Version DL/3

EGT2
ENGINEERING TRIPOS PART IIA

Monday 11 May 2026 9.30 to 11.10

Module 3D5

HYDRAULICS

*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.*

STATIONERY REQUIREMENTS
Single-sided script paper
Graph paper

SPECIAL REQUIREMENTS TO BE SUPPLIED FOR THIS EXAM
CUED approved calculator allowed
Attachment: 3D5 Hydraulics data sheet (4 pages)
Engineering Data Book

10 minutes reading time is allowed for this paper at the start of the exam.

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

You may not remove any stationery from the Examination Room.

1 (a) Choose four catchment characteristics and describe their effects on the flood hydrograph. Sketch the effects of each characteristic on an illustrative hydrograph. [20%]

(b) What is a flow duration curve? Describe the steps to follow to construct a flow duration curve. Sketch generic flow duration curves for a perennial stream with low variability and for an ephemeral stream. [30%]

(c) The following rainfall is recorded in each of four consecutive hours: 15 mm, 20 mm, 20 mm, 5 mm. Use Horton's *f*-capacity equation, with $f_0 = 10$ mm hr^{-1}, $f_c = 5$ mm hr^{-1} and $K_f = 0.3$ hr^{-1}, to determine the infiltration and run-off volumes (measured in mm depth) over each hour of that period. Assume that there are constant interception losses of 1 mm hr^{-1} and that the soil is initially dry. Briefly explain why infiltration capacity declines over time. [50%]

2 (a) Explain the terms *pore water pressure, pressure head* and *potential head* with reference to the groundwater flow in granular media. [10%]

(b) What is the difference between the water table and the phreatic surface when water is present in a soil layer? [10%]

(c) An earth dam was constructed with silty clay as shown in Fig. 1 by compacting layers of soil using a roller. The dam can be considered to have 'no air-entry'. A blanket drain of length 12 m from the downstream toe of the dam was constructed. The reservoir was filled to a height of 12 m above the base. The laboratory test of a core sample, taken after the dam construction, gave a vertical hydraulic conductivity of 2.4×10^{-6} m s^{-1} and a horizontal hydraulic conductivity of 9.6×10^{-6} m s^{-1}.

(i) Determine the seepage loss through this dam by constructing a suitable flow net diagram. Consider 1 m length of the dam into the plane of the paper, and express your answer in the units of litre day^{-1} m^{-1}. Identify any shortcomings in the flow net that was constructed. [35%]

(ii) The saturated density of the compacted silty clay was 1830 kg m^{-3}. Estimate the pore water pressures and the effective stresses at four points A, B, C and D. Points A and B are on the centre line of the dam, while points C and D are 10 m from the centre line on either side. Points B, C and D are 1 m above the base. Estimate the hydraulic gradient between points C and D. [35%]

(iii) Explain what will happen to the seepage flow if the earth dam was constructed in a way that the silty clay was isotropic. No further calculations are required. [10%]

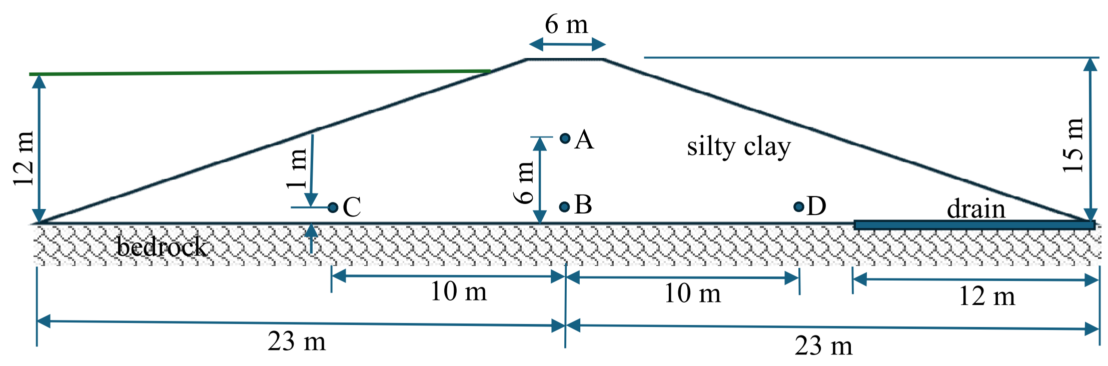


Fig. 1 (not to scale)

3 (a) Explain briefly how you would conduct a falling head permeameter test on a fine grained soil sample. [10%]

(b) Show that the following expression can be used to determine the hydraulic conductivity of fine grained soil with the falling head permeameter. Explain the meanings of all symbols. [15%]

$$K = \frac{4aL}{\pi D^2} \frac{1}{(t_2 - t_1)} \ln\left(\frac{h_1}{h_2}\right)$$

(c) A fine grained soil sample of diameter 50.8 mm and a height of 100 mm was placed in a falling head permeameter. The inner diameter of the falling head tube is 8 mm. The following observations were made with this falling head permeameter.

Time (min)	0.5	1	2	5	10	20	40	60	120	200	240	360	480
Head (mm)	155	154	153	148	138	125	110	100	84	80	68	51	50

Determine the hydraulic conductivity of the soil sample. Comment on the suitability of this apparatus and whether a constant head permeameter could have been used instead on a sample of the same size. [35%]

(d) To determine the soil thermal conductivity, a hot plate that maintains 75 °C is placed on top of the soil sample while a heat sink that maintains a temperature of 10 °C is placed at the bottom of the soil sample. A 24 V DC power supply is used to heat up the hot plate. The electric current is measured to be 0.25 Amps, once the steady state is reached. Determine the thermal conductivity of the soil sample. [20%]

(e) Estimate the volumetric heat capacity of the soil sample, if the saturated unit weight of the soil sample is 17.5 kN m^{-3}. You can take the specific heat capacity of saturated soil to be 1.5 kJ kg^{-1} K^{-1}. Then, calculate the thermal diffusivity of the soil sample. [20%]

4 (a) Explain the terms *mild slope channel* and *steep slope channel*. [10%]

(b) Use hydraulic principles to explain why weirs can be used to measure flowrates. [10%]

(c) The slope of a long channel changes from being mild to being steep at the midpoint. When the flow is steady, explain why the flow at the midpoint has to be critical. [25%]

(d) A canal has a total length of 1270 km and a uniform bed elevation drop of 100 m from the upstream to the downstream ends. The cross-sectional shape is trapezoidal, with a base width of 22 m and side slope of 1:2, as shown in Fig. 2. The Manning roughness coefficient is estimated to be 0.015 s m$^{-1/3}$. When the water depth is 8 m:

(i) calculate the water discharge rate of the canal; and [40%]

(ii) calculate the roughness height of the canal lining. [15%]

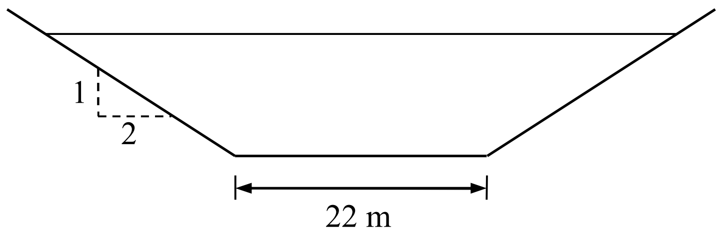


Fig. 2

END OF PAPER

THIS PAGE IS BLANK

UNIVERSITY OF CAMBRIDGE

Engineering Tripos Part IIA Third Year

Module 3D5: Hydraulics

Data Book (SI units [m, kg, s] unless otherwise noted)

Hydrology

Horton's infiltration model (*f*-capacity) $f = f_c + (f_0 - f_c)e^{-K_f t}$

$$\int_{t_1}^{t_2} f \cdot dt = f_c(t_2 - t_1) - \frac{1}{K_f}(f_0 - f_c)\left(e^{-K_f t_2} - e^{-K_f t_1}\right)$$

Rational method $Q = CiA$

Boundary Layer

For fully developed boundary layer flow with a free surface (uniform flow in a very wide channel):

Eddy viscosity coefficient $\nu_t = \kappa u_* z\left(1 - \frac{z}{h}\right)$

Velocity in hydraulically smooth regime ($u_* k_s/\nu < 5$) $\frac{\bar{u}(z)}{u_*} = \frac{1}{\kappa}\ln\left(9.0\frac{zu_*}{\nu}\right)$

Velocity in hydraulically rough regime ($u_* k_s/\nu > 70$) $\frac{\bar{u}(z)}{u_*} = \frac{1}{\kappa}\ln\left(\frac{30.0z}{k_s}\right)$

Open Channel Flow

Chézy coefficient in large Reynolds-number flows $C = 7.8\ln\left(\frac{12.0 \cdot R_h}{k_s}\right)$

Manning formula $C = \frac{1}{n} \cdot R_h^{1/6}$

Bed shear stress $\tau_b = \rho g R_h S_f = \frac{C_f}{2}\rho \cdot U^2 = \frac{\lambda}{8}\rho \cdot U^2 = \frac{g}{C^2}\rho \cdot U^2 = \frac{g \cdot n^2}{R_h^{1/3}}\rho \cdot U^2 = \rho \cdot u_*^2$

Froude number $Fr = \frac{U}{\sqrt{g\,A/B}}$

Uniform flows (Chézy formula) $U = C\sqrt{R_h S_b}$

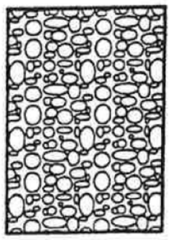
Hydraulic jumps in rectangular channels $U_1 U_2 = g\frac{h_1 + h_2}{2}$

Gradually varied steady flows: $\frac{d}{dx}\left(h + \frac{U^2}{2g}\right) = S_b - S_f$

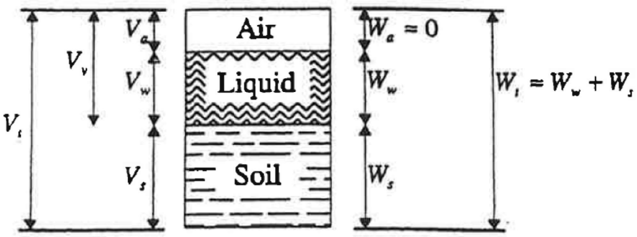
or $$\frac{dh}{dx} = \frac{S_b - S_f}{1 - Fr^2} = \frac{S_b - \frac{U^2}{C^2 \cdot R_h}}{1 - Fr^2} = \frac{S_b - \frac{n^2 \cdot U^2}{R_h^{4/3}}}{1 - Fr^2}$$

Groundwater

Soil: general definitions



considered as



Soil structure Volumes Weights

Specific gravity of solid	G_s
Voids ratio	$e = V_v/V_s = n/(1-n)$
Specific volume	$v = V_t/V_s = 1 + e$
Porosity	$n = V_v/V_t = e/(1+e)$
Water content	$w = W_w/W_s$
Degree of saturation	$S_r = V_w/V_v = wG_s/e$
Unit weight of water	$\gamma_w = 9.81\ kN/m^3$
Unit weight of soil	$\gamma = W_t/V_t = \left(\frac{G_s + S_r e}{1+e}\right)\gamma_w$
Buoyant unit weight	$\gamma' = \gamma - \gamma_w = \left(\frac{G_s - 1}{1+e}\right)\gamma_w$ (soil saturated)
Unit weight of dry soil	$\gamma_d = W_s/V_t = \left(\frac{G_s}{1+e}\right)\gamma_w$

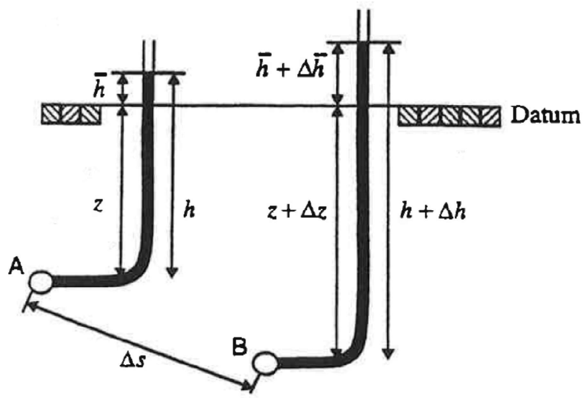
Classification of particle sizes

Boulders	larger than			200mm
Cobbles	between	200mm	and	60mm
Gravel	between	60mm	and	2mm
Sand	between	2mm	and	0.06mm
Silt	between	0.06mm	and	0.002 mm
Clay	smaller than	0.002 mm (two microns)		

D	equivalent diameter of soil particle
D_{10}, D_{60} etc.	particle size such that 10% (or 60% etc.) by weight of a soil sample is composed of finer grains.
C_U	uniformity coefficient D_{60}/D_{10}

Seepage

Excess pore water pressure



Total gauge pore water pressure at A: $p = \gamma_w h = \gamma_w(\bar{h} + z)$

B: $p + \Delta p = \gamma_w(h + \Delta h) = \gamma_w(\bar{h} + z + \Delta\bar{h} + \Delta z)$

Excess pore water pressure at A: $\bar{p} = \gamma_w \bar{h}$

B: $\bar{p} + \Delta\bar{p} = \gamma_w(\bar{h} + \Delta\bar{h})$

Hydraulic gradient A B $i = \frac{\Delta\bar{h}}{\Delta s} = -\frac{1}{\gamma_w}\frac{\Delta\bar{p}}{\Delta s}$

Darcy's law $v = Ki$

v = superficial seepage velocity

K = coefficient of permeability or hydraulic conductivity

Typical hydraulic conductivities

D_{10} > 10 mm	:	non-laminar flow
10 mm > D_{10} > 1 µm	:	$K \cong 0.01(D_{10} \text{ in mm})^2$ m/s
clays	:	$K \cong 10^{-9}$ to 10^{-11} m/s