Faculty of Engineering
Department of Civil Engineering

Highway and airport engineering

Route Location

- **Techniques for Highway surveys**

✓Ground surveys

✓Remote sensing

- **Principles of Highway location**

❖Office study: engineering, topography, geology etc.

❖Reconnaissance استطلاع : is to identify several feasible routes

❖Preliminary location survey are used to evaluate the economic & environmental feasibility of the alternatives routes

❖Final location survey

- **Preparation of highway plans**

Geometric Design

The fundamental objective of Geometric Design is to produce:

- **Alignment**
- **Profile**
- **Cross section**
- **Intersection and interchange**

Horizontal Alignment

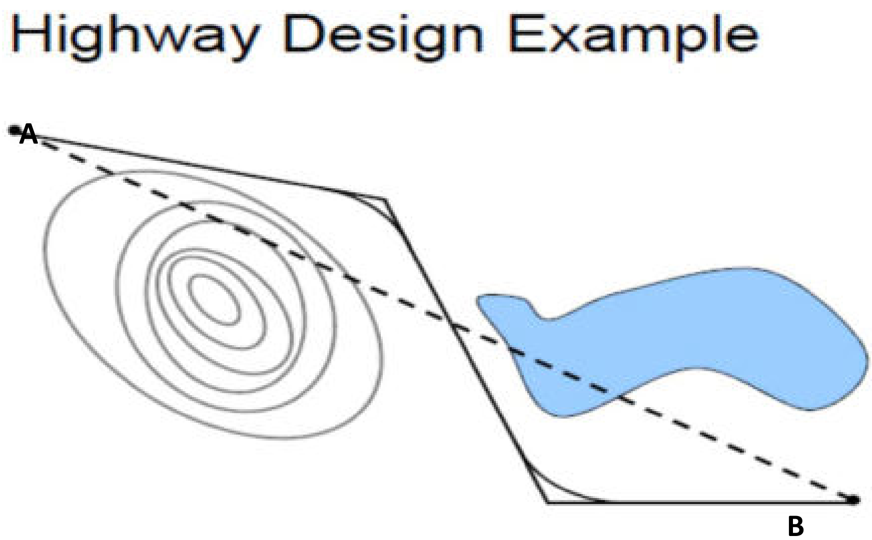
The Horizontal Alignment consists of straight section of the road (tangents) connected by curves.

The curves are usually segments of circles, which have radii that will provide for a smooth flow of traffic.

The design of horizontal alignment entails

- ✓ Determination of the minimum radius (R),
- ✓ Determination of the length of the curve (L),
- ✓ Computation of the horizontal offsets (E) from the tangents to the curve to facilitate locating the curve in the field.

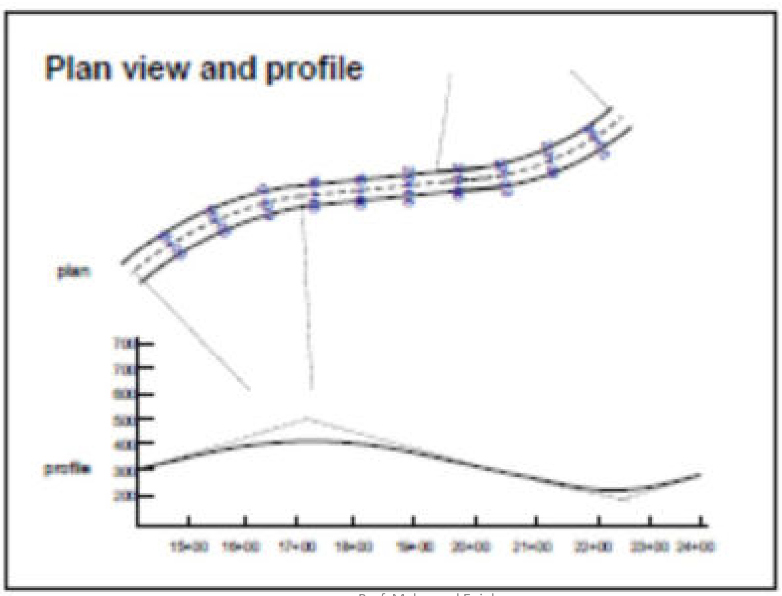
Horizontal Alignment



15-11-2022 Prof. Mahmoud Enieb 5

5

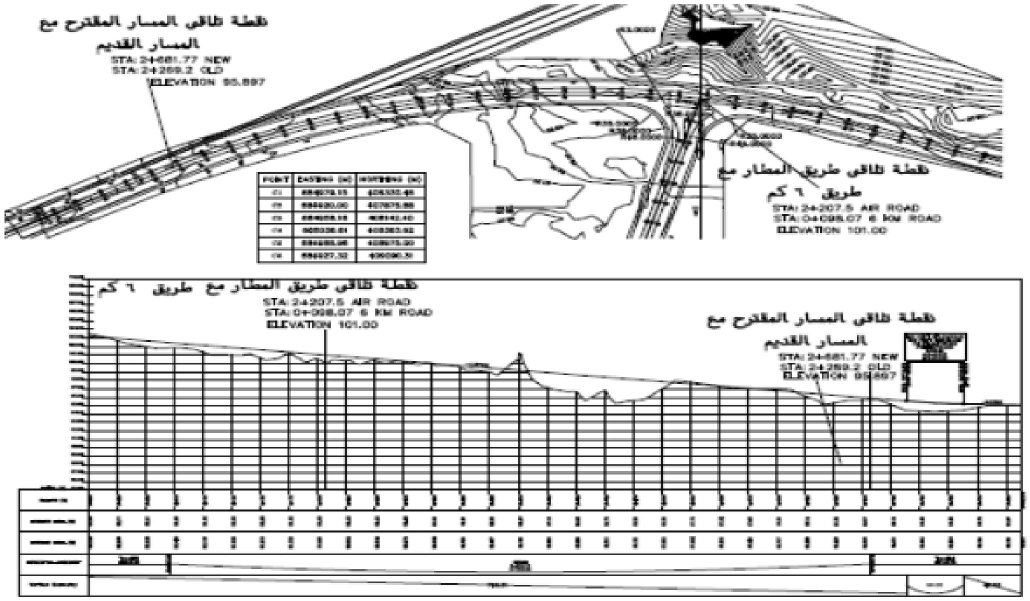
Horizontal Alignment



15-11-2022 Prof. Mahmoud Enieb 6

6

Horizontal Alignment



15-11-2022 Prof. Mahmoud Enieb 7

7

Horizontal Curves

- Surveying and Stationing
- Staking: route surveyors define the geometry of a highway by "staking" out the horizontal and vertical position of the route and by marking of the cross-section at intervals of 25 m.
- Station: Start from an origin by stationing 0, regular stations are established every 25 m., numbered 0+000, 0+025 (= 25 m), 1+150 (1000 m + 150) etc.

15-11-2022 Prof. Mahmoud Enieb 8

8

General Types of Horizontal Alignment

- **Straight**

There are four types of Horizontal Curves

- **Simple Curve**
- **Compound Curve**
- **Reverse Curve**
- **Transition (Spiral) Curve**

Straight

Straight Highway

Straight Railway

Simple Curve

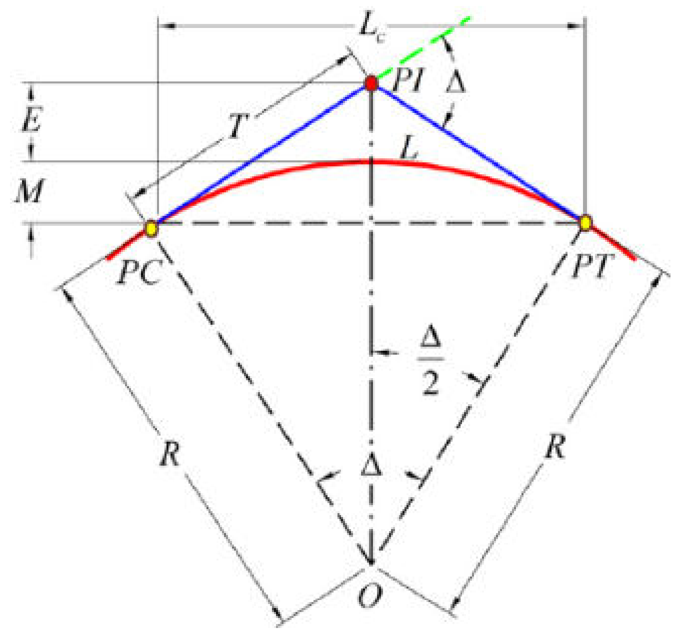
Highway

Railway

15-11-2022 Prof. Mahmoud Enieb 11

11

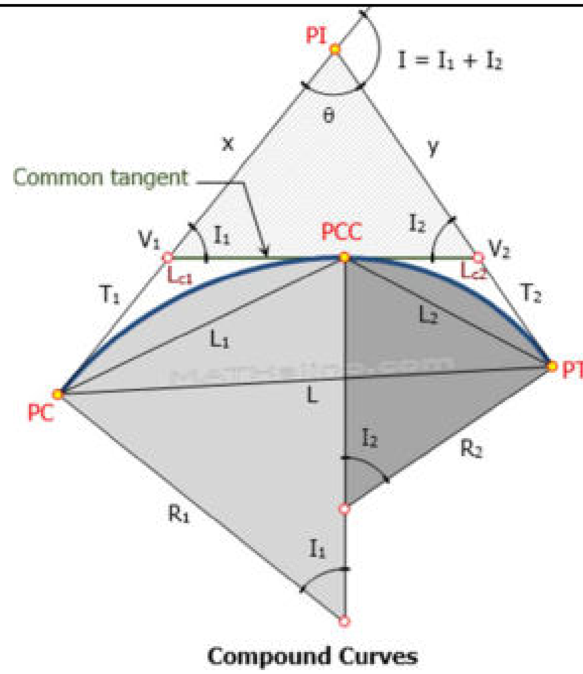
Simple Curve



15-11-2022 Prof. Mahmoud Enieb 12

12

Compound Curve



15-11-2022 Prof. Mahmoud Enieb 13

13

Highway Reverse Curves

15-11-2022 Prof. Mahmoud Enieb 14

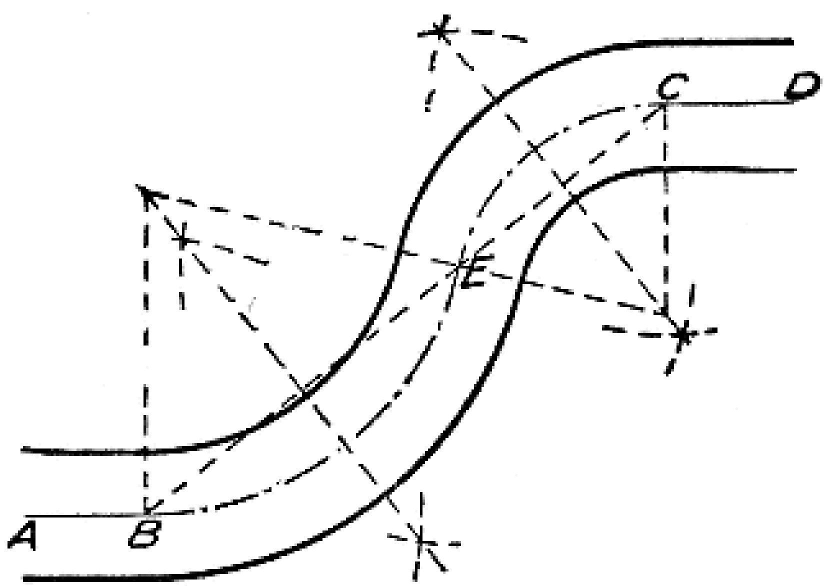
14

Railway Reverse Curves

15-11-2022 Prof. Mahmoud Enieb 15

15

Reverse Curves



15-11-2022 Prof. Mahmoud Enieb 16

16

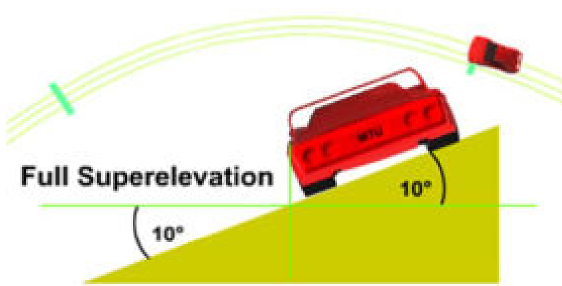
Continuously Curved

17

Minimum Radius of a Circular Curve

When a vehicle moves in a circular path, it undergoes a centripetal acceleration that cause motorists believe in pushing them outward. This force called centrifugal force.

In order to balance the effect of the centripetal acceleration, the road is inclined toward the center of the curve. The inclination of the roadway toward the center of the curve is known as superelevation



18

Minimum Radius of a Circular Curve

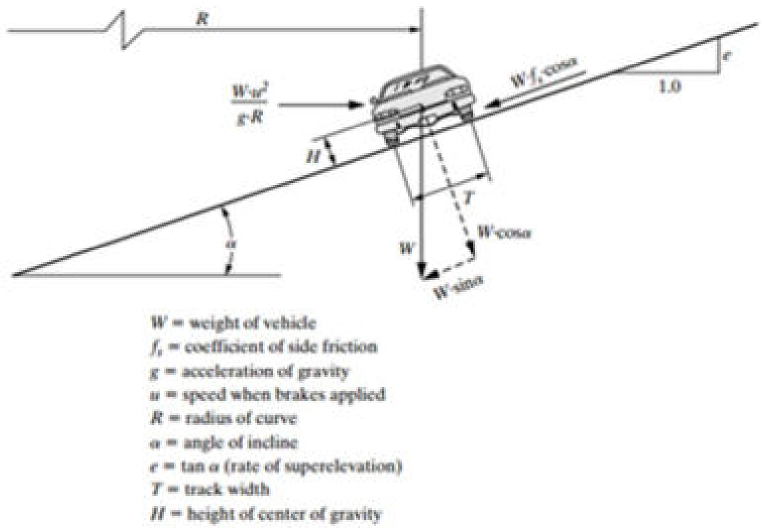


Figure 3.8 Forces Acting on a Vehicle Traveling on a Horizontal Curve Section of a Road

Minimum Radius

When the vehicle is in equilibrium with respect to incline (that is, vehicle moves forward but neither up nor down the incline), we may equate the three relevant forces and obtain:

$\frac{WV^2}{gR}\cos\alpha = W\sin\alpha + W f_s \cos\alpha$

Where f_s = coefficient of side friction and

$\frac{V^2}{g} = R(\sin\alpha/\cos\alpha + f_s) = R(\tan\alpha + f_s)$ then:

$tan\alpha = e$

$R = \frac{V^2}{g(e + f_s)}$

Minimum Radius

$$R = \frac{u^2}{g(e + f_s)}$$

Metric Unit

$$R = \frac{(0.278^2)V^2}{9.81(e_{max} + f_s)} = \frac{V^2}{127(e_{max} + f_s)} \quad \text{(meter)}$$

u with km/h

Britch Unit

$$R = \frac{(1.47^{\,2})V^2}{32.2(e_{max} + f_s)} = \frac{V^2}{15(e_{max} + f_s)} \quad \text{(feet)}$$

u with mph

Radius Calculation

- **R_{min}** uses max **e** and max f_s (defined by AASHTO and graphed in Green Book) and design speed.
- f_s is a function of speed, roadway surface, weather condition, tire condition, and based on comfort – drivers' brake, make sudden lane changes, and change position within a lane when acceleration around a curve becomes "uncomfortable"
- f_s decreases as speed increases (less tire/pavement contact)

Max e

- Controlled by 4 factors:
  - Climate conditions (amount of ice and snow)
  - Terrain (Flat, Rolling, Mountainous)
  - Type of area (Rural or Urban)
  - Frequency of slow-moving vehicles who might be influenced by high superelevation rates

15-11-2022 Prof. Mahmoud Enieb 23

23

Max e

- Highest in common use = 10%, 12% with no ice and snow on low volume gravel-surfaced roads
- 8% is logical maximum to minimize slipping by stopped vehicles, considering **snow and ice**
- Iowa uses a maximum of 6% on new projects
- For consistency use a **single rate** within a project or on a highway

- Limiting values:
- 10 % recommended value for regions without snow and ice conditions,
- 8% for Rural roads and high-speed Urban roads,
- 4, 6% for Urban and suburban areas.

15-11-2022 Prof. Mahmoud Enieb 24

24

Coefficient of side friction for different design speed (f_s)

Table 3.3 Coefficient of Side Friction for Different Design Speeds

Design Speed (mi/h)	*Coefficients of Side Friction, f_s*
30	0.20
40	0.16
50	0.14
60	0.12
70	0.10

Values of side friction recommended by AASHTO

Design speed, km/h	Maximum side friction factor
30	0.17
40	0.17
50	0.16
60	0.15
70	0.14
80	0.14
90	0.13
100	0.12
110	0.11
120	0.09

Source: From *A Policy on Geometric Design of Highways and Streets.* Copyright 1994 by the American Association of State Highway and Transportation Officials, Washington, DC. Used by permission.

Recommended minimum radius of curvature

Design speed, km/h	Manimum curve raidus, m
30	35
40	60
50	100
60	150
70	215
80	280
90	375
100	490
110	635
120	870

Source: From *A Policy on Geometric Design of Highways and Streets.*. Copyright 1994 by the American Association of State Highway and Transportation Officials, Washington, DC. Used by permission.

Example 1

An existing horizontal curve on a highway has a radius of 268 ft, which restricts the maximum speed on this section of the road to only 60 % of the design speed of the highway. If the curve is to be improved so that maximum speed will be that of the design speed of the highway,

determine the minimum radius of the new curve.

Assume the coefficient of side friction is 0.15 for the existing curve and the rate of superelevation is 0.08 for both the existing curve and new curve to be designed.

Solution

The maximum permissible speed on the existing curve.

$268 = \frac{u^2}{15(0.08 + 0.15)}$ $u_e = 30.4$ mph

Determine the design speed of the highway.

$u_h = 30.4 / 0.6 = 50.67$ mph

Design speed = 50 mph

From table f_s for 50 mph = 0.14

$R = \frac{(50)^2}{15(0.08 + 0.14)} = 757.57$ ft.

Example 2

Example 3.9 Minimum Radius of a Highway Horizontal Curve

An existing horizontal curve on a highway has a radius of 465 ft, which restricts the posted speed limit on this section of the road to only 61.5% of the design speed of the highway. If the curve is to be improved so that its posted speed will be the design speed of the highway, determine the minimum radius of the new curve. Assume that the rate of superelevation is 0.08 for both the existing curve and the new curve to be designed.

Solution:

- Use Eq. 3.34 to find the posted speed limit on the existing curve. Since the posted speed limit is not known, assume f_s is 0.16.

$$R = \frac{u^2}{15(e + f_s)}$$

$$465 = \frac{u^2}{15(0.08 + 0.16)}$$

$$u = 40.91 \text{ mi/h}$$

- The posted speed limit is 40 mi/h, as speed limits are usually posted at intervals of 5 mi/h.
- Check assumed f_s for 40 mi/h = 0.16.
- Determine the design speed of the highway.

$$\frac{40}{0.615} = 65.04 \text{ mi/h}$$

- Design speed = 65 mi/h.
- Find the radius of the new curve by using Eq. 3.34 with the value of f_s for 65 mi/h from Table 3.3 (f_s = 0.11, interpolating between 60 mi/h and 70 ~~65~~ mi/h).

$$R = \frac{65^2}{15(0.08 + f_s)}$$

$$= \frac{(65)^2}{15(0.08 + 0.11)} = 1482.45 \text{ ft}$$

15-11-2022 Prof. Mahmoud Enieb 31

31

Example 3

A horizontal curve is to be designed for a section of a highway having a design speed of 60 mph. if the physical conditions restrict the radius of the curve to 500 ft, what value is required for the superelevation at this curve? Will this be a good design?

Solution

From table f_s for 60 mph = 0.12

$$500 = \frac{60^2}{15(0.01e + 0.12)}$$

e = 36 %

This value is not good design because highest in common use 10%, to 12% with no ice and snow and 8% considering snow and ice

15-11-2022 Prof. Mahmoud Enieb 32

32

Example 4

Determine the minimum radius required at a curved section of a highway if the design speed is 70 mph and the superelevation is 8%.

Solution

From table f_s for 70 mph = 0.10

$$R = \frac{70^2}{15(0.01x8 + 0.10)}$$

R = 1814.8 ft

From Table 3.7 (Slide 38) calculated radius is 1814.8 ft and rounded radius is 1810 ft.

Example 5

Design radius example: assume a maximum e of 8% and design speed of 100 km/h, what is the minimum radius (Rural situation)?

Solution

f_s = 0.12 from table

$$R = \frac{100^2}{127(0.01x8 + 0.12)}$$

R_{min} = 393.7 m (Rounded radius 400 m)

Example 6

For e_{max} = 4%? (urban situation)

$$R = \frac{100^2}{127\,(0.01x4 + 0.12)}$$

R_{min} = 492.12 m (Rounded radius 500 m)

15-11-2022 Prof. Mahmoud Enieb 35

35

Example 7

- What is the minimum radius of curvature allowable for a roadway with a 100 km/h design speed, assuming that the maximum allowable superelevation rate is 0.12? Compare this with the minimum curve radius recommended by AASHTO.
- What is the actual maximum superelevation rate allowable under AASHTO recommended standards for a 100 km/h design speed, if the value of *f* is the maximum allowed by AASHTO for this speed? Round the answer down to the nearest whole percent.

15-11-2022 Prof. Mahmoud Enieb 36

36

Solution

- Minimum radius of curvature for 100 km/h design speed

$$R = \frac{V^2}{127(f + e)} = \frac{100^2}{127(0.12 + 0.12)} = 328 \text{ m}$$

- Minimum radius recommended by AASHTO is 490 m. Actual maximum superelevation rate for AASHTO recommended standards for 100 km/h is:

$$e = \frac{V^2}{127R} - f = \frac{100^2}{127(490)} - 0.12 = 0.041$$

- Rounding

$$e_{max} = 0.04 = 4\%$$

Table 3-7. Minimum Radius Using Limiting Values of e and f

Metric						U.S. Customary					
Design Speed (km/h)	Maximum e (%)	Maximum f	Total (e/100 + f)	Calculated Radius (m)	Rounded Radius (m)	Design Speed (mph)	Maximum e (%)	Maximum f	Total (e/100 + f)	Calculated Radius (ft)	Rounded Radius (ft)
15	4.0	0.40	0.44	4.0	4	10	4.0	0.38	0.42	15.9	16
20	4.0	0.35	0.39	8.1	8	15	4.0	0.32	0.36	41.7	42
30	4.0	0.28	0.32	22.1	22	20	4.0	0.27	0.31	86.0	86
40	4.0	0.23	0.27	46.7	47	25	4.0	0.23	0.27	154.3	154
50	4.0	0.19	0.23	85.6	86	30	4.0	0.20	0.24	250.0	250
60	4.0	0.17	0.21	135.0	135	35	4.0	0.18	0.22	371.2	371
70	4.0	0.15	0.19	203.1	203	40	4.0	0.16	0.20	533.3	533
80	4.0	0.14	0.18	280.0	280	45	4.0	0.15	0.19	710.5	711
90	4.0	0.13	0.17	375.2	375	50	4.0	0.14	0.18	925.9	926
100	4.0	0.12	0.16	492.1	492	55	4.0	0.13	0.17	1186.3	1190
						60	4.0	0.12	0.16	1500.0	1500
15	6.0	0.40	0.46	3.9	4	10	6.0	0.38	0.44	15.2	15
20	6.0	0.35	0.41	7.7	8	15	6.0	0.32	0.38	39.5	39
30	6.0	0.28	0.34	20.8	21	20	6.0	0.27	0.33	80.8	81
40	6.0	0.23	0.29	43.4	43	25	6.0	0.23	0.29	143.7	144
50	6.0	0.19	0.25	78.7	79	30	6.0	0.20	0.26	230.8	231
60	6.0	0.17	0.23	123.2	123	35	6.0	0.18	0.24	340.3	340
70	6.0	0.15	0.21	183.7	184	40	6.0	0.16	0.22	484.8	485
80	6.0	0.14	0.20	252.0	252	45	6.0	0.15	0.21	642.9	643
90	6.0	0.13	0.19	335.7	336	50	6.0	0.14	0.20	833.3	833
100	6.0	0.12	0.18	437.4	437	55	6.0	0.13	0.19	1061.4	1060
110	6.0	0.11	0.17	560.4	560	60	6.0	0.12	0.18	1333.3	1330
120	6.0	0.09	0.15	755.9	756	65	6.0	0.11	0.17	1656.9	1660
130	6.0	0.08	0.14	950.5	951	70	6.0	0.10	0.16	2041.7	2040
						75	6.0	0.09	0.15	2500.0	2500
						80	6.0	0.08	0.14	3047.6	3050

15	8.0	0.40	0.48	3.7	4	10	8.0	0.38	0.46	14.5	14
20	8.0	0.35	0.43	7.3	7	15	8.0	0.32	0.40	37.5	38
30	8.0	0.28	0.36	19.7	20	20	8.0	0.27	0.35	76.2	76
40	8.0	0.23	0.31	40.6	41	25	8.0	0.23	0.31	134.4	134
50	8.0	0.19	0.27	72.9	73	30	8.0	0.20	0.28	214.3	214
60	8.0	0.17	0.25	113.4	113	35	8.0	0.18	0.26	314.1	314
70	8.0	0.15	0.23	167.8	168	40	8.0	0.16	0.24	444.4	444
80	8.0	0.14	0.22	229.1	229	45	8.0	0.15	0.23	587.0	587
90	8.0	0.13	0.21	303.7	304	50	8.0	0.14	0.22	757.6	758
100	8.0	0.12	0.20	393.7	394	55	8.0	0.13	0.21	960.3	960
110	8.0	0.11	0.19	501.5	501	60	8.0	0.12	0.20	1200.0	1200
120	8.0	0.09	0.17	667.0	667	65	8.0	0.11	0.19	1482.5	1480
130	8.0	0.08	0.16	831.7	832	70	8.0	0.10	0.18	1814.8	1810
						75	8.0	0.09	0.17	2205.9	2210
						80	8.0	0.08	0.16	2666.7	2670
15	10.0	0.40	0.50	3.5	4	10	10.0	0.38	0.48	13.9	14
20	10.0	0.35	0.45	7.0	7	15	10.0	0.32	0.42	35.7	36
30	10.0	0.28	0.38	18.6	19	20	10.0	0.27	0.37	72.1	72
40	10.0	0.23	0.33	38.2	38	25	10.0	0.23	0.33	126.3	126
50	10.0	0.19	0.29	67.9	68	30	10.0	0.20	0.30	200.0	200
60	10.0	0.17	0.27	105.0	105	35	10.0	0.18	0.28	291.7	292
70	10.0	0.15	0.25	154.3	154	40	10.0	0.16	0.26	410.3	410
80	10.0	0.14	0.24	210.0	210	45	10.0	0.15	0.25	540.0	540
90	10.0	0.13	0.23	277.3	277	50	10.0	0.14	0.24	694.4	694
100	10.0	0.12	0.22	357.9	358	55	10.0	0.13	0.23	876.8	877
110	10.0	0.11	0.21	453.7	454	60	10.0	0.12	0.22	1090.9	1090
120	10.0	0.09	0.19	596.8	597	65	10.0	0.11	0.21	1341.3	1340
130	10.0	0.08	0.18	739.3	739	70	10.0	0.10	0.20	1633.3	1630
						75	10.0	0.09	0.19	1973.7	1970
						80	10.0	0.08	0.18	2370.4	2370
15	12.0	0.40	0.52	3.4	3	10	12.0	0.38	0.50	13.3	13
20	12.0	0.35	0.47	6.7	7	15	12.0	0.32	0.44	34.1	34
30	12.0	0.28	0.40	17.7	18	20	12.0	0.27	0.39	68.4	68
40	12.0	0.23	0.35	36.0	36	25	12.0	0.23	0.35	119.0	119
50	12.0	0.19	0.31	63.5	64	30	12.0	0.20	0.32	187.5	188
60	12.0	0.17	0.29	97.7	98	35	12.0	0.18	0.30	272.2	272
70	12.0	0.15	0.27	142.9	143	40	12.0	0.16	0.28	381.0	381
80	12.0	0.14	0.26	193.8	194	45	12.0	0.15	0.27	500.0	500
90	12.0	0.13	0.25	255.1	255	50	12.0	0.14	0.26	641.0	641
100	12.0	0.12	0.24	328.1	328	55	12.0	0.13	0.25	806.7	807
110	12.0	0.11	0.23	414.2	414	60	12.0	0.12	0.24	1000.0	1000
120	12.0	0.09	0.21	539.9	540	65	12.0	0.11	0.23	1224.6	1220
130	12.0	0.08	0.20	665.4	665	70	12.0	0.10	0.22	1484.8	1480
						75	12.0	0.09	0.21	1785.7	1790
						80	12.0	0.08	0.20	2133.3	2130

Note: In recognition of safety considerations, use of e_{max} = 4.0% should be limited to urban conditions.

US Customary

Design Speed (mph)	Maximum e (%)	Limiting Values of f	Total (e/100 + f)	Calculated Radius (ft)	Rounded Radius (ft)						
15	4.0	0.175	0.215	70.0	70						
20	4.0	0.170	0.210	127.4	125						
25	4.0	0.165	0.205	203.9	205						
30	4.0	0.160	0.200	301.0	300						
35	4.0	0.155	0.195	420.2	420						
40	4.0	0.150	0.190	563.3	565						
45	4.0	0.145	0.185	732.2	730						
50	4.0	0.140	0.180	929.0	930						
55	4.0	0.130	0.170	1190.2	1190						
60	4.0	0.120	0.160	1505.0	1505						
15	6.0	0.175	0.235	64.0	65	15	10.0	0.175	0.275	54.7	55
20	6.0	0.170	0.230	116.3	115	20	10.0	0.170	0.270	99.1	100
25	6.0	0.165	0.225	185.8	185	25	10.0	0.165	0.265	157.8	160
30	6.0	0.160	0.220	273.6	275	30	10.0	0.160	0.260	231.5	230
35	6.0	0.155	0.215	381.1	380	35	10.0	0.155	0.255	321.3	320
40	6.0	0.150	0.210	509.6	510	40	10.0	0.150	0.250	426.1	430
45	6.0	0.145	0.205	660.7	660	45	10.0	0.145	0.245	552.9	555
50	6.0	0.140	0.200	836.1	835	50	10.0	0.140	0.240	696.8	695
55	6.0	0.130	0.190	1065.0	1065	55	10.0	0.130	0.230	879.7	880
60	6.0	0.120	0.180	1337.8	1340	60	10.0	0.120	0.220	1094.6	1095
65	6.0	0.110	0.170	1662.4	1660	65	10.0	0.110	0.210	1345.8	1345
70	6.0	0.100	0.160	2048.5	2050	70	10.0	0.100	0.200	1638.5	1640
75	6.0	0.090	0.150	2508.4	2510	75	10.0	0.090	0.190	1980.3	1980
80	6.0	0.080	0.140	3057.8	3060	80	10.0	0.080	0.180	2378.3	2380
15	8.0	0.175	0.255	59.0	60	15	12.0	0.175	0.295	51.0	50
20	8.0	0.170	0.250	107.0	105	20	12.0	0.170	0.290	92.3	90
25	8.0	0.165	0.245	170.8	170	25	12.0	0.165	0.285	146.7	145
30	8.0	0.160	0.240	250.8	250	30	12.0	0.160	0.280	215.0	215
35	8.0	0.155	0.235	348.7	350	35	12.0	0.155	0.275	298.0	300
40	8.0	0.150	0.230	465.3	465	40	12.0	0.150	0.270	396.4	395
45	8.0	0.145	0.225	602.0	600	45	12.0	0.145	0.265	511.1	510
50	8.0	0.140	0.220	760.1	760	50	12.0	0.140	0.260	643.2	645
55	8.0	0.130	0.210	963.5	965	55	12.0	0.130	0.250	809.4	810
60	8.0	0.120	0.200	1204.0	1205	60	12.0	0.120	0.240	1003.4	1005
65	8.0	0.110	0.190	1487.4	1485	65	12.0	0.110	0.230	1228.7	1230
70	8.0	0.100	0.180	1820.9	1820	70	12.0	0.100	0.220	1489.8	1490
75	8.0	0.090	0.170	2213.3	2215	75	12.0	0.090	0.210	1791.7	1790
80	8.0	0.080	0.160	2675.6	2675	80	12.0	0.080	0.200	2140.5	2140

Note: In recognition of safety considerations, use of e_{max} = 4.0% should be limited to urban conditions.

Source: *A Policy on Geometric Design of Highways and Streets* (The Green Book). Washington, DC. American Association of State Highway and Transportation Officials, 2001 4th Ed.

Exhibit 3-14. Minimum Radius for Design of Rural Highways, Urban Freeways, and High-Speed Urban Streets Using Limiting Values of e and f

US CUSTOMARY

R (ft)	V_d = 15 mph			V_d = 20 mph			V_d = 25 mph			V_d = 30 mph			V_d = 35 mph			V_d = 40 mph			V_d = 45 mph			V_d = 50 mph			V_d = 55 mph			V_d = 60 mph		
	e (%)	L (ft) 2 Lns	L (ft) 4 Lns	e (%)	L (ft) 2 Lns	L (ft) 4 Lns	e (%)	L (ft) 2 Lns	L (ft) 4 Lns	e (%)	L (ft) 2 Lns	L (ft) 4 Lns	e (%)	L (ft) 2 Lns	L (ft) 4 Lns	e (%)	L (ft) 2 Lns	L (ft) 4 Lns	e (%)	L (ft) 2 Lns	L (ft) 4 Lns	e (%)	L (ft) 2 Lns	L (ft) 4 Lns	e (%)	L (ft) 2 Lns	L (ft) 4 Lns	e (%)	L (ft) 2 Lns	L (ft) 4 Lns
23000	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0
20000	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0
17000	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0
14000	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0
12000	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0
10000	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0
8000	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	RC	51	77	RC	63	80
6000	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	RC	48	72	RC	51	77	2.3	61	92
5000	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	RC	44	67	RC	48	72	2.3	59	88	2.6	67	100
4000	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	RC	41	62	RC	44	67	2.3	55	83	2.6	66	100	2.8	75	112
3500	NC	0	0	NC	0	0	NC	0	0	NC	0	0	RC	39	58	RC	41	62	2.2	49	73	2.6	60	90	2.7	69	103	3.0	80	120
3000	NC	0	0	NC	0	0	NC	0	0	NC	0	0	RC	39	58	2.1	43	65	2.4	53	80	2.7	65	97	2.9	74	111	3.3	88	132
2500	NC	0	0	NC	0	0	NC	0	0	RC	36	55	RC	39	58	2.4	50	74	2.6	58	87	2.9	70	104	3.2	82	123	3.5	93	140
2000	NC	0	0	NC	0	0	RC	34	51	RC	36	55	2.3	45	67	2.6	54	81	2.9	64	97	3.2	77	115	3.6	89	134	3.8	101	152
1800	NC	0	0	NC	0	0	RC	34	51	2.1	38	57	2.4	46	70	2.7	56	84	3.0	67	100	3.3	79	119	3.7	94	141	3.9	104	156
1600	NC	0	0	NC	0	0	RC	34	51	2.2	40	60	2.6	50	75	2.9	60	90	3.2	71	107	3.5	84	126	3.8	97	146	4.0	107	160
1400	NC	0	0	NC	0	0	RC	34	51	2.4	44	66	2.7	52	78	3.0	62	93	3.4	76	113	3.7	89	133	3.9	100	149	R_{min} = 1606		
1200	NC	0	0	RC	32	48	2.2	38	57	2.5	45	68	2.9	56	84	3.2	66	99	3.6	80	120	3.9	94	140	4.0	102	153			
1000	NC	0	0	RC	32	48	2.4	41	62	2.7	49	74	3.1	60	90	3.5	72	108	3.8	84	127	4.0	96	144	R_{min} = 1190					
900	NC	0	0	2.1	34	51	2.6	43	64	2.9	53	79	3.3	62	93	3.6	74	112	3.9	87	130	R_{min} = 930								
800	NC	0	0	2.2	36	54	2.8	45	67	3.0	55	82	3.4	66	99	3.8	79	118	4.0	89	133									
700	RC	31	46	2.3	37	56	2.7	46	69	3.2	58	87	3.6	70	105	3.9	81	121	R_{min} = 730											
600	RC	31	46	2.5	41	61	2.9	50	75	3.4	62	93	3.8	74	110	4.0	83	124												
500	2.1	32	48	2.6	42	63	3.1	53	80	3.6	65	98	3.9	75	113	R_{min} = 665														
450	2.2	34	51	2.7	44	66	3.2	55	82	3.7	67	101	4.0	77	116															
400	2.3	35	53	2.9	47	71	3.4	58	87	3.8	69	104	R_{min} = 420																	
350	2.4	37	55	3.0	49	73	3.6	62	93	3.9	71	106																		
300	2.6	40	60	3.2	52	78	3.7	63	95	4.0	73	109																		
250	2.7	42	63	3.4	55	83	3.9	67	100	R_{min} = 300																				
200	3.0	46	69	3.7	60	90	R_{min} = 205																							
150	3.3	51	76	3.9	63	95																								
100	3.8	58	88	R_{min} = 126																										
75	4.0	62	92																											
	R_{min} = 76																													

e_{max} = 4%
R = radius of curve
V_d = assumed design speed
e = rate of superelevation
L = minimum length of runoff (does not include tangent runout) as discussed in "Tangent-to-Curve Transition" section
NC = normal crown section
RC = remove adverse crown, superelevate at normal crown slope
Use of e_{max} = 4% should be limited to urban conditions

Urban conditions e_{max} = 4%

Exhibit 3-21. Values for Design Elements Related to Design Speed and Horizontal Curvature (Continued)

METRIC

R (m)	V_d = 20 km/h			V_d = 30 km/h			V_d = 40 km/h			V_d = 50 km/h			V_d = 60 km/h			V_d = 70 km/h			V_d = 80 km/h			V_d = 90 km/h			V_d = 100 km/h			V_d = 110 km/h			V_d = 120 km/h			V_d = 130 km/h		
	e (%)	L (m) 2 Lns	L (m) 4 Lns	e (%)	L (m) 2 Lns	L (m) 4 Lns	e (%)	L (m) 2 Lns	L (m) 4 Lns	e (%)	L (m) 2 Lns	L (m) 4 Lns	e (%)	L (m) 2 Lns	L (m) 4 Lns	e (%)	L (m) 2 Lns	L (m) 4 Lns	e (%)	L (m) 2 Lns	L (m) 4 Lns	e (%)	L (m) 2 Lns	L (m) 4 Lns	e (%)	L (m) 2 Lns	L (m) 4 Lns	e (%)	L (m) 2 Lns	L (m) 4 Lns	e (%)	L (m) 2 Lns	L (m) 4 Lns	e (%)	L (m) 2 Lns	L (m) 4 Lns
7000	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0
5000	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0
3000	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	RC	16	24	RC	16	24	2.3	22	33	2.5	26	39
2500	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	RC	15	22	RC	16	25	2.1	20	30	2.7	28	38	3.0	31	46
2000	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	RC	14	22	2.5	18	24	2.8	20	31	3.0	26	37	3.3	31	47	3.7	34	51
1500	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	RC	13	20	2.2	16	24	2.7	21	31	3.3	25	38	3.6	32	47	4.2	40	59	4.7	44	73
1400	NC	0	0	NC	0	0	NC	0	0	NC	0	0	NC	0	0	RC	13	20	2.4	17	26	2.9	21	32	3.3	27	41	3.8	33	50	4.4	42	63	5.0	51	77
1300	NC	0	0	NC	0	0	NC	0	0	NC	0	0	RC	12	18	2.1	14	21	2.6	18	27	3.0	22	33	3.5	28	43	4.0	35	53	4.7	45	67	5.3	55	82
1200	NC	0	0	NC	0	0	NC	0	0	NC	0	0	RC	12	18	2.2	14	22	2.7	19	28	3.2	23	35	3.7	30	46	4.2	37	55	4.9	47	71	5.6	60	90
1000	NC	0	0	NC	0	0	NC	0	0	RC	11	17	2.1	13	19	2.6	17	26	3.1	22	33	3.6	26	40	4.3	34	52	4.8	42	64	5.4	54	80	6.0	62	93
900	NC	0	0	NC	0	0	NC	0	0	RC	11	17	2.3	14	21	2.8	18	27	3.4	24	37	3.8	30	45	4.4	37	55	5.0	45	67	5.8	59	83	R_{min} = 950		
800	NC	0	0	NC	0	0	NC	0	0	RC	11	17	2.5	15	23	3.1	20	30	3.6	26	39	4.2	32	48	4.8	40	60	5.4	47	71	6.0	57	86			
700	NC	0	0	NC	0	0	RC	10	15	2.1	12	17	2.8	17	26	3.4	22	33	4.0	29	43	4.6	36	55	5.3	43	64	5.8	51	76	R_{min} = 755					
600	NC	0	0	NC	0	0	RC	10	15	2.4	13	20	3.1	19	28	3.8	25	37	4.4	31	46	5.0	38	57	5.6	46	69	6.0	53	79						
500	NC	0	0	NC	0	0	2.1	11	16	2.6	16	23	3.1	21	32	4.2	27	41	4.8	35	52	5.4	41	62	6.0	46	72	R_{min} = 560								
400	NC	0	0	RC	10	14	2.5	13	19	3.3	18	27	4.0	24	36	4.7	30	46	5.4	38	57	6.0	44	66	R_{min} = 435											
300	NC	0	0	RC	10	14	2.9	16	24	3.8	22	32	4.6	28	41	5.4	35	53	5.9	42	63	R_{min} = 335														
250	NC	0	0	2.2	11	17	3.3	18	27	4.2	25	35	5.0	30	44	5.8	38	57	6.0	43	66															
200	NC	0	0	2.6	13	20	3.8	20	30	4.7	24	36	5.5	33	50	6.0	38	57	R_{min} = 250																	
175	RC	9	14	3.0	16	22	4.2	24	35	5.0	29	42	5.8	35	52	R_{min} = 195																				
150	RC	9	14	3.3	17	24	4.6	23	34	5.4	29	44	5.9	36	54																					
140	RC	9	14	3.5	17	26	4.8	23	34	5.5	30	45	6.0	36	54																					
130	2.1	9	14	3.6	17	26	4.9	24	35	5.6	31	47	R_{min} = 135																							
120	2.2	10	15	3.8	18	27	5.0	25	37	5.8	32	47																								
110	2.4	11	16	3.9	19	29	5.1	26	39	5.9	32	48																								
100	2.5	11	17	4.1	20	30	5.3	27	40	6.0	33	50																								
90	2.7	12	18	4.3	21	32	5.4	28	42	R_{min} = 90																										
80	3.0	14	21	4.5	22	33	5.6	29	43																											
70	3.2	14	22	4.7	23	34	5.8	30	45																											
60	3.5	16	24	4.9	24	36	6.0	31	46																											
50	3.8	17	26	5.2	25	38	R_{min} = 55																													
40	4.2	19	28	5.5	26	40																														
30	4.7	21	32	6.0	29	43																														
20	5.5	23	35	R_{min} = 30																																
	R_{min} = 16																																			

e_{max} = 6%
R = radius of curve
V_d = assumed design speed
e = rate of superelevation
L = minimum length of runoff (does not include tangent runout) as discussed in "Tangent-to-Curve Transition" section
NC = normal crown section
RC = remove adverse crown, superelevate at normal crown slope

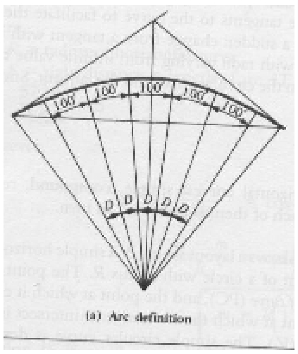
e_{max} = 6%

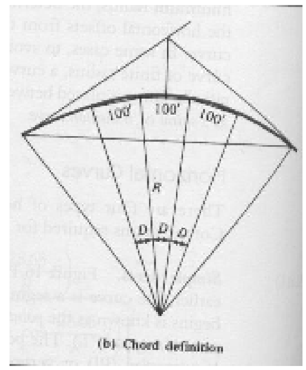
Exhibit 3-22. Values for Design Elements Related to Design Speed and Horizontal Curvature

Properties of Circular Curves

Degree of Curvature

- Traditionally, the "steepness" of the curvature is defined by either the **radius (R)** or the **degree of curvature (D)**
- In highway work we use the ARC definition
- Degree of curvature = angle subtended by an arc of length 100 feet





Degree of Curvature

Equation for D

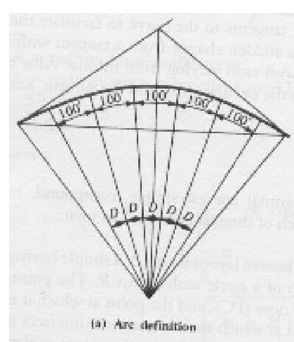
Degree of curvature = angle subtended by an arc of length 100 feet

By simple ratio: D/360 = 100/2*Pi*R

Therefore

R = 5730 / D

(Degree of curvature is <u>not</u> used with metric units because D is defined in terms of feet.)



Length of Curve

By simple ratio: D/ Δ = ?

D/ Δ = 100/L

L = 100 Δ / D

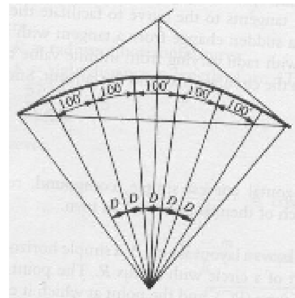
Therefore

L = 100 Δ / D

Or (from R = 5730 / D, substitute for D = 5730/R)

L = Δ R / 57.30

(D is not Δ .)



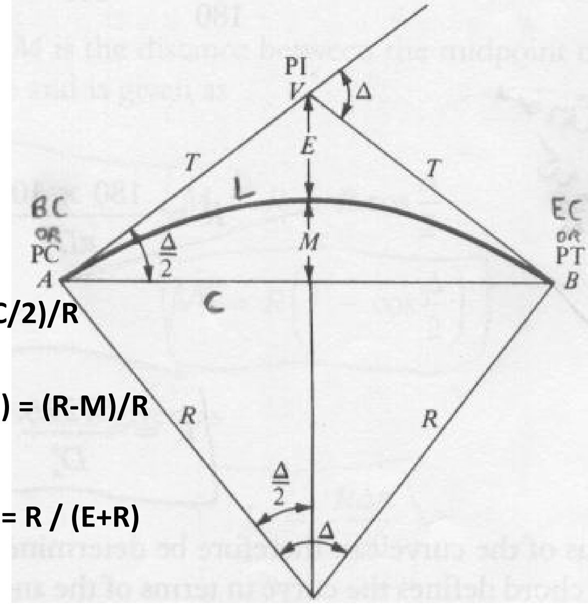
(a) Arc definition

Simple Curves

-The point at which the curve **begins** (A) is known as the **point of curve** (PC)
-The point at which the curve **ends** (B) is known as the **point of tangent (PT).**
-The point at the two tangents **intersection** is known as the **point of intersection (PI)** or vertex (V).
-**External distance (E)** The **distance** from the point of intersection to the curve on a radial line.
- **middle ordinate (M)** The **distance** between the midpoint of the long chord and the midpoint of the curve.
-The **angle (Δ)** that is formed by the two tangents is known as the intersection angle

Properties of Circular Curves

Other Formulas…



Tangent: $\tan(\Delta/2) = T/R$

$T = R \tan(\Delta/2)$

Chord: $\sin(\Delta/2) = (C/2)/R$

$C = 2R \sin(\Delta/2)$

Mid Ordinate: $\cos(\Delta/2) = (R-M)/R$

$M = R - R\cos(\Delta/2)$

External Distance: $E = R\sec(\Delta/2) - R$

$\cos(\Delta/2) = R/(E+R)$

Formulas Simple Curves

$$T = R\tan\frac{\Delta}{2}$$

T = tangent length

$$E = R\left(\frac{1}{\cos\frac{\Delta}{2}} - 1\right)$$

E = external distance

$$C = 2R\sin\frac{\Delta}{2}$$

Length (C) of the chord (AB) or (long chord)

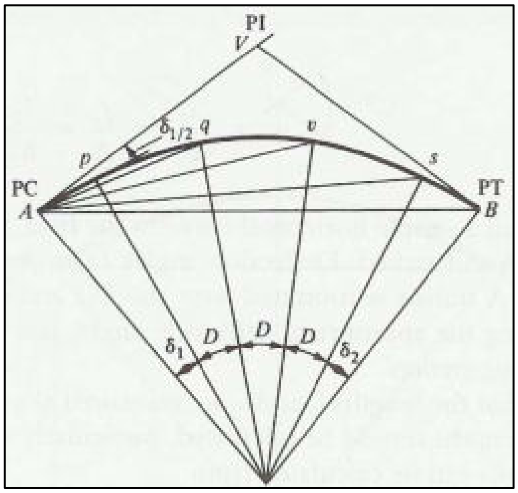
$$M = R\left(1 - \cos\frac{\Delta}{2}\right)$$

M = middle ordinate

$$L = \frac{R\Delta\pi}{180}$$

Length of the curve (L)

Field location of a simple horizontal curve - Defection Angles method



$$l_1 = \frac{R\pi}{180}\delta_1$$

$$\delta_1 = \frac{180}{R\pi} l_1$$

Setting Horizontal curve using Angular method (Example)

- The deflection angle of a 4° curve is 55°25'. If the PC is located at station (238+44.75), determine the length of the curve and the station of PT. Also determine the deflection angles and chords for setting out the curve at whole stations from the PC.

Solution

D= 4° curve Δ = 55°25’ PC is located at station (238+44.75).

Let's review some terms.

What is station?!!

The Concept of Station

- The position of a specific point on a highway is traditionally determined using concept of stations
- A datum point on a highway alignment is specified. This initial point is designated station 0+ 00.00
- The positions of all other points on the highway are calculated by measuring corresponding distances on a horizontal plane along the highway from the initial point. For example, the point on a highway located 23844.75 ft from the previously specified point, is designated station 2 + 384.475 or 238+44.75

Continuation.

- Now calculate the following:

length of curve

$$L = \frac{R\Delta\pi}{180}$$

curve radius (R=5727.27/D)

R= $\frac{5727.27}{4}$ = 1431.82 ft.

Length of curve= $\frac{1431.82*3.14*55°25'}{180}$= 1385.42 ft.

1385.42 is written as 13+85.42

Station of PT= station of PC + Length of curve.

= (238+44.75) + (13+85.42)= 252+30.17

Setting curve using Angular method

$$l_1 = \frac{R\pi}{180}\delta_1$$

$$\delta_1 = \frac{180}{R\pi} l_1$$

R = 1431.82 ft

Station	Chord length	Deflection angle/2	cumulative deflection angle	Cumulative chord length
238+44.75	0	0	0	0
239+00	55.25	1'6'17.99''	1.10499	55.25
240+00	100	1'59'59.99''	3.04989	155.25
241+00	100	1'59'59.99	5.04988	255.25
242+00	100	1'59'59.99	7.04987	355.25
243+00	100	1'59'59.99	9.04986	455.25
244+00	100	1'59'59.99	11.04985	555.25
245+00	100	1'59'59.99	13.04984	655.25
246+00	100	1'59'59.99	15.04983	755.25
247+00	100	1'59'59.99	17.04982	855.25

Setting curve using Angular method

$$l_1 = \frac{R\pi}{180}\delta_1$$

$$\delta_1 = \frac{180}{R\pi}l_1$$

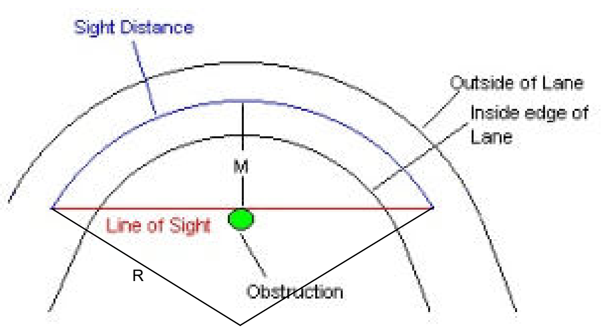
R = 1431.82 ft

Station	Chord length	Deflection angle/2	cumulative deflection angle	Cumulative chord length
248+00	100	1'59'59.99	19.04981	955.25
249+00	100	1'59'59.99	21.04980	1055.25
250+00	100	1'59'59.99	23.04979	1155.25
251+00	100	1'59'59.99	25.04978	1255.25
252+00	100	1'59'59.99	27.04977	1355.25
252+30.17	30.17	0'36'12.24''	27.653169	1385.42

15-11-2022 Prof. Mahmoud Enieb 55

55

Horizontal Curve Sight Distance



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

- Sight line is a chord of the circular curve
- Sight Distance is curve length measured along centerline of inside lane

15-11-2022 Prof. Mahmoud Enieb 56

56

Horizontal Curve Sight Distance

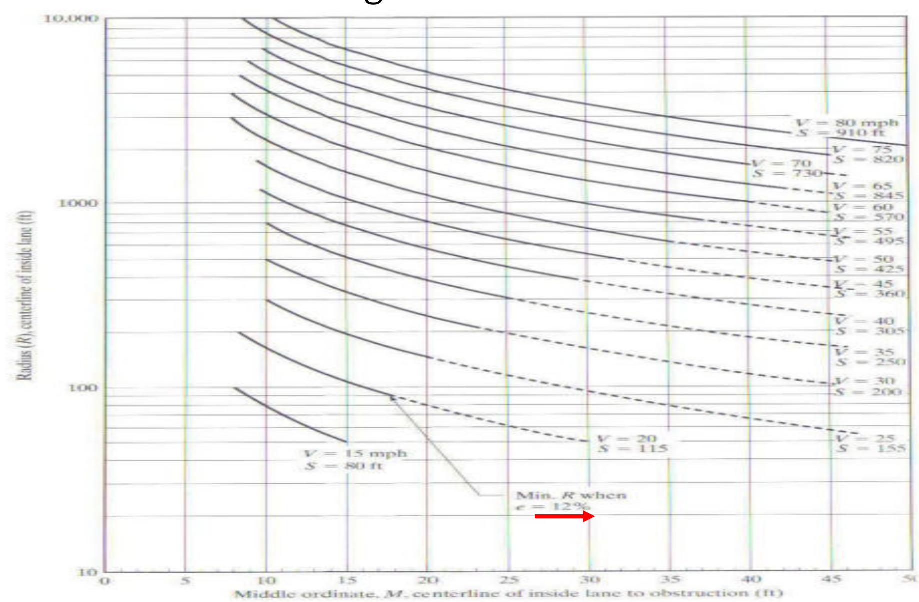
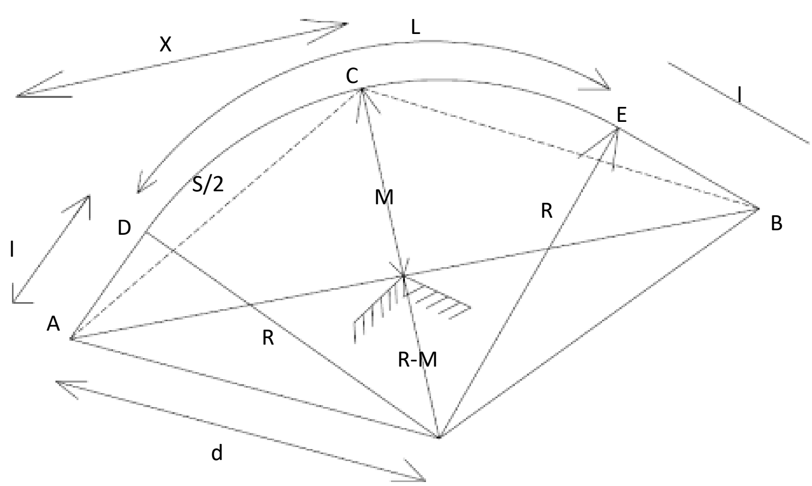


Figure 6-10 Design Controls for Stopping Sight Distance on Horizontal Curves (AASHTO, 2001).

SSD > Length of curve (S= L+2l)



$S > L$

$S = L + 2l$

Therefore $l = (S - L) / 2$

By geometry,

$(S/2)^2 = X^2 + M^2$

$X^2 = d^2 - (R-M)^2$

$(S/2)^2 = d^2 - (R-M)^2 + M^2$

$l = (S-L)/2$

$d^2 = ((S-L)/2)^2 + R^2$

$(S/2)^2 = ((S-L)/2)^2 + R^2 - (R-M)^2 + M^2$

$S^2/4 = (S-L)^2/4 + R^2 - R^2 + 2RM - M^2 + M^2$

$S^2 = (S-L)^2 + 8RM$

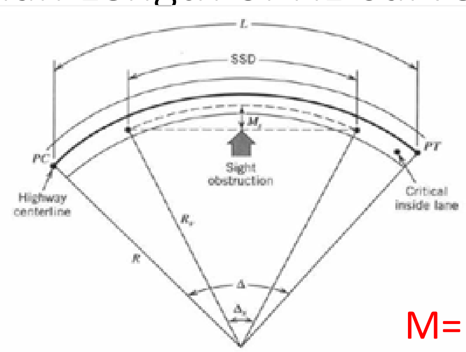
$S^2 = S^2 - 2SL + L^2 + 8RM$

$L (2S - L) = 8RM$

$M = (L (2S - L)) / 8R$

SSD less than Length of Hz curve

$S \geq L$



$M = S^2 / 8R$

Figure 3.14 Stopping sight distance considerations for horizontal curves.

R = radius measured to the centerline of the road in ft (m),

R_v = radius to the vehicle's traveled path (usually measured to the center of the innermost lane of the road) in ft (m),

Δ = central angle of the curve in degrees,

Δ_s = angle (in degrees) subtended by an arc equal in length to the required stopping sight distance (SSD),

L = length of curve in ft (m),

M_s = middle ordinate necessary to provide adequate stopping sight distance (SSD) in ft (m).

SSD = stopping sight distance in ft (m),

PC = point of curve (the beginning point of the horizontal curve), and

PT = point of tangent (the ending point of the horizontal curve).

Middle ordinate (M) necessary to provide adequate SSD

$$SSD = 0.278\,Vt + \frac{V^2}{254(f \pm G)}\ (Metric\ unit)$$

- $SSD = 1.47Vt + \frac{V^2}{30(f \pm G)}$ $(Britch\ unit)$
- M= $\frac{L(2S-L)}{8\,R}$ $(\,SSD \quad L)$
- M= $\frac{S^2}{8\,R}$ $(\,SSD \leq L)$

Example 1

A traveling car parked suddenly on a sharp horizontal curve (R= 150m) and the driver hit a horse. The curve is around a corner of a house with distance from inner edge pavement = 4 m. The tracing distance of car on pavement was 60 m, perception reaction time = 2.5 sec. Required:

a) The speed of car before braking.
b) The proposed speed to satisfy SSD at this site.

Solution

$$D = \frac{V^2}{254(f \pm G)}\ (Metric)$$

- Assume coefficient of friction $f = 0.3$ and $G = 0.0$
- $60 = \frac{V^2}{254(0.3 \pm 0)}$
- V = 67.62 km/h
- The speed of car before braking = 67.62 km/h

Solution

M = 4 + 3.75/2 = 5.875 m

Assume S < L

- $\mathbf{M} = \frac{S^2}{8\,R}$ $(\,SSD < L)$
- $S^2 = 5.875 \text{ x } 8 \text{ x } 150 = 7050$
- $S = \sqrt{7050} = 83.96$ m
- $\mathbf{83.96 = 0.278\, x\, 2.5V} + \frac{V^2}{254(0.30 \pm 0.0)}$
- $V^2 + 52.95\,V - 6398 = 0$
- $V = \frac{-b \pm \sqrt{(b^2 - 4ac)}}{2a}$
- $\quad = \frac{-52.95 \pm \sqrt{(52.95^2 + 4x6398)}}{2x1}$
- $\quad = 57.7$ km/h
- The proposed speed to satisfy SSD at this site = 57.7 km/h

15-11-2022 Prof. Mahmoud Enieb 63

63

Example 2

A car moves along a 2 lanes circular curved portion whose degree of curvature = 7 º with a design speed 50 mph. What is the minimum safe distance from the center line to corner of an existing obstruction?

Solution

$R = \frac{5730}{7} = 818.57$ ft

- From table coefficient of friction $f = 0.31$ or assumed = 0.3, $G = 0$
- $\boldsymbol{SSD} = \mathbf{1.47x50x2.5} + \frac{50^2}{30(0.31 \pm 0)} = \boldsymbol{452.57\,ft}$
- $\mathbf{M} = \frac{S^2}{8\,R}$ $(\,SSD < L)$
- $\mathbf{M} = \frac{452.57^2}{8\,x\,818.57} = \mathbf{31.28}\,\boldsymbol{ft}.$
- The minimum safe distance from the center line to corner of an existing obstruction = 31.28 +6 = 37.28 ft.

15-11-2022 Prof. Mahmoud Enieb 64

64

Example 3

A two lane 24 ft. rural highway has a horizontal curve of 8° extending for 650 ft. along its C.L. It has of a 10 ft. wide shoulder on each side, add a corner of building 9 ft. from the edge of the shoulder. What should be the superelevation (e) on the above curve. Draw a longitudinal cross section in the curved portion, rotating the pavement about center line.

Solution

$$R = \frac{5730}{8} = 716.25 \text{ ft}$$

pavement about center
M = 6 + 10 + 9 = 25 ft.

$$25 = \frac{S^2}{8 \, x \, 716.25} \quad (SSD < L)$$

SSD = 378.48 ft

- Assumed $f = 0.30$, $G = 0$
- $SSD = 1.47xVx2.5 + \frac{V^2}{30(0.3 \pm 0)} = 378.48 \text{ ft}$

15-11-2022 Prof. Mahmoud Enieb 65

65

- $378.48 = 3.675V + \frac{V^2}{30(0.30 \pm 0.0)}$
- $V^2 + 33.075\,V - 3406.32 = 0$
- $V = \frac{-b \pm \sqrt{(b^2 - 4ac)}}{2a}$
- $= \frac{-33.075 \pm \sqrt{(33.075^2 + 4x3406.32)}}{2x1}$
- V = 44.12 mph
- From table f_s for 44.12 mph = 0.15
- $R = \frac{44.12^2}{15(0.01xe + 0.15)} = 716.25$
- $44.12^2 = 716.25 \text{ x } 15x(0.01e + 0.15)$
- (0.01e+0.15) = 0.181
- e = (0.181 – 0.15) / 0.01 = 3.1 %
- Rounding

The super elevation (e) on the above curve = 3%

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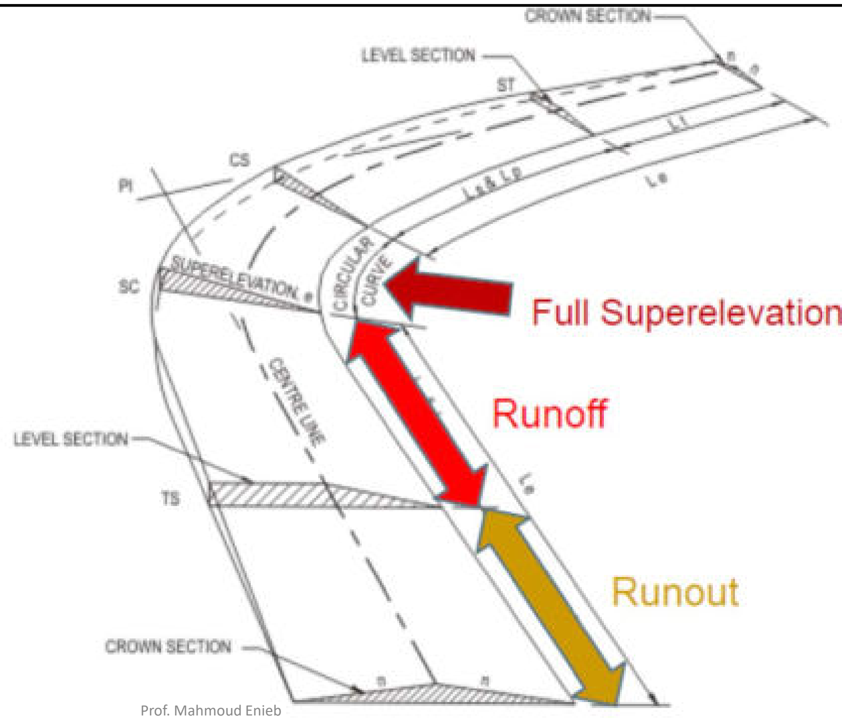
66

Methods of Attaining Superelevation

- Revolve traveled way with normal cross slopes about the centerline profile.
- Revolve traveled way with normal cross slope about the inside-edge profile.
- Revolve traveled way with normal cross slope about the outside-edge profile.

Superelevation Transitions

- Consists of Runoff and Tangent Runout sections
- Runoff: length of roadway needed to accomplish a change in outside lanes cross slope from zero to full
- Runout: length of roadway needed to accomplish a change in outside lanes cross slope from normal rate to zero



69

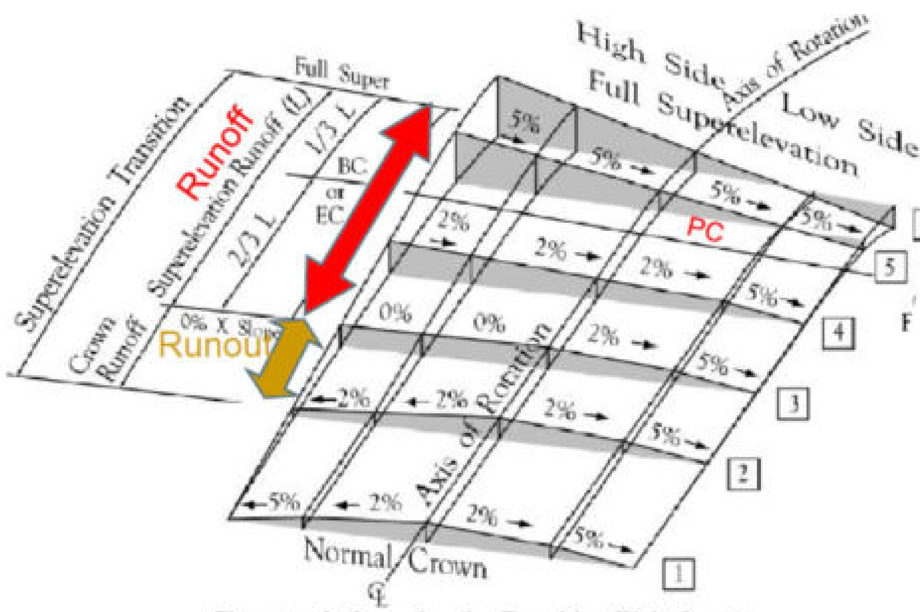
Runoff

- For appearance and comfort, the length of super elevation runoff should be based on a maximum acceptable difference between the longitudinal grades of the axis of rotation and the edge of pavement
- Proper runoff design can be attained through the exclusive use of the maximum relative gradient

70

Runoff

- Locating a portion of the runoff on the tangent, in advance of the PC, is preferable, since this tends to minimize the peak lateral acceleration and resulting side friction demand.
- For non-spiral curves, the North Dakota Department of Transportation (NDDOT) places 2/3 of the runoff on the tangent, and 1/3 of the runoff on the curve.
- For spiral curves, places 1/2 of the runoff on the tangent, and 1/2 of the runoff on the curve



Elements of a Superelevation Transition (Right Curve)

Runout

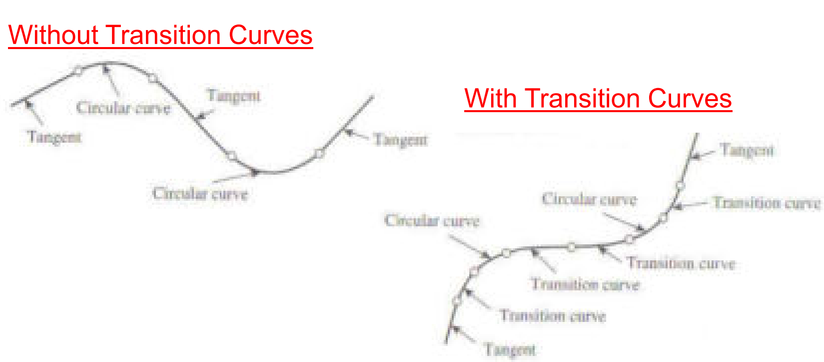
- Determined by the amount of adverse cross slope to be removed and the rate at which is removed.
- To affect a smooth edge of pavement profile, the rate of removal should equal the relative gradient used to define the super elevation runoff length

15-11-2022 Prof. Mahmoud Enieb 73

73

Transition Curves

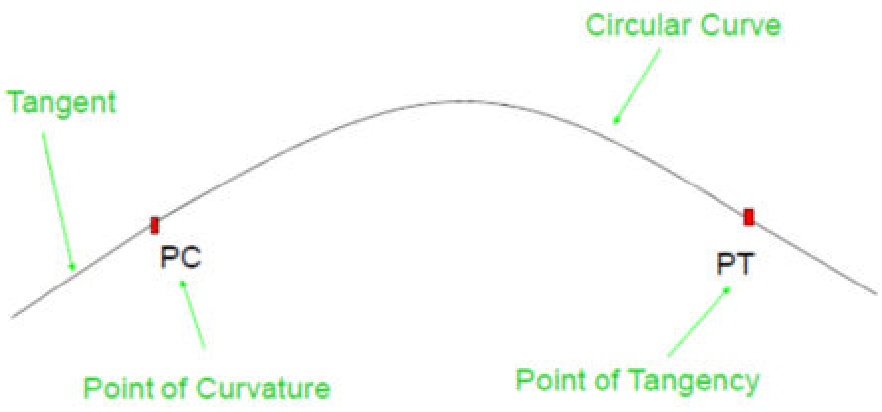
- Gradually changing the curvature from tangents to circular curves



15-11-2022 Prof. Mahmoud Enieb 74

74

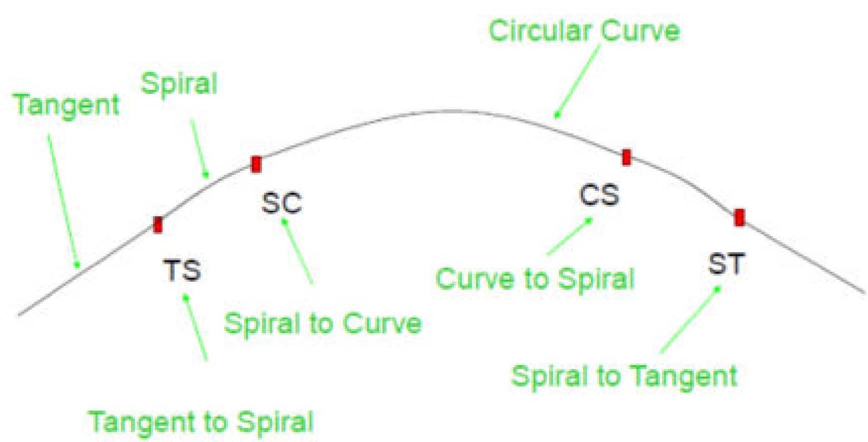
Simple Curve



15-11-2022 Prof. Mahmoud Enieb 75

75

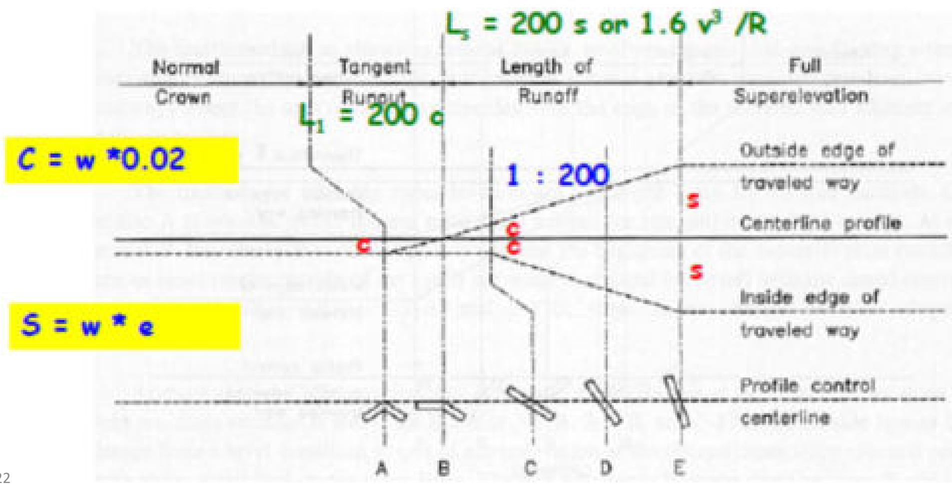
Curve with Spiral Transition



15-11-2022 Prof. Mahmoud Enieb 76

76

Method 1 Rotation about Centerline



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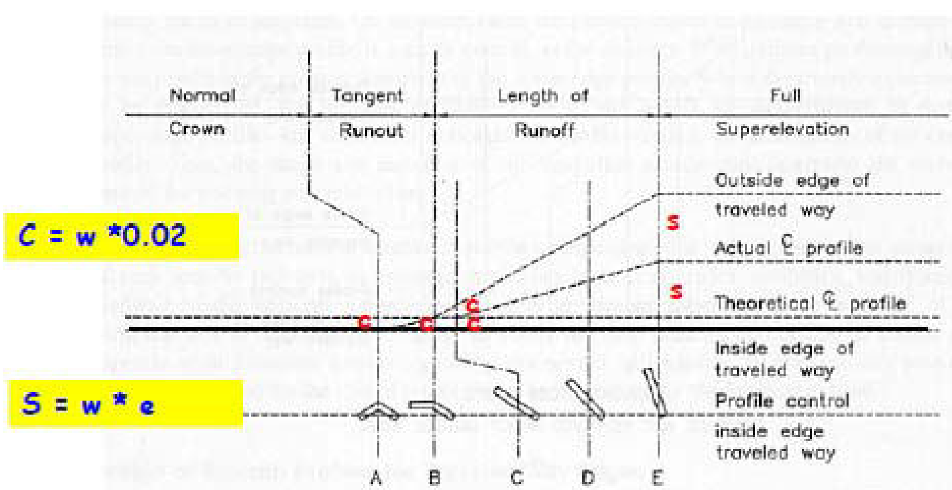
77

Method 2 Rotation about inside edge



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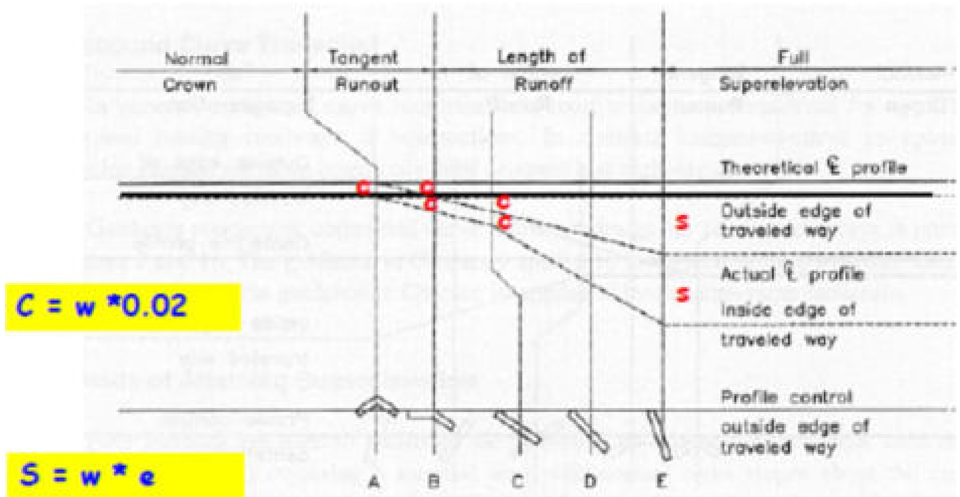
78

Method 3 Rotation about outside edge



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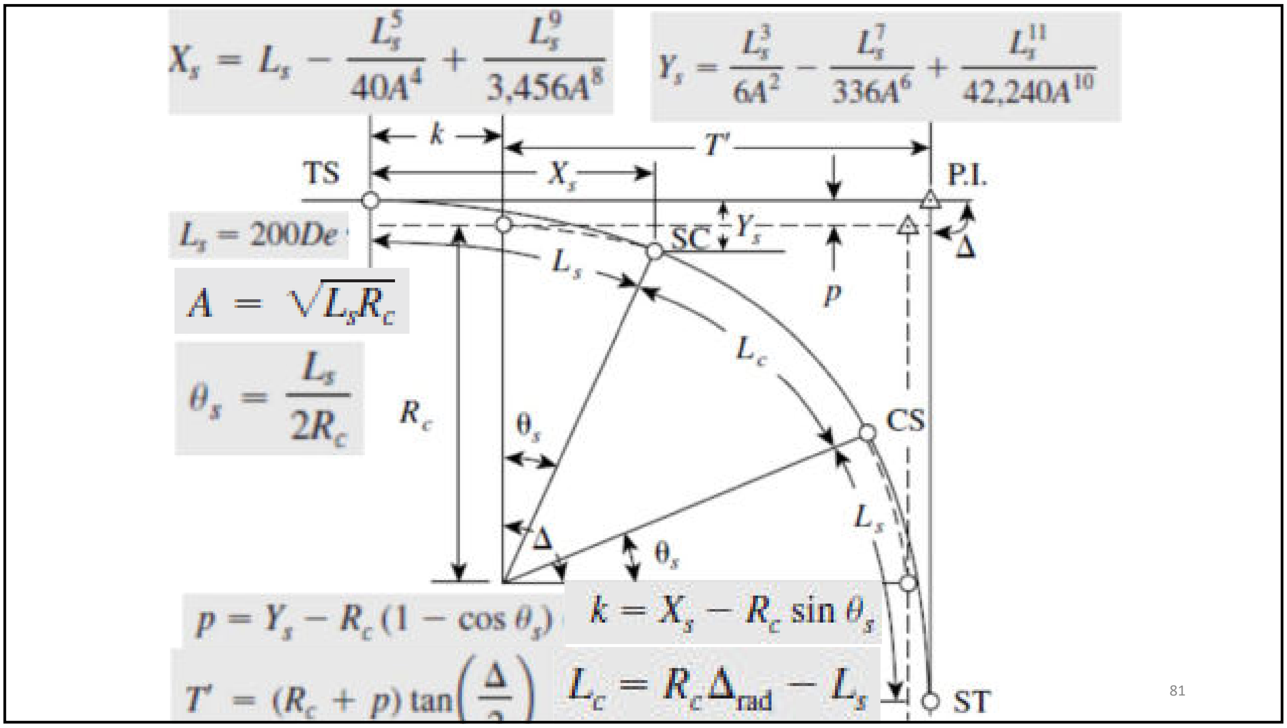
79

Which Method?

- In overall sense, the method of rotation about the centerline (Method 1) is usually the most adaptable.
- Method 2 is usually used when drainage is a critical component in the design.
- In the end, an infinite number of profile arrangements are possible; they depend on drainage, aesthetic, topography among others

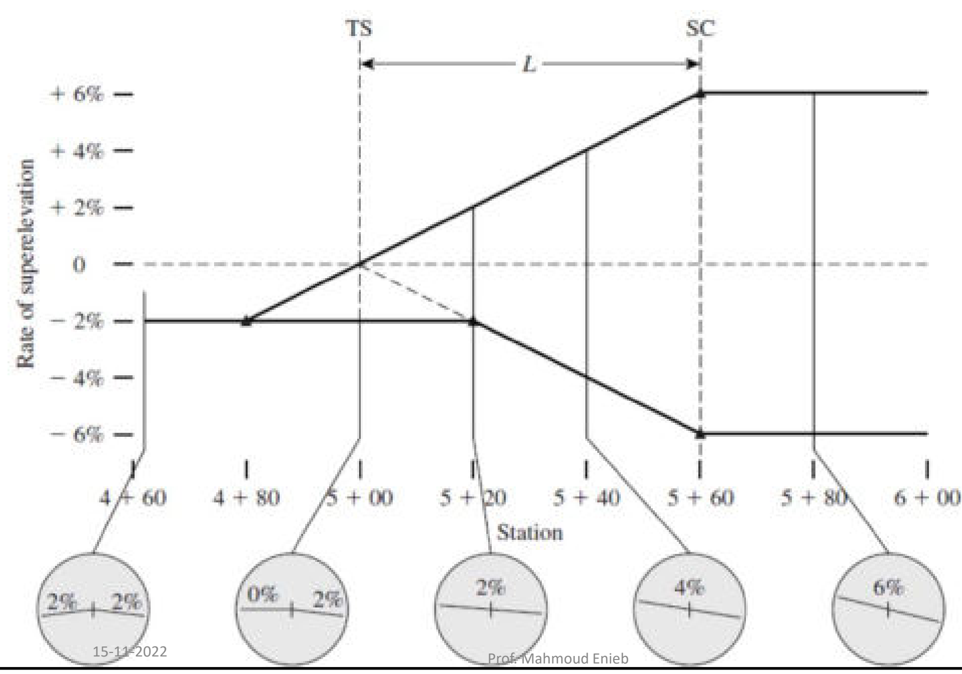
15-11-2022 Prof. Mahmoud Enieb 80

80



81

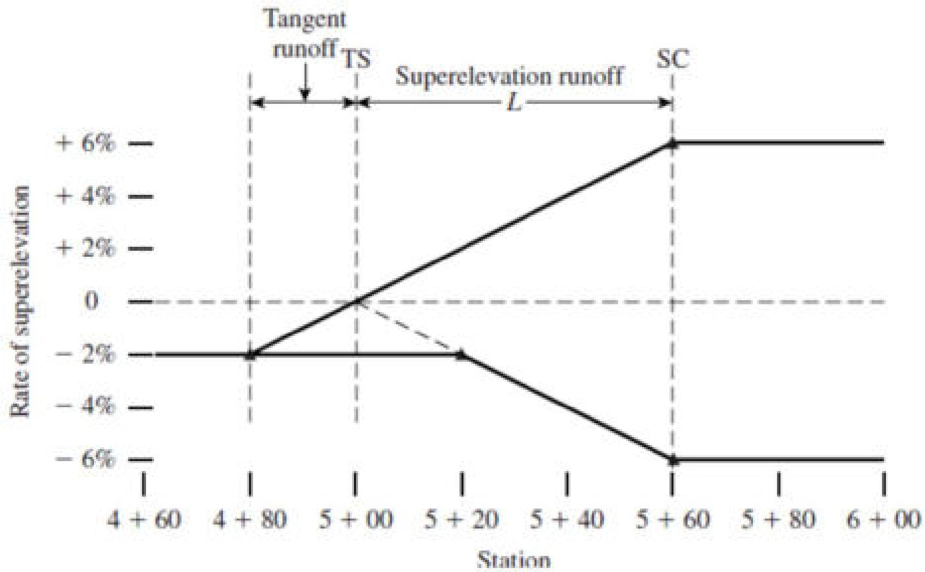
Super elevation diagram, showing roadway cross sections



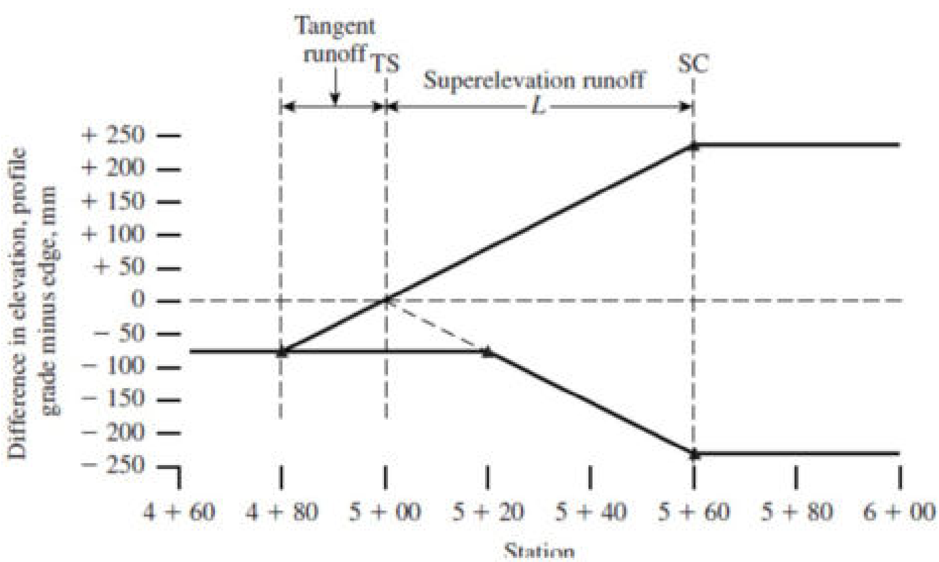
15-11-2022 Prof. Mahmoud Enieb 82

82

Super elevation diagram, showing rate of super elevation



Superelevation diagram, showing difference in elevation



Transition Curves (Britch unit)

- Gradually changing the curvature from tangents to circular curves
  - Use a spiral curve

L: min length of spiral (ft)
V: speed (mph)
R: curve radius (ft)
C: rate of increase of centrifugal acceleration (ft/sec^3), 1~3
Take C = 2 ft/sec^3

$$Ls = \frac{1.577 * V^3}{R} feet\_or\_Ls = \frac{1.6 * V^3}{R}$$

85

Transition Curves Metric unit

- Gradually changing the curvature from tangents to circular curves
  - Use a spiral curve

L: min length of spiral (m)
V: speed (km/h)
R: curve radius (m)
C: rate of increase of centripetal acceleration (m/s^3), 0.3~0.9
Take C = 0.6 m/s^3

$$Ls = \frac{V^3}{28R} meter$$

86

Transition Curves

- More commonly, super elevation transition lengths for highways are based on appearance or comfort criteria.
- One such criterion is a rule that the difference in longitudinal slope (grade) between the centerline and edge of traveled way of a two-lane highway should not exceed 1/200

Transition Curves

- $L \geq 200De$
- Where D the distance from centerline to edge of pavement, e rate of superelevation.
- L is normally rounded up to some convenient length, such as a multiple of 20 m

Example

- A two-lane highway (3.6 m/lane) with a design speed of 100 km/h has a 400 m radius horizontal curve connecting tangents with bearings of N75E° and S78E°.
- Determine the superelevation rate, the length of spiral if the difference in grade between the centerline and edge of traveled way is limited to 1/200, and the stations of the TS, SC, CS, and ST, given that the temporary station of the P.I. is 150+00.
- The length of the spiral should be rounded up to the next highest 20 m interval

Solution

- $$e = \frac{V^2}{127R} - f = \frac{100^2}{127(400)} - 0.12 = 0.08$$ *f* = 0.12 at 100 km/h
- Determine length of superelevation transition and spiral:
- *Ls* =200*De* =200(3.6)(0.08) =57.6 m Round to 60 m
- Determine spiral angle and coordinates of SC point:

$$\theta_s = \frac{L_s}{2R_c} = \frac{60}{2(400)} = (0.075)\text{ rad}$$

- *A* =√*LsRc* =√(60)(400) = 154.9

$$X_s = L_s - \frac{L_s^5}{40A^4} + \frac{L_s^9}{3{,}456A^8} = 60 - \frac{60^5}{40(154.9)^4} + \frac{60^9}{3{,}456(154.9)^8}$$

- X_S = 60 - 0.034 + 0.000 = 59.966 m

Solution

$$Y_s = \frac{L_s^3}{6A^2} - \frac{L_s^7}{336A^6} + \frac{L_s^{11}}{42{,}240A^{10}}$$

$$= \frac{60^3}{6(154.9)^2} - \frac{60^7}{336(154.9)^6} + \frac{60^{11}}{42{,}240(154.9)^{10}}$$

Y_S = 1.500 - 0.001 + 0.000 = 1.499 m

- Determine *p*, *k*, Δ, *T*, and *Lc*
- *p = Ys - Rc* (1 - cos θ*s*)=1.499-400[1-cos(0.075*180/π)]

  = 0.375 m

k = Xs - Rc sin θs =59.996 -400 sin(0.075*180/π) =30.036 m

Δ= (90° – 75°) + (90° – 78°) = 27° = 0.471 radian

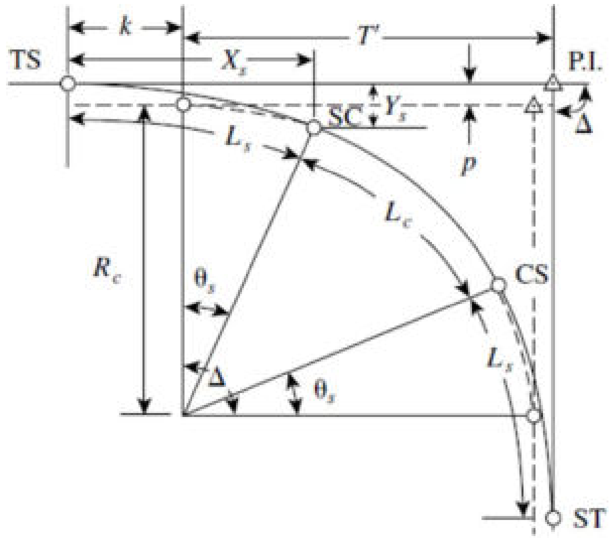
T′ =(R_C+p) tan(Δ/2)=(400+0.375)tan (27/2) = 96.122m

Solution

- $L_C = R_C \Delta_{rad} - L_S$ = 400(0.471) - 60 = 128.4 m
- Determine station of critical points:
- TS station = P.I. station – (T′ + *k*)
- = (150+00) – {(0+96.1) + (0+30.0)}
- = 148 + 73.9
- SC station = TS station + L_S
- = (148 + 73.9) + (0 + 60)
- = 149 + 33.9
- CS station = SC station + L_C
- = (149 + 33.9) + (1 + 28.4)
- = 150 + 62.3

Solution

- ST station = CS station + L_S
- = (150 + 62.3) + (0 + 60)
- = 151 + 22.3



Traveled Way Widening on H^z Curves

- Traveled way widening for horizontal curves may be required to make the operating conditions on the curve similar to those on the tangents. The traveled way widening values for two-lane highway with the specified roadway widths, curve radii and a WB-15 truck are obtained from Table 3 shown below.
- Often, traveled ways on horizontal curves may need to be widened to produce operational characteristics that are similar to tangent sections. While the need for widening on modern highways is less than that for past roadways, there are some cases where speed, curvature, or width may require appropriate traveled way widening

Table 3. Calculated and Design Values for Travel Way Widening

Metric																		
Radius of curve (m)	Roadway width = 7.2 m Design Speed (km/h)						Roadway width = 6.6 m Design Speed (km/h)						Roadway width = 6.0 m Design Speed (km/h)					
	50	60	70	80	90	100	50	60	70	80	90	100	50	60	70	80	90	100
3000	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.2	0.3	0.3	0.3	0.3	0.5	0.5	0.6	0.6	0.6	0.6
2500	0.0	0.0	0.0	0.0	0.0	0.0	0.2	0.3	0.3	0.3	0.3	0.3	0.5	0.6	0.6	0.6	0.6	0.6
2000	0.0	0.0	0.0	0.0	0.0	0.1	0.3	0.3	0.3	0.3	0.3	0.4	0.6	0.6	0.6	0.6	0.6	0.7
1500	0.0	0.0	0.1	0.1	0.1	0.1	0.3	0.3	0.4	0.4	0.4	0.4	0.6	0.6	0.7	0.7	0.7	0.7
1000	0.1	0.1	0.1	0.2	0.2	0.2	0.4	0.4	0.4	0.5	0.5	0.5	0.7	0.7	0.7	0.8	0.8	0.8
900	0.1	0.1	0.2	0.2	0.2	0.3	0.4	0.4	0.5	0.5	0.5	0.6	0.7	0.7	0.8	0.8	0.8	0.9
800	0.1	0.2	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.5	0.6	0.6	0.7	0.8	0.8	0.8	0.9	0.9
700	0.2	0.2	0.2	0.3	0.3	0.4	0.5	0.5	0.5	0.6	0.6	0.7	0.8	0.8	0.8	0.9	0.9	1.0
600	0.2	0.3	0.3	0.3	0.4	0.4	0.5	0.6	0.6	0.6	0.7	0.7	0.8	0.9	0.9	0.9	1.0	1.0
500	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9	0.9	1.0	1.0	1.1	1.1
400	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	0.8	0.8	0.9	0.9	1.0	1.0	1.1	1.1	1.2	1.2
300	0.5	0.6	0.6	0.7	0.8	0.8	0.8	0.9	0.9	1.0	1.1	1.1	1.1	1.2	1.2	1.3	1.4	1.4
250	0.6	0.7	0.8	0.8	0.9		0.9	1.0	1.1	1.1	1.2		1.2	1.3	1.4	1.4	1.5	
200	0.8	0.9	1.0	1.0			1.1	1.2	1.3	1.3			1.4	1.5	1.6	1.6		
150	1.1	1.2	1.3	1.3			1.4	1.5	1.6	1.6			1.7	1.8	1.9	1.9		
140	1.2	1.3					1.5	1.6					1.8	1.9				
130	1.3	1.4					1.6	1.7					1.9	2.0				
120	1.4	1.5					1.7	1.8					2.0	2.1				
110	1.5	1.6					1.8	1.9					2.1	2.2				
100	1.6	1.7					1.9	2.0					2.2	2.3				
90	1.8						2.1						2.4					
80	2.0						2.3						2.6					
70	2.3						2.6						2.9					

Notes: Values shown are for WB-15 design vehicle and represent widening in meters. For other design vehicles, use adjustments in Exhibit 3-48.
Values less than 0.6 m may be disregarded.
For 3-lane roadways, multiply above values by 1.5.
For 4-lane roadways, multiply above values by 2.

Travel lane widening for alternative vehicle types can be obtained by adding the values defined in Table 4 for the appropriate curve radius and vehicle type to the value obtained from Table 3.
Very little benefit is gained from small amount of widening. Therefore, the minimum widening will be 0.6 meters with widening amounts less than 0.6 meters being disregarded. Widening should be applied on the inside edge of the curve only and the widening should transition over the super elevation runoff length with 2/3 of the transition length along the tangent and 1/3 of the transition length along the curve. The edge of the traveled way through the widening transition should be a smooth curve with the transition ends avoiding an angular break at the pavement edge.

Table 4. Adjustments for Traveled Way Widening Values

Metric							
Radius of curve	Design vehicle						
(m)	SU	WB–12	WB–19	WB–20	WB–20D	WB–30T	WB–33D
3000	–0.3	–0.3	0.0	0.0	0.0	0.0	0.1
2500	–0.3	–0.3	0.0	0.0	0.0	0.0	0.1
2000	–0.3	–0.3	0.0	0.0	0.0	0.0	0.1
1500	–0.4	–0.3	0.0	0.1	0.0	0.0	0.1
1000	–0.4	–0.4	0.1	0.1	0.0	0.0	0.2
900	–0.4	–0.4	0.1	0.1	0.0	0.0	0.2
800	–0.4	–0.4	0.1	0.1	0.0	0.0	0.2
700	–0.4	–0.4	0.1	0.1	0.0	0.0	0.3
600	–0.5	–0.4	0.1	0.1	0.0	0.1	0.3
500	–0.5	–0.4	0.1	0.2	0.0	0.1	0.4
400	–0.5	–0.4	0.2	0.2	0.0	0.1	0.5
300	–0.6	–0.5	0.2	0.3	–0.1	0.1	0.6
250	–0.7	–0.5	0.2	0.3	–0.1	0.1	0.8
200	–0.8	–0.6	0.3	0.4	–0.1	0.2	1.0
150	–0.9	–0.7	0.4	0.6	–0.1	0.2	1.3
140	–0.9	–0.7	0.4	0.6	–0.1	0.2	1.4
130	–1.0	–0.7	0.5	0.6	–0.2	0.2	1.5
120	–1.1	–0.8	0.5	0.7	–0.2	0.3	1.6
110	–1.1	–0.8	0.6	0.8	–0.2	0.3	1.7
100	–1.2	–0.9	0.6	0.8	–0.2	0.3	1.9
90	–1.3	–0.9	0.7	0.9	–0.2	0.3	2.1
80	–1.4	–1.0	0.8	1.1	–0.2	0.4	2.4
70	–1.6	–1.1	0.9	1.2	–0.3	0.5	2.8

Notes: Adjustments are applied by adding to or subtracting from the values in Exhibit 3-47.
Adjustments depend only on radius and design vehicle; they are independent of roadway width and design speed.
For 3-lane roadways, multiply above values by 1.5.
For 4-lane roadways, multiply above values by 2.0.