Sight Distance on Vertical Curves

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Stopping sight distance is an important factor in vertical curve design (Section 2B-1 of this manual provides more information regarding vertical curves and Section 6D-1 of this manual provides more information regarding stopping sight distance). The crest of a crest vertical obscures objects on the other side of the curve, as can be seen in Figure 1. Thus, crest curves must be designed to ensure the crest does not interfere with stopping sight distance.

Headlight sight distance is the controlling factor in sag vertical curves, though stopping sight distance is used in the actual design of a sag vertical curve. Related to sag curves is the issue of undercrossings. Structures placed over a roadway, especially a two-lane roadway, in an area of a sag curve can obscure objects on the other side of the curve. The vertical clearance of structures over a roadway in a sag curve must allow for adequate stopping sight distance.

Definition of "K"

Along equally spaced successive points of a vertical curve, the rate of change of grade is the same and is calculated as A/L, where A is the algebraic difference between grades and L is the length of the curve. The reciprocal, L/A, is the horizontal distance required to produce a one percent change in gradient. The quantity L/A, defined as K, is a measure of curvature. Expressed algebraically, K=L/A. The value of K is helpful in determining desirable lengths of vertical curves for various design speeds. Once the algebraic difference between grades is known, the designer can use K values provided in this section or in Section 1C-1 to determine the desirable length for a vertical curve. The example below demonstrates how K is used to determine the desirable length for a curve.

Example

A crest vertical curve is used to join two tangent sections of a rural expressway (see Figure 1 on the next page): g1 is +2.7% and g2 is –2.3%. Determine the desirable length that should be used for this curve.

First determine A:

$A = +2.7\% - (-2.3\%) = 5.0\%$

Using the table in Section 1C-1 for Expressways and looking under the column for Rural, the desirable K value for a crest vertical curve is 405 for English units or 120 for metric units.

Now solve for L, the desirable length of the curve:

$L = K \times A = 405 \times 5 = 2025$ feet, or

$L = 120 \times 5 = 600$ meters.

Crest Vertical Curves

Figure 1 illustrates the parameters used to determine the length of a vertical curve required to provide any specified value of sight distance required.

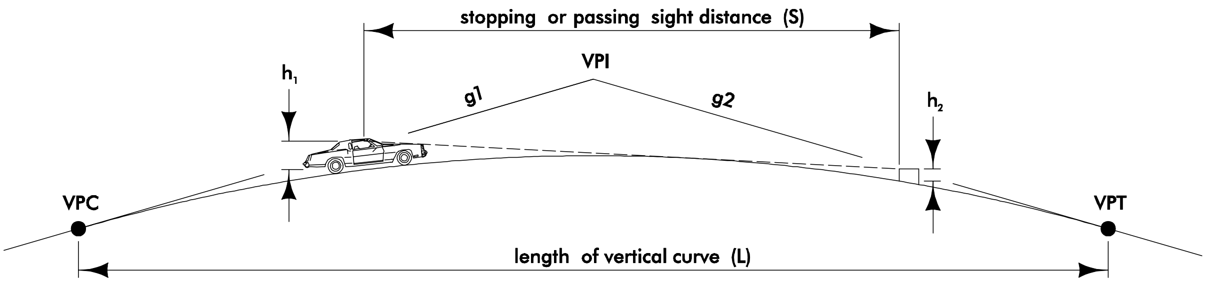

Figure 1: Parameters used to determine length of vertical curve.

where:

L = length of vertical curve in feet (meters)

S = stopping sight distance in feet (meters)

A = algebraic difference in grades in percent

h_1 = height of eye above roadway surface in feet (meters)

h_2 = height of object above roadway surface in feet (meters)

The general equations below provide the relationships between the parameters in Figure 1 for crest vertical curves.

$$L = \frac{AS^2}{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2} \qquad \text{if S<L}$$

$$L = 2S - \frac{200\left(\sqrt{h_1} + \sqrt{h_2}\right)^2}{A} \qquad \text{if L<S}$$

Stopping Sight Distance

With the height of the eye of the driver (h_1) set at 3.5 feet (1080 millimeters) and the height of the object (h_2) set at 6 inches (150 millimeters), the general equations simplify to:

$$L = \frac{AS^2}{1329} \text{ English units} \qquad L = \frac{AS^2}{407} \text{ metric units} \qquad \text{if S<L}$$

$$L = 2S - \frac{1329}{A} \text{ English units} \qquad L = 2S - \frac{407}{A} \text{ metric units} \qquad \text{if L<S}$$

where L, S, and A are as described before.

Table 1 provides desirable K values for stopping sight distance on crest vertical curves for various design speeds. See Section 6D-1 of this manual for more information regarding stopping sight distance. Desirable K values should be provided on all Iowa DOT projects. For situations when it is not possible to use desirable K values, K values found in Exhibit 3-76 of the 2001 AASHTO Greenbook may be used. The designer should contact the Geometric Design squad in the Methods Section in the Office of Design when considering K values between desirable and AASHTO values. Vertical crest curves with K values less than those provided in Table 1 must have the approval of the Section Engineer and/or Project Management Team (PMT). The Project

Engineer is responsible for documenting PMT approval. The use of K values less than AASHTO values is not acceptable.

Table 1: Desirable K Values for Stopping Sight Distance.

English units

design speed (mph)	stopping sight distance (ft.)	K_{des}
30	200	35
35	250	50
40	305	70
45	360	100
50	425	140
55	495	185
60	570	245
65	645	315
70	730	405

metric units

design speed (km/h)	stopping sight distance (m)	K_{des}
50	65	15
60	85	20
70	105	30
80	130	45
90	160	65
100	185	85
110	220	120

Drainage Considerations

When portions of a crest vertical curve on a curbed roadway have longitudinal grades of less than 0.3%, drainage may be a concern. If the length of this "flat" portion of the crest is less than 100 feet (30 meters), drainage should not be a problem. K values of 167 or less for English units or 51 or less in metric units will result in the "flat" portion of the crest being less than 100 feet (30 meters). K values greater than 167 for English units or 51 for metric units don't necessarily need to be avoided in such situations; rather, the designer must examine the drainage more carefully to ensure problems will not develop.

Passing Sight Distance

The same general equations given previously apply for passing sight distance. Section 6D-3 of this manual provides more information regarding passing sight distance. The object height (h_2) is set at 3.5 feet to represent an approaching driver's eye level. The general equations simplify to:

$$L = \frac{AS^2}{2800} \text{ English units} \qquad L = \frac{AS^2}{864} \text{ metric units} \qquad \text{if } S<L$$

$$L = 2S - \frac{2800}{A} \text{ English units} \qquad L = 2S - \frac{864}{A} \text{ metric units} \qquad \text{if } L<S$$

where L, S, and A are as described before.

Table 2 provides K values for passing sight distance on crest vertical curves for various design speeds. The high K values in Table 2 demonstrate how flat vertical curves need to be to provide passing sight distance. Typically, vertical curves are not designed for provide for passing sight distance because of the cut required to design the curve.

Table 2: K Values for Passing Sight Distance

English units

design speed (mph)	passing sight distance (ft.)	K
30	1090	424
35	1280	585
40	1470	772
45	1625	943
50	1835	1203
55	1985	1407
60	2135	1628
65	2285	1865
70	2480	2197

metric units

design speed (km/h)	passing sight distance (m)	K
50	345	138
60	410	195
70	485	272
80	540	338
90	615	438
100	670	520
110	730	617

Sag Vertical Curves

The four main controlling factors for determining sag vertical curve lengths are headlight sight distance, passenger comfort, drainage control, and appearance.

Headlight Sight Distance

A headlight height of two feet (600 millimeters) is assumed, as is a 1-degree upward angle of the headlight beam. With these assumptions the relationship between L, S, and A becomes:

$$L = \frac{AS^2}{400 + 3.5S} \quad \text{English units} \qquad L = \frac{AS^2}{120 + 3.5S} \quad \text{metric units} \qquad \text{if } S<L$$

$$L = 2S - \left(\frac{400 + 3.5S}{A}\right) \quad \text{English units} \qquad L = 2S - \left(\frac{120 + 3.5S}{A}\right) \quad \text{metric units} \qquad \text{if } L<S$$

where L, S, and A are as described before.

Table 3 on the next page provides K values based on stopping sight distances for various design speeds. Headlight and stopping sight distance are similar enough that K is based on stopping sight distance. The designer should consider using values greater than these whenever site conditions allow.

Table 3: K Values for Sag Vertical Curves.

English units

design speed (mph)	stopping sight distance (ft.)	K
30	200	37
35	250	49
40	305	64
45	360	79
50	425	96
55	495	115
60	570	136
65	645	157
70	730	181

metric units

design speed (km/h)	stopping sight distance (m)	K
50	65	13
60	85	18
70	105	23
80	130	30
90	160	38
100	185	45
110	220	55

Passenger Comfort

Riding comfort on sag curves typically doesn't become a problem as long as centripetal acceleration does not exceed 1 ft./s^2 (0.3 m/s^2). With this limit, the relationship between L and A becomes:

$$L = \frac{AV^2}{46.5} \quad \text{English units} \qquad L = \frac{AV^2}{395} \quad \text{metric units}$$

where L and A are as described before and V is the design speed in mph. Lengths needed to provide ride comfort are typically about half that needed to meet headlight sight distance requirements, thus headlight, and subsequently stopping, sight distance control the length of a sag curve.

Drainage

The same drainage criterion used for crest vertical curves on curbed roadways applies to sag vertical curves: K = 167 for English units and K = 51 metric units. As before, these should not be considered maximums but rather an area where drainage should be examined more closely, when design speeds of 70 mph (110 km/h) or more are used.

Appearance

The general controlling factor for appearance of a sag curve is K ≥ 100 for English units and K ≥ 30 for metric units for small to intermediate values of A, which corresponds to speeds of 50 mph (80 km/h) and greater. Thus, for design speeds less than 50 mph (80km/h) the designer will want to strongly consider using K values greater than presented in Tables 1 and 3 whenever site conditions allow. In general, the larger the K value, the better the appearance of a curve. The designer should always design a curve with the maximum K value site conditions will allow.

Undercrossings

Sight distance through undercrossings usually does not present a problem in the design of vertical curves. The vertical clearance of most overhead structures is such that stopping sight distance along the undercrossing roadway is easily met. The most common controlling factor is passing sight distance on a two-lane highway. Figure 2 shows the parameters involved with the sight distance at an undercrossing.

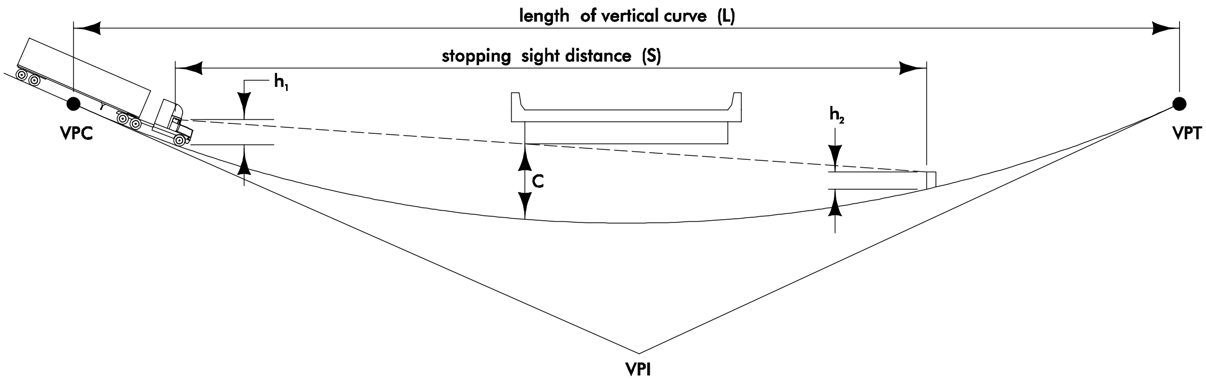

Figure 2: Sight distance at an undercrossing.

The equations for sag vertical curve length at an undercrossing are:

$$L = \frac{AS^2}{800\left(C - \frac{h_1 + h_2}{2}\right)} \qquad \text{if S<L}$$

$$L = 2S - \frac{800\left(C - \frac{h_1 + h_2}{2}\right)}{A} \qquad \text{if L<S}$$

where L, S, A, h_1, and h_2 are as described earlier in this section and C is the vertical clearance in feet (meters).

With the height of the eye of the driver set at 8 feet (2.4 meters) for a truck driver and the height of the object set at 6 inches (150 millimeters) for stopping sight distance, these equations simplify to:

$$L = \frac{AS^2}{800(C - 4.25)} \quad \text{English units} \qquad L = \frac{AS^2}{800(C - 1.1275)} \quad \text{metric units} \qquad \text{if S<L}$$

$$L = 2S - \frac{800(C - 4.25)}{A} \quad \text{English units} \qquad L = 2S - \frac{800(C - 1.275)}{A} \quad \text{metric units} \qquad \text{if L<S}$$

With the height of the eye of the driver set at 8 feet (2.4 meters) for a truck driver and the height of the object set at 3.5 feet (1080 millimeters) for passing sight distance, these equations simplify to:

$$L = \frac{AS^2}{800(C - 5.75)} \quad \text{English units} \qquad L = \frac{AS^2}{800(C - 1.740)} \quad \text{metric units} \qquad \text{if S<L}$$

$$L = 2S - \frac{800(C - 5.75)}{A} \quad \text{English units} \qquad L = 2S - \frac{800(C - 1.740)}{A} \quad \text{metric units} \qquad \text{if L<S}$$

Example

A bridge is being designed to pass over a rural two-lane highway with a design speed of 60 mph. The section of the two-lane highway where the bridge crosses over is a 1740 foot vertical sag curve with A = 3.15. The bridge clearance is 16.8 feet. Does adequate passing sight distance exist on the two-lane highway or does the bridge clearance need to be adjusted?

Start by assuming S<L and solve the appropriate equation for S

$$S = \sqrt{\frac{800L(C-5.75)}{A}} = 2{,}210 \text{ feet}$$

S is actually greater than L so solve the appropriate equation for S

$$S = \frac{L}{2} + \frac{400(C-5.75)}{A} = 2{,}273 \text{ feet}$$

Passing sight distance for a design speed of 60 mph is 2,135 feet, so adequate sight distance exists with a bridge clearance of 16.8 feet.

The same procedure is used for metric units.