Montogue

QUIZ GT502
Geometric Design

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▸ PROBLEMS

PROBLEM 1 [Mannering & Washburn, 2013, w/ permission (modified)]

A 520-ft-long equal-tangent crest vertical curve connects tangents that intersect at station 340 + 00 and elevation 1325 ft. The initial grade is +4.0% and the final grade is 2.5%. True or false?

1.( ) The station of the initial point of vertical curve (PVC) lies beyond (i.e., is greater than) 338 + 00, and the elevation is greater than 1315 ft.
2.( ) The elevation of the final point of vertical curve (PVT) is greater than 1317 ft.
3.( ) The station of the high point lies beyond (i.e., is greater than) 340 + 50, and the elevation is greater than 1320 ft.

PROBLEM 2 [Mannering & Washburn, 2013, w/ permission (modified)]

An equal-tangent crest vertical curve is designed with a PVI at station 110 + 00 (elevation 927.5 ft) and a PVC at station 107 + 43.3 (elevation 921.55 ft). If the high point is at station 110 + 93, what is the design speed of the curve?

A) *V* = 40 mi/h
B) *V* = 50 mi/h
C) *V* = 60 mi/h
D) *V* = 70 mi/h

PROBLEM 3 (Mannering & Washburn, 2013, w/ permission)

An equal-tangent crest vertical curve connects a +3.2% grade and a −1.1% grade. The point of vertical intersection (PVI) is at station 98 + 20. Due to drainage considerations, the highest point of the curve is at station 100 + 79.35. True or false?

1.( ) The station of the initial point of vertical curve (PVC) lies beyond (i.e., is greater than) 93 + 00.
2.( ) The station of the final point of vertical curve (PVT) lies beyond (i.e., is greater than) 104 + 00.
3.( ) The design speed of the curve is 70 mi/h.

PROBLEM 4 (Mannering & Washburn, 2013, w/ permission)

An equal-tangent crest curve connects a +1.0% and a −0.5% grade. The PVC is at station 54 + 24 and the PVI is at station 56 + 92. Is this curve long enough to provide passing sight distance for a 60-mi/h design speed?

α) The curve is long enough for this design speed.
β) The curve is not long enough for this design speed.
γ) There is not enough information.

PROBLEM 5 (Mannering & Washburn, 2013, w/ permission)

An equal-tangent crest curve connects a +2% initial grade with a –1% final grade, and is designed for 55 mi/h. The station of the point of tangent intersection (PVI) is 233 + 40 with elevation 1203 ft. What is the elevation of the curve at station 234 + 00?

A) y = 1191.7 ft

B) y = 1195.1 ft

C) y = 1198.5 ft

D) y = 1201.9 ft

PROBLEM 6 (Mannering & Washburn, 2013, w/ permission)

A vertical curve is designed for 55 mi/h and has an initial grade of +2.5% and a final grade of –1.0%. The final point of vertical curve (PVT) is at station 114 + 50. It is known that a point on the curve at station 112 + 35 is at elevation 245 ft. Consider the following statements.

Statement 1: The station of the PVC lies beyond (i.e., is greater than) 110 + 25 and its elevation is greater than 241 ft.

Statement 2: The station of the high point lies beyond (i.e., is greater than) 114 + 00 and its elevation is greater than 246 ft.

A) Both statements are true.

B) Statement 1 is true and Statement 2 is false.

C) Statement 1 is false and Statement 2 is true.

D) Both statements are false.

PROBLEM 7 (Garber & Hoel, 2009, w/ permission)

A +2 percent grade on an arterial highway intersects with a –1 percent grade at station 535 + 24.25 at an elevation of 300 ft. If the design speed of the highway is 65 mi/h, determine the stations and elevations of the initial point of vertical curve (PVC), the final point of vertical curve (PVT), the high point, and the elevation of each 100-ft station.

PROBLEM 8 (Garber & Hoel, 2009, w/ permission)

Determine the minimum length of a sag vertical curve if the grades are –4% and +2%. The design speed is 70 mi/h. Make sure to apply criteria for stopping sight distance, comfort, and general appearance. When assessing stopping sight distance, use 2.5 s as the reaction time and 11.2 ft/s^2 as the deceleration rate.

A) L_{min} = 600 ft

B) L_{min} = 632 ft

C) L_{min} = 1050 ft

D) L_{min} = 1180 ft

PROBLEM 9 (Garber & Hoel, 2009, w/ permission)

A horizontal curve is designed for a two-lane road in mountainous terrain. The following data are known.

→ Intersection angle = 40°
→ Tangent length = 436.76 ft
→ Station of point of tangent intersection (PI) = 2700 + 10.65
→ Side friction factor f = 0.12
→ Superelevation e = 0.08

True or false?

1.( ) The design speed of the curve is greater than 50 mi/h.

2.( ) The station of the initial point of horizontal curve (PC) lies beyond (i.e., is greater than) 2695 + 90.

3.( ) The station of the final point of horizontal curve (PT) lies beyond (i.e., is greater than) 2704 + 50.

4.( ) The chord length to the first even 100 ft station is greater than 25 ft.

PROBLEM 10A (Mannering & Washburn, 2013, w/ permission)

A horizontal curve on a two-lane highway (10-ft lanes) is designed for 50 mi/h with a 6% superelevation. The central angle of the curve is 35 degrees and the point of tangent intersection (PI) is at station 482 + 72. What is the station of the final point of horizontal curve (PT)?

A) Station of PT = 482 + 50.3

B) Station of PT = 485 + 20.4

C) Station of PT = 488 + 30.6

D) Station of PT = 491 + 25.1

PROBLEM 10B

In the previous problem, how many feet have to be cleared from the lane's shoulder edge to provide adequate stopping sight distance?

A) D = 13.27 ft

B) D = 17.43 ft

C) D = 21.72 ft

D) D = 25.80 ft

PROBLEM 11 (Mannering & Washburn, 2013, w/ permission)

A horizontal curve on a single-lane highway has its initial point of horizontal curve (PC) at station 123 + 70 and its point of tangent intersection (PI) at station 130 + 90. The curve has a superelevation of 0.06 ft/ft and is designed for 70 mi/h. What is the station of the final point of horizontal curve (PT)?

A) Station of PT = 137 + 54.6

B) Station of PT = 140 + 10.3

C) Station of PT = 143 + 30.2

D) Station of PT = 146 + 44.2

PROBLEM 12 (Findley et al., 2016)

A sign is located 7 ft from the edge of the pavement of a 3° horizontal curve. Determine if the sign should be relocated further from the edge of the highway to provide the necessary stopping sight distance. The two-lane highway has a design speed of 50 mi/h with 12-ft wide lanes.

α) The sign must be relocated.

β) The sign needn't be relocated.

γ) There is not enough information.

PROBLEM 13 (Mannering and Washburn, 2013, w/ permission)

You are asked to design a horizontal curve for a two-lane road. The road has 12-ft lanes. Due to an expensive excavation, it is determined that a maximum of 34 ft can be cleared from the road's centerline toward the inside lane to provide for stopping sight distance. Also, local guidelines dictate a maximum superelevation of 0.08 ft/ft. Among the following values, which one is the highest safe design speed for this curve?

A) V = 30 mi/h

B) V = 40 mi/h

C) V = 50 mi/h

D) V = 60 mi/h

▶ ADDITIONAL INFORMATION

Table 1 Values of *K* for crest vertical curves based on stopping sight distance

Design Speed (mi/h)	Stopping Sight Distance (ft)	Rate of Vertical Curvature, K^a Calculated	Rate of Vertical Curvature, K^a Design
15	80	3.0	3
20	115	6.1	7
25	155	11.1	12
30	200	18.5	19
35	250	29.0	29
40	305	43.1	44
45	360	60.1	61
50	425	83.7	84
55	495	113.5	114
60	570	150.6	151
65	645	192.8	193
70	730	246.9	247
75	820	311.6	312
80	910	383.7	384

Table 2 Minimum radius using limiting values of superelevation (*e*) and friction factor (*f*)

Design speed (mi/h)	Maximum e (%)	Limiting values of f_s	Total (e/100 + f_s)	Calculated radius, R_v (ft)	Rounded radius, R_v (ft)
10	4.0	0.38	0.42	15.9	16
15	4.0	0.32	0.36	41.7	42
20	4.0	0.27	0.32	86.0	86
25	4.0	0.23	0.27	154.3	154
30	4.0	0.20	0.24	250.0	250
35	4.0	0.18	0.22	371.2	371
40	4.0	0.16	0.20	533.3	533
45	4.0	0.15	0.19	710.5	711
50	4.0	0.14	0.18	925.9	926
55	4.0	0.13	0.17	1186.3	1190
60	4.0	0.12	0.16	1500.0	1500
10	6.0	0.38	0.44	15.2	15
15	6.0	0.32	0.38	39.5	39
20	6.0	0.27	0.33	80.8	81
25	6.0	0.23	0.29	143.7	144
30	6.0	0.20	0.26	230.8	231
35	6.0	0.18	0.24	340.3	340
40	6.0	0.16	0.22	484.8	485
45	6.0	0.15	0.21	642.9	643
50	6.0	0.14	0.20	833.3	833
55	6.0	0.13	0.19	1061.4	1060
60	6.0	0.12	0.18	1333.3	1330
65	6.0	0.11	0.17	1656.9	1660
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
10	8.0	0.38	0.46	14.5	14
15	8.0	0.32	0.40	37.5	38
20	8.0	0.27	0.35	76.2	76
25	8.0	0.23	0.31	134.4	134
30	8.0	0.20	0.28	214.3	214
35	8.0	0.18	0.26	314.1	314
40	8.0	0.16	0.24	444.4	444
45	8.0	0.15	0.23	587.0	587
50	8.0	0.14	0.22	757.6	758
55	8.0	0.13	0.21	960.3	960
60	8.0	0.12	0.20	1200.0	1200
65	8.0	0.11	0.19	1482.5	1480
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

Table 2 (*Continued*)

Design speed (mi/h)	Maximum e (%)	Limiting values of f_s	Total (e/100 + f_s)	Calculated radius, R_v (ft)	Rounded radius, R_v (ft)
10	10.0	0.38	0.48	13.9	14
15	10.0	0.32	0.42	35.7	36
20	10.0	0.27	0.37	72.1	72
25	10.0	0.23	0.33	126.3	126
30	10.0	0.20	0.30	200.0	200
35	10.0	0.18	0.28	291.7	292
40	10.0	0.16	0.26	410.3	410
45	10.0	0.15	0.25	540.0	540
50	10.0	0.14	0.24	694.4	694
55	10.0	0.13	0.23	876.8	877
60	10.0	0.12	0.22	1090.9	1090
65	10.0	0.11	0.21	1341.3	1340
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
10	12.0	0.38	0.50	13.3	13
15	12.0	0.32	0.44	34.1	34
20	12.0	0.27	0.39	68.4	68
25	12.0	0.23	0.35	119.0	119
30	12.0	0.20	0.32	187.5	188
35	12.0	0.18	0.30	272.2	272
40	12.0	0.16	0.28	381.0	381
45	12.0	0.15	0.27	500.0	500
50	12.0	0.14	0.26	641.0	641
55	12.0	0.13	0.25	806.7	807
60	12.0	0.12	0.24	1000.0	1000
65	12.0	0.11	0.23	1224.6	1220
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

▸ SOLUTIONS

P.1 ■ Solution

1. False. Given the distance D_1 = 520/2 = 260 ft between the PVI and the PVC, the stationing of the PVC is determined as

$$\text{Station of PVC} = \text{Station of PVI} - D_1 = (340+00) - 260$$

$$\therefore \text{Station of PVC} = 34{,}000 - 260 = (337+40)$$

The distance between the PVI and the PVC is equivalent to 2.6 stations. Equipped with this quantity and the grade G_1 = +4.0%, the elevation of the PVC is determined to be

$$\text{Elevation of PVC} = \text{Elevation of PVI} - G_1 \times N_{\text{PVC-PVI}}$$

$$\therefore \text{Elevation of PVC} = 1325 - 4.0 \times 2.6 = 1314.6 \text{ ft}$$

2. True. The distance between the PVT and the PVI is D_2 = 520/2 = 260 ft, which corresponds to 2.6 stations. Equipped with this quantity and the grade G_2 = −2.5%, the elevation of the PVT is determined as

$$\text{Elevation of PVT} = \text{Elevation of PVI} - G_2 \times N_{\text{PVI-PVT}}$$

$$\therefore \text{Elevation of PVT} = 1325 - (-2.5) \times 2.6 = 1318.5 \text{ ft}$$

3. True. The vertical curve can be described by a parabola of the general form $y = ax^2 + bx + c$. Differentiating this equation gives the slope of the curve,

$$\frac{dy}{dx} = 2ax + b$$

Coefficients a and b depend on the grades and the length of the curve; that is,

$$a = \frac{G_2 - G_1}{2L} = \frac{-2.5 - 4.0}{2 \times 5.20} = -0.625$$

$$b = G_1 = 4.0$$

so that

$$y' = 2 \times (-0.625) \times x + 4.0$$

$$\therefore y' = -1.25x + 4.0$$

Since the high point is an extremum of the curve, the slope of the curve at that point must equal zero. Accordingly, we set the foregoing equation to zero and solve for *x*,

$$0 = -1.25x + 4.0 \rightarrow x = 3.2 \text{ stations} = 320 \text{ ft}$$

We are now able to compute the stationing of the high point,

$$\text{Station of high point} = \text{Station of PVC} + x$$

$$\therefore \text{Station of high point} = (337 + 40) + (3 + 20)$$

$$\therefore \text{Station of high point} = 340 + 60$$

The elevation of the high point is obtained by substituting *x* = 3.2 stations in the equation of the parabola,

$$y = -0.625 \times 3.2^2 + 4 \times 3.2 + 1314.6 = 1321 \text{ ft}$$

P.2 ■ Solution

The first step is to compute the number of stations between the PVC and the PVI,

$$N_{PVC-PVI} = \text{Station of PVI} - \text{Station of PVC} = (110 + 00) - (107 + 43) = 2 + 57$$

$$\therefore N_{PVC-PVI} = 2.57 \text{ stations}$$

The initial grade of the vertical curve is calculated next,

$$\text{Elevation of PVC} + G_1 \times N_{\text{PVC-PVI}} = \text{Elevation of PVI}$$

$$\therefore G_1 = \frac{\text{Elevation of PVI} - \text{Elevation of PVC}}{N_{\text{PVC-PVI}}} = \frac{927.5 - 921.55}{2.57} = 2.32\%$$

The design speed of the curve depends on the value of rate of vertical curvature *K* in the AASHTO formula

$$x_{\text{hi}} = KG_1 \rightarrow K = \frac{x_{\text{hl}}}{G_1} \quad \text{(I)}$$

where x_{hi} is the distance from the PVC to the high point and can be determined as

$$x_{\text{hl}} = \text{High point} - \text{Elevation of PVC} = (110 + 93) - (107 + 43.3)$$

$$\therefore x_{\text{hl}} = 3 + 49.7 = 349.7 \text{ ft}$$

Backsubstituting in equation (I) gives

$$K = \frac{349.7}{2.32} \approx 151$$

Referring to Table 1 with this quantity, we read a design speed of 60 mi/h for the curve in question.

► The correct answer is **C**.

P.3 ■ Solution

1. False. The difference between the stationing of the highest point and the stationing of the PVI is (100 + 79.35) – (98 + 20) = 259 ft. Given the distance x_{hl} = *L*/2 + 259 from the PVC to the high point of the curve, the length of the curve is shown to be

$$x_{hl} = K \times |G_1| \rightarrow x_{hl} = \frac{L}{|G_1 - G_2|} \times |G_1|$$

$$\therefore \left(\frac{L}{2} + 259\right) = \frac{L}{|3.2 - (-1.1)|} \times 3.2$$

$$\therefore L = 1060 \text{ ft}$$

The distance between the PVI and the PVC for an equal-tangent curve such as the present one is D_1 = 1060/2 = 530 ft. The stationing of the PVC is determined as follows,

$$\text{Station of PVC} = \text{Station of PVI} - \frac{D_1}{100} = (98+20) - \frac{530}{100}$$

$$\therefore \text{Station of PVC} = 92+90$$

2. False. The distance between the PVT and the PVI is D_2 = 1060/2 = 530 ft. Accordingly, the stationing of the PVT is determined next,

$$\text{Station of PVT} = \text{Station of PVI} + \frac{D_2}{100} = (98+20) + \frac{530}{100}$$

$$\therefore \text{Station of PVT} = 103+50$$

3. True. From the AASHTO formula, we have $L = KA$. Substituting and solving for K gives

$$L = KA \rightarrow K = \frac{L}{|G_1 - G_2|}$$

$$\therefore K = \frac{1060}{|3.2 - (-1.1)|} = 246.5 \approx 247$$

Referring to Table 1 with this rate of vertical curvature, the design speed is seen to be 70 mi/h.

P.4 ■ Solution

The length of the curve in question is calculated as

$$\frac{L}{100} = 2 \times (\text{Station of PVI} - \text{Station of PVC})$$

$$\therefore L = 200 \times [(56+92) - (54+24)]$$

$$\therefore L = 200 \times (56.92 - 54.24) = 536 \text{ ft}$$

The minimum length of vertical curve based on stopping sight distance is given by $L = KA$, where coefficient K, for a design speed of 60 mi/h, is found as K = 151 (Table 1). Accordingly,

$$L_{\min} = KA = 151 \times [1.0 - (-0.5)] = 226.5 \text{ ft}$$

Since $L > L_{\min}$, we conclude that the curve is indeed long enough to provide a design speed of 60 mi/h.

► The correct answer is **α**.

P.5 ■ Solution

To begin, we determine the minimum length of the curve with the AASHTO formula $L_{\min} = KA$. For a design speed of 55 mi/h, we read K = 114 (Table 1). Thus,

$$L_{\min} = 114 \times |2.0 - (-1.0)| = 342 \text{ ft}$$

For an equal-tangent crest curve, the distance between the initial point of vertical curve and the point of tangent intersection is D_1 = 342/2 = 171 ft. The stationing of the PVC is calculated as

$$\text{Station of PVC} = \text{Station of PVI} - \frac{D_1}{100} = (233+40) - \frac{171}{100} = 231+69$$

Given the 1.71 stations between the PVC and the PVI, the elevation of the PVC is determined next,

$$\text{Elevation of PVC} + G_1 \times N_{\text{PVI-PVC}} = \text{Elevation of PVI}$$

$$\therefore \text{Elevation of PVC} = \text{Elevation of PVI} - G_1 \times N_{\text{PVI-PVC}}$$

$$\therefore \text{Elevation of PVC} = 1203 - 2.0 \times 1.71 = 1199.6 \text{ ft}$$

The curve is described by a parabola of general equation $y = ax^2 + bx + c$. Coefficients *a* and *b* are such that

$$a = \frac{G_2 - G_1}{2L} = \frac{-1.0 - 2.0}{2 \times 3.42} = -0.439$$

$$b = G_1 = 2.0$$

while *c* = 1199.6 ft is the elevation of the PVC. We aim for the elevation at station 234 + 00, that is, the elevation for *x* = 2.34 stations. Accordingly,

$$y = -0.439 \times 2.34^2 + 2.0 \times 2.34 + 1199.6 = \boxed{1201.9 \text{ ft}}$$

► The correct answer is **D**.

P.6 ■ Solution

With recourse to Table 1, coefficient *K* for this design speed is 114. The minimum length of the vertical curve follows as

$$L_{\min} = KA = 114 \times [2.5 - (-1.0)] = 399 \text{ ft}$$

The stationing of the PVC is determined as

$$\text{Station of PVC} = \text{Station of PVT} - \frac{L_{\min}}{100} = (114+50) - \frac{399}{100}$$

$$\therefore \text{Station of PVC} = (114+50) - 3.99 = 110+51$$

The distance between the available point, which is at station 112 + 35, and the PVC is

$$D = \text{Station of point} - \text{Station of PVC}$$

$$\therefore D = (112+35) - (111+11)$$

$$\therefore D = 1+24 = 124 \text{ ft}$$

The curve is described by a parabola of general form $y = ax^2 + bx + c$. Solving for *c*, which is the elevation of the PVC, brings to

$$c = y - ax^2 - bx$$

Coefficients *a* and *b* are such that

$$a = \frac{G_2 - G_1}{2L} = \frac{-1.0 - 2.5}{2 \times 3.99} = -0.439$$

$$b = G_1 = +2.5$$

Substituting these variables, along with elevation *y* = 245 ft and distance *D* = 1.24 stations, gives

$$\text{Elevation of PVC} = y - aD^2 - bD$$

$$\therefore \text{Elevation of PVC} = 245 - (-0.439) \times 1.24^2 - 2.5 \times 1.24^2 = 241.8 \text{ ft}$$

To determine the stationing of the high point, recall that this is an extremum of the curve and hence the slope therein must be zero. Thus, setting *dy/dx* = 0 and solving for *x* yields

$$\frac{dy}{dx} = 2ax + b \rightarrow 2\times(-0.439)x + 2.5 = 0$$

$$\therefore x = 2.85 \text{ stations}$$

Therefore, the station of the high point is

$$\text{Station of high point} = \text{Station of PVC} + x$$

$$\therefore \text{Station of high point} = (111+11)+(2+85) = 113+96$$

The elevation of the high point is obtained by inserting x = 2.85 stations in the equation of the parabola,

$$\text{Elevation of high point} = -0.439\times 2.85^2 + 2.5\times 2.85 + 241.8 = 245.4 \text{ ft}$$

► The correct answer is **B**.

P.7 ■ Solution

With recourse to Table 1, the K factor for a speed of 65 mi/h is 193. The grade difference is A = +2 – (–1) = 3.0%. The curve length is given by the product

$$L = KA = 193\times 3.0 = 579 \text{ ft}$$

The station of the PVC is calculated as

$$\text{Station of PVC} = \text{Station at 300 ft } -\frac{L}{2} = (535+24.25) - \frac{579}{2} = 532+34.75$$

Similarly, the station of the PVT follows as

$$\text{Station of PVT} = \text{Station at 300 ft } +\frac{L}{2} = (535+24.25) + \frac{579}{2} = 538+13.75$$

Given the elevation Y = 300 ft, the tangent elevation of the PVC is determined as

$$\text{Tangent elevation of PVC} = Y - \frac{G_1 x}{200} = 300 - \frac{2\times 579}{200} = 294.21 \text{ ft}$$

The distance from the PVC is x = 53,300 – 53,234.8 = 65.2 ft, and the offset is

$$\text{Offset} = \frac{Ax^2}{200L} = \frac{3.0\times 65.25^2}{200\times 579} = 0.110 \text{ ft}$$

The curve elevation is then

$$\text{Curve elevation} = \text{Tangent elevation} - \text{Offset} = 294.21 - 0.110 = 294.10 \text{ ft}$$

The tangent elevation for the next station, for instance, is given by

$$\text{Tangent elevation} = 294.21 + 2\times\frac{66.25}{100} = 295.52 \text{ ft}$$

while the curve elevation becomes

$$\text{Curve elevation} = 295.52 - 0.110 = 295.41 \text{ ft}$$

The remaining calculations are tabulated below. The curve elevation is the difference between the data in the blue and red and columns.

Station	Distance from PVC (x) (ft)	Tangent elevation (ft)	Offset (ft)	Curve Elevation (ft)
532 + 34.75	0	294.21	0	294.20
533 + 00	65.25	295.52	0.110	295.41
534 + 00	165.25	297.52	0.707	296.81
535 + 00	265.25	299.52	1.82	297.70
536 + 00	365.25	301.52	3.46	298.06
537 + 00	465.25	303.52	5.61	297.91
538 + 00	565.25	305.52	8.28	297.24
538 + 13.75	579	305.80	8.69	297.11

The distance from the high point of the PVC is given by

$$X_{\text{high}} = \frac{LG_1}{(G_1 - G_2)} = \frac{579\times 2}{\left[2-(-1)\right]} = 386\text{ ft}$$

The station of the high point follows as

$$\text{Station of the high point} = \text{Station of PVC} + X_{\text{high}} = (532+34.75)+(3+86)$$

$$\therefore \text{Station of the high point} = 536+20.75$$

P.8 ■ Solution

The first step is to compute the stopping sight distance *S*, which is given by

$$S = 1.47ut + \frac{u^2}{30\left[\left(\frac{a}{32.2}\right)-G\right]}$$

Here, u = 70 mi/h is the vehicle speed when brake is applied, t = 2.5 s is the reaction time, a = 11.2 ft/s^2 is the deceleration rate, and G = 0.04 is grade percentage. Substituting the pertaining variables gives

$$S = 1.47\times 70\times 2.5 + \frac{70^2}{30\times\left(\frac{11.2}{32.2}-0.04\right)} = 788\text{ ft}$$

Assume first that the sight distance is greater than the length of the curve, $S > L$. The equation to apply in this case is

$$L_{\min} = 2S - \frac{(400+3.5S)}{A} = 2\times 788 - \frac{(400+3.5\times 788)}{\left[2-(-4)\right]} = 1050\text{ ft}$$

Since $S \ngtr L$, this relation is not valid. Next, assume instead that $S < L$. The applicable equation in this case is

$$L_{\min} = \frac{AS^2}{400+3.5S} = \frac{6\times 788^2}{400+3.5\times 788} = 1180\text{ ft}$$

which indeed happens to be greater than *S*. A second aspect to verify is the comfort criterion, whereby the curve should have a minimum length such that

$$L_{\min} = \frac{Au^2}{46.5} = \frac{6\times 70^2}{46.5} = 632\text{ ft}$$

Finally, the appearance criterion imposes a minimum length such that

$$L_{\min} = 100A = 100\times 6 = 600\text{ ft}$$

In summary, the lengths we obtained are 1180 ft as per the sight distance criterion, 632 ft as per the comfort criterion, and 600 ft as per the appearance criterion. The highest value controls, and hence we take L_{min} = 1180 ft as the minimum length of the curve.

► The correct answer is **D**.

P.9 ■ Solution

1. True. The design speed can be determined by dint of the equation for radius of traveled path,

$$R = \frac{V^2}{15(e+f)} \rightarrow V = \sqrt{15R(e+f)}$$

To proceed, we must determine the radius *R*. This can be determined with the relation

$$T = R\tan\left(\frac{\Delta}{2}\right) \rightarrow R = T\cot\left(\frac{\Delta}{2}\right)$$

where T = 436.76 ft is the tangent length and Δ = 40° is the intersection angle. Thus,

$$R = 436.76 \times \cot\left(\frac{40^{\circ}}{2}\right) = 1200 \text{ ft}$$

Returning to the expression for design speed, we find that

$$V = \sqrt{15 \times 1200 \times (0.08 + 0.12)} = 60 \text{ mi/h}$$

2. False. The station of the point of curve is the difference of the station of the PI and the tangent length. Mathematically,

$$\text{Station of PC} = \text{Station of PI} - \text{Tangent length} = (2700 + 10.65) - 436.76$$

$$\therefore \text{Station of PC} = (2700 + 10.65) - (4 + 36.76)$$

$$\therefore \text{Station of PC} = 2695 + 73.9$$

3. False. The station of the PT is given by

$$\text{Station of PT} = \text{Station of PC} + L$$

where L is the length of curve, which can be estimated as

$$L = \frac{R\Delta\pi}{180} = \frac{1200 \times 40^{\circ} \times \pi}{180} = 837.8 \text{ ft}$$

Backsubstituting in the first equation gives

$$\text{Station of PT} = \text{Station of PC} + L = (2695 + 73.89) + (8 + 37.8)$$

$$\therefore \text{Station of PT} = 2703 + 111.69 = 2704 + 11.7$$

4. True. The chord length for the first even 100-ft station can be estimated as

$$C_1 = 2R\sin\left(\frac{\delta_1}{2}\right)$$

Here, δ_1 is the deflection angle, which is calculated as

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

where l_1 = 100 – 73.9 = 26.1 ft is the length of the first arc. Solving for δ_1 and substituting gives

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

$$\therefore \delta_1 = \frac{180 \times 26.1}{\pi \times 1200} = 1.25^{\circ}$$

Finally, C_1 is computed as

$$C_1 = 2 \times 1200 \times \sin\left(\frac{1.25^{\circ}}{2}\right) = 26.2 \text{ ft}$$

P.10 ■ Solution

Part A: Referring to Table 2 with a design speed of 50 mi/h and a superelevation of 6%, we read a limiting coefficient of side friction of 0.14. The radius of the travel path is determined next,

$$R_v = \frac{V^2}{g\left(f + \frac{e}{100}\right)} = \frac{(50 \times 1.467)^2}{32.2 \times \left(0.14 + \frac{6}{100}\right)} = 835.4 \text{ ft}$$

We should add 10/2 ft to account for one of the lanes, with the result that R = 835.4 + 10/2 = 840.4 ft. Given the central angle of the curve Δ = 35°, the length of the tangent is computed as

$$T = R \times \tan\left(\frac{\Delta}{2}\right) = 840.4 \times \tan\left(\frac{35^{\circ}}{2}\right) = 264.9 \text{ ft}$$

The length *L* of the curve, in turn, is estimated as

$$L = \frac{\pi R \Delta}{180} = \frac{\pi \times 840.4 \times 35^{\circ}}{180} = 513.4 \text{ ft}$$

The station of the PT follows from the relation

$$\text{Station of PT} = \text{Station of PC} + \frac{L}{100} \quad \text{(I)}$$

Before proceeding, we require the station of PC. This is given by

$$\frac{T}{100} = \text{Station of PI} - \text{Station of PC}$$

$$\therefore \text{Station of PC} = \text{Station of PI} - \frac{T}{100}$$

$$\therefore \text{Station of PC} = (482 + 72) - \frac{264.9}{100} = 480 + 07$$

Backsubstituting into equation (I) gives

$$\text{Station of PT} = (480 + 07) + \frac{513.4}{100} = \boxed{485 + 20.4}$$

▶ The correct answer is **B**.

Part B: To assess the need for width space in the shoulder edge, we first calculate the necessary middle ordinate M_s,

$$M_s = R_v\left[1 - \cos\left(\frac{90 \times SSD}{\pi R_v}\right)\right]$$

Reading Table 1, the stopping sight distance for a design speed of 50 mi/h is 425 ft. Accordingly,

$$M_s = 840.4 \times \left[1 - \cos\left(\frac{90 \times 425}{\pi \times 840.4}\right)\right] = 26.72 \text{ ft}$$

The distance that needs to be cleared from the lane's shoulder is given by the difference

$$D = M_s - (\text{Lane width})/2 = 26.72 - 10/2 = \boxed{21.72 \text{ ft}}$$

▶ The correct answer is **C**.

P.11 ■ Solution

For the specified superelevation and design speed, Table 2 gives a limiting friction factor of 0.10. The radius of the travel path follows as

$$R_v = \frac{V^2}{g\left(f + \frac{e}{100}\right)} = \frac{(70 \times 1.467)^2}{32.2 \times \left(0.10 + \frac{6}{100}\right)} = 2046.8 \text{ ft}$$

The length of the tangent is

$$\frac{T}{100} = \text{Station of PI} - \text{Station of PC} \rightarrow T = (\text{Station of PI} - \text{Station of PC}) \times 100$$

$$\therefore T = [(130 + 90) - (123 + 70)] \times 100 = 720 \text{ ft}$$

The station of the final point of horizontal curve (PT) is

$$\text{Station of PT} = \text{Station of PC} + \frac{L}{100} \quad \text{(I)}$$

Before proceeding, we must compute the length of the horizontal curve, *L*, which is given by

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

The central angle of the curve, Δ, is determined as

$$T = R\tan\left(\frac{\Delta}{2}\right) \rightarrow \frac{T}{R} = \tan\left(\frac{\Delta}{2}\right)$$

$$\therefore \frac{\Delta}{2} = \arctan\left(\frac{T}{R}\right)$$

$$\therefore \Delta = 2\arctan\left(\frac{T}{R}\right) = 2\times\arctan\left(\frac{720}{2046.8}\right) = 38.76^{\circ}$$

so that

$$L = \frac{\pi\times 2046.8\times 38.76}{180} = 1384.6 \text{ ft}$$

Backsubstituting into equation (I) gives

$$\text{Station of PT} = (123+70) + \frac{1384.6}{2} = \boxed{137+54.6}$$

► The correct answer is **A**.

P.12 ■ Solution

With reference to Table 1, the minimum stopping sight distance for a speed of 50 mi/h is 425 ft. The radius of the curve is estimated as

$$R = \frac{18,000}{\pi D} = \frac{18,000}{\pi\times 3} = 1909.9 \text{ ft}$$

The radial distance to the middle of the inside lane is r = 1909.9 – 6 = 1903.9 ft. The middle ordinate M_s is determined next,

$$M_s = r\left[1-\cos\left(\frac{28.65\times S}{r}\right)\right] = 1903.9\times\left[1-\cos\left(\frac{28.65\times 425}{1903.9}\right)\right] = 11.85 \text{ ft}$$

The middle ordinate is 11.85 ft measured from the middle of the inside lane to the edge of the sight obstruction. The minimum distance for this case from the edge of pavement is 11.85 – 6 = 5.85 ft. Since the provided distance of 7 ft is greater than the minimum distance of 5.85 ft, the location of the sign does not restrict the recommended stopping sight distance on the curve.

► The correct answer is **B**.

P.13 ■ Solution

To begin, we compute the middle ordinate distance M_s, which is given by the difference

$$M_s = \text{Distance available} - \frac{\text{Lane width}}{2} = 34 - 12/2 = 28 \text{ ft}$$

Assume a design speed of 60 mi/h. Referring to Table 2, the limiting coefficient of side friction is 0.12. Substituting this and other pertaining variables in the equation for radius of traveled path brings to

$$(R_v)_{60} = \frac{V^2}{g\left(f+\frac{e}{100}\right)} = \frac{(60\times 1.467)^2}{32.2\times\left(0.12+\frac{8}{100}\right)} = 1203 \text{ ft}$$

Reading Table 1, we see that a design speed of 60 mi/h corresponds to a stopping sight distance of 570 ft. Evoking the equation for middle ordinate M_s and substituting the pertaining data, we get

$$(M_s)_{60} = (R_v)_{60}\left\{1-\cos\left[\frac{90\times SSD}{\pi(R_v)_{60}}\right]\right\} = 1203\times\left[1-\cos\left(\frac{90\times 570}{\pi\times 1203}\right)\right] = 33.58\text{ ft}$$

Since this is more than the available M_s of 28.0 ft obtained in the first equation, we conclude that a design speed of 60 mi/h would not be adequate for this curve. In a second trial, let the design speed be 50 mi/h. From Table 1, the coefficient of friction is now 0.14. The radius of traveled path, in turn, is calculated as

$$(R_v)_{50} = \frac{(50\times 1.467)^2}{32.2\times\left(0.14+\frac{8}{100}\right)} = 759.5\text{ ft}$$

With reference to Table 2, we take a stopping sight distance of 425 ft. The value of M_s is now

$$(M_s)_{50} = 759.5\times\left[1-\cos\left(\frac{90\times 425}{\pi\times 759.5}\right)\right] = 29.53\text{ ft}$$

Again, this is above the available middle ordinate of 28.0 ft, and hence we conclude that a design speed of 50 mi/h would not be safe either. In a third attempt, let the design speed be 40 mi/h. From Table 1, the coefficient of friction is now 0.16. The radius of traveled path, in sequence, follows as

$$(R_v)_{40} = \frac{(40\times 1.467)^2}{32.2\times\left(0.16+\frac{8}{100}\right)} = 445.6\text{ ft}$$

With reference to Table 1, we extract a stopping sight distance of 305 ft. The value of M_s is then

$$(M_s)_{40} = 445.6\times\left[1-\cos\left(\frac{90\times 305}{\pi\times 445.6}\right)\right] = 25.85\text{ ft}$$

This, at last, is less than the available middle ordinate of 28 ft. The speed is suitable. Among the design speeds provided, the highest value for which the curve would be deemed safe is 40 mi/h.

► The correct answer is **B**.

► ANSWER SUMMARY

Problem 1		T/F
Problem 2		C
Problem 3		T/F
Problem 4		α
Problem 5		D
Problem 6		B
Problem 7		Open-ended pb.
Problem 8		D
Problem 9		T/F
Problem 10	10A	B
	10B	C
Problem 11		A
Problem 12		β
Problem 13		B

► REFERENCES

- FINDLEY, D., SCHROEDER, B., CUNNINGHAM, C., and BROWN, T. (2016). *Highway Engineering*. Oxford: Butterworth-Heinemann.
- GARBER, N. and HOEL, L. (2009). *Traffic and Highway Engineering*. 4th edition. Stamford: Cengage Learning.
- MANNERING, F. and WASHBURN, S. (2013). *Highway Engineering and Traffic Analysis*. 5th edition. Hoboken: John Wiley and Sons.

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