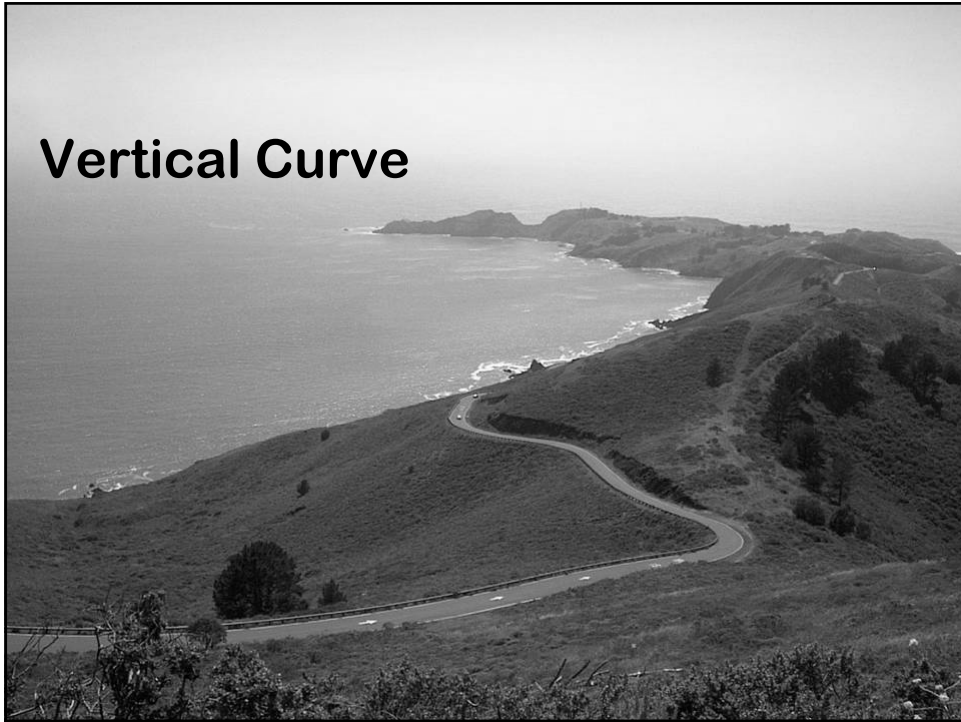
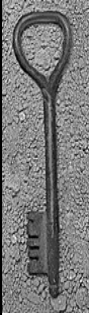

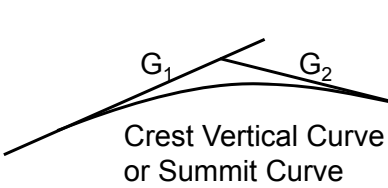


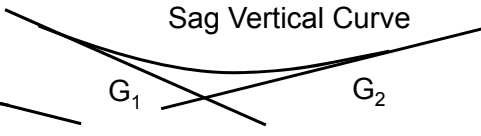
Vertical Curve



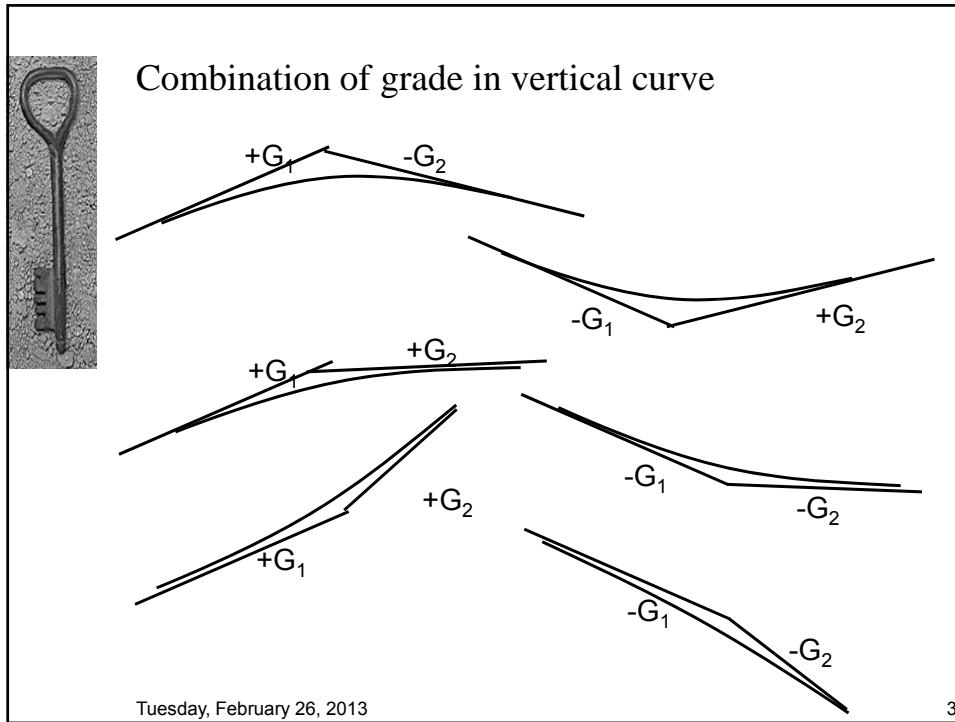
 Grade line
= sloping line
= line having gradient

 Grade line

 Crest Vertical Curve
or Summit Curve

 Sag Vertical Curve

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

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

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

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

- ◆ y is the roadway elevation
- ◆ x is distance from the beginning of the curve

Parabola provides a **constant rate of change of grade**, it is **ideal and** almost always applied for vertical alignments used by vehicular traffic.

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Vertical Curve Fundamentals

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

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

$$a = ?, b = ?, c = ?$$

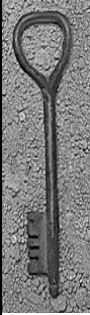
$$c = Y$$

$$b = G_1$$

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

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

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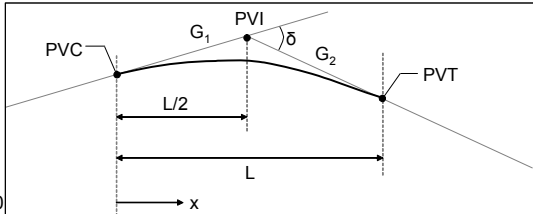


Relationships

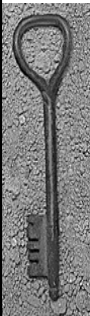
At the PVC: $x = 0$ and $Y = c$

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

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



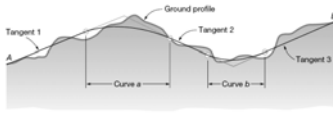
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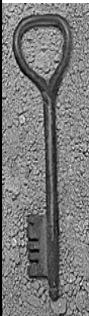
Factors to be Considered

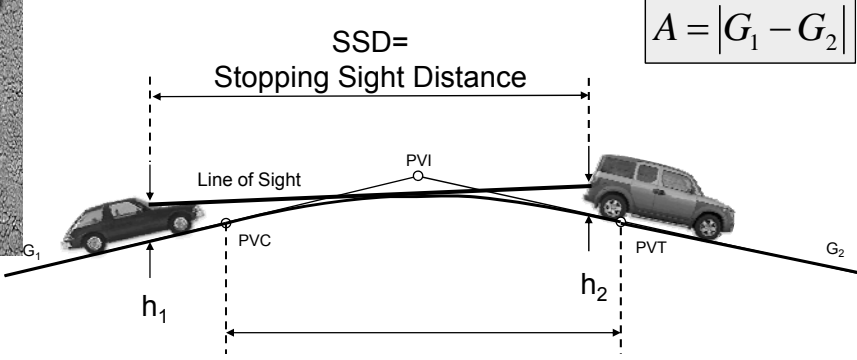
There are several factors that must be taken into account when designing a grade line of tangents and curves on any highway or railroad projects. They include:

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.



Crest Vertical Curves





$A = |G_1 - G_2|$

For $SSD < L$

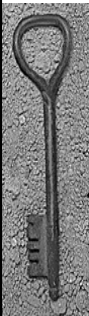
$$L = \frac{A(SSD)^2}{100(\sqrt{2h_1} + \sqrt{2h_2})^2}$$

For $SSD > L$

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

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Crest Vertical Curves



◆ Assumptions for design

- h_1 = driver's eye height = 3.5 ft.
- h_2 = tail light height = 2.0 ft.

$A = |G_1 - G_2|$

◆ Simplified Equations

For $SSD < L$

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

For $SSD > L$

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

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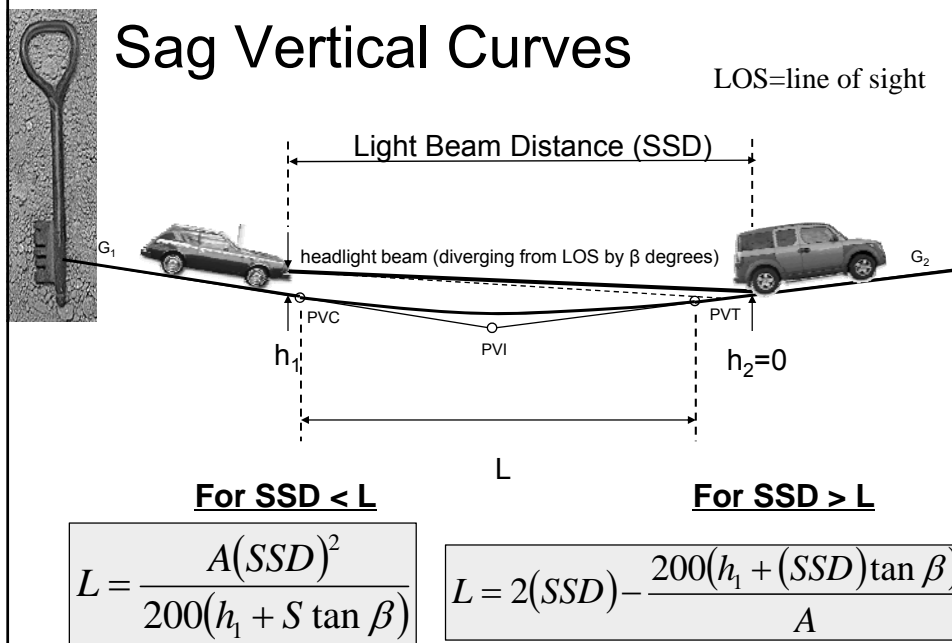
Design Controls for Crest Vertical Curves

Metric				US Customary			
Design speed (km/h)	Stopping sight distance (m)	Rate of vertical curvature, K ^a		Design speed (mph)	Stopping sight distance (ft)	Rate of vertical curvature, K ^a	
		Calculated	Design			Calculated	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). $K = L/A$

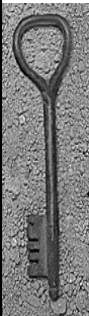
Tuesday, February 26, 2013 from AASHTO's *A Policy on Geometric Design of Highways and Streets 2004*

Sag Vertical Curves



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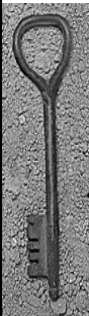


Sag Vertical Curves

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

<u>For $SSD < L$</u>	<u>For $SSD > L$</u>
$L = \frac{A(SSD)^2}{400 + 3.5(SSD)}$	$L = 2(SSD) - \left(\frac{400 + 3.5(SSD)}{A} \right)$

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Sag Vertical Curves

- ◆ Assuming $L > SSD$...

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

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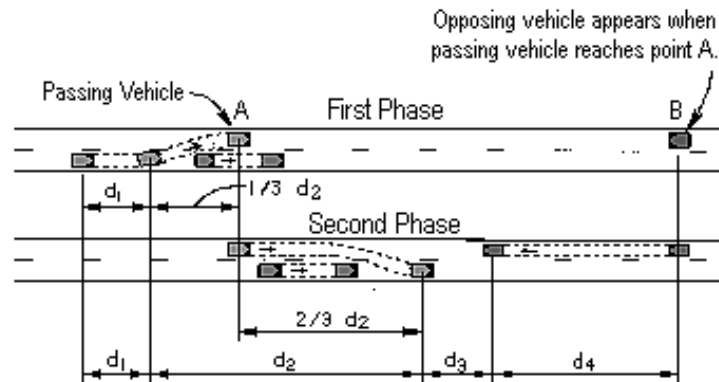
Design Controls for Sag Vertical Curves

Metric				US Customary			
Design speed (km/h)	Stopping sight distance (m)	Rate of vertical curvature, K^a		Design speed (mph)	Stopping sight distance (ft)	Rate of vertical curvature, K^a	
		Calculated	Design			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). $K = L/A$

Tuesday, February 26, 2013 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

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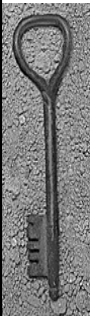
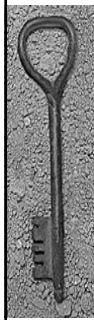


TABLE 6-2m Maximum Grades for Urban Arterials^a

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

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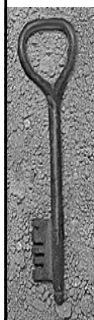


Design of Vertical Alignment of Road (Design speed is known and grades are known or decided by designers)

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

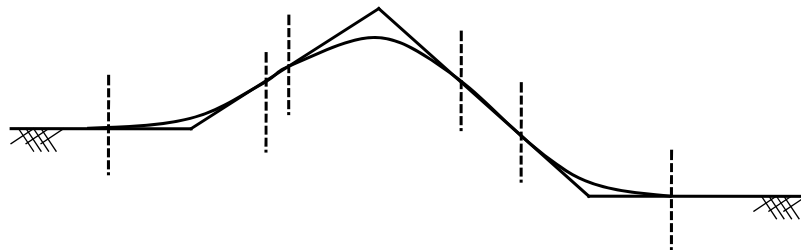
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Comments

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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