Design Standards and References

The information that was used to write and update this book was based on the exam specifications at the time of publication. However, as with engineering practice itself, the PE examination is not always based on the most current design standards or cutting-edge technology. Similarly, design standards and regulations adopted by state and local agencies often lag issuance by several years. It is likely that the design standards that are most current, the design standards that you use in practice, and the design standards that are the basis of your exam will all be different.

PPI lists on its website the dates and editions of the design standards and regulations on which NCEES has announced the PE exams are based (**ppi2pass.com**). It is your responsibility to find out which design standards are relevant to your exam. In the meantime, here are the design standards that have been incorporated into this edition.

DESIGN STANDARDS AND REFERENCES USED ON THE EXAM

AASHTO: *AASHTO Guide for Design of Pavement Structures* (GDPS-4-M), 1993, and 1998 supplement, American Association of State Highway and Transportation Officials, Washington, DC

AASHTO: *A Policy on Geometric Design of Highways and Streets*, ~~6th ed., 2011 (including November 2013 errata)~~, American Association of State Highway and Transportation Officials, Washington, DC

AASHTO: *Guide for the Planning, Design, and Operation of Pedestrian Facilities*, 1st ed., 2004, American Association of State Highway and Transportation Officials, Washington, DC

AASHTO: *Highway Safety Manual*, 1st ed., 2010, vols. 1–3 (including September 2010, February 2012, and March 2016 errata), American Association of State Highway and Transportation Officials, Washington, DC

AASHTO: *Mechanistic-Empirical Pavement Design Guide: A Manual of Practice*, 2nd ed., July 2015, American Association of State Highway and Transportation Officials, Washington, DC

AASHTO: *Roadside Design Guide*, 4th ed., 2011 (including February 2012 and July 2015 errata), 2011, American Association of State Highway and Transportation Officials, Washington, DC

AI: *The Asphalt Handbook* (MS-4), 7th ed., 2007, Asphalt Institute, Lexington, KY

FHWA: *Hydraulic Design of Highway Culverts*, Hydraulic Design Series No. 5, Publication No. FHWA-HIF-12-026, 3rd ed., April 2012, U.S. Department of Transportation—Federal Highway Administration, Washington, DC

HCM: *Highway Capacity Manual*, 6th ed., Transportation Research Board—National Research Council, Washington, DC

MUTCD: *Manual on Uniform Traffic Control Devices*, 2009 (including Revisions 1 and 2, May 2012), U.S. Department of Transportation—Federal Highway Administration, Washington, DC

PCA: *Design and Control of Concrete Mixtures*, 16th ed., 2016, Portland Cement Association, Skokie, IL

PROWAG: *Proposed Accessibility Guidelines for Pedestrian Facilities in the Public Right-of-Way*, July 26, 2011, and supplemental notice of February 13, 2013, United States Access Board, Washington, DC

RECOMMENDED REFERENCES

You may also find the following references helpful in completing problems in *Transportation Depth Six-Minute Problems for the PE Civil Exam*, as well as during the exam.

Manual of Traffic Signal Design. Institute of Transportation Engineers.

Manual of Transportation Engineering Studies, Institute of Transportation Engineers.

Parking Structures: Planning, Design, Construction, Maintenance and Repair. Chrest, Anthony P., Mary S. Smith, and Sam Bhuyan

Principles of Highway Engineering and Traffic Analysis. Mannering, Fred L., Walter P. Kilareski, and Scott S. Washburn

Route Location and Design. Hickerson, Thomas F.

Route Surveying and Design. Meyer, Carl F., and David Gibson

Traffic Engineering Handbook, Institute of Transportation Engineers, Wolshon, Brian and Anurag Pande

1 Traffic Engineering

PROBLEM 1

AASHTO's *A Policy on Geometric Design of Highways and Streets* (GDHS) specifies criteria for safe design speed on highway curves. Which of the following criteria normally apply to designing a safe curve?

I. curve radius
II. passenger comfort factor
III. sight distance
IV. ~~shoulder width~~
V. speed-limit posting
VI. side friction factor
VII. superelevation rate
VIII. weather conditions

(A) I, II, III, and VII only
(B) I, III, VII, and VIII only
(C) I, II, III, VI, VII, and VIII only
(D) I, II, III, IV, V, and VIII only

Hint: Safe speed on a curve balances the forces needed to keep a vehicle on the roadway against the forces tending to push the vehicle off the roadway.

PROBLEM 2

A four-lane divided highway in a suburban area has the following characteristics.

lane width	10 ft
average grade	<2%
left clearance	4 ft
right clearance	2 ft
percentage of heavy vehicles	7%
access spacing	300 ft
design speed	60 mph
posted speed limit	55 mph
directional design hour volume	2540 vph
peak hour factor (PHF)	0.92

What is the level of service (LOS) of the highway?

(A) C
(B) D
(C) E
(D) F

Hint: Roadway configuration restrictions affect the free-flow speed (FFS). Design speed can be considered to be the base free-flow speed (BFFS) if there is no information to the contrary.

PROBLEM 3

A freeway in rolling terrain has the following characteristics.

commuter traffic volume (one way)	1970 vph
number of lanes (in each direction)	4
percentage of trucks	3%
percentage of buses	3%
percentage of RVs	1%
peak hour factor (PHF)	0.85

What is most nearly the peak hour flow rate?

(A) 480 pcphpl
(B) 580 pcphpl
(C) 620 pcphpl
(D) 660 pcphpl

Hint: The peak hour flow rate is the per-lane passenger-car equivalent of the hourly count of total vehicle flow. Use the formulas for equivalent passenger-car flow rates from the *Highway Capacity Manual* (HCM).

PROBLEM 27

A study zone contains 600 households, each averaging 3.5 persons and 2.2 autos. The modal split is 0.94/0.05 auto to transit, with 0.01 assigned to other modes. The following model has been determined to show the relationship for the number of trips per household.

$$T = 0.78 + 1.3P + 2.3A$$

T is the number of daily trips per household, P is the number of persons per household, and A is the number of autos per household. Approximately how many auto trips per day are generated by the study zone?

(A) 10 trips/day

(B) 5900 trips/day

(C) 6200 trips/day

(D) 98×10^3 trips/day

Hint: The number of auto trips is a portion of the total number of household trips.

PROBLEM 28

On a highway facility, how does the observed hourly vehicle volume differ from the design peak-period flow rate?

(A) The highest 15 min vehicle volume is divided by the highest 1 hr flow rate to obtain the peak-period flow rate.

(B) The observed hourly vehicle volume includes a mix of heavy vehicles, while the design peak-period flow rate has been adjusted for passenger-car equivalents of heavy vehicles, the peak hour factor, and the number of lanes.

(C) The observed hourly vehicle volume is divided by the number of observation hours to obtain the peak-period flow rate.

(D) The observed vehicle volume is divided by the number of observation hours and the number of lanes over which the observation took place.

Hint: Various vehicle sizes must be converted to a common unit of vehicle measure.

PROBLEM 29

Each lane of a four-lane freeway has a directional capacity of 2100 vph. The normal directional flow is 3100 vph. An incident blocks one lane for 20 min and then is cleared to allow the full traffic capacity flow. Approximately how long does it take to dissipate the queue after the blockage has been cleared?

(A) 18 min

(B) 30 min

(C) 50 min

(D) 58 min

PROBLEM 30

~~A car brakes suddenly and skids to a stop from 60 mph. The car initially skids 150 ft on pavement with a friction factor of 0.30. The skid continues onto wet grass on hard soil with a friction factor of 0.10. Both parts of the skid are on a 3% upgrade. Approximately how long is the skid on the grassy surface?~~

(A) 540 ft

(B) 750 ft

(C) 1300 ft

(D) 1600 ft

Hint: An upgrade decreases the length of skid from a given speed.

PROBLEM 31

A car traveling at 70 mph on a 5% downgrade skids 350 ft before striking a retaining wall head-on. The coefficient of friction between the tires and the road is 0.30. What was the approximate speed of the car at impact?

(A) 35 mph

(B) 42 mph

(C) 48 mph

(D) 51 mph

Hint: A downgrade increases the required stopping distance for a given speed.

PROBLEM 32

A car traveling on a 3% upgrade at 60 mph in a construction area skids into a stack of concrete barriers. Skid marks leading to the crash measure 150 ft long. The pavement has a friction factor of 0.30.

(D) This incorrect answer does not correct for passenger-car equivalents.

SOLUTION 29

The base flow arrival rate is

$$\frac{3100\ \frac{\text{veh}}{\text{hr}}}{60\ \frac{\text{min}}{\text{hr}}} = 51.7\ \text{vpm}$$

The normal directional capacity is the capacity per lane times the number of lanes in each direction.

$$\begin{aligned} V_n &= \left(\frac{\text{capacity}}{\text{hr-lane}}\right)(\text{no. of lanes}) \\ &= \left(\frac{2100\ \frac{\text{veh}}{\text{hr-lane}}}{60\ \frac{\text{min}}{\text{hr}}}\right)(2) \\ &= 70\ \text{vpm} \end{aligned}$$

One lane remains open during the incident blockage. Check the one-lane departure rate adjusted for incident blockage departure rate (see *Highway Capacity Manual* (HCM) Exh. 11-23).

$$\begin{aligned} \text{incident blockage departure rate} &= \left(\frac{2100\ \frac{\text{veh}}{\text{hr}}}{60\ \frac{\text{min}}{\text{hr}}}\right)(0.70) \\ &= 24.5\ \text{vpm} \end{aligned}$$

Since the arrival rate exceeds the incident blockage departure rate, an upstream queue will develop. The maximum queue length will occur when the blockage is cleared. The queue length is determined by the number of arrivals during the blockage minus departures during the blockage.

$$\begin{aligned} &\left(51.7\ \frac{\text{veh}}{\text{min}}\right)(20\ \text{min}) \\ &\quad - \left(24.5\ \frac{\text{veh}}{\text{min}}\right)(20\ \text{min}) = 1034\ \text{veh} - 490\ \text{veh} \\ &\quad = 544\ \text{veh} \end{aligned}$$

The accumulated volume of the queue will dissipate at the available net departure rate.

$$\begin{aligned} \text{net departure rate} &= 70\ \text{vpm} - 51.7\ \text{vpm} \\ &= 18.3\ \text{vpm} \end{aligned}$$

$$\begin{aligned} \text{dissipation time } (t) &= \frac{544\ \text{veh}}{18.3\ \frac{\text{veh}}{\text{min}}} \\ &= 29.7\ \text{min} \quad (30\ \text{min}) \end{aligned}$$

The queue will be dissipated in approximately 30 min.

The answer is (B).

Why Other Options Are Wrong

(A) This incorrect answer results from not adjusting the single lane flow during the incident by the capacity reduction factor (CAF).

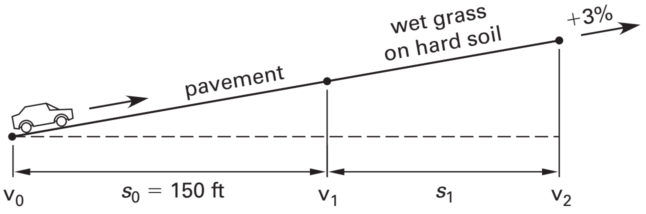
(C) This incorrect answer results from adding the 20 min blockage time to the queue departure time after the blockage.

(D) This incorrect answer results from not subtracting the single lane departure during the incident blockage.

SOLUTION 30

~~The skid distance is~~

$$\begin{aligned} s_b &= \frac{v_1^2 - v_2^2}{2g(f+G)} \\ &= \frac{(v_1^2 - v_2^2)\left(5280\ \frac{\text{ft}}{\text{mi}}\right)^2}{(2)\left(32.2\ \frac{\text{ft}}{\text{sec}^2}\right)\left(3600\ \frac{\text{sec}}{\text{hr}}\right)^2(f+G)} \\ &= \frac{v_1^2 - v_2^2}{\left(30\ \frac{\text{mi}^2}{\text{hr}^2\text{-ft}}\right)(f+G)} \end{aligned}$$



~~Solve for the initial speed approaching the skid on wet grass.~~

$$\begin{aligned} v_1 &= \sqrt{v_0^2 + \left(-30(f+G)\right)s_0} \\ &= \sqrt{\left(60\ \frac{\text{mi}}{\text{hr}}\right)^2 + \left(\left(-30\ \frac{\text{mi}^2}{\text{hr}^2\text{-ft}}\right)\left(0.30 + 0.03\ \frac{\text{ft}}{\text{ft}}\right)\right) \times (150\ \text{ft})} \\ &= 46\ \text{mph} \end{aligned}$$

Determine the skid distance on the grass.

$$\begin{aligned} s_1 &= \frac{v_2^2 - v_1^2}{-30(f+G)} \\ &= \frac{\left(0\ \frac{\text{mi}}{\text{hr}}\right)^2 - \left(46\ \frac{\text{mi}}{\text{hr}}\right)^2}{\left(-30\ \frac{\text{mi}^2}{\text{hr}^2\text{-ft}}\right)\left(0.10 + 0.03\ \frac{\text{ft}}{\text{ft}}\right)} \\ &= 542\ \text{ft} \quad (540\ \text{ft}) \end{aligned}$$

The answer is (A).

Why Other Options Are Wrong

(B) This incorrect answer results from not including the effect of the grade on the stopping distance.

(C) This incorrect answer results from not using a negative conversion constant, −30, to denote deceleration.

(D) This incorrect answer results from inserting the speed value in feet per second in place of the speed value in miles per hour.

SOLUTION 31

The braking distance is

$$\begin{aligned} s_b &= \frac{v_1^2 - v_2^2}{2g(f+G)} \\ &= \frac{(v_1^2 - v_2^2)\left(5280\ \frac{\text{ft}}{\text{mi}}\right)^2}{(2)\left(32.2\ \frac{\text{ft}}{\text{sec}^2}\right)\left(3600\ \frac{\text{sec}}{\text{hr}}\right)^2 (f+G)} \\ &= \frac{v_1^2 - v_2^2}{\left(30\ \frac{\text{mi}^2}{\text{hr}^2\text{-ft}}\right)(f+G)} \end{aligned}$$

The grade is negative since the car skids downhill. This has the effect of reducing the initial speed for a given length of the skid.

Rearrange the equation and solve for v_2.

$$\begin{aligned} v_2 &= \sqrt{v_1^2 - s_b 30(f+G)} \\ &= \sqrt{\begin{array}{l}\left(70\ \frac{\text{mi}}{\text{hr}}\right)^2 - (350\ \text{ft})\left(30\ \frac{\text{mi}^2}{\text{hr}^2\text{-ft}}\right) \\ \quad \times\left(0.30 - 0.05\ \frac{\text{ft}}{\text{ft}}\right)\end{array}} \\ &= 47.7\ \text{mph} \quad (48\ \text{mph}) \end{aligned}$$

The answer is (C).

Why Other Options Are Wrong

(A) This incorrect answer results from adding the grade to the friction factor instead of subtracting.

(B) This incorrect answer results from not including the grade but considering tire friction only.

(D) This incorrect answer results from assuming v_2 is 0 mph and reducing the form to the equation to solve for v.

SOLUTION 32

The final speed is 0 mph. The stopping distance is

$$\begin{aligned} s_b &= \frac{v_1^2}{2g(f+g)} \\ &= \frac{v_1^2\left(5280\ \frac{\text{ft}}{\text{mi}}\right)^2}{(2)\left(32.2\ \frac{\text{ft}}{\text{sec}^2}\right)\left(3600\ \frac{\text{sec}}{\text{hr}}\right)^2 (f+G)} \\ &= \frac{v_1^2}{\left(30\ \frac{\text{mi}^2}{\text{hr}^2\text{-ft}}\right)(f+G)} \end{aligned}$$

Solve for the total braking distance from 60 mph assuming the car did not strike the concrete barriers.

$$\begin{aligned} s_b &= \frac{\left(60\ \frac{\text{mi}}{\text{hr}}\right)^2}{\left(30\ \frac{\text{mi}^2}{\text{hr}^2\text{-ft}}\right)\left(0.30 + 0.03\ \frac{\text{ft}}{\text{ft}}\right)} \\ &= 364\ \text{ft} \end{aligned}$$

(B) This incorrect answer results from confusing the curve deflection to point P with the degree of curve. The deflection from AG to the chord AP is one half of the angle AOP, incorrectly assumed to be 2°.

(D) This incorrect answer is the result of using the long chord and mid-ordinate formulas to solve for y and incorrectly doubling the deflection angle.

SOLUTION 4

With the deflection and external distance known, solve for the first radius. Use the formula that relates the external distance to the curve radius and curve deflection.

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

Rearrange.

$$R = \frac{E}{\frac{1}{\cos\frac{I}{2}} - 1} = \frac{35 \text{ ft}}{\frac{1}{\cos\frac{67°45'}{2}} - 1}$$
$$= 171.192 \text{ ft}$$

Find the degree of curve.

$$D = \frac{(180°)(100)}{\pi R} = \frac{(180°)(100 \text{ ft})}{\pi(171.192 \text{ ft})}$$
$$= 33.469°$$

Since the nearest whole degree is 33°, find the radius for a 33° curve.

$$R = \frac{5729.58}{D} = \frac{5729.578°\text{-ft}}{33°}$$
$$= 173.624 \text{ ft} \quad (170 \text{ ft})$$

The answer is (B).

Why Other Options Are Wrong

(A) Determining the secant from the inverse of the sine (instead of from the inverse of the cosine) will result in this incorrect answer.

(C) This incorrect answer is the radius before rounding the deflection to an even 33°.

(D) Incorrectly using the formula for the mid-ordinate (instead of the external distance) results in this answer.

SOLUTION 5

Solve for the length of the curve tangent.

$$T = R\tan\frac{I}{2} = (2500 \text{ ft})\left(\tan\frac{35°}{2}\right)$$
$$= 788.25 \text{ ft}$$

Find the station of the point of curvature (PC).

PI sta	485	+	26.75
−	7		88.25
PC sta	477	+	38.50

The length of the curve is added to the PC station to determine the station of the PT. Solve for length of curve.

$$L = RI\left(\frac{2\pi}{360°}\right) = (2500 \text{ ft})(35°)\left(\frac{2\pi}{360°}\right)$$
$$= 1527.16 \text{ ft}$$

Find the station of the PT.

PC sta	477	+	38.50	
+	15		27.16	
PC sta	492	+	65.66	(PC sta 492 + 65)

The answer is (C).

Why Other Options Are Wrong

(A) Using the full deflection angle instead of dividing by 2 in the tangent length equation will produce the wrong PC station.

(B) Using the formula for the chord length and adding that dimension to the PC station results in a station that is too low, because the stationing will not follow the centerline.

(D) Adding the tangent length to the PI results in a possible second station of the PT, but this is not correct practice.

SOLUTION 6

As recommended by GDHS, Eq. 3-7 is used for determining the maximum comfortable speed on horizontal curves.

$$f_{\text{max}} = \frac{\text{v}^2}{15R} - \frac{e}{100\%}$$

Rearrange to find R.

$$R = \frac{v^2}{15\left(\frac{e}{100\%} + f_{max}\right)}$$

The maximum friction factor, f_{max}, is shown in Fig. 3-6 to be 0.20 for a design speed of 30 mph.

Solve for the radius.

$$\begin{aligned} R &= \frac{\left(30\ \frac{\text{mi}}{\text{hr}}\right)^2}{\left(15\ \frac{\text{mi}^2}{\text{hr}^2\text{-ft}}\right)\left(\frac{-4\%}{100\%} + 0.20\right)} \\ &= 375\ \text{ft} \end{aligned}$$

Alternate Solution

From Table 3.13~~(b)~~, for a design speed of 30 mph and $e = -4\%$, select 375 ft as the minimum radius.

The answer is (D).

Why Other Options Are Wrong

(A) This incorrect answer results from entering the cross slope directly in percent without converting to feet per foot, and then ignoring the negative sign in the answer.

(B) This incorrect answer results from referring to Table 3.13(a), using the column titled v = 30 km/h, and converting the answer from meters to feet.

(C) This incorrect answer results from ignoring the negative sign for the cross slope.

SOLUTION 7

Find the curve tangent.

$$\begin{aligned} T &= R \tan\frac{I}{2} = (1400\ \text{ft})\left(\tan\frac{32°20'}{2}\right) \\ &= 405.85\ \text{ft} \end{aligned}$$

Determine the PT coordinates using the tangent bearing and distance from the point of intersection (PI) coordinates.

$$\begin{aligned} N_{PT} &= N_{PI} + T\sin(90° - \text{bearing angle}) \\ &= 5280\ \text{ft} + (405.85\ \text{ft})\sin(90° - 55°40') \\ &= 5508.90\ \text{ft} \quad (5510\ \text{ft}) \end{aligned}$$

The answer is (C).

Why Other Options Are Wrong

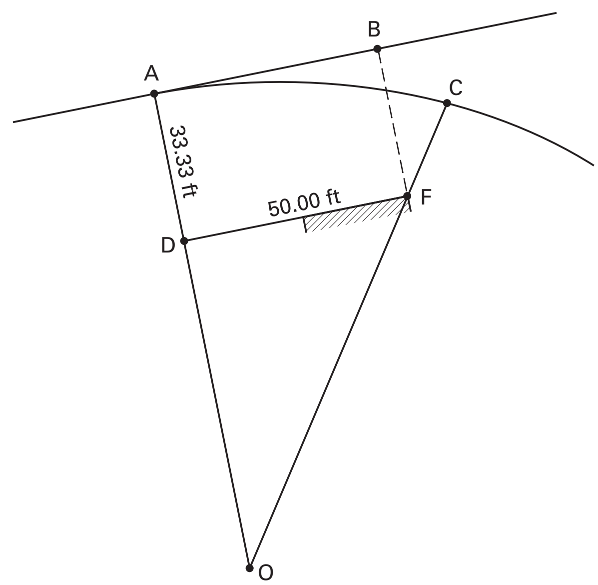
(A) This incorrect answer is the result of calculating the east coordinate instead of the north coordinate.

(B) This incorrect answer results from using the curve deflection angle to locate the PT coordinates from the PI instead of using the bearing of the ahead tangent.

(D) This incorrect answer results from neglecting to subtract the tangent bearing from 90° when determining the PT coordinate.

SOLUTION 8

Set up triangle AOC using the center of the curve as point O. Point A is the curve PC, and point C is the point on the curve that is radial from the pier corner, point F.



Find the distance OD.

$$\begin{aligned} OD &= 200\ \text{ft} - 33.33\ \text{ft} \\ &= 166.67\ \text{ft} \end{aligned}$$

Find the distance OF using the Pythagorean theorem.

$$\begin{aligned} OF &= \sqrt{(DF)^2 + (OD)^2} = \sqrt{(50.00\ \text{ft})^2 + (166.67\ \text{ft})^2} \\ &= 174.01\ \text{ft} \end{aligned}$$

Find the distance FC by subtracting OF (174.01 ft) from the curve radius.

$$\begin{aligned} FC &= 200.00\ \text{ft} - 174.01\ \text{ft} \\ &= 25.99\ \text{ft} \quad (26\ \text{ft}) \end{aligned}$$

The answer is (A).

Why Other Options Are Wrong

(B) This incorrect answer results from using the formula for the offset from tangent to a point on a curve, then subtracting the result from the offset to the pier foundation corner.

(C) This incorrect answer results from considering triangle AOB. The hypotenuse, BO, is 206.16 ft. Subtracting the offset of 33.33 ft from the hypotenuse length yields 34.36 ft, which is the incorrect clearance distance to the closest corner of the pier foundation.

(D) This incorrect answer results from subtracting the squares of the side lengths in the Pythagorean theorem instead of adding the squares of the sides.

SOLUTION 9

Stopping distance around an obstruction is the distance along the centerline of the innermost lane of the curve, which is on a 250 ft radius. The sight line is along the chord of the curve. The clearance distance, $Z_{\text{clearance}}$, plus one-half of the inside lane width, is the horizontal sight offset (HSO). The HSO is the mid-ordinate, M, of the circular curve centered at the point of closest clearance to the edge of the road.

$$\begin{aligned}\text{HSO} = M &= Z_{\text{clearance}} + \frac{\text{lane width}}{2}\\ &= 14\ \text{ft} + \frac{12\ \text{ft}}{2}\\ &= 20\ \text{ft}\end{aligned}$$

Determine the curve length using the mid-ordinate and the radius. First, find the deflection, I, of the curve arc. The deflection is the angle subtended by the ends of the sight-line chord.

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

Rearrange to solve for I.

$$\begin{aligned}I &= 2\arccos\left(1 - \frac{M}{R}\right)\\ &= 2\arccos\left(1 - \frac{20\ \text{ft}}{250\ \text{ft}}\right)\\ I &= 46.148^\circ\end{aligned}$$

Determine the length of curve, L, using the radius and the degree of curve, D.

$$\begin{aligned}L &= \frac{100I}{D} = \frac{\pi IR}{180^\circ} = \frac{\pi(46.148^\circ)(250\ \text{ft})}{180^\circ}\\ &= 201.4\ \text{ft}\end{aligned}$$

Determine the chord length for the sight distance.

$$\begin{aligned}C &= 2R\sin\frac{I}{2} = (2)(250\ \text{ft})\left(\sin\frac{46.148}{2}\right)\\ &= 196\ \text{ft}\end{aligned}$$

Using AASHTO's *A Policy on Geometric Design of Highways and Streets* Table 3-1, a stopping distance of 196 ft is good for 30 mph.

The answer is (C).

Alternate Solution

Using AASHTO's *A Policy on Geometric Design of Highways and Streets* Fig. 3-22b, from a point at 20 ft mid-ordinate on the bottom horizontal scale, intersect a line from a point at a 250 ft radius on the left vertical scale. The intersection lies on the v = 30 mph curve.

Why Other Options Are Wrong

(A) After determining $I/2$ from the mid-ordinate equation, this incorrect answer results from not doubling the answer for the length-of-curve equation.

(B) This answer results from incorrectly using the radius of the inside edge of the lane as the sight line.

(D) This answer results from incorrectly using the radius of the outside edge of the traveled lane as the sight line.

SOLUTION 10

Change the design speed from miles per hour to feet per second.

$$\begin{aligned}v_{\text{ft/sec}} &= \frac{\left(70\ \frac{\text{mi}}{\text{hr}}\right)\left(5280\ \frac{\text{ft}}{\text{mi}}\right)}{3600\ \frac{\text{sec}}{\text{hr}}}\\ &= 102.7\ \text{ft/sec}\end{aligned}$$

The roadway is already sloped down to the right at 0.01 ft/ft, and the superelevation will increase the slope of the roadway down to the right since this is a right-hand curve. Therefore, there will be no reverse cross slope to run out on the right side. Determine the difference between normal slope and full superelevation.

$$\begin{aligned}\text{required slope transition} &= 0.08\ \frac{\text{ft}}{\text{ft}} - 0.01\ \frac{\text{ft}}{\text{ft}}\\ &= 0.07\ \text{ft/ft}\end{aligned}$$

Determine the change in edge of pavement elevation for a three-lane half width of roadway.

$$\begin{aligned}\Delta e &= ew \\ &= \left(0.065\ \frac{\text{ft}}{\text{ft}}\right)\left(12\ \frac{\text{ft}}{\text{lane}}\right)(3\text{ lanes}) \\ &= 2.34\text{ ft}\end{aligned}$$

Use the edge transition rate of 1:200 to determine the transition length.

$$\begin{aligned}L_{\text{tr}} &= (\Delta e)G_r \\ &= (2.34\text{ ft})\left(200\ \frac{\text{ft}}{\text{ft}}\right) \\ &= 468\text{ ft}\quad (470\text{ ft})\end{aligned}$$

The slope ratio transition length, 468 ft, is greater than the spiral formula length, 346 ft. Using the longer of the two criteria, set the spiral length to 470 ft.

The answer is (B).

Why Other Options Are Wrong

(A) This incorrect answer is the spiral length using the spiral formula, which is shorter than the edge transition criterion.

(C) This incorrect answer is the result of using the full slope transition without considering that the pavement is already sloped 0.015 ft/ft at the beginning of the transition.

(D) This incorrect answer results from using the entire six-lane width to determine the edge transition elevation.

SOLUTION 17

The design speed determines the distance necessary to change from one curve radius to the next, which gives the driver time to adjust to the new radius. When calculating spiral length, AASHTO's *A Policy on Geometric Design of Highways and Streets* (GDHS), recommends keeping the change in lateral acceleration in the range of 1.0–3.0 ft/sec^2, with most cases being satisfied using an average of 2.0 ft/sec^2. *GDHS* Eq. 3-25 can be used for transition between curves of any radius, in addition to the traditional tangent to curve condition. The length of spiral required is the length necessary to transition from the equivalent radius of a 3° curve to a 2° curve. The radius of a curve is

$$R = \frac{(180°)(100\text{ ft})}{\pi D}$$

Solve for each curve.

$$\begin{aligned}R_1 &= \frac{(180°)(100\text{ ft})}{\pi(3°)} \\ &= 1909.86\text{ ft} \\ R_2 &= \frac{(180°)(100\text{ ft})}{\pi(2°)} \\ &= 2864.79\text{ ft}\end{aligned}$$

Determine the length of the transition by finding the distance along the spiral in which the radius changes from R_1 to R_2.

$$\begin{aligned}L_s &= L_1 - L_2 = \frac{1.6\text{v}^3}{R_1} - \frac{1.6\text{v}^3}{R_2} \\ &= \left(\frac{\left(1.6\ \frac{\text{ft}^2\text{-hr}^3}{\text{mi}^3}\right)\left(70\ \frac{\text{mi}}{\text{hr}}\right)^3}{1909.86\text{ ft}}\right) \\ &\quad - \left(\frac{\left(1.6\ \frac{\text{ft}^2\text{-hr}^3}{\text{mi}^3}\right)\left(70\ \frac{\text{mi}}{\text{hr}}\right)^3}{2864.79\text{ ft}}\right) \\ &= 95.78\quad (100\text{ ft})\end{aligned}$$

The answer is (A).

Why Other Options Are Wrong

(B) This incorrect answer is the length of spiral needed at the tangent end of a 2° curve.

(C) This incorrect answer is the length of spiral needed at the tangent end of a 3° curve.

(D) This incorrect answer is the length of spiral needed if a full spiral were introduced between the curves that transitioned to tangent and then transitioned into the second curve. This method is not a true compound spiral curve but rather two fully spiraled curves back-to-back.

SOLUTION 18

The formula given for the spiral length in the problem is from AASHTO's *A Policy on Geometric Design of Highways and Streets* (GDHS). It is based on speed in miles per hour and radius in feet, when the change in lateral acceleration is 2.0 ft/sec^2. The curve radius calculation

The distance traveled in 2.73 sec is the minimum length of vertical curve required.

$$\begin{aligned} L_{\min} &= t\mathrm{v}_{\mathrm{horiz}} = (2.73\ \mathrm{sec})\left(220\ \frac{\mathrm{ft}}{\mathrm{sec}}\right) \\ &= 601\ \mathrm{ft} \quad (600\ \mathrm{ft}) \end{aligned}$$

The answer is (C).

Why Other Options Are Wrong

(A) Using the difference in absolute vertical velocity values results in too short a curve.

(B) Neglecting to convert miles per hour into feet per second results in too short a curve.

(D) Inserting the metric value for gravitational acceleration and not converting to feet per second squared to determine the vertical acceleration limit results in too long a curve.

SOLUTION 5

Check for the approximate required sight distance from AASHTO's *A Policy on Geometric Design of Highways and Streets* (GDHS) Table 3-1. The recommended stopping distance for 70 mph is 730 ft. Therefore, the curve length of 1500 ft is probably greater than the required stopping sight distance.

Check the available sight distance. Use the GDHS formula for crest vertical curves for stopping sight distances less than the curve length.

$$L = \frac{AS^2}{2158} = \frac{(G_2 - G_1)S^2}{2158}$$

Solve for the sight distance available.

$$\begin{aligned} S &= \sqrt{\frac{2158L}{A}} = \sqrt{\frac{(2158\ \mathrm{ft})(1500\ \mathrm{ft})}{3.0\% - (-2.5\%)}} \\ &= 767\ \mathrm{ft} \end{aligned}$$

From GDHS Table 3-3, 767 ft is in the lower range of 50 mph sight distance conditions. However, designing for minimum stopping sight distance on freeways is not entirely safe. A car braking rapidly or coming to a full stop can cause multiple rear-end crashes in heavier traffic found on freeways, especially when rain or fog are present. Therefore, avoidance maneuvers A and B do not apply, and one of the remaining conditions, C, D, or E, applies. Avoidance maneuvers C, D, and E allow for a greater perception-reaction time and allow time for the driver to change vehicle path or speed when a full stop is undesirable. Avoidance maneuver C applies to rural roads; therefore, the speed should be posted at 50 mph.

The answer is (A).

Why Other Options Are Wrong

(B) Posting for 60 mph places the 767 ft stopping sight distance within the range of 610 ft to 1150 ft for avoidance manuevers A and B, which does not leave the additional distance required for lane change decisions and adverse weather conditions.

(C) Misinterpreting GDHS Table 3-2 by using the former criterion of a 0.6 ft object height yields a longer stopping sight distance required than does using the newer criteria. Applying the value to GDHS Table 3-2 yields a speed limit of 65 mph.

(D) Incorrectly using the stopping distance values from GDHS Table 3-1 and Table 3-2 for a design speed of 70 mph ignores the additional sight distance needed for avoidance maneuvers. Such measures may be required on the downgrade at the end of the vertical curve where the ramp merges into the mainline traffic, especially when experience has shown that a higher rate of crashes occur at this location.

SOLUTION 6

Assume $S < L$. From AASHTO's *A Policy on Geometric Design of Highways and Streets* (GDHS) Table 3-34, the stopping sight distance for a 50 mph design speed is 425 ft. Equation 3-43 is used with the eye height as 3.5 ft and the object height as 2.0 ft.

$$\begin{aligned} L &= \frac{AS^2}{2158} = \frac{\big(3\% - (-4\%)\big)(425\ \mathrm{ft})^2}{2158\ \mathrm{ft}} \\ &= 586\ \mathrm{ft} \quad (590\ \mathrm{ft}) \end{aligned}$$

Assume $S > L$, and solve for L.

$$\begin{aligned} L &= 2S - \frac{2158}{A} = (2)(425\ \mathrm{ft}) - \frac{2158\ \mathrm{ft}}{\big(3\% - (-4\%)\big)} \\ &= 542\ \mathrm{ft} \quad (540\ \mathrm{ft}) \end{aligned}$$

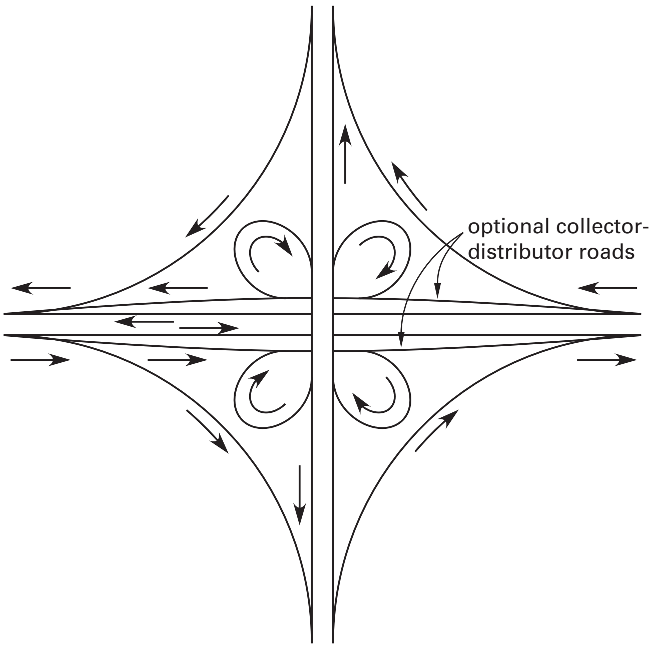
Since 542 ft is greater than the stopping sight distance required, the first assumption—that the stopping sight distance is less than the curve length—is valid. The length can be checked using the minimum design K value from GDHS Table 3-34.

$$\begin{aligned} L &= KA = \left(84\ \frac{\mathrm{ft}}{\%}\right)\big(3\% - (-4\%)\big) \\ &= 588\ \mathrm{ft} \quad (590\ \mathrm{ft}) \end{aligned}$$

4 Intersection Geometry

PROBLEM 1

Construction and operational characteristics of a full cloverleaf interchange between two freeways can be described by which of the following statements?



(A) Only one bridge is necessary, making the interchange less costly to build.

(B) The layout makes the most efficient use of real estate and is easily understood by drivers.

(C) All movements can be made as a direct connection at nearly the same speed as mainline travel.

(D) All ramp entrances and exits are on the right side of the roadway, but may be too closely spaced to handle higher traffic volumes in the weaving zones.

Hint: A full cloverleaf interchange has four tight circular ramps tucked between broad outer ramps and the mainline.

PROBLEM 2

Beech St. is a 40 ft wide street through a residential neighborhood. Parking is permitted on both sides. Columbus Blvd. is a commercial multilane artery that runs parallel to Beech St. Congestion on Columbus Blvd. causes traffic to divert to Beech St. as a bypass. Cross streets, which are 38 ft wide with parking on both sides, occur frequently between Beech St. and Columbus Blvd. The location is subject to frequent snow and ice conditions.

Roundabouts are to be installed along Beech St. to discourage bypass traffic, especially large multi-trailer trucks. The design must accommodate school buses, municipal waste trucks, fire trucks, snow plows, and occasional WB-50 semi-trailer moving vans. The design should also consider that large semi-trailer rigs will occasionally stray onto Beech St. Assuming sufficient right-of-way is available, most nearly, what should be the minimum inscribed radius of the outside curb and central island treatment for the roundabouts?

(A) 30 ft; 10 ft diameter paved center island surrounded by a mountable curb

(B) 35 ft; landscaped center island surrounded by a barrier curb

(C) 45 ft; paved center island surrounded by a mountable curb

(D) 45 ft; no center island

Hint: Roundabouts are introduced to reduce left-turn conflicts and to moderate speed through intersections, replacing other traffic control measures.