Open Channel Flow Design and Analysis
22CVB101

Semester 2 2023 | In-Person Exam Paper

This examination is to take place in-person at a central University venue under exam conditions. The standard length of time for this paper is **3 hours**.

You will not be able to leave the exam hall for the first 30 or final 15 minutes of your exam. Your invigilator will collect your exam paper when you have finished.

Help during the exam

Invigilators are not able to answer queries about the content of your exam paper. Instead, please make a note of your query in your answer script to be considered during the marking process.

If you feel unwell, please raise your hand so that an invigilator can assist you.

You may use a calculator for this exam. It must comply with the University's Calculator Policy for In-Person exams, in particular that it must not be able to transmit or receive information (e.g. mobile devices and smart watches are **not** allowed).

This examination consists of two sections.
Answer **BOTH QUESTIONS** in Section A.
Answer **TWO QUESTIONS** in Section B.

All questions carry equal marks.

Continues/…

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SECTION A
(Answer **BOTH QUESTIONS in Section A**)

1. a) With reference to relevant literature, discuss the relative importance of experimental data and numerical modelling in hydraulic engineering.

[15 marks]

b) Using a control volume approach and balancing, inflow, outflow and mass accumulation over some small time δt, show that the mass continuity equation for a one-dimensional incompressible flow is given by:

$$\frac{\partial h}{dt} + \frac{\partial q_x}{\partial x} = 0$$

where $q_x$is the discharge per unit width in the downstream direction (x) and h is the water depth.

[7 marks]

c) How can engineering solutions contribute to achieving the Human Right to Safe Drinking Water For All? Name at least three of the Human Right to Water criteria and give one practical example of how this might be achieved.

[3 marks]

2. a) A rectangular channel has a width of 12.5 m. A discharge of 20 m^3/s flows through the channel with a depth of 1.2 m. The Manning's roughness coefficient of the channel is $n =$ 0.02 m$^{-1/3}$s. Calculate the channel bed slope.

[5 marks]

b) Given that an optimum cross-section minimizes the wetted perimeter (P_w) for a given cross-sectional area (A), show that for a rectangular channel, the condition for optimum cross-section is:

$$b = 2h$$

where b is the channel width and h is the flow depth.

[8 marks]

c) Draw a graph plotting normalised flow depth, h/h_c, against normalised specific energy, E/h_c, where h_c is the critical depth. Indicate both axis values at the point of minimum energy and label regions of sub-critical and super-critical flow with their corresponding Froude number ranges.

[4 marks]

Question 2 continues/…

…/question 2 continued

d) A reservoir discharges over a broad-crested weir into a river channel. The surface area of the reservoir is a function of the height above the weir crest, such that:

$$A(H) = 1.1 \times 10^5 + 6 \times 10^3 H$$

The broad-crested weir equation is:

$$Q = 8.6H^{3/2}$$

By balancing the change in reservoir volume with the discharge over the weir (assuming no inputs to or other outputs from the reservoir), determine the time taken for the water level to fall from 0.4 m to 0.2 m.

[8 marks]

SECTION B
(Answer **TWO QUESTIONS in Section B)**

3. a) When applying the gradually varying flow equations, what value is assumed for the Reynolds number?

[1 mark]

b) There is a proposal to undertake some river channel straightening 2 km upstream of where the river reaches a reservoir. You have been asked to determine the magnitude of the backwater effect at this point. Explain which form of the gradually varying flow equations you would use to analyse this and which numerical method you would adopt, providing clear reasoning for your choice.

[4 marks]

c) When deriving the height form for the gradually varying equations, we obtain a term dA/dx that is subsequently written as:

$$\frac{dA}{dx} = T\frac{dh}{dx}$$

where A is cross-sectional area, h is the height and x is the distance down the channel. State how the top width, T, can be expressed as a derivative and provide a physical interpretation of this derivative.

[3 marks]

d) A 3 m wide, rectangular culvert has been designed such that its normal depth equates to critical depth given its bed slope of 0.01 and a Manning roughness coefficient of 0.022. Determine the critical/normal depth for this culvert. (Hint: once you have rearranged in terms of critical depth, D_{crit}, pick a large value (e.g. 5 m) and the solution will converge by iteration).

[8 marks]

Question 3 continues/…

e) A particular flow is observed to have a depth that lies below both the critical depth and the normal depth. The critical depth is greater than the normal depth. State if the flow is subcritical or supercritical, if it will transition to the normal depth steeply or gradually, and what will have caused such a flow to arise.

[3 marks]

f) Describe one example of where each of the following transitions may occur in a natural or constructed open channel. For each one, comment on the extent of energy loss that may occur across the transition.

i) supercritical to subcritical flow

ii) subcritical to supercritical flow

[4 marks]

g) Briefly explain two potential limitations or issues with the use of rating curves for river flow measurement.

[2 marks]

4. a) Suggest three potential sources of water supply to meet the domestic water needs of a small community in rural and outback areas and briefly explain their advantages or disadvantages.

[5 marks]

b) Over three days in July 2021, the mega city of Zhengzhou in central, inland China, with a population of 12.6 million, experienced heavy rain, with the hourly rainfall reaching a record-breaking level of 201.9 mm (7.95 in). This triggered a devastating flood disaster, left 398 people dead or missing, damaged over 400,000 cars and created huge direct economic loss.

i) What type of flood did Zhengzhou experience in July 2021 and why?

[3 marks]

ii) Provide 4 potential reasons to explain the increased flood risk in Zhengzhou.

[4 marks]

iii) What could be done to better manage flood risk and prevent such disaster from happening again in the future.

[7 marks]

c) Explain anaerobic biological processes. Give an example of how they can be applied in wastewater treatment and briefly explain how it works.

[3 marks]

d) What are the two common parameters for assessing wastewater quality? Explain each and give their units.

[3 marks]

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…/continued

5. a) Briefly describe how the different flow quadrants contribute to (I) Reynolds stress and (II) sediment entrainment in different ways assuming a boundary-layer is well-developed. When answering the latter point, distinguish between bedload entrainment and suspended sediment entrainment. A diagram may be helpful.

[5 marks]

b) Sediment diffusivity, K_s, is considered to be a linear function of distance from the bed of the channel. The sediment concentration, C, is considered to be a function of the sediment diffusivity, the settling velocity, ω_s, and the concentration gradient according to:

$$\omega_s C = -K_s \frac{dC}{dz}$$

where z is the vertical coordinate. Derive the form for the concentration profile, that is, the manner by which the concentration varies with height. How is the Rouse number helpful for interpreting this result?

[8 marks]

c) What terms are used to define a grain size Reynolds number and why is this important for modelling bedload entrainment using a Shields' approach?

[4 marks]

d) What is an eddy viscosity and why is it useful in the context of the modelling of the Reynolds stress tensor?

[4 marks]

e) Give examples of two common river engineering practices that might negatively impact upon river ecology and in each case state how a particular organism might be affected.

[4 marks]

6. a) Describe two different embankment dam failure mechanisms and how they can be mitigated.

[4 marks]

b) With the help of a diagram, identify the three primary loads that must be considered when determining the overturning stability of a gravity dam and the direction in which they act

[4 marks]

Question 6 continues/…

c) The discharge over a 12 m wide spillway into a stilling basin of the same width is 280 m^3/s. The reservoir has a surface elevation of 60 m and the elevation of the river water surface downstream of the hydraulic jump is 40 m. The water depth before the jump is 1.05 m. Calculate the energy loss along the spillway and the energy loss across the jump, making use of the fact that

$$\frac{h_2}{h_1} = \frac{\sqrt{1 + 8Fr_1^2} - 1}{2}$$

[8 marks]

d) Reservoir flood routing calculations rely on the principle of mass conservation, such that the change in storage (S) is related to the inflows (I) and outflows (O). Write an appropriate equation for mass conservation and, by considering some time step ΔT, show that the following is true:

$$\phi_2 = \phi_1 - 2O_1 + I_2 + I_1$$

where $\phi_i = 2S_i/\Delta T + O_i$ and $t_2 = t_1 + \Delta T$.

[5 marks]

e) A deep-water wave has a general expression for the wave angular frequency of:

$$\omega = \sqrt{gk + \frac{\sigma}{\rho}k^3}$$

where σ is the surface tension and k is the wavenumber. How does this equation simplify in the case of (i) capillary waves and (ii) large-scale deep water waves? Explain what these two cases mean physically.

[4 marks]

T Marjoribanks
C Keylock
Q Liang
T Radu
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