UNIVERSITI
TEKNOLOGI
PETRONAS

FINAL EXAMINATION
JANUARY 2023 SEMESTER

COURSE	**:**	**VEB4523 - STRUCTURAL REPAIR & REHABILITATION**
DATE	**:**	**5 APRIL 2023 (WEDNESDAY)**
TIME	**:**	**9.00 AM - 12.00 NOON (3 HOURS)**

INSTRUCTIONS TO CANDIDATES

1. Answer **ALL** questions in the Answer Booklet.
2. Begin **EACH** answer on a new page in the Answer Booklet.
3. Indicate clearly answers that are cancelled, if any.
4. Where applicable, show clearly steps taken in arriving at the solutions and indicate **ALL** assumptions, if any.
5. **DO NOT** open this Question Booklet until instructed.

Note :

i. There are **THIRTEEN (13)** pages in this Question Booklet including the cover page and appendices.

ii. **DOUBLE-SIDED** Question Booklet.

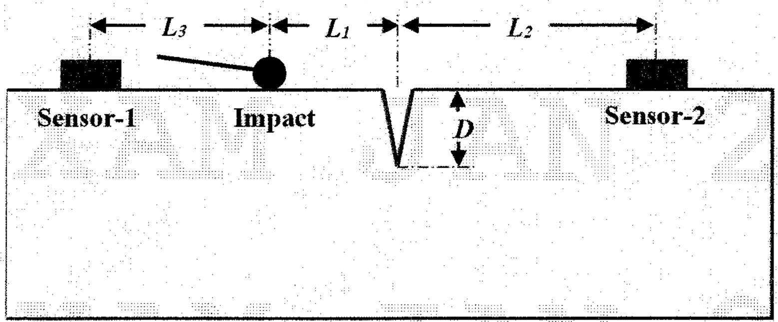
1. a. **FIGURE Q1a** shows a schematic representation of a 1 m deep post-tensioned beam of a highway bridge that encountered a crack at the mid-span. By performing field tests, the forensic department suggested a detailed study of the crack geometry and configuration (crack width and depth).

i. Select an appropriate field method to measure the crack width and justify.

[5 marks]

ii. An Echo impact (EI) test was performed for crack depth measurement. **FIGURE Q1a** describes the test setup, such as the location of sensors and impact point. The data obtained during field measurement; L_1 is 0.07 m, L_2 is 0.12 m, V_p is 1500 m/s, and Δt is 0.000025 seconds. Estimate the crack depth, D.

[8 marks]



Schematic Representation of a Crack Formed in PT Beam

FIGURE Q1a

b. **FIGURE Q1b** shows a 20-year-old RC bridge recently inspected by the qualified bridge inspection team. Based on preliminary investigation, the main girder is suggested to be rehabilitated after performing a redesign using field measurement data. **TABLE Q1** shows the pulse velocity data of concrete, V_c measured on the main girder. Three concrete cores were extracted from the same girder and sent for laboratory testing under the fully saturated condition. The average pulse velocity of the fully saturated core samples, V_1, was obtained as 4.65 Km/s, and the average compressive strength, f_1, of the fully saturated samples were 48 Mpa. Estimate the concrete compressive strength, f_2, for each value of V_c, and the characteristic strength of concrete, f_k.

[12 marks]

TABLE Q1

No	V_c (Km/s)
1	3.92
2	3.93
3	3.97
4	4.03
5	4.09
6	4.10
7	4.12
8	4.13
9	4.16
10	4.19

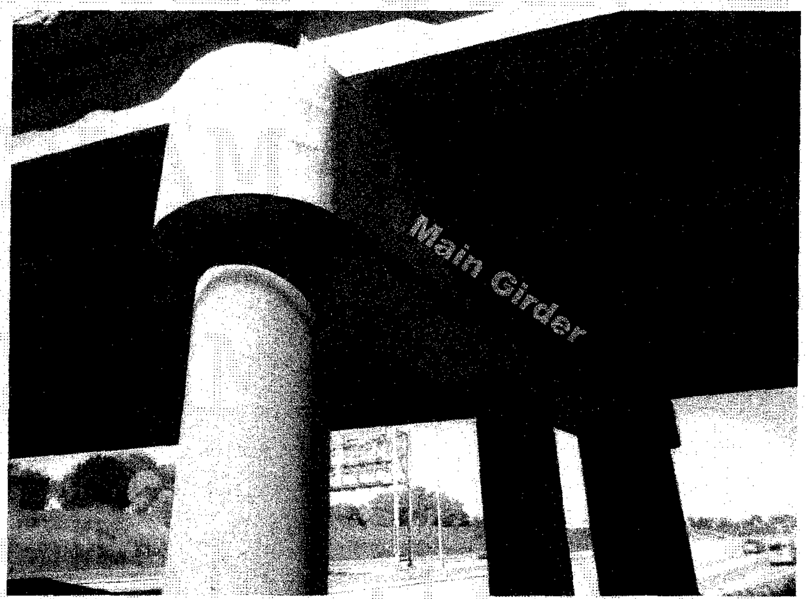


FIGURE Q1b

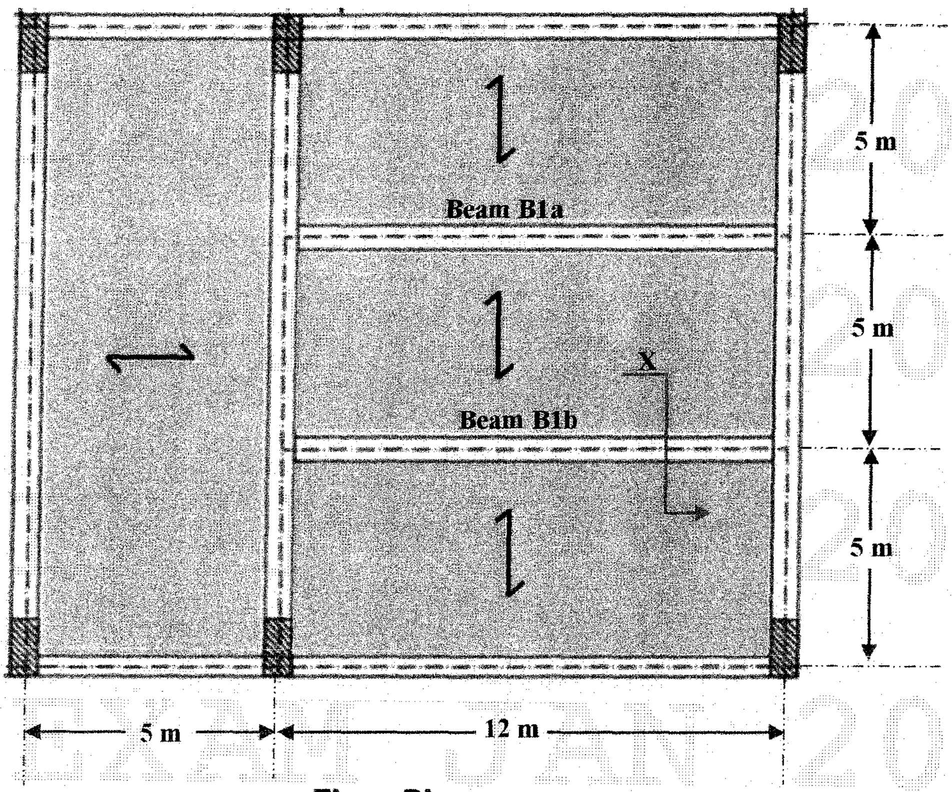
2. **FIGURE Q2** shows the floor plan and section-X passing through beam B1b of the existing admin floor of Lotus Mall. The management has decided that the admin will shift to a new building, and this floor to be used for a storage area. For converting the floor to the storage area, the minimum live load requirement is 6 kN/m^2. To verify floor slab capacity to support the required live load, a non-destructive examination is conducted to estimate the design capacity. The condition assessment and the NDE for beam B1b showed that the beam is 250 mm wide and 800 mm deep, the reinforcement location scan confirmed the effective depth, d is 740 mm, the slab thickness is 200 mm, and the finishing load to be 2 kN/m^2. The statistical analysis of the UPV data of beam B1b showed that characteristic compressive strength, f_{ck} is 40 N/mm^2. Assume the beam is singly reinforced, and f_{yk} is 500 N/mm^2.

a. Estimate the moment capacity, M_R of the beam B1b.

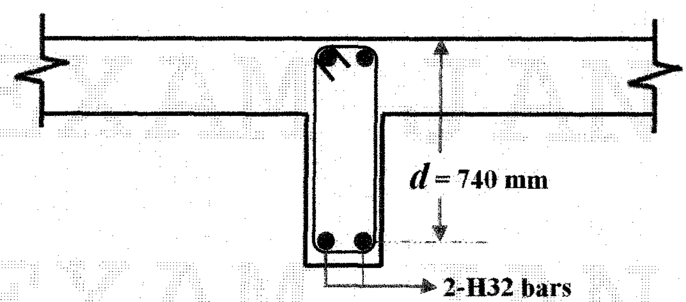
[10 marks]

b. Analyze whether the beam safely transfers 6 kN/m^2 live load from the adjoining slabs.

[15 marks]



Floor Plan



Section X Passing through Beam B1b

FIGURE Q2

3. a. **FIGURE Q3a** shows a picture of the recent earthquake in Turkey in February 2023. It is seen that some buildings are still intact, and other buildings have become rubble. Compare the structural mechanism of two types of buildings; the first type remained intact during the earthquake, and the other type became rubble.

[10 marks]

FIGURE Q3a

b. **FIGURE Q3b** shows a 5-year-old concrete roof slab of a warehouse building in the middle east, where the drying shrinkage cracks are clearly visible. The warehouse owner is willing to construct three other buildings but requires that the drying shrinkage should be prevented in the new design. Develop a strategy to prevent drying shrinkage cracking in the new design.

[10 marks]

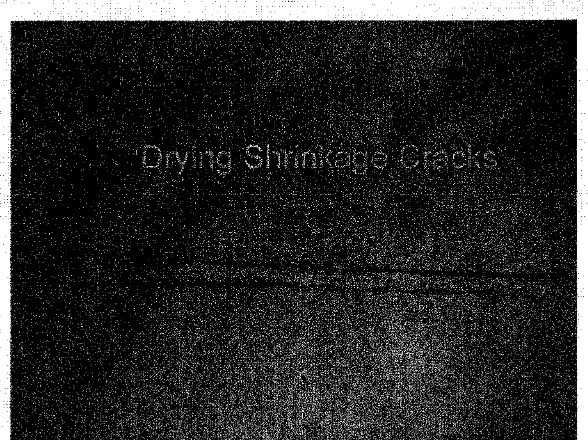


FIGURE Q3b

c. **FIGURE Q3c** shows a concrete core extracted from an old bridge. The core is 10 cm long, and its diameter is 5 cm. The core is used for the water permeability test using Darcy's method. The inlet pressure P_1 is measured as 1 atm, and the outlet pressure P_2 is 4 atm. The water flow rate in the sample is measured as 1.2 cm^3/s, and the water viscosity is given as 1 CP. Estimate the coefficient of water permeability, k.

[5 marks]

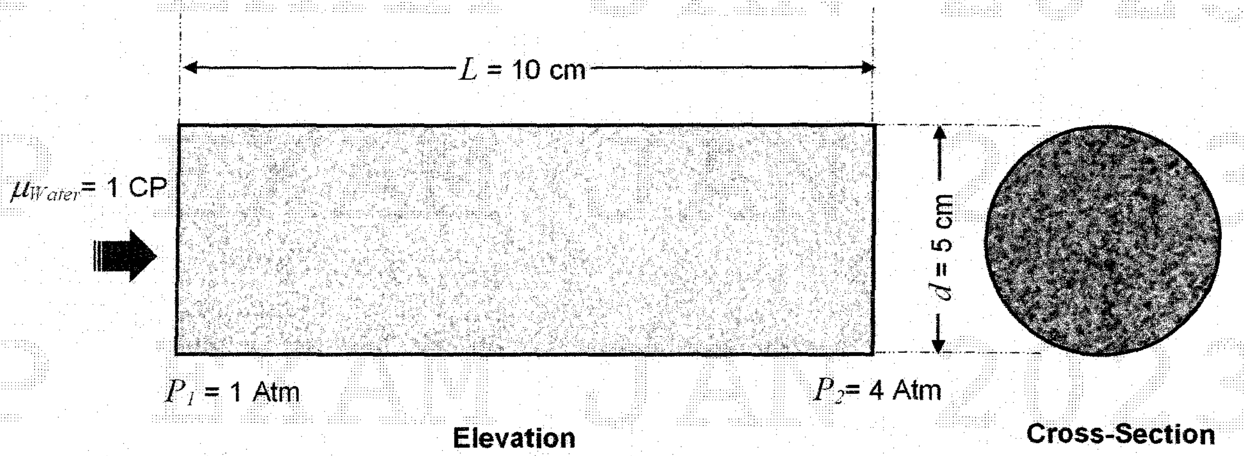


FIGURE Q3c

4. a. **FIGURE Q4a** shows the ground floor main lobby of a 20-year-old international convention center. Due to increased demand and new requirements in the design code, the building is undergoing renovation and upgrading. The reanalysis of columns confirmed that all columns should be strengthened and retrofitted for an additional 50% structural capacity compared to the present capacity of columns. Develop an appropriate jacketing scheme for column strengthing to meet the new requirements. Illustrate your proposal using appropriate sketches.

[10 marks]

FIGURE Q4a

b. **FIGURE Q4b** shows the cross-section of a 200 mm x 800 mm concrete beam strengthened with 200 mm wide and 1.5 mm thick CFRP wrap to increase the moment capacity of the beam. The following data is given:

- Concrete strength, f'_c = 35 N/mm^2
- Steel strength, f_y = 500 N/mm^2
- Modulus of elasticity of CFRP, E_{FRP} = 250,000 N/mm^2
- Modulus of elasticity of steel, E_S = 200,000 N/mm^2
- The ultimate strain of CFRP, $\varepsilon_{CFRP,u}$ = 1.26%
- Assume failure happens at the condition; compression in concrete is equal to Tension in (steel +CFRP), and steel will fail at CFRP strain at 0.006.

Consider that the beam is designed as a singly-reinforced beam. Estimate the moment capacity, M_R, after strengthing with CFRP laminate.

[15 marks]

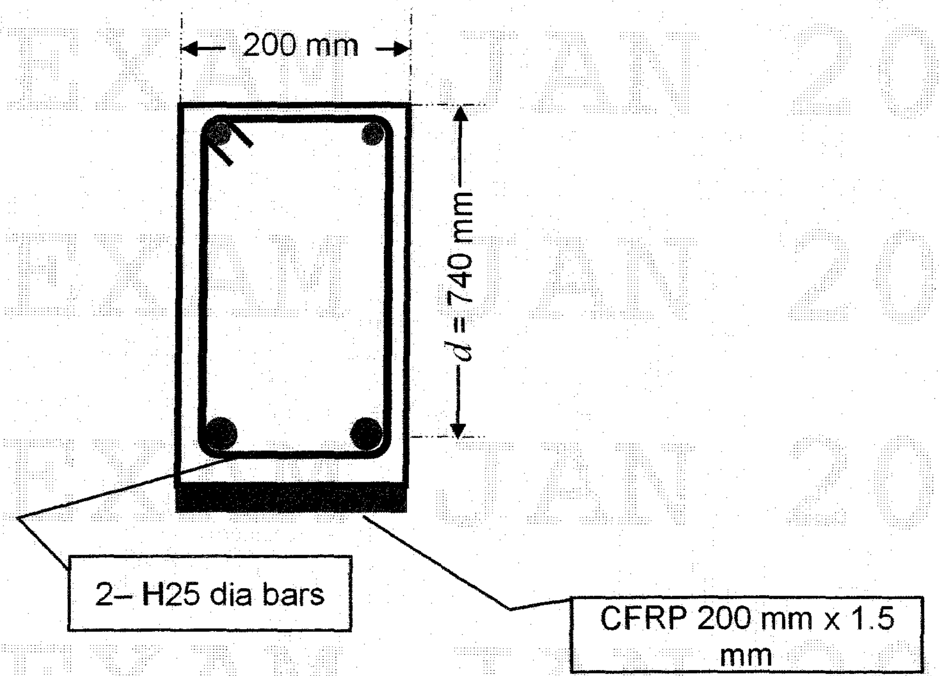


FIGURE Q4b

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APPENDIX-1

$$\log_e \frac{f_1}{f_2} = kf_1(V_1 - V_2)$$

where f_1 is the strength of a 'standard' saturated specimen
f_2 is the 'actual' strength of the in-situ concrete
V_1 is the pulse velocity of the 'standard' saturated specimen
V_2 is the pulse velocity of the in-situ concrete

k is a constant reflecting compaction control
= 0.015 for normal concrete
= 0.025 for poorly compacted concrete

$$f_k = f_m - 1.64s$$

where f_k = characteristic strength, f_m = mean strength and s = standard deviation, The standard deviation is given by the standard formula:

$$s = \left[\frac{\sum(f_c - f_m)^2}{n-1}\right]^{\frac{1}{2}} = \left[\frac{n\sum(f_c)^2 - \left(\sum f_m\right)^2}{n-1}\right]^{\frac{1}{2}}$$

The following equations may be used to calculate the moment of resistance of a given section with a known area of steel reinforcement.

For equilibrium of the compressive force in the concrete and the tensile force in the steel in figure 4.4:

$$F_{cc} = F_{st}$$

or

$$0.567 f_{ck} b \times s = 0.87 f_{yk} A_s$$

Therefore depth of stress block is

$$s = \frac{0.87 f_{yk} A_s}{0.567 f_{ck} b} \quad (4.11)$$

and

$$x = s/0.80$$

Therefore the moment of resistance of the section is

$$\begin{aligned} M &= F_{st} \times z \\ &= 0.87 f_{yk} A_s (d - s/2) \\ &= 0.87 f_{yk} A_s \left(d - \frac{0.87 f_{yk} A_s}{1.134 f_{ck} b} \right) \end{aligned} \quad (4.12)$$

These equations assume the tension reinforcement has yielded, which will be the case if $x < 0.617d$. If this is not the case, the problem would require solving by trying successive values of x until

$$F_{cc} = F_{st}$$

with the steel strains and hence stresses being determined from equations 4.2 and 4.1, to be used in equation 4.12 instead of $0.87 f_{yk}$.

PERMEABILITY

$$q = \frac{k * A * (P_1 - P_2)}{\mu * L}$$

Echo Impact assessment

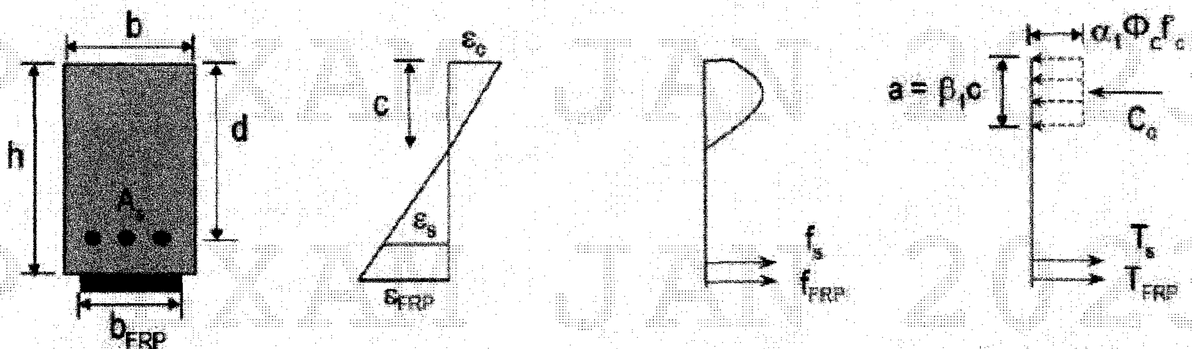
$$D = \sqrt[2]{\left[\frac{(V_P \times \Delta t)^2 + {L_1}^2 - {L_2}^2}{2 \times V_P \times \Delta t}\right]^2 - {L_1}^2}$$

APPENDIX-2

CFRP Strengthening of Concrete Beam

Material resistance factors (CHBDC):

- Concrete $\phi_c = 0.75$
- Steel reinforcement:
  - Reinforcing bars $\phi_s = 0.90$
  - Prestressing strands $\phi_p = 0.95$
- Base ϕ_{FRP} for pultruded FRP:
  - AFRP $\phi_{FRP} = 0.55$ (for externally bonded applications)
  - AFRP $\phi_{FRP} = 0.65$ (for NSMR)
  - CFRP $\phi_{FRP} = 0.80$ (for externally bonded applications and NSMR)
  - GFRP $\phi_{FRP} = 0.70$ (for externally bonded applications and NSMR)
- Non-pultruded FRP made by wet lay-up: 0.75 times base ϕ_{FRP}



Cross Section | Strain Distribution | Stress Distribution | Equiv. Stress Distribution

$T_s = \phi_s A_s f_s$ $\quad T_{FRP} = \phi_{FRP} A_{FRP} E_{FRP} \varepsilon_{FRP}$ $\quad C_c = \phi_c \alpha_1 f'_c \beta_1 bc$

$$\alpha_1 = 0.85 - 0.0015 f'_c > 0.67$$

$$\beta_1 = 0.97 - 0.0025\, f'_c > 0.67$$

1) Force equilibrium in the section

Compression forces =Tension forces

$$C_c = T_s + T_{FRP}$$

2) Moment equilibrium in the section:

External applied moment= Internal moment

$$M_{applied} = T_s \left[d - \frac{a}{2} \right] + T_{FRP} \left[h - \frac{a}{2} \right]$$

Compression in concrete = Tension in (Steel + FRP)

$$\alpha_1 \phi_c f'_c b \beta_1 c = \phi_s f_y A_s + \phi_{FRP} E_{FRP}\, \varepsilon_{FRP} A_{FRP}$$

$$M_r = Ts \left[d_s - \frac{\beta_1 c}{2} \right] + T_{FRP} \left[h - \frac{\beta_1 c}{2} \right]$$

$$= \phi_s f_y A_s \left[d_s - \frac{\beta_1 c}{2} \right] + \phi_{FRP} E_{FRP}\, \varepsilon_{FRP} A_{FRP} \left[h - \frac{\beta_1 c}{2} \right]$$