

DEPARTMENT: CIVIL ENGINEERING
SEMESTER: IV- SEMESTER
SUBJECT CODE / Name: CE2253 / Applied Hydraulic Engineering

UNIT 1 OPEN CHANNEL FLOW

2 MARK QUESTIONS AND ANSWERS

1. Define open channel flow with examples.

Flow of liquid with a free surface (i.e., surface exposed to atmosphere) through any passage is known as open channel flow. The liquid flowing through any closed passage without touching the top can also be treated as open channels.

Examples:

1. Flow in natural waterfalls, river and streams
2. Flow in artificial or man-made channels such as irrigation channels and flumes.
3. Closed conduit or pipe carries liquid partially (sewers that carry domestic or industrial waste water). Generally, liquid flowing in open channel in water.

2. Explain laminar and turbulent flow.

(a) Laminar flow:

If Reynolds number of flow is less than 500, it is called as Laminar flow. The value of Reynolds number is between 500 and 2000, the flow is transitional.

(b) Turbulent flow:

For values of Reynolds number greater than 2000, the flow is turbulent.

3. What are the various types of flow in open channels?

The flow in open channel is classified into the following types:

- (a) Steady and unsteady flow
- (b) Uniform and non-uniform flow
- (c) Laminar and turbulent flow
- (d) Subcritical, critical and supercritical flow.

4. Define the term uniform flow.

If the depth of flow, slope of the bed of channel and cross section remain constant with respect to distance is called uniform flow.

$$\left(\frac{\partial y}{\partial s}\right) = 0, \quad \left(\frac{\partial V}{\partial s}\right) = 0$$

5. Define non uniform flow.

Flow properties, such as depth of flow, velocity of flow are not constant with respect to distance is called non uniform flow.

$$\left(\frac{\partial y}{\partial s}\right) \neq 0, \quad \left(\frac{\partial V}{\partial s}\right) \neq 0$$

6. Distinguish between steady and unsteady flow.

In steady flow, various characteristics of flowing fluids such as velocity, pressure, density, temperature etc. at a point do not change with time. In other words, a steady flow may be defined as that in which the various characteristics are independent of time. Mathematically it can be expressed as

$$\left(\frac{\partial u}{\partial t}\right) = 0, \quad \left(\frac{\partial v}{\partial t}\right) = 0 ; \quad \left(\frac{\partial w}{\partial t}\right) = 0$$

$$\left(\frac{\partial p}{\partial t}\right) = 0, \quad \left(\frac{\partial \rho}{\partial t}\right) = 0$$

In unsteady flow, various characteristics of flowing fluids such as velocity, pressure, density, etc. at a point change with respect to time.

Mathematically,

$$\left(\frac{\partial v}{\partial t}\right) \neq 0 \text{ and (or) } \left(\frac{\partial p}{\partial t}\right) \neq 0 \quad \dots \text{ etc}$$

Unsteadiness refers to the change of flow pattern with the passage of time at a position in the flow.

7. Explain the terms: (i) Gradually varied flow and (ii) Rapidly varied flow. [Anna Univ.Nov'07&Nov'08]

1. Gradually varied flow

If the depth of flow changes gradually over a long length of the channel, the flow is said to gradually varied flow (GVF)

2. Rapidly varied flow.

If the depth of flow changes rapidly over a small length of the channel, the flow is said to be rapidly varied flow.

8. Write down the formula for Froude number

$$\text{Froude Number } F = \frac{V}{\sqrt{gD}} < 1.0$$

Where

V = Average velocity of flow in m/s

g = Acceleration due to gravity = 9.81 m / s²

D = Hydraulic depth in meter

$$= \frac{\text{Cross Section Area of flow}}{\text{Top Width}} = \frac{A}{T}$$

9. Define hydraulic mean depth.

D = Hydraulic depth in meter

$$= \frac{\text{Cross Section Area of flow}}{\text{Top Width}} = \frac{A}{T}$$

10. Define specific energy. [Anna Univ. Nov'06 & Nov'08]

Specific energy of a flowing liquid is defined as energy per unit weight of a liquid with respect to the bottom of the channel. By a symbol *E*.

$$E = y + \frac{V^2}{2g}$$

Where

E = Specific Energy

V = Velocity of flow

y = Depth of flow

11. Define critical flow.

Depth of flow of water at which the specific energy, E is minimum is called as critical depth (y_c)

For rectangular channel, critical depth,

$$h_c = \left(\frac{q^2}{g} \right)^{\frac{1}{3}}$$

12. Define critical velocity.

Velocity of flow at the critical depth is called critical velocity V_c

$$V_c = \sqrt{g * y_c}$$

Where

y_c = Critical Depth

g = Acceleration due to gravity

13. Distinguish between critical, sub critical and subcritical flows.

Critical flow:

Depth of flow of water at which the specific energy is minimum is called as critical flow. Otherwise, flow corresponding to critical depth is called as critical flow.

For Critical Depth

$$\text{Froude Number } F = \frac{V}{\sqrt{gD}} = 1.0$$

Where D = Hydraulic Mean Depth

$$\frac{\text{Area of flow}}{\text{Top Width}} = \frac{A}{T}$$

Sub critical flow:

When the depth of flow in a channel is greater than the critical depth y_c , the flow is called as sub critical flow. It is otherwise, called as streaming flow or tranquil flow.

For sub critical flow, Froude number, $F < 1$

Sub critical flow:

When the depth of flow in a channel is less than the critical flow, y_c , the flow is called as sub critical flow or torrential flow. For supercritical flow,

Froude number, $F > 1$ **14. Differentiate prismatic and non-prismatic channels.****Prismatic channel**

Geometric dimensions of the channel, such as cross section and bottom slope are constant throughout the length of the channel is called as a prismatic channel. Eg. Most of the artificial channels of circular, rectangular, trapezoidal and triangular cross section are called prismatic channels.

Non- prismatic channel

Geometric dimensions of the channel, such as cross section and bottom slope are constant for length of the channel is called as a non-prismatic channel. Eg. All natural channels such as river, are non-prismatic channels.

15. Explain specific force (F_c) [Anna Univ. Nov'08]

Specific force is the sum of the pressure force (F) and momentum force due to flow (M) per unit weight of the liquid at a section.

$$\text{Specific Force} = F_s = \frac{F + M}{\gamma}$$

Where

$$\gamma = \text{weight density of Liquid}$$

16. What is specific energy and what is condition for obtaining only one depth for a given specific energy? [Anna Univ. May'07]

Total Energy on open channel flow

$$E = Z + y + \frac{V^2}{2g}$$

Considering the channel bed as datum line, $z = 0$

$$\text{Specific Energy } E = y + \frac{V^2}{2g}$$

From Specific Energy curve ,Corresponding to the Minimum specific energy $E_{(min)}$, there is only one depth of floe that is called Critical depth

17. Differentiate closed flow closed conduit flow and open channel flow. [Anna Univ. May'07]

S.No	Closed conduit flow	Open channel flow
1.	Water does not have with free surface.	Water flows with a free surface.
2.	Water does not contact with atmosphere pressure but it has only hydraulic pressure.	Water contents with atmospheric pressure.
3.	Flow may be due to either by pump pressure or by gravity flow	Flow is obtained only by gravity.

18. Define sub critical flow:

If the Froude number is less than one then the flow is said to be sub critical flow

19. Define critical flow:

If the Froude number is less equal to one it is called as critical flow.

20. Define supercritical flow:

If the Froude number is greater than one it is called as super critical flow

21. What are the possible types of flow in open channel with respect to space and time?

- A. steady and unsteady flow
- B. uniform and non-uniform flow

22. what do you know about uniform and non uniform flow?

Uniform flow: If the given length of the channel ,depth ,velocity ,the rate of flow, cross section are constant.

Non Uniform flow: If the given length of the channel ,depth ,velocity ,the rate of flow, cross section are not constant.

23. Define specific energy:

It is defined as energy per unit weight of the liquid with respect to the bottom of the channel.

24. Define critical depth:

It is defined as the depth of flow of water at which the specific energy is minimum.

25. Define critical velocity:

The velocity of flow at the critical depth is known as critical velocity.

26. Define gradually varying flow

If the change in depth in a varying flow is gradual so that the curvature of the streaming line is not excessive such flow is called gradually varying flow.

27. Define Rapidly varying flow

If the curvature in a varied flow is large and depth changes appreciably over short length it is called rapidly varying flow.

28. What are the conditions of rectangular channel of best section?

The two conditions are breadth is equal to two times the depth ($b=2d$)
and
hydraulic mean depth is equal to half the depth ($m=d/2$)

29. What do you mean by open channel flow?

1. Open channel flow has a free surface which is subjected to atmospheric pressure.
2. In open channel flow the cross section is irregular.

30. List the instrument used to measure open channel flow

1. pitot tube
2. ultrasonic flow instrument.
3. Dropper instrument
4. Gurley instrument.

31.What are the assumptions of gradually varying flow profile?

- 1.Pressure distribution at any section is assumed to be hydrostatic.
- 2.The velocity distribution at the channel section is fixed
- 3.The channel is prismatic
- 4.The roughness coefficient is independent of the depth of flow

32.What do you mean by specific energy curve?

It is defined as the curve which shows the variation of specific energy with respect to depth of flow.

33.Define open channel flow?

The term *open channel flow* denotes the gravity-driven flow of a liquid with a free surface.

34.What do you mean by stream lining?

Streamlining is adding a faired tail section to reduce the extent of separated flow on the downstream portion of an object .

35. What do you meant by Open channel flow? Give few Examples.

Open Channel Flow is defined as fluid flow with a free surface open to the atmosphere. Examples include streams, rivers and culverts not flowing full. Open channel flow assumes that the pressure at the surface is constant and the hydraulic grade line is at the surface of the fluid.

36. Define the term Critical depth

Depth of flow at which specific energy is a minimum; depth in a conduit at which maximum flow will occur if the conduit is at critical slope, the water is flowing at critical velocity, and an adequate supply of water exists.

37. What is meant by Critical Slope

The slope at which maximum flow will occur at minimum velocity; the slope equal to loss of head per foot resulting from flow at a depth giving uniform flow at critical depth.

38. Define the term Hydraulic Gradient

Pressure gradient, or a line representing pressure or piezometric head in a pipe flowing full, or the water surface in open channel flow.

39. What is meant by Hydraulic jump

A hydraulic jump is a phenomenon in the science of hydraulics which is frequently observed in open channel flow such as rivers and spillways. When liquid at high velocity discharges into a zone of lower velocity, a rather abrupt rise occurs in the liquid surface. The rapidly flowing liquid is abruptly slowed and increases in height, converting some of the flow's initial kinetic energy into an increase in potential energy, with some energy irreversibly lost through turbulence to heat. In an open channel flow, this manifests as the fast flow rapidly slowing and piling up on top of itself similar to how a shockwave forms

16 MARK QUESTIONS AND ANSWERS

1. Calculate the Specific energy, Critical depth and the velocity of the flow of $10 \text{ m}^3/\text{s}$ in a cement lined rectangular channel 2.5m wide with 2 m depth of water. Is the given flow is sub critical or super critical

Given Data

$$Q = 10 \text{ m}^3/\text{s}$$

$$b = 2.5 \text{ m}$$

$$y = 2 \text{ m}$$

SOLUTION:

- To find
1. Specific Energy
 2. Critical Depth
 3. Velocity for the flow

STEP 1: To find the Specific Energy:

$$E = y + \frac{V^2}{2g} \qquad V = \frac{Q}{A} = \frac{10}{2.5 * 2} = 2 \text{ m / s}$$

$$E = 2 + \frac{2^2}{2 * 9.81}$$

$$E = 2 + 0.20 \text{ m}$$

$$E = 2.20 \text{ m}$$

STEP 2: To find Critical Depth:

$$y_c = \left(\frac{q^2}{g} \right)^{\frac{1}{3}}$$

$$= \left(\frac{4^2}{9.81} \right)^{\frac{1}{3}}$$

$$= 1.18 \text{ m}$$

$$q = \frac{Q}{b} = \frac{10}{2.5} = 4 \text{ m}^2 / \text{s}$$

STEP 3: Velocity of flow:

$$\begin{aligned}V_c &= \sqrt{g * y_c} \\&= \sqrt{9.81 * 1.18} \\&= 3.4 \text{ m / s}\end{aligned}$$

STEP 3: To find weather the flow is Sub critical of Super critical:

$$\begin{aligned}F &= \frac{V}{\sqrt{g * D}} \\&= \frac{2}{\sqrt{9.81 * 2}} \\&= 0.45 < 1.0\end{aligned}$$

Hence the flow is Sub-critical

2. A Trapezoidal channel has a bottom width of 6.1 m and side Slopes of 2 H : 1 V .When the depth of the flow is 1.07 m. The flow is 10.47 m³/s. What is the Specific energy of flow? Is the Flow is sub critical or super critical

Given Data

$$\begin{aligned}b &= 6.1 \text{ m} \\m &= 2 \text{ m} \\Q &= 10.47 \text{ m}^3/\text{s}\end{aligned}$$

SOLUTION:

To find 1. Specific Energy
 3. Flow is tranquil or Rapid

STEP 1: To find the Specific Energy:

$$\begin{aligned}A &= (b + my) y \\&= (6.1 + 2 * 1.07) 1.07 \\&= 8.82 \text{ m}^2\end{aligned}$$

$$V = \frac{Q}{A}$$

$$= \frac{10.47}{8.82}$$

$$= 1.19 \text{ m/s}$$

$$E = y + \frac{V^2}{2g}$$

$$E = 1.07 + \frac{1.19^2}{2 * 9.81}$$

$$E = 1.14 \text{ m}$$

STEP 3: To find weather the flow is Sub critical of Super critical:

$$F = \frac{V}{\sqrt{g * D}}$$

$$\left(D = \frac{A}{T} \right)$$

$$A = (b + my) y = (6.1 + 2 * 1.07) 1.07 = 8.82 \text{ m}^2$$

$$T = (b + 2my) = (6.1 + 2 * 2 * 1.07) = 10.38 \text{ m}$$

$$D = \frac{8.82}{10.38}$$

$$D = 0.85 \text{ m}$$

$$= 0.45 < 1.0$$

Finally we can get

$$F = \frac{1.19}{\sqrt{9.81 * \frac{8.82}{10.38}}}$$

$$F = 0.41 < 1.0$$

Hence the flow is Tranquil flow or Sub-Critical Flow

3. Calculate the Specific Energy of $12 \text{ m}^3/\text{s}$ of water flowing with a velocity of $1.5 \text{ m}^3/\text{s}$ in a Rectangular channel 8 m wide. Find the depth of water in the channel when the Specific energy would be minimum. What would be the value of Critical as well minimum Specific Energy

Given Data

$$V = 1.5 \text{ m / s}$$

$$m = 2 \text{ m}$$

$$b = 8 \text{ m}$$

SOLUTION:

- To find**
1. Specific Energy
 2. Critical velocity
 3. minimum Specific Energy

STEP 1: To find the Specific Energy:

$$Q = V * A \qquad A = \frac{Q}{V} = b * d = \frac{Q}{V}$$

note

$$d = \frac{Q}{V * b}$$

$$A = b * d$$

$$b = \frac{12}{1.5 * 8} = 1 \text{ m} = y$$

We Know that $b = y$, Finally we Will Get

$$\begin{aligned} E &= y + \frac{V^2}{2g} \\ &= 1.0 + \frac{1.5^2}{2 * 9.81} \\ &= 1.115 \text{ m} \end{aligned}$$

Critical Depth (h_c) is given by (y_c)

$$y_c \text{ (or) } h_c = \left(\frac{q^2}{g} \right)^{\frac{1}{3}}$$

note

$$q = \frac{Q}{b} = \frac{12}{8} = 1.5 \text{ m}^2 / \text{s}$$

$$= \left(\frac{1.5^2}{9.81} \right)^{\frac{1}{3}}$$
$$= 0.612 \text{ m}$$

STEP 2: To find the Critical velocity V_c :

$$V_c = \sqrt{g * y_c}$$
$$= \sqrt{9.81 * 0.612}$$
$$= 2.45 \text{ m / s}$$

STEP 3: To find the minimum Specific Energy:

$$E_{\min} = \frac{3}{2} y_c$$
$$E_{\min} = \frac{3}{2} * 0.612$$
$$= 0.918 \text{ m}$$

4. A 8 m wide Channel conveys 15 cumecs of water at a depth of 1.2 m. Determine the
- (1) Specific energy of the flowing water
 - (2) Critical depth, Critical velocity and minimum Specific Energy
 - (3) Froude number and the weather flow is sub-critical or Super-critical

Given Data

$$V = 1.5 \text{ m / s}$$
$$m = 2 \text{ m}$$
$$b = 8 \text{ m}$$

SOLUTION:

To find

- (1) Specific energy of the flowing water
- (2) Critical depth, Critical velocity and minimum Specific Energy
- (3) Froude number and the weather flow is sub-critical or Super-critical

STEP 1: To find the Specific Energy:

$$\begin{aligned}V &= \frac{Q}{A} \\&= \frac{15}{8 * 1.2} \\&= 1.563 \text{ m / s}\end{aligned}$$

$$\begin{aligned}E &= y + \frac{V^2}{2g} \\&= 1.2 + \frac{1.563^2}{2 * 9.81} \\&= 1.32 \text{ m}\end{aligned}$$

Step 2: To find Critical Depth

$$q = \frac{Q}{b} = \frac{15}{8} = 1.875 \text{ m}^2 / \text{s}$$

$$y_c = \left(\frac{q^2}{g} \right)^{\frac{1}{3}}$$

$$y_c = \left(\frac{1.875^2}{9.81} \right)^{\frac{1}{3}}$$

$$= 0.71 \text{ m}$$

Step 3 :To find Critical Velocity

$$\begin{aligned}V_c &= \sqrt{g * y_c} \\&= \sqrt{9.81 * 0.71} \\&= 2.63 \text{ m / s}\end{aligned}$$

Step 4 :To Minimum Specific Energy:

$$\begin{aligned}E_{\min} &= \frac{3}{2} y_c \\E_{\min} &= \frac{3}{2} * 0.71 \\&= 1.06 \text{ m}\end{aligned}$$

Step 5 :To find the Froude Number:

$$F = \frac{V}{\sqrt{gD}} = \frac{V}{\sqrt{gy}}$$

note

$$D = \frac{A}{T} = \frac{b * y}{b} = y$$

$$\begin{aligned}&= \frac{1.563}{\sqrt{9.81 * 1.2}} \\&= 0.455 < 1.0\end{aligned}$$

Hence the Flow is Sub-Critical

5. Find the critical depth for a specific energy of 1.5 m in:

(1) Rectangular channel of bottom width 2m

(2) Triangular channel of side slope 1:1.5

Given Data

$$E = 1.5 \text{ m}$$

SOLUTION:

To find critical depth for

Rectangular Trapezoidal and Triangular Channel

Step 1 :Rectangular Channel:

$$E = \frac{3}{2} y_c$$

$$E * \frac{2}{3} = y_c$$

$$\frac{1.5 * 2}{3} = y_c$$

$$y_c = 1.0 \text{ m}$$

Step 2 :Triangular Channel:

$$E = \frac{5}{4} y_c$$

$$E * \frac{4}{5} = y_c$$

$$\frac{1.5 * 4}{5} = y_c$$

$$y_c = 1.20 \text{ m}$$

6. A Trapezoidal channel with side slope of 2H:3V Has to carry $20 \text{ m}^3/\text{s}$. Find the slope of the channel when the bottom width of the channel is 4 m and the depth of the water is 3 m .Take manning's $n=0.03$

Given Data

$$\begin{aligned}b &= 4 \text{ m} \\y &= 3 \text{ m} \\m &= 2 \text{ m} \\Q &= 20 \text{ m}^3/\text{s} \\n &= 0.03\end{aligned}$$

SOLUTION:

To find Slope of the trapezoidal Channel

$$\begin{aligned}A &= (b + my) y \\&= (4 + 2 * 3) 2 \\&= 30 \text{ m}^2\end{aligned}$$

$$\begin{aligned}P &= (b + 2my) \\&= (4 + 2 * 2 * 3) \\&= 16 \text{ m}\end{aligned}$$

$$R = \frac{A}{P}$$

$$= \frac{30}{16}$$

$$= 1.875 \text{ m}$$

Use manning's constant Formulae

$$C = \frac{1}{N} R^{\frac{1}{6}}$$

$$= \frac{1}{0.03} (1.875)^{\frac{1}{6}}$$

$$= 36.49$$

To find the Slope of the Channel

$$Q = AC\sqrt{RS}$$

$$= 18 * 36.49 \sqrt{1.875 * S}$$

Take Square root on Both Sides

$$400 = 324 * 1369 * 1.875 * S$$

$$400 = 832117.11 * S$$

$$S = \frac{400}{832117.11}$$

$$= 0.00048$$

$$S = \frac{1}{2080}$$

This is the required Slope range for the given Trapezoidal Channel.

Problem 7.0 A rectangular channel has a width of 2.0 m and carries discharge of 4.80 m³/s with a depth of 1.60 m. At a section a small smooth hump with a flat top of height 0.10 m is proposed. Neglecting energy loss, calculate the likely change in water surface level.

Solution:

$$Q = 4.80 \text{ m}^3/\text{s} \quad B = 2.0 \text{ m}; \quad y_1 = 1.60 \text{ m}$$

$$\therefore V_1 = \frac{Q}{B y_1} = \frac{4.80}{2 \times 1.60} = 1.5 \text{ m/s}$$

$$\therefore \frac{V_1^2}{2g} = \frac{1.5^2}{2 \times 9.81} = 0.115 \text{ m.}$$

$$F_1 = \frac{V_1}{\sqrt{g y_1}} = \frac{1.5}{\sqrt{9.81 \times 1.6}} = 0.379 < 1$$

and hence flow is subcritical
and therefore hump will cause
a drop in depth of flow.

$$E_1 = 1.6 + 0.115 = 1.715 \text{ m.}$$

At section (2) - (2)

$$E_2 = E_1 - \Delta Z = 1.715 - 0.10 = 1.615 \text{ m.}$$

$$y_c = \left[\frac{q^2}{g} \right]^{1/3} ; q = \frac{Q}{B} = \frac{4.80}{2.0} = 2.4 \text{ m}^3/\text{s}/\text{m}$$

$$= \left[\frac{2.4^2}{9.81} \right]^{1/3} = 0.837 \text{ m.}$$

$$\therefore E_c = \frac{3}{2} y_c = 1.5 \times 0.837 = 1.256 \text{ m.}$$

$$\text{As } E_c < E_2$$

$$y_2 > y_c$$

$$y_2 + \frac{V_2^2}{2g} = E_2$$

$$y_2 + \frac{q^2}{2g y_2} = 1.615$$

$$y_2 + \frac{2.4^2}{2 \times 9.81 \times y_2^2} = 1.615$$

By trial and error, $y_2 = 1.481 \text{ m.}$

Problem 8.0 In the previous prob. if the height is 0.5 m estimate the depth of flow over the hump and at a section before the hump.

(b) Estimate the minimum size of the hump to cause critical flow over the hump.

Solution:

Previous problem: $F_1 = 0.379$; $E_1 = 1.715$ m

$$y_c = y_{c_2} = 0.837 \text{ m.}$$

$$\begin{aligned} \text{At section (2) - (2). } E_2 &= E_1 - \Delta z \\ &= 1.715 - 0.5 = 1.215 \text{ m.} \end{aligned}$$

$$E'_2 = 1.5 y_{c_2} = 1.5 \times 0.837 = 1.256 \text{ m.}$$

As the minimum specific energy at section (2) - (2) $> E_2$,

Hence, depth at section (2) - (2) will be $y_2 = y_{c_2} = 1.256$ m.

$$E'_1 = E_{c_2} + \Delta z$$

$$Y'_1 + \frac{V_1'^2}{2g} = E_{c_2} + \Delta z$$

$$Y'_1 + \frac{q^2}{2g y_1'^2} = 1.256 + 0.5 = 1.756$$

$$Y'_1 + \frac{(2.4)^2}{2 \times 981 \times y_1'^2} = 1.756$$

$$Y'_1 + \frac{0.2936}{y_1'^2} = 1.756.$$

By trial and error, selecting +ve roots which gives

$$y'_1 > y_2$$

We have $Y'_1 = 1.648$ m $> y_1$

(b) $F_1 = 0.379$; $Y_1 = 1.6$ m using eqn. (1.20)

$$\frac{\Delta Z_m}{y_1} = \left[1 + \frac{F_1^2}{2} - \frac{3}{2} F_1^{2/3} \right]$$

$$\frac{\Delta Z_m}{1.6} = \left[1 + \frac{0.379^2}{2} - \frac{3}{2} (0.379)^{2/3} \right] = 0.2866$$

$$\therefore \Delta Z_m = 1.6 \times 0.2866 = 0.459 \text{ m}$$

Another method:

$$\Delta Z_m = E_1 - E_c = 1.715 - 1.256 = 0.459 \text{ m}$$

9. How do you classify open channels? Explain in detail. Also explain the velocity distribution in open channel. (AUC Nov/Dec 2010)

Flow takes place through a passage which may be river, canal, channel, drain etc., Rivers are naturally formed water courses, whereas channels, canals, channels and drainage pipes are designed by engineers to carry water for specific purposes. Common to all the above water courses are (1) There is free surface over water (2) and there is air above the free surface at atmospheric pressure. Even in a closed conduit if the flow is not full – it is a channel flow. Ganga, Cauvery are also open channels.

Availability or source of water may be at one place and place of necessity or utilisation may be at a different place and therefore engineers plan & design these water ways at an economical cost with maximum benefit to the society.

In all the above natural or artificial channels there will be bed slope as water can flow from a higher altitude to lower altitude only and is due to gravity and is similar to motion along an inclined plane.

TYPES OF CHANNELS:



A prismatic channel has the cross section shape and size and bed slope along the length of the channel constant. Engineers design usually channels with rectangular, trapezoidal triangular and circular channels. All natural channels and rivers have varying cross section and bed slopes. The cross section and bed slopes of river Cauvery are different at Metur, Trichy and Kumbakonam and hence are non-prismatic.

CLASSIFICATION OF FLOWS IN AN OPEN CHANNEL:

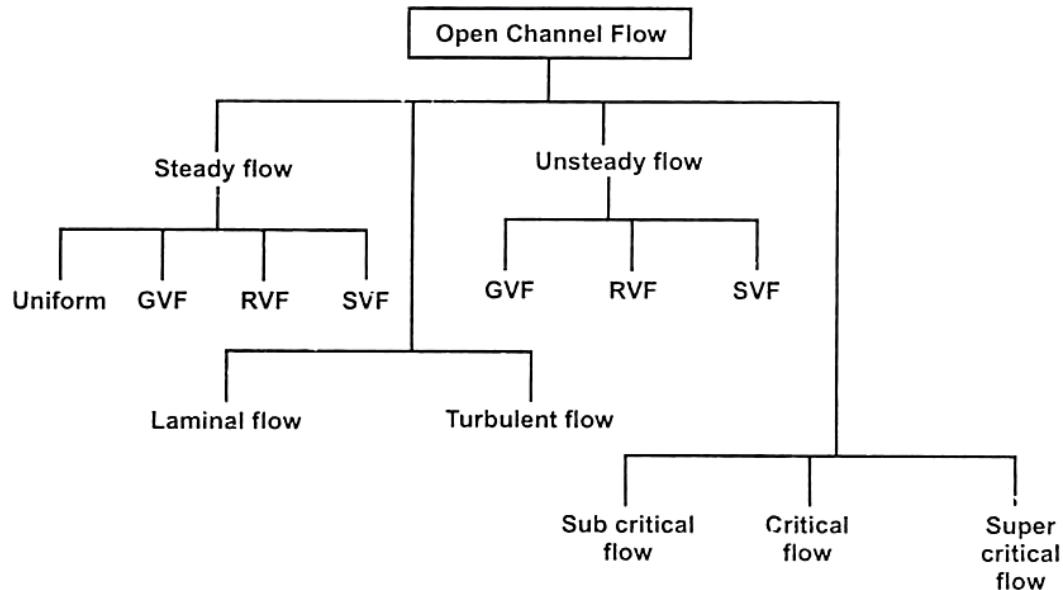


Fig. 1.2

1. Steady flow and unsteady flow:

In a steady flow there is no 'temporal' change in (i) depth of flow (ii) velocity of flow and (iii) rate of discharge in with respect to time at the same point.

\therefore At any point in a channel with usual notations we can say $\frac{\partial V}{\partial t} = 0$; $\frac{\partial y}{\partial t} = 0$;
 $\frac{\partial Q}{\partial t} = 0$.

In an unsteady flow at any point in the channel, the depth of flow, velocity of flow or rate of flow may change with respect to time.

$$\therefore \frac{\partial V}{\partial t} \neq 0; \frac{\partial y}{\partial t} \neq 0; \frac{\partial Q}{\partial t} \neq 0.$$

2. Uniform flow and non-uniform flow:

At any particular time, at different points along the length of the channel, if the (i) depth of flow (ii) velocity of flow (iii) slope of channel and (iv) discharge rate are constant, it is said to be a uniform flow and if otherwise the flow is a non-uniform flow.

$$\text{For uniform flow, } \frac{\partial y}{\partial s} = 0; \frac{\partial v}{\partial s} = 0$$

2. Uniform flow and non-uniform flow:

At any particular time, at different points along the length of the channel, if the (i) depth of flow (ii) velocity of flow (iii) slope of channel and (iv) discharge rate are constant, it is said to be a uniform flow and if otherwise the flow is a non-uniform flow.

$$\text{For uniform flow, } \frac{\partial y}{\partial s} = 0; \frac{\partial v}{\partial s} = 0$$

$$\text{For non-uniform flow } \frac{\partial y}{\partial s} \neq 0; \frac{\partial v}{\partial s} \neq 0$$

3. Varied flow:

Non-uniform flow is called as VARIED FLOW.

Varied flow is classified into two types

- (i) Gradually varied flow – GVF
- (ii) Rapidly varied flow – RVF.

In a gradually varied flow (GVF) the depth of flow changes gradually over a long length of the channel.

If the depth of flow changes suddenly within a short length of the channel it is called rapidly varied flow (RVF). The following sketch is self explanatory.

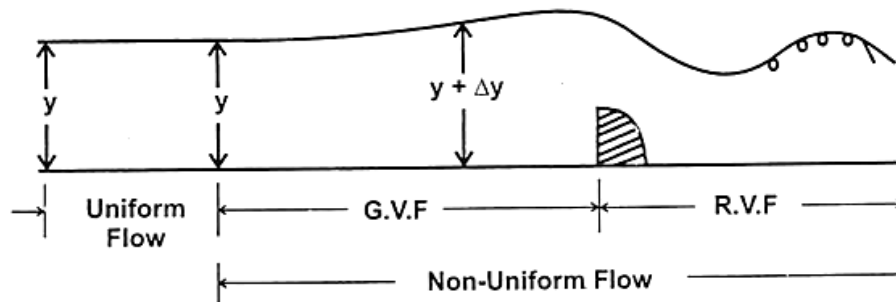


Fig. 1.3

4. Laminar flow and turbulent flow:

In an open channel flow although there is no viscous flow, it is classified according to the Reynolds number $Re: \frac{\rho V R}{\mu}$

where R = Hydraulic mean depth or hydraulic radius.

$$R = \frac{A}{P} = \frac{\text{Area of C.S.}}{\text{wetted perimeter}}$$

$R_e > 2000 \rightarrow$ Turbulent flow

$500 < R_e < 2000 \rightarrow$ Transition state

$R_e < 500 \rightarrow$ Laminar flow.

5. Sub-Critical, Critical, Super Critical Flow:

This classification is based on Froude Number. F_e

$F_e = \frac{V}{\sqrt{gD}}$ where D is hydraulic depth of channel equal to $\frac{\text{Area of C.S}}{\text{Top width of flow}}$

$\therefore D = \frac{A}{T}$ when T is the top width of flow of water.

$F_e < 1.0 \rightarrow$ Sub-critical flow.

$F_e = 1.0 \rightarrow$ Critical flow

$F_e > 1.0 \rightarrow$ Super critical flow

10. Write short notes on the following:

(i) Critical flow and its computations

(ii) Channel Transition

(AUC Nov/Dec 2010)

1. Critical flow and its computations

i) Critical flow:

Depth of flow of water at which the specific energy is minimum is called as critical flow. Otherwise, flow corresponding to critical depth is called as critical flow.

For Critical Depth

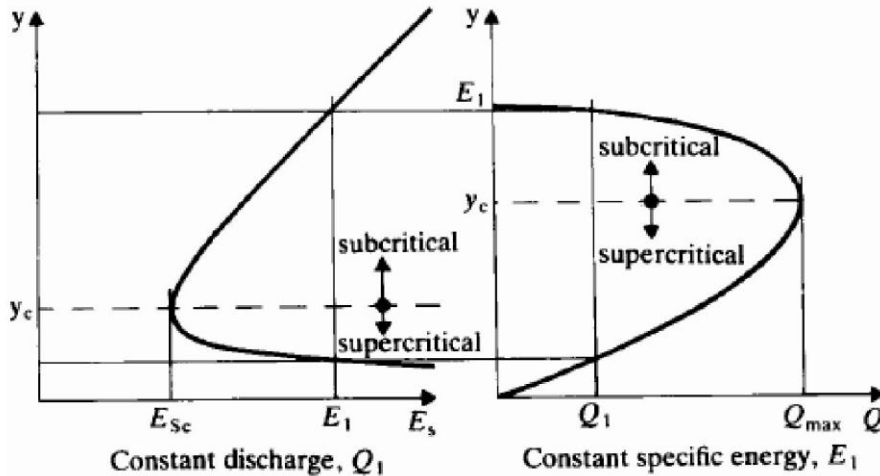
$$\text{Froude Number } F = \frac{V}{\sqrt{gD}} = 1.0$$

Where $D = \text{Hydraulic Mean Depth}$

ii) Sub critical flow:

When the depth of flow in a channel is greater than the critical depth y_c , the flow is called as sub critical flow. It is otherwise, called as streaming flow or tranquil flow.

For sub critical flow, Froude number, $F < 1$



iii) Sub critical flow:

When the depth of flow in a channel is less than the critical flow, y_c , the flow is called as sub critical flow or torrential flow. For supercritical flow, Froude number, $F > 1$

2.Channel Transition:

Change in channel shape, having a hump or depression in the bed or change in width either in the form of contraction or expansion or combination of above are all called transition.

1. Effect of Transition on open channel flow:

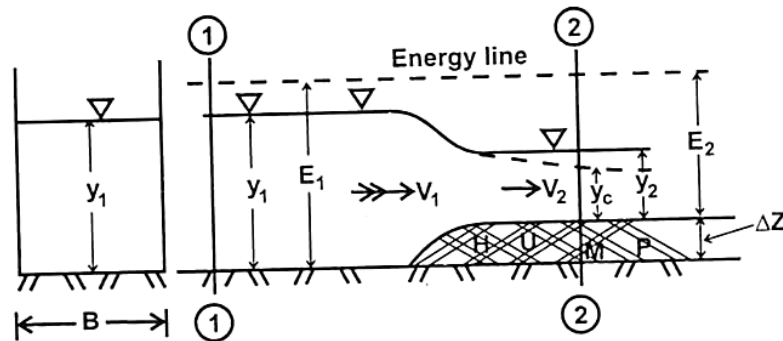
In subcritical flow transitions are designed to provide smooth and gradual changes in the boundary in order to prevent flow separation and energy losses.

In supercritical flows, shock wave related disturbances are to be suppressed in the transition. Simple transitions in rectangular channels are dealt with hereunder for illustration purpose.

2. Hump in the channel:

A small rise in a bed of channel at a point along the length of channel is known as 'hump'. The effect of this sort of hump in (a) subcritical flow, (b) critical flow and subcritical flow are illustrated below.

3. Hump present in a sub-critical flow:



4. Hump in a critical flow:

1.7.4(a) Friction not being considered:

So it is a smooth frictionless hump of height ΔZ in a rectangular channel with sub-critical flow.

Considering sections (1) - (1) & (2) - (2), we have

$$E_1 = E_2 + \Delta Z \quad \dots (1.19)$$

Value of $\Delta Z > \Delta Z_{\max}$ would cause critical flow.

$$\therefore \Delta Z = \Delta Z_{\max}; E_1 = E_c + \Delta Z_{\max}.$$

$$\therefore E_2 = E_c = \frac{3}{2} y_c$$

$$\frac{\Delta Z_{\max}}{y_1} = \left[1 + \frac{F_1^2}{2} - \frac{3}{2} \left(\frac{q^2}{g} \right)^{1/3} \times \frac{1}{y_1} \right]$$

$$\frac{\Delta Z_{\max}}{y_1} = \left[1 + \frac{F_1^2}{2} - \frac{3}{2} F_1^{2/3} \right] \quad \dots (1.20)$$

4(b) Friction taken into account:

Let h_L be the head loss due to friction equal to the energy loss pressure per unit weight expressed as head.

\therefore Eqn. (1.19) becomes

$$E_1 = E_2 + \Delta Z + h_L \quad \dots (1.21)$$

adopting the same procedure we have

$$\left[\frac{\Delta Z_{\max}}{y_1} + \frac{h_L}{y_1} \right] = \left[1 + \frac{F_1^2}{2} - \frac{3}{2} F_1^{2/3} \right]$$

which gives energy loss in transition due to friction when a hump is introduced in the down stream of a channel.

5. Hump in supercritical flow:

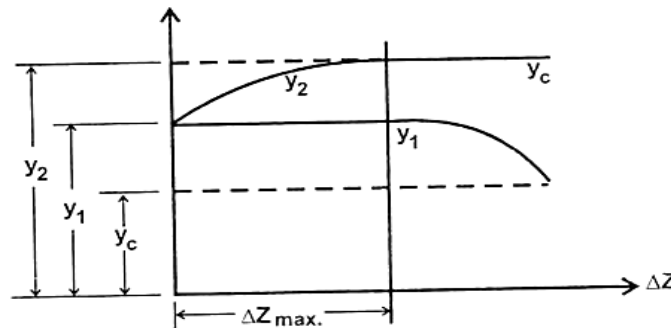
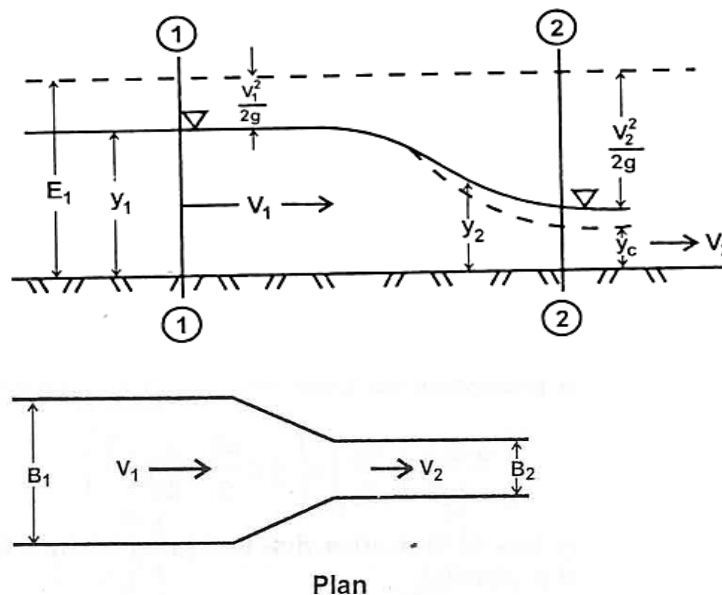


Fig. 1.12

Where y_1 is in super critical region where there is decrease of specific energy, there will be increase in y_1 . y_2 increases to y_c at $\Delta Z = \Delta Z_{\max}$

The depth of flow over the hump will remain constant and equal to y_c and y_1 changes to have higher specific energy E'_1 . This variation is shown in fig. 1.12

6. Transition in an open channel due to contraction or expansion due to change in width:



Case (i) Subcritical flow – frictionless channel.

Section (1) – (1) Width B_1 ; Discharge Q , depth of flow y_1 ; velocity $= V_1$

Section (2) – (2) Width reduces to b_2 , Q remains same No losses; velocity increases to V_2 .

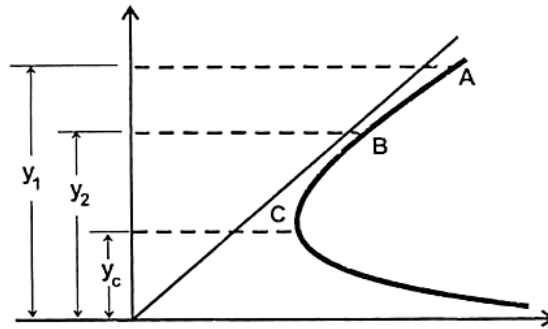
$$\therefore E_1 = y_1 + \frac{V_1^2}{2g} = y_1 + \frac{Q^2}{2g B_1^2 y_1^2} = y_1 + \frac{q_1^2}{2g y_1^2} \left[\because q_1 = \frac{Q}{B_1} \right]$$

$$E_2 = y_2 + \frac{V_2^2}{2g} = y_2 + \frac{Q^2}{2g B_2^2 y_2^2} = y_2 + \frac{q_2^2}{2g y_2^2} \left[\because q_2 = \frac{Q}{B_2} \right]$$

But $q_2 > q_1$ ($\because B_2 < B_1$)

In a frictionless flow as energy $E_1 = E_2$, y_2 becomes less than y_1

In the specific energy curve point A corresponding q_1 moves to point B corresponding to q_2 .



Case (ii) Critical flow.

When flow tends to be critical at section (2) – (2).

$y_2 \rightarrow y_c$ when q_2 becomes equal to q_m which will be the max. discharge intensity $\left(\frac{Q}{B} = q_m \right)$ for a specific energy considered at a minimum width and point A moves to C.

$$\therefore E_1 = E_{c \max} = y_{c \max} + \frac{Q^2}{2g B_{2 \max}^2 y_{cm}^2}$$

$$y_c = \frac{2}{3} E_c$$

$$y_2 = y_{cm} = \frac{2}{3} E_1$$

11. Define specific energy. How would you express the specific energy for a wide rectangular channel with depth of flow 'D' and velocity of flow 'V'? Draw the typical specific energy diagram and explain its features.

It is defined as energy per unit weight of the liquid with respect to the bottom of the channel. The extra information needed to solve the above problem can be provided by the *specific energy equation*. Specific energy, E_s , is defined as the energy of the flow with reference to the channel bed as the datum:

Total Energy on open channel flow

$$E = Z + y + \frac{V^2}{2g}$$

Considering the channel bed as datum line, $z = 0$

$$\text{Specific Energy } E = y + \frac{V^2}{2g}$$

From Specific Energy curve, Corresponding to the Minimum specific energy $E_{(min)}$, there is only one depth of flow that is called Critical depth

In analysing flow problems and defining critical depth, the understanding of specific energy is very useful.

In computing the total energy of flow, if the bed of the channel is taken as Datum, then the total energy of flow per unit weight will be the sum of the pressure head and velocity head. This sum is known as specific energy and is represented as

$$E = y + \frac{V^2}{2g}$$

for uniform flow E is constant

for varied flow E may decrease or increase. If bed slope i and energy correction factor α are to be included then equation (1.7) becomes

$$E = y \cos i + \alpha \frac{V^2}{2g}$$

for constant discharge through an open channel

$$E = y + \frac{Q^2}{2g A^2}$$

$E = f(y, Q)$ and when Q becomes constant,

$E = f(y)$ is represented by a cubic parabola as shown in fig.

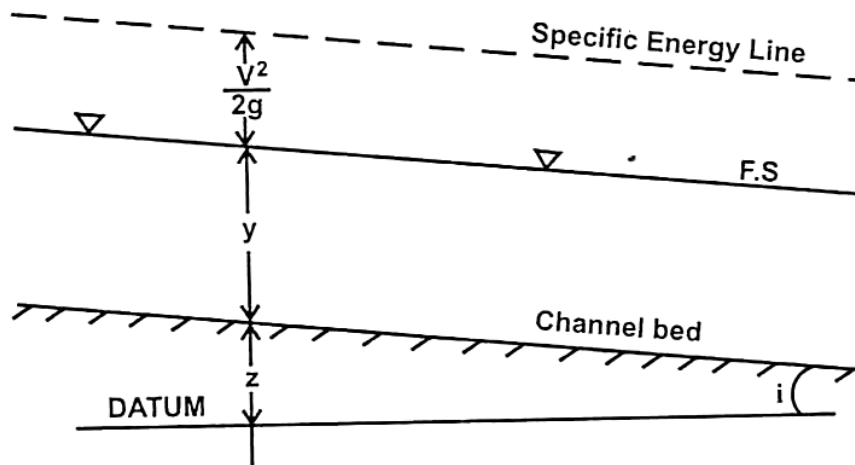
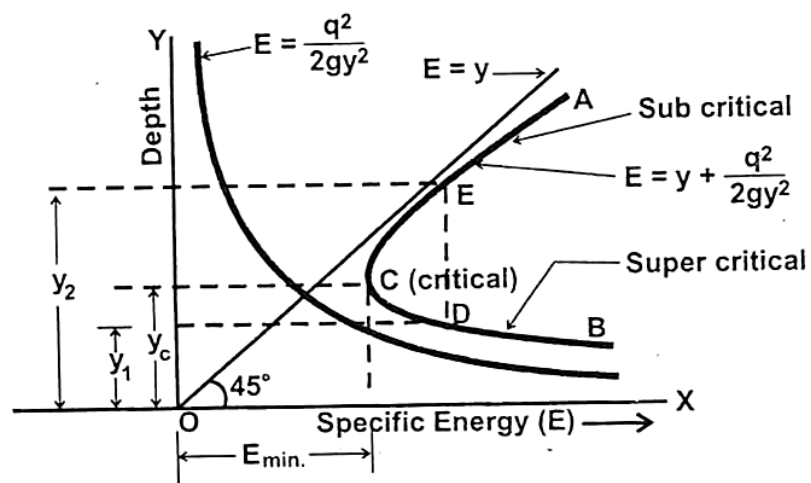


Fig. 1.7



1. Specific Energy Curve:

Specific Energy curve is defined as the curve which shows the variation of specific energy with the depth of flow.

From equation (1.7) the specific energy of flow is

$$E = y + \frac{V^2}{2g} = E_{p_0.E} + E_{K.E}$$

where $E_{p_0.E}$ = Pressure energy = depth of flow = Y

and $E_{K.E}$ = Kinetic energy of flow = $\frac{V^2}{2g}$.

Let a steady but non-uniform flow take place in a rectangular channel.

For steady flow this can be written in terms of discharge Q

$$E_s = y + \frac{\alpha(Q/A)^2}{2g}$$

For a rectangular channel of width b , $Q/A = q/y$

$$E_s = y + \frac{\alpha q^2}{2gy^2}$$
$$(E_s - y)y^2 = \frac{\alpha q^2}{2g} = \text{constant}$$
$$(E_s - y) = \frac{\text{constant}}{y^2}$$

This is a cubic in y . It has three solutions but only two will be positive (so discard the other).

Let 'b' be the base width of channel

Y be the depth of flow

Q be the discharge rate through the channel

q be the discharge per unit width = $\frac{Q}{b}$

$$\text{Velocity of flow } V = \frac{Q}{A} = \frac{Q}{b \times y} = \frac{q}{y}$$

Substituting in equation (1.7) we have

$$E = y + \frac{q^2}{2g y^2} = E_{PE} + E_{KE}$$

When a graph between specific energy in X-axis and y along Y-axis is plotted equation (1.10) is obtained in graphical form for various depth of flow (y). For any discharge with different depth of flow the corresponding value can be obtained from the plot.

2. Plotting Specific Energy Curve:

Step 1: First $E_{PE} = y$ is drawn, which is a straight line inclined at an angle of 45° to x-axis.

Step 2: Draw another curve $E_{KE} = \frac{q^2}{2g y^2}$ which is a parabola is drawn.

Step 3: Combining them, specific energy curve ACB is obtained.

12. Define Froude number F_R . Describe the flow for $F_R = 1$, $F_R < 1$ and $F_R > 1$. Represent a discharge versus depth curve for a constant specific energy and explain its features.

Froude Number

Froude number in connection with open surface flow is defined as V/\sqrt{gl} . In the case of open channel flow, the characteristic length, l , is the depth y and V is the flow velocity. Hence Froude number can be represented by the ratio, Flow velocity/wave velocity. As already indicated, there are three possible flow situations namely $(V/c) < 1$, $(V/c) = 1$ and $(V/c) > 1$ or the Froude number for the flow is less than or equal to or greater than 1.

Case (i) If $Fr < 1$, then $V < c$ and any disturbance can travel upstream.

The downstream conditions can change the flow conditions upstream. Such a flow is called subcritical or **tranquil** flow. Only gradual changes occur in such a situation.

Case (ii) $Fr = 1$. The flow is called critical flow. Disturbances cannot travel upstream.

A standing wave may generally result.

Case (iii) $Fr > 1$, such flows are called supercritical or rapid or shooting flows. Disturbances cannot travel upstream.

Downstream conditions cannot be felt upstream. Changes occur only in the downstream flow. These are similar to subsonic, sonic and supersonic flows in the case of flow of compressible fluids where Mach number is the governing factor also defined as V/c , where c is the sonic speed or velocity of propagation of small disturbance in the fluid.

13. How are the flows classified under specific energy concepts?

It is defined as energy per unit weight of the liquid with respect to the bottom of the channel. The extra information needed to solve the above problem can be provided by the *specific energy equation*. Specific energy, E_s , is defined as the energy of the flow with reference to the channel bed as the datum:

Total Energy on open channel flow

$$E = Z + y + \frac{V^2}{2g}$$

Considering the channel bed as datum line, $z = 0$

$$\text{Specific Energy } E = y + \frac{V^2}{2g}$$

From Specific Energy curve, Corresponding to the Minimum specific energy $E_{(\min)}$, there is only one depth of flow that is called Critical depth

1.0 Critical Flow:

When the flow in an open channel has the lowest value of specific energy, the flow is said to be a critical flow. In a critical flow the depth will be critical depth. Therefore the relationship between the critical depth and critical velocity is given by

$$V_c = \sqrt{g y_c} \quad \text{or} \quad \frac{V_c}{\sqrt{g y_c}} = 1$$

But $\frac{V_c}{\sqrt{g y_c}}$ is the Froude number and therefore

where $F_c = 1$, the flow is critical flow.

2.0 Tranquil flow or sub-critical flow:

When the depth of flow $y > y_c$ i.e. when $F_e < 1.0$, the flow is a subcritical. It is also called tranquil flow or streaming flow.

3.0 Super-critical flow or shooting flow:

When the depth of flow $y < y_c$ the flow is a super-critical flow. It is also called as shooting flow or Torrential flow $F_e > 1$.

*****ALL THE BEST*****

1.20. QUESTION BANK

PART A

1. Differentiate open channel flow from pipe flow.
2. What is specific energy and is the condition for getting only one depth for a given specific energy?
3. How will do you distinguish between critical, sub- critical, super- critical flow.
4. Sketch the velocity distribution in a trapezoidal channel.
5. What is the use of a pitot–tube?
6. Briefly write a note on anemometers
7. Find the relationship between Chezy's 'C' and Manning's 'n'.
8. Sketch the velocity distribution in rectangular and triangular channels.
9. What are the possible types of flow in open channel with respect to space and time?
10. What are the equations for critical depth for rectangular channel?
11. Distinguish between steady uniform flow and unsteady non – uniform flow.
12. Define specific energy.

PART B

1. Explain any two formulae for estimation of velocity in open channels?
2. A trapezoidal channel has side slopes of 1 horizontal to 2 vertical and the slope of the bed is 1 in 2000. The area of the section is 42 m². Find the dimensions of the section if it is to be most economical. Determine the discharge of the most economical section of $C = 60$.
3. Describe various types of flow in an open channel.
4. A rectangular channel with a base width of 0.60 m carries a discharge of 100 lps. The Chezy's C is 60. If the depth of flow is 0.25 m, determine the bed slope of the channel
5. In a flow through a rectangular channel for a certain discharge froude number corresponding the two alternate depths are y_1 and y_2 . show that
$$(F_2/F_1)^{(3/2)} = (2+F_2^2)/(2+F_1^2)$$
6. A rectangular channel 1.5m wide and depth 2.25m, discharge is 10m³/sec. calculate the specific energy and depth alternate to the given depth.
7. A trapezoidal channel has a bottom width 6m, and side slope of 2h to 1v if a depth of flow is 1.2m at a discharge of 10m³/sec. compute the specific energy and critical depth.
8. Define wide open channel and also what are the important assumptions in hydraulic parameters?
9. The rectangular channel carries a discharge of 30m³/sec. The bottom width of the channel is 6.0m and flow velocity is 1.75m/sec. Determine two alternate depths possible in the channel.
10. If y_1 and y_2 are alternate depths in a rectangular channel show that $Y_{C3} = (2y_1^2 y_2^2) / (y_1 + y_2)$ And hence the specific energy $E = (y_1^2 + y_1 y_2 + y_2^2) / (y_1 + y_2)$
11. For a constant specific energy of 3.0m, what maximum flow may occur in a rectangular channel of 4.5m bed width?
12. The specific energy for a 3m wide channel is 8N.m/N. What is the maximum possible discharge in the channel?

13. Show that in a rectangular channel maximum discharges occurs when the flow is critical for a given value of specific energy.
14. The specific energy for a 5m wide rectangular channel is 4m, the discharge of water through the channel is 19cumecs. Determine the alternate depths of flow.
15. Show that the minimum specific energy in a rectangular channel is 1.5 times the critical depth.
16. Show that the relation between alternate depths y_1 and y_2 in a rectangular channel can be expressed by $2y_1^2 y_2^2 / (y_1 + y_2) = y_c^3$ where y_c is the critical depth of flow.
17. For a constant energy of 2.4N.m/N. Calculate the maximum discharge that may occur in a rectangular channel 4m wide.
18. For a purpose of discharge measurement the width of a rectangular channel is reduced gradually from 3m to 2m and floor is raised by 0.3m at a given section when the approaching depth of flow is 2m, what rate flow will be indicated by a drop of 0.15m in the water surface elevation at the contracted section?
19. How to estimate the hydraulic jump and draw sketch of the jump?