Version DL/3

EGT2
ENGINEERING TRIPOS PART IIA

Wednesday 7 May 2014   9.30 to 11

Module 3D5

WATER ENGINEERING

Answer not more than ***three*** *questions.*

All questions carry the same number of marks.

The ***approximate*** *percentage of marks allocated to each part of a question is indicated in the right margin.*

Write your candidate number ***not*** *your name on the cover sheet.*

The values of relevant parameters are listed at the end of the Data Book unless otherwise noted in the question.

STATIONERY REQUIREMENTS
Single-sided script paper
Graph paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Attachment: 3D5 Water Engineering Data Book (5 pages).
Engineering Data Book

You may not start to read the questions printed on the subsequent pages of this question paper until instructed to do so.

1 (a) A rainfall event lasts for 8 hours. The excess rainfall intensity is 7 mm h^{-1} in the first 4 hours, and is 14 mm h^{-1} in the second 4 hours. The following hydrograph at the catchment outlet is generated.

Duration (h)	0-4	4-8	8-12	12-16	16-20	20-24	24-28	28-32
Excess rainfall (mm h^{-1})	7	14	0	0	0	0	0	0
Discharge (m^3 s^{-1})	250	860	930	520	240	90	20	0

(i) Show that the area of the catchment is around 500 km^2. [10%]

(ii) The catchment discharge of 250 m^3 s^{-1} at 0-4 hours is entirely due to the first 4-hour rainfall of excess intensity of 7 mm h^{-1}. Assuming the catchment response is linear, what is the catchment discharge in the initial 4 hours due to a 4-hour rainfall with 14 mm h^{-1} excess intensity? Based on this, show that the 7 mm h^{-1} excess rain occuring at 0-4 hours generates a discharge of 360 m^3 s^{-1} at 4-8 hours. [20%]

(iii) Following procedure (ii), show that the 7 mm h^{-1} excess rain occurring at 0-4 hours generates 210 m^3 s^{-1} discharge at 8-12 hours, and prove that the 4-hour unit hydrograph of the catchment is: [25%]

Duration (h)	0-4	4-8	8-12	12-16	16-20	20-24	24-28
Discharge (%)	26	37	22	10	4	1	0

(iv) In an entirely separate rainfall event over this catchment, the rain falls at 20 mm h^{-1} in the first two hours, and then at 8 mm h^{-1} in the second two hours before it finally stops. The infiltration-related coefficients are $f_0 = 20$ mm h^{-1}, $f_c = 6$ mm h^{-1}, and $K_f = 0.4$ h^{-1}. Estimate the peak discharge generated by this rainfall event. [35%]

(b) In the rational method, the runoff coefficient can be taken as high as 0.95 for urban areas and as low as 0.05 for rural areas. Explain why a higher value is normally adopted for urban areas. [10%]

2 (a) The uniform flow rate and water depth in a channel of trapezoidal cross-section are 21.0 $m^3\ s^{-1}$ and 1.25 m, respectively. The bottom width of the channel is 8.9 m, and the slope of the sides is 1:1. The Manning's roughness factor is 0.025 $s\ m^{-1/3}$.

(i) Calculate the bed slope. [15%]

(ii) Prove that the flow is sub-critical. [10%]

(b) In a rectangular channel, the friction at the bed and walls can be neglected. The bed slope is 0.005. The flow is steady, with a unit-width flow rate of 3.13 $m^2\ s^{-1}$. The water depth at the entrance is 0.8 m. Prove the following:

(i) the water depth continues to decrease along the channel after entrance. [20%]

(ii) the water depth along the channel, h in m, and the longitudinal distance from the entrance, x in m, follow the relationship: [25%]

$$h^3 - (0.005 \cdot x + 1.58) \cdot h^2 + 0.5 = 0 \ .$$

(c) A long rectangular river, with a uniform depth of 4 m and a velocity of 1 $m\ s^{-1}$, flows into a lake. A landslide in the lake causes the water depth at the river mouth to linearly rise to 4.05 m in 20 s and then linearly drop back to 4 m in the next 20 s. Neglect the river slope and bed friction in the analysis. At 1 km upstream of the river mouth, calculate:

(i) the time at which the water depth starts to rise and the duration needed for the water depth to rise from 4 m to 4.05 m. [20%]

(ii) the duration needed for the water depth to subsequently fall from 4.05 m to 4 m. [10%]

3 (a) A wide channel has a rectangular cross-section, and a uniform bed slope of 0.004. The unit-width discharge is 2 $m^2\ s^{-1}$. Take the grain-related roughness height of the bed to be three times of the grain size.

(i) With a sediment size of 3 mm and a bedform-related roughness height estimated to be 0.05 m, show that the water depth is around 0.85 m, and calculate the bedload in kg $m^{-1}\ s^{-1}$ using Van Rijn's formula. [25%]

(ii) To prevent sediment transport in the channel, the channel surface is covered with large pebbles and all the bedforms are eliminated. Estimate the minimum diameter of the pebbles that need to be used. It can be assumed that the critical Shields parameter for large pebbles is 0.055. [25%]

(b) A small river of rectangular cross-section is 2 m wide. The flow depth is 1.5 m, and the flow rate is 3 $m^3\ s^{-1}$. A toxic chemical is spilled into the river from a factory in a short period of time. At the river monitoring station 10 km downstream of the factory, the levels of the chemical concentration are monitored to be 0.02 g m^{-3} and 2 g m^{-3} at 2 hours and 3 hours, respectively, after the spill.

(i) Based on the above information, estimate the longitudinal dispersion coefficient and the total mass of the spilled chemical. [25%]

(ii) Given that the bed slope of the river is 0.001, estimate the longitudinal dispersion coefficient using the analytical formula in the data book, and explain why this formula underestimates the longitudinal dispersion coefficient. [10%]

(c) Briefly explain why the fall velocity is proportional to the square of the particle size for very fine sand particles, but is proportional to the square root of the particle size for very large particles. [15%]

4 Water flows through a 450 mm diameter cast iron (k_s = 0.27 mm) pipeline linking two reservoirs over a length of 1500 m. The water level at Reservoir A, the pipeline level at Section X, the ground level at Section Y, and the local loss coefficients are all labelled in Fig. 1. Assume that the water kinematic viscosity, density and vapour pressure head are 1.14×10^{-6} m^2 s^{-1}, 1000 kg m^{-3} and –10.1 m, respectively. The length of the pipeline between Reservoir A and Section X is 500 m, and the water pressure at Section X is 120 kN m^{-2} above atmospheric pressure.

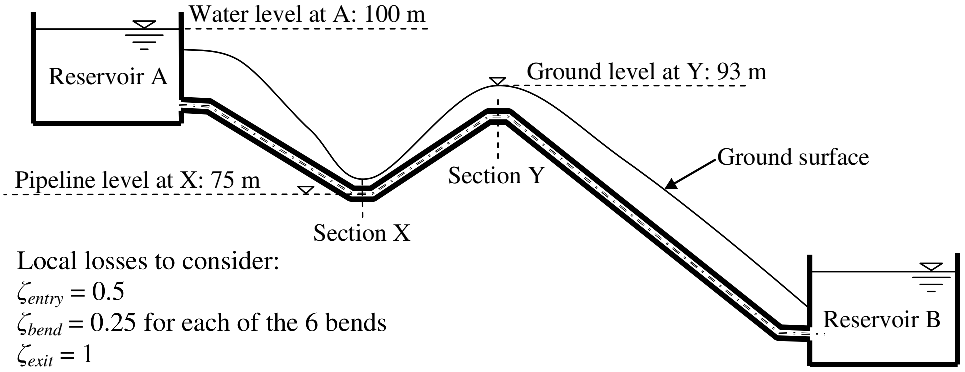

Fig. 1 (Not to scale)

(i) Show that the flow rate to reservoir B is around 0.54 m^3 s^{-1}. [20%]

(ii) Show that the water level in reservoir B is around 36.5 m below that in reservoir A. [10%]

(iii) The length of the pipeline between Reservoir A and Section Y is 800 m. Determine the minimum excavation depth at Y required to prevent cavitation. Explain why in practice the pressure in the pipeline is often required to be above the atmospheric pressure. [20%]

(iv) If a pump with the characteristic shown in the table below is installed on the pipeline to reverse the flow, what flow rate will be delivered? [35%]

Q (m^3 s^{-1})	0	0.2	0.4	0.6	0.8
H (m)	100.0	91.2	75.4	53.2	24.3

(v) Explain why the pump mentioned in (iv) should be positioned close to Reservoir B, rather than Reservoir A. [15%]

END OF PAPER

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