King Saud University
College of Engineering
Civil Engineering Department

CE 431: Highway Engineering
Tutorial Note 3: Chapter 7
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7.1 Given Δ = 35°, R = 1,350 ft, and the PI station 75 + 28.10, compute the curve data and the station of the PT using conventional US units. Compute the deflection angles at even 100-ft stations.

$$PC\ Sta. = \ PI\ Sta. - T \qquad PT\ Sta. = \ PC\ Sta. + L$$

$$T = R \tan\frac{\Delta}{2} \qquad L = \frac{2\pi R\Delta}{360}$$

$$T = 1350 \tan\frac{35}{2} = 425.65\ ft$$

$$L = \frac{2\pi \times 1350 \times 35}{360} = 824.67\ ft$$

$$PC\ Sta. = \ 7528.1 - \ 425.65 = 7102.45\ ft \rightarrow\rightarrow 71 + 02.45$$

$$PT\ Sta. = \ 7102.45\ +\ 824.67 = 7927.12\ ft \rightarrow\rightarrow 79 + 27.12$$

The deflection angle to the P.T. is Δ/2.

The deflection angle to intermediate stations is proportional to the distance from the P.C.

The distance to station 72 + 00 is = 7200 – 7102.45 = 97.55 ft.

$$Deflection\ angle\ = \frac{\Delta}{2} \times \frac{79.55}{824.67} = 2^{\circ} 4' 12''$$

Other deflection angles are computed similarly:

Station	Deflection Angle (degrees-minutes-seconds)
72 + 00	2° 04’ 12”
73 + 00	4° 11’ 32”
74 + 00	6° 18’ 51”
75 + 00	8° 26’ 11”
76 + 00	10° 33’ 30”
77 + 00	12° 40’ 49”
78 + 00	14° 48’ 09”
79 + 00	16° 55’ 28”
79 + 27.12	17° 30’ 0”

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7.2 Given a horizontal curve with a radius of 410 m, a Δ angle of 32°, and PI station of 1 + 120.744, compute the curve data and the station of the PT. compute the deflection angles at even 20-m stations.

$$PC\ Sta. = PI\ Sta. - T \qquad PT\ Sta. = PC\ Sta. + L$$

$$T = R\tan\frac{\Delta}{2} \qquad L = \frac{2\pi R\Delta}{360}$$

$$T = 410\tan\frac{32}{2} = 117.566\ m$$

$$L = \frac{2\pi \times 410 \times 32}{360} = 228.987\ m$$

$$PC\ Sta. = 1120.744 - 117.566 = 1003.178\ m \rightarrow\rightarrow 1 + 003.178$$

$$PT\ Sta. = 1003.178 + 228.987 = 1232.165\ m \rightarrow\rightarrow 1 + 232.165$$

The deflection angle to the P.T. is Δ/2.

The deflection angle to intermediate stations is proportional to the distance from the P.C.

The distance to station 1 + 020.000 is = (1020.000) – (1003.178) = 16.822 m.

$$Deflection\ angle = \frac{\Delta}{2} \times \frac{16.822}{228.987} = 1^{\circ}10'31''$$

Other deflection angles are computed similarly:

Station	Deflection Angle (degrees-minutes-seconds)
1 + 020	1° 10’ 31”
1 + 040	2° 34’ 22”
1 + 060	3° 58’ 13”
1 + 080	5° 22’ 04”
1 + 100	6° 45’ 55”
1 + 120	8° 9’ 46”
1 + 140	9° 33’ 37”
1 + 160	10° 57’ 27”
1 + 180	12° 21’ 18”
1 + 200	13° 45’ 09”
1 + 220	15° 09’ 00”
1 + 232.165	16° 00’ 00”

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7.3 What superelevation rate would you recommend for a roadway with a design speed of 75 mph and a radius of curvature of 1,400 ft? Assume *f* = 0.11.

$$0.01e + f = \frac{V^2}{15R} \rightarrow\rightarrow e = \left(\frac{V^2}{15R} - f\right) \times 100 = \left(\frac{75^2}{15 \times 1400} - 0.11\right) \times 100 = 15.79\%$$

Based on Table 7-4 and Figure 7-8, this superelevation rate is too large for highway design.

Change design speed or R.

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7.4 What superelevation rate would you recommend for a roadway with a design speed of 100 km/hr and a radius of curvature of 500m? Assume f = 0.11.

$$0.01e + f = \frac{V^2}{127R} \rightarrow\rightarrow e = \left(\frac{V^2}{127R} - f\right) \times 100 = \left(\frac{100^2}{127 \times 500} - 0.11\right) \times 100 = 4.75\%$$

Based on Table 7-4 and Figure 7-8, this superelevation rate is acceptable for highway design.

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7.5 A 1-mile racetrack is to be designed with a ¼-mile turns at each end. Determine the superelevation rate for a design speed of 70 mph, assuming *f* = 0.20.

$$L = 0.25mi \times \frac{5280ft}{1mi} = 1320ft$$

$$L = \frac{2\pi R\Delta}{360} \rightarrow R = \frac{360L}{2\pi\Delta} = \frac{360 \times 1320}{2\pi \times 180} = 420.17\ ft$$

$$0.01e + f = \frac{V^2}{15R} \rightarrow\rightarrow e = \left(\frac{V^2}{15R} - f\right) \times 100 = \left(\frac{70^2}{15 \times 420.17} - 0.2\right) \times 100 = 57.75\%$$

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7.6 A 1-km racetrack is to be designed with turn 250 m in length at each end. Determine the superelevation rate you would recommend for a design speed of 140 km/hr, assuming *f* = 0.20.

$$L = 250\ m$$

$$L = \frac{2\pi R\Delta}{360} \rightarrow R = \frac{360L}{2\pi\Delta} = \frac{360 \times 250}{2\pi \times 180} = 79.578\ m$$

$$0.01e + f = \frac{V^2}{127R} \rightarrow\rightarrow e = \left(\frac{V^2}{127R} - f\right) \times 100 = \left(\frac{140^2}{127 \times 79.578} - 0.2\right) \times 100 = 173.9\%$$

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7.7 A plus 5.1 percent grade intersects a minus 2.8 grade at station 68 + 70 at an elevation of 327.5 ft. Calculate the centerline elevation at every 100-ft station for 500-ft vertical curve.

$$PVC\ Sta. = PVI - \frac{L}{2} = 6870 - \frac{500}{2} = 6620\ ft \rightarrow\rightarrow 66 + 20$$

$$PVT\ Sta. = PVC + L = 6620 + 500 = 7120\ ft \rightarrow\rightarrow 71 + 20$$

$$E_{PVC} = E_{PVI} - \frac{G}{100} \times \frac{L}{2} = 327.50 - \frac{5.1}{100} \times \frac{500}{2} = 314.75\ ft$$

The distance to station 67 + 00 is = 6700 – 6620 = 80 ft.

$$E_x = E_{PVC} + \frac{G_1}{100} x + \frac{(G_2 - G_1)x^2}{200L}$$

$$E_{67+00} = 314.75 + \frac{5.1}{100} \times 80 + \frac{(-2.8 - 5.1) \times 80^2}{200 \times 500} = 318.32\ ft$$

Other elevations are computed similarly:

Station	Elevation, ft
67 + 00	318.32
68 + 00	321.37
69 + 00	322.84
70 + 00	322.72
71 + 00	321.03
71 + 20	319.0

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7.8 A plus 2.8 percent grade intersects a minus 5.1 grade at station 2 + 087.224 at an elevation of 190.28m. Calculate the centerline elevation at every 20-m station for 150-m vertical curve.

$$PVC\ Sta. = PVI - \frac{L}{2} = 2087.224 - \frac{150}{2} = 2012.224 \rightarrow\rightarrow 2 + 012.224$$

$$PVT\ Sta. = PVC + L = 2012.224 + 150 = 2162.224 \rightarrow\rightarrow 2 + 162.224$$

$$E_{PVC} = E_{PVI} - \frac{G}{100} \times \frac{L}{2} = 190.28 - \frac{2.8}{100} \times \frac{150}{2} = 188.180\ m$$

The distance to station 2 + 020 is = 2020 – 2012.224 = 7.8 m.

$$E_x = E_{PVC} + \frac{G_1}{100}x + \frac{(G_2 - G_1)x^2}{200L}$$

$$E_{2+020} = 188.180 + \frac{2.8}{100} \times 7.8 + \frac{(-5.1 - 2.8) \times 7.8^2}{200 \times 150} = 188.382\ m$$

Other elevations are computed similarly:

Station	Elevation, ft
2 + 020	188.382
2 + 040	188.754
2 + 060	188.916
2 + 080	188.867
2 + 100	188.608
2 + 120	188.138
2 + 140	187.457
2 + 160	186.566
2 + 162.2	186.455

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7.9 A vertical parabolic curve is to be used as a sag curve, and it is desired to know the location and elevation of low point. The curve is 750 ft long, and the minus grade of 3.6 percent intersects with the plus grade of 6.2 percent at station 240 + 80.00. Calculate the low point of the curve if the intersection at station 240 + 80.00 is at elevation 426.84.

$$PVC\ Sta. = PVI - \frac{L}{2} = 24080 - \frac{750}{2} = 23705\ ft \rightarrow\rightarrow 237 + 05$$

$$PVT\ Sta. = PVC + L = 23705 + 750 = 24455\ ft \rightarrow\rightarrow 244 + 55$$

$$x_m = \left|\frac{G_1 L}{G_2 - G_1}\right| = \left|\frac{-3.6 \times 750}{6.2 - (-3.6)}\right| = 275.51\ ft$$

$$E_{PVC} = E_{PVI} - \frac{G}{100} \times \frac{L}{2} = 426.84 - \frac{-3.6}{100} \times \frac{750}{2} = 440.34\ ft$$

$$E_{x_m} = E_{PVC} + \frac{G_1}{100} x_m + \frac{(G_2 - G_1) x_m^2}{200L}$$

$$E_{x_m} = 440.34 + \frac{-3.6}{100} \times 275.51 + \frac{(6.2 - (-3.6)) \times 275.51^2}{200 \times 750} = 435.38\ ft$$

$$Low\ point\ Sta. = PVC + x_m = 23705 + 275.51 = 23980.51\ ft \rightarrow\rightarrow 239 + 80.51$$

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7.10 A vertical parabolic curve is to be used under a grade separation structure. The curve is 250 m long, and the minus grade of 3.8 percent intersects with the plus grade of 5.4 percent at station 0 + 120.424. Calculate the low point of the curve if the intersection at station 0 + 120.424 is at elevation 230.085.

$$PVC\ Sta. = PVI - \frac{L}{2} = 120.424 - \frac{250}{2} = -4.576\ m \rightarrow\rightarrow 0 - 004.576$$

$$PVT\ Sta. = PVC + L = -4.576 + 250 = 245.424\ m \rightarrow\rightarrow 0 + 245.424$$

$$x_m = \left|\frac{G_1 L}{G_2 - G_1}\right| = \left|\frac{-3.8 \times 250}{5.4 - (-3.8)}\right| = 103.261\ m$$

$$E_{PVC} = E_{PVI} - \frac{G}{100} \times \frac{L}{2} = 230.085 - \frac{-3.8}{100} \times \frac{250}{2} = 234.835\ m$$

$$E_{x_m} = E_{PVC} + \frac{G_1}{100} x_m + \frac{(G_2 - G_1) x_m^2}{200L}$$

$$E_{x_m} = 234.835 + \frac{-3.8}{100} \times 103.261 + \frac{(5.4 - (-3.8)) \times 103.261^2}{200 \times 250} = 232.873\ m$$

$$Low\ point\ Sta. = PVC + x_m = -4.576 + 103.261 = 98.685\ m \rightarrow\rightarrow 0 + 098.685$$

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7.11 Calculate the stopping sight distance over the crest of a 1,500 ft vertical curve with a plus grade of 4.4 percent and a minus grade of 2.3 percent.

$A = G_2 - G_1 = -2.3 - 4.4 = -6.7\%$

Assume S < L per equation 7-11a,

$$L = \frac{AS^2}{2158} \rightarrow\rightarrow S = \sqrt{\frac{2158L}{A}} = \sqrt{\frac{2158 \times 1500}{6.7}} = 695.08\ ft$$

Check assumption: 695.08 < 1500, OK

Therefore, **S = 695.08 ft** and equation 7-11a applies. [Otherwise, use equation 7-12a and check that assumption].

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7.12 Calculate the stopping sight distance over the crest of a 450 m vertical curve with a plus grade of 5.6 percent and a minus grade of 3.2 percent.

$A = G_2 - G_1 = -3.2 - 5.6 = -8.8\%$

Assume S < L per equation 7-11b,

$$L = \frac{AS^2}{658} \rightarrow\rightarrow S = \sqrt{\frac{658L}{A}} = \sqrt{\frac{658 \times 450}{8.8}} = 183.433\ m$$

Check assumption: 183.433 < 450, OK

Therefore, S = 183.433 m and equation 7-11b applies. [Otherwise, use equation 7-12b and check that assumption].

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7.13 Calculate the passing sight distance over the crest described in problem 7.11.

Assume S < L per equation 7-9

$$L = \frac{AS^2}{100\left[\sqrt{2h_1} + \sqrt{2h_2}\right]^2}$$

$$1500 = \frac{6.7 \times S^2}{100\left[\sqrt{2 \times 3.5} + \sqrt{2 \times 3.5}\right]^2} \rightarrow\rightarrow S \ = \ 791.75\ ft$$

Check assumption: 791.75 < 1500, OK,There, **S = 791.75 ft** and equation 7-9 applies. [Otherwise, use equation 7-10 and check that assumption]

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7.14 Calculate the passing sight distance over the crest described in problem 7.12.

Assume S < L per equation 7-9

$$L = \frac{AS^2}{100\left[\sqrt{2h_1} + \sqrt{2h_2}\right]^2}$$

$$450 = \frac{8.8 \times S^2}{100\left[\sqrt{2 \times 1.08} + \sqrt{2 \times 1.08}\right]^2} \rightarrow\rightarrow S \ = \ 210.195\ m$$

Check assumption: 210.195 < 450, OK, There, **S = 210.195 m** and equation 7-9 applies.

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7.15 Given a horizontal curve with a 1,360 ft radius, estimate the minimum length of spiral necessary for a smooth transition from tangent alignment to circular curve.

Assume design speed, V = 65 mph. By equation 7-5a,

$$L_s = \frac{3.5V^3}{RC} = \frac{3.5 \times 65^3}{1360 \times 4} = 159.02\ ft$$

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7.16 Given a horizontal curve with a 410 m radius, estimate the minimum length of spiral necessary for a smooth transition from tangent alignment to circular curve. The design speed is 90 km/hr.

By equation 7-5b,

$$L_s = \frac{0.0214V^3}{RC} = \frac{0.0214 \times 65^3}{1360 \times 1.2} = 31.709\ m$$

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