The Project for Improving Public Bus Service in Yangon

*****th Traffic Engineering Training**

Introduction of Road Alignment (2/2)
(Vertical Alignment)

XXXX,2020

Contents

0.Road Alignment

Road Alignment

Horizontal Alignment

- Horizontal Curve
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- Pavement Widening
- Sight Distance

Vertical Alignment

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  - Crest Curve
  - Sag Curve

0.Vertical Alignment

- The vertical alignment should provide at Natural Ground with various slops magnitudes.
- The vertical alignment should provide for a smooth consistent with the general topography.
- The vertical alignment includes:
  - Different Grades
  - Vertical Curve
- These are being influenced by the following factors:
  - Vehicle Speed
  - Sight Distance
  - Confortable deceleration/acceleration, etc

Source: https://theconstructor.org/

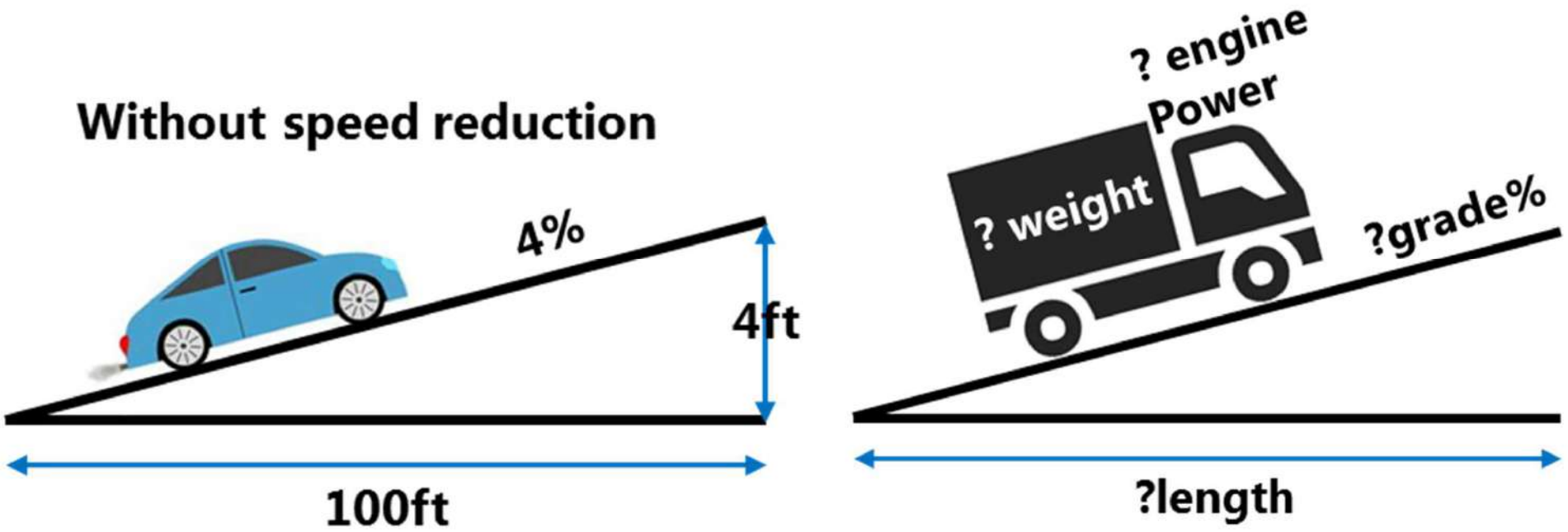
1. Grade

Grade

- **The grade of the road** is very important for the safety for road users. Most of us have experienced how a rolling bicycle has a tendency to pick up speed as it goes downhill, and how when going uphill the bicycle will slow down unless the cyclist pedals harder. The same situation must be considered when constructing modern highways.
- If a grade is too steep, vehicle operators must use excessive braking when going downhill. In contrast, vehicle operators going uphill will have to slow down severely, possibly affecting traffic flow adversely.

Vehicle Operation Characteristic on Grade

- **Passenger cars** can readily negotiate grades as steep as 4% to 5% without speed reduction.
- **Trucks:**
  - Effect on speed much more important
  - Maximum speed on upgrade is determined length and steepness of grade, and the truck's weight/power ratio (gross weight/engine power)



Control Grades for Design

❑ Maximum Grade:

- About **5%** for design speed of **110 kmp (70mph)**
- **7-12%** for **50kmh (30mph)**
- For other design speed, values should fall between these extremes.
- Can use **1% steeper** if **upgrade length is below 150m (500ft)**

*****Should be provided flatter grade. The maximum design grade should be used for the extreme cases.

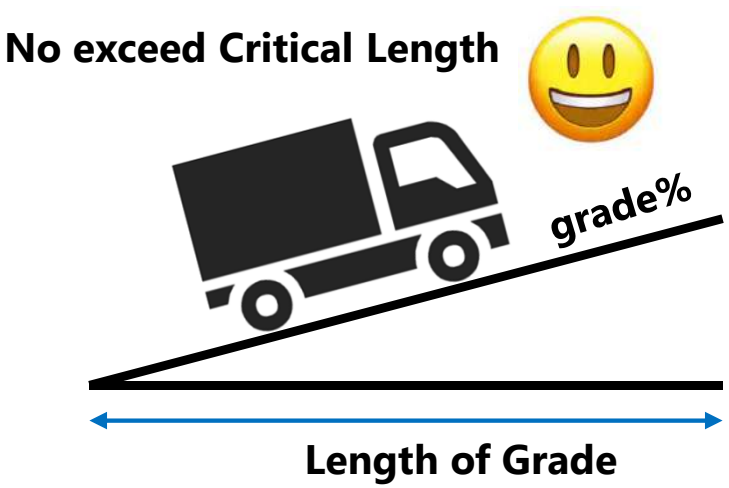
❑ Minimum Grade:

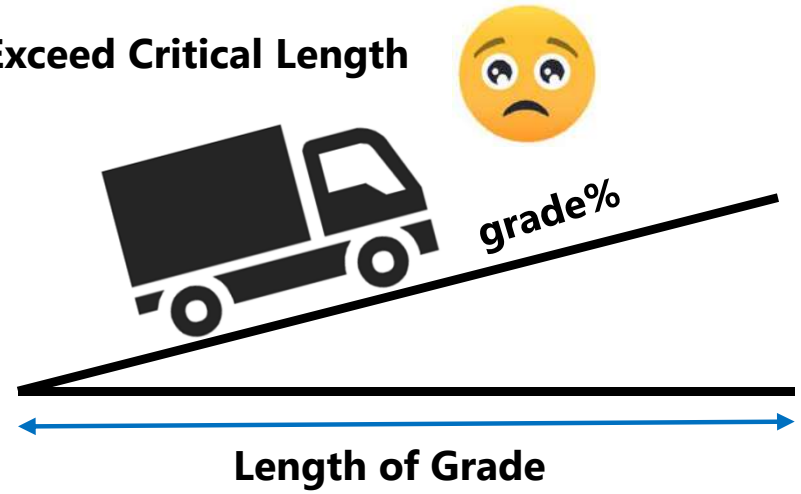
- The minimum grade is provided for drainage purpose.
- Typically 0.3% to 0.5% for high type pavement
- Particular Attention should be given to the design of storm water inlet and their spacing

Source :AASHTO

Critical Length of Grade

- Maximum grade itself is not a complete design control-length should be considered for desirable vehicle operation.
- To maintain design freedom of operation on grades longer than critical, design adjustment such as change in location to reduce grades or addition of extra lanes should be considered.
- **The critical length** is the maximum length of a designated on which a loaded truck can operate without an unreasonable reduction in speed.

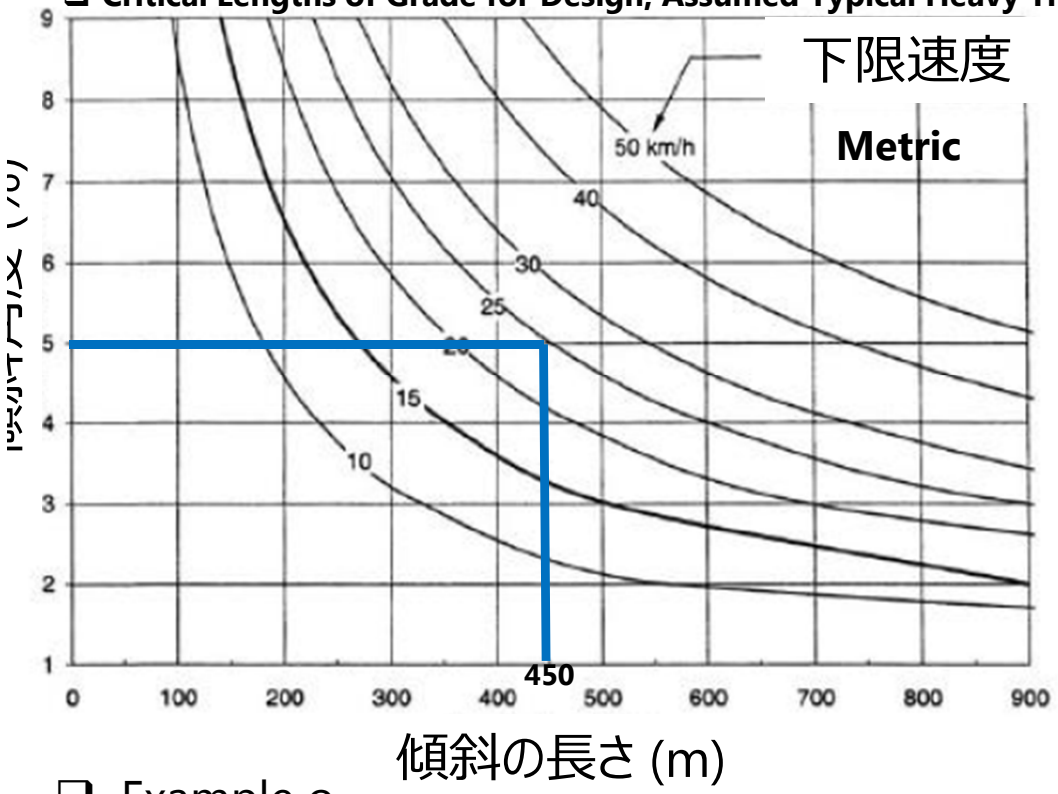


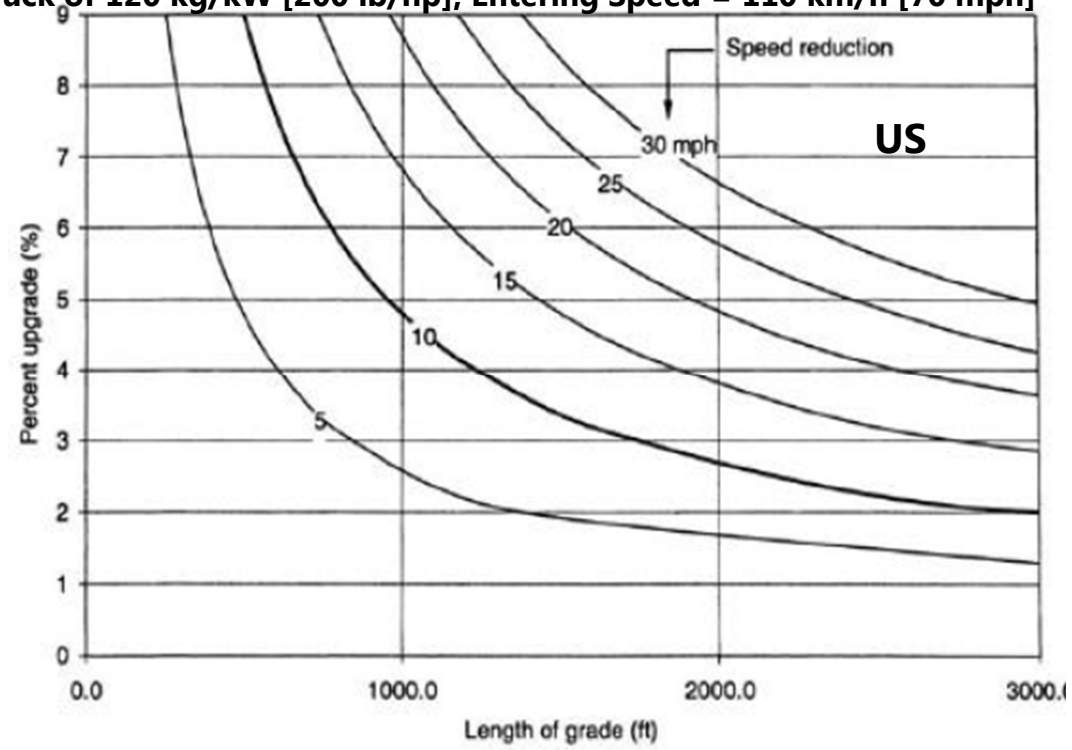


Source :AASHTO

Critical Length of Grade

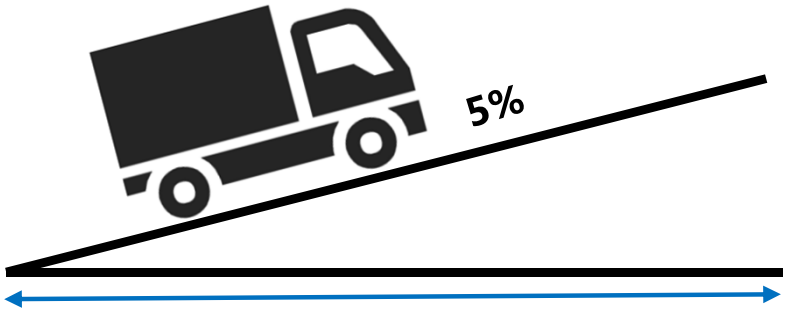
❑ **Critical Lengths of Grade for Design, Assumed Typical Heavy Truck of 120 kg/kW [200 lb/hp], Entering Speed = 110 km/h [70 mph]**





❑ Example of Critical Length

Average Running Speed of Typical Truck	100km/hr
Up Grade %	5%
Speed Reduction Limit	25km/hr
Critical Length of Grade	???



Critical Length of Grade = 450 m

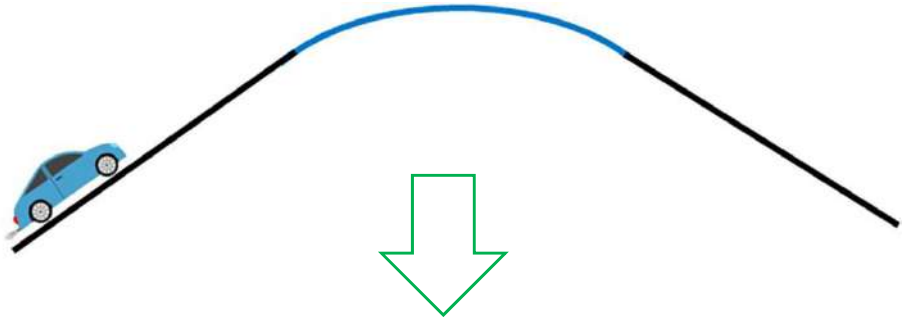
Source :AASHTO

2. Vertical Curve

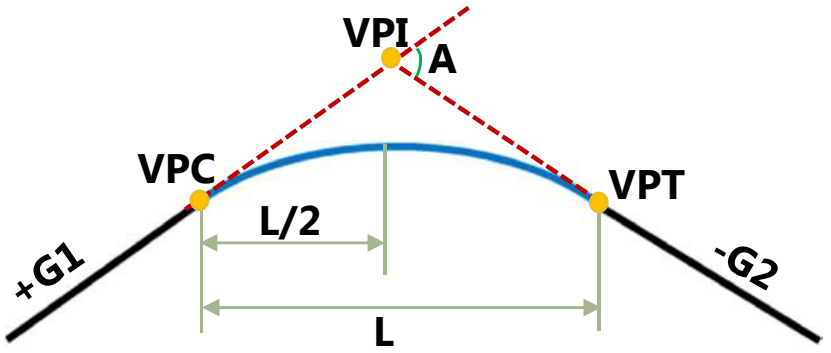
Vertical Curve

- The vertical curve is a parabolic curve that is applied to make a smooth and safe transition between two grades on a roadway or a highway.
- The vertical curves are applied for the following purpose:
  - To intersect (join) the two slopes on the roadway.
  - To provide a safe and comfort ride for vehicles on the roadway.
- There are two kinds of vertical curves:

i. Crest Curve (Summit Curve)
ii. Sag Curve (Valley Curve)



VPC = Vertical Point of Curvature
VPT = Vertical Point of Tangency
VPI = Vertical Point of Intersection
G1, G2 = Tangent Grade in %
A = Algebraic difference in grades (G1-G2)
L = Length of Vertical Curve

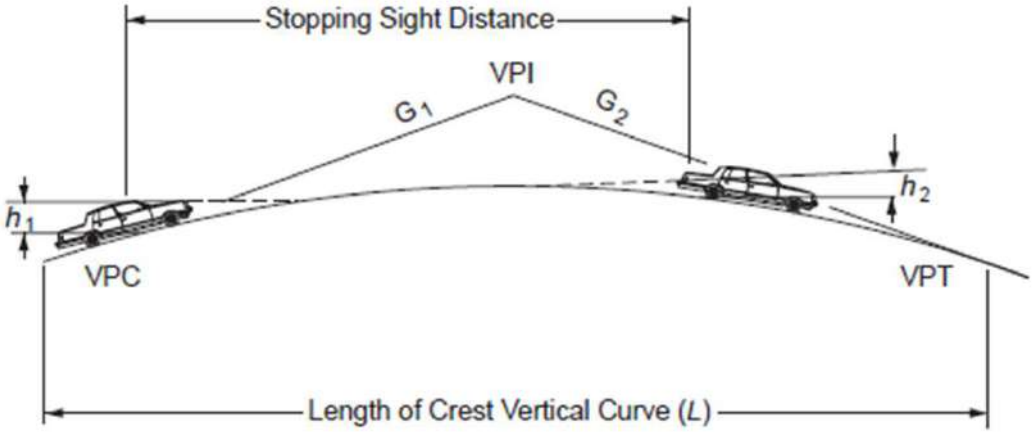


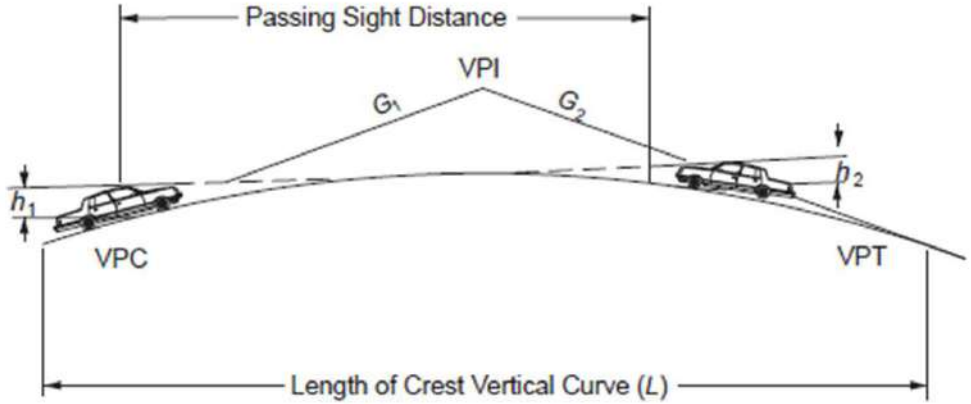
2.1 Crest Curve (Summit Curve)

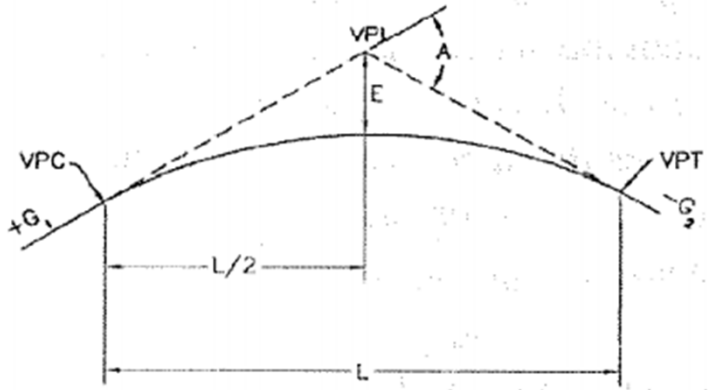
Crest Curve (Summit Curve)

- Minimum length of a crest vertical curve needs to satisfy the safety, comfort, and appearance criteria.
- Minimum length of a crest vertical curve is equal 3V ft (0.6V m) the design speed.
- To determine the length of curve based on the following parameters

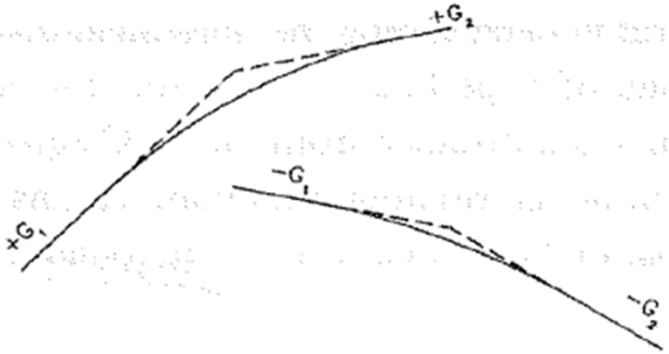
1) Stopping Sight Distance
2) Passing Sight Distance (use infrequently)







TYPE I



TYPE II

Source :AASHTO

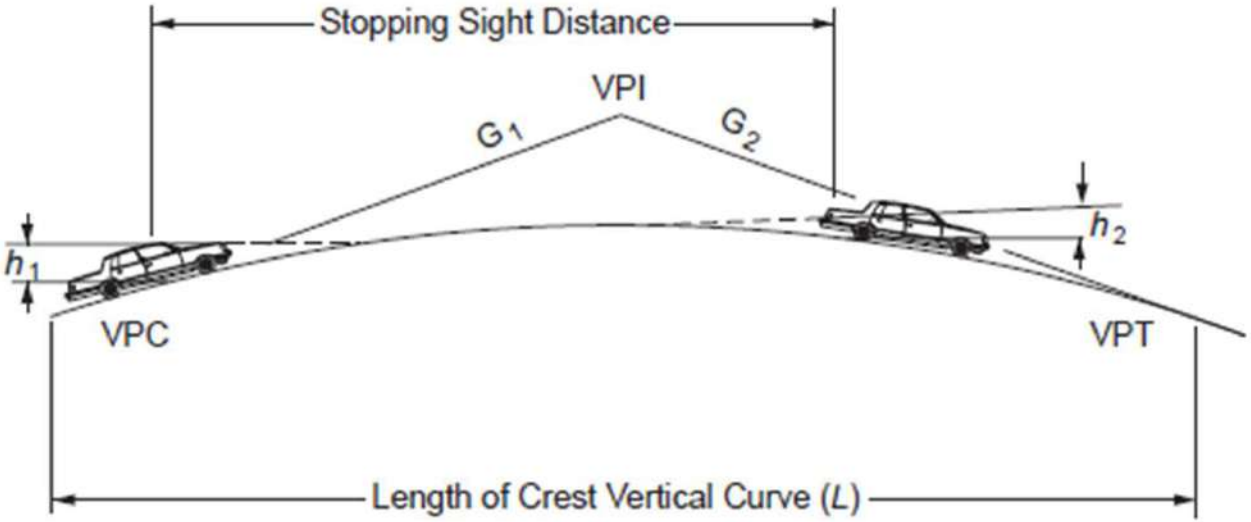
CREST VERTICAL CURVES

Crest Curve Length Basic Formula by Stopping Sight Distance

- When the height of eye and the height of object are 1.08 and 0.60 m [3.50 ft and 2.00 ft], respectively, as used for stopping sight distance, the equations become:

Metric	US Customary
When S is less than L, $L = \frac{AS^2}{658}$	When S is less than L, $L = \frac{AS^2}{2158}$
When S is greater than L, $L = 2S - \frac{658}{A}$	When S is greater than L, $L = 2S - \frac{2158}{A}$

L= length of Curve
A= Algebraic difference in grades (G1-G2)
S= Stopping Sight Distance



Source :AASHTO

- These equations are often used to check the design speed of an existing vertical curve.
- **K values are preferred to be used when design a new vertical curve because it provides a better safety distance.**

K-Value

- The horizontal distance in feet (meters) needed to make 1% change in gradient.
- K value is applied
  - To determine the minimum length of vertical curve.
  - To determine the horizontal distance from the VPC to the high point of Type I or Low point of Type III.
- K values can also be used when S > L because there is no significant error between S>L and S<L.

$$K = L/A$$

Where, L= length of curve

A=Algebraic difference in grades (G1-G2)

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

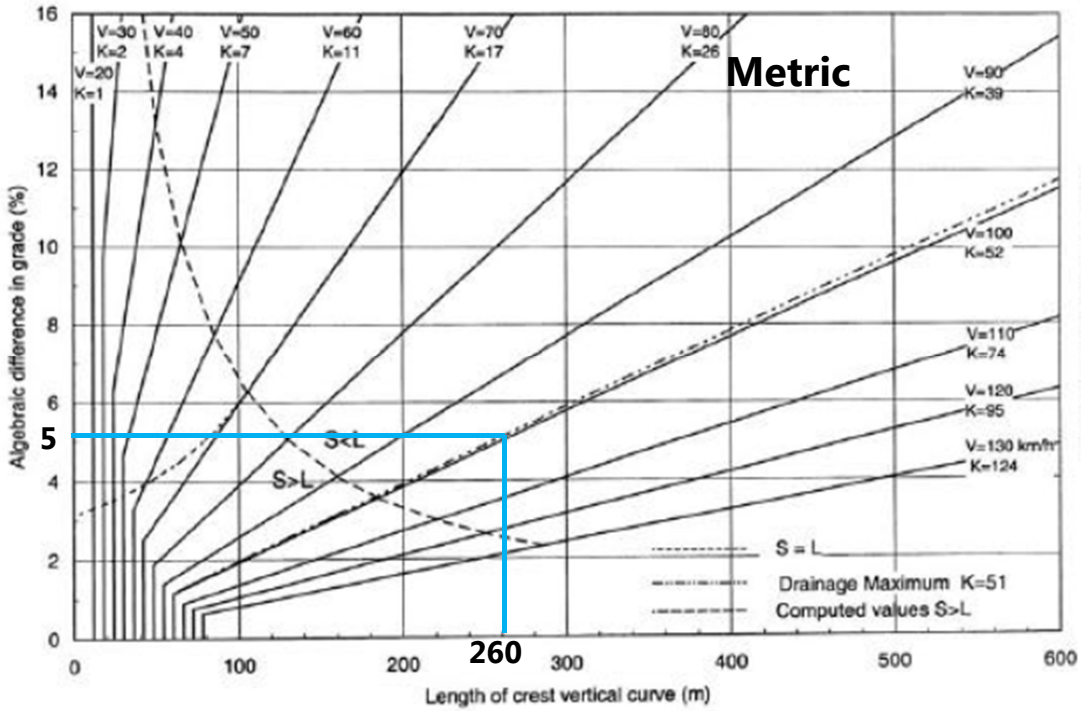
[a] Rate of vertical curvature, K, is the length of curve per percent algebraic difference in intersecting grades (A). K = L/A

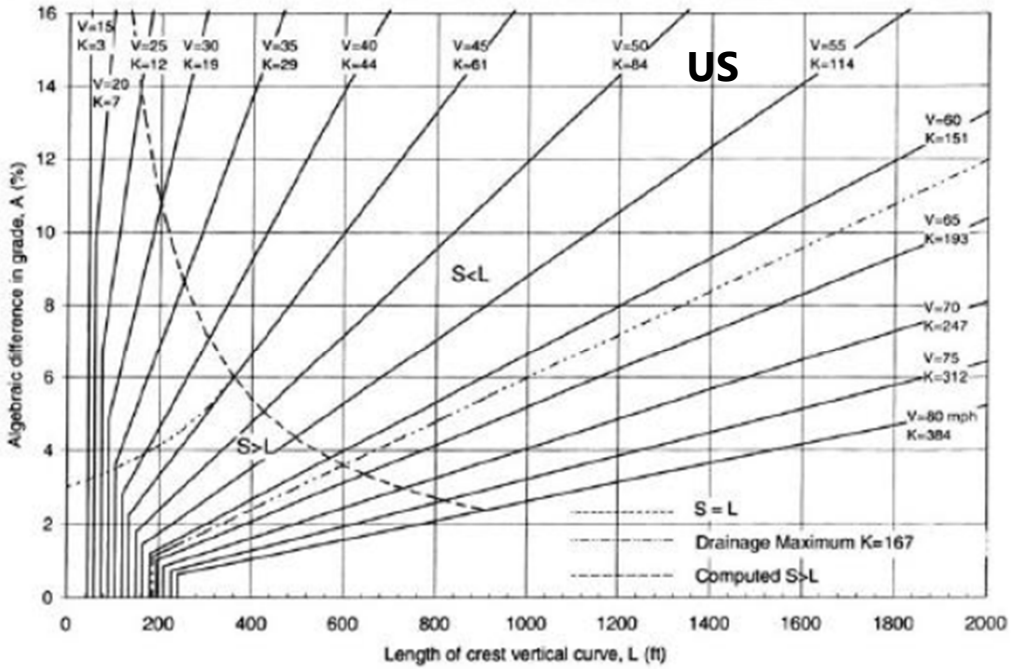
Source :AASHTO

Design Controls for Crest Vertical Curves Based on Stopping Sight Distance

K-Value and Example Question of Length of Crest Curve

❑ Design Controls for Crest Vertical Curves—Open Road Conditions





❑ Example of Crest Curve Length

Design Speed	100km/hr
Up Grade % (G1)	3%
Down Grade % (G2)	-2%
Min design Length of curve	???

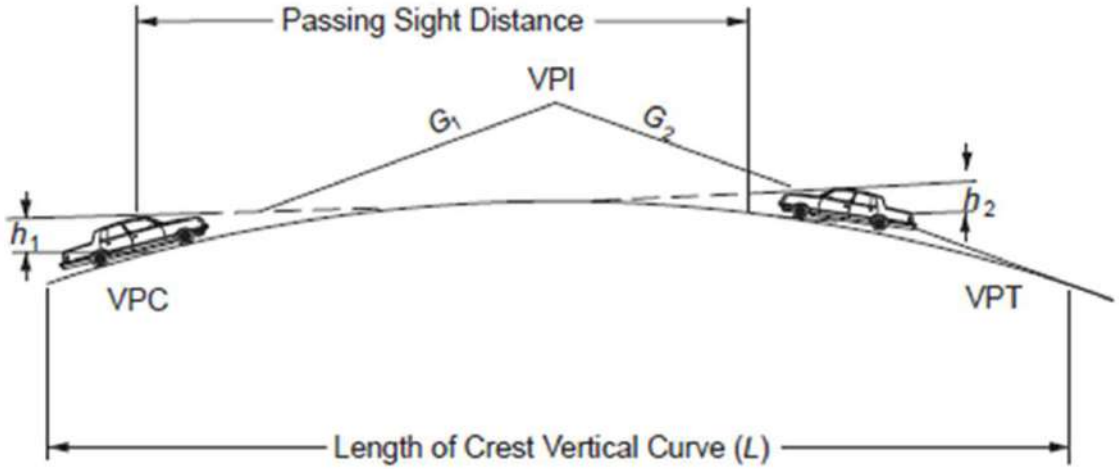
K=L/A, L=K*A, A=3-(-2)=5
K=52 m (see previous slide)
L=52*5=260m or
By using above table
L=260m

Source :AASHTO

Crest Curve Length Basic Formula by Passing Sight Distance

- Generally, it is impractical to design crest curves to provide for Passing Sight Distance because of high cost and difficulty for fitting long curve in terrain.
- When the height of eye and the height of object are 1.08 and 0.60 m [3.50 ft and 2.00 ft], respectively, as used for passing sight distance, the equations become:

Metric	US Customary
When S is less than L, $L = \frac{AS^2}{864}$	When S is less than L, $L = \frac{AS^2}{2800}$
When S is greater than L, $L = 2S - \frac{864}{A}$	When S is greater than L, $L = 2S - \frac{2800}{A}$



L= length of Curve
A= Algebraic difference in grades (G1-G2)
S= Passing Sight Distance

- These equations are often used to check the design speed of an existing vertical curve.
- **K values are preferred to be used when design a new vertical curve because it provides a better safety distance.**

Source :AASHTO

K-Value

- The horizontal distance in feet (meters) needed to make 1% change in gradient.
- K value is applied
  - To determine the minimum length of vertical curve.
  - To determine the horizontal distance from the VPC to the high point of Type I or Low point of Type III.
- K values can also be used when S > L because there is no significant error between S>L and S<L.
- The length of curve can be estimated by using the following table and graphs in slide 17

$$K = L/A$$

Where, L= length of curve

A=Algebraic difference in grades (G1-G2)

Metric			US Customary		
Design speed (km/h)	Passing sight distance (m)	Rate of vertical curvature, K* design	Design speed (mph)	Passing sight distance (ft)	Rate of vertical curvature, K* design
30	200	46	20	710	180
40	270	84	25	900	289
50	345	138	30	1090	424
60	410	195	35	1280	585
70	485	272	40	1470	772
80	540	338	45	1625	943
90	615	438	50	1835	1203
100	670	520	55	1985	1407
110	730	617	60	2135	1628
120	775	695	65	2285	1865
130	815	769	70	2480	2197
			75	2580	2377
			80	2680	2565

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

Design Controls for Crest Vertical Curves Based on Passing Sight Distance

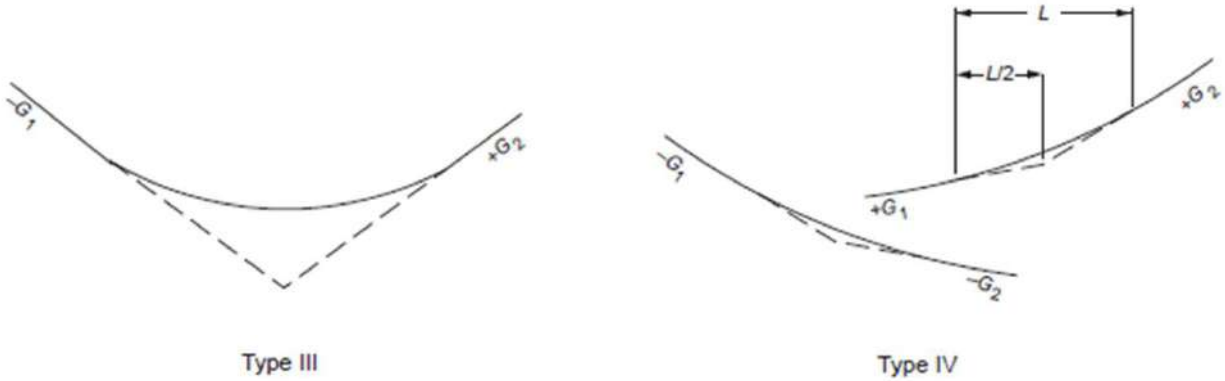
Source :AASHTO

2.2 Sag Curve (Valley Curve)

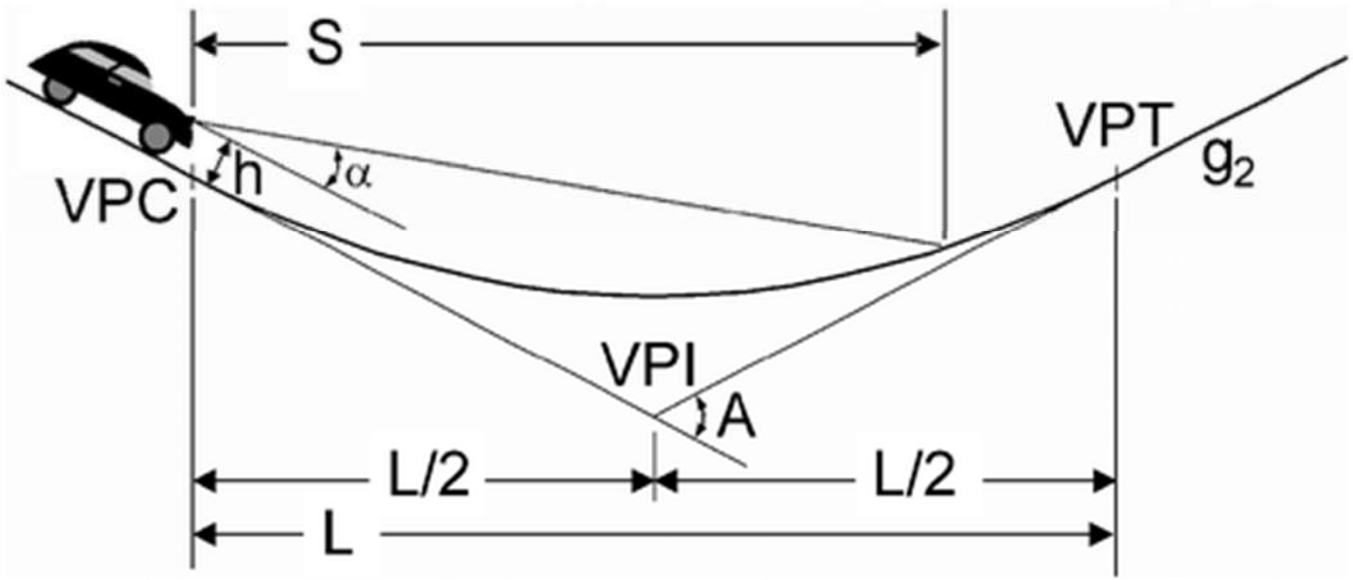
Sag Curve (Valley Curve)

- At least four different criteria for establishing lengths of sag vertical curves are recognized to some extent.

1) Headlight sight distance
2) Passenger comfort
3) Drainage control
4) General Appearance



Sag Vertical Curves



Source :AASHTO

Sag Curve Length Basic Formulas

❑ Headlight Distance

Metric S<L

$$L = \frac{AS^2}{120 + 3.5S}$$

US S<L

$$L = \frac{AS^2}{400 + 3.5S}$$

Metric S>L

$$L = 2S - \left(\frac{120 + 3.5S}{A}\right)$$

where:

L = length of sag vertical curve, m;
S = light beam distance, m;
A = algebraic difference in grades, percent

US S>L

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

where:

L = length of sag vertical curve, ft;
S = light beam distance, ft;
A = algebraic difference in grades, percent

❑ Passenger Comfort

Metric

$$L = \frac{AV^2}{395}$$

where:

L = length of sag vertical curve, m;
A = algebraic difference in grades, percent;
V = design speed, km/h

US

$$L = \frac{AV^2}{46.5}$$

where:

L = length of sag vertical curve, ft;
A = algebraic difference in grades, percent;
V = design speed, mph

*The head light sight distance needs to be designed almost equal to the stopping sight distance because of safety criterion. Therefore, stopping sight distance values can be use for S value in general equation. Therefore, **K values can be used to calculate the length of the curve.**

- ❑ Drainage of curbed roadways needs to retain a grade at least 0.5 percent or sometimes 0.3 percent for outer edges of the roadway.
- ❑ For General appearance, the minimum curve length can be calculated by equation L=100A for small or intermediate values of A.

Source :AASHTO

K-Value

- The horizontal distance in feet (meters) needed to make 1% change in gradient.
- K value is applied
- To determine the minimum length of vertical curve.
- To determine the horizontal distance from the VPC to the high point of Type I or Low point of Type III.

$$K = L/A$$

Where, L= length of curve

A=Algebraic difference in grades (G1-G2)

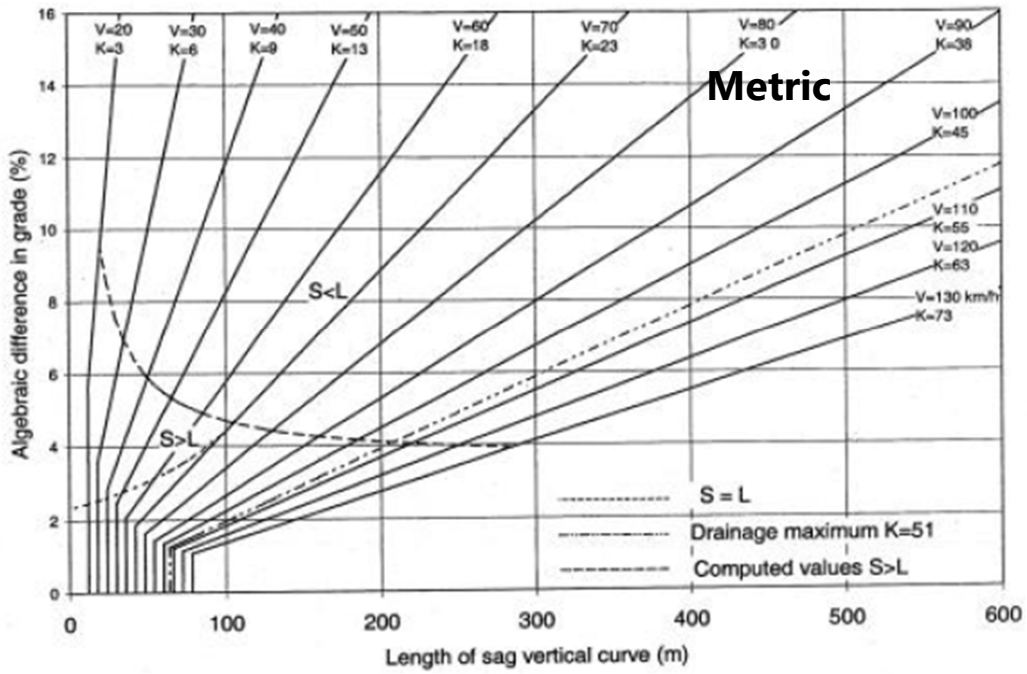
Metric				US Customary			
Design speed (km/h)	Stopping sight distance (m)	Rate of vertical curvature, K[a]		Design speed (mph)	Stopping sight distance (ft)	Rate of vertical curvature, K[a]	
		Calculated	Design			Calculated	Design
20	20	2.1	3	15	80	9.4	10
30	35	5.1	6	20	115	16.5	17
40	50	8.5	9	25	155	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

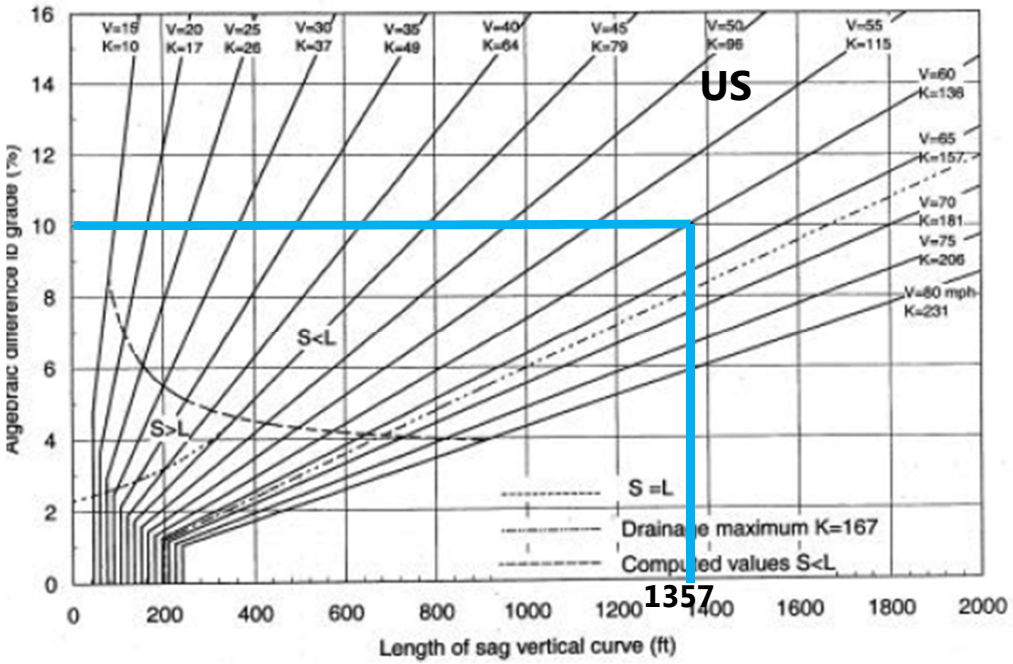
[a] Rate of vertical curvature, K, is the length of curve (m) per percent algebraic difference intersecting grades (A). K = L/A

Source :AASHTO

K-Value and Example Question of Length of Crest Curve

❑ Design Controls for Sag Curve





❑ Example of Crest Curve Length

Design Speed	60mil/hr
A	10%
Stopping Sight Disance	570 ft
Assume (S<L)	
Min design Length of curve	???

Source :AASHTO

By using Headlight Formula

$L = 10x570^2/(400+(3.5x570)=1357$ ft

Checking Passenger Comfort

By Using Pax Comfort Formla

$L= 10x60^2/46.5=774$ft < 1357ft OK

By using above table

L=1357 ft

Sag Curve Length Basic Formulas at Undercrossing

- Sight distance on the highway through a grade separation should be at least as long as the minimum stopping sight distance and preferably longer.
- Design of the vertical alignment is the same as at any other point on the highway except in some cases of sag vertical curves underpassing a structure.

Sight distance greater than length of vertical curve (S>L)

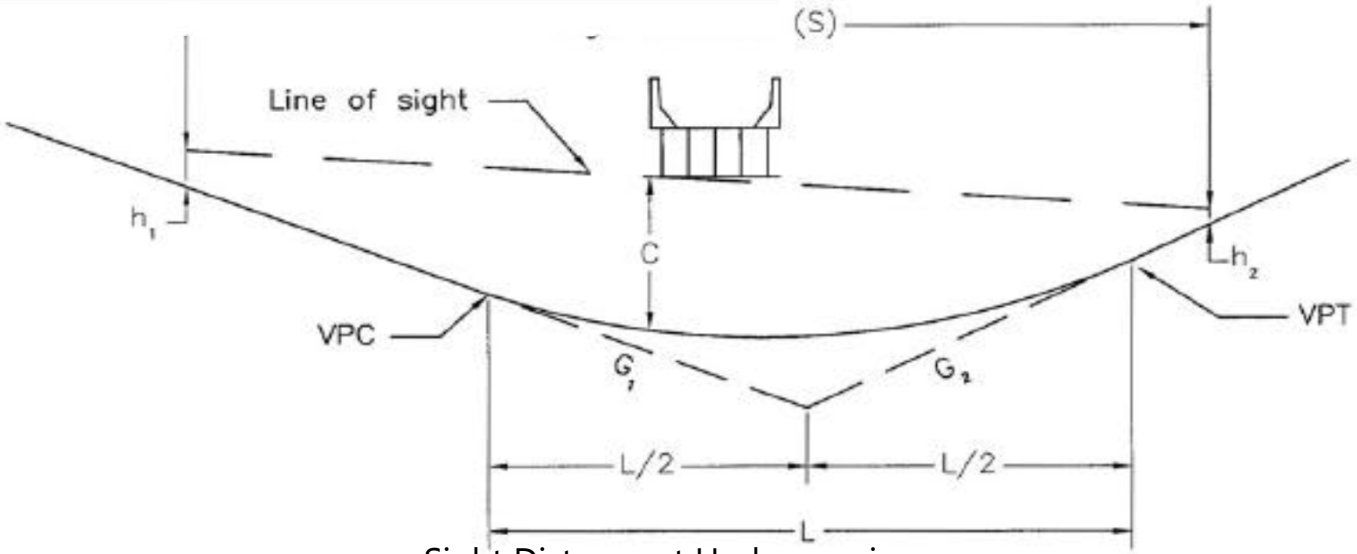
Metric	US Customary
$L = 2S - \left(\frac{800(C-1.5)}{A}\right)$	$L = 2S - \left(\frac{800(C-5)}{A}\right)$

Sight distance less than length of vertical curve (S<L)

Metric	US Customary
$L = \frac{AS^2}{800(C-1.5)}$	$L = \frac{AS^2}{800(C-5)}$

where:

L = length of vertical curve, ft;
S = sight distance, ft;
A = algebraic difference in grades, percent;
C = vertical clearance, ft;



Source :AASHTO

Sight Distance at Undercrossings

Other Design Consideration for Vertical Curve Design

- Paying more attention to the drainage design when value of K >167ft (51m)
- The length of vertical curve can be computed by using K values in both crest and sag vertical curves.
- The “roller-coaster” or the “hidden up” type of profile should be avoided.
- Two vertical curves in the same direction separated by a short section of tangent grade should be avoided.
- On long grades, the steepest grades should be placed at the bottom of the curve and flatten the grades near the top of ascent.
- It is desirable to reduce the grade through the intersection where at-grade intersection occur on roadway sections with moderate to steep grades.
- Sag vertical curves should be avoided in cuts unless adequate drainage can be provided.
- The stopping sight distance for trucks is not necessary to be considered in designing vertical because the truck driver able to see farther than passenger car. For that reason, the stopping sight distance for trucks and passenger cars is balance.
- Most of cases the stopping sight distance will be used for vertical design length, but engineering judgments also get involve in decision making