City & Guilds

9210-108
Level 6 Graduate Diploma in Engineering
Highway engineering

Sample Paper

You should have the following for this examination • one answer book • non-programmable calculator • pen, pencil, drawing instruments	**A worksheet booklet is attached**

General instructions
- This examination paper is of **three hours** duration.
- This examination paper consists of **seven** questions in two sections.
- Answer **five** questions selecting at least **two** questions from each section.
- All questions carry equal marks. The maximum marks for each section within a question are given against that section.
- An electronic, non-programmable electronic calculator may be used, but candidates **must** show clearly the steps prior to obtaining final numerical values.
- Drawings should be clear, in good proportion and in pencil. Do **not** use red ink.

Section A

1 a) A section of a highway is known to have a free flow speed of 80 km/h and a capacity of 2200 veh/hr. In a given hour, 1800 vehicles were counted at a specified point along the highway section during an un-congested period. Assume a linear speed-density relationship is applicable to this flow.

i) Calculate the jam density of the flow. (1 mark)

ii) Derive the flow-speed model for this traffic stream. (2 marks)

iii) What is the speed, when the vehicle flow is 1800 veh/hr and during the period when the survey was carried out? (2 marks)

iv) For the conditions stated in c), calculate the time headway and space headway. (3 marks)

v) If the peak hour traffic recorded was 2000 veh/hr and the traffic, volume is expected to grow annually at 4%, in how many years would there be a need to add new lanes to the highway? (2 marks)

b) On an arterial road, it was found that the mean free flow speed was 70 km/h and the jam density was 140 veh/km. Assuming a linear speed density relationship, calculate the following:

i) Speed and spacing (space headway) corresponding to a density of 70 veh/km. (2 marks)

ii) Time headway corresponding to a density of 120 veh/ km. What is the speed at this density? (2 marks)

iii) Spacing corresponding to time headway of 3.0 seconds. (2 marks)

iv) If a new model is proposed to model the traffic flow as given below,
$v = v_0 \ln(k_j/k)$
Where, v – speed, v_0 – speed at maximum flow, k – density, k_j – jam density.
Derive an equation to calculate capacity using this model. (3 marks)

v) Highlight one limitation in applying this model to the above road. (1 mark)

2 Two routes connect a city and suburb. During the peak-hour morning commute, a total of 4500 vehicles travel from the suburb to the city.
Route 1 has a 60 km/hr speed limit (at free flow condition) and 6 km in length.
Route 2 has a 45 km/hr speed limit (at free flow condition) and 3 km in length.
The number of vehicles in route 1 and route 2 are given as V_1 and V_2 respectively.
Note: vehicle number is given in '000s.
Studies show that the total travel time (T_1, in minutes) on route 1 increases 4 mins for every extra 1000 vehicles added. Travel time (T_2, in minutes) on route 2 increase with the square of the no. of vehicles expressed in 000's.

a) Derive equations for travel times (T_1 and T_2) using V_1 and V_2. (5 marks)

b) Write the User Equilibrium conditions for the above problem and determine user equilibrium flow. (10 marks)

c) Calculate the user equilibrium link travel time and the network travel time. (5 marks)

3 A functionally classified road network is shown in Figure 3.

a) Propose operating speeds for the roads classified in Figure 3. (4 marks)

b) Propose a geometric layout for roads in a) with desirable dimensions compatible with the design speed to maintain a safe road environment in the road network. (8 marks)

c) What are the traffic control devices proposed for intersections of Arterial/Collector, collector/collector, collector/local, local/local? (4 marks)

d) There is a need to connect the collector road in Figure 3 to the arterial road with a grade-separated structure to facilitate cross traffic (from A to B and from C to A) smoothly. Sketch the interchange layout to facilitate all the traffic movement with a minimum disturbance to the existing layout. (4 marks)

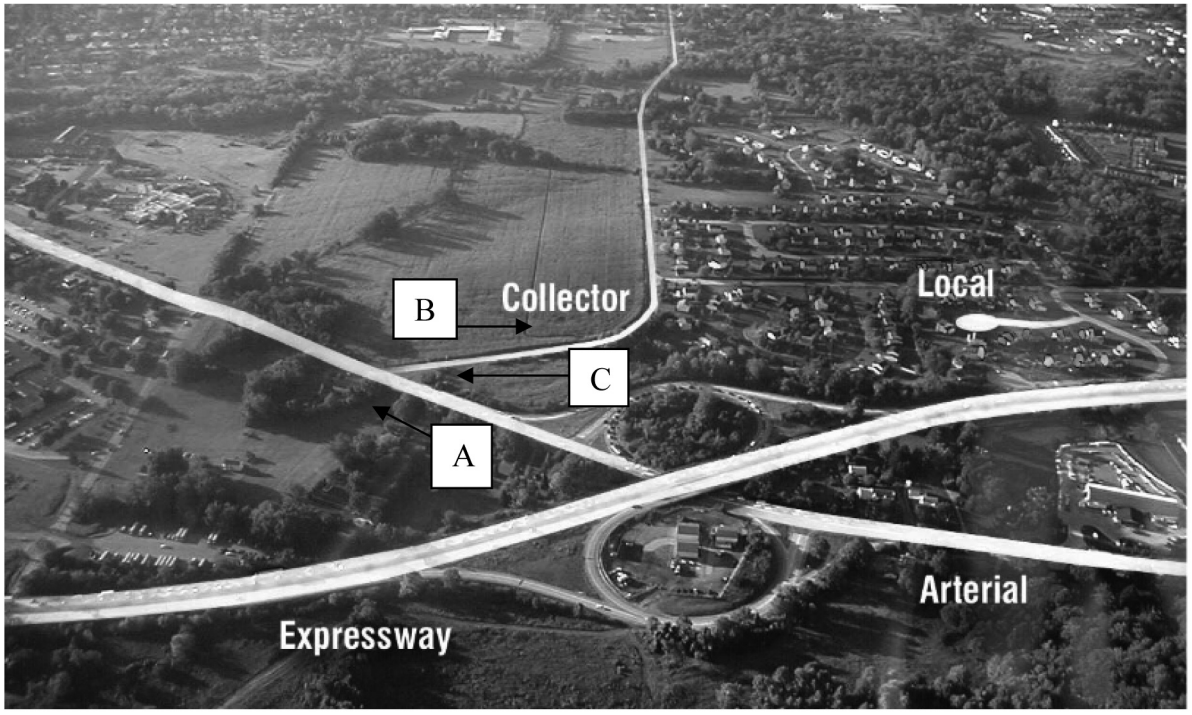

Figure 3 Suburban Road Network

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Section B

4 a) What are the nominal sizes of aggregates you would recommend for first and second seal in DBST construction? (2 marks)

b) What are the penetration grades of bitumen recommended for a tropical country? (At least 2 grades). (2 marks)

c) What are the measurements and testing involved in the marshal mix design criteria? (4 marks)

d) What is the compaction level best represented for heavy and medium traffic roads in the marshal mix design? (2 marks)

e) What are the aggregate properties specified for asphalt concrete? (2 marks)

f) The following statement was extracted from a specification on subgrade layer preparation 'Any new layer shall be bonded to the previous layer by scarifying and new layer plus the scarified portion should not be less than 100 mm'. Describe the importance of the above statement in designing layer thickness of pavement material and its applicability in preparation of the base layer. (4 marks)

g) State **four** parameters affecting time available for compaction of asphalt concrete. (2 marks)

h) What are the climatic conditions specified for PG 64-28 grade bitumen in super pave binder classification? (2 marks)

5 A proposed major expressway connecting two district centres is located in a hilly terrain. Designers have proposed 5 tunnels to maintain a smooth gradient in the expressway as per the design standard. Details of the tunnel locations are given in Table 5. It is expected to maintain the operation speed of 80 km/h in tunnel sections and 100 km/h in the rest of the road sections. Typical cross section for a cut section is shown in Figure 5.

a) What are the approximate gradients of the existing ground profile at the two tunnel locations (Tunnel 2 and Tunnel 3) if the portals (entrance and exit of the tunnels) are located in a level terrain? (2 marks)

b) What is the cut height of the two locations (without tunnel 2 and 3) to maintain design speed of the expressway? (4 marks)

c) Sketch the land acquiring boundary at tunnel location 2 if a vertical curve is proposed instead of a tunnel.
Hint: Clearly state the assumptions. (4 marks)

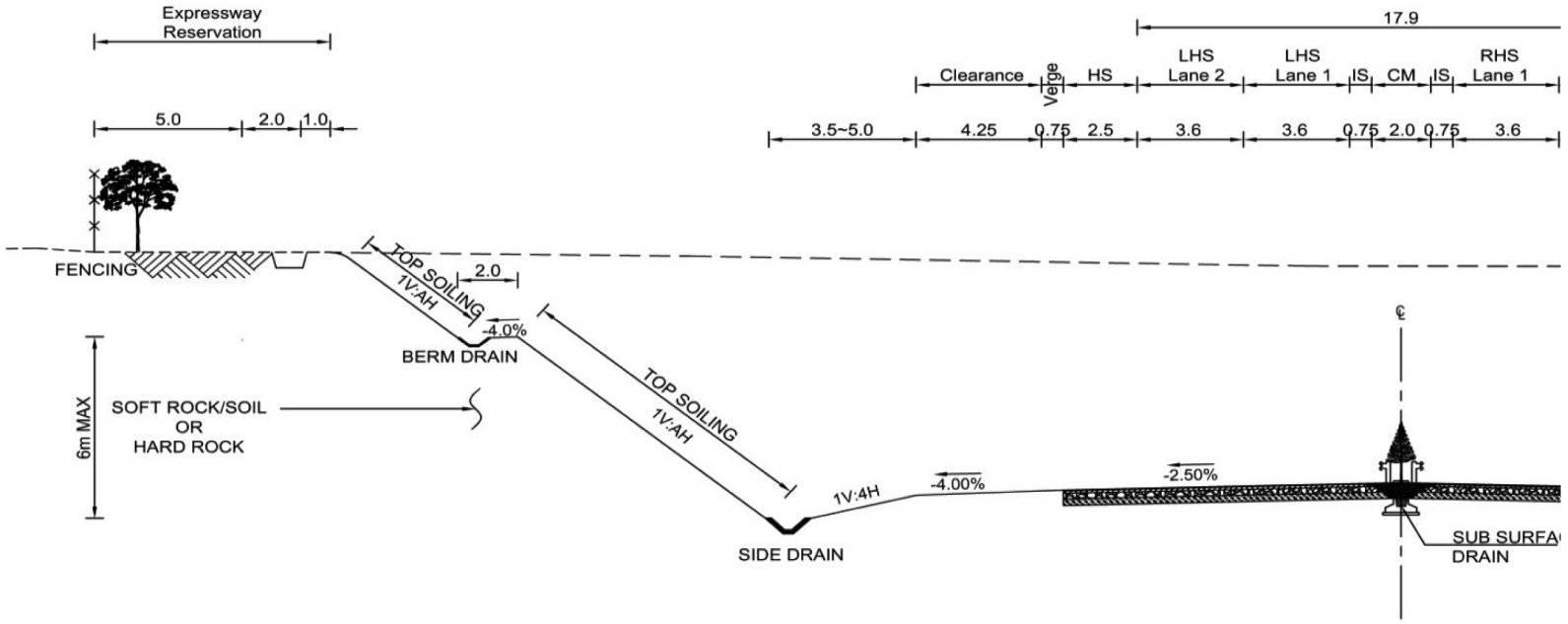
d) A consultant of the expressway project states that vertical curves in the expressway are not required to design for passing sight distance. As a design engineer working for the same project, do you agree with the statement of the consultant? Support your answer based on geometric design principles. (3 marks)

e) Propose a cross section for a fill section in the expressway.
Hint: Provide a sketch including all necessary dimensions. (3 marks)

f) A Viaduct (road on concrete piers) has been proposed after the tunnel 3 from 29 + 260 to 29 + 710 in the expressway as a solution for the flood prone area where a minor water stream is connected to the Kaluganga. State two negative and positive social and environmental impacts of the viaduct. (4 marks)

Chain age Range			Proposed Length	Ground elevation at the highest point, m	Tunnel formation level, m
Tunnel	From	To			
1	26420	26730	310	57	39
2	27270	27540	270	107	41
3	27850	28590	740	240	39
4	30210	30560	350	94	32
5	33050	33520	470	122	30

Table 5. Details of the tunnel locations



Excavation slope 1V: 1.5 H in soft rock/ soil, 1V: 0.25H in Hard Rock
Figure 5. Typical cut section

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6 A proposed tunnel cross section for one direction of traffic (towards Ratnapura) in the Ruwanpura expressway is shown in Figure 6. Operating speed of the tunnels is 80 km/h. A consultant has proposed to place the tunnel 5 in Table 5 in a horizontal curve to avoid the horizontal curve before the tunnel. Assume reaction time of 90th percentile of the users as 1.5 sec.

a) Determine the minimum stopping sight distance at the design speed. (2 marks)

b) Determine the minimum curve radius you would recommend for the selected design speed if the curve is located to the right direction
Hint: Cross slopes are given in Figure 6. (3 marks)

c) What is the object height and driver eye height used in determining stopping sight distance availability in roads? (2 marks)

d) What is the lateral clearance available for stopping sight distance in the given tunnel section? (3 marks)

e) What is the required lateral clearance for the design speed? (5 marks)

f) Propose an optimum cross section (layout of lanes, shoulders and drains) to accommodate the design speed. (5 marks)

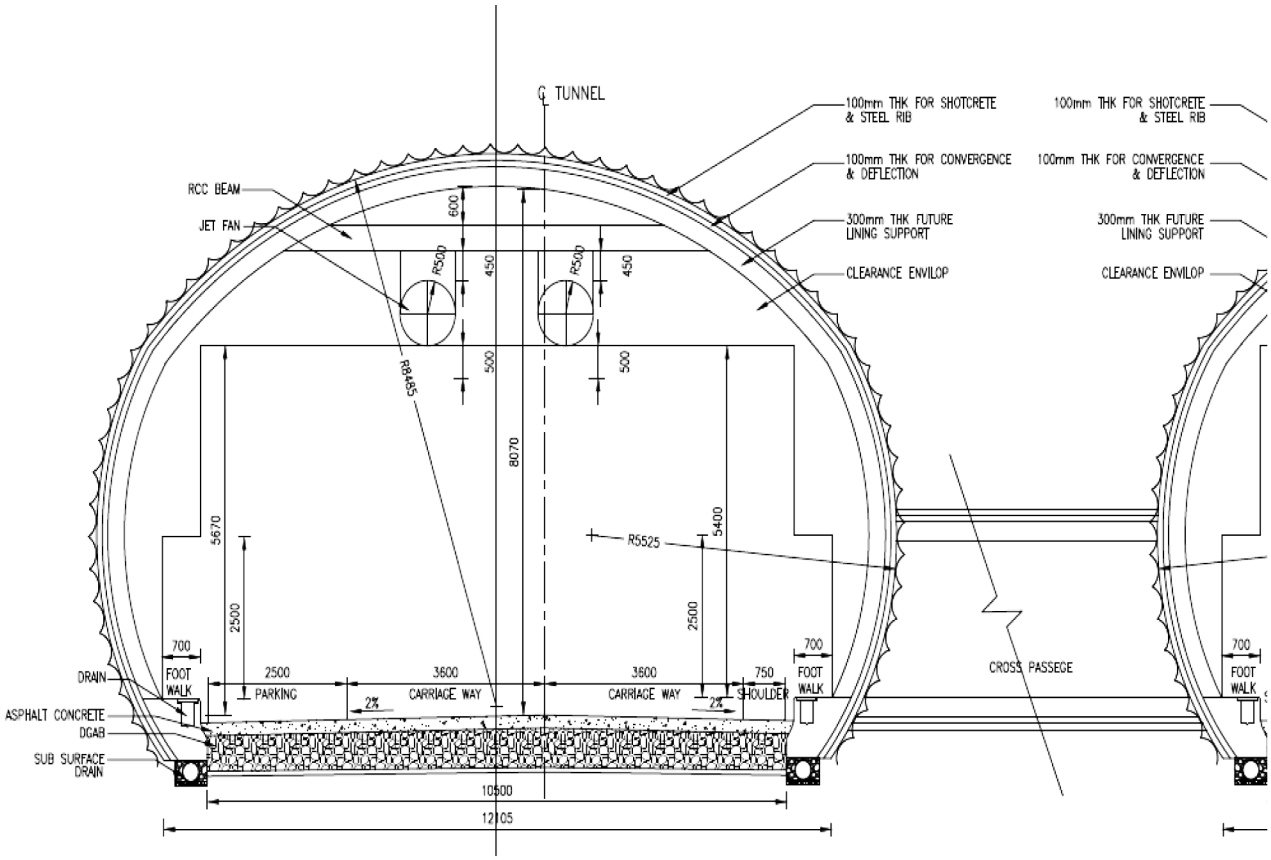

Figure 6 Tunnel Section for one direction

7 You have been assigned to review a mix design provided by a contractor. Contractor has blended aggregates from 4 bins to get the proportion as given in Table 7.1

Sieve (mm)	Selected Grading %	Specification limits	
		Job mix	
		max	min
25	100	100	100
19	100	100	88
9.5	65	71	59
4.75	44.2	50	38
2.36	33.8	38	28
1.18	25.6	33	21
0.600	18.6	24	14
0.300	13.3	18	8
0.150	7.5	12	4
0.075	4.4	6	2

Table 7.1 Selected gradation for the mix design

Hot mix asphalt data by the Marshall Method is given below,

Compacted blows 75; Specific gravity of bitumen (G_b) = 1.020
Mixing temperature = 150-160 C
Bulk specific gravity of aggregate (G_{sb}) = 2.771
Effective specific gravity of aggregate (G_{se}) = 2.791
Three (3) specimens were cast for each binder content and computed average values are given in Table 7.2. The contractor has selected 4.4% as the design binder content.
Specification requirement for Type 5 aggregates are
Bitumen content 4.0- 6.0, Voids: 3-5, VMA (%) >14, Stability > 7 and Flow 8-16
Binder tolerance allowed = ± 0.4

% AC	Air voids	VMA	Adjusted Stability	Flow value
3.5	6.7	15.4	15.1	9.2
4.0	5.3	14.9	17	9.8
4.5	4.1	14.6	18	10.8
5.0	2.9	15.2	17.7	11.9
5.5	2.5	16.1	16.1	12.8

Table 7.2 Hot Mix Asphalt Laboratory Collected Data

a) Does the selected blending proportion satisfy the specification? (2 marks)
b) What are the missing data in the specification? (2 marks)
c) What is the design binder content? (All necessary plots should be provided in the review report). (8 marks)
d) Can the selected bitumen content be approved if the binder tolerance is only +0.2 and minus is not allowed? (2 marks)
e) The contractor has not done a plant trial. You have to provide necessary instructions to do a plant trial. What results would you expect from the contractor? (4 marks)
f) The consultant has checked the bulk density of core samples collected from a paved section and found that the degree of compaction is below 97%. What would be the reason/s for low degree of compaction if the right number of roller passes had been applied?
(State at least **two** reasons) (2 marks)