Hydraulic Engineering
Fourth Semester
BCEF184T20

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UNIT-I- Open Channel Flow

Introduction to Open Channel Flow-Comparison between open channel flow and pipe flow, geometrical parameters of a channel, classification of open channels, classification of open channel flow, Velocity Distribution of channel section. Specific energy, Specific energy curve, critical flow, discharge curve, Specific force. Specific depth, and Critical depth.

Open Channel Flow

Introduction to Open Channel

- An open channel means a passage through which water flows with its surface freely exposed to the atmosphere.
- The water at its surface is at atmospheric pressure throughout.
- The channel may be open or may be provided with a cover or top.
- In case the channel is provided with a cover or top, it must not be running full and the air above the water surface is at atmospheric pressure.
- A pipe in which the water is not running full also acts as a channel.
- The section of a channel may be uniform or non-uniform.
- For example, a canal, a sewer, an aqueduct, etc. are channels of uniform section,
- while rivers and streams are channels of non-uniform section.

Comparison between open channel flow and pipe flow

Parameters	Open Channel flow	Pipe flow
Condition	It is usually uncovered, have a free surface at the top and atmospheric pressure at free surface.	It is covered and as no free surface.
Cross section	It may have any shape. Ex. Rectangular, trapezoidal, circular, parabolic.	Generally pipe flow as a circular cross section
Cause of flow	Flow is due to gravity	Flow is due to pressure
Surface roughness	Its roughness varies between wide limits and also varies from place to place	Its roughness depends upon the material of the pipe
Velocity distribution	Velocity is maximum at little distance below the water surface in open channel flow. The shape of the velocity profile of the open channel depends upon the channel surface.	Velocity is maximum at the centre of flow and reduces to zero at the pipe wall. Velocity distribution is symmetrical about the pipe axis in pipe flow
Surface head	negligible	Dominant for small diameter pipes
Piezo metric head	Z+y, where y= depth of flow. HGL coincides with the water surface in open channel flow.	$Z + {}^{p}/_{y}$, where p= pressure in the pipe. HGL does not coincide with the water surface line.

Classification of Open Channel

Open Channels

Artificial Channel

Such channels are regular in shape and alignment. Surface roughness is also uniform.

Ex: irrigation, water supply, water power development etc

Prismatic Channel

A channel is said to be prismatic when the cross section is uniform and the bed slope is constant.

Ex: Rectangular, trapezoidal, cular, parabolic.

Natural channels

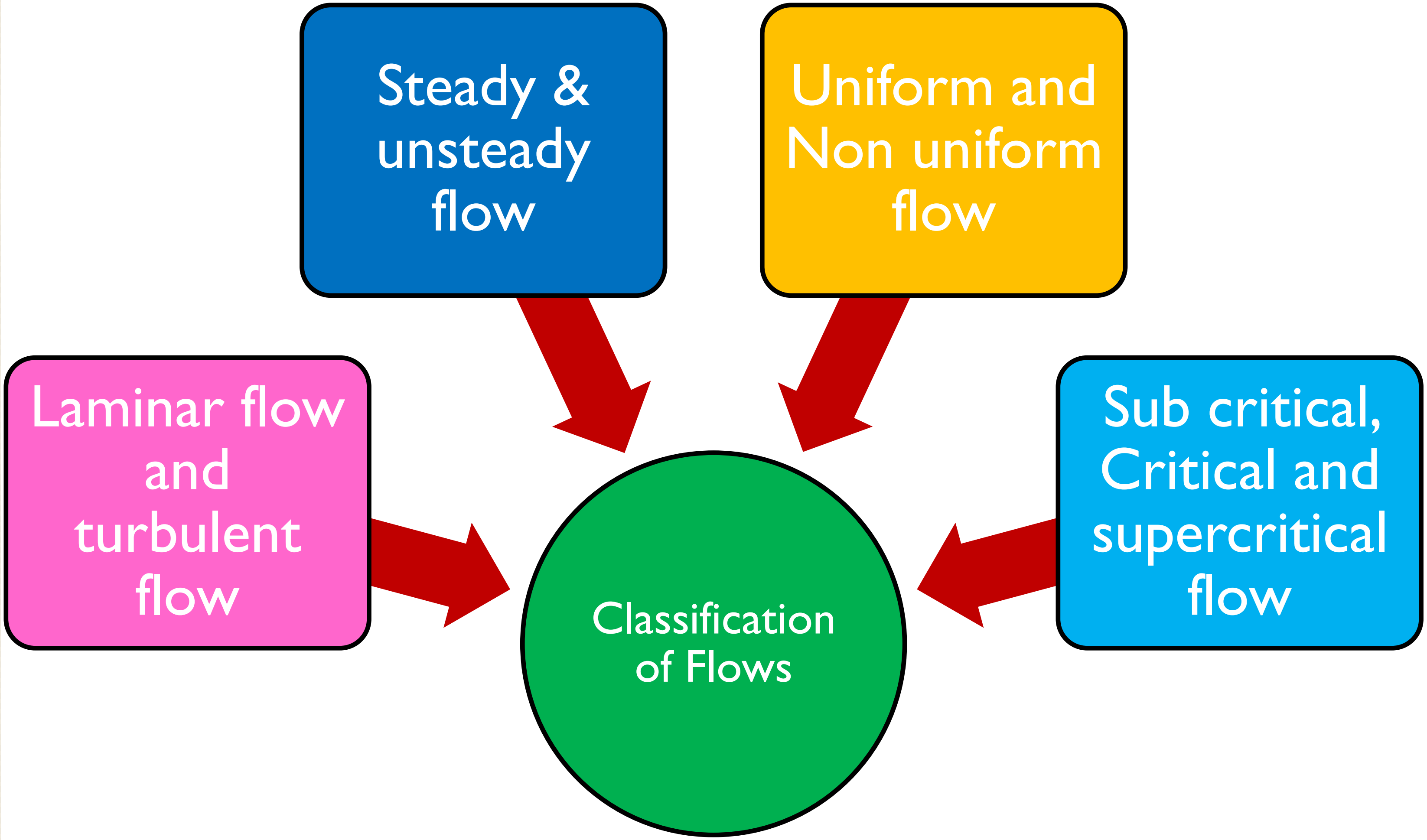
The irregular sections of varying shapes are the natural channels.

Ex: Rivers streams and drains etc.

Non-Prismatic Channel

A channel is said to be non-prismatic when its cross section and for slope change.

Ex: River, Streams & Estuary.


Steady & unsteady flow
Uniform and Non uniform flow
Laminar flow and turbulent flow
Classification of Flows
Sub critical, Critical and supercritical flow

Steady Flow and Unsteady Flow	Uniform Flow and Non-uniform flow

Steady flow

is that type of flow in which fluid parameters (velocity, pressure, density etc.) at any point in the flow field do not change with time.

$$\frac{\partial v}{\partial t} = 0 \ , \frac{\partial Q}{\partial t} = 0 \ \frac{\partial y}{\partial t} = 0$$

Unsteady Flow

The flow is unsteady if the depth is changes with time.

$$\frac{\partial v}{\partial t} \neq 0 \qquad \frac{\partial Q}{\partial t} \neq 0 \qquad \frac{\partial y}{\partial t} \neq 0$$

Uniform Flow

If for a given length of channel, the velocity of flow, depth of flow, slope of the channel and cross section remain constant, the flow is said to be uniform.

$$\frac{\partial y}{\partial s} = 0 \qquad \frac{\partial v}{\partial t} = 0$$

Non-uniform flow

If for a given length of channel, the velocity of flow, depth of flow, slope of the channel and cross section is not constant, the flow is said to be non-uniform.

$$\frac{\partial v}{\partial s} \neq 0 \qquad \frac{\partial y}{\partial s} \neq 0$$

Classification of Flows

Types of Non-Uniform Flow

Gradually Varied Flow (GVF)

If the depth of the flow in a channel changes **gradually** over a length of the channel is said to be Gradually Varied Flow.

Rapidly Varied Flow (RVF)

If the depth of the flow in a channel changes **abruptly** over a small length of channel is said to be Rapidly Varied Flow.

Laminar and Turbulent Flow (Based on Re)

Both laminar and turbulent flow can occur in open channels depending on the Reynolds number (Re)

$$Re = \rho v d/\mu$$

Where,

ρ = density of water = 1000 kg/m^3

μ = dynamic viscosity

d = Hydraulic Mean Depth = Area / Wetted Perimeter

If the Reynolds number **Re is less than 500 or 600,** then the flow is called **laminar flow**.

If the Reynolds number is **more than 2000**, then the flow is said to be **turbulent**.

A flow that has Reynolds number between **500 and 2000** is said to be in the **transition state**.

Based on Froude Number

Critical Flow

- Critical flow has a Froude number equal to one Fe=1.0

Sub-Critical Flow

- Froude number less than one **($F_e < 1.0$)**
- Subcritical occurs when the actual water depth is greater than critical depth

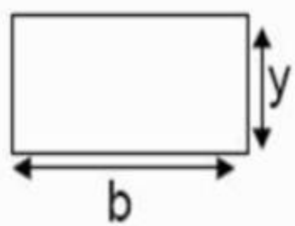
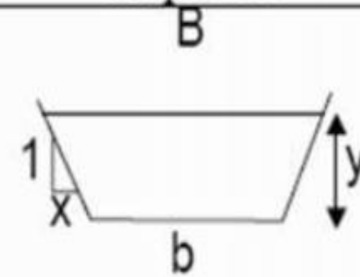
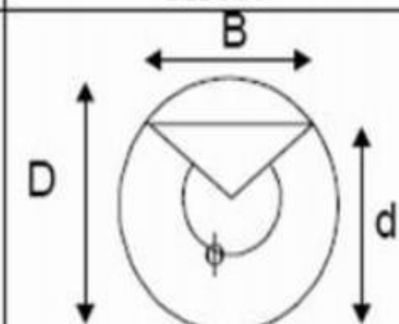
Super Critical Flow

- Froude number greater than one $F_e > 1.0$
- The actual depth is less than critical depth

Geometric properties of open channels

- y : depth of flow
- m : side slope
- T : top width
- S_o: channel bottom slope
- b: bottom channel width
- v: average flow density
- F_e: Froude number
- Q: flow rates, Q = AV
- R: hydraulic radius at cross section
- θ : flow temperature
- Re : Reynolds number
- L : length of channel
- A : area of the flow
- P : wetted perimeter
- D : hydraulics water depth
- V : volume
- E : specific energy
- Δz : weir height
- q = discharge per unit width (m2/s)

Type of channel	Top width, T	Area, A	Wetted Perimeter, P
Rectangular	B	By	B+2y
Trapezoidal	B+2my	$By + my^2$	$B + 2y\sqrt{1+m^2}$

	Rectangle	Trapezoid	Circle
			
Area, A	by	$(b+xy)y$	$\frac{1}{8}(\phi - \sin\phi)D^2$
Wetted perimeter P	$b+2y$	$b+2y\sqrt{1+x^2}$	$\frac{1}{2}\phi D$
Top width B	b	$b+2xy$	$(\sin\phi/2)D$
Hydraulic radius R	$by/(b+2y)$	$\frac{(b+xy)y}{b+2y\sqrt{1+x^2}}$	$\frac{1}{4}\left(1-\frac{\sin\phi}{\phi}\right)D$
Hydraulic mean depth D_m	y	$\frac{(b+xy)y}{b+2xy}$	$\frac{1}{8}\left(\frac{\phi-\sin\phi}{\sin(1/2\phi)}\right)D$

Velocity Distribution of channel section

- In an open channel flow, velocity distribution is non-uniform which means velocity is different at different depths.
- Various Factors such as channel slope, alignment, shape, roughness etc., plays key role in velocity distribution.
- The measured velocity in an open channel will always vary across the channel section because of friction along the boundary.
- Neither is this velocity distribution usually axisymmetric (as it is in pipe flow) due to the existence of the free surface.

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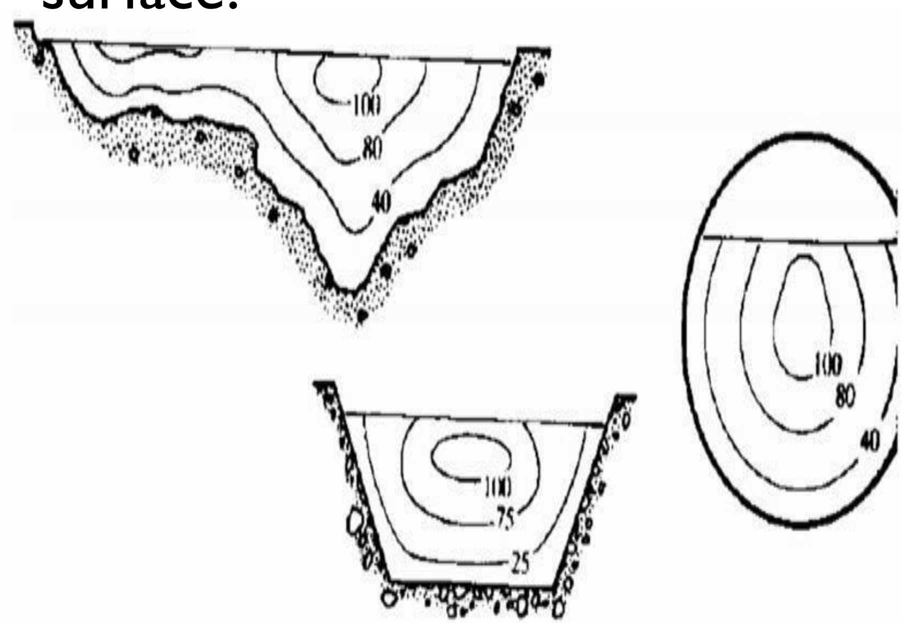
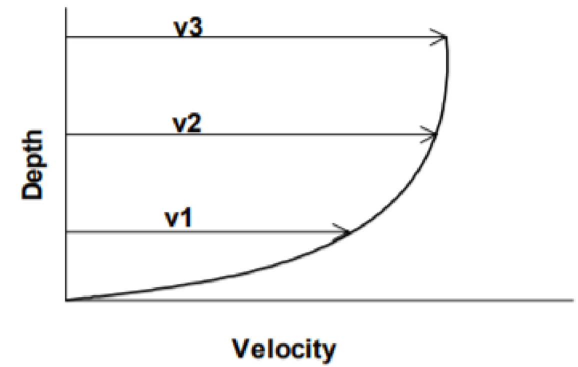
- It might be expected to find the maximum velocity at the free surface where the shear force is zero but this is not the case.
- The maximum velocity is usually found just below the surface.





Questions

PART-A

1. Define open channel flow with examples.
2. What are the various types of flow in open channels?
3. Explain Laminar and Turbulent flow.
4. Define the term Uniform and non-uniform flow.
5. Distinguish between steady and unsteady flow.
6. Define hydraulic mean depth.
7. Define specific energy.
8. Define critical depth.
9. Distinguish between Subcritical, critical and supercritical flow
10. Define alternate depths.
11. What is the relationship between minimum specific energy and critical depth?
12. Explain specific force (F_c)
13. Differentiate closed conduit flow and open channel flow.
14. What is specific energy and what is the condition for obtaining only one depth for a given specific energy?
15. Explain the terms (i) Gradually varied flow and (ii) rapidly varied flow.
16. Differentiate prismatic and non-prismatic channels.
17. Sketch the velocity distribution of a trapezoidal channel section.
18. Draw the hydraulic gradient line and total energy line.
19. What is flow regime? Name the types.

Questions

PART-B

1. (a) Define specific energy. Write an expression for the specific energy in case of a wide rectangular channel with depth of flow y and velocity of flow v. Also express the specific energy in terms of the discharge per unit width of the rectangular channel. Represent the later expression for specific energy on a discharge per unit width versus depth of flow for constant specific energy. Mention any two applications of such a discharge curve.

(b)A rectangular channel 2.5m wide has a specific energy of 1.5m when carrying a discharge of 6.48 m^3/s. Calculate the alternate depths and corresponding Froude numbers.

2. (a) Find the critical depth for a specific energy head of 1.5m in the following channels:

i)Rectangular channel of width B = 2.0m

ii)Triangular channel having side slope 1.5 horizontal to 1 vertical

iii)Trapezoidal channel having bottom width 2m and side slope 1 horizontal to 1 vertical.

For purpose of identification and analysis, how open channels are classified? Give one example for each.

3. (a) The discharge of water through a rectangular channel of width 8m , is 1.5m^3/s when the depth of flow of water is 1.2m.Calculate

i)Specific energy

ii)Critical depth and critical velocity

iii)Minimum specific energy.

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4. (a) Define Specific energy. Draw a neat sketch of specific energy curve and explain the salient points.

(b)Find the slope of the bed of a rectangular channel of width 5m when the depth of flow of water is 2m and the rate of flow is given as 20 m^3/s. Assume C=50.

5. (a) Derive the equations for

(i) Critical depth

(ii) Critical velocity

(iii) Minimum specific energy in terms of critical depth.

(b) Find the critical depth and critical velocity of water flowing through a rectangular channel of width 5m, when discharging 15 m^3/s.

6. Calculate the Critical depth, critical velocity and critical specific energy for a flow of 12 m^3/s in a rectangular channel of width 3.5m and energy co-efficient 1.1. What is the state of flow when the depth is 0.9m? Find the Froude's number at this depth.

7. (a) Describe the various types of flow in an open channel.

(b) Find the discharge through a rectangular channel of width 2m, having a bed slope of 4in 8000. The depth of flow is 1.5m. Use Chezy's formula. Take C= 76.

8. A rectangular channel which is laid on a bottom slope of 0.0064 is to carry 20 m^3/s of water. Determine the width of the channel when the flow is in critical condition. Take Manning's n= 0.015.

9. For a constant specific energy of 1.8N.m/N, Calculate the maximum discharge that may occur in a rectangular channel 5.0m wide.

Thank You