M.E. (Water Resources & Hydraulic Engineering) Examination, 2025

(1st Semester)

FREE SURFACE FLOW

(Paper - Program Elective 1)

Time : Three Hours Full Marks : 100

Answer any ***five*** questions.

1. a) With the Help of the diagram show the variation of Y_1 and Y_2 in supercritical flow over a hump.

   b) A 3 m wide rectangular channel carries 3 m^3/s of water at a depth of 1.0 m. If the width is to be reduced to 2.0 m and bed raised by 10 cm, what would be the depth of flow in the contracted section? Neglect the loss of energy in transition. What maximum rise in the bed level of contracted section is possible without affecting the depth of flow upstream of transition.

5+15=20

2. a) Define the term Specific Energy

   b) In rectangular channel F_1 and F_2 are Froud number corresponding to the alternative depths of a certain discharge Show that

$$\left(\frac{F_2}{F_1}\right)^{\frac{2}{3}} = \frac{2 + {F_2}^2}{2 + {F_1}^2}$$

   c) Explain the concept of critical depth in open channel flow under a constant discharge situation.

3+12+5=20

3. (a) The following pressures were measured on a wall. Find the force per unit length of the wall, pressure coefficient at the base of the wall and force in excess of the hydrostatic value.

Distance below free Surface (mm)	Pressure of water (mm)
0	0
40	50
80	102
120	158
160	212
200 (Base of Wall)	255

   (b) Deduce the expression for calculating the equivalent roughness of a channel.

10+10=20

[Turn over

4. (a) A discharge of 0.056 m^3/s flows in a 0.45 m wide rectangular channel having smooth sides (n_w = 0.010) and a rough bottom. The depth of flow is 0.25 m. and S = 2.8 * 10^{-3}. Find the hydraulic radius with respect to the bed, bed shear stress, and roughness coefficient of the bed.
   (b) The velocity distribution in a semi-circular channel of diameter $2R_0$ follows the law $\frac{u}{U_0} = (\frac{y}{R_0})^{\frac{1}{7}}$ in which y is the distance normal to the surface at which the velocity is u and U0 is the velocity at the centre of the semi-circle. If R_0 = 1.5 m and U_0= 2.5 m/s. Calculate U, α and β 10+10=20

5. (a) Water having kinematic viscosity 1.1 * 10^{-6} m^2/s flows in a channel (effective roughness ks = 2 mm) of bottom width 4 m and side slope 1.25:1 (H:V) at a depth of 1 m and a slope of 1 * 10^{-4}. Find the mean velocity of flow and indicate whether the boundary is smooth, rough or in transition.
   (b) An alluvial stream has a constant slope of 1.1 * 10^{-3} and sediment of 0.30 mm diameter on the bed. Find the regime of flow that will be obtained when R = 0.15 m and when R = 0.60 m.
   10+10=20

6. a) Describe C and A type GVF profiles with neat sketches.
   b) In a rectangular channel three reaches A, B and C in series, with reach A being upstream of reach B, have the following characteristics.

Reach	Width	Discharge	Bed slope	Manning's coefficient
	(m)	(m^3/s)	(m/m)	(-)
A	3.3	10.0	0.0004	0.018
B	3.0	10.0	0.0160	0.011
C	2.7	10.0	0.0100	0.014

   Sketch the resulting water-surface profiles due to changes in the channel characteristics as above. The length of the reaches can be assumed to be sufficiently long for the GVF profiles to develop fully.

8+12 = 20

7. a) Find out the GVF differential equation by direct integration method.
   b) Derive the following relationship required for the Standard Step Method from the differential energy equation of GVF.

$$\Delta y_2 = \frac{-H_E}{\left[1+\left(1+C_e\right)F_2^2+\frac{5S_{f2}\Delta x}{3R_2}\right]}$$

   Assume proper notations, if required.

9+11 = 20

8. a) Show that for a wide rectangular channel the slope is mild or steep according to bed slop less than or greater than

$$\frac{n^2 g^{10/9}}{q^{2/9}}$$

b) In a wide river the depth of flow at a section is 3 m, bed slope is 1 in 5000 and discharge intensity is 3 m^3/s per meter width. If the Chezy formula with C = 70 is used, estimate the slope of the water surface relative to the bed at that section of the river.

c) Show that the differential equation of gradually varied flow in a rectangular channel of variable width B can be expresses as

$$\frac{dy}{dx} = \frac{S_0 - S_f + \left(\frac{Q^2 y}{gA^3}\frac{dB}{dx}\right)}{1 - \frac{Q^2 B}{gA^3}}$$

Further, show that for a horizontal, frictionless rectangular channel of varying width B, the above relation reduces to

$$\left(1 - \mathrm{Fr}^2\right)\frac{dy}{dx} - \mathrm{Fr}^2\left(\frac{y}{B}\right)\frac{dB}{dx} = 0$$

where Fr is Froude number.

TABLE 3A. 1 Values of ϕ For Trapezoidal Channels

$\phi = \left[\frac{nQ}{S_0^{1/2} B^{8/3}}\right]$, $\eta_0 = (y_0 / B)$,

η_0	Values of ϕ			
	$m = 0.00$	$m = 0.50$	$m = 1.00$	$m = 1.25$
0.100	0.019079	0.020428	0.021390	0.021785
0.105	0.020581	0.022112	0.023207	0.023659
0.110	0.022118	0.023845	0.025086	0.025599
0.115	0.023690	0.025627	0.027024	0.027603
0.120	0.025294	0.027457	0.029021	0.029671
0.125	0.026930	0.029334	0.031078	0.031803
0.130	0.028597	0.031256	0.033193	0.034000
0.135	0.030294	0.033224	0.035365	0.036259
0.140	0.032019	0.035237	0.037595	0.038582
0.145	0.033772	0.037293	0.039882	0.040968
0.150	0.035551	0.039393	0.042227	0.043416
0.155	0.037357	0.041536	0.044627	0.045927
0.160	0.039188	0.043721	0.047084	0.048501
0.165	0.041043	0.045947	0.049597	0.051137
0.170	0.042922	0.048215	0.052166	0.053835
0.175	0.044824	0.050523	0.054790	0.056596
0.180	0.046748	0.052872	0.057470	0.059419
0.185	0.048694	0.055261	0.060205	0.062304
0.190	0.050660	0.057689	0.062995	0.065251
0.195	0.052648	0.060157	0.065840	0.068260

η_0	Values of ϕ			
	m = 0.00	m = 0.50	m = 1.00	m = 1.25
0.200	0.054655	0.062663	0.068741	0.071331
0.205	0.056682	0.065208	0.071696	0.074465
0.210	0.058727	0.067791	0.074705	0.077661
0.215	0.060791	0.070412	0.077770	0.080919
0.220	0.062873	0.073070	0.080889	0.084239
0.225	0.064972	0.075766	0.084063	0.087622
0.230	0.067088	0.078499	0.087291	0.091067
0.235	0.069220	0.081268	0.090574	0.094575
0.240	0.071369	0.084074	0.093911	0.098146
0.245	0.073533	0.086916	0.097303	0.101779
0.250	0.075713	0.089795	0.100749	0.105476
0.255	0.077908	0.092709	0.104250	0.109235
0.260	0.080117	0.095659	0.107805	0.113057
0.265	0.082341	0.098645	0.111415	0.116943
0.270	0.084578	0.101666	0.115079	0.120892
0.275	0.086829	0.104722	0.118799	0.124905
0.280	0.089094	0.107813	0.122572	0.128981
0.285	0.091371	0.110939	0.126401	0.133121
0.290	0.093661	0.114100	0.130284	0.137325
0.295	0.095963	0.117295	0.134222	0.141593
0.300	0.098278	0.120525	0.138215	0.145925
0.310	0.102942	0.127087	0.146366	0.154784
0.320	0.107651	0.133786	0.154737	0.163901
0.330	0.112404	0.140620	0.163329	0.173280
0.340	0.117199	0.147589	0.172142	0.182920

η_0	Values of ϕ			
	m = 0.00	m = 0.50	m = 1.00	m = 1.25
0.600	0.252330	0.374808	0.482159	0.530843
0.610	0.257818	0.385301	0.497329	0.548183
0.620	0.263321	0.395925	0.512751	0.565834
0.630	0.268840	0.406678	0.528425	0.583796
0.640	0.274373	0.417563	0.544353	0.602071
0.650	0.279921	0.428578	0.560536	0.620662
0.660	0.285483	0.439724	0.576976	0.639569
0.670	0.291058	0.451001	0.593673	0.658796
0.680	0.296646	0.462410	0.610628	0.678343
0.690	0.302247	0.473950	0.627844	0.698212
0.700	0.307861	0.485622	0.645321	0.718406
0.710	0.313487	0.497427	0.663061	0.738925
0.720	0.319124	0.509363	0.681064	0.759773
0.730	0.324773	0.521432	0.699332	0.780949
0.740	0.330433	0.533634	0.717867	0.802458
0.750	0.336104	0.545968	0.736668	0.824299
0.760	0.341786	0.558436	0.755739	0.846475
0.770	0.347478	0.571038	0.775080	0.868988
0.780	0.353180	0.583773	0.794691	0.891839
0.790	0.358892	0.596643	0.814576	0.915030
0.800	0.364614	0.609647	0.834733	0.938564
0.810	0.370345	0.622785	0.855166	0.962441
0.820	0.376085	0.636059	0.875875	0.986664
0.830	0.381834	0.649467	0.896862	1.01123

9. a) Establish a relationship between the depths of flow upstream and downstream of hydraulic jump in terms of upstream Froude number (F_1). Depending on the value of upstream Froude number (F_1), explain when the flow in a channel is subcritical, critical and supercritical.

b) Establish a relationship to evaluate the loss of energy in hydraulic jump.

c) A spillway discharges a flood flow at a rate of 9.5 m^3/s per metre width. At the upstream horizontal apron the depth of flow was found to be 0.55 m. What tailwater depth is needed to form a hydraulic jump? If a jump is formed, find its (a) type of jump (b) head loss (c) energy loss as a percentage of the initial energy.

d) Water flows at a rate of 1.0×10^6 cm^3/s along a channel of rectangular section 1.75 m in width. Calculate the critical depth. If a hydraulic jump formed at a point where the upstream depth is 25 cm, what would be the rise in water level and power lost in the jump

8+4+4.5+3.5=20