ENGINEERING TRIPOS PART IIA

Friday 27 April 2007 2.30 to 4

Module 3D5

ENVIRONMENTAL ENGINEERING I

*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.*

Attachment: Environmental Engineering I Data Sheet (6 pages)

STATIONERY REQUIREMENTS	SPECIAL REQUIREMENTS
Single-sided script paper	Engineering Data Book
Graph paper	CUED approved calculator allowed

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

1 (a) Rain falls uniformly and at constant intensity for 3 hours over a small urban catchment of area 20 km^2. The distribution percentages for the outflow hydrograph over six successive 3 hour periods starting at the beginning of the rainfall are 5, 17, 28, 23, 16, 11. Assuming that the catchment is impervious, estimate the distribution percentages over successive one hour intervals from uniform rainfall of one hour duration and of 15 mm hr^{-1} intensity. Plot the shape of this hydrograph and estimate the peak outflow in m^3s^{-1}. [40%]

(b) Explain why a steady flow in an open channel cannot undergo a smooth transition from upstream supercritical flow to downstream subcritical flow. [40%]

(c) Explain why the fall velocity of sand particles (of diameter D) in water (as given on the Data Sheet) is proportional to $D^{1/2}$ for large particles, but proportional to D^2 for small particles. [20%]

2 A wide flat smooth channel of rectangular cross-section and of length 500 m is carrying a steady flow with depth 1.8 m and mean velocity 0.6 m s^{-1} towards a power station at its downstream end. At time $t = 0$ the power station releases a large quantity of water into the channel causing the depth in the channel adjacent to the power station to rise at a rate of 1 metre per minute for 2 minutes. The depth adjacent to the power station remains constant thereafter. At what time t does the depth at the upstream end of the channel reach a maximum? [100%]

3 A straight wide open channel of uniform cross-section has a bed-slope of 0.00015. The flow is steady and has a depth of 1.2 m. The suspended sediment can be considered to be the sediment carried above the bed layer, which is 0.015 m thick. The concentration of suspended sediment at the top of the bed layer is 8.6 kg m^{-3}.

Assume that the Karman constant is 0.4, the bed roughness height is 0.015 m, the specific gravity of the sediment grains is 2.65, all grain diameters are 0.09 mm, the kinematic viscosity of water ν is 10^{-6} m^2 s^{-1} and the water temperature is 20°C.

(a) Estimate the flow velocity at the top surface of the channel. [30%]

(b) Estimate the sediment transport rate in suspension per metre width above the bed layer. [50%]

(c) What, according to various theories, would be the bed regime? [20%]

(TURN OVER

4 (a) A centrifugal pump when run at 750 rpm gave the following relationship between head, discharge and efficiency:

Discharge (litres per second)	Head (metres)	Efficiency (%)
0	32.3	-
5	32.0	59
9.5	31.4	74
14	29.3	81
18.5	23.8	79
23	0	-

The pump is connected to a pipe system which discharges to atmosphere at 20 m above sump level, and the total energy losses (in metres) can be found from the equation:

$$h_f = 0.02\,Q^2 \qquad \text{(where } Q \text{ is in litres/second)}$$

Calculate the discharge and the pump input power.

Note: $Q_1/Q_2 = N_1/N_2$ and $H_1/H_2 = N_1^2/N_2^2$ where N is pump speed. [50%]

(b) It is expected that future encrustation in the pipe will reduce the pipe diameter and increase the friction factor so that the total energy losses in the system will become:

$$h_f = 0.03\,Q^2 \qquad \text{(where } Q \text{ is in litres/second)}$$

Calculate the new pump speed required in order to maintain the same flow. If the cost of electricity is 6p/kW hour calculate the extra cost each day of running the pump. [50%]

END OF PAPER

UNIVERSITY OF CAMBRIDGE

Engineering Tripos Part IIA THIRD YEAR

Module 3D5: Environmental Engineering I

Data Sheet

(SI units throughout)

f-capacity equation

$$f = f_c + (f_0 - f_c)\, e^{-K_f t}$$

Spatially-varied flow (backwater curves)

$$\delta d = \ell \left(\frac{S - \overline{U}^2 C_f / 2gR}{1 - \overline{U}^2 / gd} \right)$$

Open-channel characteristics

$$\overline{U} + 2c - g(S - S_f)t = const \qquad \frac{dx}{dt} = \overline{U} + c$$

$$\overline{U} - 2c - g(S - S_f)t = const \qquad \frac{dx}{dt} = \overline{U} - c$$

Fall velocity of particles of sand in water (20°C)

For D < 0.0005 m $\qquad W \doteq 56 \times 10^4 D^2 (\rho_s - \rho) / \rho$

For D > 0.002 m (and shape factor=0.7) $\qquad W \doteq 3.3\, D^{1/2} \left((\rho_s - \rho) / \rho \right)^{1/2}$

Initial motion of sediment on a flat bed

$$\frac{u_* k_s}{\nu} > 70 \qquad \frac{\tau_c}{(\rho_s - \rho) g D} = 0.05$$

Velocity in uniform flow in a channel

Chézy $\qquad \overline{U} = C R^{\frac{1}{2}} S^{\frac{1}{2}}$

Manning $\qquad \overline{U} = \frac{1}{n} R^{\frac{2}{3}} S^{\frac{1}{2}}$

Prandtl-Karman

Hydraulically smooth $\left(\frac{u_* k_s}{\nu} < 5\right)$

$$\frac{u}{u_*} = 2.5 \log_e\left(\frac{9.05 y u_*}{\nu}\right)$$

$$\frac{\bar{U}}{u_*} = 2.5 \log_e\left(\frac{3.66 R u_*}{\nu}\right)$$

Hydraulically rough $\left(\frac{u_* k_s}{\nu} > 70\right)$

$$\frac{u}{u_*} = 2.5 \log_e\left(\frac{30.2 y}{k_s}\right)$$

$$\frac{\bar{U}}{u_*} = 2.5 \log_e\left(\frac{12.1 R}{k_s}\right)$$

Variation of the concentration of sediment in suspension with distance from the bed

$$\frac{C}{C_a} = \left[\left(\frac{d-y}{y}\right)\left(\frac{a}{d-a}\right)\right]^{\frac{W}{Ku_*}}$$

Sediment load in suspension

$$\int_b^d C u\, dy = 11.6 u_* C_b b\left[I_1 \log_e(Ad) + I_2\right]$$

where $A = \frac{9.05 u_*}{\upsilon}$ for a hydraulically smooth bed

$= \frac{30.2}{k_s}$ for a hydraulically rough bed

b/d	W/Ku$_*$ = 0.2		W/Ku$_*$ = 0.6		W/Ku$_*$ = 1.0		W/Ku$_*$ = 1.5	
	I_1	I_2	I_1	I_2	I_1	I_2	I_1	I_2
0.02	5.003	5.960	1.527	2.687	0.646	1.448	0.310	0.873
0.01	8.892	11.20	2.174	4.254	0.788	2.107	0.341	1.146
0.005	15.67	20.47	3.033	6.448	0.934	2.837	0.366	1.431
0.004	18.77	24.73	3.364	7.318	0.981	3.094	0.372	1.525
0.003	23.71	31.53	3.838	8.579	1.042	3.444	0.379	1.647
0.002	32.88	44.23	4.608	10.65	1.129	3.967	0.389	1.819
0.001	57.46	78.30	6.247	15.17	1.277	4.944	0.401	2.117
0.0005	100.2	137.7	8.413	21.26	1.426	6.027	0.409	2.413
0.0001	363.9	504.9	16.50	44.53	1.773	8.947	0.422	3.113

Limiting shear stress for a particle on a slope

$$\frac{(\tau_c)_\theta}{\tau_c} = \cos\theta\left(1 - \frac{Tan^2\theta}{Tan^2\phi}\right)^{\frac{1}{2}}$$

"Regime" formulae

$$\overline{U} = 0.635 \quad f^{\frac{1}{2}} R^{\frac{1}{2}}$$

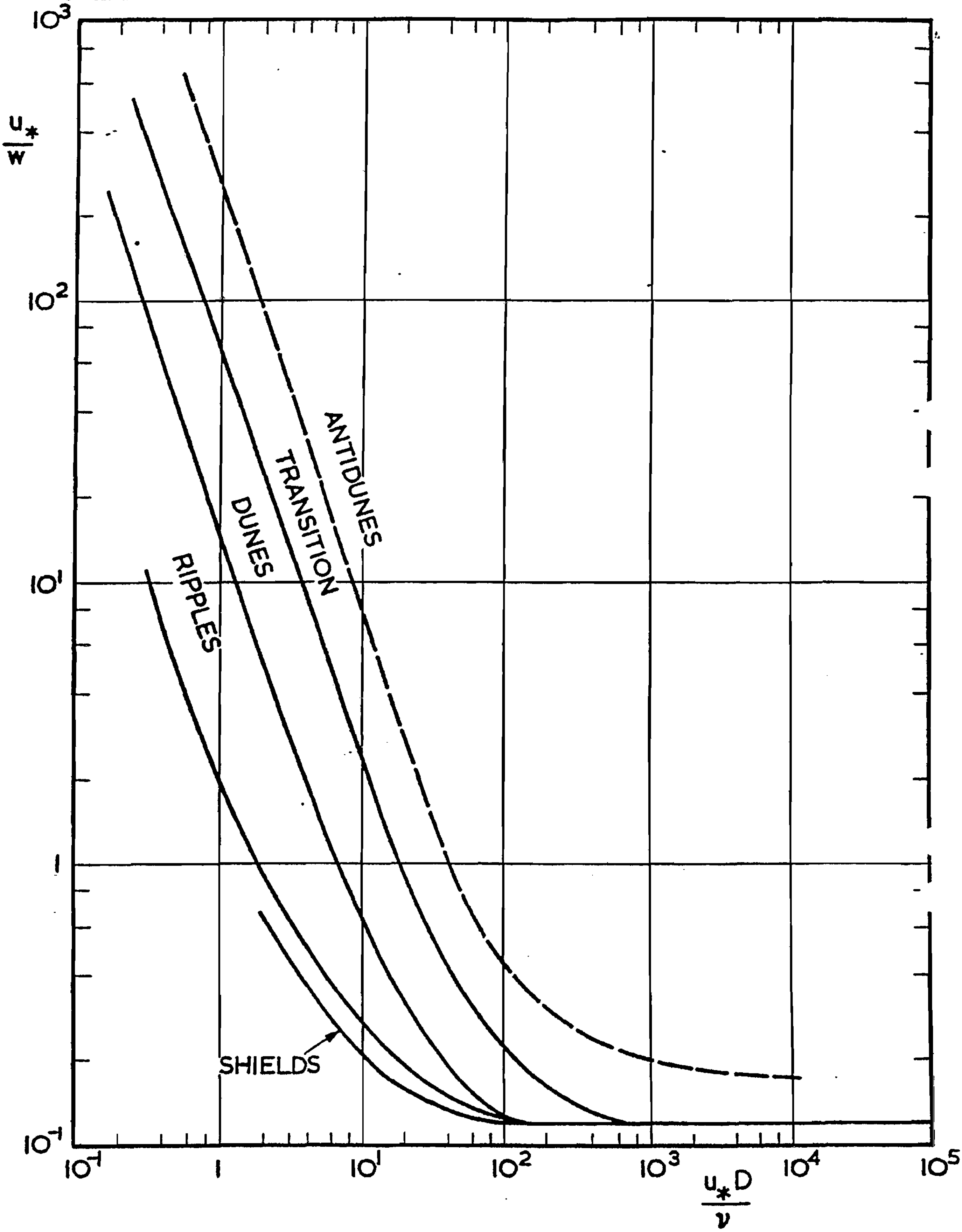
$$P = 4.83 \quad Q^{\frac{1}{2}}$$

$$R = 0.4725 \quad Q^{\frac{1}{3}} f^{-\frac{1}{3}}$$

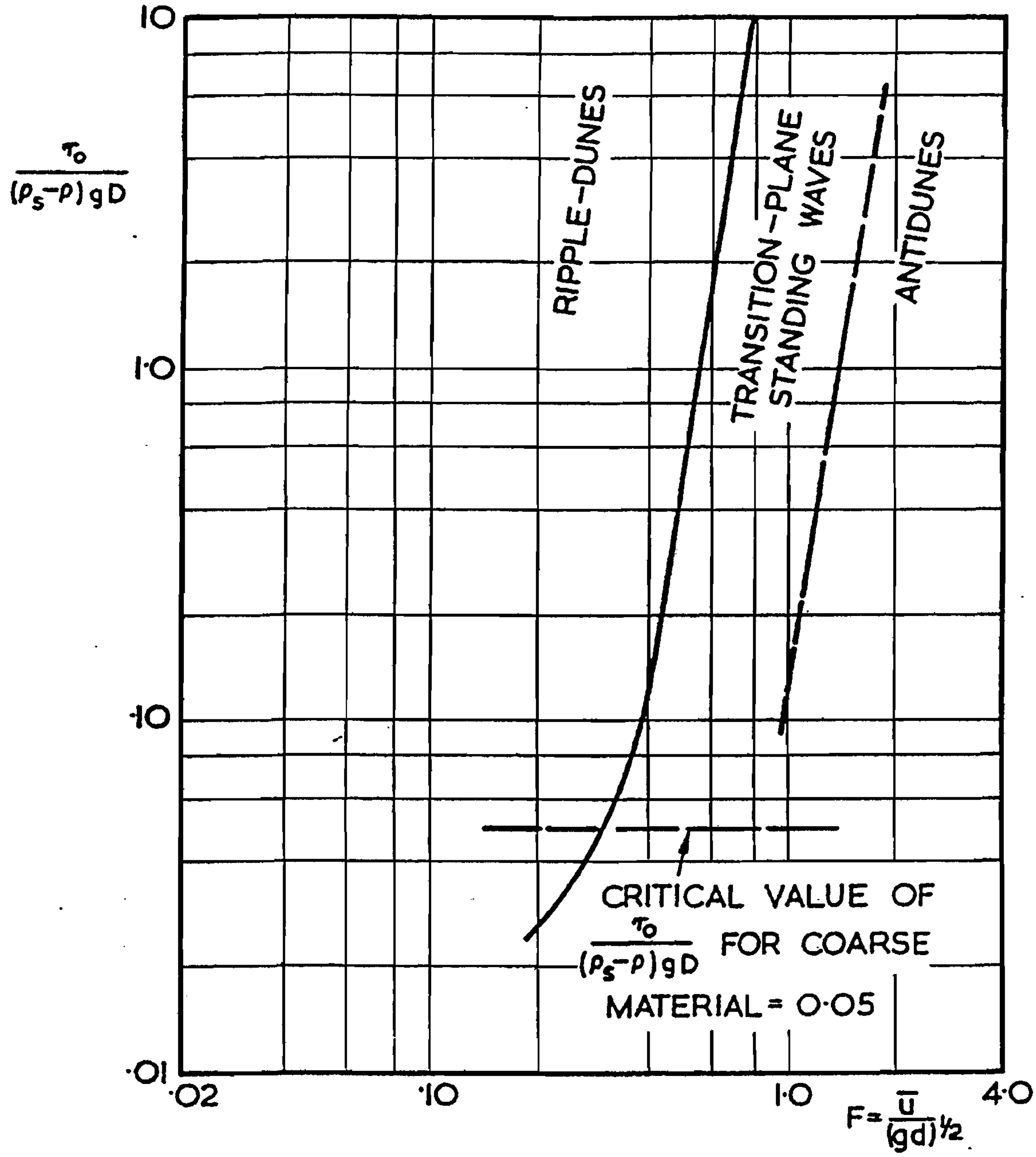
$$S = 0.000303 \quad f^{\frac{5}{3}} Q^{-\frac{1}{6}}$$

SYMBOLS

C	Concentration of sediment. Chezy roughness coefficient $\left(= (2g/C_f)^{1/2}\right)$
C_f	friction coefficient
D	grain size or body diameter
D_{65}	grain size for which 65% by weight of grains have a smaller diameter
f	Lacey silt factor
f_0, f_c	coefficients in f-capacity equation
h_r	ripple height
K	Karman constant
K_f	coefficient in f-capacity equation
k_s	roughness height
P	wetted perimeter of a channel
Q	total flow rate of water
R	hydraulic radius $(= A/P)$
S	channel slope
t	time
u	horizontal component of fluid velocity
$\overline{U}$	mean velocity
u_*	$(\tau_o/\rho)^{1/2}$
v	vertical component of fluid velocity
W	fall velocity
x,y	co-ordinates
θ	angle of a slope to the horizontal
φ	angle of repose of sediment
ν	kinematic viscosity
ρ	density of fluid
ρ_s	density of sediment
τ_o	shear stress on the bed
τ_c	critical value of τ_o for sand movement

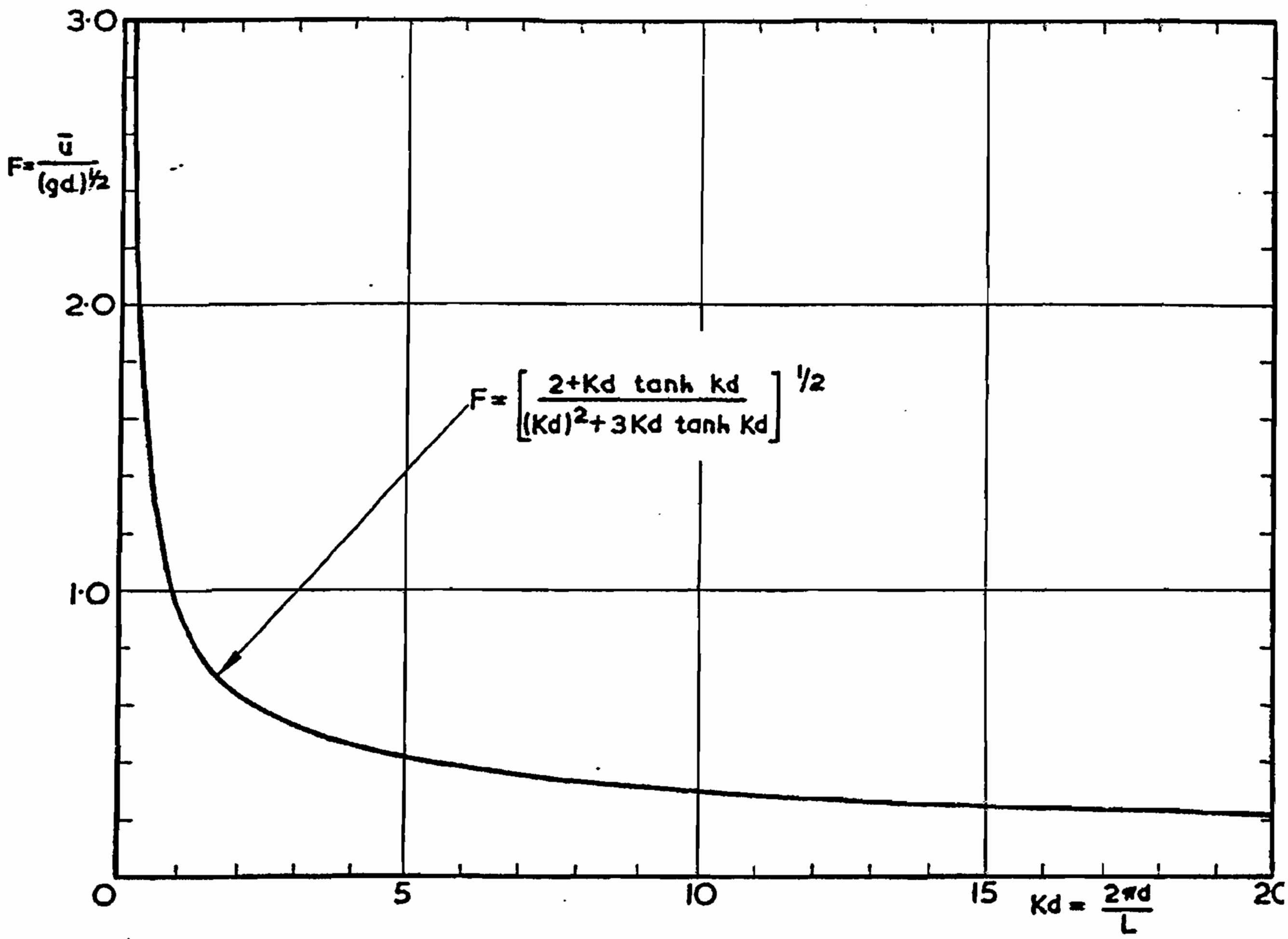


BED REGIMES IN OPEN CHANNEL FLOW (Albertson Simons & Richardson)

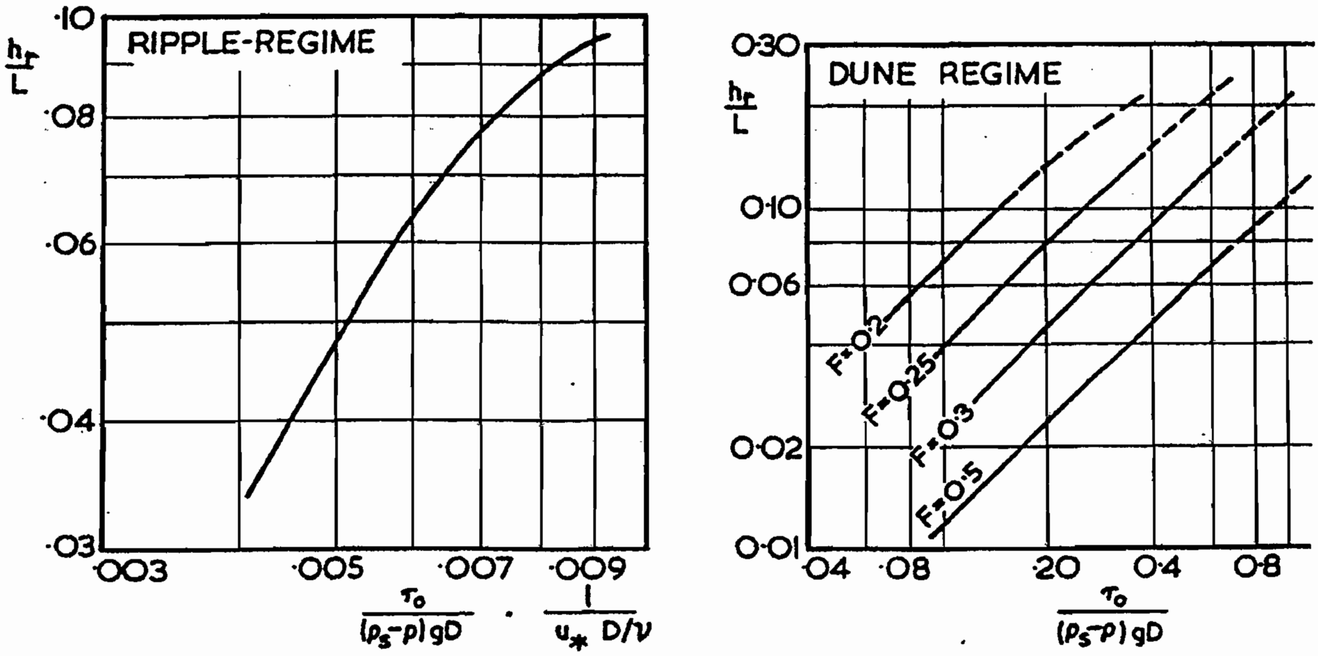


BED REGIMES IN OPEN-CHANNEL FLOW
(Garde & Albertson)

UNIVERSITY OF CAMBRIDGE



WAVELENGTH OF DUNES / ANTIDUNES (Kennedy)



RIPPLE / DUNE STEEPNESS (Garde & Albertson)

ENGINEERING TRIPOS PART IIA 2007
3D5: ENVIRONMENTAL ENGINEERING 1

Answers

1\. a) 1,4,5,5,7,8,10,10,9,7,7,6,5,5,4,3,4,0   and 8.33 m^3/s

2 174 seconds

3 a) 0.82 m/s
  b) 2.46 kg/s per metre width
  c) Dunes   (Albertson, Simons, Richardson)
      Ripple-dunes   (Garde and Albertson)

4 a) 17 litres/sec   and   5.33 kW
   b) 777 rpm   and   91p per day