Professional Engineering Exam

Transportation Engineering

Study Guide

Education and Training Evaluation Commission (ETEC)
National Center for Assessment (NCA)

www.etec.gov.sa

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Table of Contents

1. Aim:

The objective of this Instruction Manual is to provide guidelines for the NCA proposed Professional Engineers Exam. These guidelines cover the eligibility conditions, the grading and passing conditions, the structure of the exam and the distribution of exam questions among various areas. In essence, this Instruction Manual represents a "bridge" between the developed exam standards and the actual phrased questions. It is designed to help item writers prepare questions in Transportation Engineering Discipline Exam as well as a study guide for examinees.

2. Exam Structure:

2.1 Exam Type

The exam is initially paper-based with questions being a combination of multiple- choice questions (MCQ) and essays.

2.2 Exam Organization

The exam will be conducted in two sessions for one day. The duration of the first session is 2.5 hours while the second section is 4 hours long. There is one-hour break between the two sessions.

2.2.1. Session #1

The first session is the common part to be taken by all the examinees from all disciplines. This part includes seven topics: (Ethics – Professionalism - Laws for Professional Practice, Professional Laws and Regulation - Environment and Natural Resources - Engineering Management - Engineering Economics - Health, Safety & Security (HSS)).

The total duration of this session is 2.5 hours and the total number of questions is 30 MCQ and 2 essays.

2.2.2. Session #2

The second session is the Discipline Part. The following engineering disciplines are considered:

Code	Discipline
STE	Structural Engineering
GTE	Geotechnical Engineering
TRE	Transportation Engineering
WREE	Water Resources and Environmental Engineering
PE	Power Engineering
HVAC	Heating, Ventilation, and Air Conditioning (HVAC) and Refrigeration Engineering
TFSE	Thermal and Fluids Systems Engineering
CHE	Chemical Engineering
FPE	Fire Protection Engineering
ARCH	Architecture

The total duration of this session is 4 hours and the total number of questions is 30 MCQ questions and 5 essays. The examinee must answer all the MCQ questions and three essays (one compulsory and two to be chosen out of four essays).

2.3 Eligibility for the Exam

The eligibility to register for the exam is according to the requirements and conditions of the Saudi Council of Engineers (SCE).

2.4 Grades

Each part (common part and discipline part) carries a total grade of 100. The MCQs carry a grade of 60% while the essays carry a grade of 40%. Each MCQ has 4 choices for the answer. There is no negative marking for wrong answers.

2.5 Passing Rules

- The eligible candidate must take in his/her first sitting the two exam parts (common part and discipline part).
- In order to pass the exam, the candidate must obtain a grade of 60% or above in each part of the exam.
- If the candidate fails both parts of the exam (by receiving in each part a grade less than 60%), he/she can take the two parts of the exam but only when one full year has passed.
- If the candidate fails only one part of the exam (common part or discipline part), he/she must repeat only the part he/she failed, but he/she must pass this part within one year.
- If a year passed and the candidate did not succeed in passing the part he/she failed, then he/she has to take both parts of the exam.

2.6 Exam Rules

- No printed or electronic material is allowed during the exam. All necessary reference materials will be provided by NCA.
- Calculators approved by NCA are allowed.
- Comprehensive exam rules will be provided by the examination authority, NCA, in a separate manual.

3. Table of Specifications for Transportation Engineering Exam:

Major Area	Multiple Choice Questions (MCQs)		Number of Essay Questions	Engineering Standard
	%	Number of Questions		
1. Transportation Planning	6.67	2		TRE-T1
2. Traffic Engineering	16.67	5	1	TRE-T2
3. Traffic Signal Design	6.67	2	1	TRE-T3
4. Traffic Control Devices	3.33	1		TRE-T4
5. Traffic Safety	6.67	2		TRE-T5
6. Geometric Design - Alignments	13.33	4	1 (Compulsory)	TRE-T6
7. Geometric Design – Intersections	3.33	1		TRE-T7
8. Geometric Design – Roadside and Cross-Section Elements	3.33	1		TRE-T8
9. Structural Analysis and Design	10	3	1	TRE-T9
10. Materials and Mix Design	10	3		TRE-T10
11. Evaluation, Maintenance and Rehabilitations	6.67	2		TRE-T11
12. Drainage Systems	6.67	2		TRE-T12
13. Economic Analysis	6.67	2	1	TRE-T13
Total	100%	30	1 Compulsory and Choose 2 out of 4	

4. Standards for Transportation Engineering:

The Engineering Standards for the Transportation Engineering Discipline are structured around thirteen major areas:

TRE-T1. Transportation Planning.

TRE-T2. Traffic Engineering.

TRE-T3. Traffic Signal Design.

TRE-T4. Traffic Control Devices (TCD).

TRE-T5. Traffic Safety.

TRE-T6. Geometric Design – Alignments.

TRE-T7. Geometric Design – Intersections.

TRE-T8. Geometric Design – Roadside and Cross-Section Elements.

TRE-T9. Structural Analysis and Design.

TRE-T10. Materials and Mix Design.

TRE-T11. Evaluation, Maintenance and Rehabilitations.

TRE-T12. Drainage systems.

TRE-T13. Economic Analysis.

Practicing transportation engineers are applying above mentioned topics in their field practice during their engineering career. Each of these topics has a number of indicators to ensure that the engineer has the necessary experiences to work in a transportation engineering area.

Transportation Engineers are expected to possess and demonstrate command of the following Transportation Engineering skills:

Group I: TRE-T1 to TRE-T5 (40%)

TRE-T1: Transportation Planning

Indicators

TRE-T1-1 Understand and be able to perform the travel demand forecasting process (including the four-step model: trip generation, trip distribution, modal split and traffic assignment).

TRE-T1-2 Understand and be able to conduct Traffic Impact Studies.

TRE-T2: Traffic Engineering

Indicators

TRE-T2-1	Perform capacity and level of service analysis for an Uninterrupted flow facility for different modes (highway, railway, bus transit).
TRE-T2-2	Analyze interrupted flow facility for different modes (e.g., level of service, capacity, running time, travel speed) and for all road users (vehicles, pedestrians, bicycles).
TRE-T2-3	Perform roadway intersection capacity analysis (e.g., at grade, signalized, roundabout, interchange).
TRE-T2-4	Perform traffic studies and analyze it (e.g., volume studies, peak hour factor, speed studies, parking studies and design), including methods for estimating performance measures (delays, queues, travel times) for intersections and roadways and understanding the use of simulation models.
TRE-T2-5	Understand and be able to analyze traffic flow characteristics including fundamental diagrams (speed- flow- density) and parameters (capacity, free-flow speed, jam density), and models (e.g. car following (minimum following distance), lane changing, gap acceptance, and shock waves).
TRE-T2-6	Ability to analyze and design non-motorized flow facilities (e.g., pedestrian, bicycle).
TRE-T2-7	Recognize recent and emerging technologies in data collection and processing (video, radar, blue tooth, GPS cell phone records).

TRE-T3: Traffic Signal Design

Indicators

TRE-T3-1	Ability to design traffic signal timing (e.g., signal phasing, clearance intervals, pedestrian crossing timing).
TRE-T3-2	Understanding and ability to apply traffic signal warrants.
TRE-T3-3	Understanding and ability to design traffic signal interconnection and traffic signal coordination (cycle length, green times, offsets).

TRE-T4: Traffic Control Devices (TCD)

Indicators

TRE-T4-1	Recognize the types and characteristics of TCD (signs, signals and pavement markings), and its application.
TRE-T4-2	Knowledge and ability to apply signing and marking of pedestrian and bicycle facilities.

TRE-T4-3 Understanding and ability to apply signing and marking for traffic calming designs.

TRE-T4-4 Ability to apply proper temporary traffic control (e.g. at work zone).

TRE-T5: Traffic Safety

Indicators

TRE-T5-1 Conduct crash data analysis focusing on the concepts of Conflict analysis, accident rates, black spot identification, collision diagrams, and condition diagrams.

TRE-T5-2 Ability to propose appropriate accident countermeasures.

TRE-T5-3 Understand how to conduct Road Safety Audit.

TRE-T5-4 Ability to develop temporary traffic control and detour plots to address worker and road user safety.

Group II: TRE-T6 to TRE-T8 (20%)

TRE-T6: Geometric Design - Alignments

Indicators

TRE-T6-1 Analyze the basic horizontal curve elements for roads/railways, such as middle ordinate, length, chord, and radius.

TRE-T6-2 Provide solutions to a sight distance problem generated from a real road environment.

TRE-T6-3 Determine the superelevation rate for roads/railways and transitions by providing proper method and components.

TRE-T6-4 Evaluate special horizontal curves in a certain problematic road/railway condition such as compound/reverse curves, curve widening, and coordination with vertical geometry.

TRE-T6-5 Design the crest and sag vertical curve geometry, for roads/railways.

TRE-T6-6 Formulate the solutions for a given stopping and passing sight distance problem generated from Saudi roads.

TRE-T6-7 Recognize obstacles and develop the solutions to secure a vertical clearance on the road/railway.

TRE-T7: Geometric Design - Intersections

Indicators

TRE-T7-1	Provide solutions to a given practical problem about roadway intersection sight distance.
TRE-T7-2	Analyze the geometry of highway interchanges focusing on the Freeway merge, entrance and exit ramp, weaving section sizing, horizontal and vertical designs.
TRE-T7-3	Review a given at-grade road intersection layout, including a roundabout and find possible improvements.

TRE-T8: Geometric Design – Roadside and Cross-Section Elements

Indicators

TRE-T8-1	Realize the forgiving roadside concepts into the roads under operation focusing on the clear zone, recoverable slopes, roadside obstacles.
TRE-T8-2	Identify a proper highway barrier design based on its performance considering possible alternatives such as longitudinal barriers, end treatments, transitions, and crash cushions.
TRE-T8-3	Apply the roadway cross-section elements such as lane widths, shoulders, sidewalks to solve a practical problem.

Group III: TRE-T9 to TRE-T12 (33.33%)

TRE-T9: Structural Analysis and Design

Indicators

TRE-T9-1	Recognize pavement types, wheel loads and vehicle and traffic considerations in pavement structural design.
TRE-T9-2	Analyze different types of pavement design including theoretical, mechanistic and empirical methods.
TRE-T9-3	Understand the general concept of multilayered elastic system, and apply analytical solutions of pavement response parameters including stress, strain and deflection.
TRE-T9-4	Analyze and design the highway and airport pavement structures according to the mechanistic-empirical method, and evaluate and analyze pavement structure.
TRE-T9-5	Determine the traffic volumes and traffic loads required to design a pavement (considering the truck classification of KSA).

TRE-T10: Materials and Mix Design

Indicators

TRE-T10-1	Recognize properties of pavement materials and materials characterization.
TRE-T10-2	Understand requirements and tests of base and sub base materials and bituminous materials used in pavement construction.
TRE-T10-3	Recognize pavement types and their differences, differences between airport and highway pavements, and suggest the best pavement type based on traffic, environment, subgrade conditions.
TRE-T10-4	Suggest a suitable testing method for pavement sections and materials (HMA, Granular base and subbase, subgrade soil, asphalt cement, etc.) to address specific pavement distress or design.
TRE-T10-5	Understand and ability to apply design methods of high-type bituminous paving mixture.

TRE-T11: Evaluation, Maintenance and Rehabilitations

Indicators

TRE-T11-1	Recognize and ability to apply different methods of measuring pavement conditions and identify types of structural and functional pavement distresses.
TRE-T11-2	Recognize concepts of pavement serviceability and performance.
TRE-T11-3	Recognize the proper maintenance measures and rehabilitation methods.

TRE-T12: Drainage systems

Indicators

TRE-T12-1	Recognize and identify the hydrology, including runoff detention/retention/water quality mitigation measures by applying Rational method, hydrographs, SCS/NRCS method.
TRE-T12-2	Provide appropriate solutions to the hydraulics design problem, including culvert and storm water collection system design, and open-channel flow focusing on the inlet capacities, pipe flow and hydraulic energy dissipation.

TRE-T13: Economic Analysis (6.67%)

Indicators

TRE-T13-1	Ability to perform economic analyses (e.g., present worth, lifecycle costs, Benefit-Cost).

4.1 Reference Design Standards & Manuals

- Ministry of Transport (MOT) Manuals and General Specifications.
- Manual on Uniform Traffic Control Devices (MUTCD) in Saudi Arabia (Ministry of Municipal and Rural Affairs (OMRA) & MOT)
- Saudi Building Code terms and requirements that are applicable in Transportation Engineering.
- A Policy on Geometric Design of Highways and Streets (AASHTO Green Book), 7th Edition, 2018, American Association of State Highway & Transportation Officials, Washington, DC.
- Highway Capacity Manual, 6th Edition, 2016, Transportation Research Board, National Research Council, Washington, DC.
- Mechanistic-Empirical Pavement Design Guide: A Manual of Practice, 2nd edition, July 2015, American Association of State Highway & Transportation Officials, Washington, DC.
- NCHRP Report 812, Signal Timing Manual, 2nd Edition, 2015
- Guide for the Planning, Design, and Operation of Pedestrian Facilities, 1st Edition, 2004, American Association of State Highway & Transportation Officials, Washington, DC.

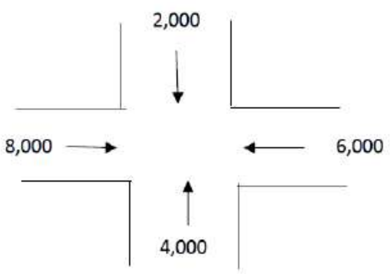
5. Sample of Questions

<table>
<tr><th>Q. No.</th><th>Topic Area</th><th>Indicator</th><th>Question Statement
(Answer's Choices)</th><th>Key
Answer</th><th>Expected Time (min.)</th><th>Supplied Reference</th></tr>
<tr><td>1</td><td>Transportation Planning</td><td>TRE-T1-1</td><td>Suburban neighborhood residents have three choices for commuting to the employment zone at the city center, which is at a distance of 20 km away. The mode available are: Auto (A), commuter rail (R) and a suburban bus line (B). The utility values for the three modes, based on a factored sum of attributes such as time, cost, etc. are "-1.23" for mode A, "-2.11" for mode R and "-1.89" for mode B. The total number of commuters originating from the neighborhood is 820. The number of Auto trips expected is most nearly:

A) 425
B) 303
C) 255
D) 153</td><td>(A)</td><td>4</td><td>None</td></tr>
<tr><td>2</td><td>Traffic Engineering</td><td>TRE-T2-5</td><td>The average number of vehicles passing a point on a highway lane is 2,200 vphpl. The vehicles travel at a space mean speed of 68 km/h. If the average length of a vehicle is 5.8 m, the gap distance between the vehicles (in meters) is most nearly:

A) 13
B) 25
C) 31
D) 40</td><td>(B)</td><td>3 - 4</td><td>None</td></tr>
<tr><td>3</td><td>Traffic Signal Design</td><td>TRE-T3-1</td><td>A three-phase traffic signal with 4 sec lost time per phase has the following critical movement conditions (Assume there is no phase overlap):

<table><tr><th></th><th>Phase A</th><th>Phase B</th><th>Phase C</th></tr><tr><td>Critical volume (vphpl)</td><td>70</td><td>400</td><td>550</td></tr><tr><td>Adjusted saturation flow rate (vphgpl)</td><td>350</td><td>1350</td><td>1960</td></tr></table>
Using the critical intersection volume-to-capacity ratio method, what is most nearly the</td><td>(C)</td><td>4</td><td>None</td></tr>
</table>

Q. No.	Topic Area	Indicator	Question Statement (Answer's Choices)	Key Answer	Expected Time (min.)	Supplied Reference
			recommended duration of the cycle (in seconds)? A) 16 B) 27 C) 54 D) 81			
4	**Traffic Safety**	TRE-T5-1	An intersection had 25 reported traffic accidents during the months of January through September. The ADT for this intersection is shown in the following figure. The accident rate per million entering vehicles (RMEV) for this intersection is most nearly:  A) 250 B) 200 C) 150 D) 100	(A)	3 - 4	None
5	**Geometric Design - Alignment**	TRE-T6-3	The coefficient of friction needed if no super-elevation is provided for a horizontal circular curve of radius 190 m and design speed of 65 km/h is: A) 0.155 B) 0.165 C) 0.175 D) 0.185	(C)	3 - 4	None
6	**Geometric Design-Cross-Sectional Elements**	TRE-T8-3	Slope of pavement shoulders should be: A) Greater than that of the pavement. B) Equal that of the pavement. C) At least 3 percent. D) As high as 7 percent.	(A)	3 - 4	None

<table>
<tr><th>Q. No.</th><th>Topic Area</th><th>Indicator</th><th>Question Statement
(Answer's Choices)</th><th>Key
Answer</th><th>Expected Time (min.)</th><th>Supplied Reference</th></tr>
<tr><td>7</td><td>Structural Analysis and Design</td><td>TRE-T9-1</td><td>A truck axle weights with full load are:
Axle weight
Front 17,000lb
Middle 20,000lb
Rear 14,000lb

Using the 4th power approximation, the total ESAL is:

A) 0.795
B) 1.524
C) 2.366
D) 2.685</td><td>(D)</td><td>4</td><td>None</td></tr>
<tr><td>8</td><td>Materials and Mix Design</td><td>TRE-T10-2</td><td>A subgrade soils has a CBR test penetration of 0.1 inch at 300 lb. Its CBR value is:

A) 0.030
B) 0.30
C) 0.10
D) 0.01</td><td>(C)</td><td>3 - 4</td><td>None</td></tr>
<tr><td>9</td><td>Evaluation, Maintenance and Rehabilitation</td><td>TRE-T11-1</td><td>Which of the following fully describes the effect of distress on Pavement Condition Index (PCI)?

A) Distress type and severity.
B) Distress severity and density.
C) Distress type, severity and area.
D) Distress type, severity and density.</td><td>(D)</td><td>3 - 4</td><td>None</td></tr>
<tr><td>10</td><td>Economic Analysis</td><td>TRE-T13-1</td><td>A city traffic engineer is considering installing a signal system at an intersection. He is trying to decide one of two alternative signal systems using a 10 year planning horizon. And the two alternatives have the following cash flows:

<table><tr><th></th><th>Year</th><th>Alt. X (SAR)</th><th>Alt. Y (SAR)</th></tr><tr><td>Initial Cost</td><td>0</td><td>1,000,000</td><td>600,000</td></tr><tr><td>Net annual benefits</td><td>1-10</td><td>316,000</td><td>212,400</td></tr></table>Assume no salvage value. If interest rate is 12%, and using Benefit/Cost Analysis, the preferred feasible alternative is most probably

A) Alt. X
B) Alt. Y
C) Either one (similar).
D) Neither one (unfeasible).</td><td>(A)</td><td>4</td><td>None</td></tr>
</table>

Essay Questions

Question. Essay # 1

A six-lane urban freeway has the following characteristics: 12-feet lanes, 6-feet clearance on the right side of the roadway, rolling terrain, a ramp density of 2.8 ramps per mile, and a PHF of 0.92. The traffic consists of 8% trucks and no RVs, and all drivers are regular users of the facility.

The peak-hour volume on the facility is currently 3,600 veh/h, which is expected to grow at a rate of 6% a year for the next 10 years.

Find the following:

a) The present freeway level of service

b) the level of service in 10 years

c) to avoid breakdown, when will substantial improvements be needed?

Topic Area: Traffic Engineering

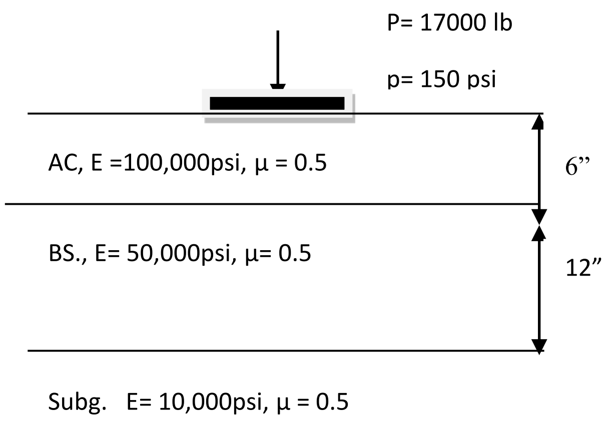
Indicator: TRE-T2-1 Perform capacity and level of service analysis for a basic freeway segment (Uninterrupted flow facility).

Expected Time: 25-30 min

Supplied Reference. Reference sheet #1

Question. Essay # 2

For the shown asphalt pavement section and using the one-layer system – flexible plate, calculate the deflection at the top of subgrade.



Topic Area: Structural Analysis and Design

Indicator: TRE-T9-1 Recognize pavement types, wheel loads and vehicle and traffic considerations in pavement structural design.

Expected Time: 15-20 min

Supplied Reference. Reference sheet #2

6. Solutions of Sample Questions

Multiple Choice Questions (MCQs)

MCQ # 1:

Topic Area: Transportation Planning

Indicator:

TRE-T1-1 Understand the travel demand forecasting process (including the four-step model: trip generation, trip distribution, modal split and traffic assignment).

Answer: A

Reference Sheet: None

Solution:

Calculations
Using the Logit model for mode choice, the probability of choosing mode (A) can be written as:
$P(A) = \frac{e^{U_A}}{e^{U_A} + e^{U_R} + e^{U_B}}$
$P(A) = \frac{e^{-1.23}}{e^{U_{-1.23}} + e^{U_{-2.11}} + e^{U_{-1.89}}}$
$P(A) = \frac{0.292}{0.292+0.121+0.151}$
$P(A) = 0.518$
Number of commuters expected to drive = 0.518 x 820 = 424.5
(~ 425 persons) (Ans.)

MCQ # 2:

Topic Area: Traffic Engineering

Indicator:

TRE-T2-5 Understand traffic flow characteristics including fundamental diagrams (speed- flow- density) and parameters (capacity, free-flow speed, jam density), and models (e.g. car following (minimum following distance), lane changing, gap acceptance, and shock waves)

Reference Sheet: None

Answer: B

Solution:

Calculations
Density, D
$D = \frac{V_p}{S} = \frac{2200}{68} = 32.35\ pcphpl$
Spacing, S
$S = \frac{1km}{D} = \frac{1000m}{32.35} = 30.9\ m/pc$
Distance between cars is the Gap.
Gap = spacing – average car length
= 30.9 - 5.8 = 25.1 m (~ 25 m) (Ans.)

MCQ # 3:

Topic Area: Traffic Signal Design

Indicator:

TRE-T3-1 Ability to design traffic signal timing (e.g., signal phasing, clearance intervals, pedestrian crossing timing).

Reference Sheet: None

Answer: C

Solution:

Calculations
Critical flow ratio, yi, for each phase i is: $y_A = \frac{V_A}{S_A} = \frac{70}{350} = 0.2$ $y_B = \frac{400}{1,350} = 0.296$ $y_A = \frac{550}{1,960} = 0.281$ $\sum_{i \epsilon ci} y_{c,i} = sum\ of\ critical\ volume - to - capacity\ rations$ = 0.2 + 0.296 + 0.281 = 0.777 The total cycle length can be estimated from Highway Capacity Manual (HCM) $X_c = \left[\frac{C}{C-L}\right] \sum_{i \epsilon ci} y_{c,i}$ From HCM, the total lost time, Li, for a three-phase signal with a default 4 sec delay per phase: L = 3 phase x 4 sec/phase = 12 sec Xc should be no more than 1.0 to avoid oversaturated flow. Hence: $\leq 1.0 = \left[\frac{C}{C - 12\ sec}\right] \times 0.77$ C = 52.2 sec (~ 54 sec) (Ans.) Although there is an examinee who chooses the "Webster's Optimum Cycle Length" for this question,

He/she will use the following formula for the optimum cycle length (C_o):

$$C_o = \frac{1.5L + 5.0}{1 - \sum(\frac{V}{S})}$$

Then, he/she will get the result as

$$C_o = \frac{1.5 \times 4 + 5.0}{1 - 0.777} = 49.31 \approx 50\ sec$$

Therefore, the examinee will choose the answer (C).

MCQ # 4:

Topic Area: Traffic Safety

Indicator:

TRE-T5-1 Conduct an accident (data) analysis focusing on the concepts of Conflict analysis, accident rates, black spot identification, collision diagrams, and condition diagrams

Reference Sheet: None

Answer: A

Solution:

Calculations
Total vehicles entering intersection = 2,000+6,000+4,000+8,000= 20,000 vpd $$Rate = \frac{(number\ of\ accidents) \times 10^6}{(ADT \times number\ of\ years \times 365\ days/year}$$ $Rate = \frac{25\times10^6}{20,000\times(9/12)\times365}$ = 4.6 RMEV (Ans.)

MCQ # 5:

Topic Area: Geometric Design - Alignment

Indicator:

TRE-T6-3 Determine the superelevation rate for roads/railways and transitions by providing proper method and components

Reference Sheet: None

Answer: C

Solution:

Calculations
The minimum radius for a given design speed can be determined from the rate of super-elevation and side friction factor. Using Metric system: $e + f = \frac{V^2}{gR}$ $f = \frac{V^2}{127eR}$ $f = \frac{65^2}{127 \times 190}$ f = 0.175 (Ans.)

MCQ # 6:

Topic Area: Geometric Design- Roadside and Cross-Sectional Elements

Indicator:

TRE-T8-3 Apply the cross-section elements such as lane widths, shoulders, sidewalks to solve a practical problem

Reference Sheet: None

Answer: A

Solution:

Calculations
Shoulder is one of the highway cross section elements. The slope of the shoulder should be greater than that of the pavement in order to efficiently carry water away from the pavement. Slope of pavement shoulders should be greater than that of the pavement. (Ans.)

MCQ # 7:

Topic Area: Structural Analysis and Design

Indicator:

TRE-T9-1 Recognize pavement types, wheel loads and vehicle and traffic considerations in pavement structural design

Reference Sheet: None

Answer: D

Solution:

Calculations
Load Equivalency Generalized fourth power approximation $\left(\frac{\text{load}}{18{,}000\text{ lb.}}\right)^4 = \text{relative damage factor}$ • $(17{,}000/18{,}000)^4 = 0.795$ • $(20{,}000/18{,}000)^4 = 1.524$ • $(14{,}000/18{,}000)^4 = 0.366$ Total = 2.685 ESALs (Ans.)

MCQ # 8:

Topic Area: Materials and Mix Design

Indicator:

TRE-T10-1 Recognize properties of pavement materials and materials characterization

Reference Sheet: None

Answer: C

Solution:

Calculations
The basic CBR test is used in design of flexible pavements. The sample is subjected to a penetration by a piston 1.95 inch in diameter. The CBR value is computed by: $CBR = \frac{unit\ load\ at\ 0.1\ in.penetration}{1000\ psi}$ $unit\ load\ of\ (300lb) = \frac{300}{\pi r^2} = 100.5\ psi$ $CBR = \frac{100.5\ psi}{1000\ psi} = 0.1$ (Ans.)

MCQ # 9:

Topic Area: Evaluation, Maintenance and Rehabilitation

Indicator:

TRE-T11-1 Recognize and identify different methods of measuring pavement conditions and identify types of structural and functional pavement distresses.

Reference Sheet: None

Answer: D

Solution:

Calculations
The effect of a pavement distress on pavement condition is fully described by: • Distress type, • Distress Severity, • Distress density. (Ans.)

MCQ # 10:

Topic Area: Economic Analysis

Indicator:

TRE-T13-1 Ability to perform economic analyses (e.g., present worth, lifecycle costs, Benefit-Cost)

Reference Sheet: None

Answer: A

Solution:

Calculations
$PW_{Alt.X}$ = 316,000 (P/A, 12%, 10) = 316,000 x 5.65 = SAR 1,785,400 $PW_{Alt.Y}$ = 212,400 (P/A, 12%, 10) = 212,400 x 5.65 = SAR 1,200,060 Find B/C ratio for each alternatives: B/C = $PW_{Benifits}$ / PW_{cost} $(B/C)_{Alt.\ X}$ = 1,785,400/1,000,000 = 1.7854 > 1.0 feasible alternative (keep) $(B/C)_{Alt.\ Y}$ = 1,200,060/600,000 = 2.00 > 1.0 feasible alternative (keep) Rank the alternatives based on least initial cost: Y down first and then X up later Find incremental $(B/C)_{X-Y}$ = (1,785,400 - 1,200,060) / (1,000,000-600,000) $(\boldsymbol{B/C})_{X-Y} = \frac{(\mathbf{1{,}785{,}400} - \mathbf{1{,}200{,}060})}{(\mathbf{1{,}000{,}000} - \mathbf{600{,}000})} = \frac{\mathbf{585{,}340}}{\mathbf{400{,}000}}$ = 1.46 > 1.0 Alt. X should be chosen (Ans.)

Solution Sheet # 1: for Essay Question 1

This question can be solved by either of two approaches:

Solution Approach 1

It is often easier to solve a problem involving multiple demand levels by simply computing the service flow rates (SF) and service volumes (SV) for the section for each level of service. Then, demand volumes can be easily compared to the results to determine the LOS for each target demand level.

Step 1: Determine the Free-Flow Speed of the Freeway:

$$FFS = 75.4 - f_{LW} - f_{LC} - 3.22TRD^{0.84}$$

where, f_{LW} = 0.0 mi/hr (ideal lane width)

f_{LC} = 0.0 (ideal lateral clearance)

then: $FFS = 75.4 - 0 - 0 - 3.22(2.8)^{0.84}$ = 67.8 mi/h

Because this value is between 67.5 and 72.5, the speed flow curve for 70 mi/h is used in this solution

Step 2: Determine the Maximum Service Flow (MSF) Rates for Each Level of Service. These are obtained from the Highway Capacity Manual with a 70-mi/h free-flow speed. These values are for LOS A=770 pc/h/ln, LOS B= 1,250 pc/h/ln, LOS C= 1,690 pc/h/ln, LOS D= 2,080 pc/h/ln, LOS E= 2,400 pc/h/ln.

Step 3: Determine the Heavy-Vehicle Adjustment Factor

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

where, P_T = 0.08 (given), P_R = 0.00 (given), E_T = 2.5 (HCM, rolling terrain)

Then,

$$f_{HV} = \frac{1}{1 + 0.08(2.5 - 1)} = \frac{1}{1.12} = 0.893$$

Step 4: Determine the Service Flow Rates and Service Volumes for each LOS:

$$SF_I = MSF_i \times N \times f_{HV} \times f_P$$

$$SV_i = SF_i \times PHF$$

where, MSF_i = as determined in Step 2

N = 3 lanes/direction (given)

f_{HV} = 0.893 (as computed in Step 3)

f_P = 1.00 (regular commuter users)

PHF = 0.92 (given)

[**Additional optional solution**: Here, you can calculate the flow rate of this facility, V_p = (3600/0.92*3*0.893*1) = 1,461 veh/h. And then check the Table 14.3 of the reference sheet # 1 with FFS = 70 mph, then you will get the LOS C (range 1,250 ~ 1,690) easily without any additional calculations.]

These computations are shown in the table below:

LOS	MSF (pcphpl)	N	f_{HV}	f_P	SF (veh/h)	PHF	SV (veh/h)
A	770	3	0.893	1.0	2,063	0.92	1,898
B	1,250	3	0.893	1.0	3,349	0.92	3,081
C	1,690	3	0.893	1.0	4,528	0.92	4,165
D	2,080	3	0.893	1.0	5,572	0.92	5,127
E	2,400	3	0.893	1.0	6,430	0.92	5,915

These service flow rates refer to the peak 15-minute interval; service volumes apply to peak-hour volumes.

(a) Since the present volume is 3,600 veh/h, the **freeway is presently operating at LOS C** (SV range 3,081 - 4,165 veh/h)

Step 5: Determine the 10-year peak demand volumes:

The problem statement indicates that present demand is 3,600 veh/h and that this volume will increase by 6% per year. Future demand volumes may be computed as:

$$V_j = V_0(1.06)^n$$

where, V_j = peak-hour demand volume in target year j

V_0 = peak-hour demand volume in year 0 (=3,600 veh/h)

N = number of years to target year

Then,

$$V_{10} = 3{,}600 \times (1.06)^{10} = 6{,}447\ veh/h$$

[**Additional optional solution**: In a similar manner, you can calculate the flow rate of this facility in 10 years later, V_p = (6448/0.92*3*0.893*1) = 2,617 veh/h. And then again check the Table 14.3 of the reference sheet # 1 with FFS = 70 mph, then you will get the LOS F (range > 2,400) easily without any additional calculations.]

(b) **the freeway level of service in 10 years is F**, since its projected volume demand exceeds freeway capacity (i.e. 6,447 > 5,915 veh/h)

The freeway capacity (LOS E) is 5,915 veh/h

Hence, volume demand will reach capacity in:

$$V_{capacity} = 5{,}915 = 3{,}600 \times (1.06)^n$$

$$n = \frac{\ln(5{,}915/3{,}600)}{\ln(1.06)} = 8.5\, years$$

[**Additional optional solution**: For sub-question (c), you need to check the V_p the upper bound of the LOS E at the FFS, 70 mph. From the Table 14.3 of the reference sheet # 1, it is 2,400.

Therefore, V_p = (V/0.92*3*0.893*1) < 2,400 veh/h.

Then, V < 5,916 veh/h

And, from 3,600 x $(1.06)^n$ < 5,916, you can get the n as 8.52 years.]

(c) It usually takes 4-5 year to develop substantial improvements plans and secure its funding, then to avoid freeway breakdown (LOS F after 8.5 years), **planning for such improvements should start at most after about 4 years**.

<u>Solution Approach 2</u>

Step 1: Determine the Free-Flow Speed of the Freeway:

$$FFS = 75.4 - f_{LW} - f_{LC} - 3.22TRD^{0.84}$$

where, f_{LW} = 0.0 mi/hr (ideal lane width)

f_{LC} = 0.0 (ideal lateral clearance)

then: $FFS = 75.4 - 0 - 0 - 3.22(2.8)^{0.84}$ = 67.8 mi/h

Because this value is between 67.5 and 72.5, the speed flow curve for 70 mi/h is used in this solution

Step 2: Determine the 15-minutes equivalent flow rate (pcphpl)

$$V_p = \frac{V}{PHF \times N \times f_{HV} \times f_P}$$

$$V_p = \frac{3{,}600}{0.92 \times 3 \times 0.893 \times 1.0} = 1{,}461\ pcphpl$$

Step 3: Determine the average passenger speed at this flow (S, mph)

Using the appropriate equation for speed-flow curve (HCM):

Using FFS of 70 mph curve, the break-point is 1,200 (pcphpl),

hence for V_p= 1,461 pcphpl:

$$S = 70 - 0.00001160 \times (V_p - 1{,}200)^2$$

$$S = 70 - 0.00001160 \times (1{,}461 - 1{,}200)^2 = 69.21$$

Step 4: Determine the prevailing density (concentration), D (pc/mile/lane):

$$D = \frac{V_p}{S} = \frac{1{,}461}{69.21} = 21.1\ pcpmpl$$

From HCM LOS criteria for basic freeway segments:

(a) Since for LOS C the density, D, range: $> 11 \leq 26$. The present LOS is C

Step 5: Determine the 10-year peak demand volumes:

The problem statement indicates that present demand is 3,600 veh/h and that this volume will increase by 6% per year. Future demand volumes may be computed as:

$$V_j = V_0(1.06)^n$$

where, V_j = peak-hour demand volume in target year j

V_0 = peak-hour demand volume in year 0 (=3,600 veh/h)

N = number of years to target year

Then,

$$V_{10} = 3{,}600 \times (1.06)^{10} = 6{,}447\ veh/h$$

$$V_p^{10} = \frac{6{,}447}{0.92 \times 3 \times 0.893 \times 1.0} = 2{,}616\ pcphpl$$

But the 70-mph FFS freeway capacity (LOS E) is only 2,400 pcphpl < 2,616 (V_p^{10})

(b) Hence, the level of service in 10 years is F

Step 6: Determine the number of years for the freeway to breakdown (reaching LOS F):

The freeway capacity (LOS E) is 2,400 pcphpl

Hence, the 15-minutes equivalent flow rate will reach capacity in:

$$V_p^n = 2{,}400 = 1{,}461 \times (1.06)^n$$

$$n = \frac{\ln(2{,}400/1{,}461)}{\ln(1.06)} = 8.5\ years$$

(c) It usually takes 4-5 year to develop substantial improvements plans and secure its funding, then to avoid freeway breakdown (LOS F after 8.5 years), planning for such improvements should start at most after about 4 years.

Solution Sheet # 2: for Essay Question 2

$$\boldsymbol{a = \sqrt{\frac{P}{p\pi}} = \sqrt{\frac{17,000}{150\pi}} = 6\ inch}$$

$$\Delta_z = \frac{3p\ a^2}{2E(a^2 + Z^2)^{1/2}}$$

$p = 150\ psi$

$a = 6\ in$

$Z = 18\ in$

$E = 10{,}000\ psi$

Δ = 0.0426 in.

Reference Sheet for Questions

Reference Sheet # 1: for Essay Question 1

The free-flow speed of a freeway can be estimated as:

$$FFS = 75.4 - f_{LW} - f_{LC} - 3.22TRD^{0.84}$$

Table 14.5: Adjustment to Free-Flow Speed for Lane Width on a Freeway

Lane Width (ft)	Reduction in Free-Flow Speed, f_{LW} (mi/h)
≥12	0.0
11	1.9
10	6.6

(*Source:* Used with permission of Transportation Research Board, National Research Council, *Highway Capacity Manual*, December 2000, Exhibit 23-4, p. 23-6.)

Table 14.10: Selecting a Speed-Flow Curve in Figures 14.2 and 14.3

Free-Flow Speed is: (mi/h)	Use Speed-Flow Curve for a *FFS* of: (mi/h)
≥72.5 < 77.5	75
≥67.5 < 72.5	70
≥62.5 < 67.5	65
≥57.5 < 62.5	60
≥52.5 < 57.5	55
≥47.5 < 52.5	50
≥42.5 < 47.5	45

Table 14.6: Adjustment to Free-Flow Speed for Lateral Clearance on a Freeway

Right Shoulder Lateral Clearance (ft)	Reduction in Free-Flow Speed, f_{LC} (mi/h)			
	Lanes in One Direction			
	2	3	4	≥5
≥6	0.0	0.0	0.0	0.0
5	0.6	0.4	0.2	0.1
4	1.2	0.8	0.4	0.2
3	1.8	1.2	0.6	0.3
2	2.4	1.6	0.8	0.4
1	2.0	2.0	1.0	0.5
0	3.6	2.4	1.2	0.6

(*Source:* Used with permission of Transportation Research Board, National Research Council, *Highway Capacity Manual*, December 2000, Exhibit 23-5, p. 23-6.)

Table 14.11: Passenger-Car Equivalents for Trucks, Buses, and RVs on Extended General Terrain Sections of Freeways or Multilane Highways

Factor	Type of Terrain		
	Level	Rolling	Mountainous
E_T	1.5	2.5	4.5
E_R	1.2	2.0	4.0

(*Source:* Used with permission of Transportation Research Board, National Research Council, *Highway Capacity Manual*, December 2000, Exhibit 23-8, p. 23-9.)

Table 14.3: Maximum Service Flow Rates for Basic Freeway Sections

FFS (mi/h)	Level of Service				
	A	B	C	D	E
75	820	1,310	1,750	2,110	2,400
70	770	1,250	1,690	2,080	2,400
65	710	1,170	1,630	2,030	2,350
60	660	1,080	1,560	2,010	2,300
55	600	990	1,430	1,900	2,250

Note: All values rounded to the nearest 10 pc/h/ln.

(*Source: Draft Chapter 11: Basic Freeway Segments,* National Cooperative Highway Research Program Project 3–92, Transportation Research Board, Washington DC, Exhibit 11-18, p. 11-24.)

Reference Sheet # 1: for Essay Question 1 (Continue)

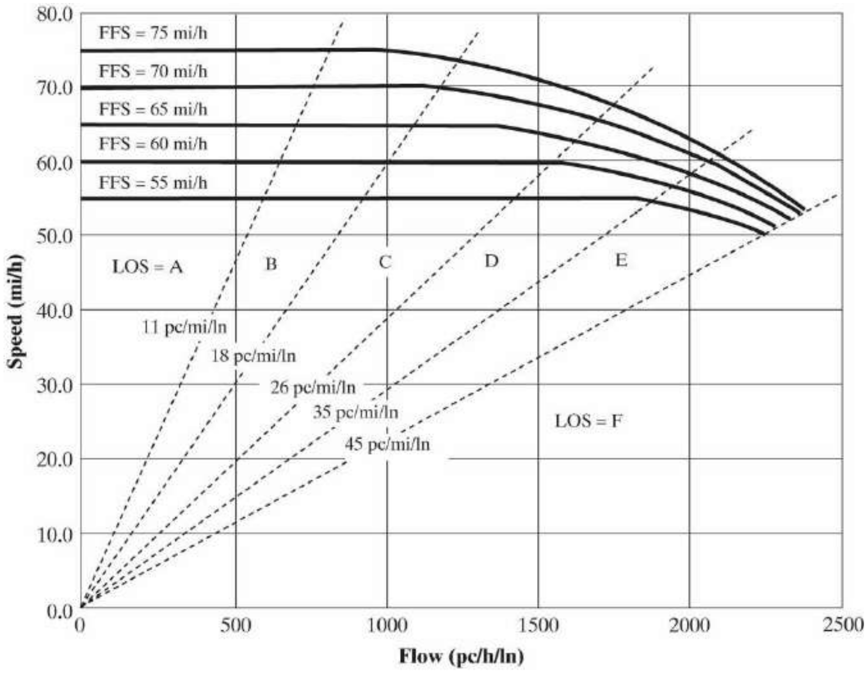


Table 14.1: Equations for Curves in Figure 14.1

FFS (mi/h)	Break-Point (pc/h/ln)	Flow Rate Range ≥ 0 ≤ Break-Point	> Break-Point ≤ Capacity
75	1,000	75	$75 - 0.00001107\,(v_p - 1{,}000)^2$
70	1,200	70	$70 - 0.00001160\,(v_p - 1{,}200)^2$
65	1,400	65	$65 - 0.00001418\,(v_p - 1{,}400)^2$
60	1,600	60	$60 - 0.00001816\,(v_p - 1{,}600)^2$
55	1,800	55	$55 - 0.00002469\,(v_p - 1{,}800)^2$

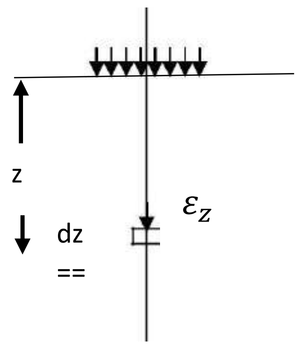
Notes:
1. FFS = free-flow speed.
2. Maximum flow rate for the equations is capacity: 2,400 pc/h/ln for 70- and 75-mph FFS; 2,350 pc/h/ln for 65-mph FFS; 2,300 pc/h/ln for 60-mph FFS; and 2,250 pc/h/ln for 55-mph FFS.

(*Source: Basic Freeway Segments*, Draft Chapter 11, NCHRP Project 3-92, Production of the 2010 *Highway Capacity Manual*, Kittelson and Associates, Portland OR, 2009, Exhibit 11-3, p. 11-4.)

Reference Sheet # 2: for Essay Question 2

Deflection using one-layered system assumed that pavement above subgrade does not contribute any deflection components to the total surface deflection. Thus, the significant deflection occurs in the subgrade. Therefore, for one-layered theory application flexible pavement deflection under load center computed as:

$$\Delta_z = \int_{\infty}^{z} \varepsilon_z \, dz$$



$$\Delta_z = \frac{(1+\mu)pa}{E}\left\{\frac{a}{(a^2+z^2)^{0.5}} + \frac{1-2\mu}{a}\left[(a^2+z^2)^{0.5} - z\right]\right\}$$

For μ=05

$$\Delta_z = \frac{3p\,a^2}{2E(a^2 + Z^2)^{1/2}}$$

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