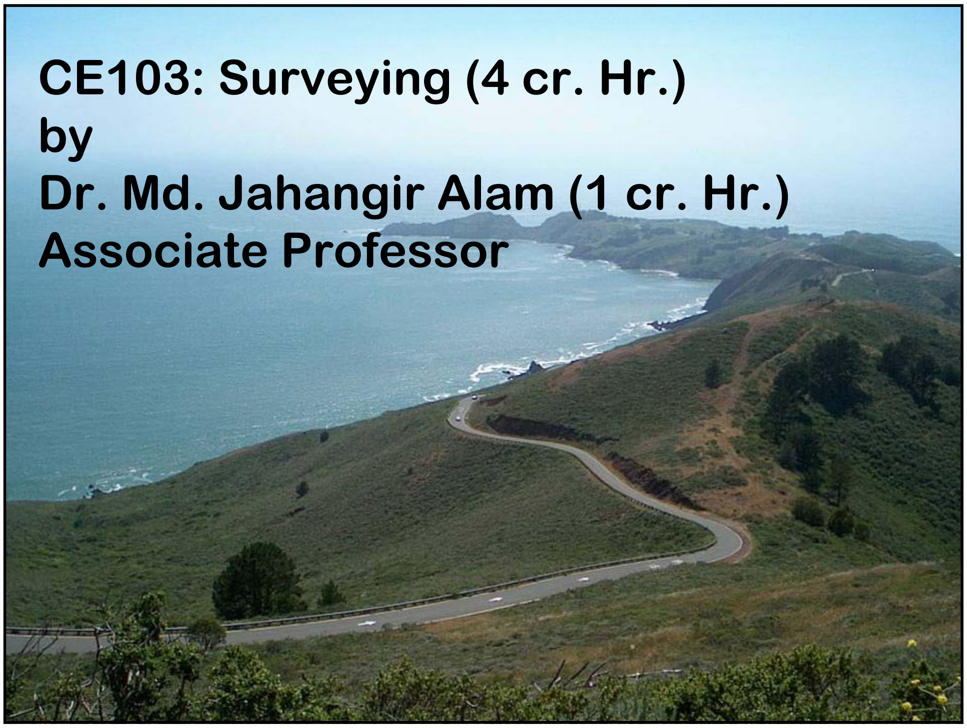

CE103: Surveying (4 cr. Hr.)
by
Dr. Md. Jahangir Alam (1 cr. Hr.)
Associate Professor

CE103: Syllabus

- Curve Setting
  - Horizontal Curve
    - Circular Curve
    - Transition Curve
  - Vertical Curve
- Remote Sensing, GIS and GPS
- Reconnaissance and Project Surveying

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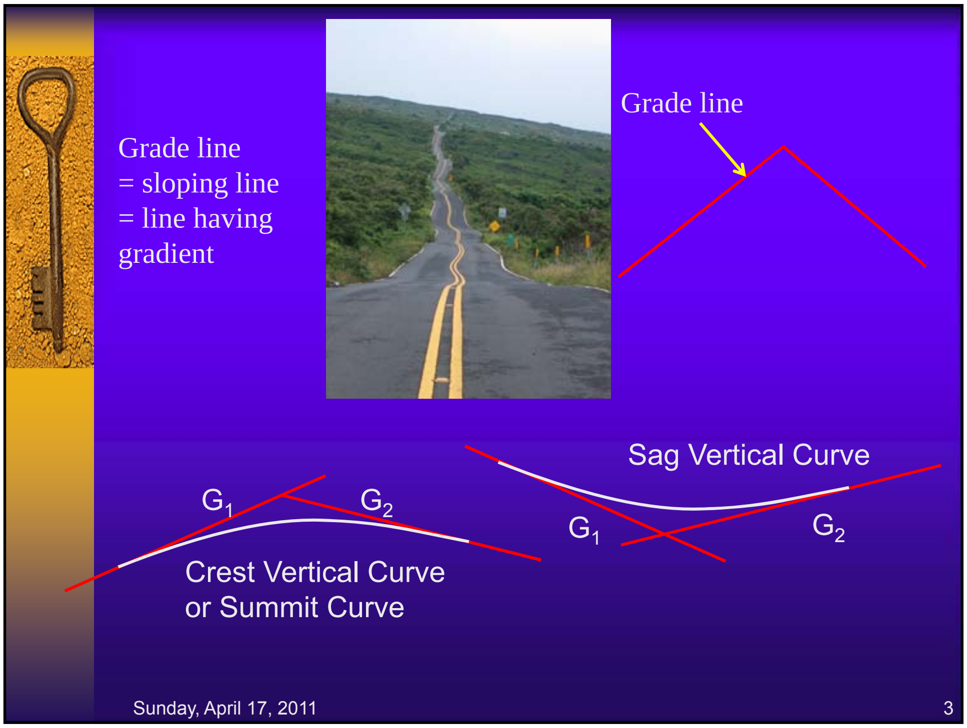
Grade line
= sloping line
= line having
gradient
Grade line
Sag Vertical Curve
G1
G2
G1
G2
Crest Vertical Curve
or Summit Curve
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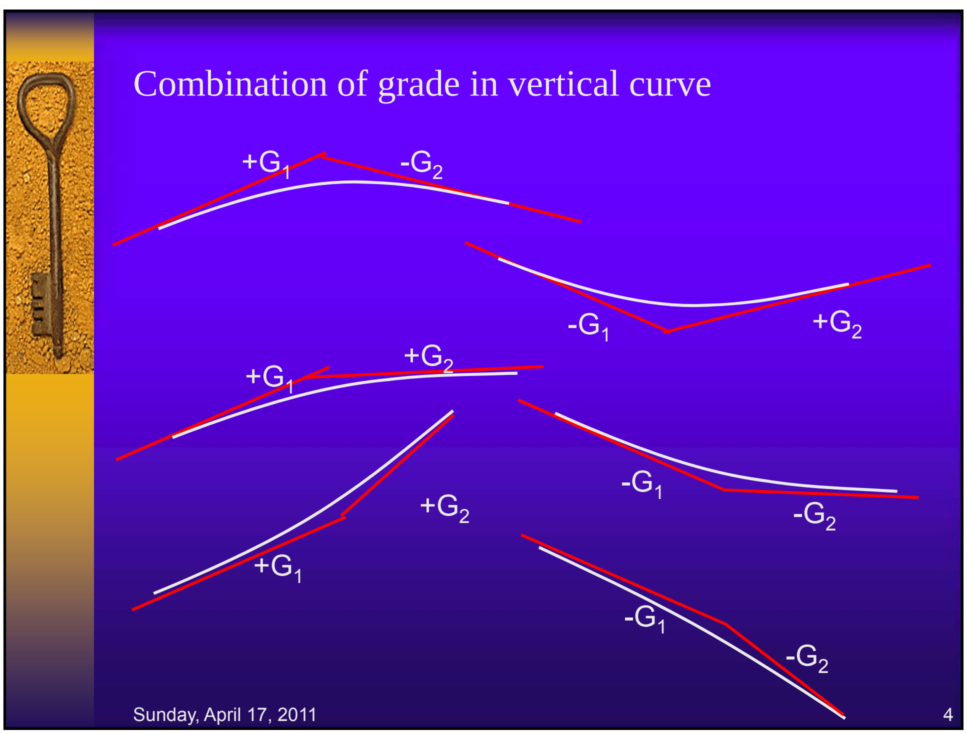
3


Combination of grade in vertical curve
+G1
-G2
-G1
+G2
+G1
+G2
-G1
-G2
+G2
+G1
-G1
-G2
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4

$$\text{gradient, m} = \frac{dY}{dx}$$

$$\text{rate of change of grade, r} = \frac{d^2Y}{dx^2}$$

- Parabolic function
  - Constant rate of change of slope
  - Implies equal curve tangents

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

- y is the roadway elevation x stations (or feet) from the beginning of the curve

Parabolas provide a **constant rate of change of grade, they are ideal and** almost always applied for vertical alignments used by vehicular traffic.

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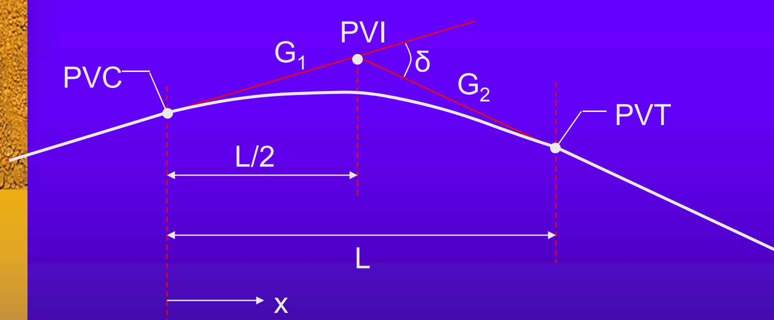
Vertical Curve Fundamentals



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

Choose Either:
- G_1, G_2 in decimal form, L in feet
- G_1, G_2 in percent, L in stations

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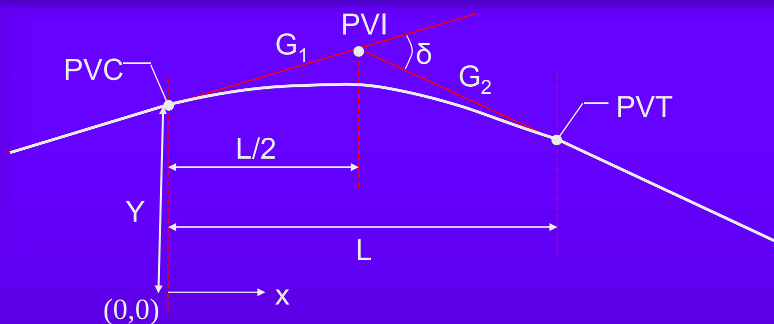


$$y = ax^2 + bx + c,$$
$$a = ?, b = ?, c = ?$$

$$c = Y$$

$$b = G_1$$

$$r = \frac{G_2 - G_1}{L}$$

$$a = \frac{G_2 - G_1}{2L}$$

Relationships

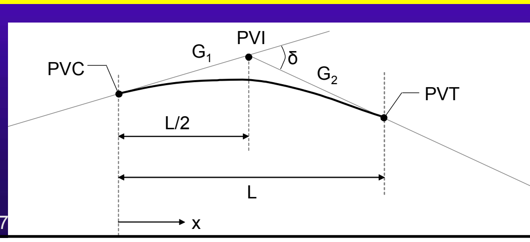
Choose Either:

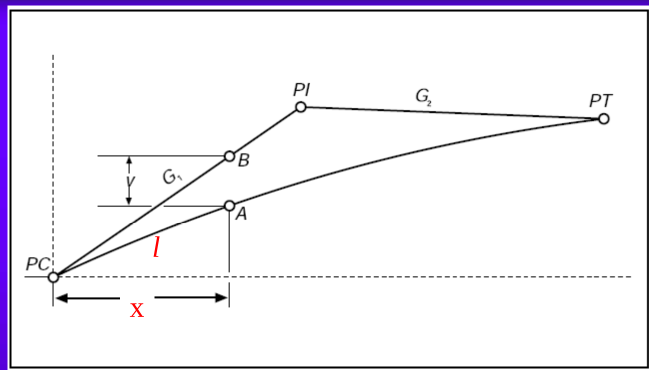
- G_1, G_2 in decimal form, L in feet
- G_1, G_2 in percent, L in stations

$$\text{At the PVC}: \ x = 0 \quad \text{and} \quad Y = c$$

$$\text{At the PVC}: \ x = 0 \quad \text{and} \quad \frac{dY}{dx} = b = G_1$$

$$\text{Anywhere}: \ \frac{d^2Y}{dx^2} = 2a = \frac{G_2 - G_1}{L} \Rightarrow a = \frac{G_2 - G_1}{2L}$$





$x = l$

at A, $y = ax^2 + bx + c$

at B, $y = bx + c$

$AB = ax^2$

$a = \dfrac{G_2 - G_1}{2L}$

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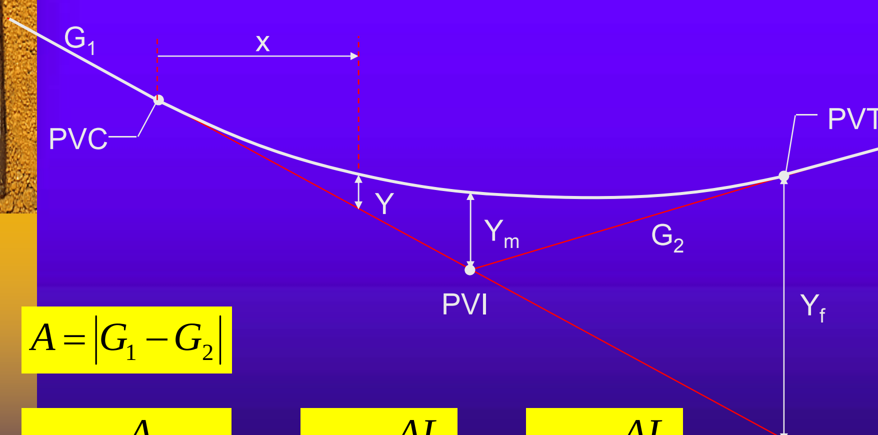
Other Properties

- G_1, G_2 in percent
- L in feet



$A = |G_1 - G_2|$

$Y = \dfrac{A}{200L} x^2$

$Y_m = \dfrac{AL}{800}$

$Y_f = \dfrac{AL}{200}$

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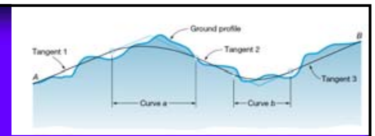
Factors to be Considered

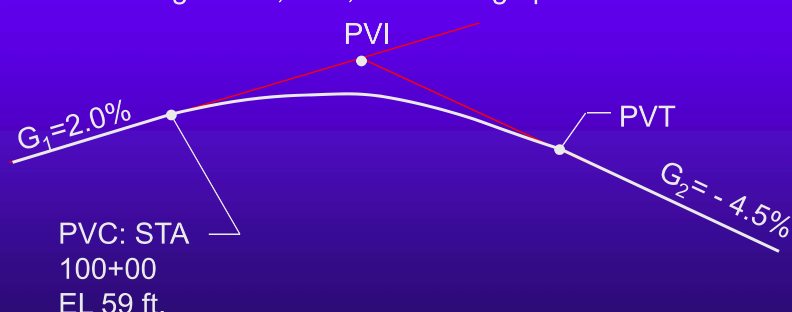


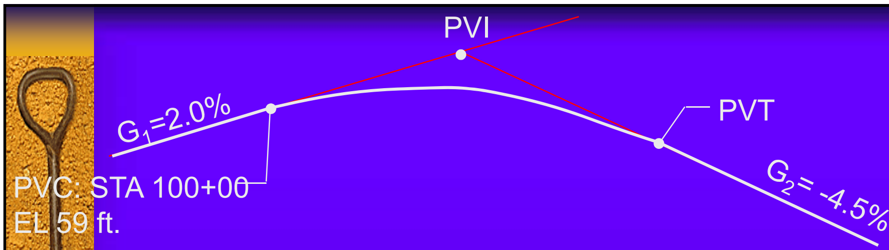
There are several factors that must be taken into account when designing a grade line of tangents and curves on any highway or railroad projects. They include:

1. Providing a good fit with the existing ground profile, thereby minimizing depths of cuts and fills.
2. Balancing the volume of cut materials against fill.
3. Maintaining adequate drainage.
4. Not exceeding maximum specified **grades (g) and meeting fixed** elevations such as intersections with other roads.
5. In addition, the curves must be designed to
    a. fit the grade lines they connect
    b. have lengths sufficient to meet specifications covering a maximum rate of change of grade (which affects the comfort of vehicle occupants)
    c. provide sufficient sight distance for safe vehicle operation.

Example

A 400 ft. equal tangent crest vertical curve has a PVC station of 100+00 at 59 ft. elevation. The initial grade is 2.0 percent and the final grade is -4.5 percent. Determine the elevation and stationing of PVI, PVT, and the high point of the curve.





400 ft. vertical curve, therefore:
•PVI is at STA 102+00 and PVT is at STA 104+00

Elevation of the PVI is 59' + 0.02(200) = 63 ft.
Elevation of the PVT is 63' – 0.045(200) = 54 ft.

High point elevation requires figuring out the equation for a vertical curve
•At x = 0, y = c => c=59 ft.
•At x = 0, dY/dx = b = G_1 = +2.0%
•a = (G_2 – G_1)/2L = (-4.5 – 2)/(2(4)) = - 0.8125

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•$y = -0.8125x^2 + 2x + 59$
•High point is where dy/dx = 0
•dy/dx = -1.625x + 2 = 0
•x = 1.23 stations

Find elevation at x = 1.23 stations
•$y = -0.8125(1.23)^2 + 2(1.23) + 59$
•y = 60.23 ft

•SSD : (Stopping Sight Distance)
is the sum of two distances: perception reaction time, and the vehicle stopping distance.

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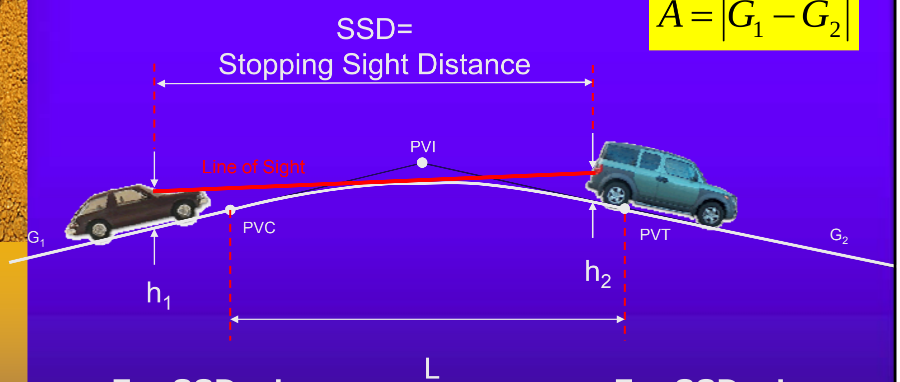
Crest Vertical Curves

$$A = |G_1 - G_2|$$



For SSD < L

$$L = \frac{A(SSD)^2}{100\left(\sqrt{2h_1} + \sqrt{2h_2}\right)^2}$$

For SSD > L

$$L = 2(SSD) - \frac{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}{A}$$

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Crest Vertical Curves

$$A = |G_1 - G_2|$$

- Assumptions for design
  - h_1 = driver's eye height = 3.5 ft.
  - h_2 = tail light height = 2.0 ft.
- Simplified Equations

For SSD < L

$$L = \frac{A(SSD)^2}{2158}$$

For SSD > L

$$L = 2(SSD) - \frac{2158}{A}$$

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Design Controls for Crest Vertical Curves

Metric				US Customary			
Design speed (km/h)	Stopping sight distance (m)	Rate of vertical curvature, K[a]: Calculated	Rate of vertical curvature, K[a]: Design	Design speed (mph)	Stopping sight distance (ft)	Rate of vertical curvature, K[a]: Calculated	Rate of vertical curvature, K[a]: Design
20	20	0.6	1	15	80	3.0	3
30	35	1.9	2	20	115	6.1	7
40	50	3.8	4	25	155	11.1	12
50	65	6.4	7	30	200	18.5	19
60	85	11.0	11	35	250	29.0	29
70	105	16.8	17	40	305	43.1	44
80	130	25.7	26	45	360	60.1	61
90	160	38.9	39	50	425	83.7	84
100	185	52.0	52	55	495	113.5	114
110	220	73.6	74	60	570	150.6	151
120	250	95.0	95	65	645	192.8	193
130	285	123.4	124	70	730	246.9	247
				75	820	311.6	312
				80	910	383.7	384

[a] Rate of vertical curvature, K, is the length of curve per percent algebraic difference in intersecting grades (A). K = L/A

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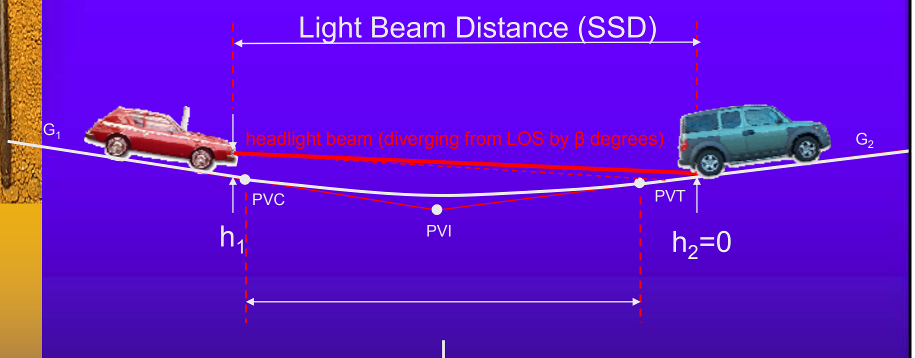
Sag Vertical Curves

LOS=line of sight



For SSD < L

$$L = \frac{A(SSD)^2}{200(h_1 + S \tan \beta)}$$

For SSD > L

$$L = 2(SSD) - \frac{200(h_1 + (SSD)\tan \beta)}{A}$$

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Sag Vertical Curves

- Assumptions for design
  - h_1 = headlight height = 2.0 ft.
  - β = 1 degree
- Simplified Equations

For SSD < L

$$L = \frac{A(SSD)^2}{400 + 3.5(SSD)}$$

For SSD > L

$$L = 2(SSD) - \left(\frac{400 + 3.5(SSD)}{A}\right)$$

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Sag Vertical Curves

- Assuming L > SSD…

$$K = \frac{SSD^2}{400 + 3.5SSD}$$

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Design Controls for Sag Vertical Curves

Metric				US Customary			
Design speed (km/h)	Stopping sight distance (m)	Rate of vertical curvature, K[a] Calculated	Design	Design speed (mph)	Stopping sight distance (ft)	Rate of vertical curvature, K[a] Calculated	Design
20	20	2.1	3	15	80	9.4	10
30	35	5.1	6	20	115	16.5	17
40	50	8.5	9	25	155	25.5	26
50	65	12.2	13	30	200	36.4	37
60	85	17.3	18	35	250	49.0	49
70	105	22.6	23	40	305	63.4	64
80	130	29.4	30	45	360	78.1	79
90	160	37.6	38	50	425	95.7	96
100	185	44.6	45	55	495	114.9	115
110	220	54.4	55	60	570	135.7	136
120	250	62.8	63	65	645	156.5	157
130	285	72.7	73	70	730	180.3	181
				75	820	205.6	206
				80	910	231.0	231

[a] Rate of vertical curvature, K, is the length of curve (m) per percent algebraic difference intersecting grades (A). K = L/A

Sunday, April 17, 2011 from AASHTO's *A Policy on Geometric Design of Highways and Streets 2004*

It is not practicable to provide passing sight distance (PSD) in vertical curve

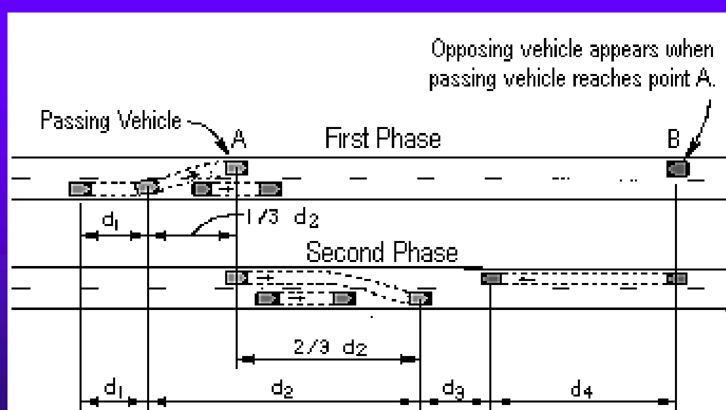

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TABLE 6-1m Relation of Maximum Grades to Design Speed for Interstate and State Highways[a]

Type Of Terrain	Design Speed (km/h)							
	60	70	80	90	100	110	120	130
	Maximum Grade (%)							
Level	5	5	4	4	3	3	3	3
Rolling	6	6	5	5	4	4	4	4
Mountainous	8	7	7	6	6	5	5	5

[a] Maximum grades may be 1% steeper for the following: urban conditions, 2 lane rural (less than 150 m tangent), and divided highways

TABLE 6-2m Maximum Grades for Urban Arterials[a]

Type Of Terrain	Design Speed (km/h)					
	50	60	70	80	90	100
	Maximum Grade (%)					
Level	8	7	6	6	5	5
Rolling	9	8	7	7	6	6
Mountainous	11	10	9	9	8	8

[a] Maximum grades for urban conditions may be 1% steeper for the following: short lengths (less than 150 m tangent) and on one-way down grades

L = Length of the curve;

This length may be computed using the formula
L = G/r, G=G2-G1,
where r is the rate of change (usually given in the design criteria).

When the rate of change is not given, L (in stations) can be computed as follows:
*for a summit curve, **L = 125** x G/4;*
*for a sag curve, **L = 100** x G/4.*

If L does not come out to a whole number of stations using these formulas, then it is usually extended to the nearest whole number. You should note that these formulas for length are for road design only, NOT railway.

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Design of Vertical Alignment of Road
(Design speed is known and grades are known or decided by designers)

- 1. Determine SSD and L from SSD. Decide L = ?
- 2. a=?, b=?, c=?
- 3. determine RL of each peg station and chainage of control points

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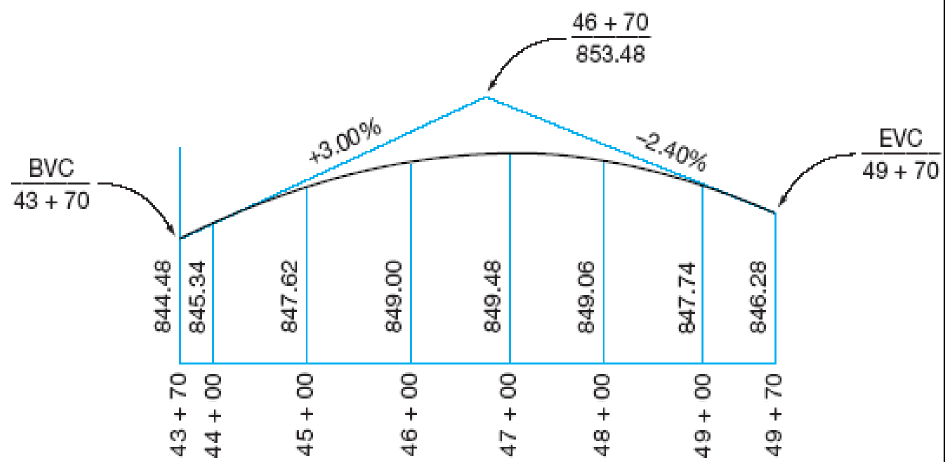

Figure 25–4 Crest curve of Example 25–1.

Example:

g1 = +3.00%, g2 = -2.40%, V station is 46+70 and V elevation is 853.48, L = 600 ft, compute the curve for stakeout at full stations.

Answer:

r = (-2.4 -3.00)/ 6 = -0.90 % station

BVC station = (46+70) - (6+00 / 2) = 43 +70

EVC station = (43 +70) + (6+00) = 49+70

Elevation of BVC = 853.48 – (3.00) (3) = 844.48

For each point, compute X and substitute in the equation below to compute Y:
$Y = 844.48 + 3.00 (X) + (-0.90/2) X^2$

For example, at station 44+00: X = 0.3,

Then, X = 1.3, 2.3, 3.3, 4.3, 5.3, end at station 49+70: X = 6 or L

High or Low Points on a Curve

- Why: sight distance, clearance, cover pipes, and investigate drainage.
- At the highest or lowest point, the tangent is horizontal, the derivative of Y w.r.t x = 0.
- Deriving the general formula gives:
- $X = g_1 l/(g_1 - g_2) = -g_1/r$ where: X is the distance in stations from BVC to the high or low point.
- Substitute in the tangent offset equation to get the elevation of that point.
- Example 25-4: compute the station and elevation of the highest point on the curve in example 25-1

- Answer: X = -3.00/-0.9 = 3.3333 stations

Plug X back into the equation get elevation = 849.48

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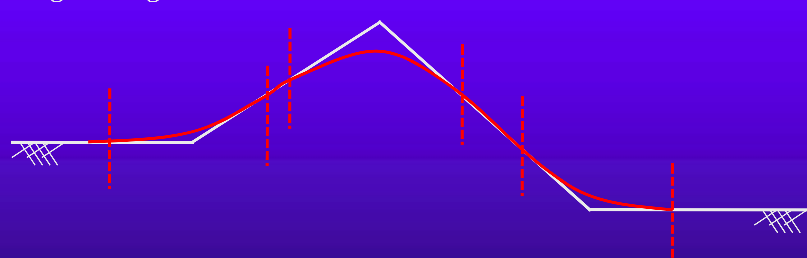
Comments

1. Please take care of ramp in parking, flyover etc.
2. Never overtake other vehicles in hilly roads
3. Please don’t blame only drivers, check twice the engineering faults in roads



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