

Civil Engineering FE CBT Exam

Knowledge: Transportation Engineering with 15 Example Problems

Contents

1 Geometric Design of Streets and Highways	2
1.1 Horizontal Circular Curves	2
1.2 Superelevation, Friction and Minimum Radius.....	2
1.3 Stopping Sight Distance (SSD) & Intersection Sight Distance (ISD)	2
1.4 Horizontal Sight Line Offset (HSO).....	2
1.5 Vertical Parabolic Curves	3
1.6 Vertical Curve Design K-Factor Table & Sight Distance Criteria	3
2 Pavement System Design	4
2.1 AASHTO Structural Number Equation & Layer Roles	4
2.2 Load Equivalency Factors (LEF) and ESALs	4
2.3 Subgrade Soil Characterization	4
3 Traffic Capacity and Flow Theory.....	5
3.1 Traffic Flow Fundamentals & Greenshields Model.....	5
3.2 Basic Freeway Segment Capacity & Free Flow Speed.....	5
3.3 Peak Hour Factor (PHF) & Level of Service (LOS).....	5
4 Traffic Control Devices & Signal Timing.....	6
4.1 Webster's Optimum Signal Cycle Length.....	6
5 Transportation Planning, Safety & Earthwork.....	7
5.1 Four-Step Travel Demand Modeling & Gravity Model.....	7
5.2 Traffic Safety & Crash Rates	7
5.3 Earthwork Volumes & Mass Haul Diagrams	7
6 Example Problems and Solutions (15 Problems)	8

1 Geometric Design of Streets and Highways

1.1 Horizontal Circular Curves

Horizontal curves connect two intersecting straight road segments (tangents) to allow vehicles to change direction smoothly. The point where the back tangent ends and curve begins is the **Point of Curvature (PC)**; the point where tangents intersect is the **Point of Intersection (PI)**; and the point where the curve ends and forward tangent begins is the **Point of Tangency (PT)**. The deflection angle between tangents is I (or Δ).

NCEES FORMULA SUMMARY: HORIZONTAL CIRCULAR CURVES

Degree of Curve (D , Arc Definition): $D = \frac{5729.58}{R}$ (R in feet)

Tangent Distance (T): $T = R \tan\left(\frac{I}{2}\right)$

Length of Curve (L): $L = \frac{\pi RI}{180} = \frac{100I}{D}$

Long Chord (LC): $LC = 2R \sin\left(\frac{I}{2}\right)$

Middle Ordinate (M): $M = R \left[1 - \cos\left(\frac{I}{2}\right) \right]$

External Distance (E): $E = R \left[\frac{1}{\cos(I/2)} - 1 \right]$

Sub-chord (c) & Sub-angle (d): $c = 2R \sin\left(\frac{d}{2}\right)$, $l = \frac{\pi Rd}{180}$

Stationing Rules: Station PC = Station PI $- T$, Station PT = Station PC $+ L$

1.2 Superelevation, Friction and Minimum Radius

To counteract centripetal acceleration around turns, roadways are banked (superelevated). The fundamental point-mass force equilibrium equation relates superelevation rate e (ft/ft or %), side friction factor f , vehicle design speed V (mph), and radius R (ft):

SUPERELEVATION & TRANSITION FORMULAS

Basic Equilibrium Equation: $e + f = \frac{V^2}{15R}$

Minimum Curve Radius: $R_{\min} = \frac{V^2}{15(e_{\max} + f_{\max})}$

Spiral Transition Length (L_s): $L_s = \frac{3.15V^3}{RC}$ (C = rate of increase of lateral acceleration, standard 1 ft/s³)

1.3 Stopping Sight Distance (SSD) & Intersection Sight Distance (ISD)

Stopping Sight Distance (SSD) is the total distance required for a driver traveling at design speed to perceive an obstacle, react, and bring the vehicle to a full stop. It combines perception-reaction distance and braking distance.

STOPPING & INTERSECTION SIGHT DISTANCE FORMULAS

SSD Equation: $SSD = 1.47Vt + \frac{V^2}{30[(a/32.2) \pm G]}$

where V = design speed (mph), t = driver reaction time (standard 2.5 sec), a = driver deceleration rate (standard 11.2 ft/s²), and G = percent grade divided by 100 (+ for upgrade, - for downgrade).

Intersection Sight Distance (ISD): $ISD = 1.47V_{\text{major}}t_g$

where t_g = gap acceptance time in sec, typically 7.5 s for passenger cars turning onto major road.

1.4 Horizontal Sight Line Offset (HSO)

When an obstruction (wall, embankment cut, guardrail, foliage) exists on the inside of a horizontal curve, drivers need a minimum lateral setback to maintain stopping sight distance around the bend.

HORIZONTAL SIGHT LINE OFFSET (HSO) FORMULA

HSO Equation: $HSO = R \left[1 - \cos \left(28.65 \frac{S}{R} \right) \right]$

For $S \leq L$, R is the inside-lane centerline radius, S is stopping sight distance, and HSO is measured from that lane centerline to the obstruction.

1.5 Vertical Parabolic Curves

The equal-tangent vertical curves treated here join two grades with a parabola. Their horizontal distances from PVC to PVI and PVI to PVT are each $L/2$.

NCEES FORMULA SUMMARY: PARABOLIC VERTICAL CURVES

Grade Algebraic Difference (A): $A = |g_2 - g_1| \times 100$

where g_1, g_2 are in decimal and A is whole-number percent. **Parabola Constant (a):** $a = \frac{g_2 - g_1}{2L}$

Rate of Change of Grade (r): $r = \frac{g_2 - g_1}{L}$

Rate of Vertical Curvature (K): $K = \frac{L}{A}$

Tangent Elevation: $Y_{\text{tangent}} = Y_{PVC} + g_1 x$

Curve Elevation: $Y_{\text{curve}} = Y_{PVC} + g_1 x + ax^2 = Y_{PVC} + g_1 x + \frac{g_2 - g_1}{2L} x^2$

High / Low Point Location (x_m): $x_m = \frac{-g_1 L}{g_2 - g_1} = \frac{g_1 L}{g_1 - g_2}$

1.6 Vertical Curve Design K-Factor Table & Sight Distance Criteria

AASHTO design guidelines tabulate minimum K-values ($L = KA$) for crest and sag curves based on design speed.

Design Speed V (mph)	Min K (Crest SSD)	Min K (Sag Headlight)	SSD (ft)
30	19	37	200
40	44	64	305
50	84	96	425
60	151	136	570
70	247	181	730

VERTICAL CURVE LENGTH & SIGHT DISTANCE EQUATIONS

Crest Vertical Curve (Eye height $h_1 = 3.5$ ft, Object height $h_2 = 2.0$ ft):

$$S \leq L: \quad L = \frac{AS^2}{2158} \quad S > L: \quad L = 2S - \frac{2158}{A}$$

Sag Vertical Curve (Headlight criteria, Headlight height = 2.0 ft, 1° divergence):

$$S \leq L: \quad L = \frac{AS^2}{400 + 3.5S} \quad S > L: \quad L = 2S - \frac{400 + 3.5S}{A}$$

Sag Vertical Curve (Riding Comfort): $L = \frac{AV^2}{46.5}$

2 Pavement System Design

Pavement design ensures that vehicular loads applied to the surface are distributed through structural layers so that stresses transmitted to the subgrade soil do not exceed its bearing capacity. The FE exam focuses on flexible pavement design using the AASHTO Structural Number method and Equivalent Single Axle Loads (ESALs).

2.1 AASHTO Structural Number Equation & Layer Roles

The Structural Number (SN) represents the total required structural strength of a flexible pavement above the subgrade soil.

AASHTO STRUCTURAL NUMBER (SN) EQUATION

SN Equation: $SN = a_1 D_1 + a_2 D_2 m_2 + a_3 D_3 m_3 + \cdots + a_n D_n m_n$

where a_i = structural layer coefficient (a_1 = asphalt surface, a_2 = base course, a_3 = subbase course), D_i = layer thickness in inches, and m_i = drainage coefficient (m_1 is assumed 1.0 for asphalt surface unless stated otherwise).

2.2 Load Equivalency Factors (LEF) and ESALs

Load-equivalency factors convert axle repetitions to reference 18-kip single-axle loads. They depend on axle configuration, pavement type, and design parameters. The table below is an illustrative set of factors, not a universal set.

Gross Axle Load (lbs)	Single Axles LEF	Tandem Axles LEF
10,000	0.0877	0.00688
14,000	0.360	0.0270
18,000 (Standard Ref)	1.000	0.0773
22,000	2.18	0.180
30,000	6.97	0.658
36,000	13.93	1.38
40,000	21.08	2.08

2.3 Subgrade Soil Characterization

The empirical $M_R \approx 1,500 CBR$ (psi) correlation is commonly used for fine-grained subgrade soils at low CBR (about 10 or less); verify applicability.

$$M_R \text{ (psi)} = 1500 CBR.$$

3 Traffic Capacity and Flow Theory

3.1 Traffic Flow Fundamentals & Greenshields Model

Traffic flow uses flow V (veh/h/ln), **space-mean speed** S (mph), and density D (veh/mi/ln), with $V = SD$. Average headway is $3600/V$ seconds/vehicle and average spacing is $5280/D$ ft/vehicle.

Greenshields Model assumes a linear relationship between speed and density. As density increases, speed drops linearly from free-flow speed (S_f) to zero at jam density (D_j).

GREENSHIELDS SPEED-DENSITY-FLOW MODEL EQUATIONS

Speed Equation: $S = S_f \left(1 - \frac{D}{D_j}\right)$

Flow Equation: $V = SD = S_f D \left(1 - \frac{D}{D_j}\right)$

Maximum Capacity (V_m): $V_m = \frac{S_f D_j}{4}$

Optimum Speed at Capacity (S_o): $S_o = \frac{S_f}{2}$

Optimum Density at Capacity (D_o): $D_o = \frac{D_j}{2}$

3.2 Basic Freeway Segment Capacity & Free Flow Speed

According to the Highway Capacity Manual (HCM) as presented in the FE Reference Handbook, the Free Flow Speed (FFS) of a basic freeway segment is calculated from base free flow speed adjusted for lane width, lateral clearance, and ramp density.

FREE FLOW SPEED & DEMAND FLOW RATE FORMULAS

Free Flow Speed (FFS): $FFS = BFFS - f_{LW} - f_{RLC} - 3.22 TRD^{0.84}$

where BFFS = base free flow speed (default 75.4 mph), f_{LW} = lane width adjustment (mph), f_{RLC} = right-side lateral clearance adjustment (mph), and TRD = total ramp density (ramps/mi).

Demand Flow Rate (v_p): $v_p = \frac{V}{PHF N f_{HV} f_p}$

where V = hourly peak volume (veh/h), PHF = peak hour factor, N = number of lanes in direction, f_{HV} = heavy vehicle adjustment factor, and f_p = driver population factor (1.0 for regular commuters).

Heavy Vehicle Adjustment (f_{HV}): $f_{HV} = \frac{1}{1 + P_T(E_T - 1) + P_R(E_R - 1)}$

PCE values (E_T): Level terrain $E_T = 2.0$; Rolling terrain $E_T = 3.0$.

3.3 Peak Hour Factor (PHF) & Level of Service (LOS)

Peak Hour Factor measures flow rate fluctuations within the peak hour:

$$PHF = \frac{V}{4V_{15}},$$

where V_{15} is the peak 15-minute volume.

LOS	Density Range (pc/mi/ln)	Operating Conditions
A	0 to ≤ 11	Free flow, complete mobility, high comfort
B	> 11 to ≤ 18	Reasonably free flow, slightly restricted maneuvering
C	> 18 to ≤ 26	Stable flow, lane changes require vigilance
D	> 26 to ≤ 35	Approaching unstable flow, freedom to maneuver severely restricted
E	> 35 to ≤ 45	At capacity (maximum flow), operating at capacity density
F	Not a fixed threshold	Breakdown flow, stop-and-go queues, demand $>$ capacity

4 Traffic Control Devices & Signal Timing

Traffic signal timing ensures safe clearance of vehicles and pedestrians through intersections. The change interval (yellow phase) alerts drivers of an impending red light, while the clearance interval (all-red phase) ensures vehicles already in the intersection clear it before cross-traffic receives green.

TRAFFIC SIGNAL INTERVAL EQUATIONS

Yellow Change Interval (y): $y = t + \frac{v}{2a \pm 64.4G}$

where t = reaction time (standard 1.0 sec), v = approach speed in ft/sec ($v = 1.47V_{mph}$), a = deceleration rate (standard 11.2 ft/s²), and G = percent grade divided by 100.

Red Clearance Interval (r): $r = \frac{W + L}{v}$

where W = intersection clearance width (ft), L = vehicle length (standard 20 ft), and v = approach speed in ft/sec.

Minimum Pedestrian Green (G_p): $G_p = 3.2 + L_{crosswalk}/S_p + 0.27N_{ped}$

where $L_{crosswalk}$ = crosswalk length (ft), S_p = pedestrian walking speed (standard 3.5 ft/sec), and N_{ped} = pedestrian volume per phase.

4.1 Webster's Optimum Signal Cycle Length

Optimal cycle length minimizes total intersection delay:

$$C_{opt} = \frac{1.5L + 5}{1 - Y},$$

where L is total lost time per cycle (sec), and Y is the sum of critical phase flow ratios (v_i/s_i).

5 Transportation Planning, Safety & Earthwork

5.1 Four-Step Travel Demand Modeling & Gravity Model

Traditional travel demand forecasting follows a 4-step process: (1) Trip Generation, (2) Trip Distribution, (3) Mode Choice, and (4) Trip Assignment. The Gravity Model distributes trips between zones based on zone attractiveness (population/jobs) and travel friction (travel time).

GRAVITY MODEL TRIP DISTRIBUTION EQUATION

Gravity Model Equation: $T_{ij} = P_i \left[\frac{A_j F_{ij} K_{ij}}{\sum_k A_k F_{ik} K_{ik}} \right]$

where T_{ij} = trips generated in zone i and attracted to zone j , P_i = total trips produced in zone i , A_j = attractiveness of zone j , F_{ij} = friction factor = $a t_{ij}^b$, and K_{ij} = socio-economic adjustment factor (usually assumed 1.0).

5.2 Traffic Safety & Crash Rates

Crash rates normalize accident frequency by exposure. Intersections are evaluated per Million Entering Vehicles (MEV); roadway segments are evaluated per 100 Million Vehicle Miles Traveled (100M VMT).

TRAFFIC SAFETY & CRASH RATE FORMULAS

Intersection Crash Rate (R_{MEV}): $R_{MEV} = \frac{A \times 1,000,000}{V_{entering}}$
 where A = number of crashes per year, and $V_{entering} = ADT \times 365$.

Segment Crash Rate (R_{MVMT}): $R_{MVMT} = \frac{A \times 100,000,000}{VMT}$
 where $VMT = ADT \times 365 \times \text{Segment Length (miles)}$.

Crash Reduction (CR): $CR = N C R_{factor} \left(\frac{ADT_{after}}{ADT_{before}} \right)$

5.3 Earthwork Volumes & Mass Haul Diagrams

Earthwork cut and fill volumes between successive cross-sections are computed using the Average End Area formula or the more precise Prismoidal formula.

EARTHWORK VOLUME FORMULAS

Average End Area Formula: $V = L \left(\frac{A_1 + A_2}{2} \right) \quad (\text{ft}^3)$

Prismoidal Formula: $V = L \left(\frac{A_1 + 4A_m + A_2}{6} \right) \quad (\text{ft}^3)$

Conversion to Cubic Yards: $V_{yd^3} = \frac{V_{ft^3}}{27}$

where A_1, A_2 = cross-sectional end areas (ft^2), A_m = area of mid-section (ft^2), and L = distance between sections (ft).

6 Example Problems and Solutions

The following 15 practice problems represent typical NCEES FE Civil exam questions across all Transportation Engineering topic areas. Each problem includes a statement, given data, handbook equation references, full step-by-step calculations, and highlighted correct answers.

Problem 1: Horizontal Curve Arc Length & Tangent Distance

NCEES Category: A. Geometric Design

Question Statement: A circular horizontal curve on a two-lane highway has a deflection angle of 39° between two tangents and a radius of 600 ft. Calculate the length of the curve (L) and the tangent distance (T).

Given Data: Intersection Angle $I = 39^\circ$, Radius $R = 600$ ft.

Solution

- FE Handbook Reference: Section 10.5 Horizontal Curves: $L = \pi RI/180$, $T = R \tan(I/2)$.
- Curve Length: $L = (\pi \cdot 600 \cdot 39)/180 = (23,400\pi)/180 = 130\pi = 408.41$ ft.
- Tangent Distance: $T = 600 \tan(39^\circ/2) = 600 \tan(19.5^\circ) = 600(0.35412) = 212.47$ ft.

FINAL ANSWER: Curve Length $L = 408.4$ ft; Tangent Distance $T = 212.5$ ft

Problem 2: Horizontal Curve Deflection Angle From Long Chord

NCEES Category: A. Geometric Design

Question Statement: A circular horizontal curve has a degree of curvature $D = 11^\circ$ (arc definition) and a long chord length $LC = 600$ ft measured straight from PC to PT. Determine the deflection angle (I) between the two tangents.

Given Data: Degree of Curve $D = 11^\circ$, Long Chord $LC = 600$ ft.

Solution

- Calculate Radius: $R = 5729.58/D = 5729.58/11 = 520.87$ ft.
- Use Long Chord Formula: $LC = 2R \sin(I/2) \Rightarrow 600 = 2(520.87) \sin(I/2)$.
- $\sin(I/2) = 600/1041.74 = 0.57596$.
- $I/2 = \arcsin(0.57596) = 35.166^\circ \Rightarrow I = 70.33^\circ$.

FINAL ANSWER: Deflection Angle $I = 70.33^\circ$ (or $70^\circ 20'$)

Problem 3: Horizontal Sight Line Offset (HSO) Around Obstruction**NCEES Category:** A. Geometric Design

A 50-mph two-lane highway curve has inside-lane centerline radius $R = 572.96$ ft and length $L \geq 424$ ft. With reaction time 2.5 s, deceleration 11.2 ft/s^2 , and level grade, find the horizontal sight-line offset needed to maintain stopping sight distance.

Given Data: $V = 50$ mph, $R = 572.96$ ft, $t = 2.5$ s, $a = 11.2 \text{ ft/s}^2$, $G = 0$.

Solution

- $SSD = 1.47Vt + V^2/[30(a/32.2)]$.
- Reaction component $= 1.47(50)(2.5) = 183.75$ ft.
- Braking component $= 50^2/[30(11.2/32.2)] = 2500/(30 \cdot 0.34783) = 2500/10.435 = 239.58$ ft.
- Total $SSD = S = 183.75 + 239.58 = 423.33$ ft.
- $HSO = R[1 - \cos(28.65S/R)]$. Angle term $= 28.65(423.33)/572.96 = 21.168^\circ$.
- $HSO = 572.96[1 - \cos(21.168^\circ)] = 572.96(1 - 0.93251) = 38.67$ ft.

FINAL ANSWER: Horizontal Sight Line Offset $HSO = 38.7$ ft

Problem 4: Vertical Curve Tangent Elevation At Pvt**NCEES Category:** A. Geometric Design

Question Statement: An equal-tangent parabolic vertical curve has a VPC station of 14+44 at elevation 792.00 ft. The entry grade $g_1 = +2.0\%$, the exit grade $g_2 = -3.0\%$, and total curve length $L = 600$ ft. Find the elevation of the Point of Vertical Tangency (PVT).

Given Data: VPC Station = 14+44, Elevation VPC = 792.00 ft, $g_1 = +0.02$, $g_2 = -0.03$, $L = 600$ ft.

Solution

- PVI is at distance $L/2 = 300$ ft from VPC.
- Elev PVI $= 792.00 + 0.02(300) = 798.00$ ft.
- Elev PVT $= 798.00 + (-0.03)(300) = 789.00$ ft.

FINAL ANSWER: Elevation of PVT = 789.00 ft

Problem 5: Crest Vertical Curve Minimum Length For High Speed Inter**STATE****NCEES Category:** A. Geometric Design

Question Statement: A parabolic vertical curve on an interstate highway with a design speed of 75 mph connects an entry grade $g_1 = +7\%$ and exit grade $g_2 = -5\%$. Assuming standard driver reaction time $t = 2.5$ sec, deceleration $a = 11.2$ ft/sec², and controlling restrictive downgrade (-5%), determine the minimum vertical curve length (L) required to satisfy stopping sight distance criteria.

Given Data: $V = 75$ mph, $g_1 = +7\%$, $g_2 = -5\%$, $t = 2.5$ s, $a = 11.2$ ft/s², $G = -0.05$.

Solution

- $A = |g_1 - g_2| = |7 - (-5)| = 12\%$.
- $SSD = 1.47(75)(2.5) + 75^2/[30((11.2/32.2) - 0.05)]$.
- Reaction component = 275.625 ft; braking denominator = $30(0.34783 - 0.05) = 8.9348$.
- Braking component = $5625/8.9348 = 629.56$ ft; total $S = 275.625 + 629.56 = 905.19$ ft.
- Assume $S \leq L$: $L = AS^2/2158 = 12(905.19)^2/2158 = 4556.27$ ft.
- Verify: $905.2 \leq 4556.3$, so the assumption holds.

FINAL ANSWER: Minimum Vertical Curve Length $L = 4,556$ ft

Problem 6: High Point Location & Elevation On Parabolic Vertical Curve**NCEES Category:** A. Geometric Design

Question Statement: A crest vertical curve has a VPC station of 10+00 at elevation 500.00 ft. The entry grade is $g_1 = +3.0\%$, exit grade is $g_2 = -2.0\%$, and total length $L = 800$ ft. Determine the station and elevation of the highest point (crest) on the curve.

Given Data: VPC Station = 10+00, Elev VPC = 500.00 ft, $g_1 = +0.03$, $g_2 = -0.02$, $L = 800$ ft.

Solution

- $x_m = -g_1 L / (g_2 - g_1) = -0.03(800) / (-0.02 - 0.03) = 480.00$ ft from VPC.
- Station High Point = $(10 + 00) + 480$ ft = Station 14+80.
- $a = (g_2 - g_1) / (2L) = (-0.02 - 0.03) / (1600) = -0.00003125$ ft⁻¹.
- Elev = $500.00 + 0.03(480) - 0.00003125(480)^2 = 507.20$ ft.

FINAL ANSWER: High Point Station = 14+80; High Point Elevation = 507.20 ft

Problem 7: Horizontal Curve Construction Stationing (PC And PT)

NCEES Category: A. Geometric Design

Question Statement: Two straight highway tangents intersect at Station 210+00 with an intersection angle $I = 75^\circ$. A horizontal circular curve with radius $R = 1000$ ft is to be designed. Determine the stationing of the Point of Curvature (PC) and Point of Tangency (PT).

Given Data: Station PI = 210+00 (21,000 ft), $I = 75^\circ$, $R = 1000$ ft.

Solution

- $T = R \tan(I/2) = 1000 \tan(37.5^\circ) = 767.33$ ft.
- $L = \pi RI/180 = (\pi \cdot 1000 \cdot 75)/180 = 1309.00$ ft.
- Station PC = 21,000 – 767.33 = 20,232.67 ft = Station 202+32.67.
- Station PT = 20,232.67 + 1309.00 = 21,541.67 ft = Station 215+41.67.

FINAL ANSWER: PC Station = 202+32.67; PT Station = 215+41.67

Problem 8: AASHTO Flexible Pavement Base Course Thickness

NCEES Category: B. Pavement System Design

Question Statement: A flexible pavement structure requires a total Structural Number $SN = 3.80$. The pavement consists of an asphalt surface course with thickness $D_1 = 4.0$ inches ($a_1 = 0.44$, $m_1 = 1.0$), a crushed stone base course ($a_2 = 0.14$, $m_2 = 0.90$), and a granular subbase course $D_3 = 8.0$ inches ($a_3 = 0.11$, $m_3 = 0.80$). Calculate the required thickness of the base course (D_2) in inches.

Given Data: $SN = 3.80$, $a_1 = 0.44$, $D_1 = 4.0$ in., $m_1 = 1.0$, $a_2 = 0.14$, $m_2 = 0.90$, $a_3 = 0.11$, $D_3 = 8.0$ in., $m_3 = 0.80$.

Solution

- $SN = a_1 D_1 m_1 + a_2 D_2 m_2 + a_3 D_3 m_3$.
- $SN_1 = 0.44(4.0)(1.0) = 1.76$.
- $SN_3 = 0.11(8.0)(0.80) = 0.704$.
- $3.80 = 1.76 + (0.14 D_2 \cdot 0.90) + 0.704 = 2.464 + 0.126 D_2$.
- $0.126 D_2 = 1.336 \Rightarrow D_2 = 1.336/0.126 = 10.60$ inches (standard specified thickness = 11.0 in.).

FINAL ANSWER: Required Base Course Thickness $D_2 = 10.6$ inches (or 11.0 in. specified)

Problem 9: Daily Equivalent Single Axle Loads (ESALS) Calculation

NCEES Category: B. Pavement System Design

Question Statement: A highway design lane experiences daily heavy vehicle traffic consisting of 500 single axles weighing 22,000 lbs each (LEF = 2.18) and 200 tandem axles weighing 36,000 lbs total combined weight (LEF = 1.38). Compute the total daily ESALs contributed by these trucks.

Given Data: Single Axles: 500 reps/day @ 22-kips (LEF = 2.18); Tandem Axles: 200 reps/day @ 36-kips (LEF = 1.38).

Solution

- $ESAL_{single} = 500(2.18) = 1,090$ ESALs/day.
- $ESAL_{tandem} = 200(1.38) = 276$ ESALs/day.
- Total Daily ESALs = 1090 + 276 = 1,366 ESALs/day.

FINAL ANSWER: Total Daily Traffic ESALs = 1,366 ESALs/day

Problem 10: Greenshields Traffic Stream Speed, Density & Capacity

NCEES Category: C. Traffic Capacity & Flow Theory

Question Statement: A multi-lane highway segment has a linear speed-density relationship given by $S = 60 - 0.20D$, where S is speed in mph and D is density in veh/mi/ln. Determine: (a) Free-flow speed (S_f), (b) Jam density (D_j), (c) Maximum lane flow capacity (V_m), and (d) Density when operating at a speed of 45 mph.

Given Data: $S = 60 - 0.20D$.

Solution

- Set $D = 0$: $S_f = 60$ mph.
- Set $S = 0$: $0 = 60 - 0.20D_j \Rightarrow D_j = 60/0.20 = 300$ veh/mi/ln.
- $V_m = S_f D_j / 4 = (60)(300)/4 = 4,500$ veh/hr/ln.
- At $S = 45$ mph: $45 = 60 - 0.20D \Rightarrow D = 15/0.20 = 75$ veh/mi/ln.

FINAL ANSWER: $S_f = 60$ mph; $D_j = 300$ veh/mi/ln; $V_m = 4,500$ veh/hr/ln; Density at 45 mph = 75 veh/mi/ln

Problem 11: Basic Freeway Segment Free Flow Speed (FFS)

NCEES Category: C. Traffic Capacity & Flow Theory

Question Statement: A 6-lane freeway (3 lanes in each direction) has 11-ft lane widths, 2-ft right-side lateral clearance, and an average total ramp density $TRD = 2.5$ ramps/mile. Base free-flow speed $BFFS = 75.4$ mph. From HCM tables, the lane width adjustment $f_{LW} = 1.9$ mph and lateral clearance adjustment $f_{RLC} = 2.4$ mph. Compute the estimated Free Flow Speed (FFS).

Given Data: $BFFS = 75.4$ mph, $f_{LW} = 1.9$ mph, $f_{RLC} = 2.4$ mph, $TRD = 2.5$ ramps/mi.

Solution

- $FFS = BFFS - f_{LW} - f_{RLC} - 3.22TRD^{0.84}$.
- $TRD^{0.84} = (2.5)^{0.84} = 2.1584$.
- Ramp term $= 3.22(2.1584) = 6.95$ mph.
- $FFS = 75.4 - 1.9 - 2.4 - 6.95 = 64.15$ mph.

FINAL ANSWER: Free Flow Speed $FFS = 64.2$ mph

Problem 12: Freeway Segment Demand Flow Rate & Level Of Service (LOS)

NCEES Category: C. Traffic Capacity & Flow Theory

Question Statement: A 6-lane freeway (3 lanes per direction, $N = 3$) carries a peak-hour directional volume $V = 2400$ veh/hr. Peak hour factor $PHF = 0.96$, free flow speed $FFS = 60$ mph. The terrain is rolling (heavy vehicle PCE $E_T = 3.0$), truck traffic $P_T = 4\%$ (0.04), and driver population factor $f_p = 1.0$. Determine the 15-min demand flow rate (v_p) and Level of Service (LOS).

Given Data: $V = 2400$ veh/h, $N = 3$, $PHF = 0.96$, $FFS = 60$ mph, $E_T = 3.0$, $P_T = 0.04$, $f_p = 1.0$.

Solution

- $f_{HV} = 1/[1 + P_T(E_T - 1)] = 1/[1 + 0.04(3.0 - 1.0)] = 1/1.08 = 0.9259$.
- $v_p = V/(PHF N f_{HV} f_p) = 2400/(0.96 \cdot 3 \cdot 0.9259 \cdot 1.0) = 900.0$ pc/h/ln.
- $D = v_p/FFS = 900.0/60 = 15.0$ pc/mi/ln.
- From the LOS table: density ≤ 11 gives LOS A; $11 < D \leq 18$ gives LOS B.

FINAL ANSWER: Demand Flow Rate $v_p = 900$ pc/h/ln; Density $D = 15.0$ pc/mi/ln; Level of Service = LOS B

Problem 13: Traffic Signal Yellow Change & Red Clearance Intervals**NCEES Category:** D. Traffic Control Devices**Question Statement:** An urban intersection approach has a design speed $V = 40$ mph (approach speed $v = 58.8$ ft/sec), driver reaction time $t = 1.0$ sec, deceleration rate $a = 11.2$ ft/sec², and level grade ($G = 0$). The intersection clearance width $W = 72$ ft and design vehicle length $L = 20$ ft. Compute the required yellow change interval (y) and red clearance interval (r).**Given Data:** $V = 40$ mph ($v = 58.8$ ft/s), $t = 1.0$ s, $a = 11.2$ ft/s², $G = 0$, $W = 72$ ft, $L = 20$ ft.**Solution**

- $y = t + v/(2a) = 1.0 + 58.8/(2 \cdot 11.2) = 1.0 + 2.625 = 3.63$ sec (use 3.6 s).
- $r = (W + L)/v = (72 + 20)/58.8 = 92/58.8 = 1.56$ sec (use 1.6 s).

FINAL ANSWER: Yellow Change Interval $y = 3.6$ sec; Red Clearance Interval $r = 1.6$ sec**Problem 14: Intersection & Roadway Segment Traffic Crash Rates****NCEES Category:** E. Transportation Planning & Safety**Question Statement:** A highway intersection experienced 15 crashes in one year with an Average Daily Traffic $ADT = 25,000$ entering vehicles/day. A 6.1-mile segment of the same highway experienced 42 crashes in one year with $ADT = 18,000$ vehicles/day. Calculate: (a) Intersection crash rate in Rate per Million Entering Vehicles (RMEV), and (b) Segment crash rate in Rate per 100 Million Vehicle Miles Traveled (RMVMT).**Given Data:** Intersection: $A = 15$ crashes, $ADT = 25,000$. Segment: $A = 42$ crashes, Length = 6.1 mi, $ADT = 18,000$.**Solution**

- $V_{entering} = 25,000(365) = 9,125,000$ vehicles/yr.
- $R_{MEV} = 15(1,000,000)/9,125,000 = 1.64$ crashes per MEV.
- $VMT = 18,000(365)(6.1) = 40,077,000$ vehicle-miles/yr.
- $R_{MVMT} = 42(100,000,000)/40,077,000 = 104.80$ crashes per 100M VMT.

FINAL ANSWER: Intersection Crash Rate = 1.64 RMEV; Segment Crash Rate = 104.80 RMVMT**Problem 15: Earthwork Cut Volume Comparison (Average End Area Vs****PRISMOIDAL)****NCEES Category:** E. Transportation Planning & Safety**Question Statement:** Two cross-sections located $L = 200$ ft apart have cut end areas $A_1 = 350$ ft² and $A_2 = 650$ ft². The middle cross-sectional area $A_m = 480$ ft². Calculate the earthwork cut volume in cubic yards (yd³) using: (a) Average End Area formula, and (b) Prismoidal formula.**Given Data:** $L = 200$ ft, $A_1 = 350$ ft², $A_2 = 650$ ft², $A_m = 480$ ft².**Solution**

- Average End Area: $V = L[(A_1 + A_2)/2] = 200[(350 + 650)/2] = 100,000$ ft³.
- $V_{AEA} = 100,000/27 = 3,703.70$ yd³.
- Prismoidal: $V = L[(A_1 + 4A_m + A_2)/6] = 200[(350 + 4(480) + 650)/6]$.
- Numerator = $350 + 1920 + 650 = 2,920$ ft².
- $V = 200(2920/6) = 97,333.33$ ft³.
- $V_{Prism} = 97,333.33/27 = 3,604.94$ yd³.

FINAL ANSWER: Average End Area Volume = 3,703.7 yd³; Prismoidal Volume = 3,604.9 yd³