

The Open University of Sri Lanka
 Faculty of Engineering Technology
 Department of Civil Engineering



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Study Programme	: Bachelor of Technology Honours in Engineering
Name of the Examination	: Final Examination
Course Code and Title	: CVX 5241 Hydraulics Engineering II
Academic Year	: 2022/2023
Date	: Tuesday, 20 th February 2024
Time	: 13:30 - 16:30 hrs
Duration	: 03 hours

General Instructions

1. Read all instructions carefully before answering the questions.
2. This question paper consists of **SIX (06)** questions on **Seven (07)** pages.
3. Answer any **FIVE (05)** questions.
4. The answer for each question should commence from a new page.
5. Necessary additional information is provided.
6. This is a Closed Book Test (CBT).
7. Answers should be in clear handwriting.
8. **DO NOT** use Red colour pen.
9. Assume acceleration of gravity as 9.81 m/s² or 32.185 ft/s² wherever required.
10. Assume reasonable values for any data not given in or with the examination paper. Clearly state such assumptions made on the answer script.
11. If you have any doubt as to the interpretation of the wording of a question, make your own decision, but clearly state it on the answer script.
12. Electronic/Communication devices are not permitted. The only equipment allowed is a calculator approved and labeled by the Faculty of Engineering.

The following information may be useful in solving the problems.

$$V = \frac{1}{n} R_h^{2/3} S_e^{1/2} \quad V = \frac{1.49}{n} R_h^{2/3} S_e^{1/2} \quad N_F = \frac{V}{\sqrt{gy}}$$

$$q = -K \frac{dh}{dx} \quad s = \frac{Q}{4\pi T} \int_u^\infty \frac{e^{-u}}{u} du \quad u = \frac{r^2 S}{4Tt}$$

$$\int_u^\infty \frac{e^{-u}}{u} du = W(u) = -0.5772 - \ln u + u - \frac{u^2}{2.2!} + \frac{u^3}{3.3!} \quad E = \frac{v^2}{2g} + y$$

$$T = \frac{2.3Q}{4\pi\Delta s} \log \left(\frac{t_2}{t_1} \right)$$

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Q1 [20 Marks]

- (a) Prove that the triangular channel section shown in **Fig. 1** is the best hydraulic section when $Z = 1.0$. (that is, achieves optimal hydraulic efficiency when Z equals 1.0.

[08 Marks]

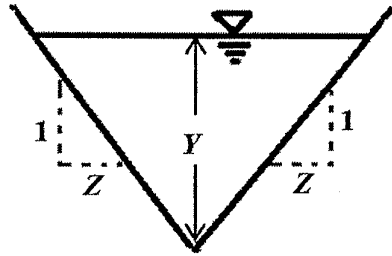


Figure 1. Triangular Channel Section

- (b) Above triangular channel with side slopes of 1:1 (H:V) carries a discharge of $900 \text{ ft}^3/\text{sec}$. If the longitudinal channel slope is 0.5 percent and Manning's coefficient is 0.02, what will be the normal depth of flow?

[08 Marks]

- (c) Calculate the specific energy of the flow.

[04 Marks]

Q2 [20 Marks]

(a) Clay has the ability to store more water compared to sand or gravel. However, clay is often considered an aquitard material. Using your knowledge of the porosity and permeability, explain the reasons for this hydraulic behaviour. **[06 Marks]**

(b) Field investigations were conducted in three different aquifers (A, B and C in **Table 1**) to investigate their suitability for a community water supply scheme. Some of the properties of these aquifers are given in **Table 1**. Rank the aquifers in order from the most suitable to the least suitable for installing a groundwater pumping well. **[05 Marks]**

Table 1 Aquifer properties

Aquifer	Porosity (%)	Specific retention (%)
A	48	43
B	32	14
C	38	28

(c) Two confined aquifers are separated by an aquitard as shown in **Fig. 2**. The piezometric head difference between the upper and lower aquifers, measured along a vertical line is 6.5 m. The vertical hydraulic conductivity and the porosity of the aquitard layer are 0.046 m/day and 0.5, respectively.

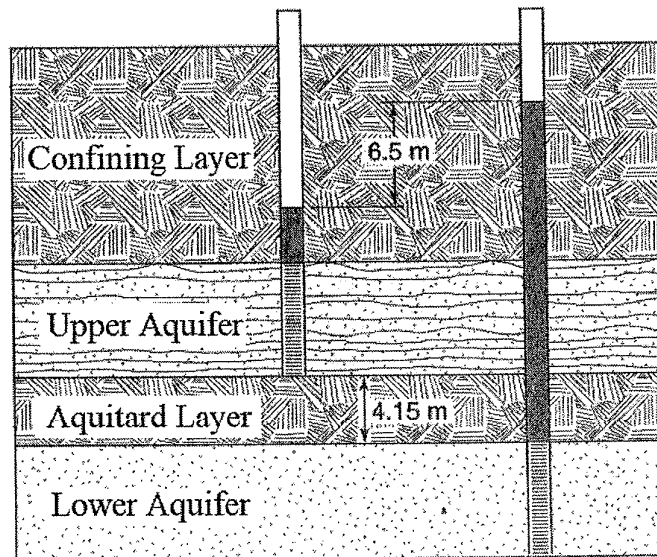


Figure 2. Aquifers formation

(c)-(i) Determine the direction and magnitude of leakage per square kilometer (1 km^2) between the upper and lower confined aquifers through the aquitard layer. **[06 Marks]**

(c)-(ii) Estimate the travel time of a water particle through the aquitard layer if the estimated thickness of the aquitard layer is 4.15 m. **[03 Marks]**

Q3 [20 Marks]

(a) Name the aquifer parameters determined by transient pumping tests in confined and unconfined aquifers. **[06 Marks]**

(b) Considering the unsteady radial flow, Theis (1935) developed the following solution for drawdown (s) in a confined aquifer;

$$s = \frac{Q}{4\pi T} \left(-0.5772 - \ln(u) + u - \frac{u^2}{2.2!} + \frac{u^3}{3.3!} - \frac{u^4}{4.4!} + \dots \right)$$

where, $u = \frac{r^2 S}{4Tt}$, with symbols having their usual meaning.

(b)-(i) Clearly state **five assumptions** used in deriving Theis (1935) solution. **[05 Marks]**

(b)-(ii) A production well pumps from a confined aquifer with a uniform thickness of 50 m at a constant rate of 0.064 m³/sec. The hydraulic conductivity and the specific storage of the confined aquifer are 25 m/day and 8×10^{-6} m⁻¹, respectively. Estimate the radius of influence of the pumping well after 1-day of pumping. **[Hint: use an appropriate assumption to simplify Theis (1935) solution.]** **[09 Marks]**

Q4 [20 Marks]

A well penetrating a confined aquifer with a thickness of 50 ft is pumped at a uniform rate of 3.34 cfs. Drawdowns during the pumping period were measured in an observation well 300 ft away and listed in **Table 2**.

- a) The Theis (1935) solution for confined aquifers is given as follows. Using this solution, derive the Cooper-Jacob solution to estimate aquifer properties. **[05 Marks]**

$$s = \frac{Q}{4\pi T} \left(-0.5772 - \ln(u) + u - \frac{u^2}{2.2!} + \frac{u^3}{3.3!} - \frac{u^4}{4.4!} + \dots \right)$$

where, $u = \frac{r^2 S}{4Tt}$, with symbols having their usual meaning.

- (b) **Using the given graph sheet (on the last page)**, calculate the hydraulic conductivity and the storativity of the aquifer using the Cooper-Jacob method. **[12 Marks]**
- (c) If the Cooper-Jacob method is valid for small u values ($u < 0.01$), after how many minutes of pumping would the Cooper-Jacob approximation be valid? **[03 Marks]**

Table 2: Obtained records during the pumping test.

Time after pumping started (min)	Drawdown (ft)	Time after pumping started (min)	Drawdown (ft)
1	0.45	60	2.34
2	0.74	80	2.50
3	0.91	100	2.67
4	1.04	200	2.96
6	1.21	400	3.25
8	1.32	600	3.41
10	1.45	800	3.50
30	2.02	1000	3.60
40	2.17	1440	3.81
50	2.30		

Q5 [20 Marks]

- (a) Considering a control volume in the vicinity of a hydraulic jump (Fig. 3), derive the following equation with symbols having their usual meaning. **[10 Marks]**

$$\frac{y_2}{y_1} = \frac{1}{2} \left[\sqrt{1 + 8N_{F1}^2} - 1 \right]$$

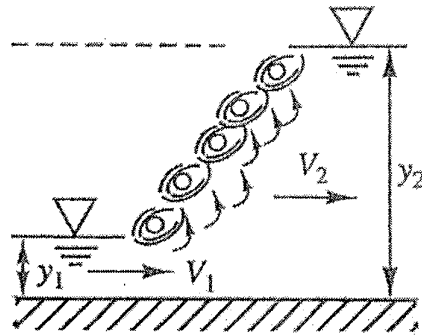


Figure 3. Hydraulic Jump

- (b) An 8-ft-wide rectangular channel carries 440 cfs of water at a depth of 1.8 ft before entering a jump. Compute the downstream water depth and the critical depth. **[10 Marks]**

Q6 [20 Marks]

A set of piers needs to be designed for a bridge across a river with a gravel bed. To design the substructure, it is necessary to estimate the erosion potential at the riverbed. The average discharge (q_w) is $0.8 \text{ m}^3/\text{s}$ per metre width of the river. The riverbed slope (S) is $1/1000$ and the water depth (d) is 1.0 m at average discharge. If the average diameter of riverbed sediments (D) is 0.003 m , estimate the annual erosion volume per metre width of the river. Assume there is no sediment supply from upstream at this location. Shields' Diagram is given in **Fig. 4**. Use Shields' formula,

$$\frac{q_b \rho_s}{q_w \rho_w S} = 10 \frac{\tau - \tau_{cr}}{(\rho_s - \rho_w)g}$$
 to estimate the bed load transport rate (q_b)

where,

q_b = Bed load per unit width ($\text{m}^3/\text{s}/\text{m}$)

q_w = Water discharge per unit width ($\text{m}^3/\text{s}/\text{m}$)

S = Bed slope

$\tau = \rho g d S$

g = acceleration due to gravity ($9.81 \text{ m}/\text{s}^2$)

D = Particle diameter (m)

d = Water depth (m)

τ_{cr} is the critical shear stress that can be read from the Shields' diagram (Figure Q6).

The density of sediment (ρ_s) and water (ρ_w) are $2650 \text{ kg}/\text{m}^3$ and $1000 \text{ kg}/\text{m}^3$. Take the kinematic viscosity of water (ν) as $0.801 \times 10^{-6} \text{ m}^2/\text{s}$.

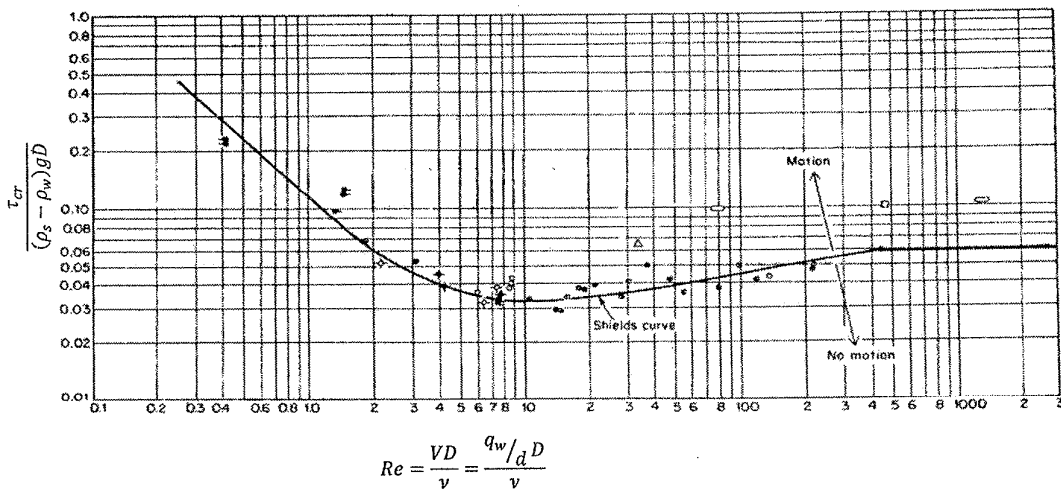


Figure 4. Shields' Diagram

In the above graph,

X axis

Y axis

$$Re = \frac{VD}{\nu} = \frac{q_w/dD}{\nu}$$

$$\frac{\tau_{cr}}{(\rho_s - \rho_w)gD}$$

Q7 [20 Marks]

- (a) To initiate the sediment motion, the equilibrium of the particle on the bed of a river should be disturbed. List the forces that may disturb these particles and trigger motion. Also, list the forces that resist the sediment motion and thereby prevent erosion.

[08 Marks]

- (b) Briefly discuss about the different modes of sediment transport in rivers, emphasising which modes of sediment transport would dominate under different flow conditions.

[06 Marks]

- (c) Discuss the two main parameters used in the design of erodible channels by method of tractive force.

[06 Marks]

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Graph Sheets for Question 4

