Chapter 30

VERTICAL ALIGNMENT

BUREAU OF LOCAL ROADS AND STREETS MANUAL

Chapter 30
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Chapter 30
VERTICAL ALIGNMENT

Chapter 30 presents Bureau of Local Roads and Streets (BLRS) criteria for the design of vertical alignment elements. This includes vertical curvature and grades for both crest and sag vertical curves.

30-1 GRADES

30-1.01 Terrain

The topography throughout most of Illinois is considered either level or rolling. However, the northwest corner of the State, southern Illinois, and bluff areas near major rivers may be considered rugged. In general, if the terrain designation is not clear (e.g., level versus rolling), select the flatter of the two terrains.

30-1.02 Maximum Grades

Figures 32-3A, 32-3B, and 32-3C in Chapter 32 present the maximum grade criteria based on functional classification, urban/rural location, type of terrain, and design speed. In addition, the designer should consider the following guidelines:

1. Grades should be as flat as is consistent with the surrounding terrain.
2. Only use maximum grades where absolutely necessary. Where practical, use grades flatter than the maximum.
3. Where grades of 4.0% or steeper are required, take special care to prevent erosion on slopes and open drainage facilities.

30-1.03 Minimum Grades

The following provides the criteria for minimum grades:

1. Uncurbed Roadways. It is desirable to provide a longitudinal grade of approximately 0.5%. This allows for the possibility of alterations to the original pavement cross slope due to swell, consolidation, maintenance operations, or resurfacing. Longitudinal grades of 0.0% may be acceptable on some pavements that have adequate cross slopes. These locations typically occur where a highway traverses a wide flood plain. In these cases, check the flow lines of the outside ditches for adequate drainage.
2. Curbed Streets. The centerline profile of streets with curb and gutter should have a minimum longitudinal grade of 0.3%; however, 0.5% is desirable. On curbed facilities,

the longitudinal grade at the gutter line will have a significant impact on the pavement drainage characteristics (e.g., water encroaching on travel lanes, flow capture rates by grates). See Chapter 38 of the *BLRS Manual* and the *IDOT Drainage Manual* for more information on pavement drainage.

3. New Bridges. For bridges on new construction and reconstruction projects, desirably provide a minimum longitudinal grade of 0.5% across the bridge for structures with curbed cross sections, in order to prevent ponding on the bridge.

30-2 VERTICAL CURVE

30-2.01 Crest Vertical Curves

30-2.01(a) Basic Equations

Crest vertical curves are in the shape of a parabola. The basic equations for determining the minimum length of a crest vertical curve are:

$$L = \frac{AS^2}{200\left(\sqrt{h_1}+\sqrt{h_2}\right)^2} \qquad \text{(Equation 30-2.1)}$$

$$L = KA \qquad \text{(Equation 30-2.2)}$$

Where:

- L = length of vertical curve, ft (m)
- A = algebraic difference between the two tangent grades, %
- S = sight distance, ft (m)
- h_1 = height of eye above road surface, ft (m)
- h_2 = height of object above road surface, ft (m)
- K = horizontal distance needed to produce a 1.0% change in gradient, ft/% (m/%)

The length of a crest vertical curve will depend upon "A" for the specific curve and upon the selected sight distance, height of eye, and height of object. The calculated value should be rounded to the next highest 10 ft (10 m) increment.

30-2.01(b) Curve Lengths

The following discusses the application of K-values:

1. Vertical Point of Intersection (PVI). For crest vertical curves, it is acceptable to use an angle point (i.e., no vertical curve) for an algebraic difference of grade (Δ) of 0.6% or less.
2. Stopping Sight Distance (SSD). The principal control in the design of crest vertical curves is to ensure that SSD is available throughout the vertical curve. Figures 30-2A and 30-2B present the minimum K-values for passenger cars on a level grade by assuming h_1 = 3.5 ft (1.080 m), h_2 = 2 ft (600 mm), and S = SSD in the basic equation for crest vertical curves (Equation 30-2.1). These values represent the lowest acceptable sight distance on a facility. Where cost effective, use higher than minimum stopping sight distances.

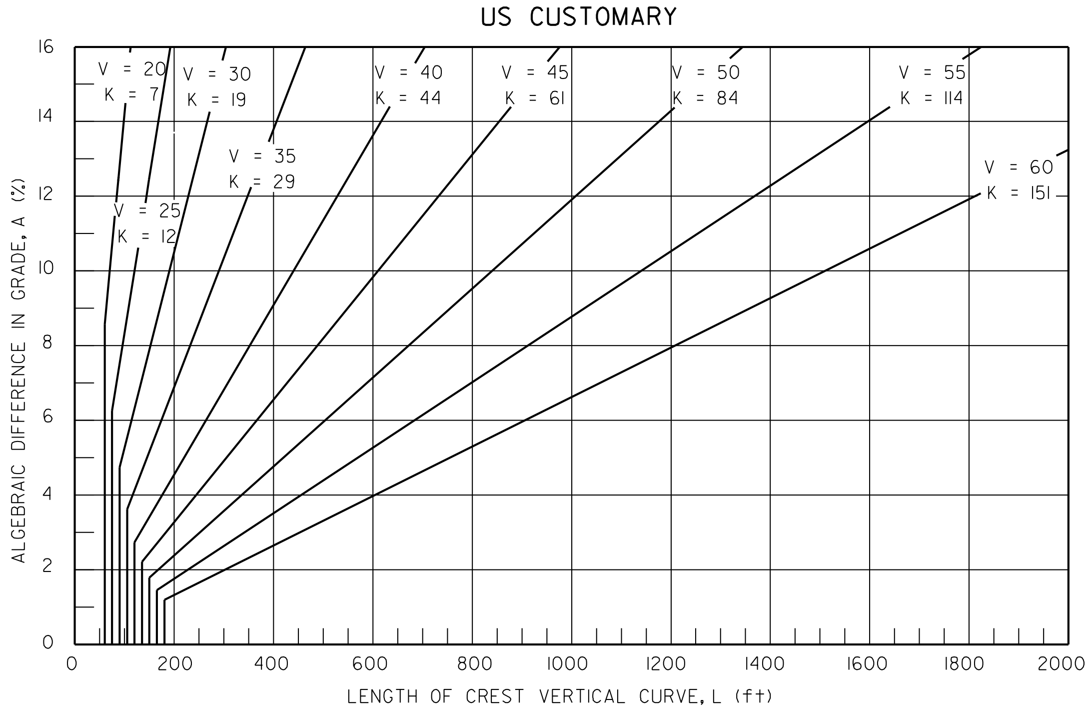
US Customary				Metric			
Design Speed (mph)	SSD[1] (ft)	Rate of Vertical Curvature, K[2][3] (ft/%)	Minimum Curve Length (ft)	Design Speed (km/h)	SSD[1] (m)	Rate of Vertical Curvature, K[2][4] (m/%)	Minimum Curve Length (m)
20	115	7	60	30	35	2	18
25	155	12	75	40	50	4	24
30	200	19	90	50	65	7	30
35	250	29	105	60	85	11	36
40	305	44	120	70	105	17	42
45	360	61	135	80	130	26	48
50	425	84	150	90	160	39	54
55	495	114	165	100	185	52	60
60	570	151	180				

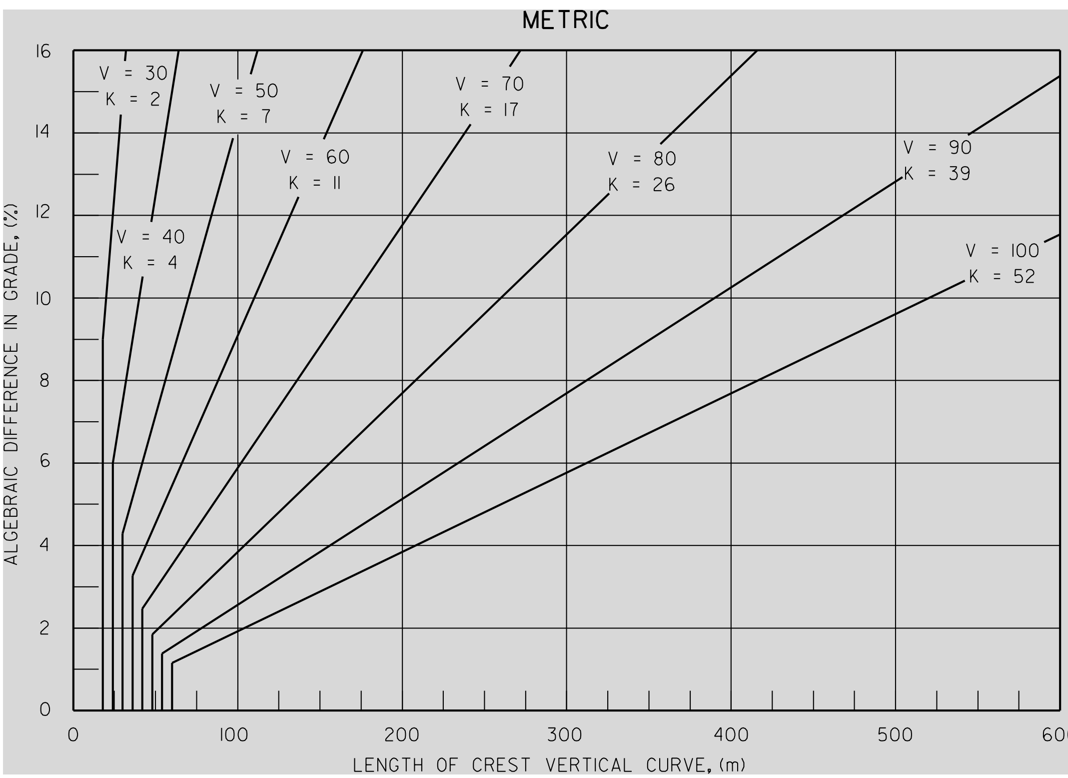
Notes:

1. *SSD values are from Figure 28-1A.*
2. *Maximum K-value for drainage on curbed roadways and bridges is 167 (51).*
3. $K = \frac{SSD^2}{2158}$, where : $h_1 = 3.5$ ft, $h_2 = 2$ ft
4. $K = \frac{SSD^2}{658}$, where : $h_1 = 1.080$ m, $h_2 = 600$ mm

K-VALUES FOR CREST VERTICAL CURVES — STOPPING SIGHT DISTANCES (Passenger Cars)

Figure 30-2A





DESIGN CONTROLS FOR CREST VERTICAL CURVES

Figure 30-2B

3. Minimum Length. Vertical curve lengths should also meet the criteria in the following equations:

$$L_{min} = 3V \quad \text{(US Customary) Equation 30-2.3}$$

$$L_{min} = 0.6V \quad \text{(Metric) Equation 30-2.3}$$

Where:

L_{min} = minimum length of vertical curve, ft (m)

V = design speed, mph (km/h)

Designs with vertical curve lengths of less than 90 ft (27 m) should be avoided, since these are difficult to construct.

4. Passing Sight Distance (PSD). At some locations, it may be desirable to provide PSD in the design of crest vertical curves. Section 28-2 discusses the application and design values for PSD on two-lane, two-way highways. These "PSD" values are used in the basic equation for crest vertical curves (Equation 30-2.1). The height of eye (h_1) is 3.5 ft (1.080 m) and the height of object (h_2) is 3.5 ft (1.080 m). Figure 30-2C presents the K-values for passenger cars using the PSD presented in Section 28-2.

5. Drainage. Proper drainage should be considered in the design of crest vertical curves where curbed sections are used. Typically, drainage problems should not be experienced if the vertical curvature is sharp enough so that a minimum longitudinal grade of at least 0.3% is reached at a point about 50 ft (15 m) from either side of the apex. To ensure that this objective is achieved, determine the length of the crest vertical curve assuming a K-value of 167 (51) or less. For crest vertical curves on a curbed section where this K-value is exceeded, carefully evaluate the drainage design near the apex.

6. Alignment Coordination. On rural facilities where crest vertical curves and horizontal curves occur at the same location, use the K-values in Figure 30-2A to ensure that the horizontal curve is visible as drivers approach the vertical curve.

4.

US Customary			Metric		
Design Speed (mph)	PSD[1] (ft)	Rate of Vertical Curvature, K[2] Design (ft/%)	Design Speed (km/h)	PSD[1] (m)	Rate of Vertical Curvature, K[3] Design (m/%)
20	710	180	30	200	46
25	900	289	40	270	84
30	1090	424	50	345	138
35	1280	585	60	410	195
40	1470	772	70	485	272
45	1625	943	80	540	338
50	1835	1203	90	615	438
55	1985	1407	100	670	520
60	2135	1628			

Notes:

1. *PSD values are from Section 28-2.*

2. $K = \frac{PSD^2}{2800}, \text{where} : h_1 = 3.5\ ft, h_2 = 3.5\ ft$

3. $K = \frac{PSD^2}{864}, \text{where} : h_1 = 1.080\ m, h_2 = 1.080\ m$

K-VALUES FOR CREST VERTICAL CURVES — PASSING SIGHT DISTANCES (Passenger Cars)

Figure 30-2C

30-2.02 Sag Vertical Curves

30-2.02(a) Basic Equations

Sag vertical curves are in the shape of a parabola. Typically, they are designed to allow the vehicular headlights to illuminate the roadway surface (i.e., the height of object = 0.0 ft (m)) for a given distance "S." The light beam from the headlights is assumed to have a 1° upward divergence from the longitudinal axis of the vehicle. These assumptions yield the following basic equations for determining the minimum length of sag vertical curves:

$$L = \frac{AS^2}{200\left[h_3 + S(\tan 1^\circ)\right]} = \frac{AS^2}{200h_3 + 3.5S} \quad \text{(Equation 30-2.4)}$$

$$L = KA \quad \text{(Equation 30-2.2)}$$

Where:

- L = length of vertical curve, ft (m)
- A = algebraic difference between the two tangent grades, %
- S = sight distance, ft (m)
- h_3 = height of headlights above pavement surface, ft (m)
- K = horizontal distance needed to produce a 1.0% change in gradient

The length of a sag vertical curve will depend upon "A" for the specific curve and upon the selected sight distance and headlight height. For design purposes, round the calculated length to the next highest 10 ft (10 m) increment.

30-2.02(b) Curve Lengths

The following discusses the application of K-values:

1. Vertical Point of Intersection (VPI). For sag vertical curves, it is acceptable to use an angle point (i.e., no vertical curve) up to an algebraic difference of grade (Δ) of 0.6% or less.
2. Stopping Sight Distance (SSD). The principal control in the design of sag vertical curves is to ensure that SSD is available for headlight illumination throughout the sag vertical curve. Figures 30-2D and 30-2E present K-values for passenger cars assuming h_3 = 2.0 ft (600 mm) and S = SSD in the basic equation for sag vertical curves (Equation 30-2.4). These values represent the lowest acceptable sight distance on a facility. However, the designer should strive to use longer than the minimum lengths of curves to provide a more aesthetically pleasing design.

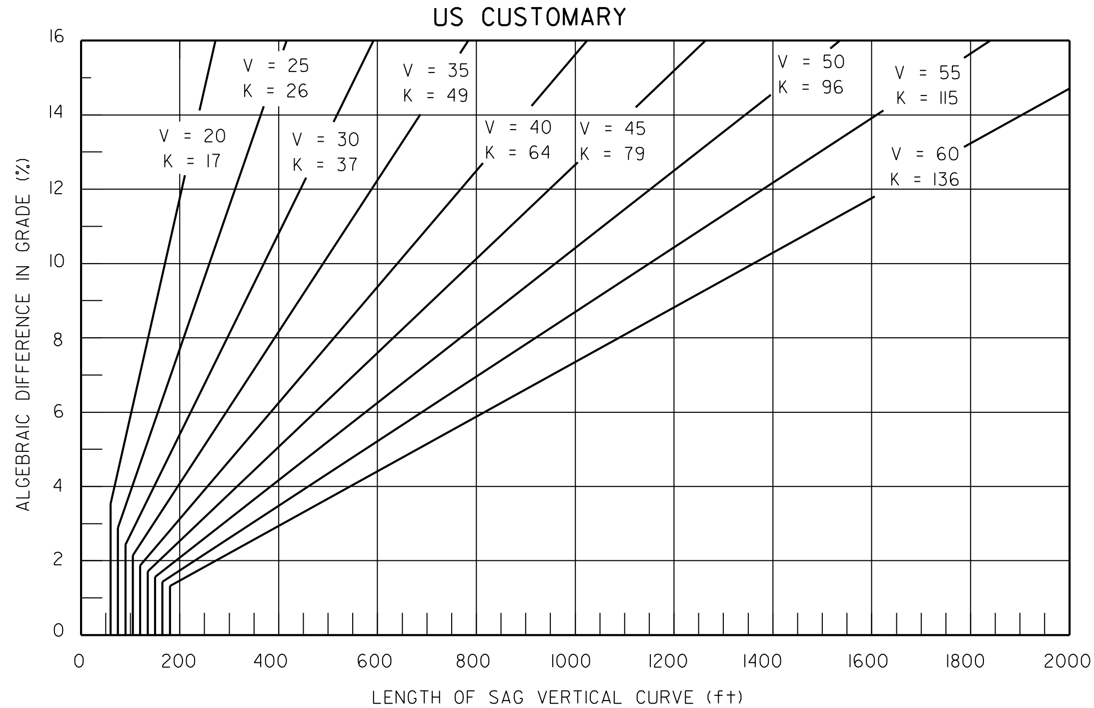
US Customary				Metric			
Design Speed (mph)	SSD[1] (ft)	Rate of Vertical Curvature, K [2][3] (ft/%)	Minimum Curve Length (ft)	Design Speed (km/h)	SSD[1] (m)	Rate of Vertical Curvature, K [2][4] (m/%)	Minimum Curve Length (m)
20	115	17	60	30	35	6	18
25	155	26	75	40	50	9	24
30	200	37	90	50	65	13	30
35	250	49	105	60	85	18	36
40	305	64	120	70	105	23	42
45	360	79	135	80	130	30	48
50	425	96	150	90	160	38	54
55	495	115	165	100	185	45	60
60	570	136	180				

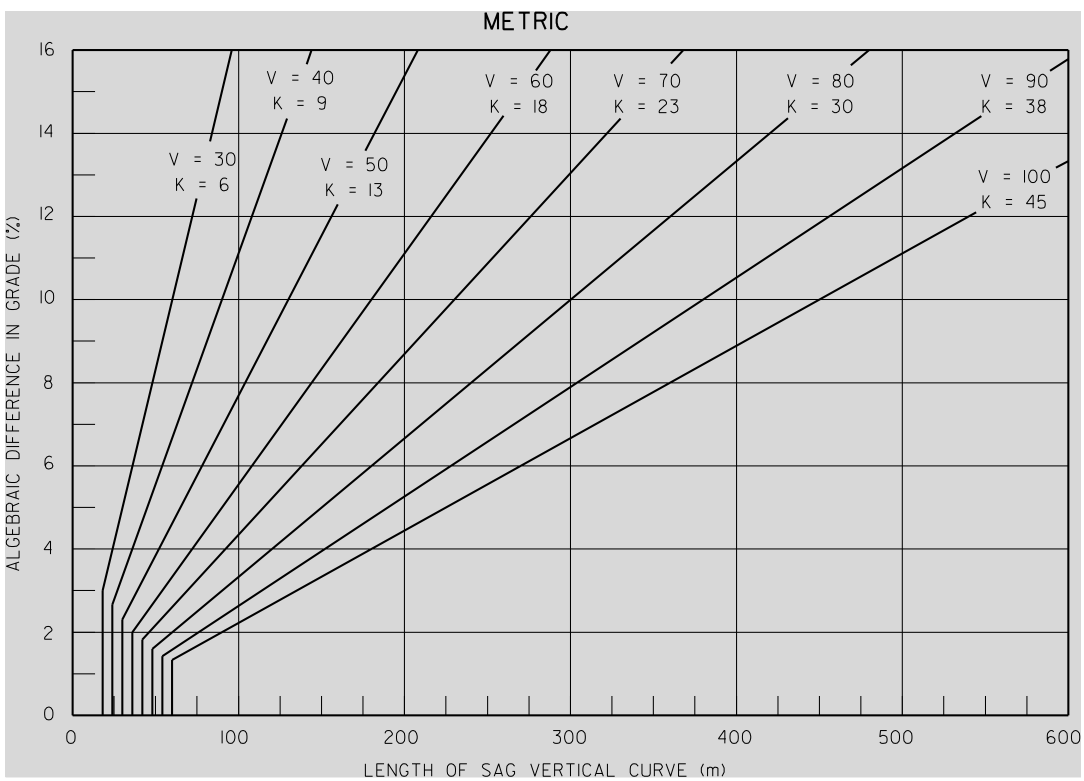
Notes:

1. *SSD values are from Figure 28-1A.*
2. *Maximum K-value for drainage on curbed roadways and bridges is 167 (51).*
3. $K = \frac{SSD^2}{400 + 3.5\ SSD}$, where : $h_3 = 2$ ft
4. $K = \frac{SSD^2}{120 + 3.5\ SSD}$, where : $h_3 = 600$ mm

K-VALUES FOR SAG VERTICAL CURVES — STOPPING SIGHT DISTANCES
(Passenger Cars)

Figure 30-2D





DESIGN CONTROLS FOR SAG VERTICAL CURVES

Figure 30-2E

3. Minimum Length. For most sag vertical curves, the minimum length of curve should also be based on the following equations:

$L_{min} = 3\ V$ (US Customary) Equation 30-2.3

$L_{min} = 0.6\ V$ (Metric) Equation 30-2.3

Where:

L_{min} = minimum length of vertical curve, ft (m)

V = design speed, mph (km/h)

Designs with vertical curve lengths of less than 90 ft (27 m) should be avoided, since these are difficult to construct.

4. Comfort Criteria. On fully lighted, continuous sections of highway and where it is impractical to provide SSD for headlights, a sag vertical curve may be designed to meet the comfort criteria. The length of curve equation for the comfort criteria is:

$$L = \frac{AV^2}{46.5}$$ (US Customary) Equation 30-2.5

$$L = \frac{AV^2}{395}$$ (Metric) Equation 30-2.5

Where:

L = length of vertical curve, ft (m)

A = algebraic difference between the two tangent grades, %

V = design speed, mph (km/h)

5. Drainage. Proper drainage must be considered in the design of sag vertical curves on curbed sections and bridges. Drainage problems are minimized if the sag vertical curve is sharp enough so that a minimum longitudinal grade of at least 0.3% is reached at a point about 50 ft (15 m) from either side of the low point. To ensure that this objective is achieved, base the length of the vertical curve upon a K-value of 167 (51) or less. This K-value is adequate for design speeds of 60 mph (100 km/h) or less.

   For uncurbed sections of highway, drainage should not be a problem at sag vertical curves.

30-3 VERTICAL CLEARANCES

The tables in Section 33-3 provide the roadway vertical clearances for 3R projects on non-freeways. The tables in Sections 36-4 and 36-5 present the minimum roadway vertical clearances for new construction and reconstruction projects. In addition to the criteria presented in Chapter 36, consider the following:

1. Existing Structures. The minimum clearance for structures allowed to remain-in-place is 14 ft-0 in (4.3 m) for all functional classifications.
2. Pedestrian Bridges/Sign Trusses. On all new or reconstruction projects, provide a minimum vertical clearance of 17 ft-3 in (5.25 m) under pedestrian bridges and sign trusses. For 3R projects existing pedestrian bridges and sign structures allowed to remain-in-place shall have a minimum clearance of 16 ft-9 in (5.1 m).
3. Traffic Signals. On all new or reconstruction projects, provide a minimum vertical clearance of 16 ft-0 in (4.9 m) with a maximum clearance of 18 ft-0 in (5.5 m). For 3R projects, a minimum vertical clearance of 14 ft-9 in (4.5 m) may be allowed to remain in place. This clearance is measured from the roadway surface to the bottom of the signal housing or to the bottom of the back plate.
4. Railroads. For all projects, the minimum vertical clearance for new and reconstructed structures over railroads is 23 ft-0 in (7.0 m) measured from the top of the highest rail. This clearance may be reduced with approval of the railroad and the Illinois Commerce Commission (ICC) (Title 92 Illinois Administrative Code, Part 1500, Chapter 3, Subpart C).

30-4 ACRONYMS

This is a summary of the acronyms used within this chapter.

3R	Rehabilitation, Restoration, and/or Resurfacing
AASHTO	American Association of State Highway and Transportation Officials
BDE	Bureau of Design and Environment
CBLRS	Central Bureau of Local Roads and Streets
ICC	Illinois Commerce Commission
IDOT	Illinois Department of Transportation
PSD	Passing Sight Distance
PVI	Point of Vertical Intersection
SSD	Stopping Sight Distance

30-5 REFERENCES

1. *A Policy on Geometric Design of Highways and Streets*, AASHTO, 2011.

2. NCHRP Report 400, *Determination of Stopping Sight Distances*, Transportation Research Board, 1997.

3. *IDOT Drainage Manual*, Illinois Department of Transportation.

4. Chapter 33 "Vertical Alignment," *Bureau of Design and Environment Manual*, IDOT.