Traffic Engineering, 4th Edition
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Solutions to Problems in Chapter 3

Problem 3-1

Information: Horizontal curve, P.I. = 11,500 + 66
Radius = 1,000 ft
Angle of deflection = 60°

Find: All relevant characteristics of the curve. Stations of the P.C. and P.T.

The degree of curvature is computed using Equation 3-1:

$$D = \frac{5{,}729.58}{R} = \frac{5{,}729.58}{1{,}000} = 5.73^{o}$$

Then:

$$T = R\ Tan\left(\Delta/2\right) = 1{,}000\ Tan\left(60/2\right) = 1{,}000\ Tan(30) = 1{,}000 * 0.5773 = 577.3\ \ ft$$

$$L = 100\left(\frac{\Delta}{D}\right) = 100\left(\frac{60}{5.73}\right) = 100 * 10.47 = 1{,}047\ \ ft$$

$$M = R\left[1 - Cos\left(\Delta/2\right)\right] = 1{,}000 * \left[1 - Cos\left(60/2\right)\right] = 1{,}000 * 0.1340 = 134\ \ ft$$

$$E = R\left[\left(\frac{1}{Cos\left(\Delta/2\right)}\right) - 1\right] = 1{,}000\left[\left(\frac{1}{Cos(30)}\right) - 1\right] = 1{,}000 * \left[0.1547\right] = 154.7\ \ ft$$

$$LC = 2R\ Sin\left(\Delta/2\right) = 2 * 1{,}000 * Sin(30) = 2{,}000 * 0.5000 = 1{,}000\ ft$$

Stationing:

P.C. = (11,500+66)-577.3=10,988.7 = 10,900+88.7
P.T. = (10,900+88.7)+1,047=13,035.7=12,000+35.7

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Problem 3-2

Information:
3.5° curve
60 mi/h design speed
Two 12-ft lanes
Use spiral transition curves
P.I. = 15,100+26
Angle of deflection =40°

Find: T.S., S.C., C.S., and S.T.

The design value of superelevation is given by Equation 3-9:

$$e = 100\left[\left(\frac{S_{des}^2}{15R}\right) - f_{des}\right]$$

From Table 3-3, the design friction factor (f_{des}) = 0.12. Then:

$$R = \frac{5{,}729.58}{D} = \frac{5{,}729.58}{3.5} = 1{,}637 \ ft$$

$$e = 100\left[\left(\frac{60^2}{15 * 1{,}637}\right) - 0.12\right] = 2.6\%$$

The length of the spiral is typically estimated using Equation 3-13:

$$L_S = 1.6\left(\frac{S^3}{R}\right) = 1.6 * \left(\frac{60^3}{1{,}637}\right) = 1.6 * 131.9 = 211 \ ft$$

It may also be computed as the length of the spiral runoff, or the length of the spiral plus tangent runoffs. These are estimated using Equations 3-10 and 3-11, using the following assumptions: Superelevation is achieved by rotating both lanes around the centerline, and the normal drainage cross-slope is 1%. Then:

$$L_r = \frac{w * n * e_d * b_w}{\Delta}$$

$$L_t = \frac{e_{NC}}{e_d} L_r$$

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Where:	w	=	12 ft
	n	=	1 lanes rotated around centerline
	e_{NC}	=	1%
	e_d	=	2.6%
	b_w	=	1.00 (See page 46, 1 lanes rotated around centerline)
	Δ	=	0.45 (Table 3.4, 60 mi/h)

Then:

$$L_r = \frac{12*1*2.6*1.00}{0.45} = 69.3 \ ft$$

$$L_t = \left(\frac{1}{2.6}\right)*69.3 = 26.7 \ ft$$

$$L_r + L_t = 69.3 + 26.7 = 96.0 \ ft$$

Equation 3-13 is based upon driver comfort. A value of 211 ft will be used.

The central angle for the spiral is given by Equation 3-14:

$$\delta = \frac{L_S \, D}{200} = \frac{211*3.5}{200} = 3.7^o$$

The central angle of deflection for the circular portion of the curve is given by Equation 3-15:

$$\Delta_S = \Delta - 2\delta = 40.0 - (2*3.7) = 32.6^o$$

Then:

$$T_S = \left[R\,Tan\left(\frac{\Delta}{2}\right)\right] + \left[\left(R\,Cos(\delta) - R + \frac{L_s^2}{6R}\right)*Tan\left(\frac{\Delta}{2}\right)\right] + \left[L_s - R\,Sin(\delta)\right]$$

$$T_S = \left[1637\,Tan\left(\frac{40}{2}\right)\right] + \left[\left(1637\,Cos(3.7) - 1637 + \left(\frac{211}{6*1637}\right)\right)*\left(Tan\left(\frac{40}{2}\right)\right)\right] + \left[211 - 1637\,Sin(3.7)\right]$$

$$T_S = 595.8 + 0.4 + 105.3 = 701.5 \ ft$$

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And:

$$L_c = 100\left(\frac{\Delta_s}{D}\right) = 100\left(\frac{32.6}{3.5}\right) = 931\ ft$$

Then:

$$T.S. = P.I. - T_s = (15{,}100 + 26) - 701.5 = 14{,}424.5 = 14{,}400 + 24.5$$
$$S.C. = T.S. + L_s = 14{,}424.5 + 211 = 14{,}635.5 = 14{,}600 + 35.5$$
$$C.S. = S.C. + L_c = 14{,}635.5 + 931 = 15{,}566.5 = 15{,}500 + 66.5$$
$$S.T. = C.S. + L_s = 15{,}566.5 + 211 = 15{,}777.5 = 15{,}700 + 77.5$$

Problem 3-3

Information: 5^o curve
65 mi/h design speed
2% upgrade
t = 2.5 s (driver reaction time)

Find: Closest placement of roadside object.

Placement of roadside objects is based upon the severity of the curve and the safe-stopping distance, computed as:

$$d_s = 1.47\,S\,t + \frac{S^2}{30(0.348 + 0.01G)} = (1.47 * 65 * 2.5) + \left(\frac{65^2}{30 * (0.348 + 0.02)}\right)$$
$$d_s = 238.9 + 382.7 = 621.6\ ft$$

Then: (Equation 3-17)

$$M = \frac{5729.58}{D}\left[1 - Cos\left(\frac{d_s D}{200}\right)\right] = \frac{5729.58}{5}\left[1 - Cos\left(\frac{621.6 * 5}{200}\right)\right]$$
$$M = 1{,}145.9 * [1 - Cos(15.54)] = 1{,}145.9 * 0.036551 = 41.9\ ft$$

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Problem 3-4

Information: R = 1,200 ft
60 mi/h design speed
6% maximum superelevation rate

Find: Appropriate superelevation rate

Using Equation 3-9:

$$e = 100\left[\left(\frac{S_{des}^2}{15R}\right) - f_{des}\right]$$

Where: f_{des} = 0.12 (Table 3.3, 60 mi/h)

$$e = 100\left[\left(\frac{60^2}{15*1200}\right) - 0.12\right] = 8.0\%$$

The maximum design superelevation rate of 6% would be used.

Problem 3-5

Information: e = 10%
70 mi/h design speed
Three 12-ft lanes
Rotation around pavement edge

Find: Length of superelevation runoff

Using Equation 3-10:

$$L_r = \frac{w*n*e_d*b_w}{\Delta}$$

Where: w = 12 ft (lane width)
N = 3 (lanes rotated)
e_d = 10% (given)
b_w = 0.67 (page 47, 3 lanes rotated)
Δ = 0.40 (Table 2.4, 70 mi/h)

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$$L_r = \frac{12 * 3 * 10 * 0.67}{0.40} = 603 \ ft$$

Problem 3-6

Information:

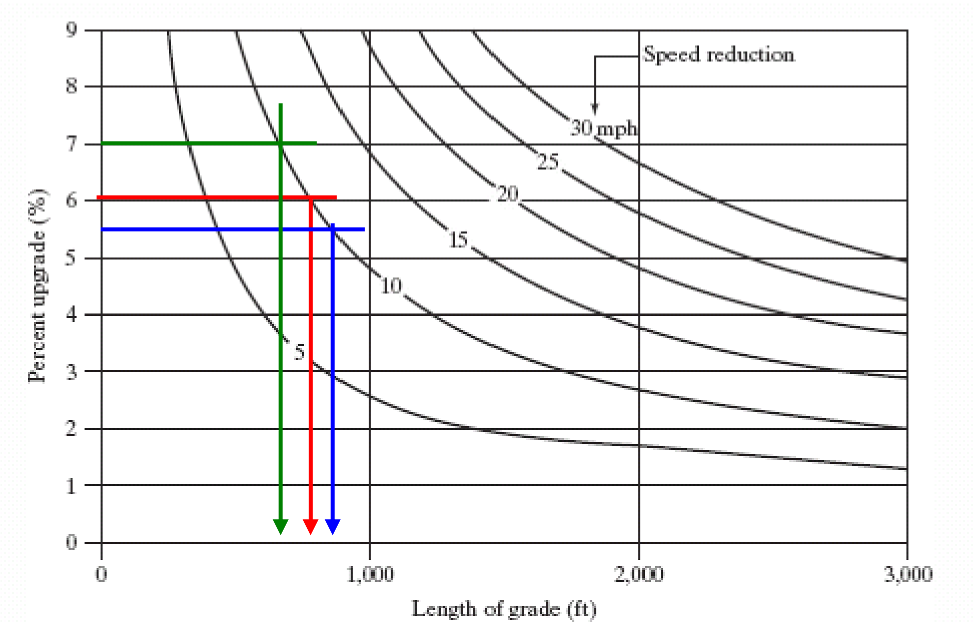
Category	Grade 1	Grade 2	Grade 3
Facility Type	Rural Freeway	Rural Arterial	Urban Arterial
Terrain	Mountainous	Rolling	Level
Design Speed	60 mi/h	45 mi/h	40 mi/h

Find: Maximum grade and critical length of grade for each

From Figure 3.15:

Maximum grades are: Grade 1 = 6%
Grade 2 = 5.5%
Grade 3 = 7%

Critical lengths of grades are found from Figure 3.18, as shown below. Because all design speeds are less than 70 mi/h, a 10% reduction in speeds is used to determine the critical length.



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Grade 1: 800 ft
Grade 2: 850 ft
Grade 3: 700 ft

Problem 3-7

Information: Vertical curve
+4% grade to -5% grade
V.P.I. = 1,500+55
Elevation of V.P.I. = 500 ft
L = 1,000 ft

Find: Stations of the V.P.C. and V.P.T.
Elevations of the V.P.C. and V.P.T.
Elevation points along the curve at 100-ft intervals
Location and elevation of the high point

Note that the curve described is a *crest vertical curve*.

An equation for this vertical curve can be constructed in the form of:

$$Y_x = ax^2 + b_c + Y_o$$

Where:

$$a = \frac{G_2 - G_1}{2L} = \frac{-5-4}{2*10} = -0.45$$
$$b = G_1 = 4$$
$$L = 10 \ (measured \ in \ 100's \, of \ \ ft)$$
$$Y_o = Y_{VPC} = 500.00 - (4*5) = 480.0 \ \ ft$$

Thus:

$$Y_x = -0.45x^2 + 4x + 480.0$$

Stations: VPC = (1500+55)-500 = 1,000+55
VPT = (1500+55)+1000 = 2,500+55

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Elevations:

$$Y_x = -0.45x^2 + 4x + 480.0$$
$$Y_o = Y_{VPC} = 480 \ ft$$
$$Y_1 = -0.45(1^2) + (4*1) + 480 = 483.55 \ ft$$
$$Y_2 = -0.45(2^2) + (4*2) + 480 = 486.2 \ ft$$
$$Y_3 = -0.45(3^2) + (4*3) + 480 = 487.95 \ ft$$
$$Y_4 = -0.45(4^2) + (4*4) + 480 = 488.80 \ ft$$
$$Y_5 = -0.45(5^2) + (4*5) + 480 = 488.75 \ ft$$
$$Y_6 = -0.45(6^2) + (4*6) + 480 = 487.85 \ ft$$
$$Y_7 = -0.45(7^2) + (4*7) + 480 = 485.95 \ ft$$
$$Y_8 = -0.45(8^2) + (4*8) + 480 = 483.20 \ ft$$
$$Y_9 = -0.45(9^2) + (4*9) + 480 = 479.55 \ ft$$
$$Y_{10} = Y_{PVT} = -0.45(10^2) + (4*10) + 480 = 475.00 \ ft$$

The high point is found as:

$$x = \frac{-G_1 L}{G_2 - G_1} = \frac{-4*10}{-5-4} = \frac{-40}{-9} = 4.44 \ (100s \, of \ ft)$$
$$Y_{4.44} = -0.45(4.44^2) + (4*4.44) + 480 = 488.9 \ ft$$

<u>Problem 3-8</u>

Information:

Grade	Entry Grade	Exit Grade	Design Speed	Reaction Time
1	3%	8%	45 mi/h	2.5 s
2	-4%	2%	65 mi/h	2.5 s
3	0%	-3%	70 mi/h	2.5 s

Find: Minimum lengths of the above vertical curves.

To find the minimum lengths of grade, the safe stopping distance for each curve must be computed. To do this, the grade used in the computation will be grade which results in the worst (or highest) safe stopping distance.

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$$d_s = 1.47\,S\,t + \frac{S^2}{30\,(0.348 + 0.01G)}$$

$$d_{s1} = (1.47 * 45 * 2.5) + \left[\frac{45^2}{30 * (0.348 + 0.01 * 3)}\right] = 165.4 + 178.6 = 344.0 \; ft$$

$$d_{s2} = (1.47 * 65 * 2.5) + \left[\frac{65^2}{30 * (0.348 - 0.01 * 4)}\right] = 238.9 + 457.3 = 696.2 \; ft$$

$$d_{s3} = (1.47 * 70 * 2.5) + \left[\frac{70^2}{30 * (0.348 - 0.01 * 3)}\right] = 257.3 + 513.6 = 770.9 \; ft$$

It should be noted that Curve 1 is a *SAG* vertical curve; Curve 2 is a *SAG* vertical curve; Curve 3 is a *CREST* vertical curve.

We will start each computation assuming that the length of the curve is *greater* than the safe stopping distance:

Curve 1 (Use Equation 3-24)

$$L = \frac{|G_2 - G_1|\; d_s^2}{400 + 3.5\,d_s} = \frac{(8-3) * 344^2}{400 + (3.5 * 344)} = \frac{591{,}680}{1{,}604} = 368.9 \; ft > 344 \; ft \quad OK$$

Curve 2 (Use Equation 3-24)

$$L = \frac{(2-(-4)) * 696.2^2}{400 + (3.5 * 696.2)} = \frac{2{,}908{,}166.6}{2{,}836.7} = 1{,}025.2 \; ft > 696.2 \; ft \;\; OK$$

Curve 3 (Use Equation 3-22)

$$L = \frac{|G_2 - G_1|\, d_s^2}{2{,}158} = \frac{3 * 770.9^2}{2{,}158} = \frac{1{,}782{,}860}{2{,}158} = 826.2 \; ft > 770.9 \; ft \;\; OK$$

Problem 3-9

Information: Vertical curve
-4% to +1%
Minimum length curve
t = 2.5 s
70 mi/h design speed

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VPI = 5100+22
Elevation of the VPI = 1,285 ft

Find: VPC and VPT
Elevation of points on 100-ft intervals
High point and station

To begin, we must determine the minimum length of curve. Note that this is a *SAG* vertical curve.

$$d_s = 1.47\,S\,t + \left(\frac{S^2}{30*(0.348+0.01G}\right)$$

$$d_s = (1.47*70*2.5) + \left[\frac{70^2}{30*(0.348-.04)}\right] = 257.3 + 530.3 = 787.6\ \ ft$$

Assuming that L > d_s, we start using Equation 3-24:

$$L = \frac{|G_2 - G_1|\,d_s^2}{400+3.5\,d_s} = \frac{5*787.6^2}{400+(3.5*787.6)} = \frac{3{,}101{,}568.8}{3{,}156.6} = 982.6\ \ ft > 787.6\ \ ft \quad OK$$

For convenience of construction, we will round off: L = 985 ft or 9.85 in hundreds of feet.

Then:

$$a = \frac{G_2 - G_1}{2L} = \frac{-4-1}{2*9.85} = -0.254$$

$$b = G_1 = -4$$

$$Y_o = Y_{VPC} = 1285 + 4(9.85/2) = 1{,}304.7$$

$$Y_x = -0.254x^2 - 4x + 1{,}304.7$$

Elevations are now computed for intervals of x = 1 (100 ft) from "0" to 9.85 (which is the end of the curve). The station of the VPC is (5100+22)-(985/2)=4600+29.4. The station of the VPT is (5100+22)+(985/2) = 5,600+14.6. The spreadsheet table below shows the resulting elevations:

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L	Y
0	1304.7
1	1300.4
2	1295.7
3	1290.4
4	1284.6
5	1278.4
6	1271.6
7	1264.3
8	1256.4
9	1248.1
9.85	1240.7

Because of the two grades involved, the high point of this curve is at its beginning, or 1,304.7 ft.

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