Length of superelevation Runoff when spiral curves are used

When spiral curve is used, the length of transition curve is equal to the length of Runoff

Minimum superelevation runout length (AASHTO 2011)

Two factors govern the tangent runout length, adverse cross slope value which is intended to be removed and the rate at which it is removed. Smooth pavement edge can be achieved by making the rate of cross slope removal equal to the relative gradient of superelevation runoff. Based on this concept, minimum length of tangent runout can be computed by the following equation

$$L_t = \frac{e_{NC}}{e_d} L_r \qquad \text{...30}$$

Where, L_t is minimum length of tangent runout, *m*; e_{NC} is normal corse slpoe rate, %; e_d is design superelevation rate, % and L_r is the minimum length of superelevation runoff.

However, in case of using spiral curve the following equation is used to determine the minimum tangent runout length:

$$L_t = \frac{e_{NC}}{e_d} L_s \qquad \text{...31}$$

Where, L_s is length of spiral curve.

1.6.4 Spiral (Transition) curve

A spiral curve is a geometric feature that can be integrated on to a regular circular curve. The spiral provides a gradual transition from moving in a straight line to moving in a curve around a point (or vise-verse). In other words, the use of transition curves provides a vehicle path that gradually increases or decreases the radial force as the vehicle enters or leaves a circular curve. Furthermore, spiral curves can be also used to introduce superelevation transition and used for aesthetic purposes especially the high type roadways.

Length of Spiral Curves

If the transition curve is a spiral, the degree of curve between the tangent and the circular curve varies from zero at the tangent end to the degree of the circular curve (R=Rc) at the curve start. However, when the transition is placed between two circular curves, the degree of curve varies from that of the first circular curve to that of the second circular curve.

Table 1.8: Maximum radius use in spiral transition curves

Metric	
Design speed (km/h)	Maximum radius (m)
20	24
30	54
40	95
50	148
60	213
70	290
80	379
90	480
100	592
110	716
120	852
130	1000

The following equations 32 and 33 are used by some highway agencies to compute the minimum length of a spiral transition curve. It should be noted that the minimum length should be the larger of the values obtained from equation 32 and 33.

$$L_{s,min} = \frac{V^3}{46.7RC} \quad \text{.......32}$$

$$L_{s,min} = \sqrt[2]{24RP_{min}} \quad \text{.......33}$$

Where; $L_{s,min}$ is the minimum length of spiral curve (m) ; V is speed (Km/h); R is the radius of curve (m); C is the rate of increase of radial acceleration $m/s^2/s$ Values range from 0.3 to 0.9 $m/s^2/s$ (1 to 3 ft/s^3) have been used for highways; P_{min} is the minimum lateral offset between the tangent and the circular curve, **0.2m**.

$$L_{s,max} = \sqrt[2]{24RP_{max}} \quad \text{.......34}$$

Where;

$L_{s,max}$ is the maximum length of spiral curve (m)

P_{min} is the maximum lateral offset between the tangent and the circular curve, **1m**

1.6.5 Stopping sight distance and horizontal curve

Adequate stopping sight distance must be provided in the design of horizontal curves. Sight distance restrictions on horizontal curves occur when obstructions are present, as presented in Figure 1.29. Such obstructions are frequently encountered in highway design due to the cost of right-of-way acquisition or the cost of moving earthen materials, such as rock outcroppings. When such an obstructions exists, the stopping sight distance is measured along the horizontal curve from the cntre of travelled lane (the assumed location of the driver's eyes)

As shown in Figure 1.29, for a specified stopping distance, some distance M (the middle vordinate of a curve that has an arc length equal to the stopping sight distance) must be visually cleared so that the line of sight is such that sufficient stopping sight distance is available.

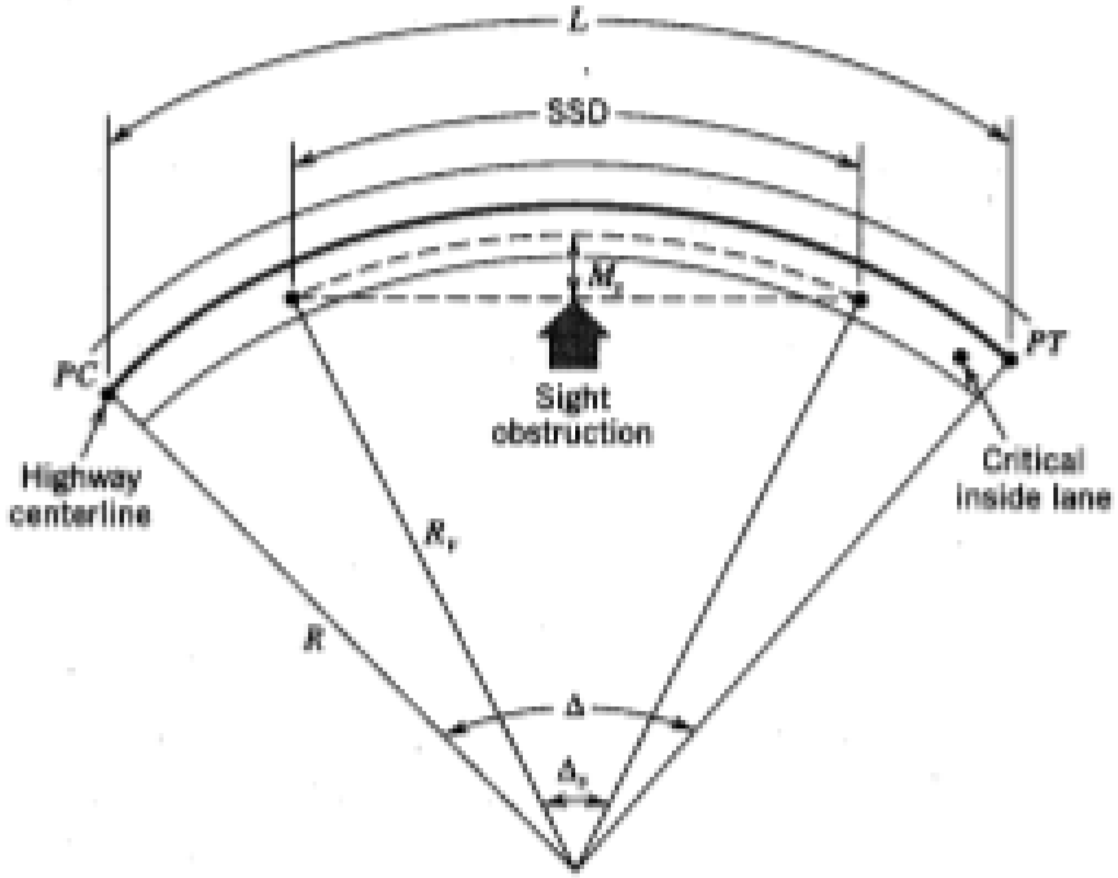


Figure 1.29: Illustration of distance to obstruction

The required distance to obstruction (m) necessary to provide a stopping sight distance (SSD) could be computed by the following formula:

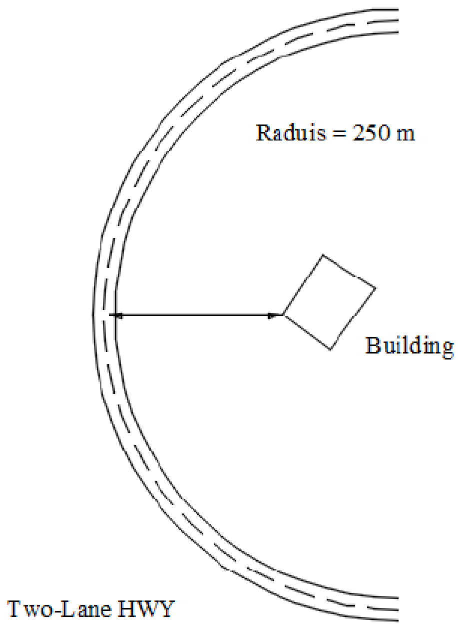
$$m = R\left(1 - \cos\frac{28.65\,SSD}{R}\right) \quad \text{.........35}$$

m= distance to obstruction, m.

R= radius of curve, m.

SSD= sight distance, m.

Example 5: A new service building needs to be constructed near the centre of curve as shown in figure below. Compute the distance from the centre of the inside lane beyond which the building can be constructed so that sight distance on the curve will not be affected. The design speed of the existing road is 60 km/h. Assume a flat area and the passing is prohibited. Hint: deceleration rate is 3.5 (m/sec^2)



$$SSD=0.278\ V.t + \frac{v^2}{254\left[\left(\frac{a}{9.81}\right)\pm G\right]}$$

$$SSD=0.278 * 60*2.5 + \frac{60^2}{254\left[\left(\frac{3.5}{9.81}\right)\pm 0\right]}$$

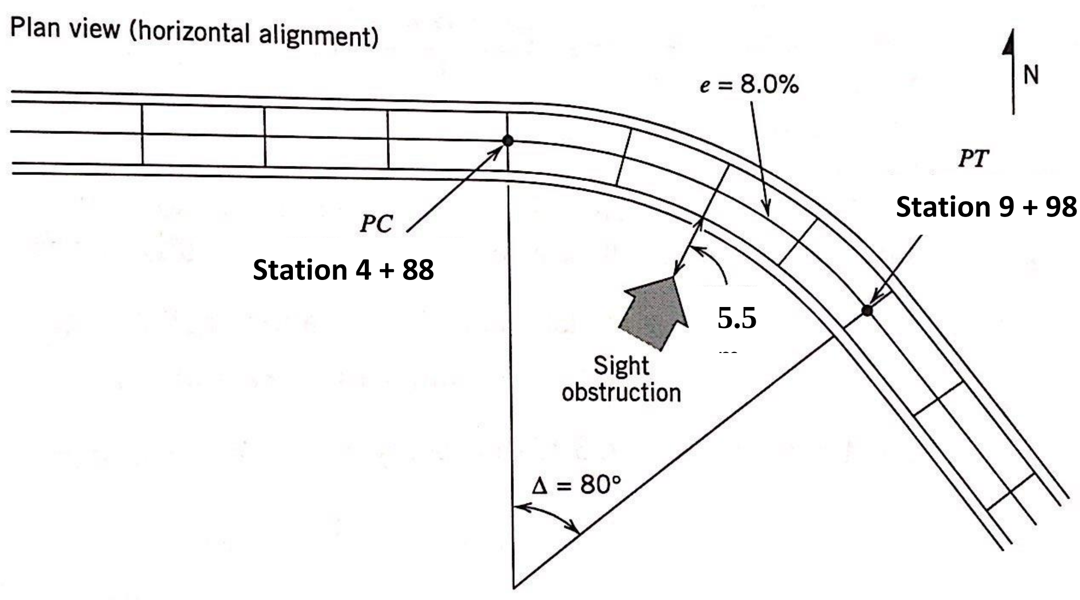
SSD = 81.4

$$m = 250 - (1- \cos \frac{28.65*81.4}{250}) = 3.34\text{m}$$

Q: *A horizontal curve is being designed through mountainous terrain for a four-ane with lanes that are 3 m wide. The central angle is known to be 40 degrees, the tangent distance is 155m, and the stationing of the tangent intersection (PI) is 8 + 23. Under specified conditions and vehicle speed, the roadway surface is determined to have a coefficient of side friction of 0.08, and the curve's superelevation is 0.09. what is the stationing of the PC and PT and what is the safe vehicle speed?*

Q: A new interstate highway is being built with a design speed of 110 km/h. For one of the horizontal curve, the radius is tentatively planned as 275m. What rate of superelevation is required for this curve?(hint: f =0.11 and e_{max}=8%)

Q: A two-lane highway (lane width of 3.6m) has a posted speed limit of 80 km/h and has horizontal curve as shown in the following figure. A recent daytime crash resulted in fatality and lawsuit alleging that the 80 Km/h posted speed limit is an unsafe speed for the curve in question and was a major cause of the crash. Evaluate and comment on the roadway design. Hint (the maximum side friction for a posted speed limit is 0.14 and the required standard stopping sight distance at 80 Km/h is 130m



1.6.5 Vertical alignment

Vertical alignment specifies the elevation of points along a roadway. The elevation of these roadway points are usually determined by the need to provide an acceptable level of driver safety, driver comfort and proper drainage. A primary concern in vertical alignment is establishing the transition of roadway elevations between two grades. This transition is achieved by means of a vertical curve. One of the most important factors that affect the design of this alignment is the topography of the area through which the proposed road is being passing as presented in Figures 1.30 and 1.31.

Vertical curves are usually parabolic in shape and can be broadly classified into crest vertical curves and sag vertical curves as illustrated in Figures 1.32 and 1.33.

Figure 1.30: Examples of vertical curves

Figure 1.31: Vertical curves in hilly areas

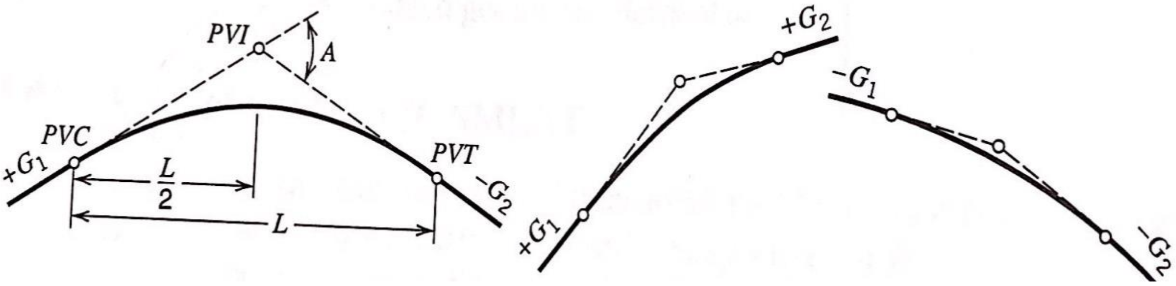


Figure 1.32: Crest vertical curves

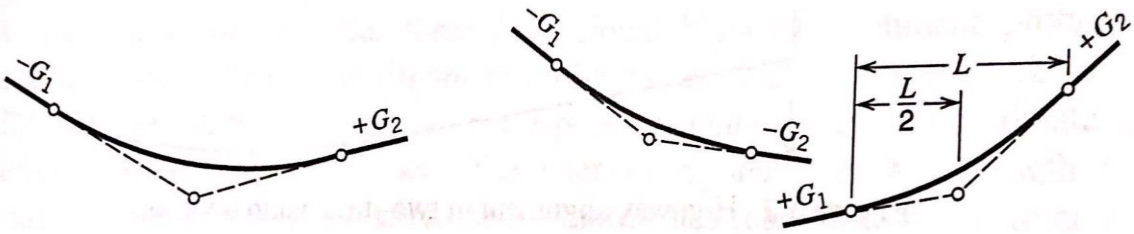


Figure 1.32: Sag vertical curves

1.6.5.1 Maximum grade

Passenger cars are normally less affected by the step grade as compared with the truck or heavy vehicle. Generally, the grade has a great effect on the heavy truck vehicles where a reduction of speed occurs on these grades. It should be noted that the selection of the grade value has a great influence on the volume of earthwork. To reduce this effect, it is customarily adopted to design the highways in such a way that ensure a reduction in the earthwork quantities and hence the cost of the project. Table 1.9 presents recommended maximum values of grades with respect to types of terrain and road.

1.6.5.2 Minimum grade

The minimum grade is generally governed by adopted drainage requirements for roadway being designed. A minimum grade of 0.3% is desirable for high type pavements.

1.6.5.3 Critical length of grade

This critical length can be defined as the maximum length of upgrade on which the design vehicle (almost heavy trucks) can run without a reasonable speed reduction. Figure 1.33 is used to assess the critical length of grade. It should be noted that a speed reduction curve of 15 Km/h is recommended to be used to find the critical length of grade.

Table 1.9: Recommended maximum value of grades

	Rural Collectors[a] *Design Speed (mi/h)*								
Type of Terrain	*20*	*25*	*30*	*35*	*40*	*45*	*50*	*55*	*60*
	Grades (%)								
Level	7	7	7	7	7	7	6	6	5
Rolling	10	10	9	9	8	8	7	7	6
Mountainous	12	11	10	10	10	10	9	9	8
	Urban Collectors[a] *Design Speed (mi/h)*								
Type of Terrain	*20*	*25*	*30*	*35*	*40*	*45*	*50*	*55*	*60*
	Grades (%)								
Level	9	9	9	9	9	8	7	7	6
Rolling	12	12	11	10	10	9	8	8	7
Mountainous	14	13	12	12	12	11	10	10	9
	Rural Arterials *Design Speed (mi/h)*								
Type of Terrain	*40*	*45*	*50*	*55*	*60*	*65*	*70*	*75*	*80*
	Grades (%)								
Level	5	5	4	4	3	3	3	3	3
Rolling	6	6	5	5	4	4	4	4	4
Mountainous	8	7	7	6	6	5	5	5	5
	Rural and Urban Freeways[b] *Design Speed (mi/h)*								
Type of Terrain	*50*	*55*	*60*	*65*	*70*	*75*	*80*		
	Grades (%)								
Level	4	4	3	3	3	3	3		
Rolling	5	5	4	4	4	4	4		
Mountainous	6	6	6	5	5	–	–		
	Urban Arterials *Design Speed (mi/h)*								
Types of Terrain	*30*	*35*	*40*	*45*	*50*	*55*	*60*		
	Grades (%)								
Level	8	7	7	6	6	5	5		
Rolling	9	8	8	7	7	6	6		
Mountainous	11	10	10	9	9	8	8		

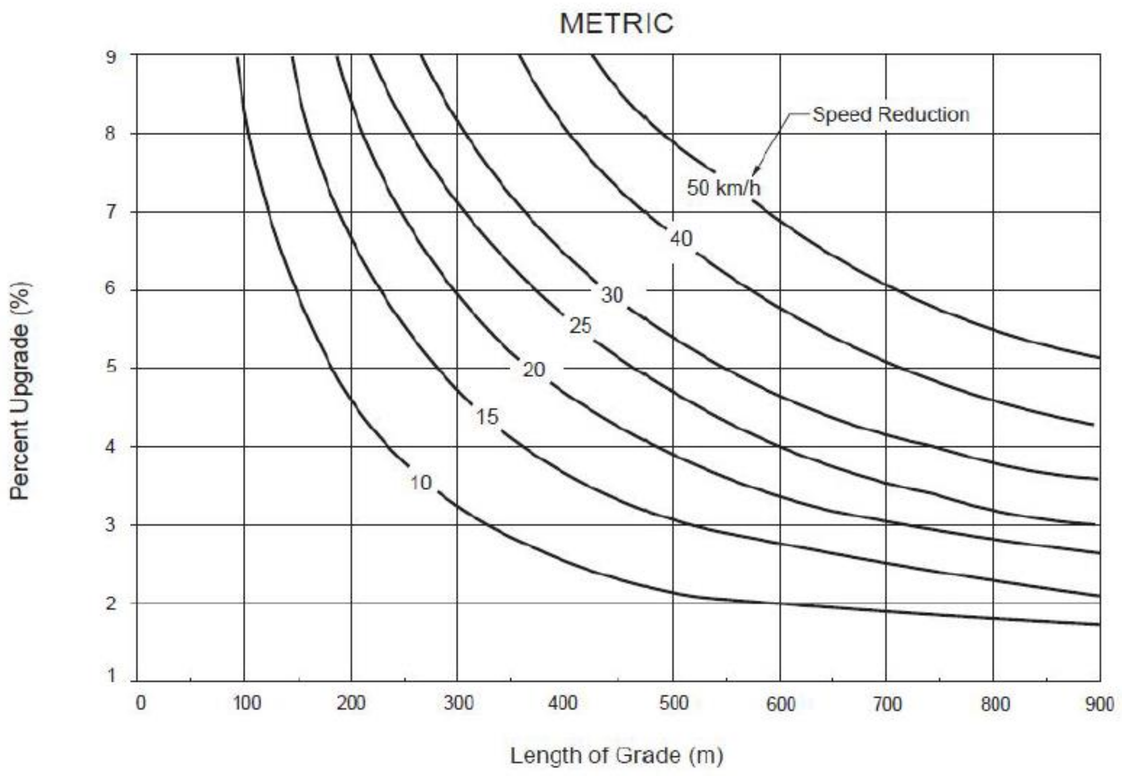


Figure 1.33: Critical length of grade

1.6.5.4 Elements of vertical curves

Elements of vertical curves can be illustrate in Figure 1.34

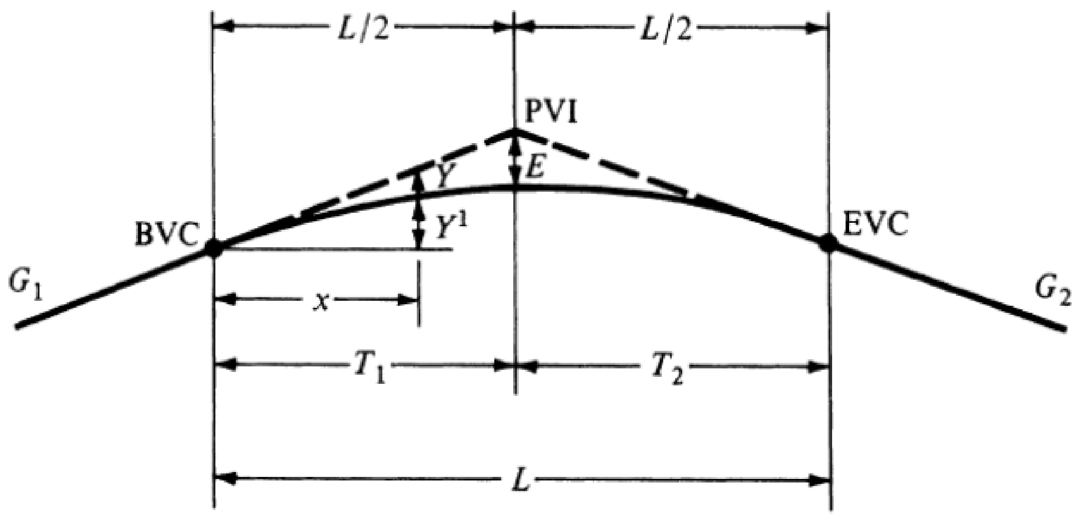


Figure 1.34: Layout and parameters of vertical curve

Where:

G_1, G_2: Grades of tangents %

L: Length of curve

E: External distance

BVC (PVC): beginning of vertical curve

EVC (PVT): End of vertical curve

PVI: point of vertical intersection

A: algebraic difference of grades, G_1-G_2

1.6.5.5 Properties of vertical curves

The determination of vertical curve elevations and elevation of critical points could be computed based on the properties of parabola as shown in equation

$$y = ax^2 + bx + c \quad \text{.........36}$$

where

y = elevation of any point on curve.

x= distance from the point of vertical curvature.

a = rate of change of gradient.

b = initial grade

c= elevation of point of curvature

Rate of change of slope = the second derivative

First derivative = 2ax+b

Second derivative = 2a ……………………………………………………..37

But, the rate of change =(G_2-G_1)/100L ………………………………………..38

Equating Eq.37 and Eq.38 gives

2a= (G_2-G_1)/100L

So, $a = \frac{G2-G1}{200L}$

And equation 36 can be rewritten as follows

Elevation of any point on curve= $\frac{G2-G1}{200\,L}$ x^2 + $\frac{G1}{100}$ x +PVC elev.

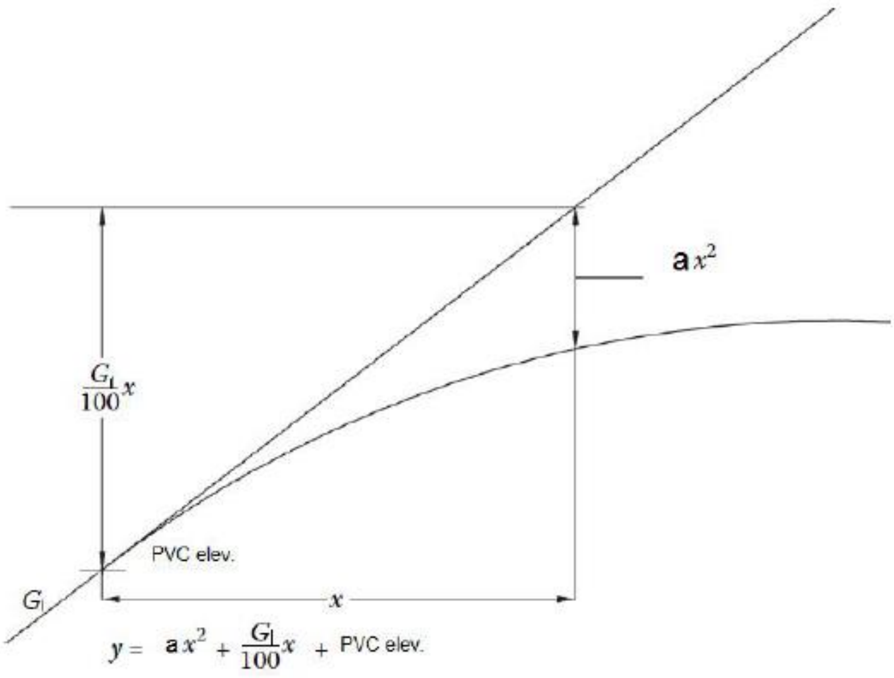


Figure 1.35: Layout and parameters of vertical curve

Offset

As shown in Figure 1.34, Y^1 can be calculated as follows:

$Y^1 = \frac{G1}{100}X - Y$ 39

where $Y = \frac{A}{200L}x^2$ 40

A: algebraic difference of grades, G_1-G_2

$Y^1 = \frac{G1}{100}X - \frac{G1-G2}{200L}x^2$

$\frac{dy1}{dx} = \frac{G1}{100} - \frac{G1-G2}{100L}x = 0$

$X_{high/low} = \frac{G1}{G1-G2} L$ ……………………………………………………….41

External distance *E* from the point of vertical intersection (PVI) to the curve is determined by substituting *L*/2 for *x* in Eq. $Y = \frac{A}{200L} x^2$

$E = \frac{AL}{800}$ ……………………………………..………………………...42

$BVC_{Station} = PVI_{station} - \frac{L}{2}$ ………………………………………………...….43

$EVC_{Station} = BVC_{station} + L$ ………………………………………………….44

$BVC_{Elevation} = PVI_{Elevation} - \frac{G_1 L}{200}$ ………………………………………….45

$EVC_{Elevation} = PVI_{Elevation} - \frac{G_2 L}{200}$ ………………………………………….46

1.6.5.6 Design Procedure for Crest and Sag Vertical Curves

Step 1. Determine the minimum length of curve to satisfy sight distance requirements and other criteria for sag curves (sight distance requirements, comfort requirements. appearance requirements, and drainage requirements.

Step 2. Determine from the layout plans the station and elevation of the point where the grades intersect (PVI).

Step 3. Compute the elevations of the beginning of vertical curve, (BVC) and the end of vertical curve (EVC).

Step 4. Compute the offsets, *Y*, (Eq. 40) as the distance between the tangent and the curve. Usually equal distances of 20m (1 station) are used, beginning with the first whole station after the BVC.

Step 5. Compute elevations on the curve for each station.

Step 6. Compute the location and elevation of the highest (crest) or lowest (sag) point on the curve