National Exams, May 2002

98-Civ-B7, Highway Design, Construction and Maintenance

3 hours duration

NOTES

1. The examination is set according to the following format: Open Book examination. Any non-communicating calculator is permitted. Candidates ***must indicate*** the type of calculator being used (name and model designation of the calculator) on the first inside left-hand sheet of the exam workbook.

2. ANSWER a total of **four** questions. Attempt **at least one** question from Section A and B. Only the first four answers as they appear in the Candidate's exam workbook will be marked.

3. All questions are of equal value. Marks for individual parts of each question are indicated in square brackets [x].

4. Pay attention to ***italicized bold*** terms and make sure you are answering the right question. Some questions indicate a suggested length of the answer (e.g., ***three lines***) as a guideline not a rule.

5. All numerical work should be shown and, where equations are used, all the variables in the equation must be defined and the units clearly stated. Make sure you clearly state all assumptions.

6. Any material in your answers taken from a textbook must be properly referenced by indicating the author, year, brief title of the textbook, and the relevant page beside your answer.

7. If doubt exists as to the interpretation of any question, the candidate is urged to submit, on the answer paper, a clear statement of any assumptions made.

SECTION A: Attempt at least one question

QUESTION A-1 [25 marks]

The Ministry of Transportation of Ontario (MTO) is considering three investment alternatives for rehabilitation of an 8.5km section of Highway 400: (i) a "do minimum" consisting of annual routine maintenance and vegetation control only, (ii) a mill and overlay consisting of removing the top 25 mm and recapping with a 50 mm hot mixed asphalt overlay, and (iii) a chip sealing option consisting of double surface treatment to a 25mm final thickness. The life-cycle costs of the three options are given in Table 1.

Table 1: Lifecycle cash flows for three investment options

Cost Item	Do minimum	(A) Mill + Overlay	(B) Chip Seal
Initial Construction ($/lane-km)		200,000.00	150,000.00
Salvage Value ($/lane-km)	5,000.00	45,000.00	15,000.00
Routine Maintenance ($/lane-km-year)	9,000.00	8,000.00	10,000.00
Road User Cost ($/lane-km-year)	75,000.00	40,000.00	55,000.00

Given the analysis period is 25 years and the discount rate is 5%.

Required:

(a) Sketch a properly labeled and signed cash flow diagram for each option. [5]

(b) Find the incremental internal rate of return (IRR_B) of Chip Seal option (using cost differences over "do minimum option). [10]

(c) Compare options A and B using incremental equivalent uniform annual costs method. [8]

(d) Based on your answer in (c) above, is the statement "$IRR_{OVERLAY} > IRR_{CHIP\ SEAL}$" true or false. [2]

QUESTION A-2 [25 marks]

The data in Table 2 was gathered from a 24-hour traffic count on the Highway 69 near Ottawa.

Table 2: Twenty-four Hours Traffic Count on Highway 69

Vehicle Type	Northbound	Southbound	Truck Factor
Passenger cars	1990	2045	-
Pickup trucks/vans	750	736	-
Recreational vehicles	231	245	0.15
2 Axle Single Unit	54	78	1.1
3 Axle Single Unit	47	56	1.3
4 Axle Single Unit	24	43	1.5
5 Axle Articulated	278	376	2.6
6 Axle Articulated	204	232	4.2
7 Axle Articulated	21	12	4.6

Increased industrial activity and an improved highway system are expected to increase the volume of traffic at a rate of 3% each year for the 25-year design life of the new **four** lane facility.
Soil investigation on the project site gave the following results:

Table 3: Subgrade Test Data

Sample No.	1	2	3	4	5	6	7	8
CBR	5.0	8.0	6.0	4.0	7.0	9.0	7.0	6.0

Required:

(a) Estimate the design traffic loading using the combined **two-way** traffic, a 50/50 directional split factor, and an appropriate lane distribution factor (LDF). Justify your LDF. [8]

(b) Estimate the design subgrade resilient modulus using the Asphalt Institute method for the traffic level found in (a). (*Hint: For ESALs > $1x10^6$ design M_r is the 87.5 percentile value*). [7]

(c) ***List*** five key properties (or test results) used in the diagnosis of Marshall asphalt mixtures. Discuss the relationship between binder content vs. air voids and their impact on performance of in-service pavement. [5]

(d) Define the terms pavement performance and present serviceability. List 5 key factors affecting pavement performance. [5]

SECTION B: Attempt at least one question (maximum 3)

QUESTION B-1 [25 marks]

(a) Moisture damage to a pavement structure arises from two primary sources of water- surface and sub-surface. ***List*** four key adverse effects of sub-surface water on the pavement structure. [5]

(b) Define the term *Open Graded Drainage Layer (OGDL)* and describe its key functions. Sketch a cross-section of a pavement structure showing a typical location of an OGDL. [5]

(c) Pavement roughness evaluation methods can be grouped into four generic types – *true profiling devices, response type devices, rolling straightedge devices, and profilometers*. Give two examples of each type. What are key differences between *profilographs* and *profilometers*? ***List*** four key applications of pavement roughness data. [15]

QUESTION B-2 [25 marks]

The results of AASHTO pavement design for conventional asphalt pavement are summarized in Table 4. The structural numbers SN_1, SN_2 and SN_3 correspond to strengths required to protect the base, the subbase, and the subgrade, respectively.

Table 4: Required AASHTO structural numbers and structural layer coefficients

Layer	Modulus (psi)	Layer coefficient (a_i)	SN_i required above layer i	Drainage coefficient (m_i)
Surface (hot mixed asphalt)	400 000	0.44	--	--
Base (untreated crushed stone)	30 000	0.14	2.5	0.8
Subbase (lime treated gravel)	15 000	0.11	3.1	0.9
Subgrade	5 000		4.2	

Required:

(a) Determine the thickness for each layer for a *conventional* pavement structure. [5]

(b) Determine the thickness for each layer for a *deep strength* pavement structure. [5]

(c) The seasonal variation of subgrade strength on a design project is summarized in Table 5. The relative damage in flexible pavements in given by $U_r = 1.18 \bullet 10^8 M_R^{-2.32}$, where M_R is resilient modulus in *psi*. Determine the effective subgrade resilient modulus. [8]

Table 5: Seasonal Variation of the Subgrade Resilient Modulus

Season	Length (months)	Modulus (psi)
Spring (thawing)	1	3 000
Summer (dry)	4	6 000
Fall (wet)	5	4 000
Winter (frozen)	2	18 000

d) What are the differences between Asphalt Institute and AASHTO flexible pavement design method? [***max. 5 lines***] [3]

e) AASHTO flexible pavement design method involves solving an equation of the form, $ESAL_{80} = f(R, SN, \Delta PSI, M_R)$ which predicts the number of load repetitions to a terminal condition. Define the terms in the equation and state how they are normally obtained during the design process. [4]

QUESTION B-3 [25 marks]

a) In the design of unsealed roads (earth surfaced), use of larger particle sizes has the benefit of better load resistance to traffic loading. What are two major disadvantages of using larger particle sizes and how is the design solution achieved? (***max 4 lines***) [2]

b) In SUPERPAVE, two tests – the Rolling Thin Film Oven test and the Pressured Aging Vessel (PAV) are used to simulate the performance of the binder at two different stages. Discuss the significance of the two tests to pavement performance at the corresponding stages. (***max 6 lines***) [5]

c) List four laboratory tests carried out on coarse mineral aggregates to ensure high performance against degradation due traffic loading and weathering effects? [5]

d) List three main types or classes of asphalt used in road construction. Briefly state the differences that distinguish cutbacks from emulsions. (***max. 6 lines***) [4]

e) A 4-km stretch of road subgrade is being cement treated. The field moisture content is 7%, whereas the lab optimum moisture content is 15.5%. The soil has a maximum dry density of 1650kg/m^3. The process involves one 150mm deep pass of scarifying. 2.5% of extra water is required for the added cement. Find the water spreader rate (litres/minute) if it can only be run at one speed of 10m per minute and it covers 2.75m width of the lane. [4]

f) With brief concise reason, discuss which type of roller is suitable for the following compaction (***Keep your answer brief - max. 3 to 4 lines each part.***): [5]

(i) Breakdown rolling,
(ii) Intermediate rolling, and
(iii) Final rolling.

QUESTION B-4 [25 marks]

a) Structural evaluation of in-service pavements is normally based on nondestructive testing techniques due to their speed, repeatability and minimal damage to the pavement structure. Nondestructive testing devices can be classified into three classes: static, steady state vibratory, and impulse devices. Using properly labeled sketches, describe the working principles of the three classes of devices. Give one example for each class and indicate what is measured and how it is related to the pavement strength. [12]

b) Describe two ways in which salvage value of a pavement structure at the end of the analysis period can be calculated. [5]

c) It is common to employ combined measures of pavement quality for reporting at the network level. Discuss the how such combined measures of pavement quality are formulated, their applications and disadvantages. [5]

d) Evaluation of in-service pavements is an important function in pavement management. Discuss two important uses of pavement evaluation. [3]

QUESTION B-5 [25 marks]

A proposed transfer ramp between highway 407 and 401 will require a vertical sag curve at the bottom, a crest curve at the top and a horizontal curve. Design parameters are given in Table 6.

Table 6: Geometric design parameters for the proposed transfer ramp

• Design speed 92 km/hr	• Grade difference between vertical tangents, A = 2%
• Driver's eye elevation 1.02 m.	• Horizontal circular curve radius at exit ramp, R = 400m
• Design traffic 20 600 AADT.	• Maximum allowable centrifugal acceleration, 0.6 ms^{-2}
• Design hourly volume = 10% AADT	• Exit ramp width - 2 lanes each 3.75 m.
• Truck traffic = 5% AADT.	• Allowable relative slope = 1/218

Required:

a) Determine the minimum stopping sight distance assuming appropriate perception reaction time [5]

b) Determine the required length of sag curve. [5]

c) Determine the required length of crest curve at the top of exit ramp assuming an appropriate size of object and 2% grade difference. [5]

d) Earthworks (i.e., cut and fills and subgrade preparation) constitute the largest proportion of initial construction cost of a road and are largely determined by vertical alignment. Economy of road transportation requires a trade off between road user costs and the initial construction cost. Discuss the implication of this tradeoff on design philosophies for: (i) high volume roads versus low volume roads, (ii) access and feeder roads versus highways. [10]