delta_3, \delta_4 \dots \delta_n$, are the angles for the first sub chord and other normal chords with their tangents, then the total deflection angles for various chords the back tangent are

$$\begin{aligned} \Delta_1 &= \delta_1 \\ \Delta_2 &= \delta_1 + \delta_2 \\ \Delta_3 &= \delta_1 + \delta_2 + \delta_3 \\ &\dots \quad \dots \quad \dots \\ &\dots \quad \dots \quad \dots \\ &\dots \quad \dots \quad \dots \\ \Delta_n &= \delta_1 + \delta_2 + \delta_3 + \dots + \delta_n. \end{aligned}$$

For a check on calculations, angle $\angle T_1T_2$ should be equal to $\Delta_n = 1/2\Delta$.

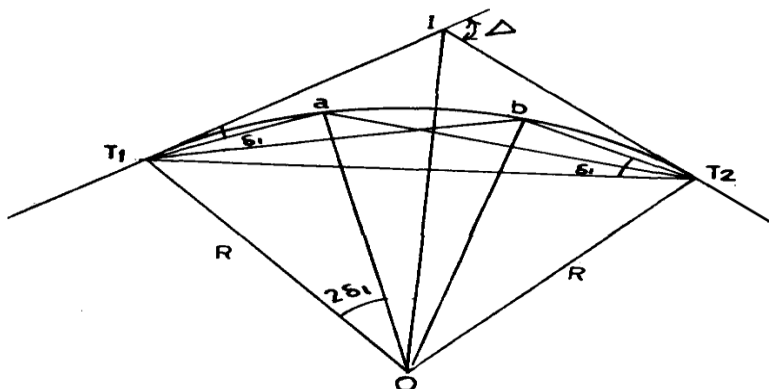
Field operations: This method involves the use of a theodolite and a chain (tape). This method is most commonly adopted for setting out the railway curves. The following steps are involved:

1. Set up the theodolite at the point of commencement of the curve, the location of which is already fixed by chaining the length of back tangent from point of intersection.
2. Let the chainage of the point of commencement finally occurs at **M** chains and **n** links.
3. Calculate the length of the first sub-chord to have a continuous chainage i.e. Length of the first sub-chord = chainage of the next full chain just after the point of commencement – chainage of the point of commencement.
4. Calculate deflection angles for the first sub-chord, normal chords and the last sub-chord. Tabulate the values of deflection angles.
5. Centre the theodolite over the point of commencement and level it fully.
6. Sight the point of intersection **I** and make the micrometer scale to read zero degree, zero minute and zero second.
7. Unclamp the upper plate of the theodolite and set the micrometer scale to read the deflection angle Δ_1 for the first sub-chord **C1**. Now, the line of telescope is along the first sub-chord.
8. With **T1** as centre and **C1** as radius, swing the chain and fix in the line of sight.
9. Set the micrometer scale to read the value of the deflection angle Δ_2 for the first normal chord, to point the telescope in the direction of the other end of the first normal chord.
10. Keeping one end of the chain at the point 'a' previously fixed on the curve, swing the chain until other end of the chain falls in the line of sight of the telescope. Pull the chain straight and fix a peg to locate the next point 'b' on the curve.
11. This procedure may be continued till the point of tangency is located.

In case there is no error in calculations, observations and distances, the last point should normally coincide with the point of tangency.



4. Two Theodolite Method.



Let T_1 and T_2 be the point of commencement and point of tangency, I is the point of intersection and O is the centre of the circular curve.

Let T_1a be the first sub-chord of length C_1 and δ_1 is its deflection angle.

From the properties of a circle, we know

$$\angle IT_1a = \frac{1}{2} \angle T_1Oa$$

But

$$\angle T_1T_2a = \frac{1}{2} \angle T_1Oa$$

$$\therefore \angle IT_1a = \angle T_1T_2a = \delta_1.$$

Similarly, it can be shown that

$$\angle IT_1b = \angle T_1T_2b \text{ and so on.}$$

Field operations: For setting out a curve with two theodolites, the following steps are involved:

1. Prepare a table of deflection angles for the first sub-chord, normal chords and the last sub-chord.
2. Set up one theodolite at T_1 and other theodolite at T_2 .
3. Theodolite at T_1 should be directed towards the point I . Theodolite at point T_2 should be directed towards T_1 .
4. The micrometer scale readings of both the theodolites should read zero.
5. Set the first deflection angle δ_1 on both theodolites so that their telescopes are in the direction of T_1a and T_2a respectively.
6. Ask the attendant to move in the line of sight of one theodolite with a ranging rod. The observer of the other theodolite keeps on viewing through the telescope till the ranging rod is intersected by the vertical wire of his theodolite. The position of the ranging rod is the required location on the curve.
7. Set the second value of the deflection angle on both the theodolites and repeat the steps (6) to get the location 'b' on the curve.
8. Continue the process for obtaining the locations of other points in a similar manner.

Note: The following points may be noted:

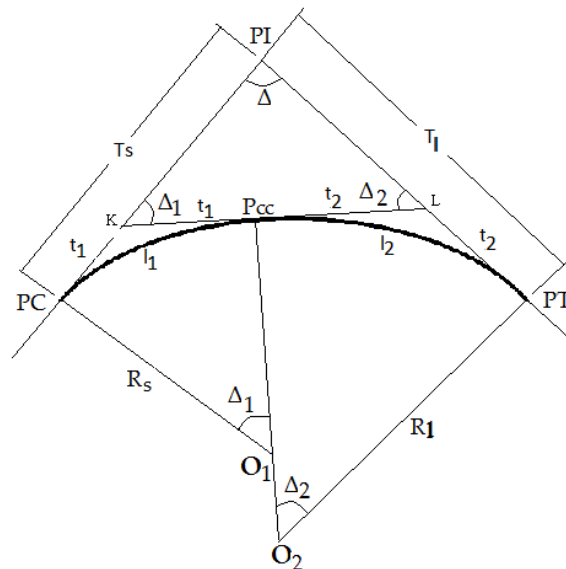


- i. When the curve is large and terrain is undulating, an experienced attendant can find the ranging rod position without spending much time.
- ii. As chaining is completely disposed off, this method may be usefully employed in undulating ground.

(B) Compound Curve

A **Compound Curve** is two or more simple curves which have different centers, bend in the same direction, lie on the same side of their common tangent, and connect to form a continuous arc. The point where the two curves connect (namely, the point at which the **PT** of the first curve equals the **PC** of the second curve) is referred to as the point of compound curvature (**PCC**). Since their tangent lengths vary, compound curves fit the topography much better than simple curves. These curves easily adapt to mountainous terrain or areas cut by large, winding rivers. However, since compound curves are more hazardous than simple curves, they should never be used where a simple curve will do.

Elements of Compound Curve



Δ = total deflection angle between the end tangents PCPI and PTPI

Δ_1 = deflection angle PI K L

Δ_2 = deflection angle PI L K

R_s = radius of small arc PCC

R_l = radius of large arc PTC

T_s = total tangent length (small), PCPI

T_l = total tangent length (large), PTPI



- Angle PC O1 C = 180° - angle PC K C = Δ_1
- Angle C O2 PT = 180° - angle C L PT = Δ_2

$$PCK = KPCC = t_1 \text{ and } PCCL = t_2$$

$$KL = KPCC + PCCL = t_1 + t_2$$

By applying sine rule to triangle PIKL

$$KPI / \sin \Delta_2 = PIL / \sin \Delta_1 = KL / \sin (180^\circ - \Delta)$$

$KPI = KL * (\sin \Delta_2 / \sin \Delta)$ because, the value of $\sin (180^\circ - \Delta)$ is equals to $\sin \Delta$

$$PIL = KL * (\sin \Delta_1 / \sin \Delta)$$

$$\text{Total tangent length (Ts)} = PCK + KPI$$

$$= t_1 + (t_1 + t_2) * (\sin \Delta_2 / \sin \Delta), \text{ but } t_1 \text{ is } R_s * \tan \Delta_1 / 2 \text{ and } t_2 \text{ is } R_L * \tan \Delta_2 / 2$$

$$= R_s * \tan \Delta_1 / 2 + (R_s * \tan \Delta_1 / 2 + R_L * \tan \Delta_2 / 2) * (\sin \Delta_2 / \sin \Delta)$$

$$\text{Total tangent length (Tl)} = PTL + LPI$$

$$= t_2 + (t_1 + t_2) * \sin \Delta_1 / \sin \Delta$$

$$= R_L * \tan \Delta_2 / 2 + (R_s * \tan \Delta_1 / 2 + R_L * \tan \Delta_2 / 2) * (\sin \Delta_1 / \sin \Delta)$$

To determine curve length (l_1 and l_2)

$$l_1 = \pi R_s \Delta_1 / 180^\circ \text{ and}$$

$$l_2 = \pi R_L \Delta_2 / 180^\circ$$

Chainage/station of point of curvature (SPC), point of compound curvature (SPCC), and station of point of tangency (SPT)

$$SPC = SPI - T_s$$

$$SPCC = SPC + l_1$$

$$SPCC = SPC + \pi R_s \Delta_1 / 180^\circ$$

$$SPT = SPCC + l_2$$

$$SPT = SPCC + \pi R_L \Delta_2 / 180^\circ$$

Example***!!!**

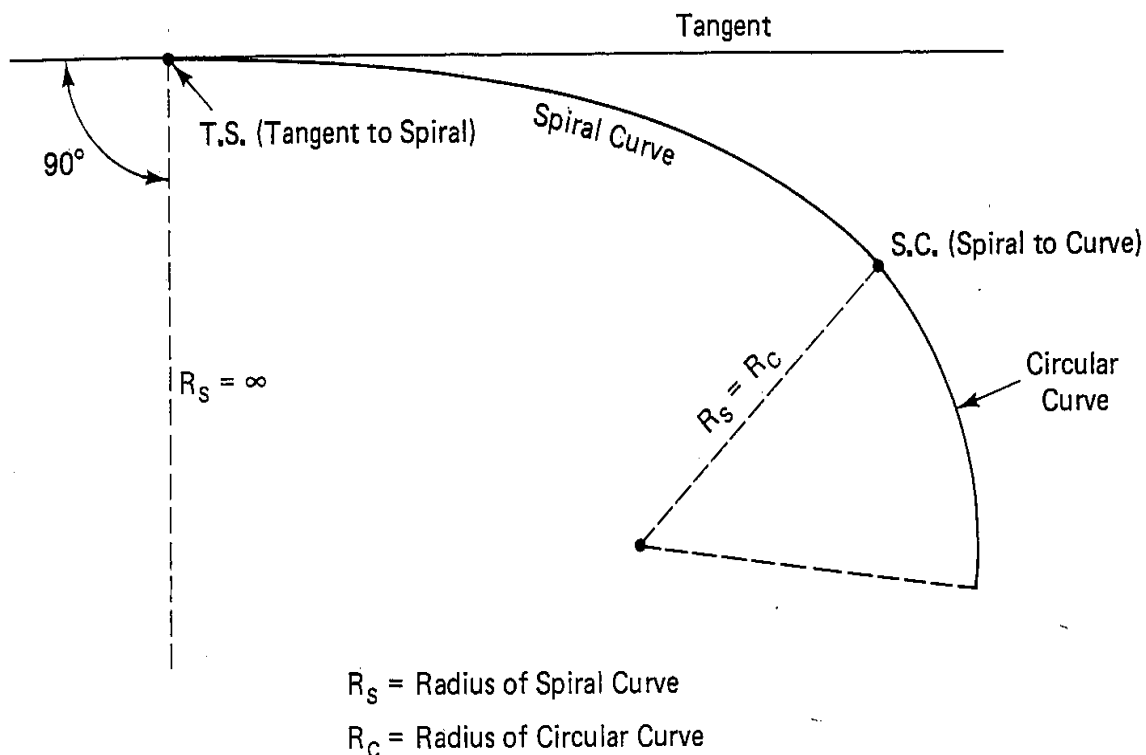


(C) Transition Curve

Transition or spiral or easement curve is a curve with a uniformly changing radius. Transitions are used in highway or railway alignment to overcome the abrupt change in direction, that occurs when the alignment changes from a tangent to a circular curve, and vice versa. The radius of transition curve is greater than the radius 'R' of the circular curve and smaller than the infinity.

When a vehicle travelling on a straight course enters a curve of finite radius it is suddenly subjected to the centrifugal force which causes shock and sway. In order to avoid this it is customary to provide a transition curve at the beginning of the circular curve, having a radius to infinity (∞) at the end of the straight and gradually reducing the radius to the radius of the circular curve where the curve begins.

Incidentally, the transition portion is also used for the gradual application of super elevation (the rising of the outer edge to the inner one) and the curve widening and improvement of general appearance.

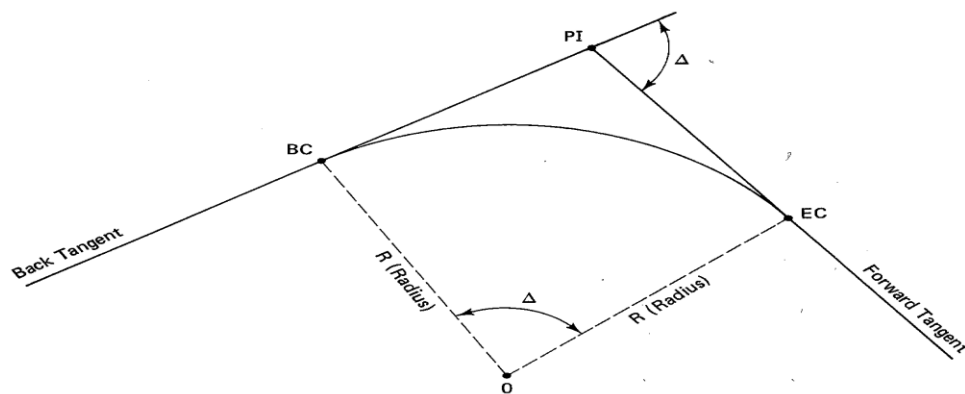


The above figure illustrates how spiral curve is inserted between tangent circular curve alignment. At the beginning of the spiral curve (TS = tangent to spiral), the radius of the spiral is the radius of the tangent line. The radius of the spiral curve decreases at a uniform rate until,

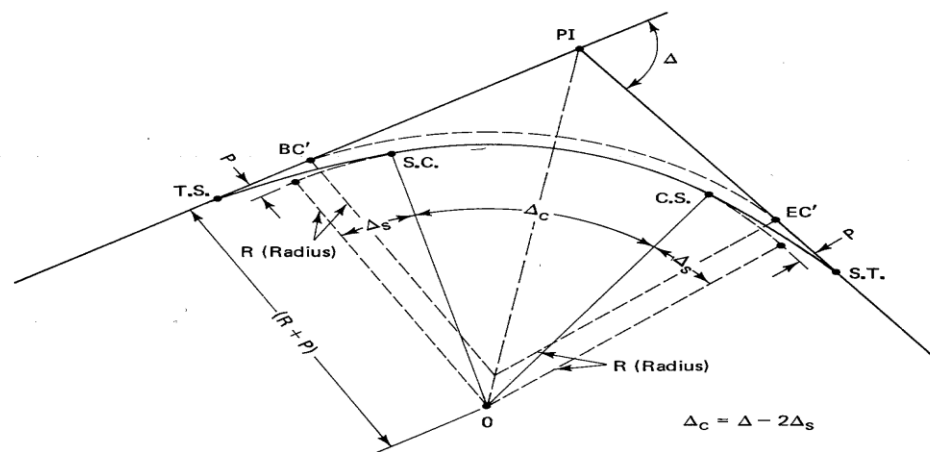
at the point where circular curve begins (SC = spiral to curve), the radius of the spiral equals the radius of the circular curve (R_c).

Spiral curve, used in horizontal alignment has a uniform rate of change of radius. This property allows the driver to leave the tangent section of highway at relatively high rate of speed without experiencing problems in safety and comfort.

The circular curve is moved inward (forward the center of the curve), leaving room for the insertion of a spiral at either end of the shortend circular curve. The amount that the curve is shifted in from the main tangent line is known as shift (S). This shift results in the curve center (O) being at the distance ($R+S$) from the main tangent line. The spirals illustrated in this handout are the common practice of using equal spirals to join the ends of a circular or compound curve to the main tangents.



(a) Circular Curve Joining Two Tangents



(b) Circular Curve Shown Shifted Inward to Permit Insertion of Spiral Curves Within the Original Tangents

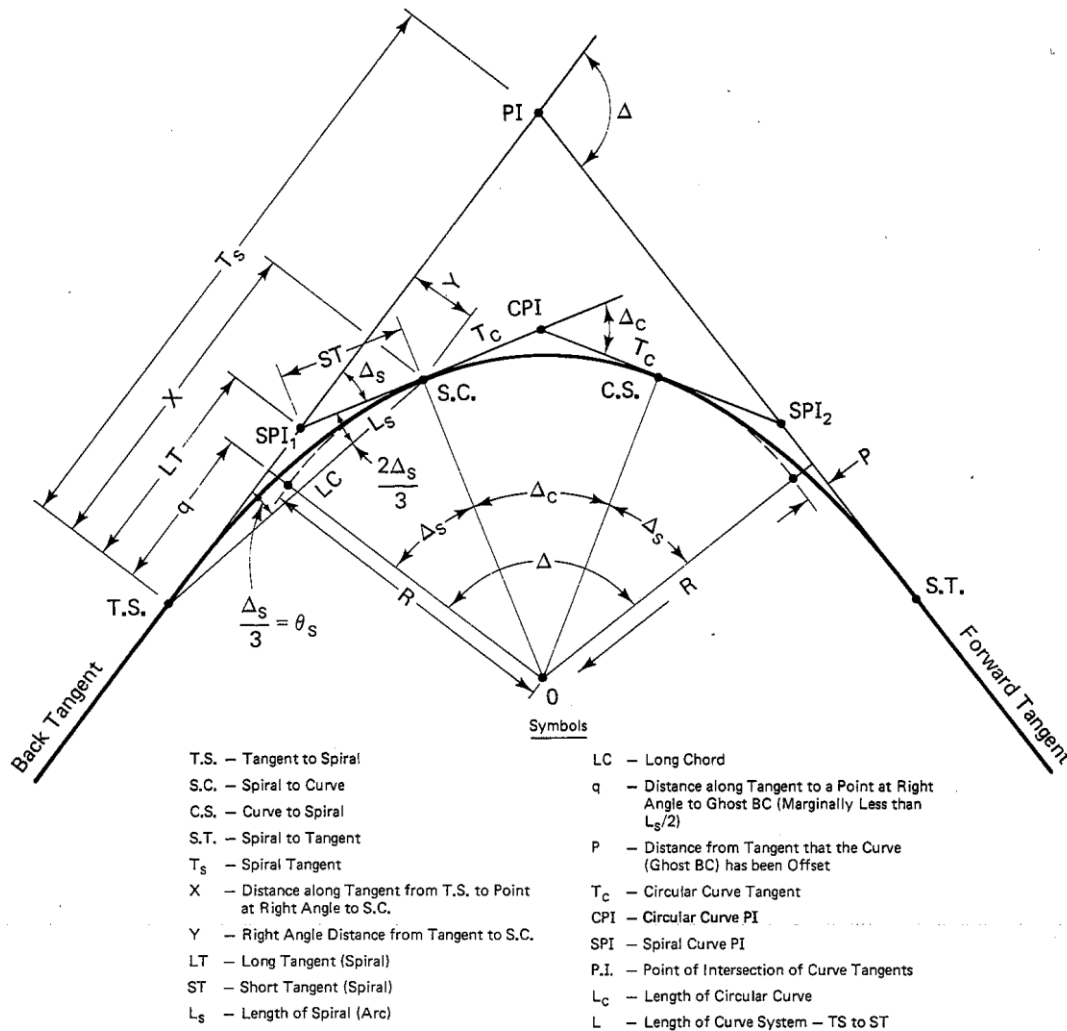
Figur: Circular curve shifting/shifted inward (towards curve center) to make room for the insertion of spiral curve at either end of the circular curve.



Advantages of Transition Curve:

- Chance of overturning of vehicles reduced at the junction of straight and the curve.
- Allows higher speed at the curve.
- The discomfort of the passengers is lessened while the vehicle negotiates the curve.
- Provides to introduce superelevation in proportion to the rate of change of curvature.

Transition Curve Computation



Most of the time, data for a spiral computation are obtained as;

- Δ is determined in the field
- R or D (degree of curve) is given by design consideration (usually defined by design speed)
- SPI is determined in the field



4. LS (length of spiral) or LT (length of transition) is chosen with respect to design speed and the number of traffic lane.

Other values such as X, Y, P, ST, and LT are routinely found in spiral tables issued by state and provincial highway agencies.

Total tangent length (TS) = $(R+S) \tan \Delta/2 + q$, where q is approximately LT/2

Total length (arc length) L = LC + 2LS

ΔS (spiral deflection) = $LS^2/2R$, in degrees

Total deflection (Δ) = $\Delta C + 2\Delta S$

Maximum spiral deflection (ΘS) = $\Delta S/3$, approximately

LT (length of transition) = $V^3/14R$

S (shift distance) = LT/24R

LC (length of circular curve) = $\pi R \Delta C / 180^\circ$

TS = Tangent to transition point

SC = Transition curve to circular curve point

CS = Circular curve to transition curve point

ST = Transition to tangent point

X = Distance along tangent from TS to point at right angle to SC

Y = Right angle distance from tangent to SC

LS = Length of spiral (arc)

S = Shift distance from tangent that the (Ghost PC) has been off-set

q = Distance along tangent to a point at right angle to Ghost PC (approximately LT/2)

TC = Circular curve tangent CPI = Circular curve point of intersection

SPI = Spiral curve point of intersection LC = Length of circular curve

PI = point of intersection of curve tangents L = Total length (LC + LS)

Example***!!!**



2.2 VERTICAL CURVE

To negotiate a change in gradient smoothly and to provide vision over the crest of a hill far enough ahead for safe driving, a curve in a vertical plane gets introduced in the adjacent segments of differing grades. Depending on the magnitude and sign of the gradients at the intersection points, vertical curves fundamentally are of *two types*: **summit or convexity upward and sag/valley or convexity downward**. Design of vertical curves is a function of the difference in grade of the intersecting tangents, stopping or passing sight distance, which in turn are functions of vehicle design speed and height of the driver's eye above the roadway, and drainage. In addition to these factors, design of a sag vertical curve also depends on headlight beam distance, rider comfort, and appearance. Details governing the design of vertical curve are beyond the scope of this course.

Vertical curves are used in highway and street vertical alignment to provide;

1. Smooth transition of vehicle from one grade to the next grade,
2. Vision over the crest of hill and enough a head to give the vehicle operator ample time to see and stop the vehicle from obstruction or danger.

Vertical curve can be of any shape that is circular or parabolic, but parabolic curve is used because parabolic curve further fulfills the requirements of a vertical curve in the following ways:

1. It is flatter at the top and hence provides a longer sight distance. Greater the sight distance, lesser is the possibility of any accident.
2. Rate of change of grade is uniform throughout and hence produces best riding qualities.
3. It is simple in computation and setting works.

Thus, a **parabolic curve** is most commonly used as a vertical curve.

Elevation of points to set out a vertical parabolic curve is computed by using (1) equation of the parabola directly or by using, (2) geometric properties of the parabola (to calculate vertical offsets from the tangent).

Purposes of Vertical Curve

There are two general purposes of vertical curve;

1. Adequate visibility or sight distance – for a vehicle to stop or to overtake safely, it is essential that on coming or any obstructions in the road can be seen at good time.
2. Passenger comfort and safety – as the vehicle travels along the curve a radial force acts on the vehicle in the vertical plane.

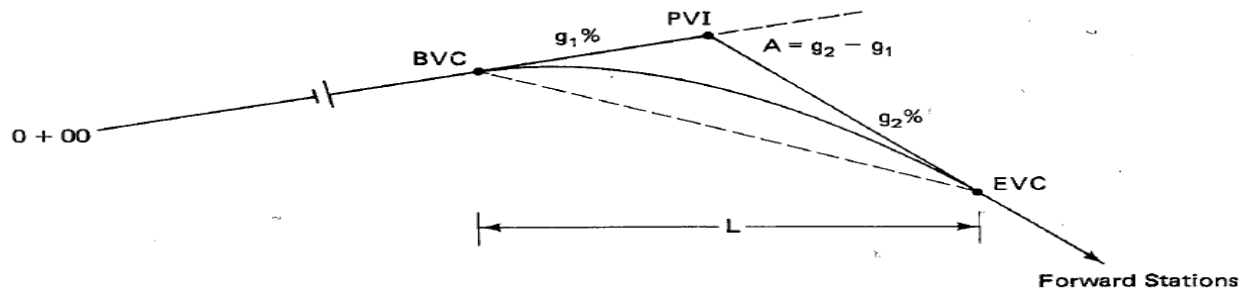


Figure: Vertical curve terminolog (profile view shown).

g_1 = slope or percentage of the lower chainage grade line

g_2 = slope or percentage of the higher chainage grade line

BVC = beginning of vertical curve

EVC = end of vertical curve

PVI = point of vertical intersection

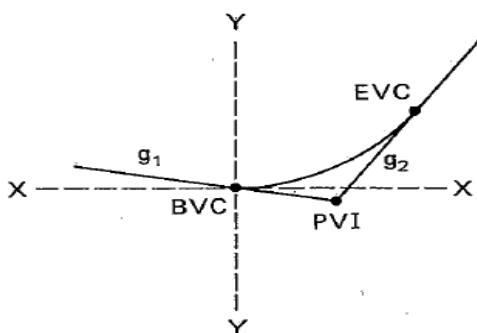
L = length of vertical curve projected on a horizontal surface

A = the algebraic change in slope direction ($g_2 - g_1 = A$) or total change in grade.

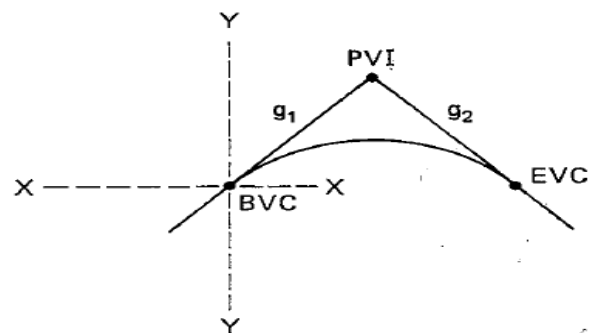
Types of Vertical Curves

Based on the total change in grade ($g_2 - g_1 = A$), there are two types of vertical curves;

1. **Crest (Summit) Curve;** a negative total change in grade when calculated from right to left.
2. **Sag (valley) curve;** a positive total change in grade when calculated from right to left. i.e.



(a) Sag Curve



(b) Crest Curve

Figure: Types of vertical curves: General.



Some highway and municipal agencies introduce vertical curves at every change in grade-line slope, whereas other agencies introduce vertical curves into the alignment only when the net change in slope direction exceeds a specific value (e.g., 1.5% or 2%).

The algebraic change in slope direction is A , where $A = g_2 - g_1$. For example, if $g_1 = +1.5\%$ and $g_2 = -3.2\%$, A would be equal to $(-3.2 - 1.5) = -4.7$.

The geometric curve used in vertical alignment design is the vertical axis parabola. The parabola has the desirable characteristics of (1) a constant rate of change of slope, which contributes to smooth alignment transition, and (2) ease of computation of vertical offsets, which permits easily, computed elevations.

The general equation of the parabola is

$$Y = ax^2 + bx + c$$

The slope of this curve at any point is given by the first derivative,

$$\frac{dy}{dx} = 2ax + b$$

And the rate of change of slope is given by the second derivative,

$$\frac{d^2y}{dx^2} = 2a$$

Which, as was previously noted, is a constant. The rate of change of slope ($2a$) can also be written as A/L .

If for convenience, the origin of the axes is placed at the BVC, the general equation becomes

$$y = ax^2 + bx$$

And because the slope at the origin is g_1 , the expression for slope of the curve at any point becomes

$$\frac{dy}{dx} = \text{slope} = 2ax + g_1$$

The general equation can finally be written as

$$y = ax^2 + g_1x$$



Geometric Properties of the Parabola

1. The difference in elevation between the BVC and a point on the g_1 grade line at a distance x units (feet or meters) is $g_1 x$ (g_1 is expressed as a decimal).
2. The tangent offset between the grade line and the curve is given by ax^2 , where x is the horizontal distance from the BVC; that is, tangent offsets are proportional to the squares of the horizontal distances.
3. The elevation of the curve at distance x from the BVC is given by $BVC + g_1 x - ax^2 = \text{curve elevation}$ (the signs would be reversed in a sag curve).
4. The grade lines (g_1 and g_2) intersect midway between the BVC and the EVC; that is, $BVC \text{ to } V = \frac{1}{2}L = V \text{ to } EVC$.
5. Offsets from the two grade lines are symmetrical with respect to the PVI (V).
6. The curve lies midway between the PVI and the midpoint of the chord; that is, $CM = MV$.

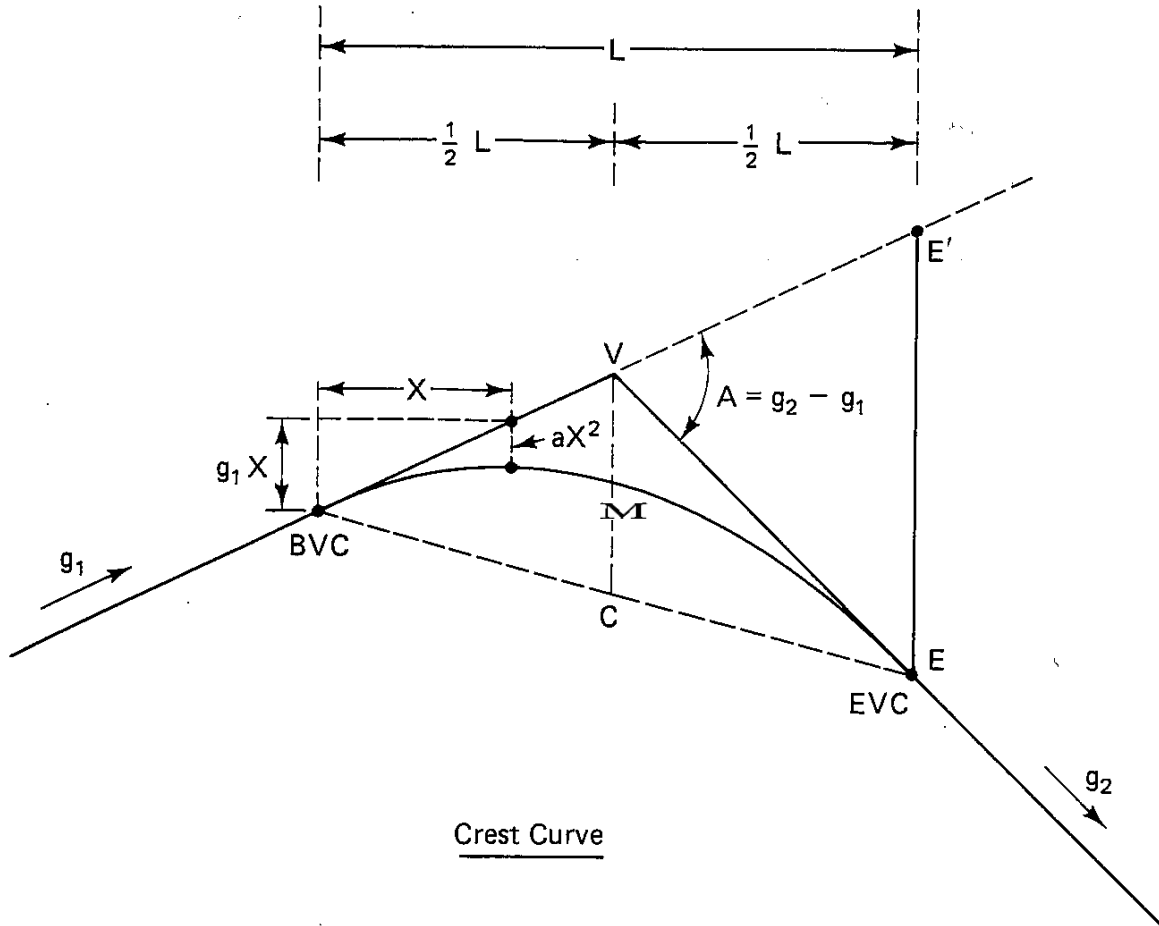


Figure: Geometric properties of vertical curve.

Computation of High or Low Point on a Vertical Curve

The locations of curve high and low points (if applicable) are important for drainage considerations; for example, on curbed streets, catch basins must be installed precisely at the drainage low point.

It was noted earlier that the slope was given by the equation

$$\text{Slope} = 2ax + g_1$$

Figure given below shows a sag vertical curve with a tangent drawn through the low point; it is obvious that the tangent line is horizontal with a slope of zero; that is,

$$2ax + g_1 = 0 \quad ***$$

Had a crest curve been drawn, the tangent through the high point would have exhibited the same characteristics.

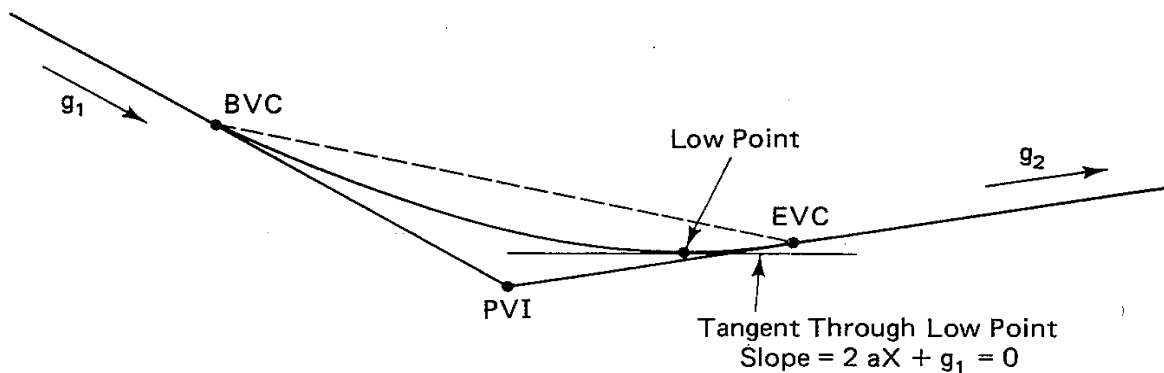


Figure: Tangent at curve low point.

Since

$$2a = \frac{A}{L},$$

Equation (***) can be re-written as

$$x = \frac{-g_1 L}{A}$$

Where x is the distance from the BVC to the high or low point.



Procedure for Computing a Vertical Curve

1. Compute the algebraic difference in grades: $A = g_2 - g_1$.
2. Compute the chainage of BVC and EVC. If the chainage of the PVI is known, $\frac{1}{2}L$ is simply subtracted and added to the PVI chainage.
3. Compute the distance from the BVC to the high or low point (if applicable):

$$x = \frac{-g_1 L}{A}$$

and determine the station of the high/low point.

4. Compute the tangent grade-line elevation of BVC and the EVC.
5. Compute the tangent grade-line elevation for each required station.
6. Compute the midpoint of chord elevation:

$$\frac{\text{Elevation of BVC} + \text{elevation of EVC}}{2}$$

7. Compute the tangent offset (d) at the PVI (i.e., distance VM):

$$d = \frac{\text{difference in elevation of PVI and midpoint of chord}}{2}$$

8. Compute the tangent offset for each individual station (see line ax^2 in the Figure):

$$\text{Tangent offset} = d \left(\frac{x}{L/2} \right)^2, \text{ or } \frac{4d}{L^2} x^2$$

9. Compute the elevation on the curve at each required station by combining the tangent offsets with the appropriate tangent grade-line elevations – add for sag curves and subtract for crest curves.

Example***!!!**



Design Considerations

Sight Distance

Vertical curves should be so constructed that drivers will have certain minimum sight distance in order to see vehicles or other objects on the road. The driver should be able to see an object of a given height at no less than the estimated distance he would travel while reacting to place his foot on the brake pedal plus the distance required to stop.

The American Association of State Highway and Transportation Officials (AASHTO) has developed criteria for the distance required to pass a vehicle moving in the same direction and the distance required to stop a vehicle in an emergency. The former distance, called the **Safe Passing Sight Distance** (S_{sp}) is based on the assumption that the eyes of the driver of a vehicle are about 3.75 ft (1.125m) above the pavement and the top of the no-coming vehicle is about 4.50ft (1.35m) above the pavement. The latter required distance, called the **Safe Stopping Sight Distance** (S_{np}) is based on the assumption that an obstruction ahead of the vehicle is 0.50ft (0.15m) above the pavement. The values of S_{sp} and S_{np} for different design speeds are given in the table below.

Design Speed (kmh)	Passing Sight Distance S_{sp} (ft)	Stopping Sight Distance S_{np} (ft)
30	1100	200
40	1500	275
50	1800	350
60	2100	475
70	2500	600
80	2700	750

If it is assumed that the safe passing sight distance is less than the length of the vertical curve L, then,

$$L = \frac{S_{sp}^2(g_1 - g_2)}{33.0}$$

but if it is assumed that the safe passing sight distance is greater than the curve length L, then,

$$L = 2S_{sp} - \frac{33.0}{g_1 - g_2}$$

If the safe stopping sight distance is assumed to be less than the length of the curve L, then,

$$L = \frac{S_{np}^2(g_1 - g_2)}{14.0}$$

but if the safe stopping sight distance is assumed to be greater than the length of the curve L, then,

$$L = 2S_{np} - \frac{14.0}{g_1 - g_2}$$

in which L, S_{sp} and S_{np} are in feet and g_1 and g_2 are expressed as ratio.

Example***!!!**

>>>>>=<<<<<<<**END!!!**