VERTICAL CURVES

CoSA/Bexar County Lunch and Learn

May 27, 2011

Topics Presented

- Requirements
- Design Parameters
  - Design Speed
    - Stopping Sight Distance
  - Curve Geometry
    - Length and Algebraic Difference
  - K-Values
    - Design vs most restrictive
- County Spreadsheet
- Vertical Curves at Intersections

Vertical Curve Requirements

Vertical Curve Design required for changes in grade with algebraic difference greater than 1.5
[See UDC 35-506(d)(2)]

These can occur:

- **Along street grades**
- **At street intersections**
- **At driveways**

Design Speed

Street Type	Local Type A	Local Type B	Collector	Secondary Arterial[1]	Primary Arterial[2]
Design Speed (mph)	30	30—35	40—45	45	45

From UDC 35-506 Table 506-3

UDC 35-506 (d)(12)Design Speed.

A. Applicability. The design speed values listed in table 506-3 shall be used in conjunction with the American Association of State Highway & Transportation Officials (AASHTO) Policy on Geometric Design of Highways and streets, or latest revision thereof in the design of the streets horizontal and vertical alignment to include but not limited to:

- Intersection sight distance; vertical K-values;
- Horizontal obstruction offset values;
- Stopping sight distance;
- Transition distance; and
- Turn bay design.

Stopping Sight Distance

Determined by calculating decision distance and braking distance required for the design speed and tangential grade on wet pavement

$$d = 1.47Vt + \frac{V^2}{30\left(\left(\frac{a}{32.2}\right) \pm G\right)}$$

V = design speed, mph
t = brake reaction time, 2.5 sec.
a = deceleration rate, ft/s^2 – 11.2 ft/s^2
G = percent of grade divided by 100

AASHTO 2004 Policy on Geometric Design of Highways and Streets aka "Green Book"

Curve Geometry

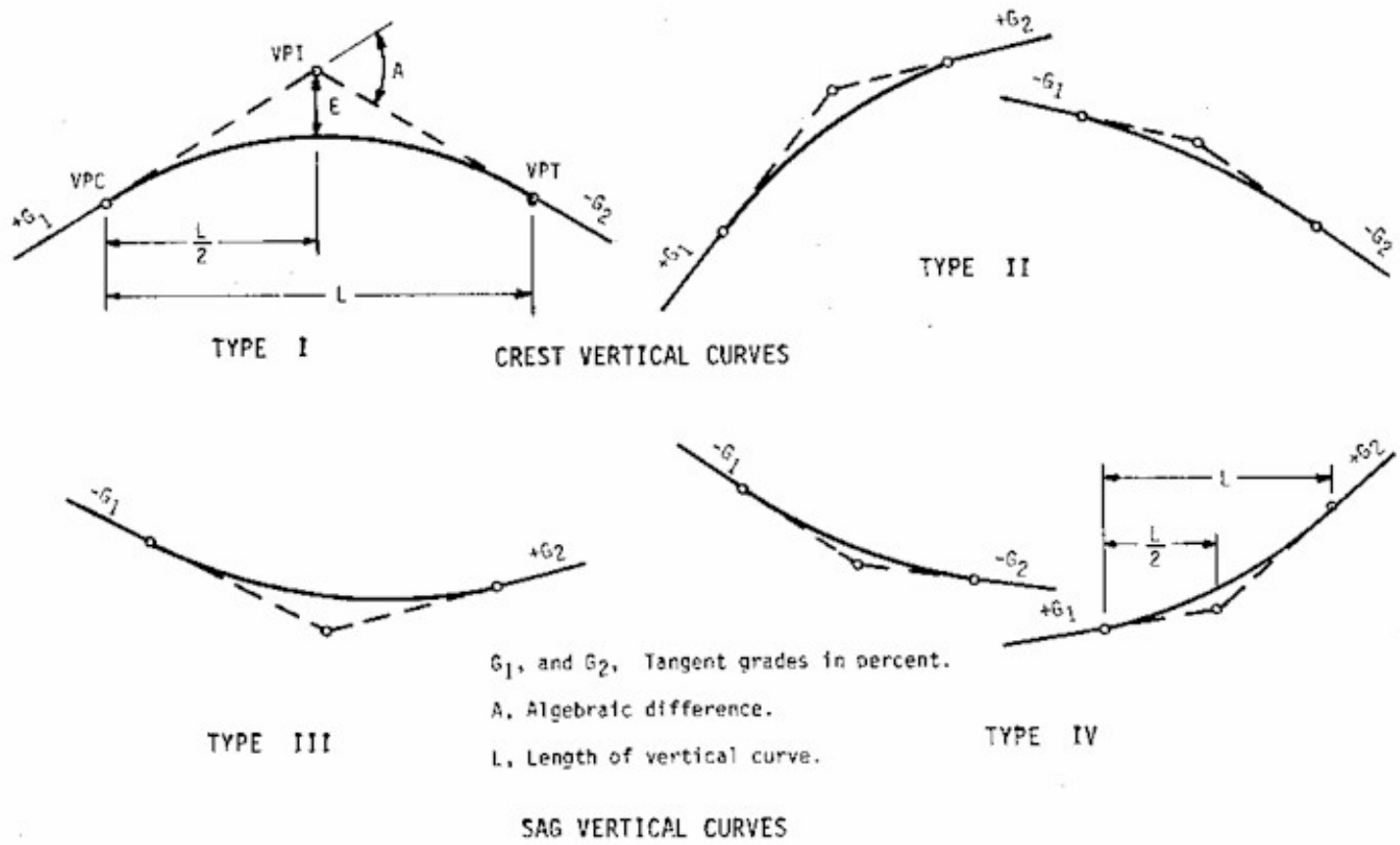


Figure III-38. Types of vertical curves.

AASHTO 2004 Policy on Geometric Design of Highways and Streets aka "Green Book"

Curve Geometry

Crest Vertical Curves

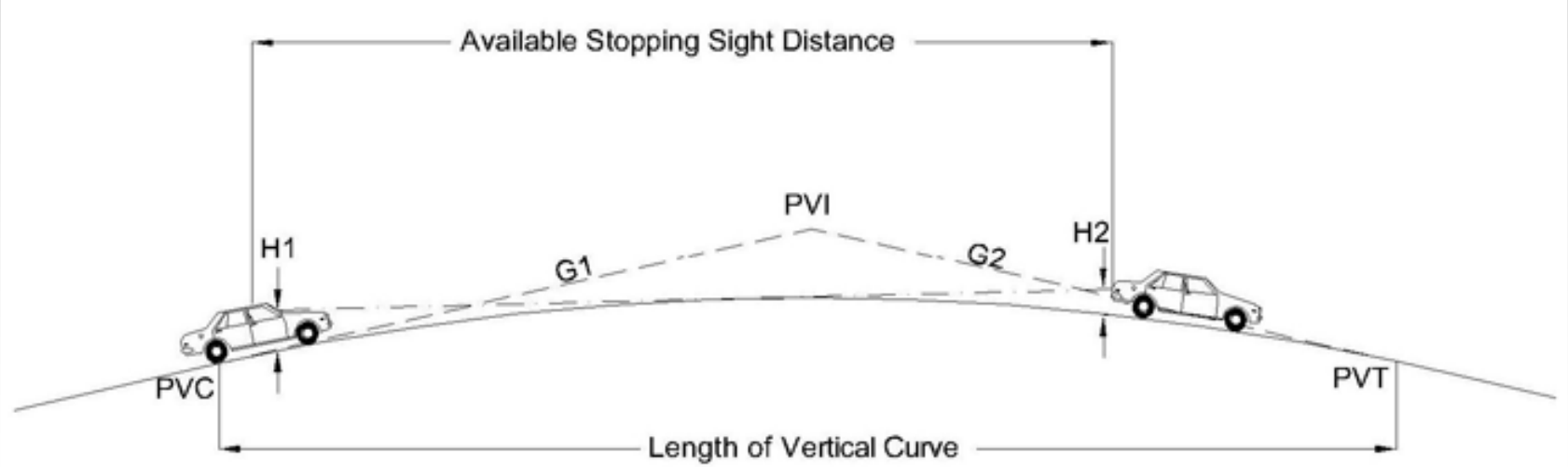
S is stopping sight distance

A is Algebraic Difference between grades

US Customary	
When S is less than L, $$L = \frac{AS^2}{2158}$$	(3-43)
When S is greater than L, $$L = 2S - \frac{2158}{A}$$	(3-44)

Eqn simplified for h_1=3.5ft and h_2=2.0ft

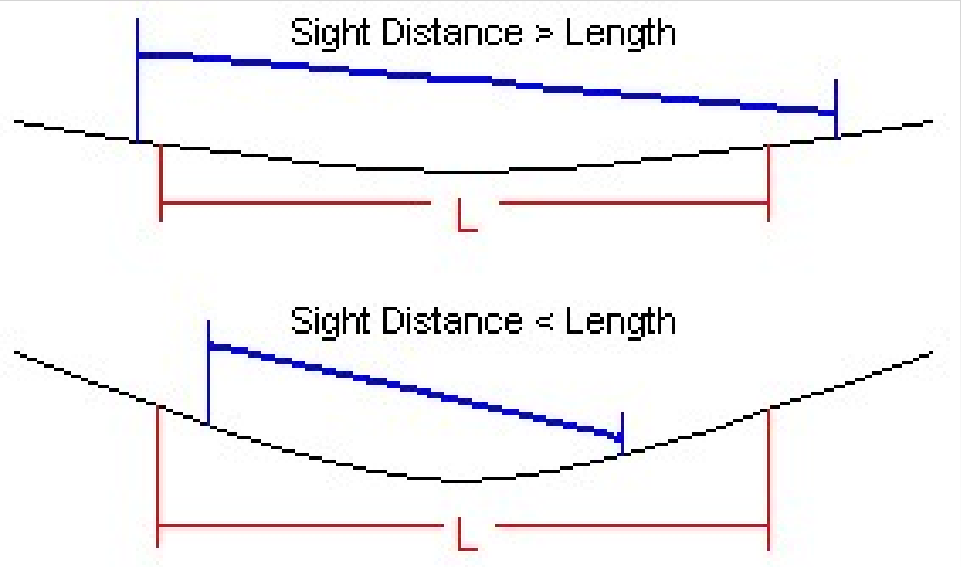
AASHTO 2004 Policy on Geometric Design of Highways and Streets aka "Green Book"



Curve Geometry

Sag Vertical Curves

For overall safety, a sag vertical curve should be long enough that the light beam distance is nearly the same as the stopping sight distance. AASHTO indicates it is appropriate to use stopping sight distances for different design speeds as the value of S in the equations.



US Customary

When S is less than L,

$$L = \frac{AS^2}{200\left[2.0 + S\left(\tan 1^\circ\right)\right]} \quad \textbf{(3-47)}$$

or,

$$L = \frac{AS^2}{400 + 3.5S} \quad \textbf{(3-48)}$$

When S is greater than L,

$$L = 2S - \frac{200\left[2.0 + S\left(\tan 1^\circ\right)\right]}{A} \quad \textbf{(3-49)}$$

or,

$$L = 2S - \left(\frac{400 + 3.5S}{A}\right) \quad \textbf{(3-50)}$$

where:

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

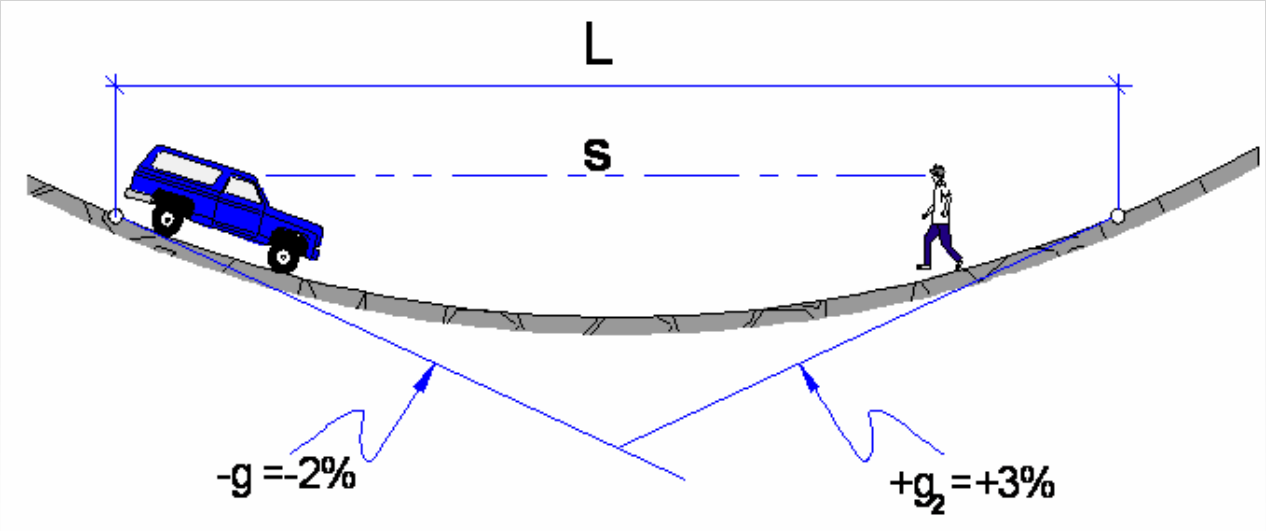
AASHTO 2004 Policy on Geometric Design of Highways and Streets aka "Green Book"

K Values

K Value represents the horizontal distance for a 1% of grade change

K=L/A

Minimum K-value required must provide for the maximum stopping sight distance encountered on the vertical curve being designed



Sight Distance

Metric						
Design speed (km/h)	Stopping sight distance (m)					
	Downgrades			Upgrades		
	3 %	6 %	9 %	3 %	6 %	9 %
20	20	20	20	19	18	18
30	32	35	35	31	30	29
40	50	50	53	45	44	43
50	66	70	74	61	59	58
60	87	92	97	80	77	75
70	110	116	124	100	97	93
80	136	144	154	123	118	114
90	164	174	187	148	141	136
100	194	207	223	174	167	160
110	227	243	262	203	194	186
120	263	281	304	234	223	214
130	302	323	350	267	254	243

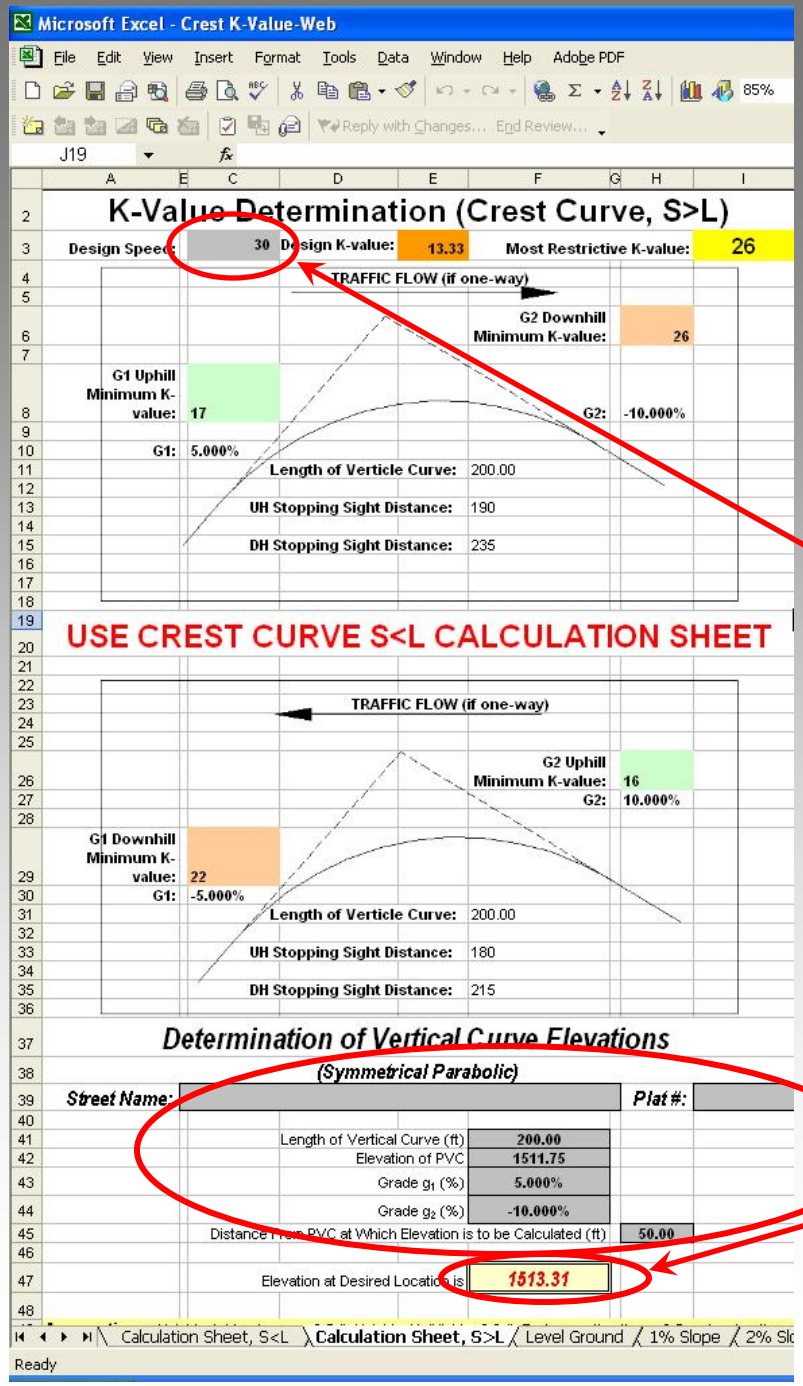
US Customary						
Design speed (mph)	Stopping sight distance (ft)					
	Downgrades			Upgrades		
	3 %	6 %	9 %	3 %	6 %	9 %
15	80	82	85	75	74	73
20	116	120	126	109	107	104
25	158	165	173	147	143	140
30	205	215	227	200	184	179
35	257	271	287	237	229	222
40	315	333	354	289	278	269
45	378	400	427	344	331	320
50	446	474	507	405	388	375
55	520	553	593	469	450	433
60	598	638	686	538	515	495
65	682	728	785	612	584	561
70	771	825	891	690	658	631
75	866	927	1003	772	736	704
80	965	1035	1121	859	817	782

Exhibit 3-2. Stopping Sight Distance on Grades

AASHTO 2004 Policy on Geometric Design of Highways and Streets aka "Green Book"

Vertical Curve Spreadsheet

- Developed as a guide and check for vertical curve design to ensure the “worst case” stopping sight distance is accommodated
- Uses AASHTO equations for stopping sight distance (SSD)
- Calculates SSD and K-values for the design speed of the road classification and the parameters of the curve being designed and can be applied for the direction of travel for grade separated roadways



Enter Parameters in Grey Fields

Can be used to determine minimum cover over utility lines and culverts

Microsoft Excel - Crest K-Value-Web

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K-Value Determination (Crest Curve, S>L)

Design Speed:	30	Design K-value:	13.33	Most Restrictive K-value:	26

TRAFFIC FLOW (if one-way)

G2 Downhill Minimum K-value:	26
G1 Uphill Minimum K-value:	17
G2:	-10.000%
G1:	5.000%
Length of Verticle Curve:	200.00
UH Stopping Sight Distance:	190
DH Stopping Sight Distance:	235

USE CREST CURVE S<L CALCULATION SHEET

TRAFFIC FLOW (if one-way)

G2 Uphill Minimum K-value:	16
G2:	10.000%
G1 Downhill Minimum K-value:	22
G1:	-5.000%
Length of Verticle Curve:	200.00
UH Stopping Sight Distance:	180
DH Stopping Sight Distance:	215

Determination of Vertical Curve Elevations

(Symmetrical Parabolic)

Street Name:		*Plat #:*	

Length of Vertical Curve (ft)	200.00
Elevation of PVC	1511.75
Grade g_1 (%)	5.000%
Grade g_2 (%)	-10.000%
Distance From PVC at Which Elevation is to be Calculated (ft)	50.00
Elevation at Desired Location is	1513.31

Calculation Sheet, S<L | Calculation Sheet, S>L | Level Ground | 1% Slope | 2% Sl

Ready

Microsoft Excel - Crest K-Value-Web

File Edit View Insert Format Tools Data Window Help Adobe PDF

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K-Value Determination (Crest Curve, S<L)

Design Speed:	30			Minimum K-value:	26
					13.33 Design K-value

TRAFFIC FLOW (if one-way)

G2 Downhill (DH) Minimum K-value:	26
G1 Uphill (UH) Minimum K-value:	17
G2:	-10.000%
G1:	5.000%
Length of Verticle Curve (L):	200.00
UH Stopping Sight Distance (S):	190
DH Stopping Sight Distance (S):	235

USE CREST CURVE S>L CALCULATION SHEET

TRAFFIC FLOW (if one-way)

G2 Uphill (UH) Minimum K-value:	16
G2:	10.000%
G1 Downhill (DH) Minimum K-value:	22
G1:	-5.000%
Length of Verticle Curve (L):	200.00
UH Stopping Sight Distance (S):	180
DH Stopping Sight Distance (S):	215

Determination of Vertical Curve Elevations

(Symmetrical Parabolic)

Street Name:		*Plat #:*	

Length of Vertical Curve (ft)	200.00
Elevation of PVC	1511.75
Grade g_1 (%)	5.000%
Grade g_2 (%)	-10.000%
Distance From PVC at Which Elevation is to be Calculated (ft)	
Elevation at Desired Location is	1511.75

Calculation Sheet, S<L | Calculation Sheet, S>L | Level Ground | 1% Slope | 2% S

Ready

Microsoft Excel - Sag K-Value-Web

K-Value Determination (Sag Curve, S>L)

Design Speed:	30	Design K-Value:	20.506	Most Restrictive K-Value: 43

TRAFFIC FLOW (if one-way)

Length of Verticle Curve:	300.0
UH Stopping Sight Distance:	185
DH Stopping Sight Distance:	220
G2:	6.950%
G1:	-7.680%
G1 Downhill Minimum K-value:	42
G2 Uphill Minimum K-value:	33

CURVE LENGTH EXCEEDS G2 UH STOPPING DISTANCE, USE SAG CURVE S<L CALCULATION SHEET

TRAFFIC FLOW (if one-way)

Length of Verticle Curve:	300.0
UH Stopping Sight Distance:	185
DH Stopping Sight Distance:	225
G2:	-6.950%
G1:	7.680%
G1 Uphill Minimum K-value:	33
G2 Downhill Minimum K-value:	43

Determination of Vertical Curve Elevations

(Symmetrical Parabolic)

Street Name: ***Plat #:***

Length of Vertical Curve (ft)	300.00
Elevation of PVC	843.11
Grade g_1 (%)	-7.680%
Grade g_2 (%)	6.950%
Distance From PVC at Which Elevation is to be Calculated (ft)	100.00
Elevation at Desired Location is	837.87

Calc Sheet, S>L, Headlights / Calc Sheet, S<L, Headlights / Level Ground / 1% S

Ready

Microsoft Excel - Sag K-Value-Web

K-Value Determination (Sag Curve, S<L)

Design Speed:	30	Most Restrictive K-Value:	43

TRAFFIC FLOW (if one-way) Design K-Value: 21

Length of Verticle Curve:	300.0
UH Stopping Sight Distance:	185
DH Stopping Sight Distance:	220
G1:	########
G2:	6.950%
G1 Downhill Minimum K-value:	42
G2 Uphill Minimum K-value:	33

TRAFFIC FLOW (if one-way)

Length of Verticle Curve:	300.00
UH Stopping Sight Distance:	185
DH Stopping Sight Distance:	225
G1:	7.680%
G2:	-6.950%
G1 Uphill Minimum K-value:	33
G2 Downhill Minimum K-value:	43

Determination of Vertical Curve Elevations

(Symmetrical Parabolic)

Street Name: ***Plat #:***

Length of Vertical Curve (ft)	300.00
Elevation of PVC	843.11
Grade g_1 (%)	-7.680%
Grade g_2 (%)	6.950%
Distance From PVC at Which Elevation is to be Calculated (ft)	36.94
Elevation at Desired Location is	840.61

Calc Sheet, S>L, Headlights / Calc Sheet, S<L, Headlights / Level Ground / 1%

Ready

Vertical Curves at Intersections

Determining K-values at intersections

- For local street intersections, where the K-value is on the street that has a stop sign control, a minimum design speed of 15 mph shall be used.
- For local street or driveway intersections connecting to a Collector street or higher, where the K-value is on the street that has a stop sign control and does not have the potential of begin signalized, a minimum design speed of 20 mph shall be used.

THROUGH STREET

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